

Automation control system

26/2/2013

OGS Alex.

Eng. Mohamed Kamal



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info@ogs.com.eg



Dear Trainee,

Congratulations on choosing **OGS**. Our staff is honoured to have **YOU** for the training course period as a member of our large family. Start the engines and enjoy a distinguished journey of a high quality service..

Unlike other training centers, We take pride in our efficient instructors chosen carefully from the petroleum sector. Instructors enjoying practical experience offer you endless help. What makes us special is that **OGS** certificates are acknowledged inside and outside the sector. We are determined to remain ahead of our counterparts by upgrading the training courses to offer you the highest potentials and largest opportunities possible..

By training at **OGS**, you have earned yourself a seat in the front rows of distinguishment. Our goal is your satisfaction. Our policy is perfection. Our hope is that you come back and tell others about us. We promise you a memorable training experience that makes your study convenient and prosperous. Feel free to dream of a better future for now dreams are possible.

Grab the Chance ... The Sky Is Your Limit

Feel Proud ... YOU ARE PART OF OGS

Human Development is our Business



H. Hafez

Dr. Eng. Hossam Hafez

Alex Center Manager

Mission & Vision



Mission:

The basic mission of OGS is to provide world class educational and vocational training programs to allow human resources and organizations access the input needed to stay on top in today's energy world. To achieve this mission, OGS is driven by an adamant determination to grow and progress through keeping itself at the cutting edge of technology and to maintain the best quality standards to help in creating energy leaders of today and tomorrow.



Vision:

To be the leading company in the region in the field of providing professional and technical services for the human development of the petroleum sector workers in line with international quality standards.

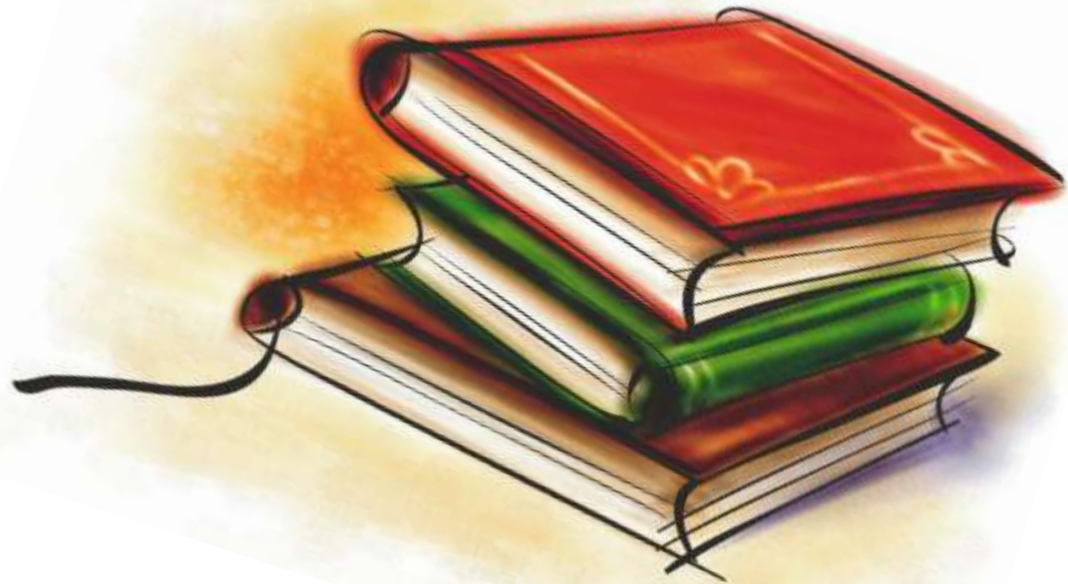
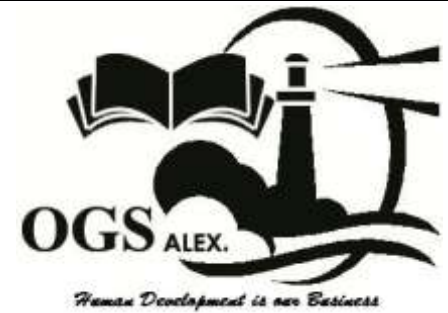


Oil & Gas Skills (OGS)

Alex Branch

Training Plan 2012/2013

(By Subject)



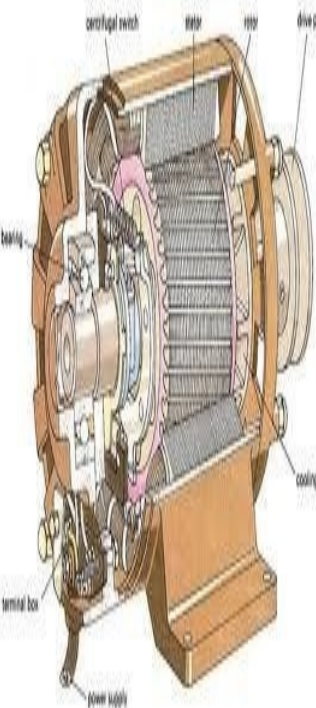
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Courses		Days	1 st Date	2 nd Date	3 rd Date	4 th Date
Electrical Engineering & Maintenance						
	Advanced Electrical Protection Relays and Systems	5	13-أبريل-14	13-سبتمبر-01	13-ديسمبر-01	
	Plant Electrical Equipment; Designing and Sizing	5	13-يناير-27	13-مايو-12		
	ESP (Electrical Submersible Pumps); Installation and Maintenance	5	13-مارس-24	13-سبتمبر-29		
	Applying Standard Electrical Documentations and Drawings	5	13-يونيو-09	13-أكتوبر-13		
	Electrical Motors; Protection, Testing and Maintenance	5	13-يناير-13	13-أكتوبر-20		
	Electrical Installation in Hazardous Areas	5	13-مارس-17	13-ديسمبر-15		
	Power Cables; Selection, Testing and Fault Locations	5	13-فبراير-17	13-نوفمبر-17		
	Electrical Power Transformers, Testing and Maintenance	5	13-فبراير-03	13-مايو-26		
	UPS Systems and Batteries Maintenance	5	13-مايو-19	13-أغسطس-18		
	Motor Control through PLC	5	13-يونيو-02	13-ديسمبر-08		
	Variable Speed Drivers for Industrial Control	5	13-مايو-05	12-ديسمبر-22		
	AC & DC Motors	5	13-مارس-10	13-سبتمبر-22		
	Power generation system and distribution	5	13-مارس-03	13-أغسطس-25	13-نوفمبر-10	
	GE power turbines	5	13-فبراير-24	13-نوفمبر-24		
	Power management system	5	13-يونيو-16	13-سبتمبر-15		
	Lighting system at oil and gas fields	5	13-فبراير-10	13-أكتوبر-27		
	Earthing & lightning electrical safety system	5	13-يونيو-23	13-سبتمبر-01		
	Cathodic protection	5	13-يناير-13	13-يونيو-30	13-أكتوبر-13	
	Gas and diesel generator	5	13-يناير-27	13-سبتمبر-08		
	Oil & Gas Production and Processing For Maintenance Team (New)	5	13-أبريل-21	13-ديسمبر-29		
Mechanical Engineering & Maintenance						
	Pumps Installation, Troubleshooting & Maintenance	5	13-مايو-19	13-أغسطس-18		
	Gas Turbine Operation, Maintenance & Troubleshooting	5	13-فبراير-03	13-يونيو-30		
	Lube Oil System (New)	5	13-مارس-24	13-سبتمبر-29		
	Compressors and Blowers Selection, Operation and Maintenance	5	13-يناير-27	13-نوفمبر-10		
	Mechanical Seals and Coupling	5	13-يناير-13	13-يونيو-16		
	Vibration Protection Systems for Turbo-machinery	5	13-مايو-26	13-أغسطس-25		
	Tower Maintenance	5	13-يونيو-23	13-سبتمبر-01		
	Pumps And Compressors (Mechanical Movers)	5	13-مارس-31	13-يونيو-09	13-سبتمبر-15	13-ديسمبر-22
	Centrifugal Pumps Theory, Operation & Maintenance	5	13-فبراير-24	13-نوفمبر-24		
	Centrifugal Pumps WorkShop (New)	5	13-مايو-05	13-نوفمبر-17		
	Positive Displacement Pumps (New)	5	13-فبراير-03	13-ديسمبر-08		
	Machine Alignment & Balancing	5	13-أبريل-14	13-سبتمبر-08		
	Mechanical Seals Technology	5	13-يونيو-02	13-أكتوبر-27		



Reciprocating Compressors Construction Operation and Maintenance	5	13-يونيو-30	13-سبتمبر-22		
Centrifugal Compressors Theory, Performance, Operation & Maintenance	5	13-مارس-17	13-ديسمبر-15		
Turbo Expanders (operation & maintenance)	5	13-مارس-10	13-ديسمبر-08		
Diesel Engines Construction, Operation & Maintenance	5	13-فبراير-17	13-نوفمبر-17		
Reciprocating Gaseous Fuel Engines	5	13-يونيو-16	13-أغسطس-25		
Refrigeration and Air Conditioning	5	13-يونيو-09	13-سبتمبر-22		
Absorption Chillers	5	13-يناير-13	13-أكتوبر-13		
Heat Exchange Equipment Operational Performance & Maintenance	5	13-يناير-27	13-نوفمبر-10		
Bearing & Lubrication Technology	5	13-مارس-03	13-سبتمبر-15	13-ديسمبر-01	
Rolling Elements Bearings	5	13-فبراير-10	13-أكتوبر-13		
Machinery Components Maintenance and Repair	5	13-أبريل-14	13-ديسمبر-29		
Manual Valves	5	13-فبراير-10	13-أكتوبر-27		
Mechanical Power Transmission	5	13-مايو-12	13-نوفمبر-10		
Hydraulic Circuits Theory, Components, & Practice	5	13-فبراير-17	13-أكتوبر-13		
Hydraulic Equipment Operation, Maintenance & Troubleshooting	5	13-مارس-31	13-سبتمبر-01	13-ديسمبر-22	
تشغيل و صيانة الأوتاش و معدات الرفع	5	13-فبراير-24	13-يونيو-23		
Steam Generation & Boilers Operation and Maintenance	5	13-مايو-26	13-سبتمبر-29		
PIPE WORK, JOINTS, and Piping components (GASKETS - FLANGES - VALVES - ETC.)	5	13-مايو-12	13-سبتمبر-08		
HAND TOOLS, MEASURING TOOLS, and POWER TOOLS	5	13-يناير-27	13-يونيو-02		
Oil & Gas Production and Processing For Maintenance Team (New)	3	13-يناير-20	13-أغسطس-18		

Instrumentation Engineering & Maintenance

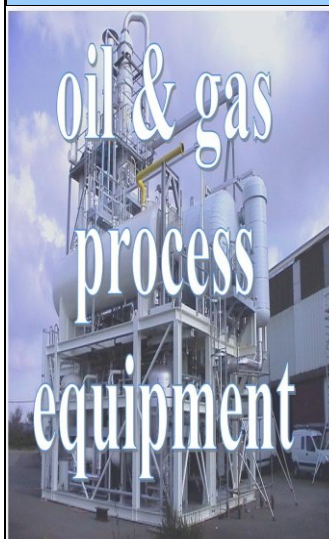


Industrial Process Measurement	5	13-يونيو-16	13-أغسطس-18		
Programmable Logic Controller; Architecture and Basic Programming PLC	5	13-مايو-19	13-سبتمبر-15		
Sizing, Selecting, and Applying Process Control Valve	5	13-يونيو-09	13-أغسطس-25		
Safety Instruments Systems; New Emergency Shutdown Approach	5	13-فبراير-24	13-أكتوبر-13	13-نوفمبر-24	
New Approaches in DCS & SCADA Systems	5	13-يونيو-23	13-سبتمبر-08		
Gas Measurement and Flow Metering Station	5	13-مارس-17	13-أكتوبر-20	13-ديسمبر-15	
Instrumentation Systems Maintenance and Troubleshooting (Workshop Course)	5	13-أبريل-14	13-ديسمبر-08		
Valves Types and Technology	5	13-فبراير-03	13-سبتمبر-22		
Advanced Turbine Control System	5	13-فبراير-10	13-سبتمبر-29		
Developing and Applying Standard Instrumentation and Control Documentation	5	13-فبراير-17	13-يونيو-30	13-أكتوبر-27	
Applying Instrumentation in Hazardous (Classified) Locations	5	13-مارس-03	13-يونيو-02	13-ديسمبر-01	
Advanced Process Control; Loops, Analysis and Troubleshooting	5	13-أبريل-14	13-نوفمبر-17		



Field Bus System; Driving Total Productivity Management	5	13-مارس-10	13-ديسمبر-08		
Fire & Gas System; Detectors and Guard Safety Controller	5	13-مايو-12	13-أغسطس-18	13-أكتوبر-13	
Safety Relief Devices	5	13-مايو-19	13-سبتمبر-01		
Programmable Logic Controller; Advanced Programming'	5	13-مايو-26	13-نوفمبر-10		
Automatic Tank Gauging	5	13-مارس-31	13-ديسمبر-22		
Pneumatic System and Logic Circuits	5	13-سبتمبر-29			
Applying Motor Controls and Drives	5	13-يناير-13	13-أكتوبر-20		
Introduction to Boiler Control Systems: Meeting NFPA Standards	5	13-مايو-05			
Industrial Electronics	5	13-مارس-17	13-ديسمبر-15		
Installing, Calibrating, and Maintaining Electronic Instruments	5	13-يونيو-09			
Introduction to the Management of Alarm Systems	5	13-مايو-12			
Overview of Grounding and Noise Reduction for Control Equipment	5	13-فبراير-24	13-نوفمبر-24		
Overview of Measurement and Control Fundamentals	5	13-فبراير-10	13-أغسطس-25		
Process and Laboratory Analytical Technologies Overview	5	13-يونيو-02			
Project Management for Automation and Control	5	13-يونيو-30			
Oil & Gas Production and Processing For Maintenance Team (New)	3	13-مارس-24	13-سبتمبر-15		

Process Technologies & Operations



Natural Gas Processing Technology	5	13-مايو-19	13-أكتوبر-20		
Oil Refining Technology	5	13-فبراير-03	13-يونيو-09		
LPG Technology	5	13-فبراير-10	13-سبتمبر-15	13-أكتوبر-27	
Process safety and Hazard Analysis (PHA & HAZOP)	5	13-فبراير-17	13-مايو-12	13-أكتوبر-13	
Process Operations for Technicians	5	13-يونيو-02	13-أغسطس-18		
water treatment systems	5	13-يونيو-16	13-سبتمبر-29		
Surface Facilities Production Operations.	5	13-فبراير-24	13-نوفمبر-24		
Hydrocarbon Storage, Shipping and Utilization.	5	13-مارس-31	13-ديسمبر-22		
Plant Operation and Troubleshooting.	5	13-يونيو-23	13-سبتمبر-08		
Fire Heater & Heat Transfer Equipments.	5	13-مايو-26	13-سبتمبر-01		
Fundamental Of Process Calculations (New)	5	13-يناير-27	13-سبتمبر-22		
Process Calculation and Simulation: by HYSYS.	5	13-أبريل-14	13-أغسطس-25		
Planned Shutdown, Critical Activities and Start-up.	5	13-مارس-17	13-ديسمبر-15		
Static and Rotary Equipment (Process Point of View).	5	13-مارس-03	13-ديسمبر-01		
Oil & Gas Field Processing.	5	13-يناير-27	13-نوفمبر-10		
Oily Water Treatment.	5	13-مايو-12	13-سبتمبر-22		



Over pressure control and Flare Systems.	5	13-مارس-10	13-أكتوبر-27	13-ديسمبر-08	
Mass and Heat Balance in Petroleum Industry.	5	13-فبراير-03	13-نوفمبر-17		
Oil and Gas Separation Equipment.	5	13-يونيو-30	13-ديسمبر-29		
Gas Processing, Plant Troubleshooting & Startup.	5	13-مارس-31	13-أكتوبر-13	13-ديسمبر-22	
Gas Dehydration Technology.	5	13-مايو-12	13-نوفمبر-24		
LPG, NGL & LNG Production and Handling.	5	13-يناير-13	13-أكتوبر-20		
Crude Oil Processing and Desalting.	5	13-أبريل-14	13-نوفمبر-10		
Distillation Processes, Calculations and Multivariable Process Control.	5	13-مارس-24	13-يونيو-02	13-سبتمبر-15	
Oil Production & Field handling Facilities	5	13-يونيو-09	13-سبتمبر-01		
Operations Accidents Investigations (New)	5	13-يناير-20	13-سبتمبر-08		
Oil & Gas Industry For Administration Team (New)	3	13-يناير-06	13-نوفمبر-17		

Maintenance Management



Reliability Centered Maintenance	5	13-مايو-19	13-أغسطس-25		
Maintenance Management Skills and Techniques	5	13-يونيو-23	13-نوفمبر-24		
Human Resource Management for the Maintenance Manager	5	13-فبراير-10			
Root Cause Failure Analysis	5	13-فبراير-03	13-مايو-26	13-نوفمبر-17	
Computerized Maintenance Management System	5	13-مارس-31	13-ديسمبر-22		
Quality Management	3	13-يناير-20	13-سبتمبر-01		
Global Maintenance	5	13-يناير-13	13-أبريل-14	13-سبتمبر-08	
Predictive Maintenance Techniques	5	13-مارس-10	13-ديسمبر-08		

Projects, Engineering Studies & Economics



Economics & Feasibility Study	5	13-مايو-19	13-سبتمبر-01		
Primavera P6 Level I - Activities	5	13-مايو-26	13-أكتوبر-13		
Project Management Professional	5	13-أبريل-14	13-سبتمبر-08		
Risk Management	5	13-مارس-17	13-ديسمبر-15		
Project Economics	5	13-مايو-12	13-أكتوبر-27		
Advanced Economics & Feasibility Studies II	5	13-يونيو-23	13-ديسمبر-01		
Microsoft Project 2003	5	13-مارس-10	13-ديسمبر-08		
Primavera Level II - Resources and Cost Control	5	13-يونيو-16	13-سبتمبر-22		

Inspection Engineering



Piping Design (Specification & Sizing)	5	13-غبرابر-10	13-سپتمبر-01		
Pipeline Construction	5	13-مايو-26	13-اكتوبر-13		
Corrosion & Corrosion Control Fundamentals in Oil & Gas Field	5	13-مايو-05	13-سپتمبر-15		
Inspection Qualification & Certification Level I (RT)	10	13-غبرابر-17	13-غبرابر-24	13-نوفمبر-17	13-نوفمبر-24
Inspection Qualification & Certification Level I (UT)	10	13-مارس-17	13-مارس-24	13-ديسمبر-15	13-ديسمبر-22
Inspection Qualification & Certification Level I (MT)	10	13-مايو-12	13-مايو-19		
Inspection Qualification & Certification Level I (PT)	10	13-يونيو-16	13-يونيو-23		
Advanced Valve Technology: Design, Selection, Installation, Applications, Sizing, Inspection, Maintenance & Troubleshooting	5	13-ابريل-14	13-سپتمبر-22		
Heat Exchanger Design, Performance, Inspection Maintenance & Operation	5	13-مارس-10	13-ديسمبر-08		
Pipeline, Vessels & Tanks: FAILURE PREVENTION, REPAIR & LIFE EXTENSION: Lessons Learned Through Case Studies	5	13-يونيو-02			
Safety Relief Valve Inspection, Maintenance, Operation, Troubleshooting & Repair (PRV & POPRV/PORV)	5	13-يونيو-09			
ASME B31.3 Piping & Pipeline Design, Construction, Inspection, Piggging, Maintenance, Repair & Integrity Assessment (ASME B31.3, API 570 & API 579 Standards)	5	13-مارس-31	13-اكتوبر-20		
Design, Fabrication and Testing of ASME VIII Division 1 Pressure Vessels	5	13-مارس-03	13-ديسمبر-01		
ASME Post Construction Code (PCC), API 579 & API 571: Inspection, Planning, Fitness-for-Service , Damage Mechanisms and Repair for Vessels, Tanks, Pipings and Process Equipment	5	13-يناير-27	13-سپتمبر-29		
API 510: PRESSURE VESSEL INSPECTION CODE: Maintenance, Inspection, Rating, Repair, & Alteration (API Exam Preparation Training)	5	13-مايو-19			
API 653: TANK INSPECTION CODE: Inspection, Repair, Alteration & Reconstruction of Steel Aboveground Storage Tanks Used in the Petrochemical Industry (API Exam Preparation Training)	5	13-يونيو-30			
API 936: Refractory Inspection Code: Installation, Inspection, Testing & Repair (API Exam Preparation Training)	5	13-غبرابر-24	13-نوفمبر-24		
API 570: PIPING INSPECTION CODE: Inspection, Repair, Alteration & Rerating of In-Service Piping Systems (API Exam Preparation Training)	5	13-غبرابر-03	13-نوفمبر-10		
API-579/580/581: Risk-Based Inspection (RBI), Fitness-for-Service (FFS) and Repair Practices of Pipeline, Piping Vessels and Tanks in Refineries, Gas, Oil and Petrochemical Facilities	5	13-غبرابر-10	13-اگسطس-18	13-اكتوبر-27	

Laboratory Engineering



Laboratory Information Management Systems (LIMS).	5	03-فبراير-13	18-أغسطس-13		
المراجعة الداخلية لمعمل المعايرة طبقاً لمواصفات الأيزو 17025	5	10-فبراير-13	27-أكتوبر-13		
Chemical Laboratory in Petroleum Industry	5	14-أبريل-13	17-نوفمبر-13		
Water treatment chemicals	5	03-مارس-13	16-يونيو-13	01-ديسمبر-13	
Universal tests for Petroleum and Petroleum Products in laboratories	5	10-مارس-13	08-ديسمبر-13		

Management Development



Basic Management Skills	5	24-فبراير-12	25-أغسطس-12	24-نوفمبر-13	
Time Management	3	05-مايو-13	20-أكتوبر-13		
Presentation Skills	3	16-يونيو-13	22-سبتمبر-13		
Strategic Planning	3	10-فبراير-13	23-يونيو-13	10-نوفمبر-13	
Negotiation Skills	3	21-أبريل-13	08-سبتمبر-13		
Communication & Interpersonal Skills	3	20-يناير-13	27-أكتوبر-13		
Strategic Leadership Workshop	3	17-مارس-13	15-ديسمبر-13		
Creative Thinking Workshop	3	06-يناير-13	29-سبتمبر-13		
Meeting Management	2	03-مارس-13	01-ديسمبر-13		
Team Building Workshop	3	28-أبريل-13	15-سبتمبر-13		
Crisis Management	3	06-يناير-13	05-مايو-13	13-أكتوبر-13	
Report Writing	5	12-مايو-13	18-أغسطس-13		
Human Resources Management	5	03-فبراير-13	24-نوفمبر-13		
Business Management Performance	3	17-فبراير-13	17-نوفمبر-13		
Corporate Governance	2	10-نوفمبر-13			
Corporate Finance	3	10-مارس-13	08-ديسمبر-13		
Inventory Management	2	06-يناير-13	01-سبتمبر-13		
Supply Chain Management (New)	3	28-أبريل-13	08-سبتمبر-13		
Quality Management	3	24-مارس-13	09-يونيو-13	22-ديسمبر-13	
Advanced Quality system (New)	3	13-يناير-13	30-يونيو-13		
How to Sharpen your Way of Thinking	3	28-أبريل-13	15-ديسمبر-13		
Organizational Behavior	3	20-يناير-13	20-أكتوبر-13		
Six Sigma; Introduction to Orange Belt	3	05-مايو-13	01-ديسمبر-13		
Problem Solving and Decision Making	5	02-يونيو-13	01-سبتمبر-13		
Filing and Archiving	2	06-يناير-13	28-أبريل-13	10-نوفمبر-13	
Decision Support System (New)	3	26-مايو-13	27-أكتوبر-13		
Executive Secretary	3	30-يونيو-13	15-سبتمبر-13		

Finance and Economics

	العقود والمناقصات	4	21-أبريل-13	27-أكتوبر-13	22-ديسمبر-13	
	الإتفاقيات البترولية	3	17-فبراير-13	17-نوفمبر-13		
	معايير المحاسبة المصرية و قانون الضرائب على الدخل	5	19-مايو-13	08-سبتمبر-13		
	الحسابات الختامية	4	21-أبريل-13	18-أغسطس-13		
	التحليل المالى	4	10-فبراير-13	15-سبتمبر-13		
	الإعتمادات المستندية وخطابات الضمان	5	17-مارس-13	15-ديسمبر-13		
	إدارة الأخطار والتأمين فى صناعة البترول	5	03-فبراير-13	01-سبتمبر-13		
	الأجور والإستحقاقات والمزايا بشركات القطاع	5	10-مارس-13	08-ديسمبر-13		
	قانون العمل الموحد والتطبيقات بقطاع البترول	4	05-مايو-13			
	التنظيم و دراسة الهيكلة الإدارية بقطاع البترول	5	25-أغسطس-13			
	مهارات توصيف وتحليل الوظائف	5	22-سبتمبر-13			
	الإدارة الفعالة للمخازن والتخلص من المخزون الراكد	4	21-أبريل-13	29-سبتمبر-13		
	مراقبة المخزون باستخدام الحاسب الآلى	4	03-مارس-13	01-ديسمبر-13		
	الإدارة الفعالة للمشتريات	5	14-أبريل-13			
	Contracting Fundamentals and Drafting Contracts	5	17-فبراير-13	17-نوفمبر-13		
	Contracts Negotiations skills (New)	5	26-مايو-13			
	Accounting Best Practice	3	24-مارس-13	20-أكتوبر-13	22-ديسمبر-13	
	Business Financial & Accounting Skills	3	20-يناير-13	27-أكتوبر-13		
	Financing Petroleum Projects - Basic	5	24-فبراير-13	24-نوفمبر-13		
	Cost Accounting in Oil & Gas Companies	5	12-مايو-13			
	Financing Petroleum Projects - Advanced	5	23-يونيو-13			
	Budget as an Effective tool for Cost Control	3	05-مايو-13	08-سبتمبر-13		
	Financial Accounting Standards (GAAP, IAS, IFRS and FASB)	5	16-يونيو-13			
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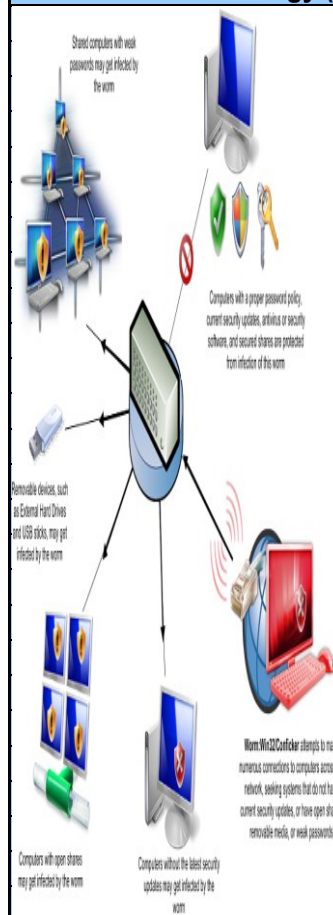
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**BASIC INSTRUMENTATION
MEASURING DEVICES
AND
BASIC PID CONTROL**

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OBJECTIVES

Note

This module covers the following areas pertaining to instrumentation and control.

- Pressure
- Flow
- Level
- Temperature
- Neutron Flux
- Control

At the end of training the participants will be able to:

Pressure

- explain the basic working principle of pressure measuring devices, bourdon tube, bellows, diaphragm, capsule, strain gauge, capacitance capsule;
- explain the basic operation of a differential pressure transmitter;
- explain the effects of operating environment (pressure, temperature, humidity) on pressure detectors;
- state the effect of the following failures or abnormalities:
 - over-pressuring a differential pressure cell or bourdon tube;
 - diaphragm failure in a differential pressure cell;
 - blocked or leaking sensing lines; and
 - loss of loop electrical power.

Flow

- explain how devices generate a differential pressure signal: orifice, venturi, flow nozzle, elbow, pitot tube, annubar;
- explain how each of the following will affect the indicated flow signal from each of the above devices:
 - change in process fluid temperature;
 - change in process fluid pressure; and
 - erosion.
- identify the primary device, three-valve manifold and flow; transmitter in a flow measurement installation;
- state the relationship between fluid flow and output signal in a flow control loop with a square root extractor;
- describe the operation of density compensating flow detectors;
- explain why density compensation is required in some flow measurements;
- state the effect on the flow measurement in process with abnormalities: Vapour formation in the throat, clogging of throat by foreign material, Leaks in HI or LO pressure sensing lines;

Level

- explain how a level signal is derived for: an open vessel, a closed vessel with dry reference leg, a closed vessel with wet reference leg;
- explain how a DP cell can be damaged from over pressure if it is not isolated correctly;
- explain how a bubbler derives level signal for an open and closed tank;
- explain the need for zero suppression and zero elevation in level measurement installations;
- describe the effects of varying liquid temperature or pressure on level indication from a differential pressure transmitter;
- explain how errors are introduced into the DP cell signal by abnormalities: leaking sensing lines, dirt or debris in the sensing lines;

Temperature

- explain the principle of operation of temperature detectors: RTD, thermocouple, bimetallic strip & pressure cylinders;
- state the advantages and disadvantages of RTDs and thermocouples
- state the effect on the indicated temperature for failures, open circuit and short circuit;

Flux

- state the reactor power control range for different neutron sensors and explain why overlap is required: Start-up instrumentation, Ion Chambers, In Core detectors;
- explain how a neutron flux signal is derived in a BF_3 proportional counter;
- explain the reasons for start-up instrumentation burn-out;
- explain how a neutron flux signal is derived in an ion chamber;
- state the basic principles of operation of a fission chamber radiation detector;
- state and explain methods of gamma discrimination for neutron ion chambers;
- explain how the external factors affect the accuracy of the ion chamber's neutron flux measurement: Low moderator level, Loss of high voltage power supply, Shutdown of the reactor;
- describe the construction and explain the basic operating principle of in-core neutron detectors;
- explain reactor conditions factors can affect the accuracy of the in-core detector neutron flux measurement: Fuelling or reactivity device movement nearby, Start-up of the reactor, long-term exposure to neutron flux, Moderator poison (shielding);

Note

- explain the reasons for power control using ion chambers at low power and in-core detectors at high power;

Note

Control

- identify the controlled and manipulated variables;
- sketch a simple block diagram and indicate set point, measurement, error, output and disturbances;
- state the difference between open and closed loop control;
- state the basic differences between feedback and feed forward control;
- explain the general on/off control operation;
- explain why a process under on/off control is not controllable at the set point;
- explain why on/off control is suitable for slow responding processes;
- explain the meaning of proportional control in terms of the relationship between the error signal and the control signal;
- explain why offset will occur in a control system, with proportional control only;
- choose the controller action for corrective control;
- convert values of PB in percentage to gain values and vice-versa;
- determine the relative magnitude of offset with respect to the proportional band setting;
- state the accepted system response, i.e., $\frac{1}{4}$ decay curve, following a disturbance;
- explain the reason for the use of reset (integral) control and its units;
- sketch the open loop response curve for proportional plus reset control in response to a step disturbance;
- state two general disadvantages of reset control with respect to overall loop stability and loop response if the control setting is incorrectly adjusted;
- calculate the reset action in MPR or RPM given a control system's parameters;
- state, the purpose of rate or derivative control;
- state the units of derivative control;
- justify the use of rate control on slow responding processes such as heat exchangers;
- explain why rate control is not used on fast responding processes.
- sketch the open loop response curve for a control system with proportional plus derivative control modes;
- state which combinations of the control modes will most likely be found in typical control schemes;

- sketch typical control schemes for level, pressure, flow and temperature applications.

Note

INSTRUMENTATION EQUIPMENT

Note

2.0 INTRODUCTION

Instrumentation is the art of measuring the value of some plant parameter, pressure, flow, level or temperature to name a few and supplying a signal that is proportional to the measured parameter. The output signals are standard signal and can then be processed by other equipment to provide indication, alarms or automatic control. There are a number of standard signals; however, those most common in a CANDU plant are the 4-20 mA electronic signal and the 20-100 kPa pneumatic signal.

This section of the course is going to deal with the instrumentation equipment normal used to measure and provide signals. We will look at the measurement of five parameters: pressure, flow, level, temperature, and neutron flux.

2.1 PRESSURE MEASUREMENT

This module will examine the theory and operation of pressure detectors (bourdon tubes, diaphragms, bellows, forced balance and variable capacitance). It also covers the variables of an operating environment (pressure, temperature) and the possible modes of failure.

2.1.1 General Theory

Pressure is probably one of the most commonly measured variables in the power plant. It includes the measurement of steam pressure; feed water pressure, condenser pressure, lubricating oil pressure and many more. Pressure is actually the measurement of force acting on area of surface. We could represent this as:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \quad \text{or} \quad P = \frac{F}{A}$$

The units of measurement are either in pounds per square inch (PSI) in British units or Pascals (Pa) in metric. As one PSI is approximately 7000 Pa, we often use kPa and MPa as units of pressure.

2.1.2 Pressure Scales

Before we go into how pressure is sensed and measured, we have to establish a set of ground rules. Pressure varies depending on altitude above sea level, weather pressure fronts and other conditions.

The measure of pressure is, therefore, relative and pressure measurements are stated as either gauge or absolute.

Gauge pressure is the unit we encounter in everyday work (e.g., tire ratings are in gauge pressure).

A gauge pressure device will indicate zero pressure when bled down to atmospheric pressure (i.e., gauge pressure is referenced to atmospheric pressure). Gauge pressure is denoted by a (g) at the end of the pressure unit [e.g., kPa (g)].

Absolute pressure includes the effect of atmospheric pressure with the gauge pressure. It is denoted by an (a) at the end of the pressure unit [e.g., kPa (a)]. An absolute pressure indicator would indicate atmospheric pressure when completely vented down to atmosphere - it would not indicate scale zero.

$$\text{Absolute Pressure} = \text{Gauge Pressure} + \text{Atmospheric Pressure}$$

Figure 1 illustrates the relationship between absolute and gauge. Note that the base point for gauge scale is [0 kPa (g)] or standard atmospheric pressure 101.3 kPa (a).

The majority of pressure measurements in a plant are gauge. Absolute measurements tend to be used where pressures are below atmosphere. Typically this is around the condenser and vacuum building.

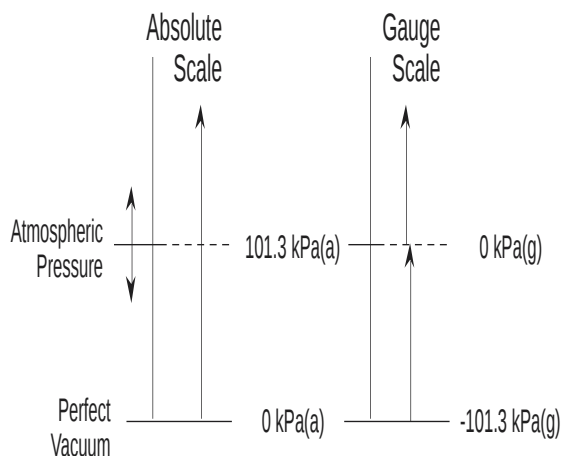


Figure 1

Relationship between Absolute and Gauge Pressures

2.1.3 Pressure Measurement

The object of pressure sensing is to produce a dial indication, control operation or a standard (4 - 20 mA) electronic signal that represents the pressure in a process.

To accomplish this, most pressure sensors translate pressure into physical motion that is in proportion to the applied pressure. The most common pressure sensors or primary pressure elements are described below.

Note

They include diaphragms, pressure bellows, bourdon tubes and pressure capsules. With these pressure sensors, physical motion is proportional to the applied pressure within the operating range.

You will notice that the term differential pressure is often used. This term refers to the difference in pressure between two quantities, systems or devices

Note

2.1.4 Common Pressure Detectors

Bourdon Tubes

Bourdon tubes are circular-shaped tubes with oval cross sections (refer to Figure 2). The pressure of the medium acts on the inside of the tube. The outward pressure on the oval cross section forces it to become rounded. Because of the curvature of the tube ring, the bourdon tube then bends as indicated in the direction of the arrow.

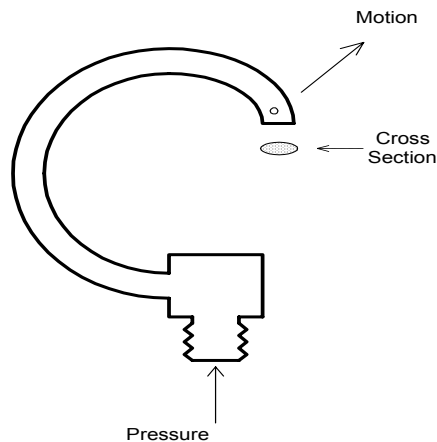


Figure 2
Bourdon Tube

Due to their robust construction, bourdon are often used in harsh environments and high pressures, but can also be used for very low pressures; the response time however, is slower than the bellows or diaphragm.

Bellows

Bellows type elements are constructed of tubular membranes that are convoluted around the circumference (see Figure 3). The membrane is attached at one end to the source and at the other end to an indicating device or instrument. The bellows element can provide a long range of motion (stroke) in the direction of the arrow when input pressure is applied.

Note

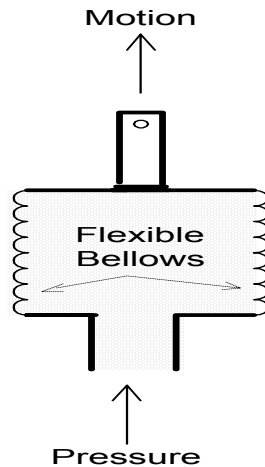


Figure 3
Bellows

Diaphragms

A diaphragm is a circular-shaped convoluted membrane that is attached to the pressure fixture around the circumference (refer to Figure 4). The pressure medium is on one side and the indication medium is on the other. The deflection that is created by pressure in the vessel would be in the direction of the arrow indicated.

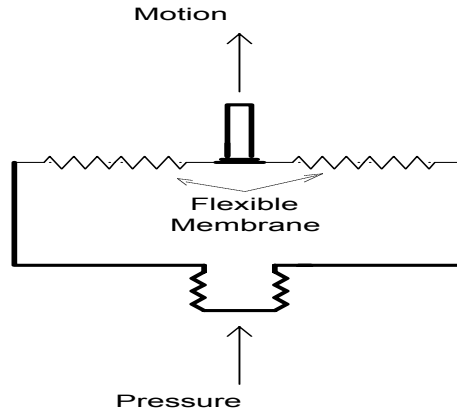


Figure 4
Diaphragm

Diaphragms provide fast acting and accurate pressure indication. However, the movement or stroke is not as large as the bellows

Capsules

There are two different devices that are referred to as capsule. The first is shown in figure 5. The pressure is applied to the inside of the capsule and

if it is fixed only at the air inlet it can expand like a balloon. This arrangement is not much different from the diaphragm except that it expands both ways.

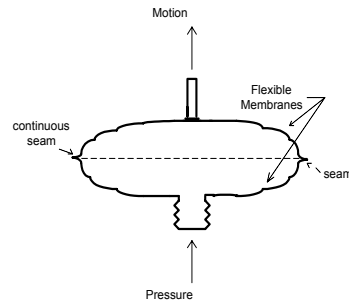


Figure 5
Capsule

The capsule consists of two circular shaped, convoluted membranes (usually stainless steel) sealed tight around the circumference. The pressure acts on the inside of the capsule and the generated stroke movement is shown by the direction of the arrow.

The second type of capsule is like the one shown in the differential pressure transmitter (DP transmitter) in figure 7. The capsule in the bottom is constructed with two diaphragms forming an outer case and the inter-space is filled with viscous oil. Pressure is applied to both side of the diaphragm and it will deflect towards the lower pressure.

To provide over-pressurized protection, a solid plate with diaphragm-matching convolutions is usually mounted in the center of the capsule. Silicone oil is then used to fill the cavity between the diaphragms for even pressure transmission.

Most DP capsules can withstand high static pressure of up to 14 MPa (2000 psi) on both sides of the capsule without any damaging effect. However, the sensitive range for most DP capsules is quite low. Typically, they are sensitive up to only a few hundred kPa of differential pressure.

Differential pressure that is significantly higher than the capsule range may damage the capsule permanently.

2.1.5 Differential Pressure Transmitters

Most pressure transmitters are built around the pressure capsule concept. They are usually capable of measuring differential pressure (that is, the

Note

difference between a high pressure input and a low pressure input) and therefore, are usually called DP transmitters or DP cells.

Note

Figure 6 illustrates a typical DP transmitter. A differential pressure capsule is mounted inside a housing. One end of a force bar is connected to the capsule assembly so that the motion of the capsule can be transmitted to outside the housing. A sealing mechanism is used where the force bar penetrates the housing and also acts as the pivot point for the force bar. Provision is made in the housing for high- pressure fluid to be applied on one side of the capsule and low-pressure fluid on the other. Any difference in pressure will cause the capsule to deflect and create motion in the force bar. The top end of the force bar is then connected to a position detector, which via an electronic system will produce a 4 - 20 ma signal that is proportional to the force bar movement.

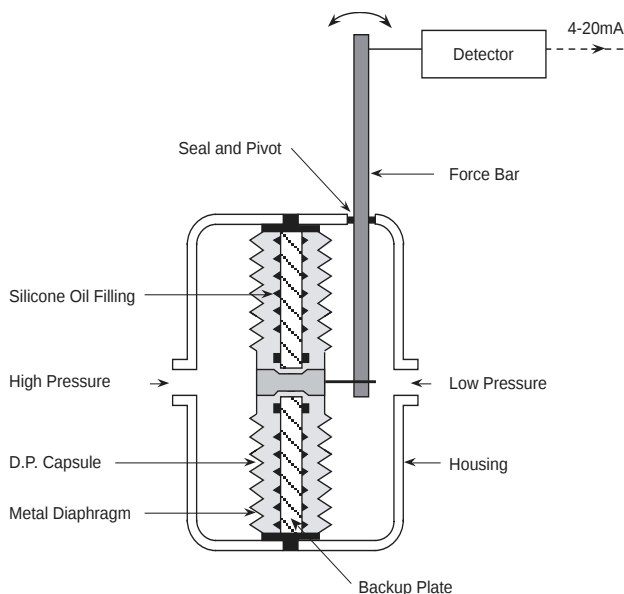


Figure 6
Typical DP Transmitter Construction

This DP transmitter would be used in an installation as shown in Figure 7.

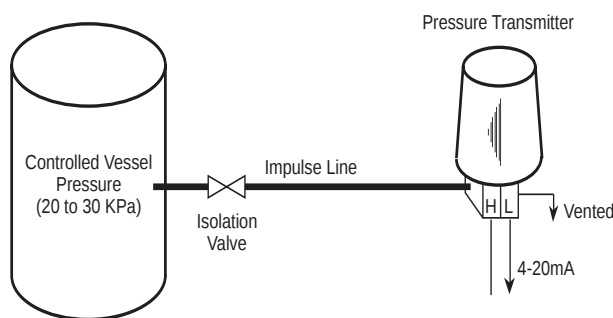


Figure 7
DP Transmitter Application

Note

A DP transmitter is used to measure the gas pressure (in gauge scale) inside a vessel. In this case, the low-pressure side of the transmitter is vented to atmosphere and the high-pressure side is connected to the vessel through an isolating valve. The isolating valve facilitates the removal of the transmitter.

The output of the DP transmitter is proportional to the gauge pressure of the gas, i.e., 4 mA when pressure is 20 kPa and 20 mA when pressure is 30 kPa.

2.1.6 Strain Gauges

The strain gauge is a device that can be affixed to the surface of an object to detect the force applied to the object. One form of the strain gauge is a metal wire of very small diameter that is attached to the surface of a device being monitored.

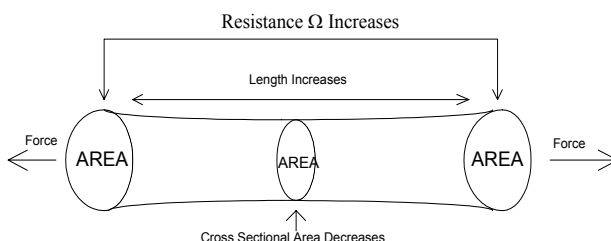


Figure 8
Strain Gauge

For a metal, the electrical resistance will increase as the length of the metal increases or as the cross sectional diameter decreases.

When force is applied as indicated in Figure 8, the overall length of the wire tends to increase while the cross-sectional area decreases.

The amount of increase in resistance is proportional to the force that produced the change in length and area. The output of the strain gauge is a change in resistance that can be measured by the input circuit of an amplifier.

Strain gauges can be bonded to the surface of a pressure capsule or to a force bar positioned by the measuring element. Shown in Figure 9 (next page) is a strain gauge that is bonded to a force beam inside the DP capsule. The change in the process pressure will cause a resistive change in the strain gauges, which is then used to produce a 4-20 mA signal.

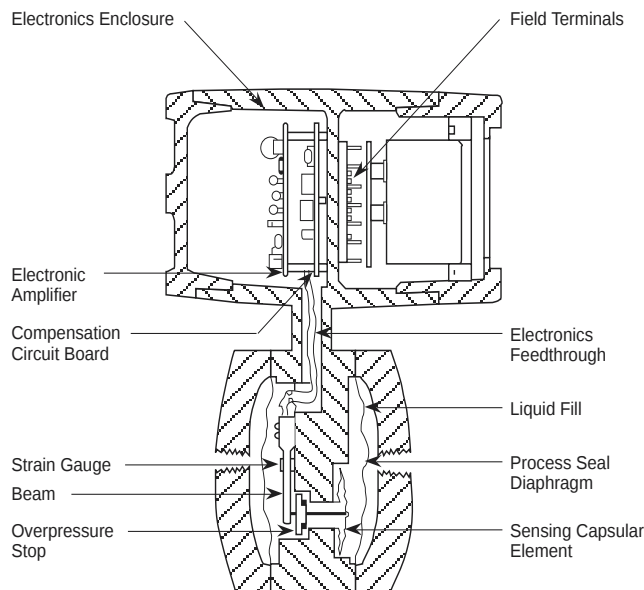


Figure 9
Resistive Pressure Transmitter

Note

2.1.7 Capacitance Capsule

Similar to the strain gauge, a capacitance cell measures changes in electrical characteristic. As the name implies the capacitance cell measures changes in capacitance. The capacitor is a device that stores electrical charge. It consists of metal plates separated by an electrical insulator. The metal plates are connected to an external electrical circuit through which electrical charge can be transferred from one metal plate to the other.

The capacitance of a capacitor is a measure of its ability to store charge. The capacitance of a capacitor is directly proportional to the area of the metal plates and inversely proportional to the distance between them. It also depends on a characteristic of the insulating material between them. This characteristic, called permittivity is a measure of how well the insulating material increases the ability of the capacitor to store charge.

$$C = \epsilon \frac{A}{d}$$

C is the capacitance in Farads

A is the area of the plates

D is the distance of the plates

ϵ is the permittivity of the insulator

By building a DP cell capsule so there are capacitors inside the cell capsule, differential pressures can be sensed by the changes in capacitance of the capacitors as the pressure across the cell is varied.

2.1.8 Impact of Operating Environment

All of the sensors described in this module are widely used in control and instrumentation systems throughout the power station.

Their existence will not normally be evident because the physical construction will be enclosed inside manufacturers' packaging. However, each is highly accurate when used to measure the right quantity and within the rating of the device. The constraints are not limited to operating pressure. Other factors include temperature, vapour content and vibration.

Vibration

The effect of vibration is obvious in the inconsistency of measurements, but the more dangerous result is the stress on the sensitive membranes, diaphragms and linkages that can cause the sensor to fail. Vibration can come from many sources.

Some of the most common are the low level constant vibration of an unbalanced pump impeller and the larger effects of steam hammer. External vibration (loose support brackets and insecure mounting) can have the same effect.

Temperature

The temperature effects on pressure sensing will occur in two main areas:

The volumetric expansion of vapour is of course temperature dependent. Depending on the system, the increased pressure exerted is usually already factored in.

The second effect of temperature is not so apparent. An operating temperature outside the rating of the sensor will create significant error in the readings. The bourdon tube will indicate a higher reading when exposed to higher temperatures and lower readings when abnormally cold - due to the strength and elasticity of the metal tube. This same effect applies to the other forms of sensors listed.

Vapour Content

The content of the gas or fluid is usually controlled and known. However, it is mentioned at this point because the purity of the substance whose pressure is being monitored is of importance - whether gaseous or fluid - especially, if the device is used as a differential pressure device in measuring flow of a gas or fluid.

Higher than normal density can force a higher dynamic reading depending on where the sensors are located and how they are used. Also, the vapour density or ambient air density can affect the static pressure sensor readings

and DP cell readings. Usually, lower readings are a result of the lower available pressure of the substance. However, a DP sensor located in a hot and very humid room will tend to read high.

Note

2.1.9 Failures and Abnormalities

Over-Pressure

All of the pressure sensors we have analyzed are designed to operate over a rated pressure range. Plant operating systems rely on these pressure sensors to maintain high accuracy over that given range. Instrument readings and control functions derived from these devices could place plant operations in jeopardy if the equipment is subjected to over pressure (over range) and subsequently damaged. If a pressure sensor is over ranged, pressure is applied to the point where it can no longer return to its original shape, thus the indication would return to some value greater than the original.

Diaphragms and bellows are usually the most sensitive and fast-acting of all pressure sensors.

They are also however, the most prone to fracture on over-pressuring. Even a small fracture will cause them to read low and be less responsive to pressure changes. Also, the linkages and internal movements of the sensors often become distorted and can leave a permanent offset in the measurement. Bourdon tubes are very robust and can handle extremely high pressures although, when exposed to over-pressure, they become slightly distended and will read high. Very high over-pressuring will of course rupture the tube.

Faulty Sensing Lines

Faulty sensing lines create inaccurate readings and totally misrepresent the actual pressure

When the pressure lines become partially blocked, the dynamic response of the sensor is naturally reduced and it will have a slow response to change in pressure. Depending on the severity of the blockage, the sensor could even retain an incorrect zero or low reading, long after the change in vessel pressure.

A cracked or punctured sensing line has the characteristic of consistently low readings. Sometimes, there can be detectable down-swings of pressure followed by slow increases.

Loss of Loop Electrical Power

As with any instrument that relies on AC power, the output of the D/P transmitters will drop to zero or become irrational with a loss of power supply.

Note

2.2 FLOW MEASUREMENT

There are various methods used to measure the flow rate of steam, water, lubricants, air, etc., in a nuclear generating station. However, in this module will look at the most common, namely the DP cell type flow detector. Also in this section we will discuss the application of a square root extractor and cut-off relay plus the possible sources of errors in flow measurements and different failure modes that can occur.

Note

2.2.1 Flow Detectors

To measure the rate of flow by the differential pressure method, some form of restriction is placed in the pipeline to create a pressure drop. Since flow in the pipe must pass through a reduced area, the pressure before the restriction is higher than after or downstream. Such a reduction in pressure will cause an increase in the fluid velocity because the same amount of flow must take place before the restriction as after it. Velocity will vary directly with the flow and as the flow increases a greater pressure differential will occur across the restriction. So by measuring the differential pressure across a restriction, one can measure the rate of flow.

Orifice Plate

The orifice plate is the most common form of restriction that is used in flow measurement. An orifice plate is basically a thin metal plate with a hole bored in the center. It has a tab on one side where the specification of the plate is stamped. The upstream side of the orifice plate usually has a sharp, edge. Figure 1 shows a representative orifice plate.

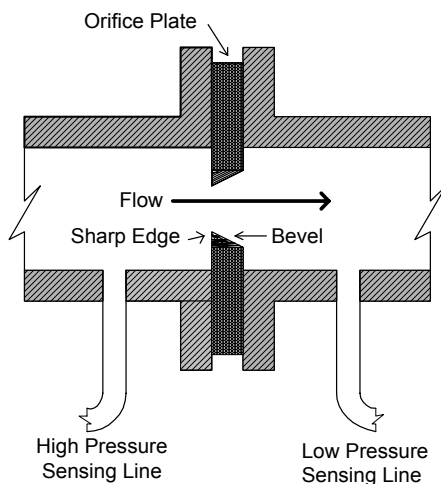


Figure 1
A Typical Orifice Plate

Note

When an orifice plate is installed in a flow line (usually clamped between a pair of flanges), increase of fluid flow velocity through the reduced area at the orifice develops a differential pressure across the orifice. This pressure is a function of flow rate.

With an orifice plate in the pipe work, static pressure increases slightly upstream of the orifice (due to back pressure effect) and then decreases sharply as the flow passes through the orifice, reaching a minimum at a point called the vena contracta where the velocity of the flow is at a maximum. Beyond this point, static pressure starts to recover as the flow slows down. However, with an orifice plate, static pressure downstream is always considerably lower than the upstream pressure. In addition some pressure energy is converted to sound and heat due to friction and turbulence at the orifice plate. Figure 2 shows the pressure profile of an orifice plate installation.

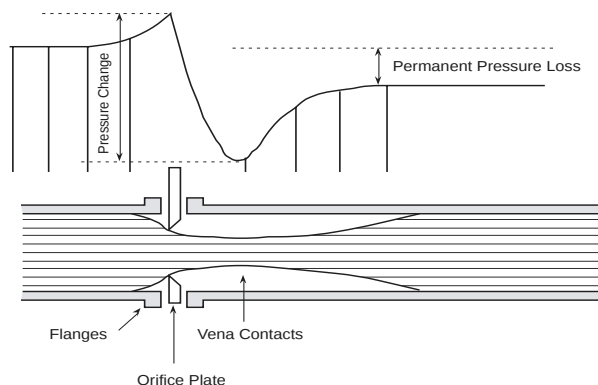


Figure 2
Orifice Plate Installation with Pressure Profile

On observing Figure 2, one can see that the measured differential pressure developed by an orifice plate also depends on the location of the pressure sensing points or pressure taps.

Flange Taps

Flange taps are the most widely used pressure tapping location for orifices. They are holes bored through the flanges, located one inch upstream and one inch downstream from the respective faces of the orifice plate. A typical flange tap installation is shown in Figure 3. The upstream and downstream sides of the orifice plate are connected to the high pressure and low-pressure sides of a DP transmitter. A pressure transmitter, when installed to measure flow, can be called a flow transmitter. As in the case of level measurement, the static pressure in the pipe-work could be many times higher than the differential pressure created by the orifice plate.

Note

In order to use a capsule that is sensitive to low differential pressure, a three-valve manifold has to be used to protect the DP capsule from being over-ranged. The three valve manifold is discussed in more detail in the section on level measurement.

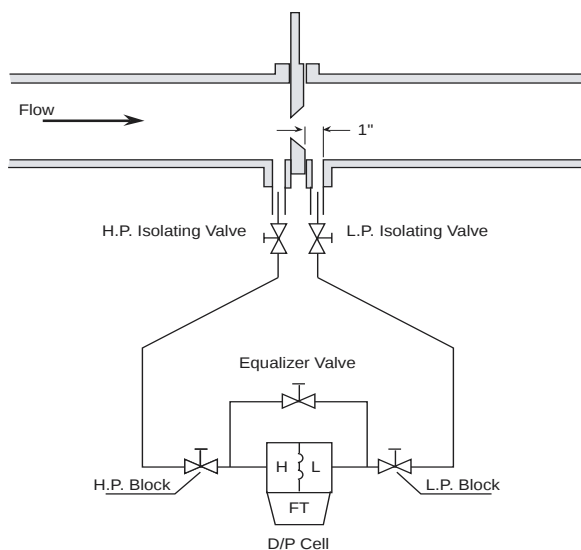


Figure 3
Orifice Plate with Flange Taps and Three Valve Manifold

Corner Taps

Corner taps are located right at upstream and downstream faces of the orifice plates (see Figure 4).

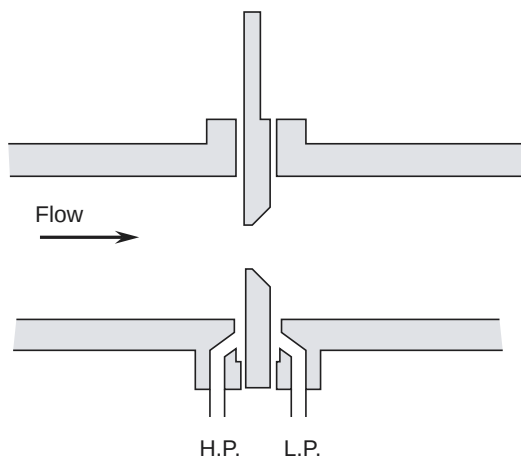


Figure 4
Orifice Plate with Corner Taps

Vena Contracta Taps

Vena contracta taps are located one pipe inner diameter upstream and at the point of minimum pressure, usually one half pipe inner diameter downstream (Figure 5).

Note

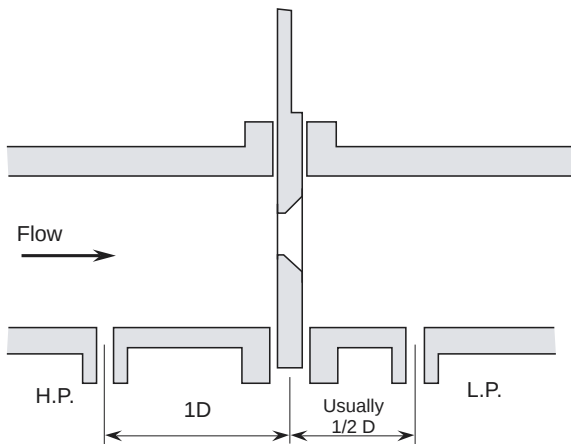


Figure 5
Orifice Plate with Vena Contracta Taps

Pipe Taps

Pipe taps are located two and a half pipe inner diameters upstream and eight pipe inner diameters downstream.

When an orifice plate is used with one of the standardized pressure tap locations, an on-location calibration of the flow transmitter is not necessary. Once the ratio and the kind of pressure tap to be used are decided, there are empirically derived charts and tables available to facilitate calibration.

Advantages and Disadvantages of Orifice Plates

Advantages of orifice plates include:

- High differential pressure generated
- Exhaustive data available
- Low purchase price and installation cost
- Easy replacement

Disadvantages include:

- High permanent pressure loss implies higher pumping cost.
- Cannot be used on dirty fluids, slurries or wet steam as erosion will alter the differential pressure generated by the orifice plate.

Note

Venturi Tubes

For applications where high permanent pressure loss is not tolerable, a venturi tube (Figure 6) can be used. Because of its gradually curved inlet and outlet cones, almost no permanent pressure drop occurs. This design also minimizes wear and plugging by allowing the flow to sweep suspended solids through without obstruction.

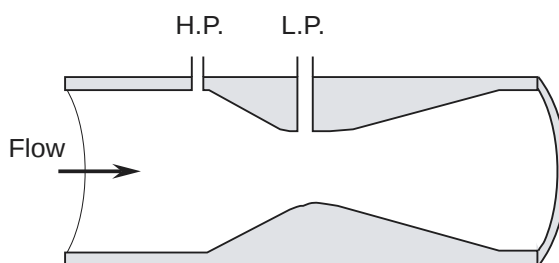


Figure 6
Venturi Tube Installation

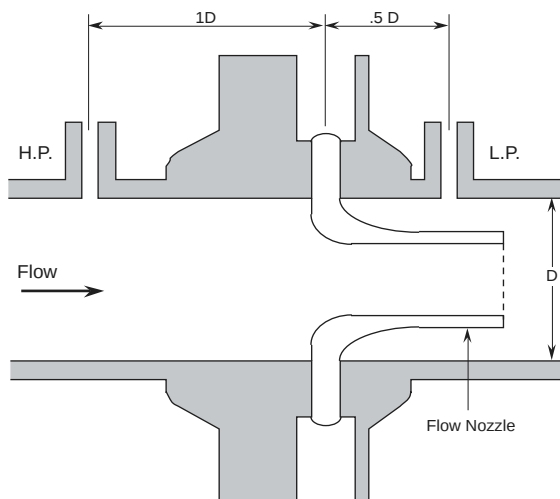
However a Venturi tube does have disadvantages:

- Calculated calibration figures are less accurate than for orifice plates. For greater accuracy, each individual Venturi tube has to be flow calibrated by passing known flows through the Venturi and recording the resulting differential pressures.
- The differential pressure generated by a venturi tube is lower than for an orifice plate and, therefore, a high sensitivity flow transmitter is needed.
- It is more bulky and more expensive.

As a side note; one application of the Venturi tube is the measurement of flow in the primary heat transport system. Together with the temperature change across these fuel channels, thermal power of the reactor can be calculated.

Flow Nozzle

A flow nozzle is also called a half venturi. Figure 7 shows a typical flow nozzle installation.



Note

Figure 7
Flow Nozzle Installation

The flow nozzle has properties between an orifice plate and a venturi. Because of its streamlined contour, the flow nozzle has a lower permanent pressure loss than an orifice plate (but higher than a venturi). The differential it generates is also lower than an orifice plate (but again higher than the venturi tube). They are also less expensive than the venturi tubes.

Flow nozzles are widely used for flow measurements at high velocities. They are more rugged and more resistant to erosion than the sharp-edged orifice plate. An example use of flow nozzles are the measurement of flow in the feed and bleed lines of the PHT system.

Elbow Taps

Centrifugal force generated by a fluid flowing through an elbow can be used to measure fluid flow. As fluid goes around an elbow, a high-pressure area appears on the outer face of the elbow. If a flow transmitter is used to sense this high pressure and the lower pressure at the inner face of the elbow, flow rate can be measured. Figure 8 shows an example of an elbow tap installation.

One use of elbow taps is the measurement of steam flow from the boilers, where the large volume of saturated steam at high pressure and temperature could cause an erosion problem for other primary devices.

Another advantage is that the elbows are often already in the regular piping configuration so no additional pressure loss is introduced.

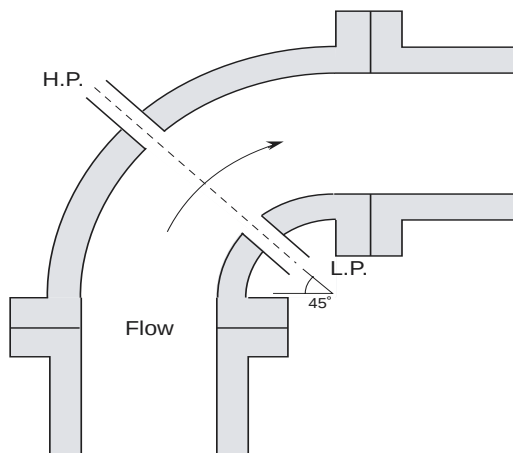


Figure 8
Elbow Tap Installation

Pitot Tubes

Pitot tubes also utilize the principles captured in Bernoulli's equation, to measure flow. Most pitot tubes actually consist of two tubes. One, the low-pressure tube measures the static pressure in the pipe. The second, the high-pressure tube is inserted in the pipe in such a way that the flowing fluid is stopped in the tube. The pressure in the high-pressure tube will be the static pressure in the system plus a pressure dependant on the force required stopping the flow.

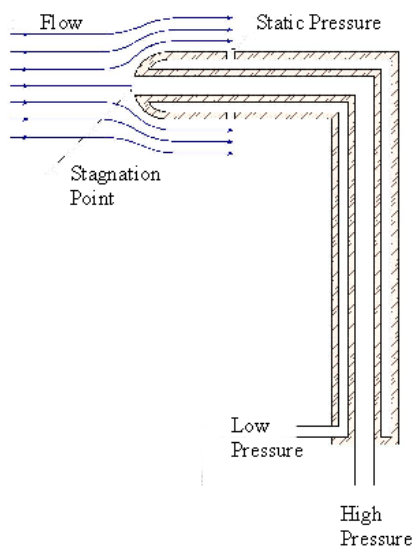


Figure 9
Pitot Tube

Pitot tubes are more common measuring gas flows than liquid flows. They suffer from a couple of problems.

Note

The pressure differential is usually small and hard to measure.

The differing flow velocities across the pipe make the accuracy dependent on the flow profile of the fluid and the position of the pitot in the pipe.

Note

Annubar

An annubar is very similar to a pitot tube. The difference is that there is more than one hole into the pressure measuring chambers. The pressure in the high-pressure chamber represents an average of the velocity across the pipe. Annubars are more accurate than pitots as they are not as position sensitive or as sensitive to the velocity profile of the fluid.

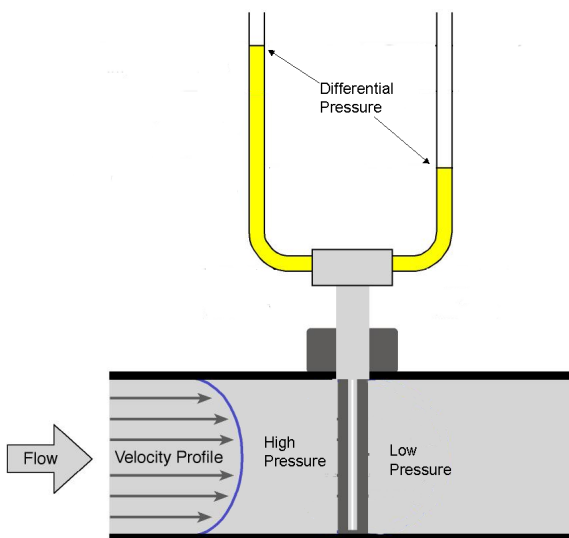
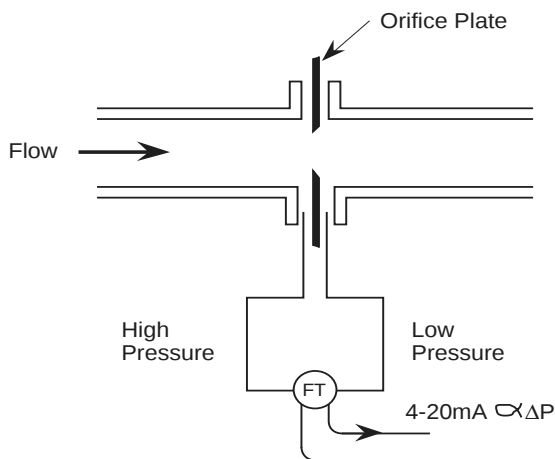


Figure 10
Annubar

2.2.2 Square Root Extractor

Up to now, our flow measurement loop can be represented by the installation shown in Figure 9. The high and low-pressure taps of the primary device (orifice type shown) are fed by sensing lines to a differential pressure (D/P) cell. The output of the D/P cell acts on a pressure to milli-amp transducer, which transmits a variable 4-20 ma signal. The D/P cell and transmitter are shown together as a flow transmitter (FT).



Note

Figure 11
A Flow Loop with Orifice Plate

This simple system although giving an indication of the flow rate (Q), is actually transmitting a signal proportional to the differential pressure (ΔP). However, the relationship between the volume of flow Q and ΔP is not linear. Thus such a system would not be appropriate in instrumentation or metering that requires a linear relationship or scale.

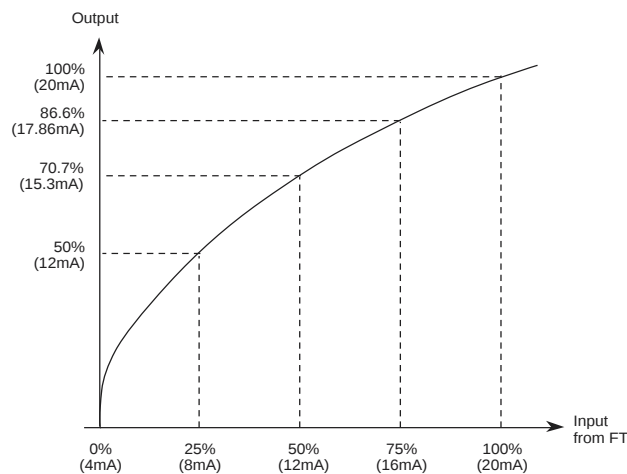
In actuality the differential pressure increases in proportion to the square of the flow rate.

We can write this as: $\Delta P \propto Q^2$

In other words the flow rate (Q) is proportional; to the square root of the differential pressure.

Volumetric Flow Rate = $Q \propto \sqrt{\Delta P}$

To convert the signal from the flow transmitter, (figure 9 above) to one that is directly proportional to the flow-rate, one has to obtain or extract the square root of the signal from the flow transmitter. Figure 10 illustrates the input - output relationship of a square root extractor.



Note

Figure 12
Square Root Extractor Input and Output

The square root extractor is an electronic (or pneumatic) device that takes the square root of the signal from the flow transmitter and outputs a corresponding linear flow signal. Several methods are used in the construction of square root extractors. However, it is beyond the scope of this course to discuss the actual circuitries.

A typical square root extractor installation is shown in Figure 13. This system would produce a 4-20-ma signal that is linear with the flow rate.

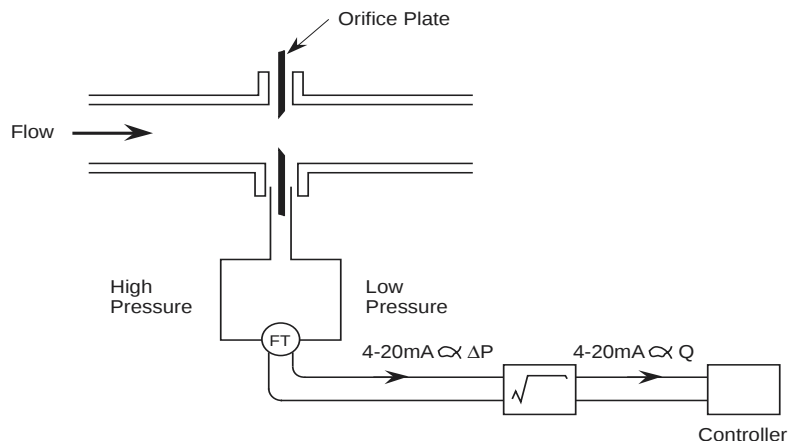


Figure 13

A Typical Square Root Extractor Installation

Square root extractors are usually current operated devices so they can be connected directly in the 4-20 mA current loop of a flow transmitter. The output of the square root extractor is again a 4-20 mA signal. This signal is directly proportional to the flow-rate in the pipe-work.

The signal from the square root extractor usually goes to a controller, as shown in Figure 13.

The controller (which can be regarded as an analog computer) is used to control the final control element, usually a valve.

Cut-off relay

Square root extractors do have a drawback. At low values of input, very small changes in the input (differential pressure) to the extractor will cause a large change in the square root output (flow indication). This system is described as having high gain at values close to zero input. Observe figure 14 below, which is an expanded version of figure 12 at the lower end. The amount of change from zero pressure to A and from A to B is identical. However, for the same input change (ΔP), the gain at low input is greater.

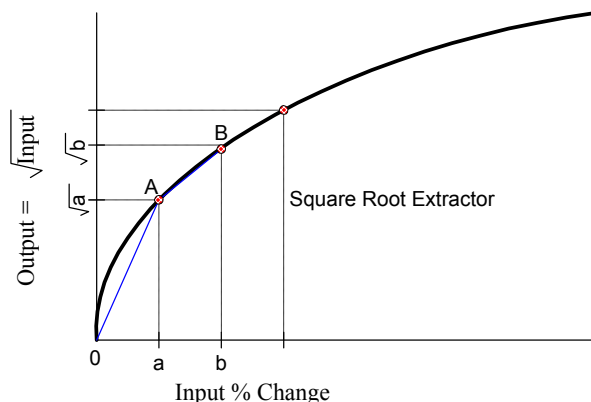


Figure 14
Square Root Extractor Graph Expanded View

To illustrate the effect of the very high gain in the square root extractor at low scale values consider a typical situation. A pipe valve is closed and the zero flow produces a 4 mA output from the flow transmitter. If due to noise, temperature or other disturbances, the input drifted from 0% to 1% (i.e., from 4 mA to 4.16 mA), the output would have changed from 0% to 10% (4 mA to 5.6 mA). It is obvious that this significant error sent to the controller has to be eliminated.

For this reason, square root extractors are equipped with cut-off relays. The setting for the relay can be adjusted from 6% to 10% of output. Shown in Figure 15 is a response curve for a cut-off relay set at 7% output. In this case, any input signal below $(0.07)^2$ or 0.49% would be ignored by the extractor. The output of the extractor would remain at 0% as long as input is below 0.49%.

Note

When the input exceeded 0.49%, the output would resume its normal curve, starting at 7%.

Note

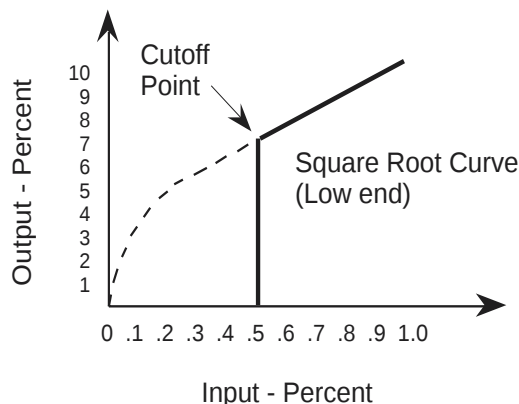


Figure 15
Response Curve for Extractor with 7% Cut-Off Setting

2.2.3 Density Compensating Flow Detectors

It must be remembered that a DP transmitter used for flow measurement, measures differential pressure, not the volume or mass of flow. We have shown that differential pressure instruments require that the square root differential pressure be taken to obtain volumetric flow Q :

$$\text{Volume of Flow} = Q \propto \sqrt{\Delta P / \rho}$$

For compressible vapour such as steam, it is more important to know the mass of the flow W rather than the volume. To determine the mass of a liquid/gas the density (ρ = mass per unit volume) must also be obtained.

$$\text{Mass of Flow} = W = \rho Q \propto \sqrt{\rho \Delta P}$$

We also know that density varies directly with pressure and inversely with temperature:

$$\rho \propto K \frac{\text{pressure}}{\text{temperature}}$$

The coefficient K (which can be obtained from tables) depends on a number of variables including the pipe size and the characteristics of the fluid/gas. It is sufficient to say that if the process temperature and static pressure is known, then the density can be obtained.

Note

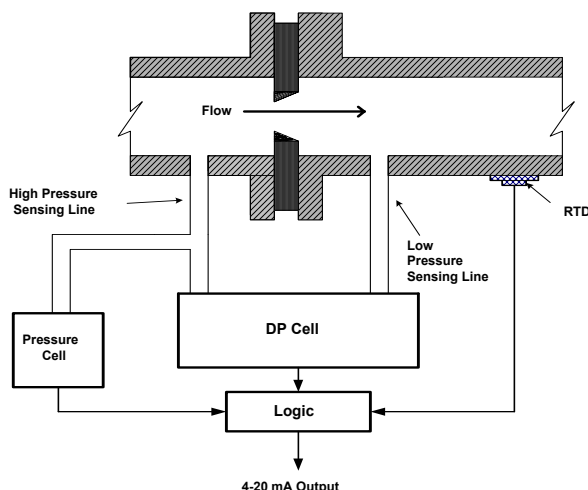


Figure 16
Density Compensating Flow Detector

The density compensating flow detector (shown schematically in figure 16) is a necessity for steam flow between the boilers, re-heaters and the turbines, where the mass (weight) of the steam is more important than the volume.

Process Conditions

As previously stated, the measurement of flow using any of the devices described above is purely inferential. It relies on the signal from a differential pressure (D/P) cell to obtain an inferred flow measurement. This flow measurement could be either the volume or mass of the liquid/gas. In either case the instrumentation can be affected by the process conditions. The three main parameters are:

Fluid Temperature

The temperature of the flow quantity has a dramatic effect on the flow measurement. Under the right conditions the liquid can either boil (producing gas pockets and turbulence) or freeze (producing blockages and distorted flow patterns) at the sensors.

At the onset of temperature related flow instrumentation problems the meter readings will become unstable. Gas pockets (causing intermittent low pressure) at the high pressure sensing lines will cause apparent low flow fluctuations. This is more predominant in orifice and flow-nozzle installations. Turbulence at the low-pressure sensor will usually increase as the temperature increases to cause a more stable but incorrect high flow reading.

Note

Temperature also affects the density of the liquid/gas, as per the following relationship (where K is a constant for the liquid/gas).

$$\rho \propto K \frac{\text{pressure}}{\text{temperature}}$$

The mass flow (i.e., pounds of steam per minute) varies inversely with temperature and must be compensated for using a density compensating flow detector.

The elbow tap sensor uses centrifugal force to detect flow and is most sensitive to density changes. The flow readings will increase as the temperature decreases.

Fluid Pressure

As we have just seen, pressure also affects the density of the fluid/gas. For the elbow tap previously mentioned, the flow readings will increase as the process pressure increases.

$$\rho \propto K \frac{\text{pressure}}{\text{temperature}}$$

For all types of D/P flow sensors, mass flow will of course increase as the pressure increases. To obtain the correct measurement of mass flow, a density compensating flow detector must be used as described previously.

2.2.4 Flow Measurement Errors

We have already discussed the pros and cons of each type of flow detector commonly found in a generating station. Some, such as the orifice, are more prone to damage by particulate or saturated steam than others. However, there are common areas where the flow readings can be inaccurate or invalid.

Erosion

Particulate, suspended solids or debris in the piping will not only plug up the sensing lines, it will erode the sensing device. The orifice, by its design with a thin, sharp edge is most affected, but the flow nozzle and even venturi can also be damaged. As the material wears away, the differential pressure between the high and low sides of the sensor will drop and the flow reading will decrease.

Over ranging Damage to the D/P Cell

Again, as previously described, the system pressures are usually much greater than the differential pressure and three valve manifolds must be correctly used.

Vapour Formation in the Throat

D/P flow sensors operate on the relation between velocity and pressure. As gas requires less pressure to compress, there is a greater pressure differential across the D/P cell when the gas expands on the LP side of the sensor. The flow sensor will indicate a higher flow rate than there actually is. The turbulence created at the LP side of the sensor will also make the reading somewhat unstable. A small amount of gas or vapour will make a large difference in the indicated flow rate.

The opposite can occur if the vapour forms in the HP side of the sensor due to cavitation or gas pockets when the fluid approaches the boiling point. In such an instance there will be a fluctuating pressure drop across the D/P cell that will give an erroneously low (or even negative) D/P reading.

Clogging of Throat

Particulate or suspended solids can damage the flow sensor by the high velocities wearing at the flow sensor surfaces. Also, the build-up of material in the throat of the sensor increases the differential pressure across the cell. The error in flow measurement will increase as the flow increases.

Plugged or Leaking Sensing Lines

The effects of plugged or leaking D/P sensing lines is the same as described in previous modules, however the effects are more pronounced with the possible low differential pressures. Periodic maintenance and bleeding of the sensing lines is a must. The instrument error will depend on where the plug/leak is:

On the HP side a plugged or leaking sensing line will cause a lower reading. The reading will become irrational if the LP pressure equals or exceeds the HP sensing pressure.

On the LP side a plugged or leaking sensing line will cause a higher reading.

Note

2.3 LEVEL MEASUREMENT

Accurate continuous measurement of volume of fluid in containers has always been a challenge to industry. This is even more so in the nuclear station environment where the fluid could be acidic/caustic or under very high pressure/temperature. We will now examine the measurement of fluid level in vessels and the effect of temperature and pressure on this measurement. We will also consider the operating environment on the measurement and the possible modes of device failure.

Note

2.3.1 Level Measurement Basics

Very simple systems employ external sight glasses or tubes to view the height and hence the volume of the fluid. Others utilize floats connected to variable potentiometers or rheostats that will change the resistance according to the amount of motion of the float. This signal is then inputted to transmitters that send a signal to an instrument calibrated to read out the height or volume.

In this module, we will examine the more challenging situations that require inferential level measurement. This technique obtains a level indication indirectly by monitoring the pressure exerted by the height of the liquid in the vessel.

The pressure at the base of a vessel containing liquid is directly proportional to the height of the liquid in the vessel. This is termed hydrostatic pressure. As the level in the vessel rises, the pressure exerted by the liquid at the base of the vessel will increase linearly. Mathematically, we have:

$$P = S \cdot H$$

where

P = Pressure (Pa)

S = Weight density of the liquid (N/m^3) = ρg

H = Height of liquid column (m)

ρ = Density (kg/m^3)

g = acceleration due to gravity (9.81 m/s^2)

The level of liquid inside a tank can be determined from the pressure reading if the weight density of the liquid is constant.

Differential Pressure (DP) capsules are the most commonly used devices to measure the pressure at the base of a tank.

When a DP transmitter is used for the purpose of measuring a level, it will be called a level transmitter.

To obtain maximum sensitivity, a pressure capsule has to be used, that has a sensitivity range that closely matches the anticipated pressure of the measured liquid. However, system pressures are often much higher than the actual hydrostatic pressure that is to be measured. If the process pressure is accidentally applied to only one side of the DP capsule during installation or removal of the DP cell from service, over ranging of the capsule would occur and the capsule could be damaged causing erroneous indications.

2.3.2 Three Valve Manifold

A three-valve manifold is a device that is used to ensure that the capsule will not be over-ranged. It also allows isolation of the transmitter from the process loop. It consists of two block valves - high pressure and low-pressure block valve - and an equalizing valve. Figure 1 shows a three valve manifold arrangement.

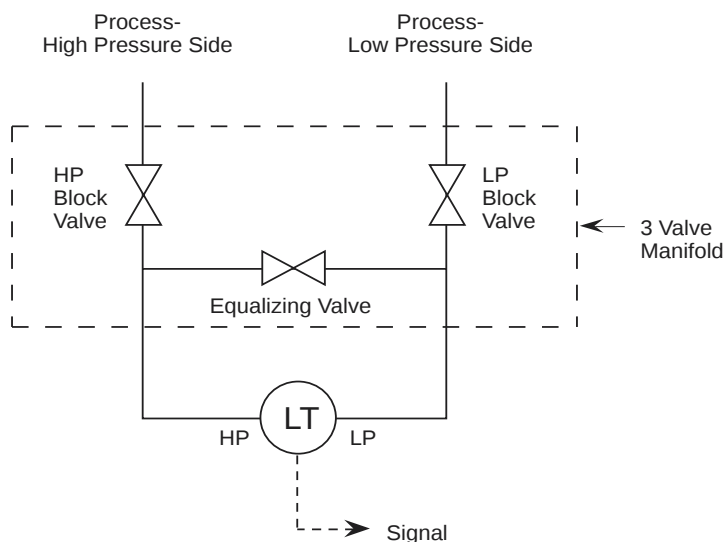


Figure 1
A Three Valve Manifold

During normal operation, the equalizing valve is closed and the two block valves are open. When the transmitter is put into or removed from service, the valves must be operated in such a manner that very high pressure is never applied to only one side of the DP capsule.

Note

Operational Sequences of Three-Valve Manifold Valving Transmitter into Service

To valve a DP transmitter into service an operator would perform the following steps:

1. Check all valves closed.
2. Open the equalizing valve – this ensures that the same pressure will be applied to both sides of the transmitter, i.e., zero differential pressure.
3. Open the High Pressure block valve slowly, check for leakage from both the high pressure and low-pressure side of the transmitter.
4. Close the equalizing valve – this locks the pressure on both sides of the transmitter.
5. Open the low-pressure block valve to apply process pressure to the low-pressure side of the transmitter and establish the working differential pressure.
6. The transmitter is now in service.

Note it may be necessary to bleed any trapped air from the capsule housing.

Removing Transmitter from Service

Reversal of the above steps allows the DP transmitter to be removed from service.

1. Close the low-pressure block valve.
2. Open the equalizing valve.
3. Close the high-pressure block valve.

The transmitter is now out of service.

Note the transmitter capsule housing still contains process pressure; this will require bleeding.

Note

2.3.3 Open Tank Measurement

The simplest application is the fluid level in an open tank. Figure 2 shows a typical open tank level measurement installation using a pressure capsule level transmitter.

Note

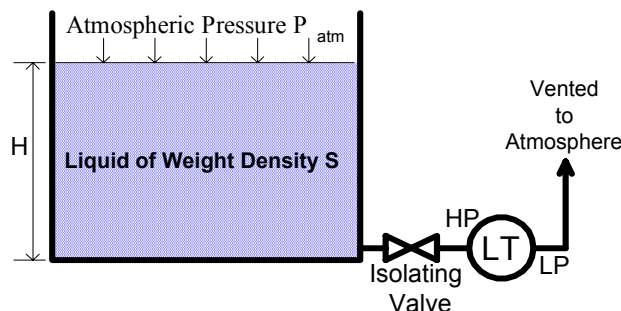


Figure 2
Open Tank Level Measurement Installation

If the tank is open to atmosphere, the high-pressure side of the level transmitter will be connected to the base of the tank while the low-pressure side will be vented to atmosphere. In this manner, the level transmitter acts as a simple pressure transmitter. We have:

$$P_{high} = P_{atm} + S \cdot H$$

$$P_{low} = P_{atm}$$

$$\text{Differential pressure } \Delta P = P_{high} - P_{low} = S \cdot H$$

The level transmitter can be calibrated to output 4 mA when the tank is at 0% level and 20 mA when the tank is at 100% level.

2.3.4 Closed Tank Measurement

Should the tank be closed and a gas or vapour exists on top of the liquid, the gas pressure must be compensated for. A change in the gas pressure will cause a change in transmitter output. Moreover, the pressure exerted by the gas phase may be so high that the hydrostatic pressure of the liquid column becomes insignificant. For example, the measured hydrostatic head in a CANDU boiler may be only three meters (30 kPa) or so, whereas the steam pressure is typically 5 MPa. Compensation can be achieved by applying the gas pressure to both the high and low-pressure sides of the level transmitter. This cover gas pressure is thus used as a back pressure or reference pressure on the LP side of the DP cell. One can also immediately see the need for the three-valve manifold to protect the DP cell against these pressures.

The different arrangement of the sensing lines to the DP cell is indicated a typical closed tank application (figure 3).

Figure 3 shows a typical closed tank installation.

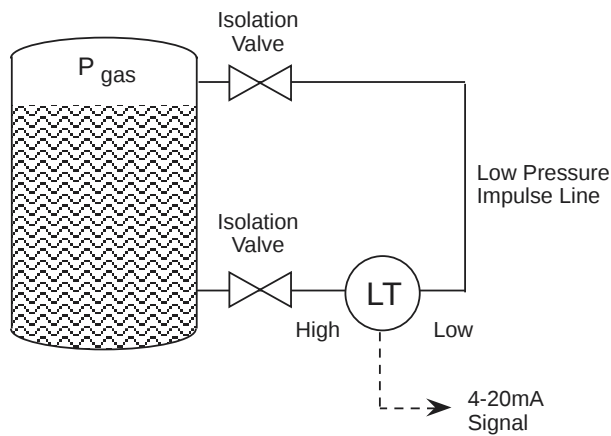


Figure 3
Typical Closed Tank Level Measurement System

We have:

$$P_{\text{high}} = P_{\text{gas}} + S \cdot H$$

$$P_{\text{low}} = P_{\text{gas}}$$

$$\Delta P = P_{\text{high}} - P_{\text{low}} = S \cdot H$$

The effect of the gas pressure is cancelled and only the pressure due to the hydrostatic head of the liquid is sensed. When the low-pressure impulse line is connected directly to the gas phase above the liquid level, it is called a dry leg.

Note

Dry Leg System

A full dry leg installation with three-valve manifold is shown in Figure 4 below.

Note

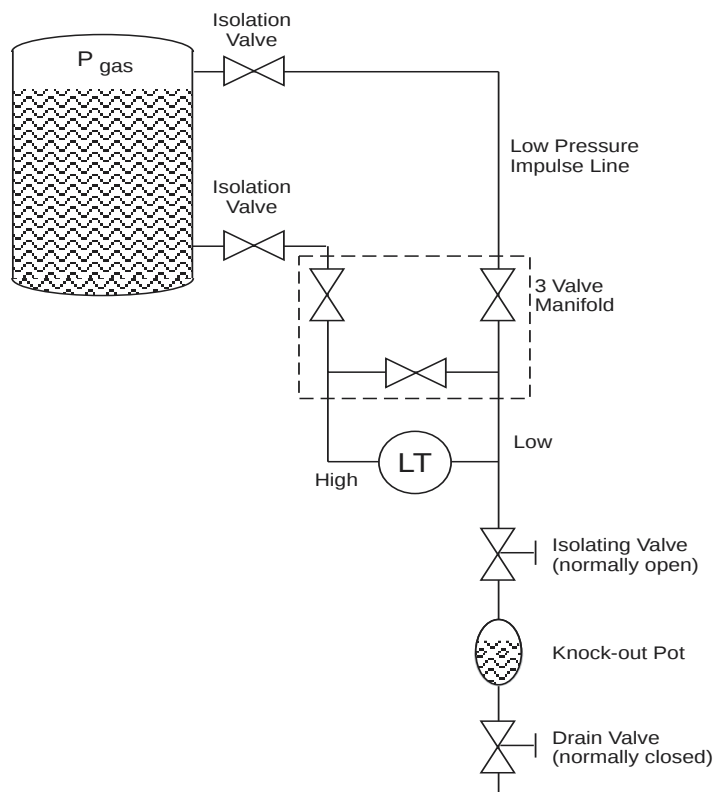


Figure 4
Dry Leg Installation with Three-Valve Manifold

If the gas phase is condensable, say steam, condensate will form in the low-pressure impulse line resulting in a column of liquid, which exerts extra pressure on the low-pressure side of the transmitter. A technique to solve this problem is to add a knockout pot below the transmitter in the low-pressure side as shown in Figure 4. Periodic draining of the condensate in the knockout pot will ensure that the impulse line is free of liquid.

In practice, a dry leg is seldom used because frequent maintenance is required. One example of a dry leg application is the measurement of liquid poison level in the poison injection tank, where the gas phase is non-condensable helium. In most closed tank applications, a wet leg level measurement system is used.

Wet Leg System

In a wet leg system, the low-pressure impulse line is completely filled with liquid (usually the same liquid as the process) and hence the name wet leg. A level transmitter, with the associated three-valve manifold, is used in an identical manner to the dry leg system.

Figure 5 shows a typical wet leg installation.

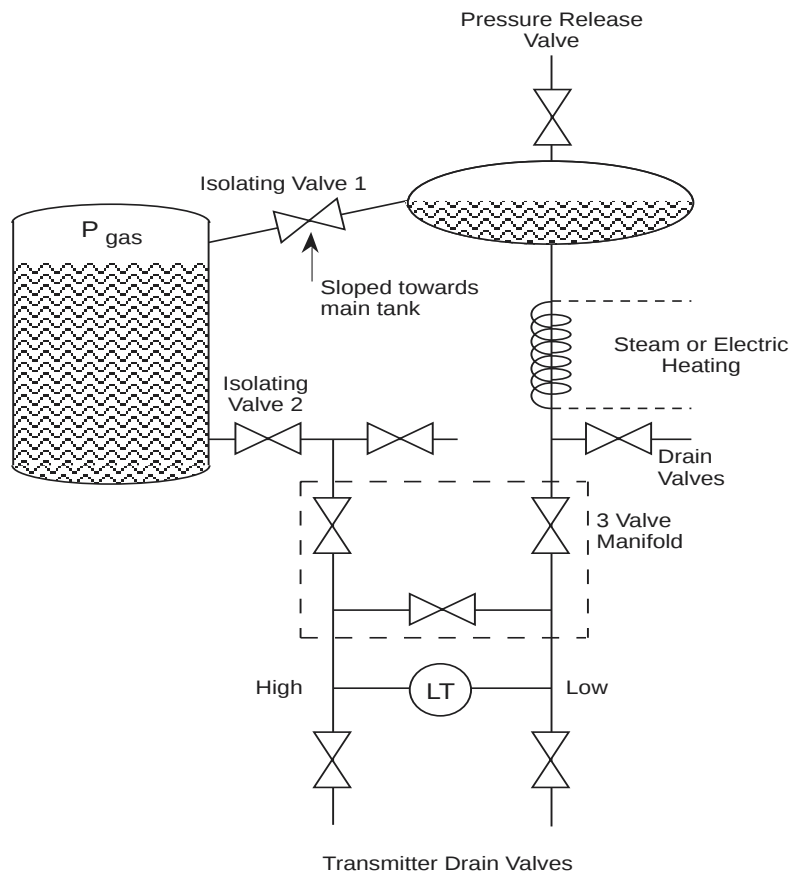


Figure 5
A Wet Leg Installation

At the top of the low pressure impulse line is a small catch tank. The gas phase or vapour will condense in the wet leg and the catch tank. The catch tank, with the inclined interconnecting line, maintains a constant hydrostatic pressure on the low-pressure side of the level transmitter. This pressure, being a constant, can easily be compensated for by calibration. (Note that operating the three-valve manifold in the prescribed manner helps to preserve the wet leg.)

Note

If the tank is located outdoors, trace heating of the wet leg might be necessary to prevent it from freezing. Steam lines or an electric heating element can be wound around the wet leg to keep the temperature of the condensate above its freezing point.

Note the two sets of drain valves. The transmitter drain valves would be used to drain (bleed) the transmitter only. The two drain valves located immediately above the three-valve manifold are used for impulse and wet leg draining and filling.

In addition to the three-valve manifold most transmitter installations have valves where the impulse lines connect to the process. These isolating valves, sometimes referred to as the root valves, are used to isolate the transmitter for maintenance.

Level Compensation

It would be idealistic to say that the DP cell can always be located at the exact the bottom of the vessel we are measuring fluid level in. Hence, the measuring system has to consider the hydrostatic pressure of the fluid in the sensing lines themselves. This leads to two compensations required.

Zero Suppression

In some cases, it is not possible to mount the level transmitter right at the base level of the tank. Say for maintenance purposes, the level transmitter has to be mounted X meters below the base of an open tank as shown in Figure 6.

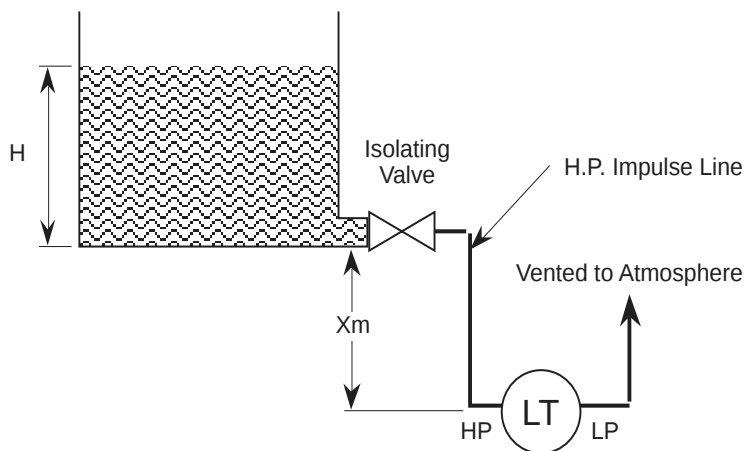


Figure 6
Level Transmitter with Zero Suppression

Note

The liquid in the tank exerts a varying pressure that is proportional to its level H on the high-pressure side of the transmitter. The liquid in the high-pressure impulse line also exerts a pressure on the high-pressure side. However, this pressure is a constant ($P = S \cdot X$) and is present at all times.

When the liquid level is at H meters, pressure on the high-pressure side of the transmitter will be:

$$P_{\text{high}} = S \cdot H + S \cdot X + P_{\text{atm}}$$

$$P_{\text{low}} = P_{\text{atm}}$$

$$\Delta P = P_{\text{high}} - P_{\text{low}} = S \cdot H + S \cdot X$$

That is, the pressure on the high-pressure side is always higher than the actual pressure exerted by the liquid column in the tank (by a value of $S \cdot X$). This constant pressure would cause an output signal that is higher than 4 mA when the tank is empty and above 20 mA when it is full. The transmitter has to be negatively biased by a value of $-S \cdot X$ so that the output of the transmitter is proportional to the tank level ($S \cdot H$) only. This procedure is called Zero Suppression and it can be done during calibration of the transmitter. A zero suppression kit can be installed in the transmitter for this purpose.

Zero Elevation

When a wet leg installation is used (see Figure 7 below), the low-pressure side of the level transmitter will always experience a higher pressure than the high-pressure side. This is due to the fact that the height of the wet leg (X) is always equal to or greater than the maximum height of the liquid column (H) inside the tank.

When the liquid level is at H meters, we have:

$$P_{\text{high}} = P_{\text{gas}} + S \cdot H$$

$$P_{\text{low}} = P_{\text{gas}} + S \cdot X$$

$$\Delta P = P_{\text{high}} - P_{\text{low}} = S \cdot H - S \cdot X$$

$$= -S (X - H)$$

The differential pressure ΔP sensed by the transmitter is always a negative number (i.e., low pressure side is at a higher pressure than high pressure side). ΔP increases from $P = -S \cdot X$ to $P = -S (X-H)$ as the tank level rises from 0% to 100%.

Note

If the transmitter were not calibrated for this constant negative error ($-S \cdot X$), the transmitter output would read low at all times.

To properly calibrate the transmitter, a positive bias ($+S \cdot X$) is needed to elevate the transmitter output.

This positive biasing technique is called zero elevation.

Note

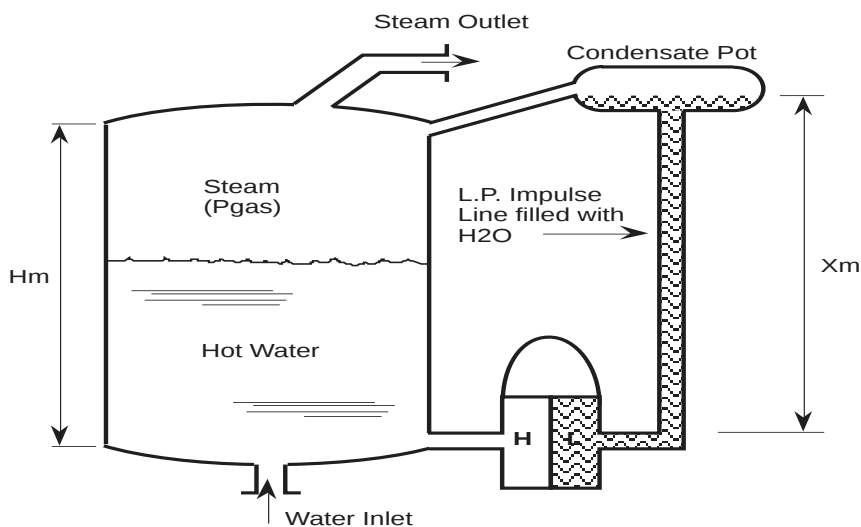


Figure 7
Requirement for Zero Elevation

2.3.5 Bubbler Level Measurement System

If the process liquid contains suspended solids or is chemically corrosive or radioactive, it is desirable to prevent it from coming into direct contact with the level transmitter. In these cases, a bubbler level measurement system, which utilizes a purge gas, can be used.

Open Tank Application for Bubbler System

Figure 8 illustrates a typical bubbler system installation.

Note

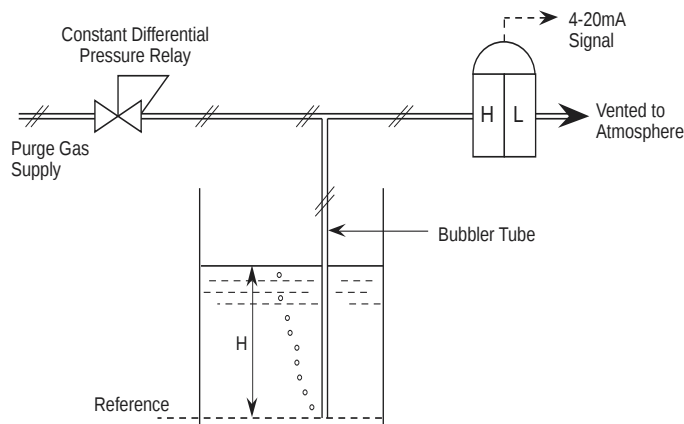


Figure 8
Bubbler Level Measurement System in Open Tank Application

As shown in Figure 8, a bubbler tube is immersed to the bottom of the vessel in which the liquid level is to be measured. A gas (called purge gas) is allowed to pass through the bubbler tube. Consider that the tank is empty. In this case, the gas will escape freely at the end of the tube and therefore the gas pressure inside the bubbler tube (called back pressure) will be at atmospheric pressure. However, as the liquid level inside the tank increases, pressure exerted by the liquid at the base of the tank (and at the opening of the bubbler tube) increases. The hydrostatic pressure of the liquid in effect acts as a seal, which restricts the escape of, purge gas from the bubbler tube.

As a result, the gas pressure in the bubbler tube will continue to increase until it just balances the hydrostatic pressure ($P = S \cdot H$) of the liquid. At this point the backpressure in the bubbler tube is exactly the same as the hydrostatic pressure of the liquid and it will remain constant until any change in the liquid level occurs. Any excess supply pressure will escape as bubbles through the liquid.

As the liquid level rises, the backpressure in the bubbler tube increases proportionally, since the density of the liquid is constant.

A level transmitter (DP cell) can be used to monitor this backpressure. In an open tank installation, the bubbler tube is connected to the high-pressure side of the transmitter, while the low pressure side is vented to atmosphere. The output of the transmitter will be proportional to the tank level.

Note

A constant differential pressure relay is often used in the purge gas line to ensure that constant bubbling action occurs at all tank levels. The constant differential pressure relay maintains a constant flow rate of purge gas in the bubbler tube regardless of tank level variations or supply fluctuation. This ensures that bubbling will occur to maximum tank level and the flow rate does not increase at low tank level in such a way as to cause excessive disturbances at the surface of the liquid. Note that bubbling action has to be continuous or the measurement signal will not be accurate.

An additional advantage of the bubbler system is that, since it measures only the backpressure of the purge gas, the exact location of the level transmitter is not important. The transmitter can be mounted some distance from the process. Open loop bubblers are used to measure levels in spent fuel bays.

Closed Tank Application for Bubbler System

If the bubbler system is to be applied to measure level in a closed tank, some pressure-regulating scheme must be provided for the gas space in the tank. Otherwise, the gas bubbling through the liquid will pressurize the gas space to a point where bubbler supply pressure cannot overcome the static pressure it acts against. The result would be no bubble flow and, therefore, inaccurate measurement signal. Also, as in the case of a closed tank inferential level measurement system, the low-pressure side of the level transmitter has to be connected to the gas space in order to compensate for the effect of gas pressure.

Some typical examples of closed tank application of bubbler systems are the measurement of water level in the irradiated fuel bays and the light water level in the liquid zone control tanks.

2.3.6 Effect of Temperature on Level Measurement

Level measurement systems that use differential pressure ΔP as the sensing method, are by their very nature affected by temperature and pressure.

Recall that the measured height H of a column of liquid is directly proportional to the pressure P exerted at the base of the column and inversely proportional to the density ρ of the liquid.

$$H \propto P/\rho$$

Density (mass per unit volume) of a liquid or gas is inversely proportional to its temperature.

$$\rho \propto 1/T$$

Note

Thus, for any given amount of liquid in a container, the pressure P exerted at the base will remain constant, but the height will vary directly with the temperature.

$$H \propto T$$

Consider the following scenario. A given amount of liquid in a container [figure 9(a)] is exposed to higher process temperatures [figure 9(b)].

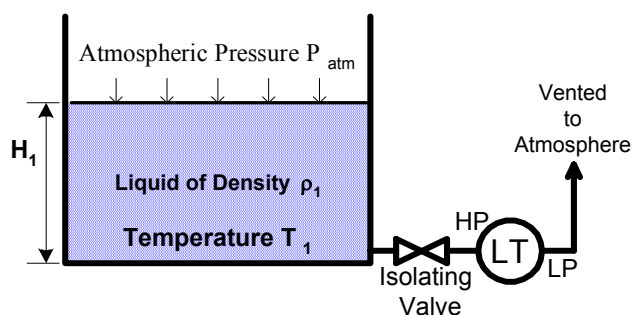


Figure 9(a)
Low Process Temperature

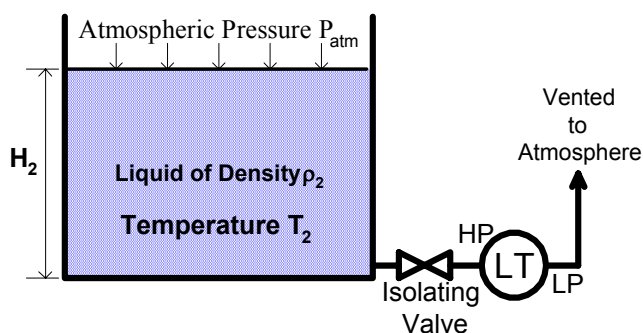


Figure 9(b)
High Process Temperature

As the amount (mass) of liquid does not change from figure 9(a) to 9(b), the pressure exerted on the base of the container has not changed and the indicated height of the liquid does not change. However, the volume occupied by the liquid has increased and thus the actual height has increased.

The above scenario of figure (9) is a common occurrence in plant operations. Consider a level transmitter calibrated to read correctly at 75°C.

If the process temperature is increased to 90°C as in figure 9 (c), the actual level will be higher than indicated.

The temperature error can also occur in wet-leg systems (figure 10).

Note

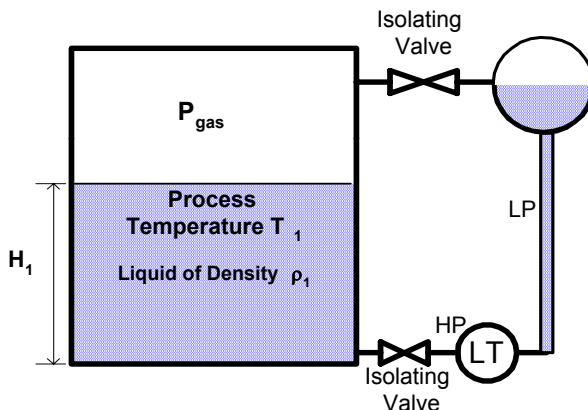


Figure 10
Temperature Effect on Wet-Leg System

If the reference leg and variable leg are at the same temperature that the level transmitter (LT) is calibrated for, the system will accurately measure liquid level. However, as the process temperature increases, the actual process fluid level increases (as previously discussed), while the indicated measurement remains unchanged.

Further errors can occur if the reference leg and the variable (sensing) leg are at different temperatures. The level indication will have increasing positive (high) error as the temperature of the wet reference leg increases above the variable (process) leg.

As an example, consider temperature changes around a liquid storage tank with a wet leg. As temperature falls and the wet leg cools off, the density of the liquid inside it increases, while the temperature in the tank remains practically unchanged (because of a much bigger volume and connection to the process). As a result the pressure of the reference leg rises and the indicated level decreases. If it happens to the boiler level measurement for a shutdown system it can even lead to an unnecessary reactor trip on boiler low level. However, high-level trips may be prevented under these circumstances. In an extreme case the wet leg may freeze invalidating the measurement scheme completely, but it could be easily prevented with trace heating as indicated earlier (Figure 5).

False high level indication can be caused by an increased wet leg temperature, gas or vapour bubbles or a drained wet leg.

Note

A high measured tank level, with the real level being dangerously low, may prevent the actuation of a safety system on a low value of the trip parameter.

The real level may even get sufficiently low to cause either the cavitation of the pumps that take suction from the tank or gas ingress into the pumps and result in gas locking and a reduced or no flow condition. If the pumps are associated with a safety system like ECI or a safety related system like PHT shutdown cooling, it can lead to possible safety system impairments and increased probability of resultant fuel damage.

2.3.7 Effect of Pressure on Level Measurement

Level measurement systems that use differential pressure ΔP as the sensing method, are also affected by pressure, although not to the same degree as temperature mentioned in the previous section.

Again the measured height H of a column of liquid is directly proportional to the pressure P_L exerted at the base of the column by the liquid and inversely proportional to the density ρ of the liquid:

$$H \propto P_L / \rho$$

Density (mass per unit volume) of a liquid or gas is directly proportional to the process or system pressure P_s .

$$\rho \propto P_s$$

Thus, for any given amount of liquid in a container, the pressure P_L (liquid pressure) exerted at the base of the container by the liquid will remain constant, but the height will vary inversely with the process or system pressure.

$$H \propto 1/P_s$$

Most liquids are fairly incompressible and the process pressure will not affect the level unless there is significant vapour content.

2.3.8 Level Measurement System Errors

The level measurement techniques described in this module use inferred processes and not direct measurements. Namely, the indication of fluid level is based on the pressure exerted on a differential pressure (DP) cell by the height of the liquid in the vessel. This places great importance on the physical and environmental problems that can affect the accuracy of this indirect measurement.

Connections

As amusing as it may sound, many avoidable errors occur because the DP cell had the sensing line connections reversed.

In systems that have high operating pressure but low hydrostatic pressure due to weight of the fluid, this is easy to occur. This is particularly important for closed tank systems.

With an incorrectly connected DP cell the indicated level would go down while the true tank level increases.

Over-Pressuring

Three valve manifolds are provided on DP cells to prevent over-pressuring and aid in the removal of cells for maintenance. Incorrect procedures can inadvertently over-pressure the differential pressure cell. If the cell does not fail immediately the internal diaphragm may become distorted. The measurements could read either high or low depending on the mode of failure.

Note that if the equalizing valve on the three-valve manifold is inadvertently opened, the level indication will of course drop to a very low level as the pressure across the DP cell equalizes.

Sensing lines

The sensing lines are the umbilical cord to the DP cell and must be functioning correctly. Some of the errors that can occur are:

Obstructed sensing lines

The small diameter lines can become clogged with particulate, with resulting inaccurate readings. Sometimes the problem is first noted as an unusually sluggish response to a predicted change in level. Periodic draining and flushing of sensing lines is a must.

Draining sensing lines

As mentioned previously, the lines must be drained to remove any debris or particulate that may settle to the bottom of the tank and in the line. Also, in closed tank dry leg systems, condensate must be removed regularly to prevent fluid pressure building up on the low-pressure impulse line. Failure to do so will of course give a low tank level reading. Procedural care must be exercised to ensure the DP cell is not over-ranged inadvertently during draining. Such could happen if the block valves are not closed and equalizing valve opened beforehand.

False high level indication can be caused by a leaking or drained wet leg.

A leaking variable (process) leg can cause false low-level indication.

Note

2.4 TEMPERATURE MEASUREMENT

Every aspect of our lives, both at home and at work, is influenced by temperature. Temperature measuring devices have been in existence for centuries. The age-old mercury in glass thermometer is still used today and why not? The principle of operation is ageless as the device itself. Its operation was based on the temperature expansion of fluids (mercury or alcohol). As the temperature increased the fluid in a small reservoir or bulb expanded and a small column of the fluid was forced up a tube. You will find the same theory is used in many modern thermostats today. In this module we will look at the theory and operation of some temperature measuring devices commonly found in a generating station. These include thermocouples, thermostats and resistive temperature devices.

Thermocouples (T/C) and resistive temperature devices (RTD) are generally connected to control logic or instrumentation for continuous monitoring of temperature. Thermostats are used for direct positive control of the temperature of a system within preset limits.

2.4.1 Resistance Temperature Detector (RTD)

Every type of metal has a unique composition and has a different resistance to the flow of electrical current. This is termed the resistivity constant for that metal. For most metals the change in electrical resistance is directly proportional to its change in temperature and is linear over a range of temperatures. This constant factor called the temperature coefficient of electrical resistance (short formed TCR) is the basis of resistance temperature detectors. The RTD can actually be regarded as a high precision wire wound resistor whose resistance varies with temperature. By measuring the resistance of the metal, its temperature can be determined.

Several different pure metals (such as platinum, nickel and copper) can be used in the manufacture of an RTD. A typical RTD probe contains a coil of very fine metal wire, allowing for a large resistance change without a great space requirement. Usually, platinum RTDs are used as process temperature monitors because of their accuracy and linearity.

To detect the small variations of resistance of the RTD, a temperature transmitter in the form of a Wheatstone bridge is generally used. The circuit compares the RTD value with three known and highly accurate resistors.

Note

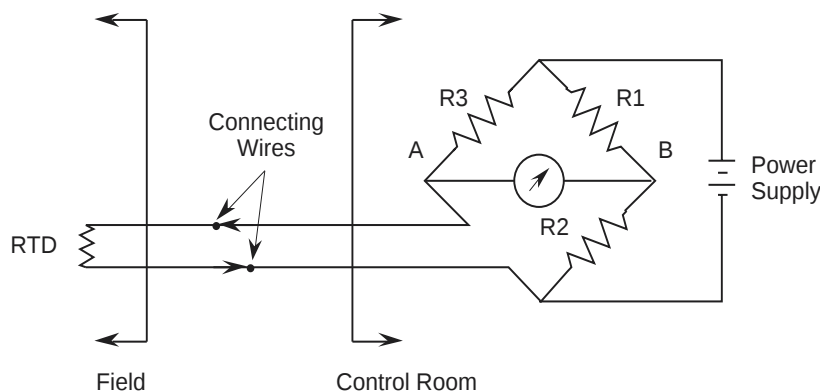


Figure 1
RTD using a Wheatstone Bridge

A Wheatstone bridge consisting of an RTD, three resistors, a voltmeter and a voltage source is illustrated in Figure 1. In this circuit, when the current flow in the meter is zero (the voltage at point A equals the voltage at point B) the bridge is said to be in null balance. This would be the zero or set point on the RTD temperature output. As the RTD temperature increases, the voltage read by the voltmeter increases. If a voltage transducer replaces the voltmeter, a 4-20 mA signal, which is proportional to the temperature range being monitored, can be generated.

As in the case of a thermocouple, a problem arises when the RTD is installed some distance away from the transmitter. Since the connecting wires are long, resistance of the wires changes as ambient temperature fluctuates. The variations in wire resistance would introduce an error in the transmitter. To eliminate this problem, a three-wire RTD is used.

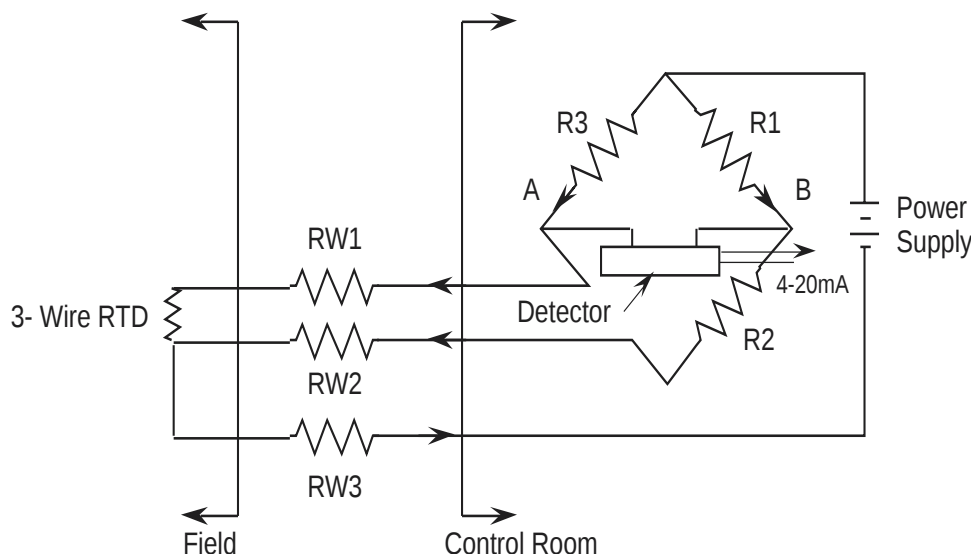


Figure 2
Three-Wired RTD

Figure 2 illustrates a three-wire RTD installation.

Note

The connecting wires (w_1 , w_2 , w_3) are made the same length and therefore the same resistance. The power supply is connected to one end of the RTD and the top of the Wheatstone bridge. It can be seen that the resistance of the right leg of the Wheatstone bridge is $R_1 + R_2 + R_{W2}$. The resistance of the left leg of the bridge is $R_3 + R_{W3} + R_{TD}$. Since $R_{W1} = R_{W2}$, the result is that the resistances of the wires cancel and therefore the effect of the connecting wires is eliminated.

Note

RTD Advantages and Disadvantages

Advantages:

- The response time compared to thermocouples is very fast – in the order of fractions of a second.
- An RTD will not experience drift problems because it is not self-powered.
- Within its range it is more accurate and has higher sensitivity than a thermocouple.
- In an installation where long leads are required, the RTD does not require special extension cable.
- Unlike thermocouples, radioactive radiation (beta, gamma and neutrons) has minimal effect on RTDs since the parameter measured is resistance, not voltage.

Disadvantages:

- Because the metal used for a RTD must be in its purest form, they are much more expensive than thermocouples.
- In general, an RTD is not capable of measuring as wide a temperature range as a thermocouple.
- A power supply failure can cause erroneous readings
- Small changes in resistance are being measured, thus all connections must be tight and free of corrosion, which will create errors.
- Among the many uses in a nuclear station, RTDs can be found in the reactor area temperature measurement and fuel channel coolant temperature.

Failure Modes:

- An open circuit in the RTD or in the wiring between the RTD and the bridge will cause a high temperature reading.
- Loss of power or a short within the RTD will cause a low temperature reading.

2.4.2 Thermocouple (T/C)

A thermocouple consists of two pieces of dissimilar metals with their ends joined together (by twisting, soldering or welding). When heat is applied to the junction, a voltage, in the range of milli-volts (mV), is generated. A thermocouple is therefore said to be self-powered. Shown in Figure 3 is a completed thermocouple circuit.

Note

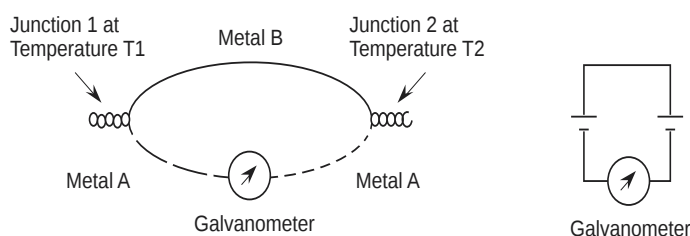


Figure 3
A Thermocouple Circuit

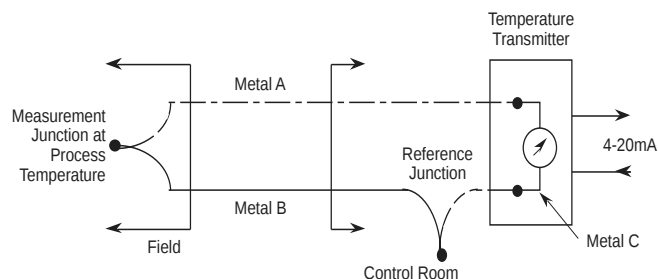
The voltage generated at each junction depends on junction temperature. If temperature T1 is higher than T2, then the voltage generated at Junction 1 will be higher than that at Junction 2. In the above circuit, the loop current shown on the galvanometer depends on the relative magnitude of the voltages at the two junctions.

In order to use a thermocouple to measure process temperature, one end of the thermocouple has to be kept in contact with the process while the other end has to be kept at a constant temperature. The end that is in contact with the process is called the hot or measurement junction. The one that is kept at constant temperature is called cold or reference junction. The relationship between total circuit voltage (emf) and the emf at the junctions is:

$$\text{Circuit emf} = \text{Measurement emf} - \text{Reference emf}$$

If circuit emf and reference emf are known, measurement emf can be calculated and the relative temperature determined.

To convert the emf generated by a thermocouple to the standard 4-20 mA signal, a transmitter is needed. This kind of transmitter is called a temperature transmitter. Figure 4 shows a simplified temperature transmitter connection.



Note

Figure 4
A Simplified Thermocouple Temperature Transmitter

In Figure 4 above, the temperature measurement circuit consists of a thermocouple connected directly to the temperature transmitter. The hot and cold junctions can be located wherever required to measure the temperature difference between the two junctions.

In most situations, we need monitor the temperature rise of equipment to ensure the safe operation. Temperature rise of a device is the operating temperature using ambient or room temperature as a reference. To accomplish this the hot junction is located in or on the device and the cold junction at the meter or transmitter as illustrated in figure 5.

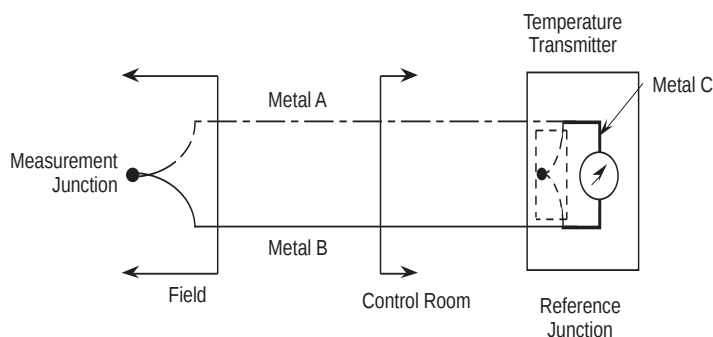


Figure 5
Typical Thermocouple Circuit

Thermocouple Advantages and Disadvantages

Advantages:

- Thermocouples are used on most transformers. The hot junction is inside the transformer oil and the cold junction at the meter mounted on the outside. With this simple and rugged installation, the meter directly reads the temperature rise of oil above the ambient temperature of the location.
- In general, thermocouples are used exclusively around the turbine hall because of their rugged construction and low cost.
- A thermocouple is capable of measuring a wider temperature range than an RTD.

Disadvantages:

- If the thermocouple is located some distance away from the measuring device, expensive extension grade thermocouple wires or compensating cables have to be used.
- Thermocouples are not used in areas where high radiation fields are present (for example, in the reactor vault). Radioactive radiation (e.g., Beta radiation from neutron activation), will induce a voltage in the thermocouple wires. Since the signal from thermocouple is also a voltage, the induced voltage will cause an error in the temperature transmitter output.
- Thermocouples are slower in response than RTDs
- If the control logic is remotely located and temperature transmitters (milli-volt to milli- amp transducers) are used, a power supply failure will of course cause faulty readings.

Note

Failure Modes:

An open circuit in the thermocouple detector means that there is no path for current flow, thus it will cause a low (off-scale) temperature reading.

A short circuit in the thermocouple detector will also cause a low temperature reading because it creates a leakage current path to the ground and a smaller measured voltage.

2.4.3 Thermal Wells

The process environment where temperature monitoring is required, is often not only hot, but also pressurized and possibly chemically corrosive or radioactive. To facilitate removal of the temperature sensors (RTD and TC), for examination or replacement and to provide mechanical protection, the sensors are usually mounted inside thermal wells (Figure 6).

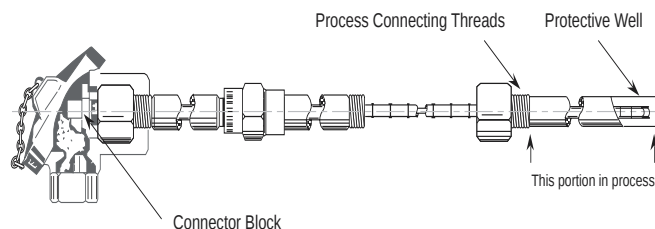


Figure 6
Typical Thermal Well Installation

A thermal well is basically a hollow metal tube with one end sealed. It is usually mounted permanently in the pipe work. The sensor is inserted into it and makes contact with the sealed end.

A drawback to thermal wells is their long response time because heat must be transferred through the well to the sensor. An example of the temperature response for bare and thermal well installed sensors is shown in Figure 7. Minimizing the air space between the sensor and the well, however, can decrease this thermal lag.

Note

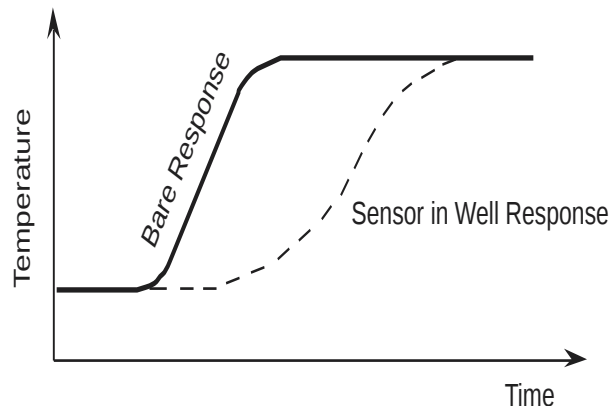


Figure 7
Response Curves of Bare and Thermal Well Installation

2.4.4 Thermostats

Thermostats have a different function than the resistive temperature detectors and thermocouples that we have just discussed. The thermostats directly regulate the temperature of a system by maintaining it constant or varying it over a specific range. The T/C or RTD could be used as the temperature-sensing element of a thermostat, but generally thermostats are direct acting devices.

The two common types of thermostats are:

Pressure cylinder

Bimetallic strip

Pressure Cylinders

The most common thermostat depends on the expansion of a fluid such as mercury or a solid with an increase in temperature as in figure 8.

Note

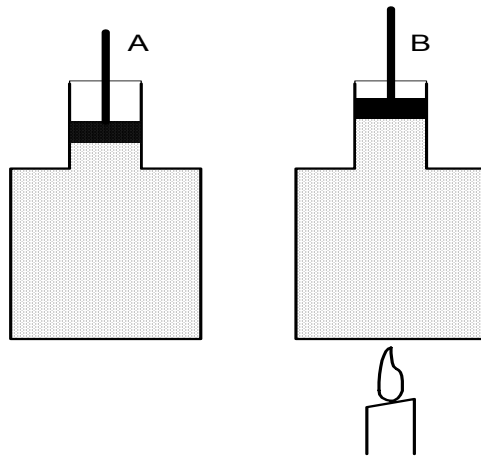


Figure 8
Thermostat Pressure Cylinder

The plunger connected to the piston is used to force contacts open and closed to control valve positions or pump control. Often the plunger is directly connected to the valve as in figure 9 below. This is the same principle as used in automobile water thermostats where the substance in the cylinder is a wax with a melting point of around 180⁰ F.

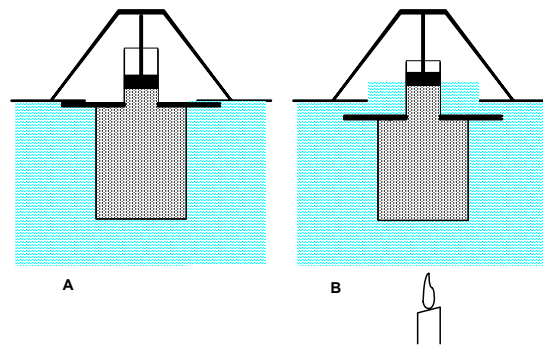


Figure 9
Thermostat Pressure Cylinder Application

Bimetallic Strips

A bimetallic strip is constructed by bonding two metals with different coefficients of thermal expansion (Figure 10). If heat is applied to one end of the strip, the metal with the higher coefficient of expansion will expand more readily than the lower one. As a result, the whole metallic strip will bend in the direction of the metal with the lower coefficient (Figure 11).

Note

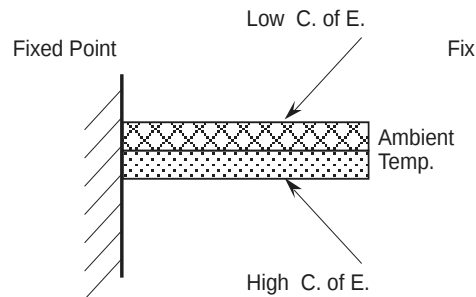


Figure 10
A Bimetallic Strip

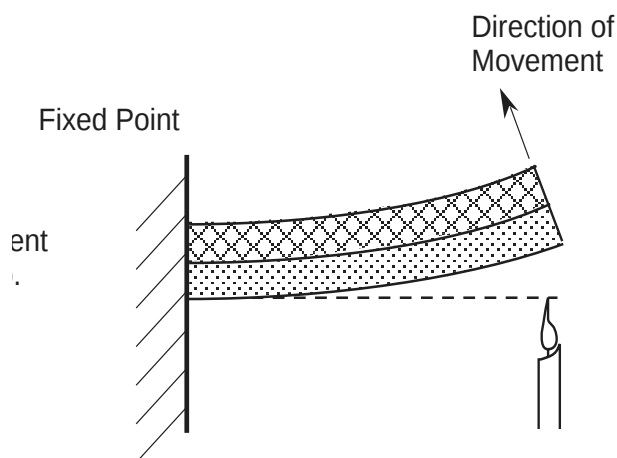
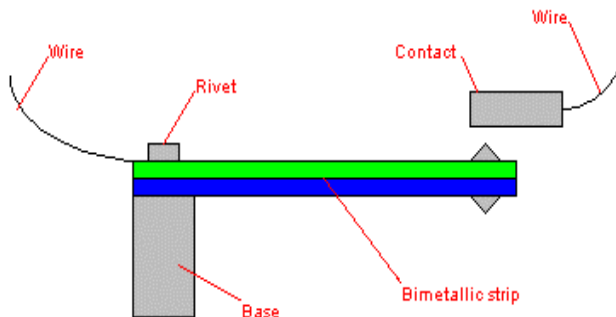


Figure 11
Bimetallic Strip Bent after Heat is Applied

When contacts are attached to the strip, it can be used as a fast acting thermostat to control air temperature as per figure 12. One drawback is that there cannot be any flammable vapours surrounding the strip due to arcing generated across the contacts.



Note

Figure 12
Bimetallic Thermostat

One main advantage of the bimetallic strip is that it can be used to operate over a range of temperatures when the strip is fashioned into a coil (for larger swing) and placed on an adjustable pivot (figure 13). Most room thermostats operate on this principle.

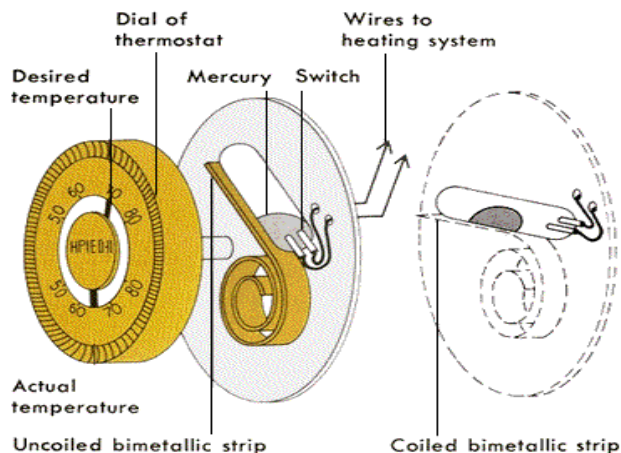


Figure 13
Application of Bimetallic Strip

Bimetallic Thermometers

Another common configuration of the bimetallic strip is coiled in a helix to increase the swing or displacement similar to the coil above. In this shape, the strip is more rugged and less subject to vibration. A helical bimetallic thermometer is shown in Figure 14 below.

Bimetallic thermometers in general are very rugged and require little maintenance. They are usually used to measure process parameters such as pump and bearing temperature.

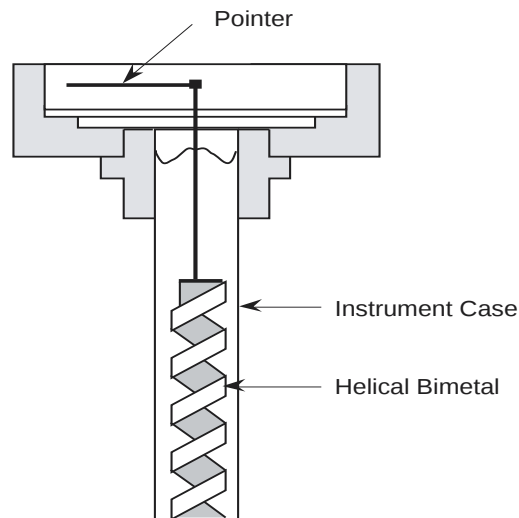


Figure 14
Helical Bimetallic Thermometer

Note

2.5 NEUTRON FLUX MEASUREMENT

A CANDU reactor generates thermal power from heat produced by nuclear fission. However, measuring the actual thermal power output proves to be too slow for the purpose of controlling the reactor (there is a time lag of about 25 seconds between neutron flux change and thermal output measurement). To control the reactor adequately, it is necessary to have fast responding instrumentation. The method of measuring reactor power by observing the radiation directly associated with the fission process is used. Each time a fission occurs; radiation (neutron, beta, gamma or alpha) is produced. The magnitude of these radiations is directly proportional to the number of fissions, which is in turn directly related to the reactor power level. The radiation we choose to monitor is neutron flux. If we can measure the neutron flux, we can estimate the thermal output of the reactor. In addition, monitoring neutron flux acts as a safeguard against the possibility of losing control of the reactor. If neutron flux exceeds a predetermined limit, shutdown systems will be triggered by the sensed neutron signal.

2.5.1 Neutron Flux Detection

Power produced by thermal nuclear reactors is generated through fission induced by slow neutrons. Hence, nuclear sensors that are part of the reactor control or safety systems are generally based on detectors that respond primarily to slow neutrons. The control of a reactor is necessary over a wide range of neutron flux levels from zero to full reactor power at 10^{14} n/(cm² s). The level of 10^7 n/(cm² s) is approximately zero thermal power for all practical purposes and significant thermal power contribution does not occur until the flux rises to $\sim 10^{12}$ (1% FP). The normal operating range of the reactor is usually between 10^{13} and 10^{14} n/(cm² s).

It is more convenient to describe the flux density in terms of the logarithmic value, with 14 being full power (10^{14} n/(cm² s) = 100%FP). By terminology, the neutron flux is said to have gone through 14 decades from zero to full power.

In order to provide instrumentation that will have complete coverage over this large range and still maintain accuracy, it is necessary to split the detection into three areas of sensitivity.

1. Sub-critical α 0 to 10^7 n/(cm² s). Neutron detection in this region is covered by two sets of start-up instrumentation:
 - In core BF₃ proportional neutron counters with a range 10^{-14} to 10^{-10} FP.
 - Out of core He-3 proportional neutron counters with a range of 10^{-11} to 10^{-6} FP.
2. Run up α 10^7 to 10^{13} n/(cm² s). Primary detection by external to core ion chambers. With a range of 10^{-7} to 1.5 FP.
3. Under-load α 10^{13} to 10^{14} n/(cm² s). Primary detection by internal core neutron detectors with a range of 0.15 to 1.5 FP.

As there are different detectors used, overlap of the detectors is necessary to provide a smooth transfer of reactor control throughout the three areas and to provide backup instrumentation if the main detectors are in question. We will look at each of these areas in more detail.

2.5.2 Neutron Detection Methods

Neutrons, like gamma rays, have no charge and therefore cannot directly interact with instrumentation, as do charged particles and electrons. Neutrons can also travel through many centimeters of matter without any type of interaction and thus can be totally invisible to a detector of common size. When a neutron does interact it is with a nucleus of the absorbing material. This interaction may either cause the neutron to disappear totally and be replaced by one or more secondary radiations or change the energy or direction of the neutron significantly.

Secondary radiations resulting from neutron interactions are almost always heavy charged particles. These particles may be produced either as a result of neutron-induced nuclear reactions or they may be the nuclei of the absorbing material itself which have gained energy from the neutron collisions.

Note

Most neutron detectors utilize some means of converting the incident neutron into secondary charged particles that can then be detected directly. For slow (thermal) neutrons, which have a small amount of kinetic energy, several different neutron reactions can be used. These include; (1) prompt capture of neutrons resulting in charged particle emission, (2) delayed activation reactions where an activated nucleus emits some form of radiation within a convenient half-life and energy and (3) fission reaction resulting from neutron capture.

2.5.3 Start-up (sub-critical) Instrumentation

If the reactor had been operating for some time and the shut-down is short (max. 2-3 weeks), the fission products will have built up to a point where the photo-neutron presence will still be large enough in the reactor to be detected by the run-up instrumentation (ion chambers).

For longer shutdowns, where the power has dropped to a relatively low level, the readings from the ion chambers are unreliable because the background gamma radiation levels heavily influence them. After some time, power will drop to a level where the installed instruments go off-scale (below about 10^{-7} FP) and the regulating system will not automatically control the power. Figure 1 shows a typical power decay curve for a CANDU reactor. It can be seen that after about 3 weeks supplementary proportional counters are necessary to maintain a reliable power record. Moreover, a subsequent approach to critical would need to be done using the proportional counters in the initial stages.

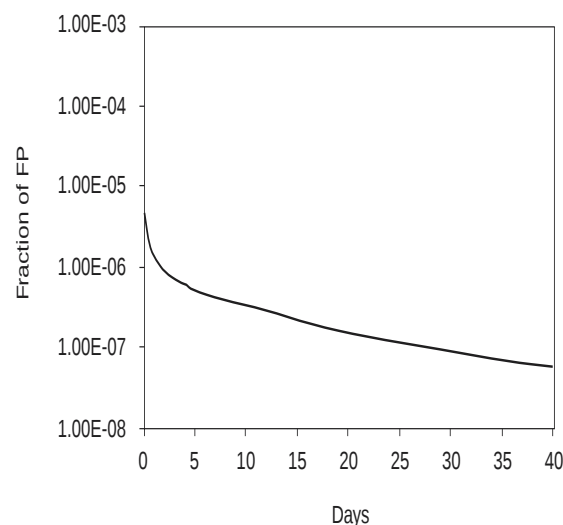


Figure 1
Power Decrease Following Shutdown

Note

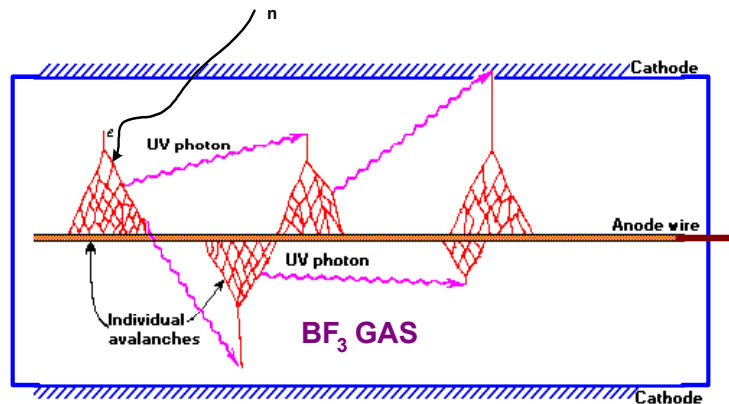
The start-up instrumentation is comprised of two separate portable neutron detection systems, one for in-core and the other for out-of-core. These systems have two decades of overlap.

The out-of-core detectors consist of He-3 filled proportional neutron counters that can be located in the ion chamber shutter holes. As we have indicated this instrumentation measures power from 10^{-11} to 10^{-6} FP.

The BF₃ (boron tri-fluoride) in-core detectors consist of boron in fluoride-filled proportional neutron counters that can be installed in the in-core detector holes. This instrumentation measures the range from 10^{-14} to 10^{-10} FP and is used for start-up with fresh fuel. The energy released per reaction is higher in B-10 than He-3, which enables the BF₃ counters to better discriminate against background gamma pulses.

The BF₃ proportional counter (Figure 2) is a self-amplifying device that uses the ions originally produced to make other ions in the same region. Inside the proportional counter is an electrode of fine wire along the axis of the second electrode that is a hollow cylinder. The effect of the wire is to give strong electric field strengths close to it. This strong field quickly accelerates the primary ions to gain enough energy in the acceleration to produce secondary ionization pairs. These newly formed secondary ions are also accelerated causing additional ionizations. The large number of events, known as a Townsend avalanche, creates a single, large electrical pulse.

Since a single pulse is produced for each incident radiation particle or photon, it is easy to directly measure the number of incident neutrons, which interacted with the detector.



Note

Figure 2
 BF_3 Proportional Counter

BF_3 (boron tri-fluoride) gases used in proportional counters are enriched to about 96% in B-10, which results in a level of efficiency five times greater than the natural boron gas. BF_3 tubes can readily discriminate against gamma rays that are often found with the neutron flux being measured. Gamma rays interact primarily in the wall of the counter and create secondary electrons that may produce ionization in the gas. Because the stopping power for electrons in BF_3 is quite low, a typical electron will only deposit a small fraction of its initial energy in the gas (little subsequent ion-pair production) before reaching the opposite wall of the counter. Most gamma ray interaction should result in low-amplitude pulses that can simply be eliminated by an electronic amplitude discrimination circuit without sacrificing detection efficiency.

These sensitive supplementary counters are removed once the standard ion chambers take control. This prevents burnout of the instrumentation by excessive neutron flux during normal reactor operation. The burnout is caused by the rapid burn-up of the high cross section emitter material used to obtain maximum sensitivity.

Due to the fast response time of the BF_3 counters, the outputs are deliberately damped at low flux levels to prevent spurious trips from the shutdown systems.

2.5.4 Fission neutron detectors

The detectors that use the fission reaction to detect neutrons are called fission chambers. These small ion chambers are typically made of stainless steel walls and electrodes, with an operating voltage from 50V to 300V.

Note

The chamber walls are usually lined with highly enriched uranium to enhance the ionization current.

Argon is the common choice for the chamber fill gas and it is used at a pressure of several atmospheres. The elevated pressure ensures that the range of fission fragments within the gas does not exceed the detector's small dimension. The pulses produced by fission fragments entering the sensitive volume of the detector are large and because the ion chamber does not produce large current flows, the output from the fission chamber is a series of pulses that can be counted.

When the detector is operating, the fissionable material on the detector walls is being consumed (by fission). To help slow the rate of depletion, a fast neutron absorber such as ^{238}U is sometimes added to the fissionable material on the wall. When ^{238}U absorbs a fast neutron, ^{239}Pu is created after beta emission. The ^{239}Pu is itself a fissionable material.

Miniaturized fission chambers can be tailored for in-core use over any power range likely to be encountered in reactor operation. These detectors can be used as traveling detectors and as a reference point to calibrate self-powered detectors.

2.5.5 Ion chamber neutron detectors

An ion chamber (see schematic in Figure 3) measures the electric charge of ions generated from the interaction of neutrons and the chamber structure and are located on the outside of the reactor core. The output of an ion chamber is a flow of current directly proportional to the incident neutron rate.

under irradiation. It can either be nitrogen-helium or hydrogen. The housing and central electrode is usually pure aluminum because of its low residual activity as a result of neutron bombardment.

Note

Since neutrons are uncharged, the lining of the chamber must be a coating of material, which will emit charged particles under neutron bombardment. Boron-10 was chosen because its high cross-section for the (n, α) reaction with thermal neutrons gives high sensitivity. This is important because ion chambers are mounted outside the reactor core where the number of neutrons is limited. Figure 4 indicates a representative location of the ion chambers, although the positioning can vary.

Note

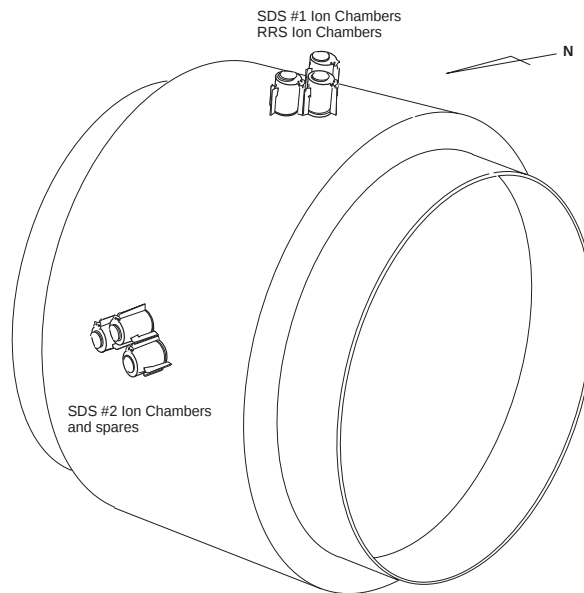


Figure 4
Typical Ion Chamber Locations

Ion Chamber Operation

The metal used for the electrode and outside casing is usually pure aluminum because of its low residual activity as a result of neutron bombardment. A high polarizing voltage (typically +600 V) is applied to the aluminum housing, while the center electrode is normally kept at ground potential (see Figure 3).

In the ion chamber, neutrons bombard the boron lining and release positively charged alpha (α) particles. When a rapidly moving alpha particle collides with a gas atom it ejects an electron from the atom leaving behind a positively charged ion. This renders the gas conductive with so-called ion pairs that are attracted to the charged electrodes by the polarizing voltage. This creates a flow of electric current, which can be detected by an external circuit. Amplifiers produce three separate signals as illustrated in Figure 5 then process the current signal:

Note

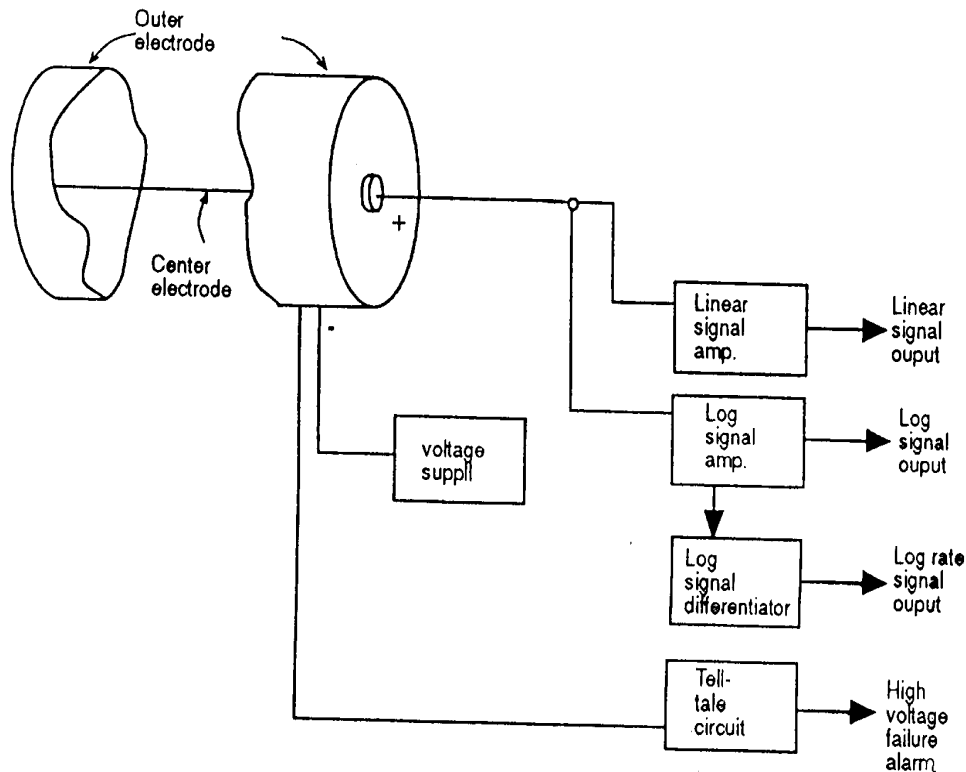


Figure 5
Ion Chamber Neutron Detector System

- A signal proportional to the linear power, $\ln n = 0$ to 150% FP
- A signal proportional to the logarithm of the power, $\text{Log } n = -0.7$ to 0 decades
- A signal proportional to the rate of change of the logarithm of power, $\text{log } n \text{ rate} = -15$ to $+15\%/ \text{sec}$

At low reactor power level, say below 15% full power, control of bulk reactor power is important. Ion chambers, because of their fast response time and high sensitivity are used for low power neutron flux detection. Ion chambers are used for the Reactor Regulating System (RRS) and Shut Down Systems (SDS) because of their fast response time.

Gamma Discrimination for Neutron Ion Chambers

One of the problems with the ion chamber is that the detector is indiscriminate and is affected by other ionizing radiation especially gamma. (The external alpha and most beta radiation cannot penetrate the housing.)

Note

Gamma rays will produce high-energy electrons (termed photo-compton electrons) and subsequent ionization. Therefore it is important to ensure both at power and after shutdown, when fission gamma radiation is predominant, that gamma radiation does not give a false (high) indication of reactor power.

Discrimination against gamma rays is achieved by:

- Employing appropriate materials in the detector and by gamma shielding (lead) in the construction of the ion chamber housings. With shielding the neutron to gamma current ratio is kept at about 1000 to 1 at high power level.
- Keeping the active part of the ion chamber relatively small.

Factors Affecting Ion Chamber Detector Accuracy

Proper functioning of ion chamber systems is essential to avoid unnecessary shutdowns, especially at low power when the in-core flux detector system is not capable of providing accurate data and therefore is not used.

A lower or negative signal can be caused by either the reactor power being off scale (that is, less than $10^{-5}\%$ FP) or a failure in the system. The other two channels will determine whether the power is off scale

A lower or off-scale reading can be caused by any of the following::

- Low moderator level. If the moderator level drops, the neutron velocity in the uncovered area will increase and will be too fast to allow displacement of the alpha particles by the Boron emitters of the ion chambers. The output of the ion chamber will indicate a lower neutron flux reading.
- Loss of HV power supply for the ion chamber polarization voltage.
- Shutdown of the Reactor. At less than $10^{-5}\%$ FP the output will be zero or irrational. Normal nuclear instruments (ion chambers and/or flux detectors) will be off-scale at their low end ($\sim 10^{-5}\%$ of full power) and so the regulating system will not automatically control the reactor.

Effect of Voltage on the Ionization Detector Process

Ionization detectors as previously discussed are a versatile instrument for detection of radiation.

These gas filled chambers can be operated as ion chambers, proportional counters, or Geiger-Mueller (GM) tubes depending on the bias voltage applied to the detector. Figure 7 illustrates the gas amplification curve (also called the six-region curve) for gas filled detectors. It is a curve of the relative electrical pulse size created at the collector compared to the voltage between the emitter and collector.

Note

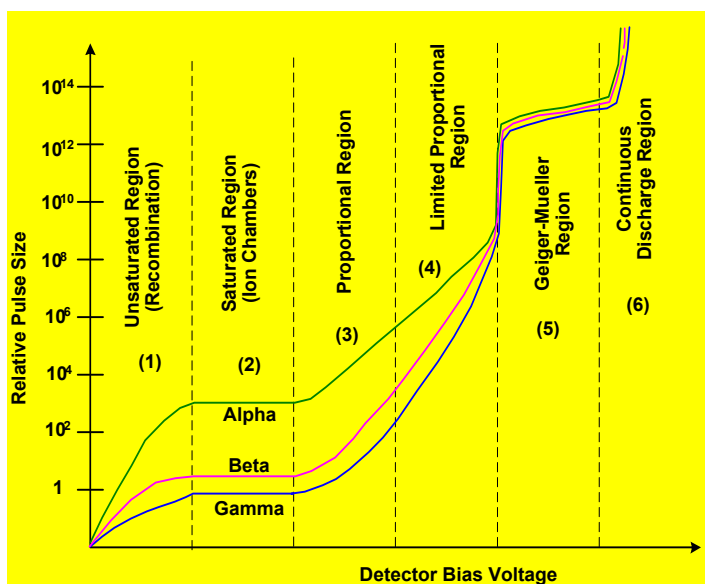


Figure 7
Six-Region Curve for Gas Filled Detectors

You will notice from the curve that at low voltages a high percentage of the ions recombine before reaching the collector. This region is not usable for detection purposes. As the bias voltage is increased into the ion chamber region, a point is reached at which essentially all of the ions are collected before they can recombine. No secondary ionization or gas amplification occurs. At this point the output current will be proportional to the radiation intensity and relatively independent of fluctuations in the power supply.

As the bias voltage is increased beyond the ion chamber region into the proportional region, the ions created by primary ionization are accelerated by the electric field towards the electrode. Unlike the ion chamber region, however, the primary ions gain enough energy in the acceleration to produce secondary ionization pairs. These newly formed secondary ions are also accelerated, causing additional ionizations.

Note

The large number of events, known as an avalanche, creates a single electrical pulse. In the proportional region, the detector output is proportional to the total ionization product in the detector.

The ratio between the primary ionizations and the total number of ion pairs produced is known as the gas amplification factor for that gas and can be in the order of one million, compared to the gas amplification factor of one for the ion chamber region.

As the bias voltage is increased beyond the proportional region, the detector enters the limited proportional region and is unusable for detection purposes. In this region, unpredictable avalanches can interfere with the overall signal.

As the bias voltage is increased even further into the Geiger-Mueller region, the secondary ions are also accelerated to very high velocities and gain sufficient energy to cause ionization themselves. The resulting avalanche caused by a single ionization, results in a single very large pulse. The avalanche continues until the large electrical field created by the ionization interferes with the detector voltage field, decreasing the acceleration of the ions and thus halting the avalanche.

At even higher voltages, the avalanche process cannot be halted, making this region unsuitable for detection purposes.

2.5.6 In-Core Neutron Detectors

Although ion chambers are very accurate neutron detectors, their relatively large size and delicate construction make them impractical to be used to detect flux distribution inside the reactor. For this purpose, simple and relatively inexpensive in-core detectors (ICD) have been developed. They are also known as Hilborn detectors, self-powered neutron (SPN) detectors or in-core flux detectors (ICFD).

The advantages of self-powered detectors when compared to other neutron sensors include size, low cost and the relatively simple electronics required to use them. Disadvantages stem from the low level of output current produced by the devices, a relatively high sensitivity of the output current to changes in the neutron energy spectrum and for many types, for instance vanadium detectors, a rather slow response time.

The basic construction of an In-Core Detector (ICD) is shown in Figure 7 with a platinum emitter, although other types of emitter materials can be used.

Note

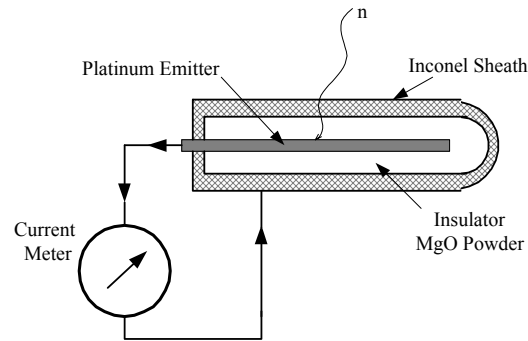


Figure 7
Simplified In-Core Detector

The detector operates by generating an electric current after the central emitter has captured the neutrons. This current is proportional to the rate at which neutrons are captured in the detector. The detector itself resembles a coaxial cable usually about a meter in length and consists of an outer inconel (an alloy of nickel, chromium and iron) sheath and an inner emitter wire, separated by a layer of insulation (usually magnesium oxide, MgO). Magnesium oxide is most commonly used as it can withstand the extreme temperature and radiation environment in the reactor core.

In-core detectors are usually denoted by the material of their emitters, which in CANDU reactors are made of vanadium, platinum, platinum clad inconel (inconel 600 core wire with a thin surface layer of platinum) and inconel.

Operation of these detectors requires no external power supply and that is why they are called self-powered. The operation [see Figures 8(a) and 8(b)] is quite simple. The current that corresponds to the beta rays given off by the emitter is measured between the emitter and the outer shell, called the collector.

Note

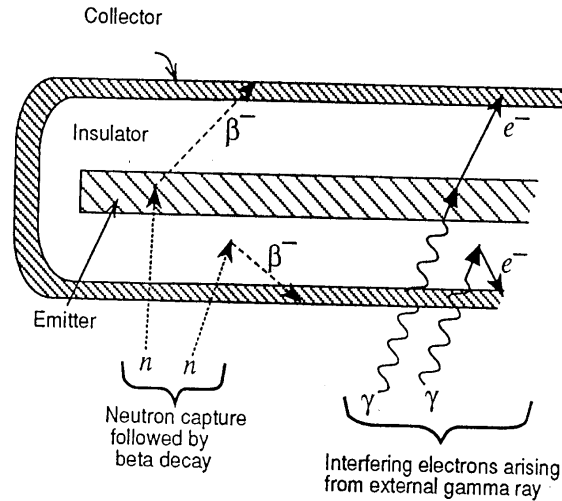


Figure 8(a)
In-Core Detector Operation (a)

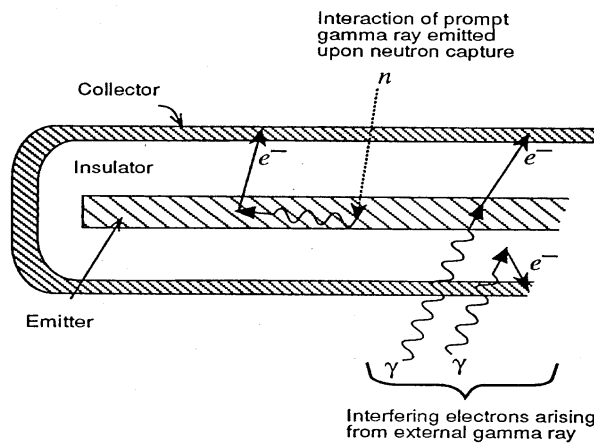


Figure 8(b)
In-Core Detector Operation (b)

Incident radiation (through the mechanisms described below) will cause electrons to be emitted mostly from the emitter. The emitter is then positively charged with respect to collector. The collected electrons pass through the external amplifier and back to the emitter producing a useful signal.

The 3 principal components of the generated current and main interactions are as follows:

Note

- (n, β) mechanism that is, beta emission [Figure 8(a)] following neutron capture mostly by the emitter (neutron activation). This beta decay current is proportional to the rate at which neutrons are captured in the detector but has a rather slow response time.
- (n, γ) followed by the emission of a Compton or photo electron, in which electrons are produced by neutron capture gamma rays [Figure 8(b)] mostly from the emitter. The radioactive capture gamma rays are emitted within a very small fraction of a second following neutron absorption.
- Photo and Compton electrons are produced by gamma ray sources external to the detector. These gammas will either be directly from fission or from the decay of fission products (Figure 8).

External electrons and beta particles from the reactor hardware and materials can also contribute to the detector signal, but this 4th mechanism usually does not add more than a couple of per cent to the overall output current.

In-core detectors can be either coiled (on an inner zircaloy tube) as shown in Figure 9 or Straight Individually Replaceable (SIR) in a flux monitor assembly. (ICD assemblies could be of various types, i.e., wet, encapsulated and HESIR or hybrid encapsulated straight individually replaceable and positioned either vertically or horizontally in the reactor core.)

Note

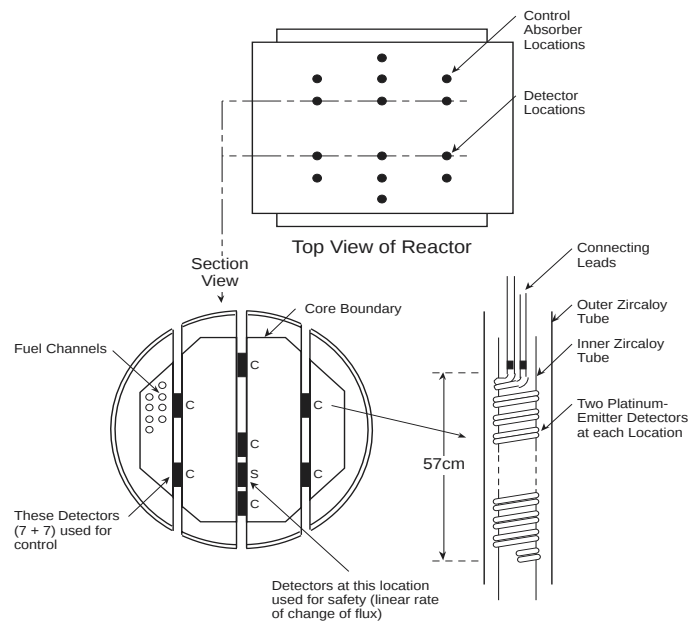


Figure 9
Typical ICD Locations

Types of In-Core Detectors

The time relationship between a device input and output is called its dynamic response. Following a step change in reactor neutron flux the current produced by each isotope in the ICD material through each of the three basic interactions can be either a prompt (immediate) response or a delayed one. Delayed responses are usually described by exponential lag terms with time constants characteristic for the isotope and mechanism. The total response of the ICD is a sum of prompt and delayed (or lag) terms.

For a change in neutron flux in the core, the three reactions exhibit different response characteristic with respect to time.

The first (a) interaction discussed previously (n, β) will normally be delayed following a change of neutron flux. The return to a new steady state condition will be dependent upon the materials used.

Interactions (b) and (c) are prompt reactions with respect to the neutron and gamma fluxes, respectively. Note again, however, that following a change in fission rate a portion of the gamma signal source (due to the presence of fission products and activation products) will exhibit a delay time before it reaches a new steady state condition. In other words, the gamma flux at the detector site has its own dynamic response (lag terms) relative to neutron flux. Thus, although the Compton and photoelectric mechanisms are prompt with respect to gamma, the current generated by it, following a change in neutron flux, will have a prompt component from prompt gammas and a delayed part from gamma rays emitted by fission products and activation

products. Those products need time to reach a new equilibrium state after a neutron flux change.

The sensitivity of the detector, that is the amount of current output per detector unit length and per unit neutron flux, changes with exposure to neutron flux and is known as burn-up. There are two main reasons for this: the current producing isotopes in the detector burn up by neutron capture and beta decay and the flux environment of the detector changes.

The sensitivity of in-core detectors to the three interactions and their dynamic response depends on the material of the emitter.

Platinum and Platinum Clad Detectors

The response of platinum detectors with respect to the 3 mechanisms is as follows:

- Output due to Beta decay following neutron activation of the platinum emitter is up to about 3%
- Input due to Compton and photo-electrons produced by neutron capture gamma rays (n, γ) from the emitter is around 60%.
- Output due to Compton and photo-electrons produced by external gamma sources is around 40%.

Output (a) is delayed with a half-life of 30 minutes, i.e., a typical time to stabilization of this component following a neutron flux change would be 150 minutes (5 half-lives).

The dynamic response of the ICD signal shows small changes with exposure to neutron radiation. For Pt and Pt-clad detectors the percentage declines with neutron exposure time from about 90% in the beginning to about 80% after very long (~ 20 years) neutron exposure.

Note that this type of ICD detects both neutron and gamma rays resulting from the fission reaction. This feature has several advantages:

- Prompt response.
- Less neutron loading on reactor (low capture cross section).
- Less temperature dependence.
- Less susceptible to local flux perturbations.
- Little change in sensitivity with respect to time.

Note

Inconel Detectors

For ICD detectors with inconel emitters the contribution of direct Compton and photoelectric mechanisms are usually estimated at less than 10%. Practically all the signal current comes from the (n, γ) followed by a Compton or photoelectric electron interaction, with zero from the (n, β) mechanism. The interesting aspect of the inconel detector dynamic response is that it is over prompt or to put it differently, its delayed component is negative. Thus, following a step change in neutron flux in the core the inconel detector responds right away with about 101-104% of the equilibrium signal. (The three main delayed components of the signal have time constants equal to 95 sec, 25.6 min. and 3.7 hrs.) Inconel detectors are used at Darlington (RRS and SDS1) and at Bruce B (SDS1).

Vanadium Detectors

We will mention the last category Vanadium detectors for reference only. They have been used for flux-mapping of the core but are seldom used at the present. Vanadium detectors are used for applications where speed of response is not as important as accuracy of neutron flux value. For this a detector, which is only neutron sensitive, is required. This feature is necessary when mapping the three-dimensional flux shape throughout the reactor. Vanadium detectors are essentially 100% neutron sensitive, i.e., the (n, β) mechanism contributes nearly 100% to the signal. The response is dependent upon the emission of beta particles from the emitter following neutron activation. The response is delayed following a change in neutron flux levels.

Factors Affecting in Core Detector Measurement

1. Fuelling or reactivity device movements nearby.

Platinum ICD signals, although very fast, do not reliably indicate average power in the zone because they only sample the flux in their region. They are therefore susceptible to localized flux changes such as refuelling or reactivity mechanism movement.

2. Start-up of the reactor.

At start-up, there is not enough neutron flux and the neutron interaction rate is very low. Good discrimination against gamma rays is essential in this range and it can be accomplished by using either fission chambers or BF₃ proportional counters. Also, Platinum ICDs have delayed components, approximately 15% to 17% of the total signal lags power change by a time constant varying from a few

seconds to hours.

So the signal produced by the detector during a power change may not accurately represent the true fuel power

Note

3. Long-term exposure to neutron flux.

ICD's suffer burn up under irradiation. However, with the use of platinum detectors, this is a relatively minor factor being limited to approximately 1% per year.

4. Moderator poison (shielding).

In the event of poison addition to the moderator, for example to provide an equivalent xenon load on start-up, the signal output will be reduced due to the presence of the neutron absorbing poison between the detector and the neutron source (fuel).

2.5.7 Reactor Control at High Power

At the higher end of the power range the ion chambers are not sufficient for power control. Although the ion chamber and the linear amplifier are accurate from $10^{-5}\%$ to 150% full power (FP), the leakage flux they monitor is not a good representation of the flux in the reactor core for the simple reason that these detectors are installed outside the reactor. The leakage flux will be strongly affected by moderator poison, fueling in adjacent channels, flux tilts, movements of nearby reactivity devices, etc., and it will be relatively insensitive to power changes in the central core or the far side of the reactor.

This is particularly important in the last decade for the following reason: above about 20% - 25% FP CANDU reactors require spatial (also called tilt) control capabilities in addition to the overall or bulk control function. This is needed in order to remove neutron flux tilts caused by local reactivity changes (due to fuelling or movements of some reactivity devices) and to prevent xenon oscillations. To provide spatial control, the Reactor Regulating System (RRS) needs neutron sensors distributed throughout the reactor. Ion chambers are too big and too fragile to be put inside the reactor core. Thus in the last power decade, the RRS switches from ion chambers to in-core detectors for measuring and controlling bulk and spatial power. However, in-core detectors can generate a reliable signal only from about 1% to 120% full power. Below 1% FP, the in-core detector signal is not distinguishable from noise. Therefore, below about 10% FP ion chambers have to be used to keep the reactor under the RRS control.

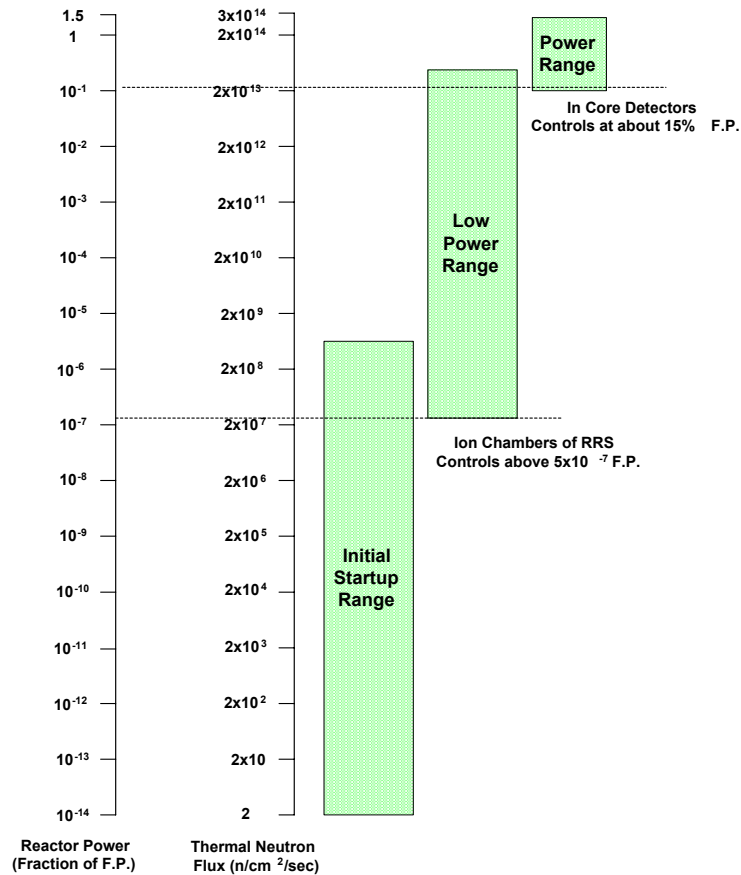
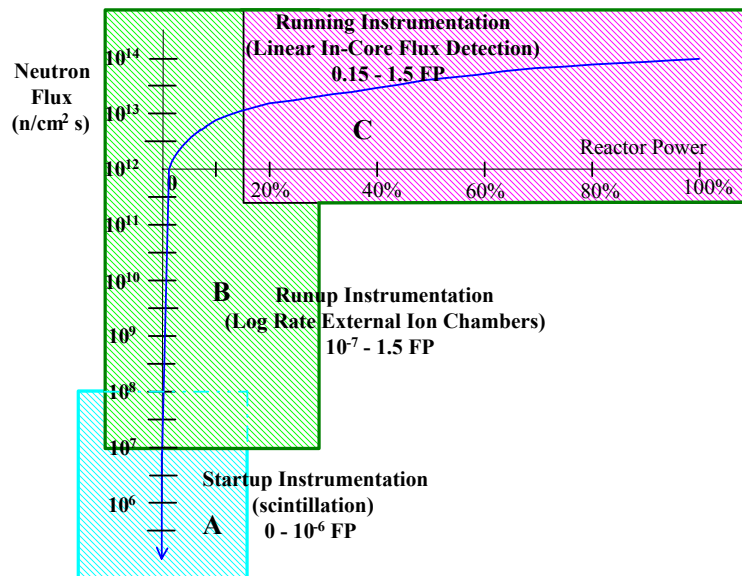


Figure 10(a)
Neutron Detector Over-Lap

2.5.8 Overlap of Neutron Detection

At various stages in the CANDU reactor operation, the proportional counters, uncompensated ion chambers and self-powered in-core flux detectors are used to give a measurement of reactor power from source level to 150% full power. A minimum overlap of one decade is provided between successive ranges of instrumentation as schematically portrayed two different ways; a bar graph Figure 10(a) and neutron flux vs. reactor power Figure 10(b). The overlap of instrumentation maintains continuity of measurement between the ranges of sensitivity.

Note



Note

Figure 10(b)
Neutron Detector Over-Lap

Notice again that the ion chambers generate a current signal proportional to the reactor power level over seven decades of flux. The in core detectors, as mentioned previously, generate a current signal over the final two decades of flux, but are used only in the last decade.

There are several means of transferring reactor control (RRS) between the over-lapped instrumentation:

The transfer between log and linear control in some locations is done at 17% FP on rising power, as measured by the ion chambers and at 13% FP on falling power, as measured by the ICD's. This 4% hysteresis prevents cycling between log and linear control and also allows for slight differences in calibration due to the different types of detector used.

Another similar method employs a 13% - 17% hysteresis, but linear power (ICD signal) is used for switchovers (in both ways) between log and linear control to ensure a bump-less transfer.

A different method that can be used requires the ion chambers to be thermally calibrated. The transfer is implemented between 5% and 15% FP by progressively phasing out the ion chamber signal and phasing in the in-core detector signal as power increases. Again, a bump-less transfer is ensured.

When the RRS transfers from ion chambers to in-core detectors, there is also another associated change, namely the power measuring and indicating scale changes from a logarithmic (log) to a linear one.

The log signal comes from a log signal amplifiers associated with ion chambers as shown in Figure 5.

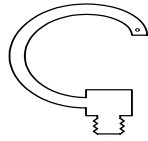
Note

A log scale is useful for measurements spanning several decades because it gives a constant signal change per decade, e.g., 2 volts per decade of neutron power. However, it bunches up (flattens out) at the top of each decade, which is inadequate for the last decade (see Figure 10b) where the most heat is generated and fine control is required. For this reason in-core detectors use a linear scale, which is more intuitive. Because of the scales, we talk about the two RRS bulk control ranges; the logarithmic range from $10^{-5}\%$ FP to about 15% FP and the linear range of control from about 15% to about 120% FP. Because of the names it is easy to forget that the really important difference is in the neutron sensors used for control and that the scale depends on the associated type of amplifier or a computer algorithm transforming a linear value to a logarithmic one or vice versa.

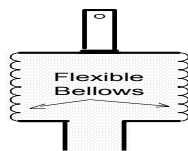
REVIEW QUESTIONS - EQUIPMENT

1. Briefly explain how each of the following devices is used to measure pressure.

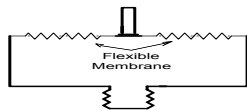
Note



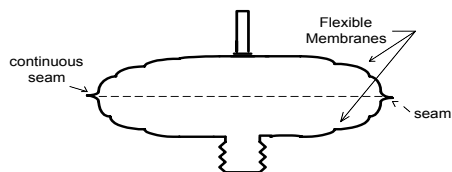
- a. Bourdon Tube



- b. Bellows



- c. Diaphragm



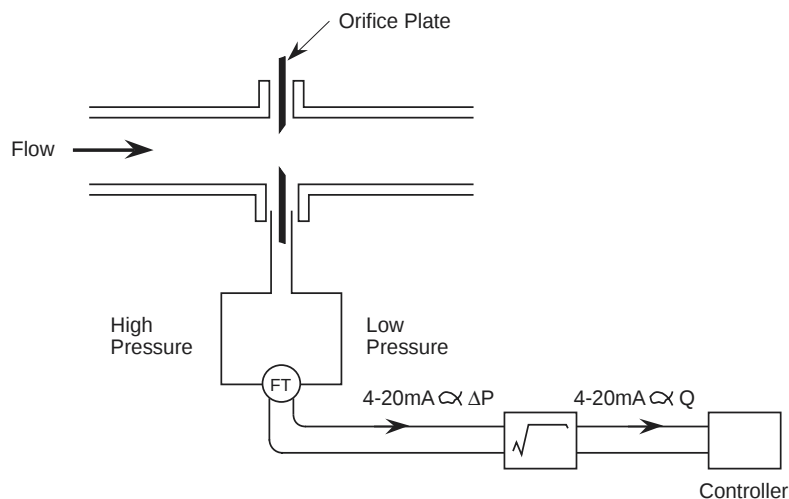
- d. Capsule

2. Explain how the capacitor capsule, differential pressure transmitter detects pressure differences.
3. Describe a strain gauge.
4. A pressure-measuring instrument is designed around a bourdon tube. Explain how extreme changes in the ambient temperature of the bourdon tube will introduce errors into the readings of the instrument.
5. Briefly describe how the ambient pressure in a room containing a pressure transmitter can affect the reading of the transmitter.
6. Explain how flow can be measured using an orifice plate, venturi or flow nozzle.
7. Explain how elbow taps are used to measure the flow in a steam line.

Note

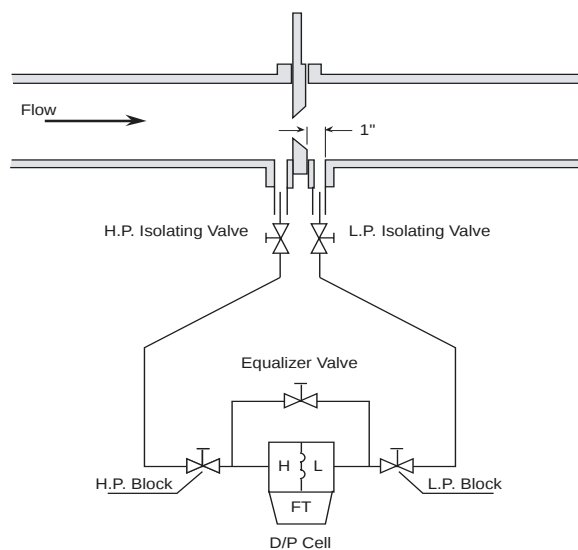
8. Briefly describe the how each of the following devices is used to measure flow.
- Orifice plate
 - Venturi
 - Flow nozzle
 - Elbow tap
 - Annubar
 - Pitot tube
9. For each of the following devices explain how flow measurements will be affected by
- Changes in fluid temperature
 - Changes in fluid pressure
 - Erosion
- Orifice plate
 - Venturi
 - Flow nozzle
 - Elbow tap
10. The drawing below shows a typical flow control loop. Explain the purpose of the square root extractor.

Note

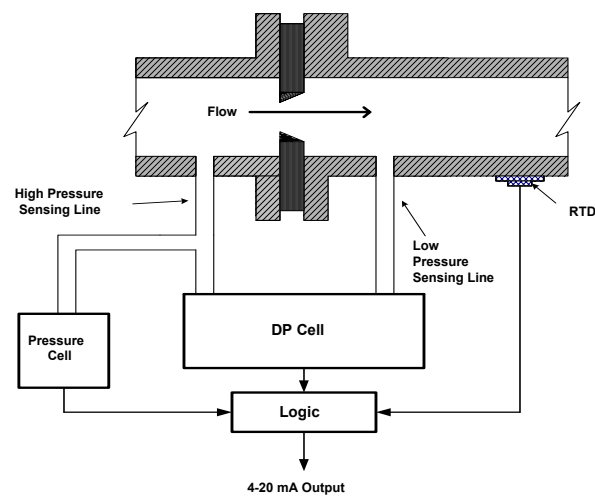


11. A differential pressure transmitter is calibrated to measure the flow of a liquid. Explain what will happen if the fluid is not pure liquid but contains some vapor bubbles.
12. On the following drawing identify the following.
 - a. Three valve manifold
 - b. Primary element
 - c. Transmitter

Note



13. The following diagram shows a density corrected flow loop. Briefly explain the operation of the loop.

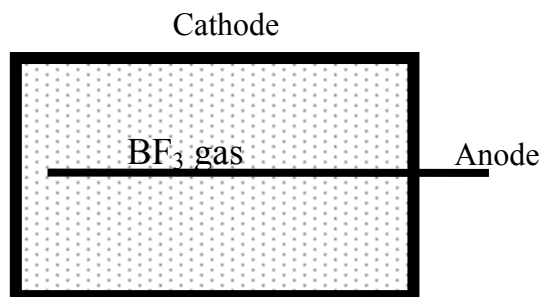


14. In a flow loop using a venturi for a primary element what will be the consequences of the following abnormalities?
 - a. Vapor formation in the throat
 - b. Clogging of the throat by foreign material
 - c. Leaks in the Hi pressure sensing line
 - d. Leaks in the low pressure sensing line
15. Sketch the typical installation of a pressure transmitter on an open tank, measuring the level of the fluid in the tank. Explain how this transmitter derives a level signal.
16. Sketch the typical installation of a dry leg level transmitter installation. Explain how this transmitter derives a level signal.
17. Sketch the typical installation of a wet leg level transmitter installation. Explain how this transmitter derives a level signal.
18. The three-valve manifold on a level transmitter must be operated correctly when either removing the transmitter for service or returning it to service. Explain how the transmitter may be damaged by incorrect operation of the manifold.
19. Zero elevation and zero suppression are calibration techniques used in level transmitter calibrations. Explain the purpose of these techniques.
20. Explain how a bubbler is used to measure the level in an open tank.
21. Explain how a bubbler is used to measure the level in a closed tank.
22. A dry leg level transmitter installation is measuring the level of a hot water tank. What happens to the level and the level indication if the temperature of the tank is increased and no water leaves the system?
23. A dry leg level transmitter installation is measuring the level of a hot water tank. What happens to the level and the level indication if the static pressure on the tank is increased and no water leaves the system?

Note

Note

24. Describe the effects on a level transmitter of the following abnormalities in a wet leg configuration.
- a leak in the high pressure sensing lines
 - a leak in the low pressure sensing line
 - a completed block low pressure sensing line
25. Explain how an RTD is used to measure temperature. Include in your answer a statement to explain why there are three leads from the temperature transmitter to the RTD.
26. What type of signal does a thermocouple produce?
27. RTDs are used to measure the temperature of the reactor outlet feeders. Thermo couples are used to measure temperatures on the turbine. Explain the reasons for the selection of these devices for their respective applications.
28. State the power ranges each of the following neutron detectors will provide the signal for bulk reactor power control.
- Start-up instrumentation
 - Ion Chambers
 - In Core Detectors
29. Why is there an overlap of the ranges over which the various neutron detectors are used to control reactor power?
30. Using the following diagram explain how a neutron flux signal is derived in a BF_3 detector



31. Explain the reason that BF₃ detectors burnout if they are left installed when the reactor is at a high power level.
32. Briefly describe how the following ion chamber develops a signal proportional to flux.

Note

37. Explain how each of the following factors can affect the accuracy of the in-core detector flux measurement
- a. Fueling or reactivity device position
 - b. Start-up of the reactor
 - c. Long term exposure to neutron flux
 - d. Moderator poison
38. State the ranges over which the in core detectors and the ion chambers are used to control reactor power. Explain why each is used over this range.

Note

CONTROL

Note

3.0 INTRODUCTION

Control of the processes in the plant is an essential part of the plant operation. There must be enough water in the boilers to act as a heat sink for the reactor but there must not be water flowing out the top of the boilers towards the turbine. The level of the boiler must be kept within a certain range. The heat transport pressure is another critical parameter that must be controlled. If it is too high the system will burst, if it is too low the water will boil. Either condition impairs the ability of the heat transport system to cool the fuel.

In this section we will look at the very basics of control. We will examine the fundamental control building blocks of proportional, integral and differential and their application to some simple systems.

3.1 BASIC CONTROL PRINCIPLES

Consider a typical process control system. For a particular example let us look at an open tank, which supplies a process, say, a pump, at its output. The tank will require a supply to maintain its level (and therefore the pump's positive suction head) at a fixed predetermined point. This predetermined level is referred to as the setpoint (SP) and it is also the controlled quantity of the system.

Clearly whilst the inflow and outflow are in mass balance, the level will remain constant. Any difference in the relative flows will cause the level to vary. How can we effectively control this system to a constant level? We must first identify our variables. Obviously there could be a number of variables in any system, the two in which we are most interested are:

The controlled variable - in our example this will be level.

The manipulated variable – the inflow or outflow from the system.

If we look more closely at our sample system (Figure 1), assuming the level is at the setpoint, the inflow to the system and outflow are balanced. Obviously no control action is required whilst this status quo exists. Control action is only necessary when a difference or error exists between the setpoint and the measured level. Depending on whether this error is a positive or negative quantity, the appropriate control correction will be made in an attempt to restore the process to the setpoint.

Henceforth, the error will always take the form of:

$$\text{Error} = \text{Setpoint} - \text{Measured Quantity}$$

OR

$$e = SP - M$$

Note

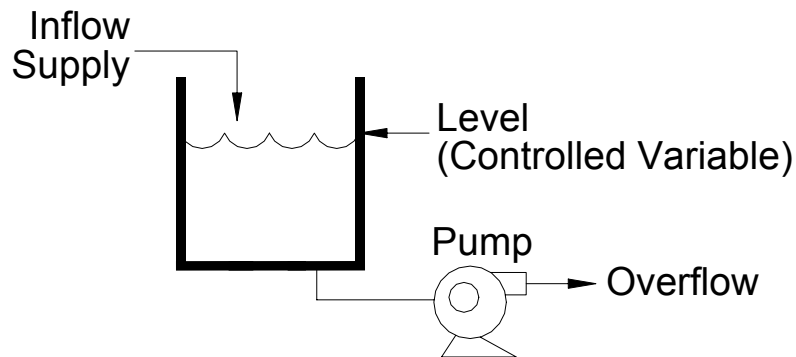


Figure 1

The control action will be either to vary the inflow or outflow from the system in order to keep the level at the setpoint. Let us consider the general format for achieving these objectives.

As can be seen from Figure 2, the process can be represented by a closed loop. The system output (level) is monitored by a process sensor and the measurement signal is fed back to a comparator at the input of the system. The second input to the comparator is the setpoint signal; the comparator's output being the difference or error signal. The amplifier, a present just a black box, will provide the appropriate correction to maintain the process at its setpoint despite disturbances that may occur. It can be seen that if the system were being operated in manual control the feedback path would not be present. The operator would provide this feedback and apply the necessary correction to the system whilst observing the effect on the controlled variable. This is termed open loop operation.

Note

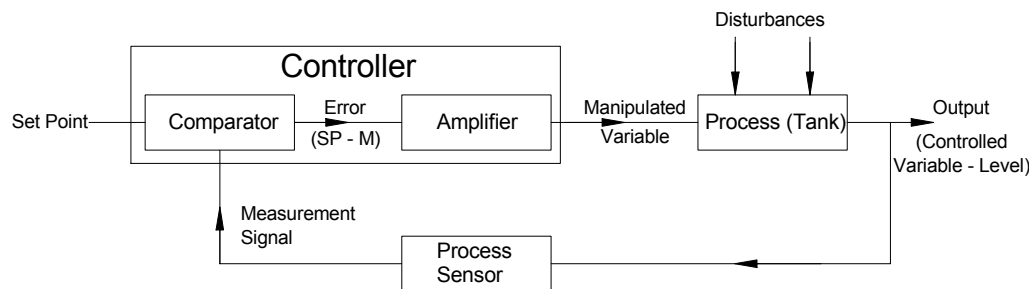


Figure 2
Feedback Control Block Diagram

3.1.1 Feedback Control

This concept justifies the use of the word negative in three ways:

- The negative aspect of feeding the measured signal backwards from the output to the input of the system. (Actual definition of negative feedback control).
- The control correction must be negative in that a correction rather than a compounding of error must occur.
- The fact that an error must occur before a correction can take place, i.e., retrospective or negative control action.

In the next section we will study in more detail the methods used to effect the necessary control corrections.

3.1.2 Feedforward Control

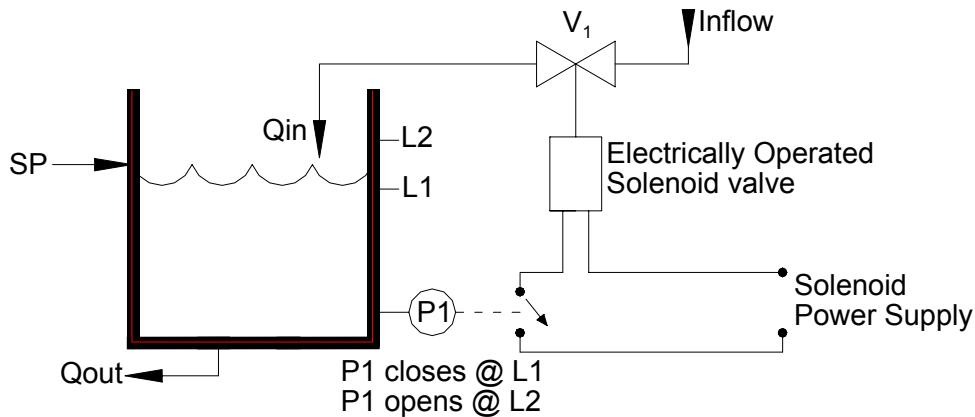
If we wish to control our process without an error first occurring, we must base our control on correction of the disturbances, which will eventually, cause a process error. This is termed feedforward control. Feedforward control is rarely if ever used on its own but is used in conjunction with feedback control to improve the response of control to process disturbances.

3.1.3 Summary

Note

- Controlled Variable – output quantity of system (Level, Temperature, etc.).
- Manipulated Variable – means of maintaining controlled variable at the setpoint.
- Error signal – equals the difference between the setpoint and the measurement. ($e = SP - M$).
- Setpoint – desired process level. (SP)
- Measurement – actual process level. (M)
- Closed Loop – automatic control.
- Open Loop – manual control.
- Feedback control is error correction following a disturbance.
- Feedforward control is control of disturbances, which could cause a process error.

Note



3.2 ON/OFF CONTROL

Figure 3
Typical On/Off Control Scheme

Let us consider our level control system in a little more practical detail. The valve in the inflow line to the system is an electrically operated solenoid valve. (Remember an electrically operated solenoid valve has only two operating positions – fully open or fully closed.) Assume that under initial conditions with a demand on the system the level will start to fall and V_1 will have to be opened to provide an inflow. This can easily be achieved by mounting a differential pressure switch, P1 at the bottom of the tank to operate when the level falls to L_1 . When the level is at L_1 the liquid will be height h_1 above switch. The pressure at the switch will be $P_1 = \rho g h_1$.

ρ – the mass density of the liquid

g – the acceleration due to gravity

h_1 – the height of the liquid

The resulting switch closure can energize the solenoid valve V_1 causing an inflow to the tank. Assuming the valve is correctly sized, this will cause a rise in the level back towards the setpoint.

In order to arrest the rise in level the built in differential feature of the switch can be employed to de-energize the solenoid valve when level L_2 is reached. This system will achieve a mean level in the tank about the desired setpoint. This method is known as ON/OFF control. Clearly it is impossible to maintain the system at the setpoint since there must be a difference in the operating levels L_1 and L_2 as the valve can only be

energized or de-energized. It is often counter productive to try to reduce the differential between L_1 and L_2 to too small a value as this will result in excessive cycling, and hence wear, of the valve. Usual practice is to control with a deadband about the setpoint as shown in Figure 4.

Note

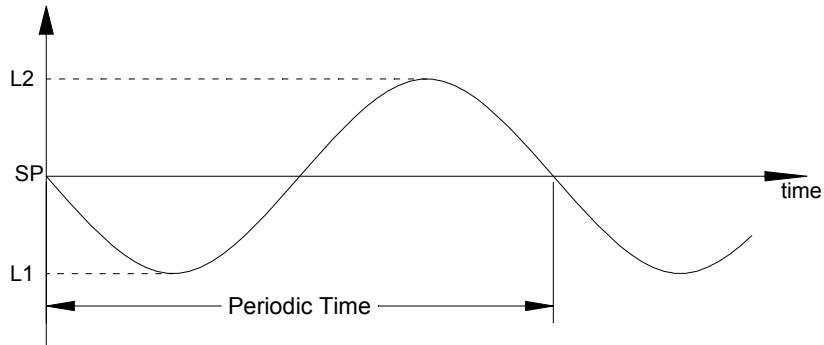


Figure 4
Typical On/Off Response

The sinusoidal cycling is typical of on/off control. on/off control can be used to advantage on a sluggish system, i.e., where the periodic time is large. Typical uses in CANDU units are electric heater controls in de-aerator tanks and PHTS bleed condenser and pressurizer.

If fine control is required a simple on/off control system is inadequate. We will discuss a method for achieving a finer control in the next section.

3.2.1 Summary

- On/off control - control signal is either 0% or 100%
- Control at setpoint not achievable, a deadband must be incorporated.
- Useful for large, sluggish systems particularly those incorporating electric heaters.

3.3 BASIC PROPORTIONAL CONTROL

Note

In our example of on/off control it was seen that an all or nothing control correction was applied as the result of an error signal occurring. Clearly it would be to our advantage if the control signal were proportional to the magnitude of error. This is the basis of proportional control and is the most frequently encountered control mode. How can this control be achieved? Referring to Figure 5 it can be seen that we can modify our system to use a pneumatically operated control valve and a level transmitter with a 20 – 100 kPa pneumatic output.

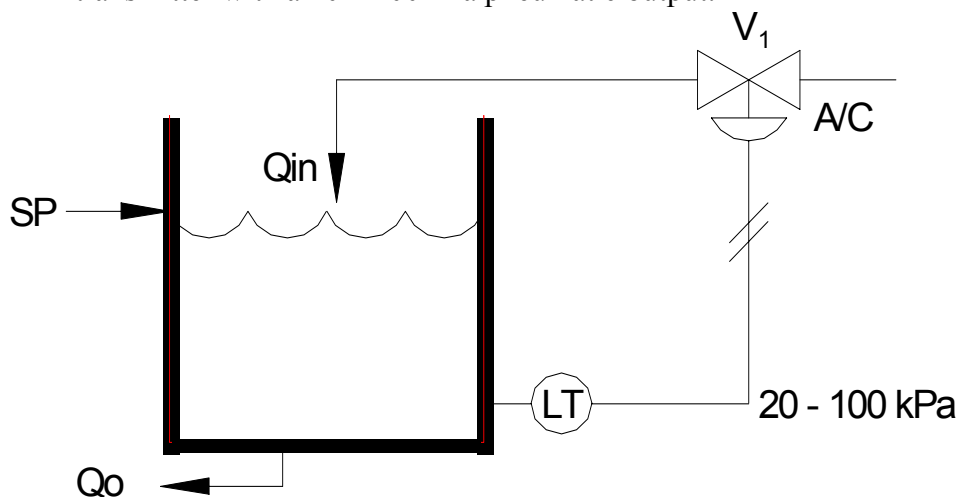


Figure 5: Level Control of Open Tank

If the outflow (Q_o) increases then the level in the tank will fall. The pressure sensed by the level transmitter, which is representative of the level in the tank, will also fall causing a decrease in the output signal from the level transmitter. This output signal is fed to the (air to close) control valve (valve fully open with 20 kPa signal, fully closed with 100 kPa signal). A falling level will therefore cause the valve to progressively open and hence raise the level in the tank. The system as shown is somewhat impractical as the initial setpoint conditions will need to be set by some manual method and then ensuring that steady state conditions are achieved with the valve at, say 50% opening and a level transmitter output of 60 kPa (50% range).

This simple system does illustrate however a major disadvantage with proportional control. Notice that the control signal (valve opening) can only change when the level signal is changing. Thus if a disturbance occurs, say an increase in demand, the level will drop and the output from the level transmitter will also fall. This will cause the air to close valve to open more, hence increasing the inflow.

After a period of time the inflow will have increased such that a new mass balance is established between inflow and outflow. But where is the level at this time?

Note

Certainly not at the setpoint. In the example given it will stabilize at some steady state level below the setpoint. This steady state deviation is known as offset and is inherent in all proportional control systems. Despite this obvious disadvantage, (we cannot return the process to the setpoint after a disturbance with proportional control) this mode of control will form the basis for all our control strategies. In the next section we will discuss a more practical control scheme using proportional control and also ways of lessening the problem of offset.

Example 1

A tank has inflow and outflow equal to 50% of maximum and its level is at the setpoint, say 50%. A step change in outflow occurs to 60% (+10%). Outflow now exceeds inflow so the level will fall. The output from the level transmitter will also fall and, for our system, will match the fall in level – say 1% change in signal for a 1% change in level. The LT signal will open the A/C valve more, by 1% in fact. The inflow is now 51%, still less than the outflow. The level will continue to fall until inflow equals outflow, i.e., (60%). This can only happen when the LT signal has changed by 10% and this change reflects a drop in level on 10%: i.e., 10% offset.

To restore the process to the setpoint requires a further increase of inflow. This increase can only be achieved by a further decrease in signal to the valve (i.e., as decrease in LT output corresponding to a further decrease in level).

With the conditions as stated in the example there is no way in which a 50% level can be achieved with a 60% outflow. A 50% level with a 60% outflow requires a 60% inflow. Our systems can only provide a 60% inflow from a 40% level signal.

Example 2

An alternative method of illustrating proportional control is by means of a simple float system (Figure 6). Assume the inflow and outflow are equal and the level is at the setpoint. If an increase in outflow occurs the level in the tank must fall. The float will also fall as the level falls. This drop in float position will cause the valve on the inflow to open more thus increasing the inflow. Eventually the fall in level will result in a valve opening, which will restore the mass balance between the inflow and the outflow.

Note an increased inflow can only be achieved as a result of a lower level in the tank. The level is no longer at the setpoint an offset has been generated.

Note

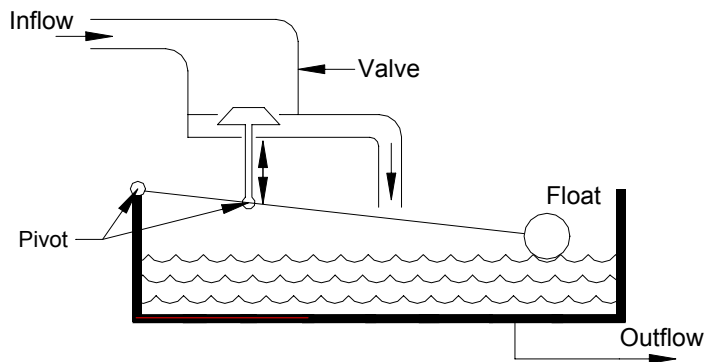


Figure 6
Simple Proportional Control

3.3.1 Summary

- Proportional control provides a control signal, proportional to the magnitude and direction of the error signal.
- After a disturbance, proportional control will provide only a new mass balance situation. A change in control signal requires a change in error signal, therefore offset will occur.
- Proportional control stabilizes an error; it does not remove it.

3.4 Proportional Control

3.4.1 Terminology

M = Measurement Signal

SP = Setpoint

e = Error

$e = SP - M$ Note: If $M > SP$ then e is negative
If $M < SP$ then e is positive

m = Controller Signal Output Δ in O/P = final – initial

k = Gain when controller uses $e = SP - M$
THEN K is negative for Direct Acting
K is positive for Reverse Acting

b = bias (usually 50% of output span)

$m = ke + b$

↑↑ Direct Action $M \uparrow m \uparrow$
↑↓ Reverse Action $M \uparrow m \downarrow$

PB = Proportional Band

Small (narrow) PB = High Gain

Large (wide) PB = Low Gain

$$\text{Gain (k)} = \frac{100\%}{PB} = \frac{\% \Delta \text{Output}}{\% \Delta \text{Input}} = \frac{\% \Delta \text{valve}}{\% \Delta \text{process}}$$

3.4.2 Practical Proportional Control

A more practical proportional control scheme can be achieved by inserting a controller between the level transmitter and the control valve. This will eliminate the setting up problems mentioned in the previous module (i.e., it will have a setpoint control) and also introduce other advantages, which will be discussed in this section.

In a practical system one of the primary considerations is the failure mode of the valve.

In our example of an open tank with a valve on the inflow it would be reasonable to assume that the valve should close in the event of an air supply failure to prevent the tank overflowing, i.e., an air to open valve.

Note

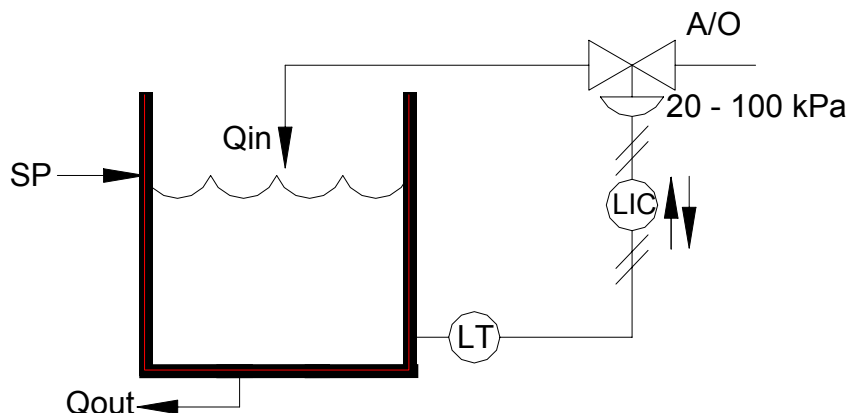


Figure 7
Open Tank Control

To achieve the necessary control action on, say, a falling tank level it is necessary to convert the decreasing output of the level transmitter to an increasing input signal to the control valve. The level controller will perform this function and is termed an indirect or reverse acting ($\uparrow\downarrow$) controller. It can be seen that if the valve action had been chosen air to close, then this reversal would not have been required and a direct ($\uparrow\uparrow$) acting controller could have been used. Normally controllers are capable of performing either control action, direct or reverse, by a simple switching process.

The controller will also accept our desired setpoint input and perform the comparison between setpoint and measurement to calculate the error's magnitude and direction.

Up to now we have only assumed proportionality constant or one, i.e., the control signal equals the input error. Is this always the best ratio? Consider the following graphs of input, output and level with respect to time:

Note

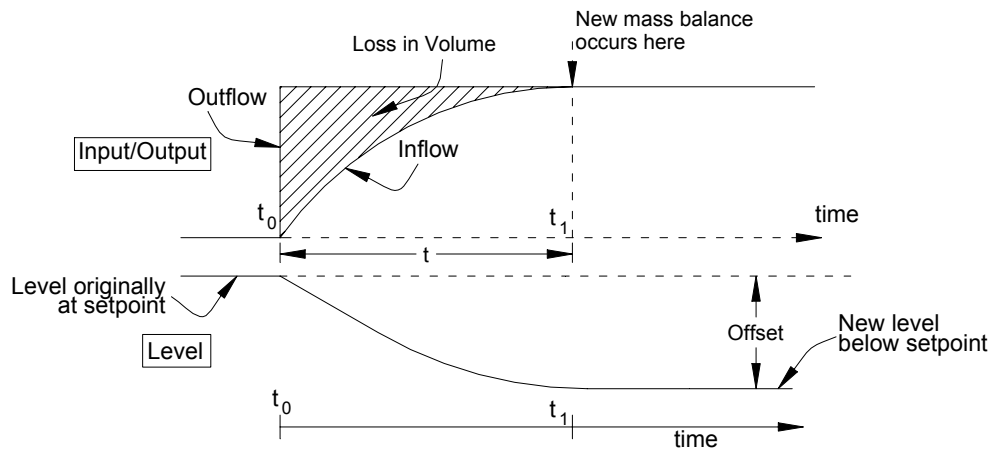
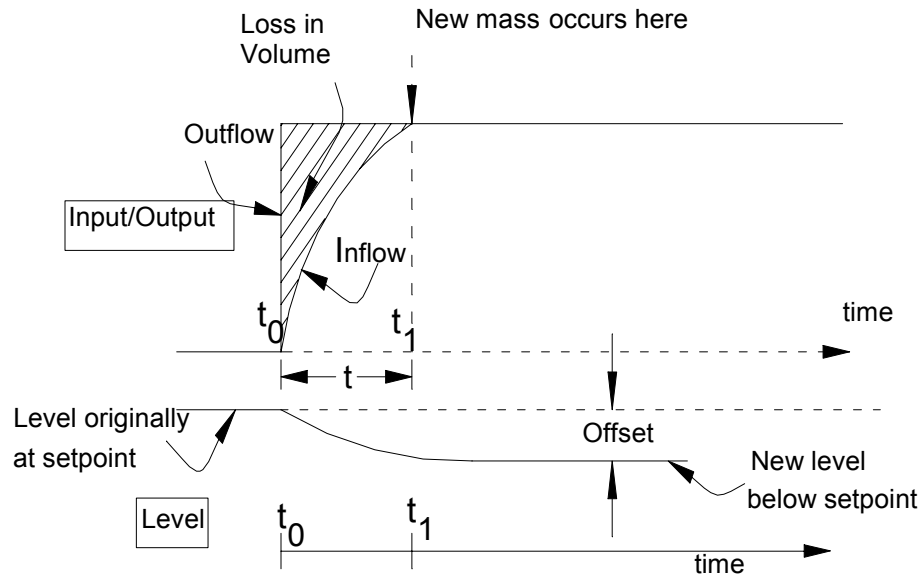


Figure 8: Proportional Control Response Curve

It can be seen that a step increase in demand (outflow) has occurred at time t_0 . the resulting control correction has caused a new mass balance to be achieved after some time t_1 . At this time, under the new mass balance conditions, the level will stabilize at some level below the original setpoint, i.e., an offset has occurred, the loss in volume being represented by the shaded area between the input and output curves.



**Figure 9
Proportional Response with a lower Proportional Band**

Consider now the same demand disturbance but with the control signal increased in relative magnitude with respect to the error signal; i.e.,

instead of control signal = error signal, control signal = error signal x gain constant (k). Clearly for any given error signal the control signal will be increased in magnitude, the inflow will be increased, and a new mass balance will be achieved in a shorter time as shown in Figure 9. (If we refer back to our simple ballcock system in section 3.3, it can be seen that the gain could be varied by adjusting the position of the valve-operating link on the float arm.) The offset is much reduced. In instrumentation this adjustment of controller gain is referred to as proportional band (PB).

Proportional band is defined as that input signal span change, in percent, which will cause a hundred percent change in output signal.

For example if an input signal span change of 100% is required to give an output change of 100% the system is said to have a proportional band of 100%. If the system was now adjusted such that the 100% change in output was achieved with only a 50% change in input signal span then the proportional band is now said to be 50%. There is a clear relationship between proportional band and gain. Gain can be defined as the ratio between change in output and change in input.

$$gain = \frac{\Delta output}{\Delta input}$$

By inspection it can be seen that a PB of 100% is the same as a gain of one since change of input equals change in output. PB is the reciprocal of gain, expressed as a percentage. The general relationship is:

$$gain = \frac{100\%}{PB}$$

Example:

What is the gain of a controller with a PB of?

- a) 40%, b) 200%

Answer:

$$a) \quad gain = \frac{100\%}{PB} = \frac{100\%}{40\%} = 2.5$$

$$b) \quad gain = \frac{100\%}{PB} = \frac{100\%}{200\%} = 0.5$$

What will the PB setting in percent for a controller with gain of?

- a) 3, b) 0.4

Answer:

$$a) PB = \frac{100\%}{\text{gain}} = \frac{100\%}{3} = 33.33\%$$

$$b) PB = \frac{100\%}{\text{gain}} = \frac{100\%}{0.4} = 250\%$$

Small values of PB (high gain) are usually referred to as narrow proportional band whilst low gain is termed wide proportional band. Note there is no magic figure to define narrow or wide proportional band, relative values only are applicable, for example, 15% PB is wider than 10% PB, 150% PB is narrower than 200% PB.

We have seen from the two earlier examples that increasing the gain, (narrowing the PB) caused the offset to be decreased. Can this procedure be used to reduce the offset to zero?

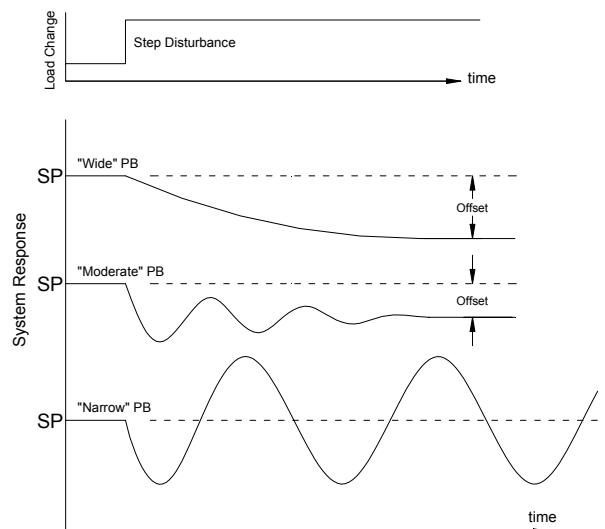


Figure 10: Response Versus PB, Proportional Control Only

Note

Note

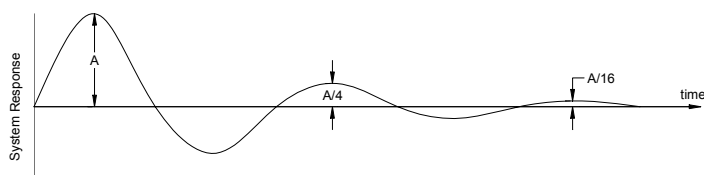


Figure 11
1/4 Decay Response Curve

With reference to Figure 10, consider a high gain system (say gain = 50, PB = 2%). Under steady state conditions with the process at the setpoint the inflow will have a constant value. This is usually taken to be a control signal of 50% for a proportional controller with the process at the setpoint. In other words we have a 50% control capability. With our high gain system it can be seen that the maximum control signal will be achieved with an error of =1% (control signal = gain x error). This control signal will cause the valve to go fully open, the level will rise and the process will cross the setpoint. The error signal will now change sign and when the error again exceeds 1% the resultant control signal will now cause the valve to fully close hence completely stopping the inflow. This process will be repeated continuously – we have reverted to an on/off control situation with all the disadvantages previously mentioned. Obviously there must be some optimum setting of PB which is a trade off between the highly stable but sluggish low gain system with large offset, and the fast acting, unstable on/off system with mean offset equal to zero. The accepted optimum setting is one that causes the process to decay in a 1/4 decay method as shown in both Figures 10 and 11.

The quarter decay curves show that the process returns to a steady state condition after three cycles of damped oscillation. This optimization will be discussed more fully in the section on controller tuning.

Recall the output of a proportional controller is equal to:

$$m = ke$$

where m = control signal

$$k = \text{controller gain} = \frac{100\%}{PB}$$

$$e = \text{error signal} = (SP - M)$$

Clearly if the error is zero the control signal will be zero, this is an undesirable situation. Therefore for proportional control a constant term or bias must be added to provide a steady state control signal when the error is zero.

For the purposes of this course we will assume the steady state output of a proportional controller when at the setpoint to be 50%. The equation for proportional control becomes:

$$m = ke + b$$

where b = bias (=50% added to output signal)

Calculation of Offset

Example:

An air to open valve on the inflow controls level in a tank. When the process is at the setpoint the valve opening is 50%. An increase in outflow results in the valve opening increasing to a new steady state value of 70%. What is the resulting offset if the controller PB is:

- a) 50%
- b) 25%

Answer:

To achieve correct control the controller will be reverse ($\uparrow\downarrow$) acting.

- a) PB = 50% $\therefore$ gain = 2
Change in valve position = $70 - 50 = 20\%$
This is the output change from the controller

$$gain = \frac{\Delta output}{\Delta input}$$

$$2 = \frac{20\%}{\Delta input}$$

$$\therefore \Delta input = 10\%$$

Since controller is reverse acting D measured variable must have been negative, i.e., -10%. This is equal to a + error or a – offset. $\therefore$ offset = -10% below setpoint.

- b) PB = 25% gain = 4
 $\therefore$ input = 5%
offset = -5% below setpoint.

Note that the narrower PB is likely to introduce some degree of oscillation into the system. Hopefully this will be a damped oscillation.

Note

3.4.3 Summary

- The controller action must be chosen (either direct ↑↑ or reverse ↑↓) to achieve the correct control response.
- Proportional Band = $\frac{100\%}{gain}$ or $gain = \frac{100\%}{PB}$
- The optimum settings for PB should result in the process decaying in a ¼ decay mode.

Note

3.5 Reset of Integral Action

Note

Most of the processes we will be controlling will have a clearly defined setpoint. If we wish to restore the process to the setpoint after a disturbance then proportional action alone will be insufficient.

Consider again the diagram (Figure 12) showing the response of a system under proportional control.

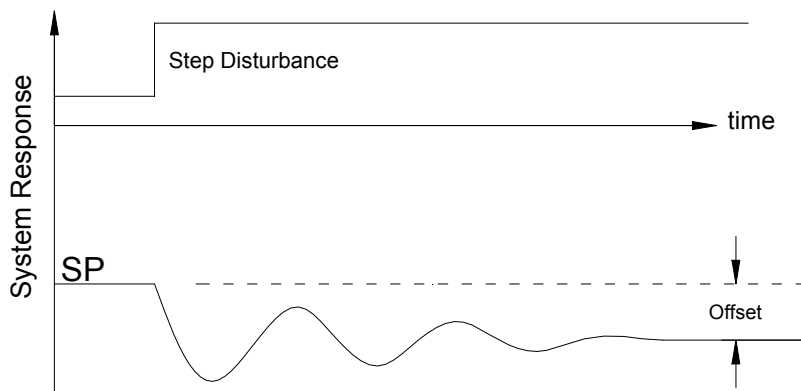


Figure 12: Response Curve: Proportional Control Only

If we wish to restore the process to the setpoint we must increase the inflow over and above that required to restore a mass balance. The additional inflow must replace the lost volume and then revert to a mass balance situation to maintain the level at the setpoint. This is shown in Figure 13. This additional control signal must be present until the error signal is once again zero.

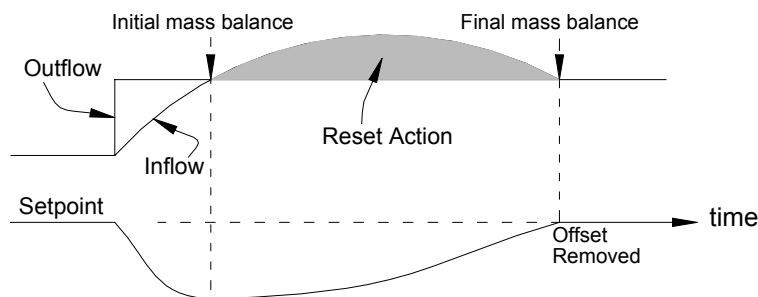


Figure 13
Additional Control Signal Restores Process to Setpoint

This additional control signal is known as Reset action, it resets the process to the setpoint. Reset action is always used in conjunction with proportional action. Mathematically, reset action is the integration of the error signal to zero hence the alternative nomenclature – Integral action.

The combination of proportional plus reset action is usually referred to as PI control.

The response of PI control is best considered in open loop form, i.e., the loop is opened just before the final control element so that the control correction is not in fact made. This is illustrated in Figure 14.

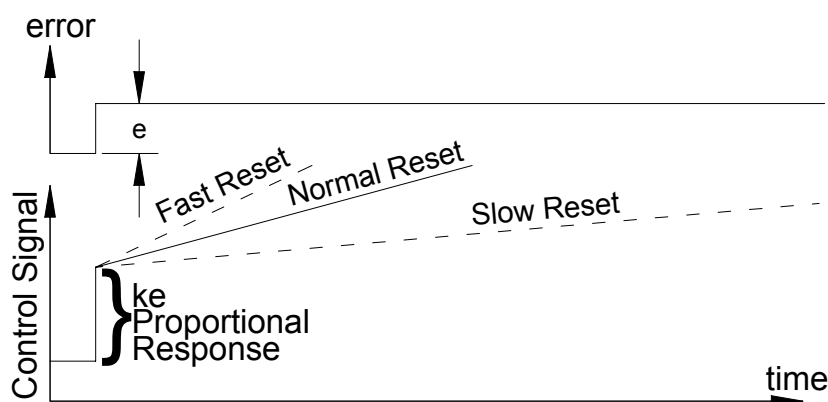


Figure 14
Proportional Plus Reset, Open Loop Response

It can be seen that proportional action will be equal to ke where k is the gain of the controller. Reset action will cause a ramping of the output signal to provide the necessary extra control action.

After time, say t , the reset action has repeated the original proportional response; this is the repeat time, the unit chosen for defining reset action. It can be seen that increased reset action would increase the slope of the reset ramp.

Note that proportional action occurs first followed by reset action.

Reset action is defined as either reset rate in repeats per minute (RPM) or reset time in minutes per repeat (MPR).

$$MPR = \frac{1}{RPM}$$

Note

Example:

A direct acting controller has a proportional band of 50% and is subjected to a sustained error. The set point is 50% and the measurement 55%. After 4 minutes the total output signal from the controller has increased by 30%. What is the reset rate setting in RPM and MPR?

Note

Answer:

$$PB = 50\% \qquad gain = \frac{100\%}{50\%} = 2$$

Since $\uparrow\uparrow k$ will be negative

$$\text{Proportional Signal} = -2 \times \text{error} = -2 \times -5\% = +10\%$$

$$\begin{aligned} \text{Total signal after 4 minutes} &= +30\% \\ &= P + I \end{aligned}$$

$$\therefore \text{Integral Signal} = +20\%$$

i.e., integral action has repeated original proportional signal twice in 4 minutes, 2 repeats per 4 minutes or 0.5 repeats per minute.

$$\begin{aligned} \text{Reset rate} &= 0.5 \text{ RPM or } \frac{1}{0.5} \text{ MPR} \\ &= 2.0 \text{ MPR} \end{aligned}$$

We have already mentioned that the optimum setting for proportional control is one, which produces a $\frac{1}{4}$ decay curve. What is the optimum setting for reset action? We will discuss this more fully in the module on controller tuning. For now, let us just consider a very slow reset rate and a very fast reset rate.

A very slow reset rate will ramp the control signal up very slowly. Eventually the process will be returned to the setpoint. The control will be very sluggish and if the system is subjected to frequent disturbances the process may not ever be fully restored to the setpoint!

If a very fast reset rate is used, the control signal will increase very quickly. If we are controlling, say, a large volume tank, the level response of the tank may lag behind the response of the controller.

The control signal will go to its limiting value (0 or 100%) and the limiting control signal will eventually cause the process to cross the setpoint. The error signal will now change its sign, and reset action will also reverse direction and quickly ramp to the other extreme.

This process will continue indefinitely, the control valve cycling, with resulting wear and tear, from one extreme to the other. The actual process level will cycle about the setpoint. This cycling is known as reset windup and will occur if the process is subject to a sustained error and a too fast reset rate. The reset rate must be decreased (reset time increased).

Note

The mathematical expression for P + I control becomes:

$$m = k \left(e + \frac{1}{TR} \int e dt \right) + b$$

m = control signal

e = error signal (e = SP – M) ∴ (+ or -)

k = controller gain (↑↑ = -) (↑↓ = +)

TR = reset time (MPR)

b = bias signal

Proportional control i.e., (proper sign of gain) inputs a 180° lag into the system (the correction must be opposite to the error). Reset action introduces a further lag. This fact must be taken into account when tuning the controller. (It follows proportional action). The total lag must be increased and is now closer to 360°. (360° lag means the feedback signal is now in phase with the input and adding to it – the system is now unstable.) Reset action causes the loop to be less stable.

3.5.1 Summary

- Reset action removes offset.
- It's units are Repeats per Minute (RPM) or Minutes per Repeat (MPR)
- If reset action is faster than the process can respond, Reset Windup can occur.
- Reset Action makes a control loop less stable.

- Do not subject process loops with reset control to sustained errors – the control signal will be ramped to the extreme value – reset windup will occur.

Note

3.6 RATE OR DERIVATIVE ACTION

Consider a control system subjected to a disturbance, which causes the error to increase in a ramped manner. Proportional control would respond to this ramped error with a similarly ramped output signal whose slope is proportional to the controller gain. We could reduce the final deviation from the setpoint, i.e., the offset, and the recovery time, if we can provide some extra control signal related to the rate of change of the error signal. This is termed rate or derivative action and is usually incorporated with proportional control.

Rate action is an anticipatory control, which provides a large initial control signal to limit the final deviation. The typical open loop response is shown in Figure 15.

It can be seen that the derivative action gives a large, immediate, control signal, which will limit the deviation. Proportional action is then superimposed upon this step. When the error stops changing derivative action ceases. Note that the displayed step response unobtainable in practice because the normal response approximates and exponential rise and decay.

The rate response gives an immediate control signal, which will be equal to what the proportional response would be after some time, say, T minutes. Derivative units are given in minutes. These are the minutes advance of proportional action. Derivative action is a leading control and, therefore, tends to reduce the overall lag in the system – the system is somewhat more stable.

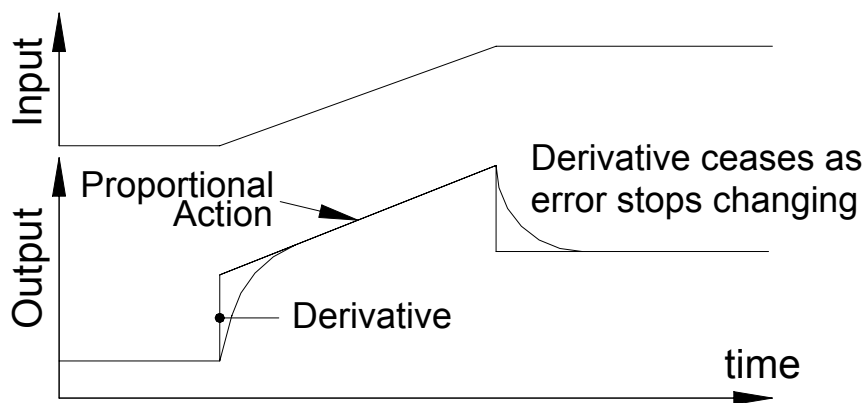


Figure 15
Proportional and Derivative—Open Loop Response

Note

Mathematically proportional plus derivative (PD) control is expressed as:

$$m = k \left(e + T_D \frac{de}{dt} \right) + b$$

m = controller signal
 k = controller gain
 T_D = derivative time
 e = error
 b = bias signal

The use of derivative control is limited. At first glance, derivative control looks attractive. It should help reduce the time required to stabilize an error. However, it will not remove offset. The control signal from derivative action ceases when the error stops changing, which will not necessarily be at the setpoint.

Its use, in practice, is also limited to slow acting processes. If used on a fast acting process, such as flow, control signals due to derivative action will often drive the control valve to extremes following quite small but steep (large $\frac{de}{dt}$) changes in input.

Consider a simple flow control system, consisting of an orifice plate with flow transmitter and square root extractor plus direct acting controller and air to close valve (refer to Figure 16). This system is subjected to a small, but fast, process disturbance. How will this control scheme perform under proportional and derivative control modes?

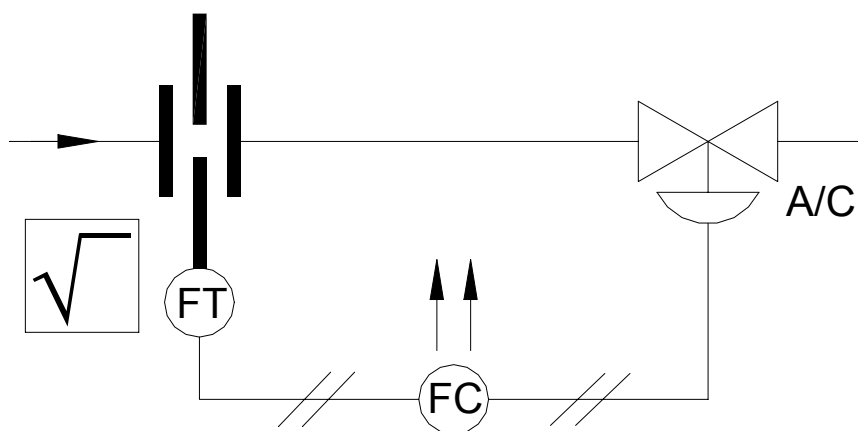


Figure 16
Simple Flow Control System

Note

To answer this question, let us consider the PD response to a fast change in process signal in an open loop system (Figure 17).

Note

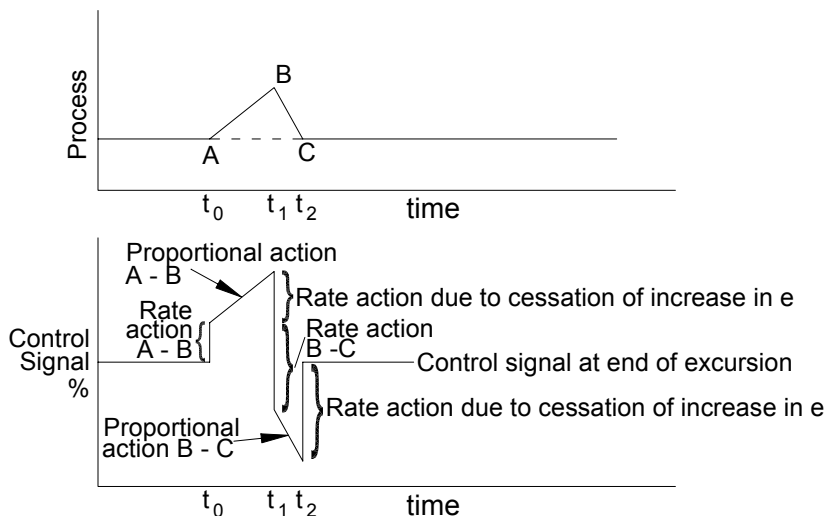


Figure 17: The open Loop Response of Proportional Plus Derivative (PD) Action to Rapidly Changing Error Signals

The upper portion of Figure 17 shows a positive process excursion, AB, from the zero error condition, followed by an equal negative excursion, BC, which returns the error to zero. Note that the rate of change, i.e., the slope of the process change, from B to C is twice the rate of change of the process, from A to B. Mathematically:

$$\frac{de}{dt}(B-C) = 2 \frac{de}{dt}(A-B)$$

The proportional control action from B to C will be equal but opposite to the proportional control action from A to B. The rate or derivative control action from B to C will be double that from A to B. The resulting open loop control signal pattern is shown in the lower portion of Figure 17. The controller gain and derivative settings remain constant.

Very shortly after time (t_0) the control signal increases abruptly to a value determined by the rate of change of the error (e), the derivative or rate time setting, and the controller gain. Proportional action ramps the control signal up, until time (t_1), to a value determined by the error (e) and the controller gain setting. This includes the direction of the error and controller action.

At time (t_1) the rate of change of the process error, de/dt , momentarily becomes zero, so the original change in the control signal due to the rate action drops out. Then, the process error change direction becomes negative, and the derivative control action now produces an abrupt

negative control signal, double the original derivative control signal. The proportional control action then ramps the control signal down until time (t_2).

Note

At time (t_2) the rate of change of the process error becomes zero, so the derivative control signal again drops out leaving the control signal at its original bias (zero) error value. Note that this final bias, (zero) error value of the control signal and, hence, the control valve position at the end of this excursion, is determined solely by the proportional. The valve has been stroked rapidly and repeated by the derivative action subjecting it to unnecessary wear, with no improvement in control.

The response of the closed loop shown in Figure 16 would be somewhat different because the resulting valve action would continuously alter the error signal. However, the valve would still be subjected to rapid and repeated stroking unnecessarily.

Thus, it can be seen from the above discussion that the use of derivative action on fast acting processes such as flow is not advisable.

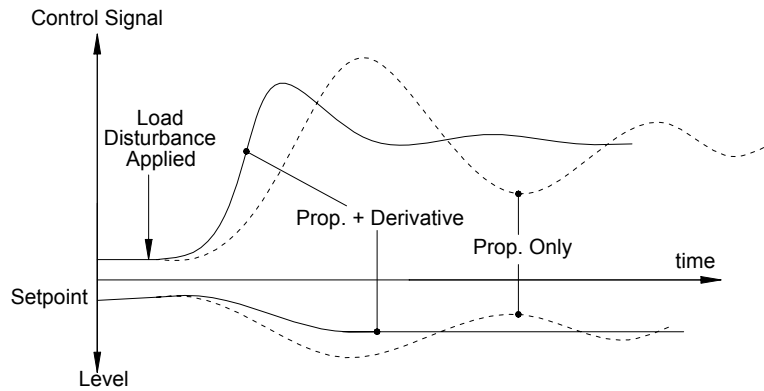
Let us look at the control of a sluggish (generally a physically large) system. As an example, consider a large tank with a variable outflow and a control valve on the inflow. A large volume change will, therefore, be necessary before any appreciable change in level occurs.

Consider a large change in the outflow. After some delay (due to the sluggishness of the system) the controller will respond.

If we have only proportional mode on the controller the delays will mean that the controller is always chasing the error initiated by the outflow disturbance. The response to proportional control is shown in Figure 18. Note that the process has not fully stabilized after a considerable period of time.

The addition of derivative action, however, causes an anticipatory response. The control signal increases more rapidly and the process is returned to a steady state in a much shorter time. Note also that:

The system is more stable (less cycling) with PD control.
Offset still exists.



Note

Figure 18
Large System Under Proportional and Proportional Plus Derivative Control

3.6.1 Summary

- Derivative or rate action is anticipatory and will usually reduce, but not eliminate, offset.
- Its units are minutes (advance of proportional action).
- It tends to reduce lag in a control loop.
- Its use is generally limited to slow acting processes.

3.7 MULTIPLE CONTROL MODES

Note

We have already discussed some of the possible combinations of control modes. These are:

Proportional only,

Proportional plus reset (integral) $P + I$,

Proportional plus derivative (rate) $P + D$.

It is also possible to use a combination of all three-control modes, Proportional plus Integral plus Derivative ($P + I + D$).

At a glance proportional only does not appear very attractive – we will get an offset as the result of a disturbance and invariably we wish to control to a fixed setpoint.

An application of proportional only control in a CANDU system is in the liquid zone level control system. The reason that straight proportional control can be used here is that the controlled variable is not level but neutron flux. The manipulated variable is the water level; therefore offset is not important as the level is manipulated to provide the required neutron flux.

In general it can be said that the vast majority of control systems (probably greater than 90%) will incorporate proportional plus integral modes. (We usually want to control to a fixed setpoint.) Flow control systems will invariably have $P + I$ control.

Derivative control will generally be limited to large sluggish systems with long inherent control time delays, (for example, that shown in Figure 18.). A good general example is the heat exchanger. The thermal interchange process is often slow and the temperature sensor is usually installed in a thermal well, which further slows the control signal response. Frequently heat exchanger temperature controllers will incorporate three-mode control ($P + I + D$).

3.8 TYPICAL NEGATIVE FEEDBACK CONTROL SCHEMES

3.8.1 Level Control

In general we can divide level measurement into three types:

Open Tanks

Closed Tanks

Bubbler Systems (Open or Closed Tanks)

If a differential pressure transmitter is used as a level detector, the low-pressure port will be vented to atmosphere in an open tank application. In a closed tank, where there is often a gas phase at pressure above the liquid, the low-pressure port will be taken to the top of the tank. Any gas pressure will then be equally sensed by the high and low sides and thus cancelled.

Remember the closed tank installation will have either a wet or dry leg on the low-pressure sides.

Open Tank Installation

Assuming the control valve is on the inflow, the best failure mode for the valve would be to fail closed, i.e., Air to Open (A/O) valve. The pressure sensed at the base of the tank on a falling level will decrease, i.e., controller input. The valve must open more, to replenish the tank, requiring an increasing signal. The controller must be reverse acting and will usually have P + I modes. The system is shown in Figure 19

If it is necessary to mount the valve in the outflow, the best failure mode would probably be to fail open (A/C). This valve action would require an increasing signal to halt a falling tank level, again a reverse acting (P + I) controller is necessary.

The same reasoning would apply to closed tank or bubbler systems, the only difference being in the sensing method employed. Remember control modes use of derivative action on large, slow, systems.

Note

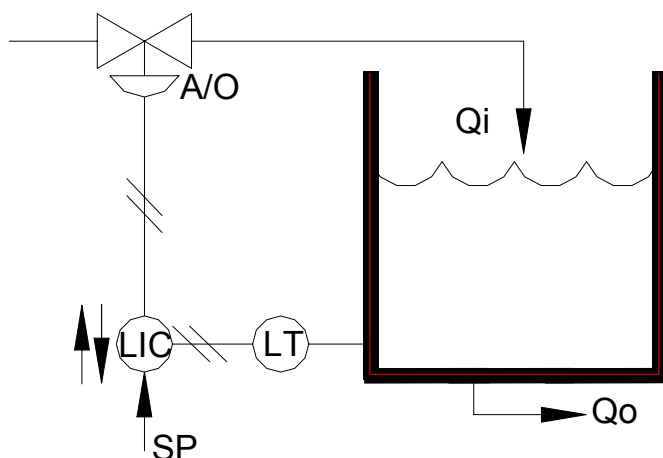


Figure 19
Open Tank Level Control

3.8.2 Flow Control

A typical flow control system requires some form of restriction to provide a pressure differential proportional to flow (e.g. orifice plate) plus a square root extractor to provide a linear signal. The controller action depends upon the choice of control valve. If an air to open valve is chosen then controller action should be reverse, as an increase in flow must be countered by a decrease in valve opening. For an air to close valve the action must of course be direct. The general format is shown in Figure 20.

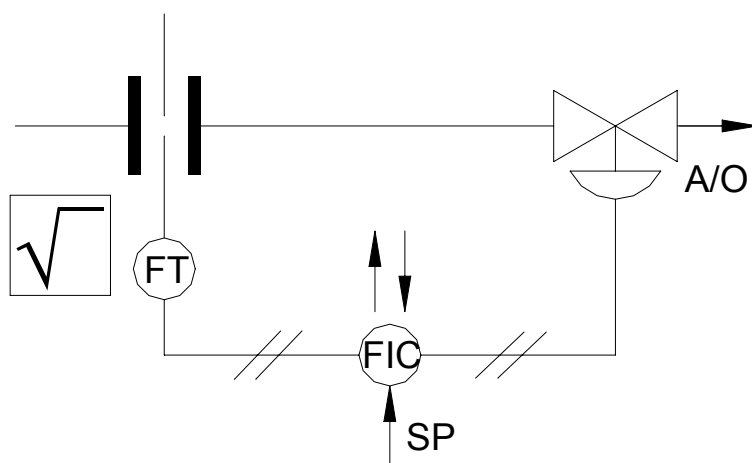


Figure 20
Typical Flow Control

The control modes will be proportional plus integral (never use derivative on a flow control loop).

Note

3.8.3 Pressure Control

The control of pressure in, say, a pressure vessel, is generally achieved in one of three ways.

1. Variable Feed with Constant Bleed
2. Constant Feed with Variable Bleed
3. Variable Feed and Bleed

Consider first Variable Feed and Constant Bleed (Figure 21).

The feed valve action is air to close (A/C). Increasing pressure will require an increasing valve signal to throttle the supply. The (P + I) controller is direct acting. For a variable bleed application the control valve will be transferred to the bleed application the control valve will be transferred to the bleed line and will need to be A/O if a direct acting controller is used.

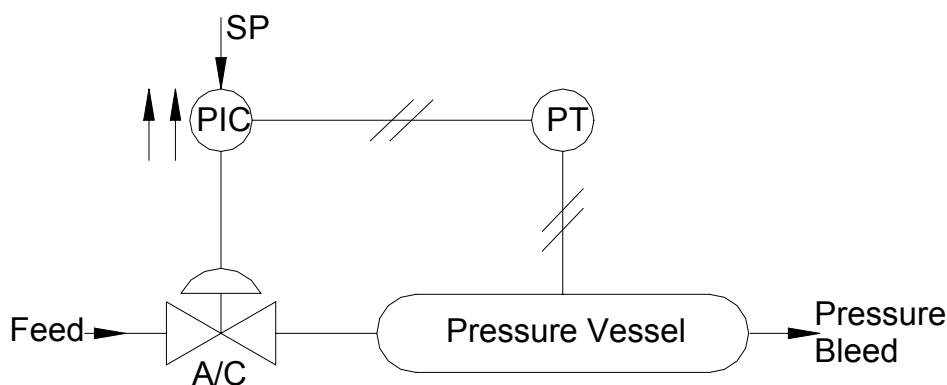


Figure 21
Pressure Control – Constant Bleed

For variable feed and bleed we can use a split range control scheme (one controller driving two valves). This is shown in Figure 22. When at the setpoint we require feed to equal bleed. If pressure increases we require less feed action and more bleed action and vice versa. The valve actions must therefore be opposite, say feed valve A/C and bleed valve A/O. On increasing pressure the direct acting controller will supply a larger signal to the feed valve (closing it) and to the bleed valve (opening it). Pressure should thus be maintained at the setpoint with proportional plus integral control.

Note

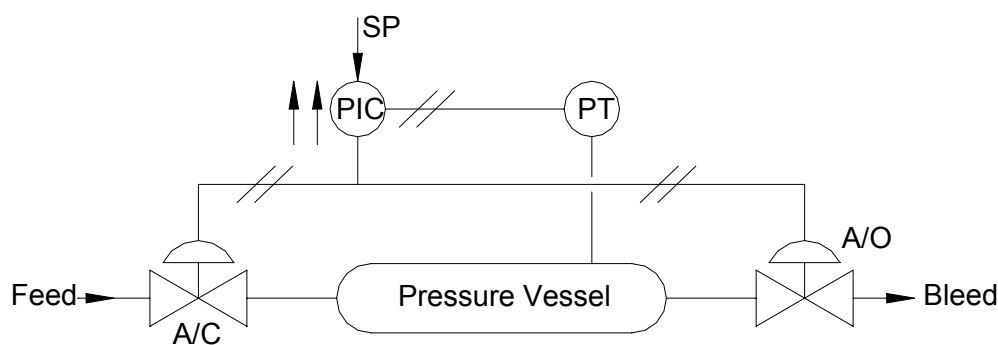
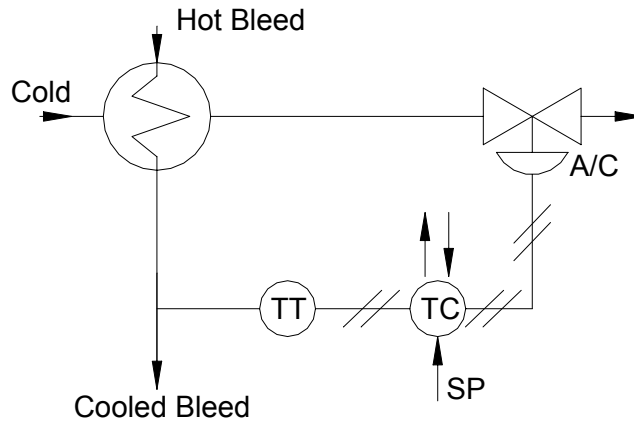


Figure 22
Split Ranged Feed and Bleed Pressure Control

3.8.4 Temperature Control

The general problem with temperature control is the slowness of response. For this reason the use of derivative action is fairly standard. Figure 23 shows a representative heat exchanger, which cools hot bleed with cold service water.

The choice of control valve would probably be air to close, i.e., fail open, to give maximum cooling in the event of a air supply failure to the valve.



Note

Figure 23
Temperature Control of a Heat Exchanger

An increase, say, in bleed temperature requires a larger valve opening, i.e., smaller valve signal. A reverse acting controller is required. Three mode, P + I + D, control is fairly usual.

REVIEW QUESTIONS - CONTROL

Note

1. Consider a system for heating a room with electric heaters; what are the controlled and manipulated variables.
2. Sketch and label a block diagram of simple process under negative feedback control. Mark setpoint, measurement, error, output, disturbances.
3. State the three important characteristics of negative feedback control.
4. State the differences between feedback and feedforward control.
5. Is driving a car (in a reasonably normal manner) an example of feedback or feedforward control? Explain.
6. Explain the operation of a process under negative feedback on/off control.
7. Why will on/off control cause cycling about the desired setpoint?
8. Why is on/off control frequently used in room heating applications?
9. If in figure 5, we located our control valve in the outflow line, what would be the required valve action for negative feedback proportional control?
10. Explain the relationship between error and controller output in a proportional controller.
11. Why does offset occur with proportional control?
12. A control scheme consists of an open tank with an air to close valve on the outflow. Sketch a simple schematic diagram showing the controller action. What would happen to the control of the system if the valve was changed to air to open but the controller action was unchanged?
13. Why can offset not be removed by narrowing the proportional band?
14. What gain is represented by a Proportional Band of 200%, 75%, 400%, 20%?
15. A disturbance causes a process to change by 5%. What will be the change in controller output if the PB is 100%, 50%, 200%?

Note

16. A tank is controlled by an air to close valve on its inflow. When at the setpoint the valve opening is 50% an outflow disturbance causes the valve opening to become 80%. The controller's PB setting is 50%. What is the offset (%)? Assume a linear valve characteristic. Remember an air to close valve requires a decrease in signal to open it further.
17. Sketch and describe the curve which would, in many processes, be the optimum process response following a disturbance.
18. What is the purpose of reset action?
19. What are the units for reset action?
20. What is reset windup?
21. Does reset action make the loop more or less stable?
22. Draw an open loop curve showing the response of a proportional plus reset control system to a step disturbance.
23. A control system with a direct action controller is operating at the setpoint. The controller proportional band is set at 50%. The system is subjected to a disturbance, which creates a positive step error of +6%. The total control output change after 18 minutes is 48%. What is the reset setting in MPR?
24. Using the same control system and control settings as in Question 23, what would be the effect on the system if it had been subjected to a disturbance which caused a step error of -8% for a period of 18 minutes?
25. What is the purpose of rate control?
26. What are the units of rate control?
27. Why should rate control not be used on a fast acting process such as flow?
28. Will rate action remove offset?
29. What is the effect on the rate signal if the error stops changing?
30. Which control setting gives the largest rate signal, 1 minute or 5 minutes? Why?

Note

31. Sketch an open loop response graph for a proportional plus derivative control system subjected to a ramped error signal.
32. A proportional plus derivative control system is subjected to a ramped error of -10% per minute for 1.5 minutes. The PB setting is 100% and the derivative setting is 3 minutes. The controller is reverse acting. Sketch an open loop response curve for the system showing control signal values at 10% intervals, with respect to time.
33. Give a typical control example where straight proportional control can be used.
34. What is the most commonly encountered combination of control modes and why?
35. Why is it advantageous to use derivative action in the temperature control of a heat exchanger?
36. Sketch a level control scheme for an open tank. The valve selected is A/C and on the inflow line. State controller action and modes.
37. A heat exchanger (cooling hot bleed with cold service water) is controlled by an air to open valve on the service water line. Sketch the circuit showing controller action. What control modes would be used and why?
38. Sketch a simple electronic control scheme for the control of flow. The valve chosen is air to close; an orifice plate develops the differential pressure. Show controller action and state the most likely control modes.

DCS



Module 1

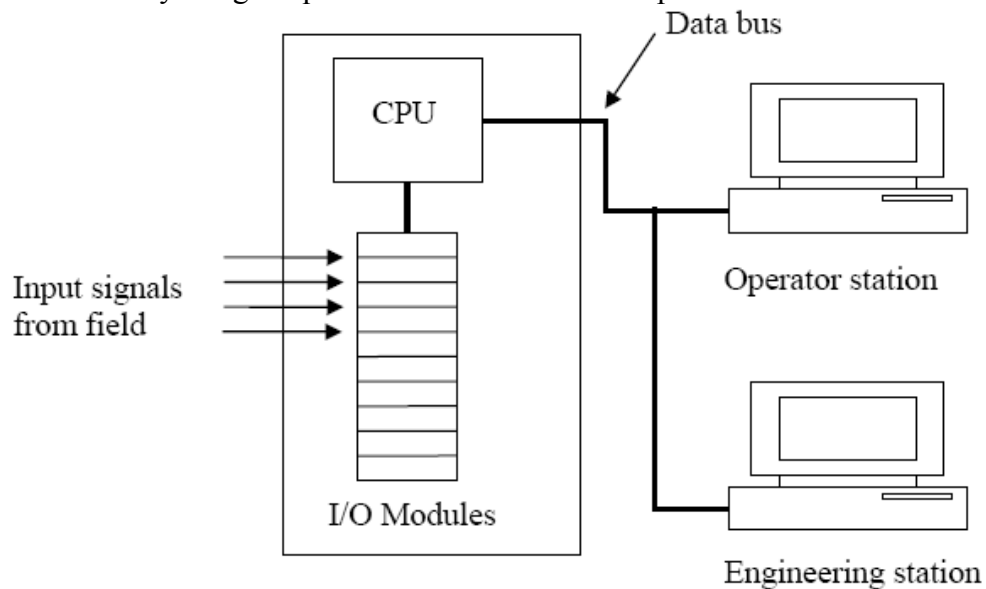
DCS Architecture

Module 1: DCS Architecture

1.1 DCS NETWORK CONSTRUCTION

DCS System consist minimum of the following components.

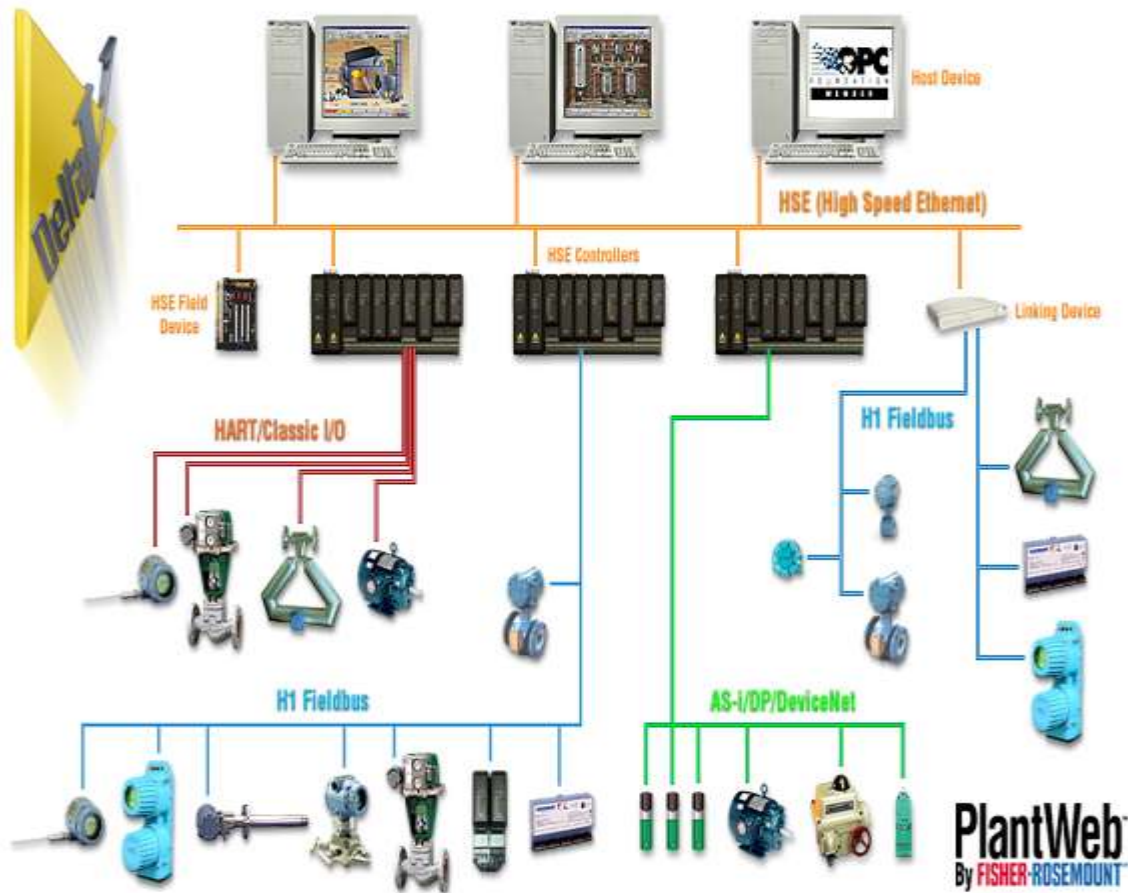
1. Field Control station (FCS): It consists of input/output modules, CPU and communication bus.
2. Operator station: It is basically human interface machine with monitor, the operator man can view the process in the plant and check if any alarm is presents and he can change any setting, print reports... etc.
3. Engineering station: It is used to configure all input & output and drawing and any things required to be monitored on Operator station monitor.



1. High speed, long-distance network communications
2. Operations work centers
3. Microprocessor-based controllers
4. Auxiliary data collection stations
5. Information management-supervisory stations

The most obvious benefit of systems architecture is its contribution to the design of an integrated plant wide information and control system through the distribution of various functions throughout the plant. Thus, operators and unit supervisors can be made aware of conditions outside their domains (e.g., upstream or downstream bottlenecks or plant

utilities constraints) and take corrective action before these factors adversely affect their operations.



Distributed architecture also can provide functionally dedicated stations to various disciplines, e.g., maintenance and engineering, so that system and process information can be dispersed throughout the plant without interfering with operations. The operator can check pressure drops across heat exchangers, for example, to determine the degree of fouling without leaving the maintenance shop.

How DCS work?

Basically, DCS system receives input signals from other devices, these signals will be processed and analyzed by DCS CPU and based on the result an action will be taken.

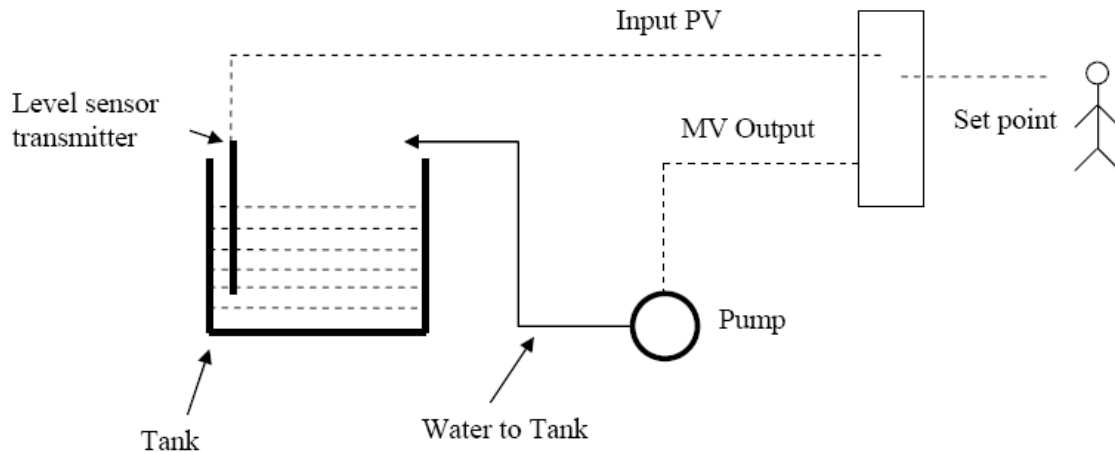
Module 1: DCS Architecture

There are many sensors and transducers inside the plant converts physical quantities such as pressure, temperature to an electrical quantity, these devices called Transmitters they transmit the electrical signals represents physical quantities to DCS System.

There could be thousand of transmitters in a factory sending signals to DCS; 4 to 20mA, 1 to 5VDC or Resistance and for digital they would be 0 or logic 1.

Then FCS receives the analog signals from different transmitters it will convert it to digital via input module then passed to CPU for processing, the CPU will compare the process measured value (PV) with value sited by the operator (SV). If the both values are not matched then DCS will generate an output called Manipulated value (MV) to the field via output modules in order to adjust the physical quantity by operating a valve for example.

The Figure shows an example of simple control mechanism. The water in the tank is required to be controlled, the level transmitter will measure the water level and send PV signal (4-20mA) to DCS. Input module in the FCS will receive this signal and pass it to CPU after converting it to digital signal. The PV data can be monitored on operator station screen in small window called Faceplate.

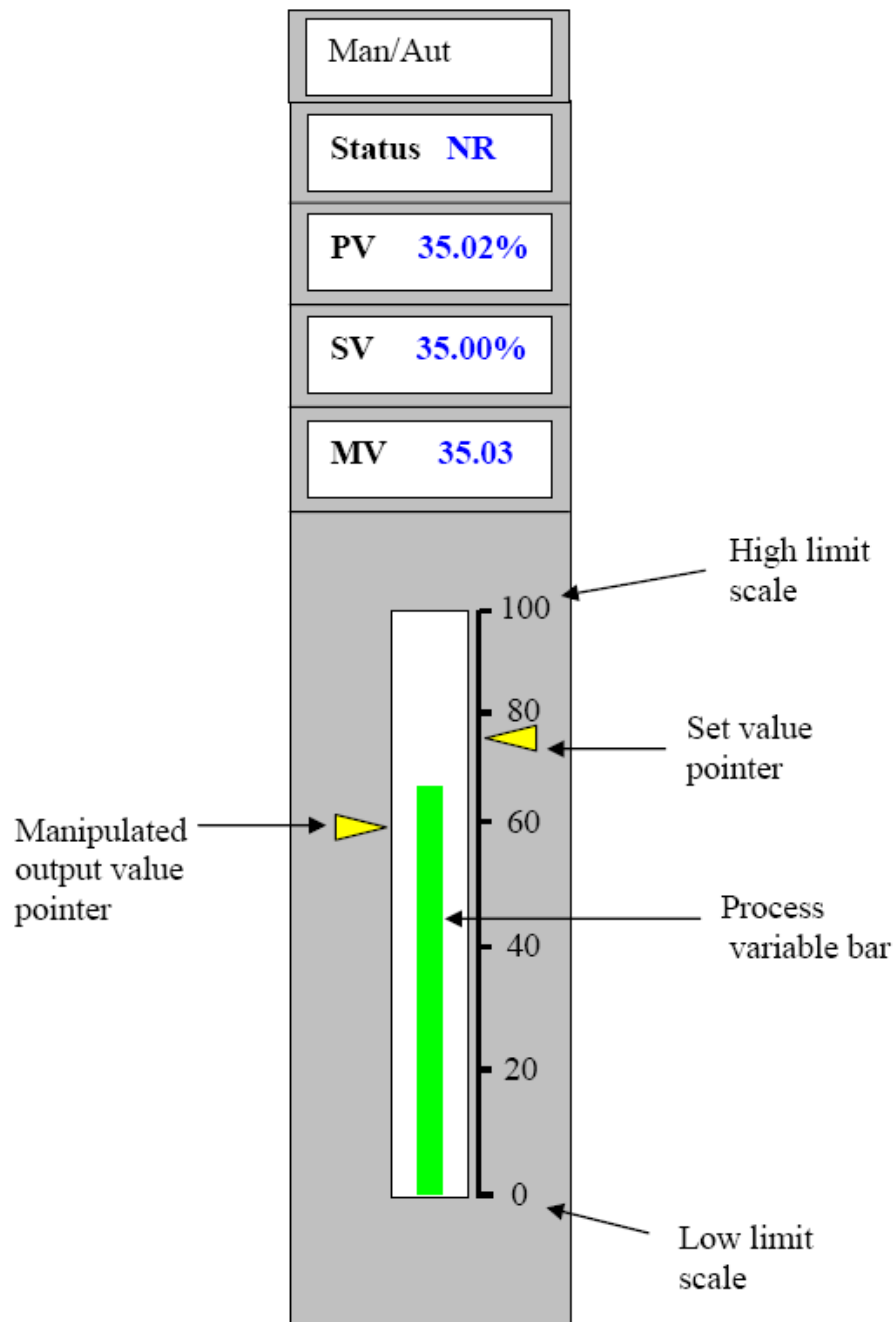


Example of simple control mechanism

On the faceplate the operator can see the three parameters reading SV, PV & MV at the top the faceplate show the status of this control process Normal or Alarm. The SV can be set to the required level by moving the yellow pointer. DCS system will operate the pump by sending MV Signal via output module to fill the tank and continue as long as PV signal received from the transmitter is less than SV, once the water level reached to required level that means $PV=SV$ the DCS will stop the pump and this happen if

faceplate mode is Auto, however in Manual mode, the operator can control MV directly and SV pointer will be disabled.

Also the faceplate shows the status of this control process normal or alarm; the alarm will be initiated if there is any problem in which PV is not able to equalize with SV.



Module 1: DCS Architecture

Example of a simple faceplate

1.2 CONTROLLER MODULE

1.2.1 Functions

Total control. The controller manages all control activities for the I/O interface channels. It also manages all communication functions for the communications network. Time stamping, alarming, and trend objects are also managed within the controller. The controller executes your control strategy. Information from an input channel is received, control strategy applied, and data sent to an output channel within 100ms.

Advanced operations. The Controller is equipped to handle the Batch option, as well as Advanced Control functions such as Neural and Model Predictive Control.

Data passthrough. The controller is equipped with the ability to pass smart HART® information from field devices to any workstation node in the control network. This means you can take advantage of applications, such as Asset Management Solutions, that enable you to remotely manage the HART information contained in your HART or FOUNDATION fieldbus-equipped devices.

1.2.2 Redundancy

No worry has to be paid about a controller failure interrupting your process and causing costly downtime. Using a redundant controller, your process is automatically protected in case of a failure.

The standby controller contains the same configuration as the active controller and tracks the operation of the active controller. When an active controller fails, the standby controller takes over, providing uninterrupted control operation without initialization or user intervention. The switchover generates *no disturbances* to the field output signals; the process continues as though nothing had happened.

The standby controller automatically becomes the active controller. A message to the operator indicates that a switchover has occurred. The Event Chronicle stores a record of each switchover and the reason it occurred (if the reason has been identified).

After the switchover has occurred, the new active controller prepares to begin executing the modules. This phase can take up to ½ second, depending on the size of the configuration. During this phase, all outputs remain at the last value. The new active controller then begins executing the modules from the exact point where the old active controller left off. All clients (graphic displays, etc.) that need controller parameters must re-register for those parameters. The time needed for this activity can be several seconds. This is dependent on the number of clients and the number of parameters requested.

By replacing the failed controller, you can resume redundant operation. The system automatically commissions the new standby controller. When you install a standby

controller into the carrier, the system automatically recognizes it as a redundant controller. You don't have to configure the new controller.

There is no physical difference between the active and standby, nor is there a preferred position for the active controller. The controller that boots first becomes the active controller. Even though each controller in a redundant pair has its own network address, a redundant controller counts as a single node on the control network in terms of network capacity. The commissioning and decommissioning function affects both controllers in the pair.

A switchover from the active to the standby controller can occur for the following reasons:

Hardware failure

A hardware fault analysis of the controller circuitry ensures that the failure of a component is detected.

Communications failure between the active controller and the I/O sub-system

Both controllers monitor their ability to communicate with the I/O. If the active controller does not talk to the I/O for more than 1 second, a switchover will occur if the standby has the ability to communicate with the I/O.

Communications failure of both the primary and secondary network connections in the active controller

Every 10 seconds, both controllers check their ability to communicate with other nodes on the control network. If the active controller detects a loss of communications, a switchover will occur if the standby has the ability to communicate on at least one (primary or secondary) of its control networks.

Removal of the controller from the carrier

If the active controller is physically removed from the carrier, a switchover will occur.

Manual switchover request

A user with Control privilege can initiate a manual switchover. Three conditions must be satisfied before a manual switchover can be done.

1. The standby controller is physically present
2. The standby controller has received a download and is ready to take over
3. Redundancy has been enabled for the pair

Power failure of the active controller

A switchover will occur so long as the standby is available.

Memory failures

To detect memory-related problems, the controller executes CRC (cyclic redundancy check) tests on the flash ROM and a RAM test. The ROM CRC test runs continually in the background, as a low priority task. RAM tests are executed every time the controller is rebooted. If the active controller detects a failure in either the RAM or ROM test, a reset will occur, resulting in a switch over to the standby controller.

Runaway software

Module 1: DCS Architecture

The controller has protection mechanisms for detecting “runaway software,” for example “infinite loops.” These mechanisms include a watchdog timer and processor exception handling.

The redundancy link ensures that the standby is updated efficiently and quickly, to provide a bumpless switchover. When a configuration is downloaded, the standby receives an “initial update” that transfers all the current parameters. Thereafter, the redundancy link goes into “change” reporting mode. In this mode the standby controller is updated with changes only that have taken place in the active controller.

1.3 POWER SUPPLY

The system power supply components fit into either position on the power/controller carrier. This interchangeability means you can expand or replace power components. Just pull out one power supply component and snap in the other. The power/controller carrier contains *internal power buses*. You don’t need to use external cabling to connect the system power supply to the controller and the I/O interface carriers. A modular power structure allows you to simply snap on additional power to future modifications and extensions.

Some systems power supplies can be redundant at 1-to-N versus 1-to-1 in other systems. The power supplies’ load-sharing capabilities enable you to add more power and provide power redundancy to your system.

The system power supplies accept a wide range of power inputs and translate the inputs into accurate power output. The I/O subsystem and controller always receive a consistent and accurate 12- or 5-VDC power supply. The field devices receive a consistent 24-VDC power supply. The system and field power provisions are completely isolated.

Hazardous Atmosphere



Nemko No. 02ATEX431U
EEx nC IIC T4
Lo=3,55 uH
Alarm relay energy limited field circuit parameters:
Uo = 30 VDC
Io = 135 mA
Li = 0
Ci = 0

System Power

Input	
12 VDC	11.4 VDC to 12.6 VDC
24 VDC	22.8 VDC to 25.2 VDC
Output Power:	10 W total at 60° C (combined outputs of 5 VDC and 3.3 VDC)
Output rating:	+12 VDC at 13.0 A (12 VDC input) +12 VDC at 4.5 A (24 VDC input) +5 VDC at 2.0 A 3.3 VDC at 2.0 A

Environmental Specifications

Ambient Temperature	0 to 60° C
Shock	10 G ½-sinewave for 11 ms
Vibration	1 mm peak-to-peak from 5 Hz to 16 Hz, 0.5 g from 16 Hz to 150 Hz
Airborne Contaminants	ISA-S71.04 –1985 Airborne Contaminants Class G3
Relative Humidity	5% to 95% non-condensing

Power supply label

1.4 PERMENANT MEMOREY

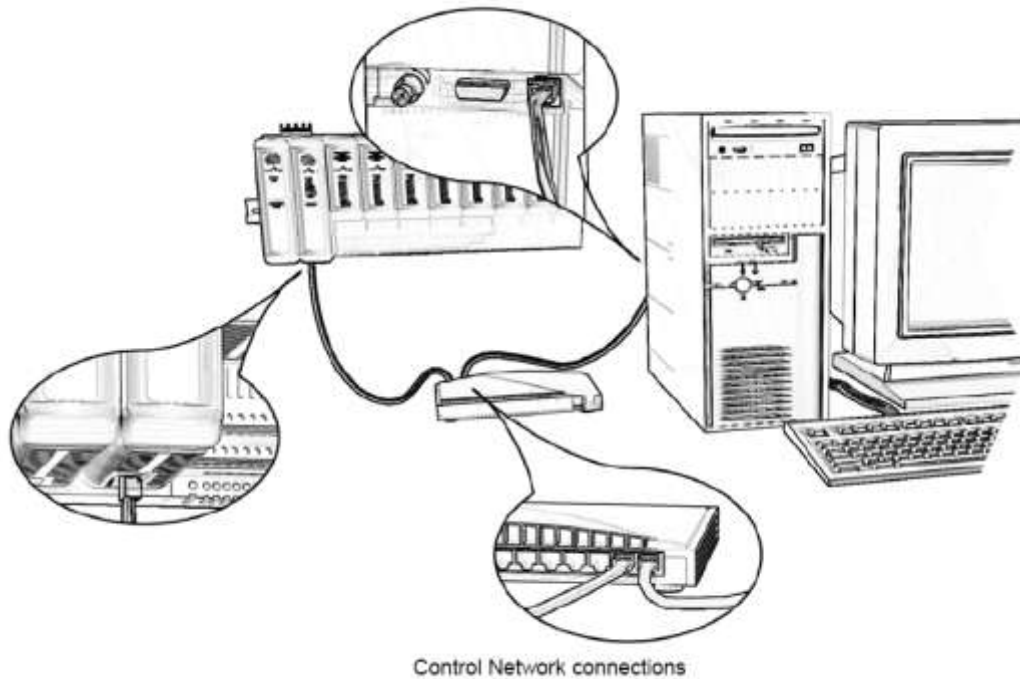
Data protection. Each time you install data in a DeltaV controller, the installation information is automatically saved. Likewise, when users make online configuration changes to a controller, the system stores these changes as well. This way, the system always retains a complete record of all the data that has been installed in the controller and any online changes that have been made.

Cold restart. This feature ensures that in case of power failure, the controller will restart without manual intervention and without any other device present on the network. Now, you don't have to reboot from the workstation. Simply set the restart state of the controller to current conditions.

1.5 COMMUNICATION INTERFACE CARD

The Control Network can be physically connected as a star or cascade (daisy-chain) topology. Other network configurations are possible, such as a combination of a star and cascade topology.

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Hubs and Switches

The Control Network can use one or more Ethernet hubs or switches for communications connections. The control network must be set up using the network equipment listed in the ordering section (or using the 3COM equipment previously sold by the manufacture).



Wiring

The maximum twisted pair cable length for the control network for any Ethernet-connected device is 100 meters (328 feet). If longer cable distances are needed for this workstation-to-switch, controller-to-switch, or switch-to-switch connections, there are various fiber-optic cable and transceiver solutions available as a standard supported solution. The Control Network supports the use of auto-negotiated 10-half, 100-half, 10 full, and 100- full duplex communications where the industry standard auto-negotiation process determines the highest speed at which two devices will communicate with each other. The latest network products that are standard supported designs make use of gigabit Ethernet via the latest Cisco Networks switches and fiber optic transceivers in multi-node models for standard 2- kilometer distances, and single-mode models for up to 10-kilometer distances. Longer distances can be supported with special designs. The

workstations and controllers contain two Ethernet ports to provide the recommended redundant communications. Early models of controllers supported 10 megabit Ethernet at half duplex only. The latest controllers auto-negotiate to any speed and duplex from 10-half to 100-full, depending on what the controller is attached to. The workstations do the same: they auto-negotiate to the highest speed and duplex available from their attached device.

Ethernet Cable

The system requires the use of Category 5 screened (ScTP) cable for the 10/100BaseT dual speed network.

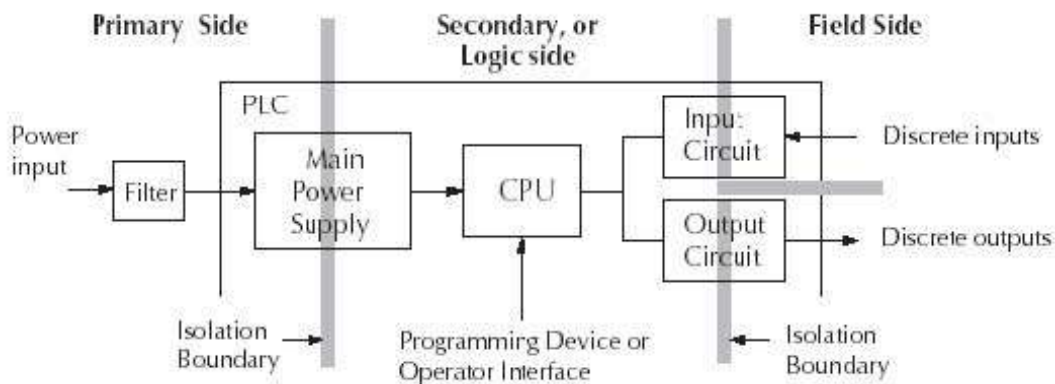
Fiber-optic Wiring

Because fiber-optic cables do not conduct electricity, they should be used in connections between buildings or in plant areas where electromagnetic interference is present. Fiber-optic cabling should also be used where wire runs are longer than 100 meters (328 ft).

1.6 Discrete I/O MODULES

1.6.1 DISCRETE I/O MODULES

DCS circuitry is divided into three main regions separated by isolation boundaries, shown in the drawing below. Electrical isolation provides safety, so that a fault in one area does not damage another. A power-line filter will provide isolation between the power source and the power supply. A transformer in the power supply provides magnetic isolation between the primary and secondary sides. Opto-couplers provide optical isolation in Input and Output circuits. This isolates logic circuitry from the field side, where factory machinery is connected. Note that the discrete inputs are isolated from the discrete outputs, because each is isolated from the logic side. Isolation boundaries protect the operator interface (and the operator) from power input faults or field wiring faults. When wiring a DCS, it is extremely important to avoid making external connections that connect logic side circuits to any field circuits.



Module 1: DCS Architecture

DCS isolation boundaries

Sinking/Sourcing Concepts

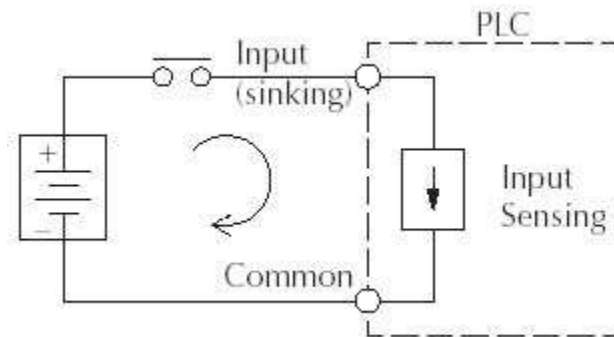
Before going further in our study of wiring strategies, we must have a solid understanding of “sinking” and “sourcing” concepts. Use of these terms occurs frequently in input or output circuit discussions. It is the goal of this section to make these concepts easy to understand, further ensuring your success in installation. First we give the following short definitions, followed by practical applications.

Sinking = Path to supply ground (–)

Sourcing = Path to supply source (+)

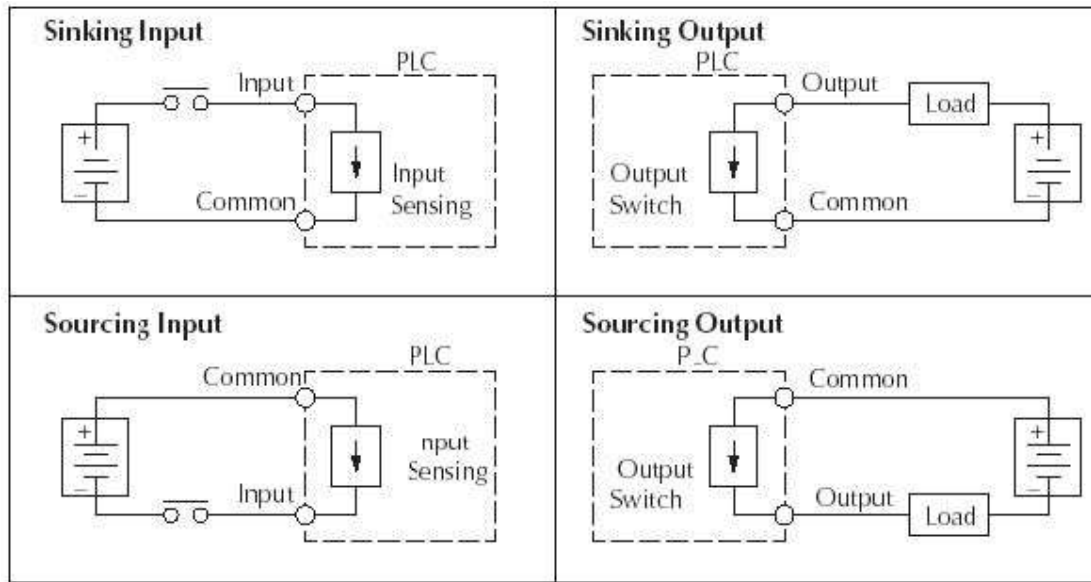
First you will notice that these are only associated with DC circuits and not AC, because of the reference to (+) and (–) polarities. Therefore, sinking and sourcing terminology only applies to DC input and output circuits. Input and output points that are either sinking or sourcing can conduct current in only one direction. This means it is possible to connect the external supply and field device to the I/O point with current trying to flow in the wrong direction, and the circuit will not operate. However, we can successfully connect the supply and field device every time by understanding “sourcing” and “sinking”.

For example, the figure below depicts a “sinking” input. To properly connect the external supply, we just have to connect it so the input provides a path to ground (–). So, we start at the DCS input terminal, follow through the input sensing circuit, exit at the common terminal, and connect the supply (–) to the common terminal. By adding the switch, between the supply (+) and the input, we have completed the circuit. Current flows in the direction of the arrow when the switch is closed.



Sinking Input

By applying the circuit principle above to the four possible combinations of input/output sinking/sourcing types, we have the four circuits as shown below.

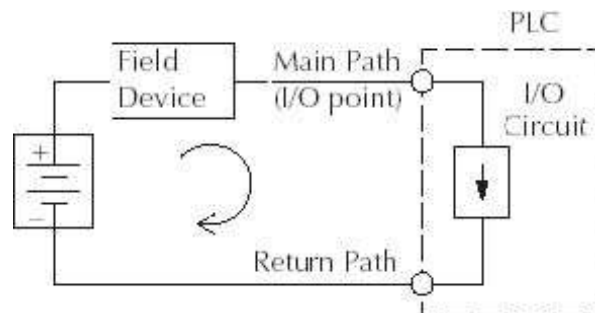


Sinking and Sourcing I/O

I/O “Common” Terminal Concepts

In order for a DCS I/O circuit to operate, current must enter at one terminal and exit at another.

This means at least two terminals are associated with every I/O point. In the figure below, the Input or Output terminal is the main path for the current. One additional terminal must provide the return path to the power supply.

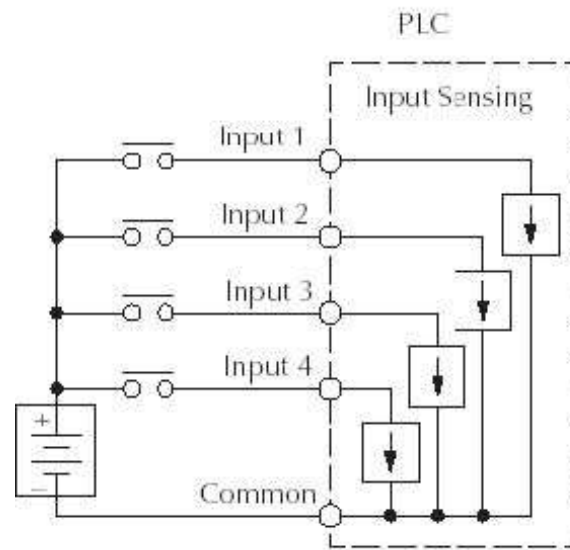


Input or Output point

If we had unlimited space and budget for I/O terminals, then every I/O point could have two dedicated terminals just as the figure above shows. However, providing this level of

Module 1: DCS Architecture

flexibility is not practical or even necessary for most applications. So, most Input or Output point groups on DCSs share the return path among two or more I/O points. The next figure shows a group (or bank) of 4 input points which share a common return path. In this way, the four inputs require only five terminals instead of eight.



Four Inputs with single common

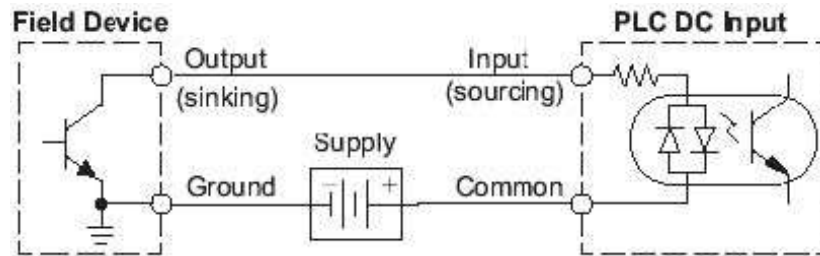
NOTE: In the circuit above, the current in the common path is equal to the sum of the energized channels. This is especially important in output circuits, where larger gauge wire is sometimes needed for the common.

Connecting DC I/O to Solid State Field Devices

In the previous section on Sourcing/Sinking concepts, we explained that DC I/O circuits sometimes will only allow current to flow one way. This is also true for many of the field devices which have solid-state (transistor) interfaces. In other words, field devices can also be sourcing or sinking. When connecting two devices in a series DC circuit, one must be wired as sourcing and the other as sinking.

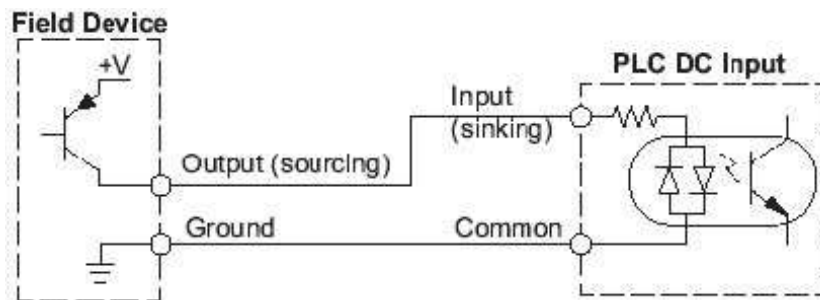
Solid State Input Sensors

The DCS DC inputs are flexible in that they detect current flow in either direction, so they can be wired as either sourcing or sinking. In the following circuit, a field device has an open collector NPN transistor output. It sinks current from the DCS input point, which sources current. The source can be a FA-24PS, +24 VDC, power supply or another supply (+12 VDC or +24VDC) of your choice, as long as the input specifications are met.



Sinking solid state sensor

In the next circuit, a field device has an open-collector PNP transistor output. It sources current to the DCS input point, which sinks the current back to ground. Since the field device is sourcing current, no additional power supply is required.

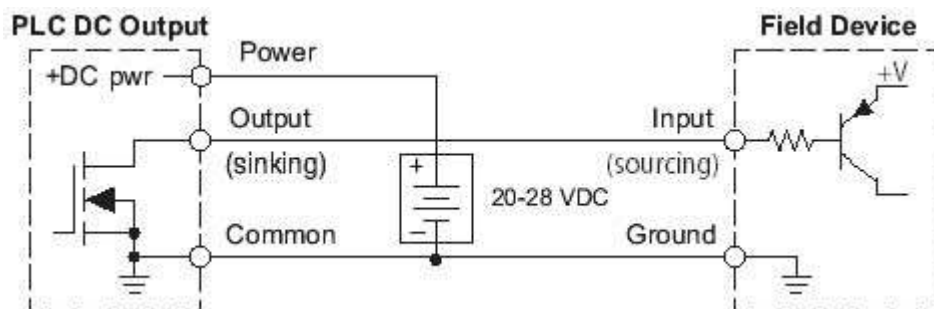


Sourcing solid state sensor

Solid State Output Loads

Sometimes an application requires connecting a DCS output point to a solid state input on a device. This type of connection is usually made to carry a low-level signal, not to send DC power to an actuator.

In the following circuit, the DCS output point sinks current to the output common when energized. It is connected to a sourcing input of a field device input.

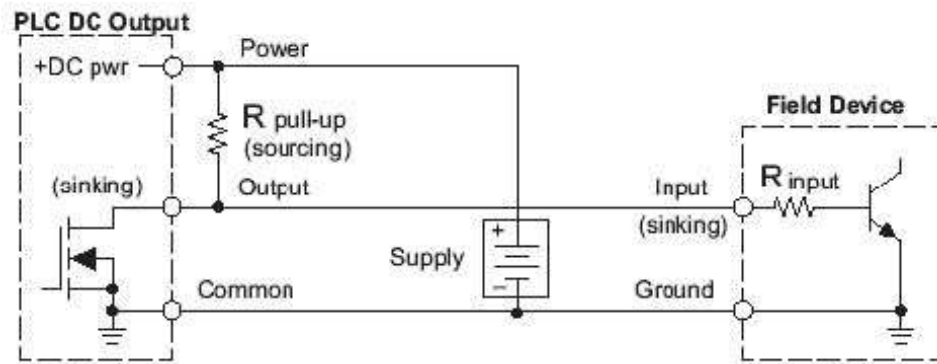


Sourcing solid state actuator

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In the next example we connect a DCS DC output point to the sinking input of a field device.

This is a bit tricky, because both the DCS output and field device input are sinking type. Since the circuit must have one sourcing and one sinking device, we add sourcing capability to the DCS output by using a pull-up resistor. In the circuit below, we connect R_{pull-up} from the output to the DC output circuit power input.



Sinking solid state actuator

NOTE: DO NOT attempt to drive a heavy load (>25 mA) with this pull-up method.

NOTE 2: Using the pull-up resistor to implement a sourcing output has the effect of inverting the output point logic. In other words, the field device input is energized when the DCS output is OFF, from a ladder logic point-of-view. Your ladder program must comprehend this and generate an inverted output. Or, you may choose to cancel the effect of the inversion elsewhere, such as in the field device.

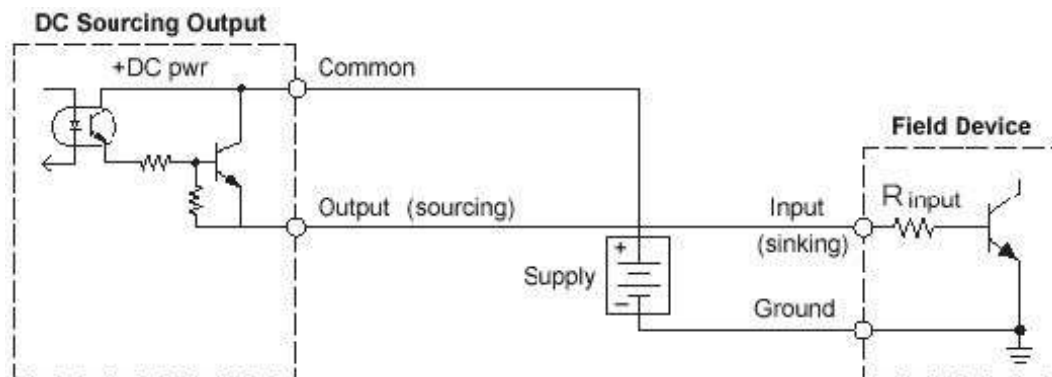
It is important to choose the correct value of R_{pull-up}. In order to do so, we need to know the nominal input current to the field device (I_{input}) when the input is energized. If this value is not known, it can be calculated as shown (a typical value is 15 mA). Then use I_{input} and the voltage of the external supply to compute R_{pull-up}. Then calculate the power P_{pull-up} (in watts), in order to size R_{pull-up} properly.

$$I_{\text{input}} = \frac{V_{\text{input (turn-on)}}}{R_{\text{input}}}$$

$$R_{\text{pull-up}} = \frac{V_{\text{supply}} - 0.7}{I_{\text{input}}} - R_{\text{input}}$$

$$P_{\text{pull-up}} = \frac{V_{\text{supply}}^2}{R_{\text{pullup}}}$$

Of course, the easiest way to drive a sinking input field device as shown below is to use a DC sourcing output module. The Darlington NPN stage will have about 1.5V ON-state saturation, but this is not a problem with low-current solid-state loads.



Sinking solid state actuator

Relay Output Guidelines

Relay outputs are available for DCSs. Relays are best for the following applications:

- Loads that require higher currents than the solid-state outputs can deliver.
- Cost-sensitive applications.
- Some output channels need isolation from other outputs (such as when some loads require different voltages than other loads).

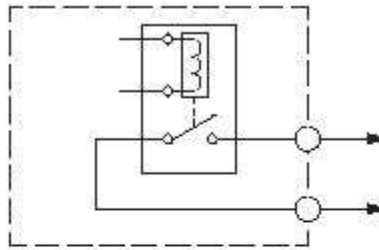
Some applications in which NOT to use relays:

- Loads that require currents under 10 mA.
- Loads which must be switched at high speed or frequently cycled.

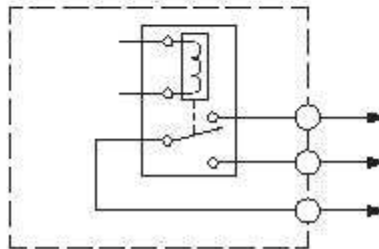
Relay outputs in DCSs are available in two contact arrangements, shown in the figure below. The Form A type or SPST (single pole, single throw) type is normally open and is the simplest to use. The Form C type or SPDT (single pole, double throw) type has a center contact which moves and a stationary contact on either side. This provides a normally closed contact and a normally open contact. Some relay output module's relays share common terminals, which connect to the wiper contact in each relay of the bank. Other relay modules have relays which are completely isolated from each other. In all cases, the module drives the relay coil when the corresponding output point is on.

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Relay with Form A contacts



Relay with Form C contacts



Form A and Form C relay contacts

Surge Suppression for Inductive Loads

Inductive load devices (devices with a coil) generate transient voltages when de-energized with a relay contact. When a relay contact is closed it “bounces”, which energizes and de-energizes the coil until the “bouncing” stops. The transient voltages generated are much larger in amplitude than the supply voltage, especially with a DC supply voltage.

When switching a DC-supplied inductive load the full supply voltage is always present when the relay contact opens (or “bounces”).

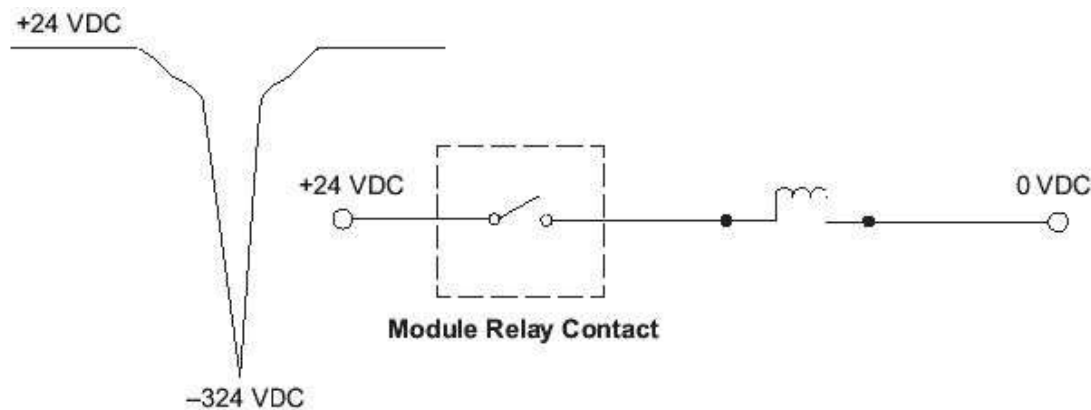
When switching an AC-supplied inductive load there is a low probability that the relay contact will open (or “bounce”) when the AC sine wave is zero crossing. If the voltage is not zero when the relay contact opens there is energy stored in the inductor that is released when the voltage to the inductor is suddenly removed. This release of energy is the cause of the transient voltages.

When inductive load devices (motors, motor starters, interposing relays, solenoids, valves, etc.) are controlled with relay contacts, it is recommended that a surge suppression device be connected directly across the coil of the field device. If the inductive device has plug-type connectors, the suppression device can be installed on the terminal block of the relay output.

Transient Voltage Suppressors (TVS or transorb) provide the best surge and transient suppression of AC and DC powered coils, providing the fastest response with the smallest overshoot.

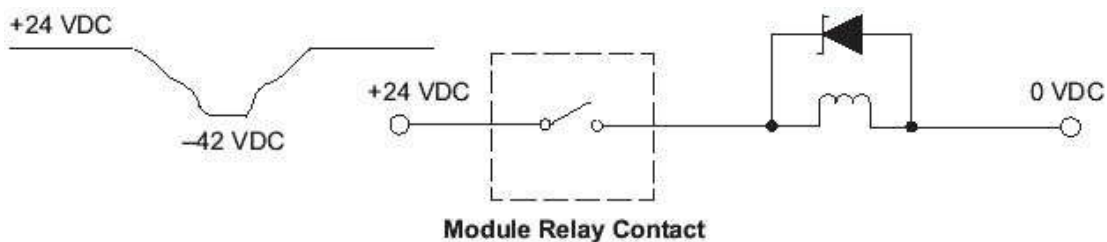
Metal Oxide Varistors (MOV) provide the next best surge and transient suppression of AC and DC powered coils.

For example, the waveform in the figure below shows the energy released when opening a contact switching a 24 VDC solenoid. Notice the large voltage spike.



Inductive load reverse voltage without suppression

This figure shows the same circuit with a transorb (TVS) across the coil. Notice that the voltage spike is significantly reduced.



Inductive load reverse voltage with suppression

Maintaining Relay Contact Life

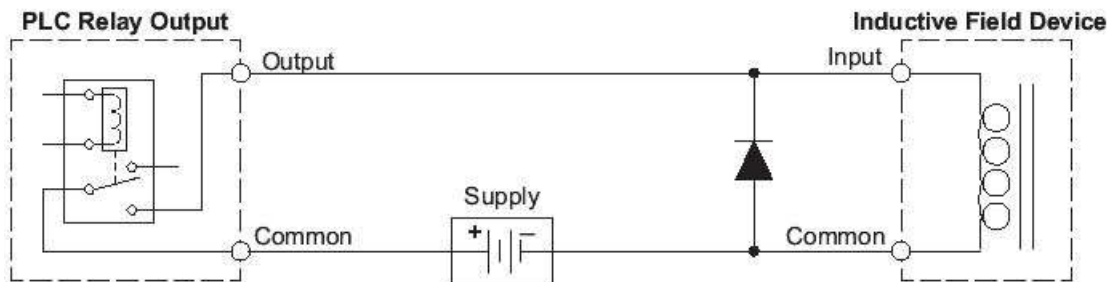
Relay contacts wear according to the amount of relay switching, amount of spark created at the time of open or closure, and presence of airborne contaminants. There are some steps you can take to help prolong the life of relay contacts, such as:

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- Switching the relay on or off only when it is necessary.
- If possible, switching the load on or off at a time when it will draw the least current.
- Take measures to suppress inductive voltage spikes from inductive DC loads such as contactors and solenoids.

For inductive loads in DC circuits we recommend using a suppression diode as shown in the following diagram (DO NOT use this circuit with AC power supplies). When the load is energized the diode is reverse-biased (high impedance). When the load is turned off, energy stored in its coil is released in the form of a negative-going voltage spike. At this moment the diode is forward-biased (low impedance) and shunts the energy to ground. This protects the relay contacts from the high voltage arc that would occur just as the contacts are opening.

Place the diode as close to the inductive field device as possible. Use a diode with a peak inverse voltage rating (PIV) at least 100 PIV, 3A forward current or larger. Use a fast-recovery type (such as Schottky type). DO NOT use a small-signal diode such as 1N914, 1N941, etc. Be sure the diode is in the circuit correctly before operation. If installed backwards, it short-circuits the supply when the relay energizes.



Inductive load with diode installed

1.6.2 ANALOGUE I/O MODULES

1.6.2.1 4-20mA

The signal-attenuation effect of conductor resistances can be minimized if varying voltage signals are transmitted as varying current signals. This technique, which also provides high immunity to induced noise, is known as current loop transmission and uses currents in the range between 4mA and 20mA to represent the voltage level of the analogue signal. It requires a voltage-to-current converter which is commonly known as a *4–20mA current loop interface*. Two voltage-controlled current sources are used, one providing a constant 4mA output that is used as the power supply current and the other providing a variable 0–16mA output that is scaled and proportional to the input voltage level. The net output current therefore varies between 4mA and 20 mA, corresponding to

analogue signal levels between zero and the maximum value. The use of a positive, non-zero current level to represent a zero value of the transmitted signal enables transmission faults to be readily identified. If the transmitted current is zero, this automatically indicates the presence of a transmission fault, since the minimum value of current that represents a proper signal is 4 mA.

1.6.2.2 What is HART?

HART ("Highway Addressable Remote Transducer") is a communication protocol designed for industrial process measurement and control applications. It's called a **hybrid** protocol because it combines analog and digital communication. It can communicate a single variable using a 4-20 ma analog signal, while also communicating added information on a digital signal. The digital information is carried by a low-level modulation superimposed on the standard 4-to-20 mA current loop.

The digital signal does not affect the analog reading because it's removed from the analog signal by standard filtering techniques. The ability to carry this added digital information is the basis for HART's key benefits.

Two-way communication

Using an analog signal, information is sent only one way, either from the device to the host (inputs) or from the host to the device (outputs). Digital information, on the other hand, can travel in both directions using the HART digital communications signal. This opens the way for an instrument that traditionally only receives control-signal information from a host — a valve controller, for example — to also send the host information about what's happening at the valve. Similarly, a transmitter that traditionally only sends a process variable to the host can now also receive information such as configuration settings.

New types of information

Traditional analog and discrete devices communicate only a single process variable — and you typically have no easy way to tell if the information they're sending is valid.

With HART, you still get the process variable — but other types of information, too. As many as 35-40 information items are standard in every HART device. Examples include

- Device Status & Diagnostic Alerts
- Process Variables & Units
- Loop Current & % Range
- Basic Configuration Parameters
- Manufacturer & Device Tag

With additional information like this, HART devices that are digitally polled by a host can tell you if they're correctly configured and operating correctly. This eliminates the need for most routine checks — and helps you detect failure conditions before they cause a major process problem.

Multivariable instruments

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In digital mode, a single pair of wires can handle multiple variables. For example, one transmitter could handle inputs from multiple sensors. For host systems that cannot use the HART digital information, information from multivariable instruments is often handled first by a device (called a tri-loop) that converts the digital information into multiple 4-20mA signals that are then independently wired into the host.

Vendor independence

With HART, there's no danger of getting locked into limited vendor-specific or regional "standards." That's because HART technology isn't owned by an individual company, nor regulated by a single nation or standards body. Instead, the technology is managed by the independent, not for profit HART Communications Foundation.

Breadth of supply

HART is currently the world's most broadly supported protocol for the process industry. Almost 600 HART-based products are available from different vendors. This breadth of available products means there's likely to be a HART product for almost any process application — often more than one, from a choice of vendors.

Interoperability

Interoperability simply means that HART-compliant devices and host systems, regardless of vendor, can work together. Some host systems use universal and common-practice commands to work with HART devices. Others go a step farther by also using Device Descriptions to understand all HART messages. Even hosts that aren't designed to handle the digital information from a HART device can still have control interoperability through the 4-20mA analog signal.

HART analog communications

HART analog communications use industry-standard 4-20 mA signals. That means HART devices can perform their basic functions with any host system that has 4-20 mA I/O capability. The limitation is that only one parameter can be communicated on a 4-20mA input or output. Typically that information is a process variable from a transmitter, or an output to a final control element.

HART digital communications

HART's digital communications carry additional kinds of information that aren't communicated by the analog signal. The key attribute of HART digital communications is that the digital signal — which uses the Bell202 standard frequency shift keying, or FSK is superimposed on the analog signal. This attribute allows the analog signal to be used by a host for process control, and the digital signal to be used by the same or a different host to communicate information related to device configuration, non-real-time diagnostics, and status monitoring. Asset management applications using this information can dramatically increase configuration and maintenance productivity, and provide diagnostic and status information that improves plant reliability and performance.

The request/reply model

HART digital communications uses a request / reply communications model. This means that, in general, HART devices won't transmit any information unless a request is sent from the host to the device. For example, if a HART device detects a failure condition in itself or the process, the HART device cannot communicate this information to the host unless the host specifically requests that information from the device. The exception to this model is something called burst mode communications.

HART burst mode communications

HART devices can send a single piece of information continuously from a device without repeated host requests. This method — called "burst mode" — is usually used to send a single variable such as a process variable digitally. Using burst mode, more than 3 messages per second can be transmitted.

Communications in multi-drop mode

The HART protocol supports multiple devices on a single wire pair. When this multi-drop mode is used, analog communication is not available. A typical message rate using request / reply digital communications is less than 2 messages a second for all devices on the wire. This limits practical use of multi-drop digital communication to slow data-acquisition applications.

Using multiplexers

Many installed hosts aren't designed to accept HART information in digital form. One solution to this problem is to have external multiplexers read the digital signal and extract the digital information from the devices. In this approach, the HART device is attached both to the control host and to the multiplexer. To minimize wiring and cost, the multiplexer can be cable-connected to the host's termination panel. Although this solution increases the cost of the HART installation, reductions in maintenance cost generally pay back the investment in a very short time.

Using “pass through”

Some hosts are able to capture and pass HART digital information to other applications — such as asset management software — using a mechanism commonly called "pass through." The HART digital bit stream is captured by the host input or output card and passed unread through the host architecture to platforms and applications that use the digital information. Hosts that support pass-through functionality reduce the cost of acquiring and using the HART information by eliminating the need to install separate multiplexer systems.

1.6.2.3 Foundation field bus

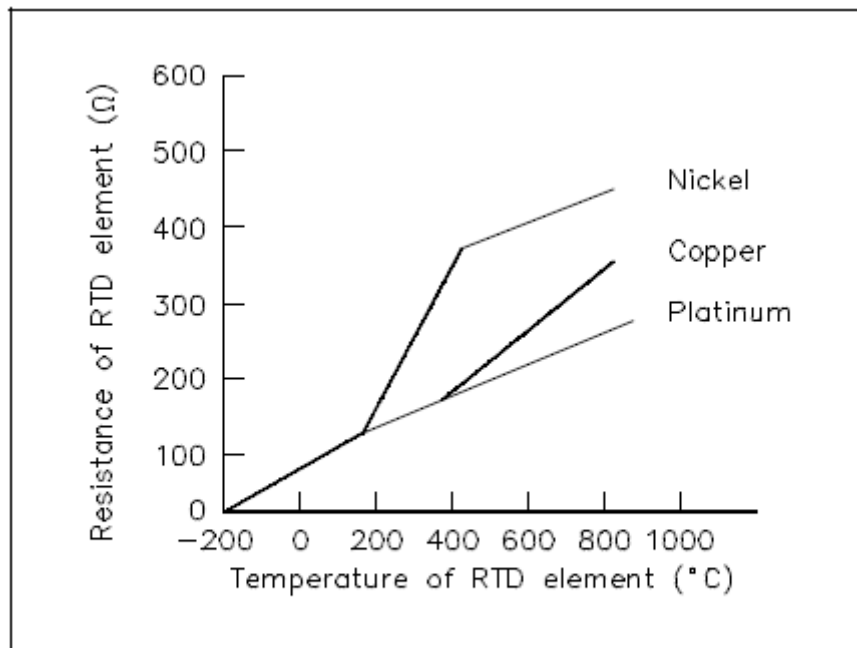
It will be deeply discussed in chapter 7

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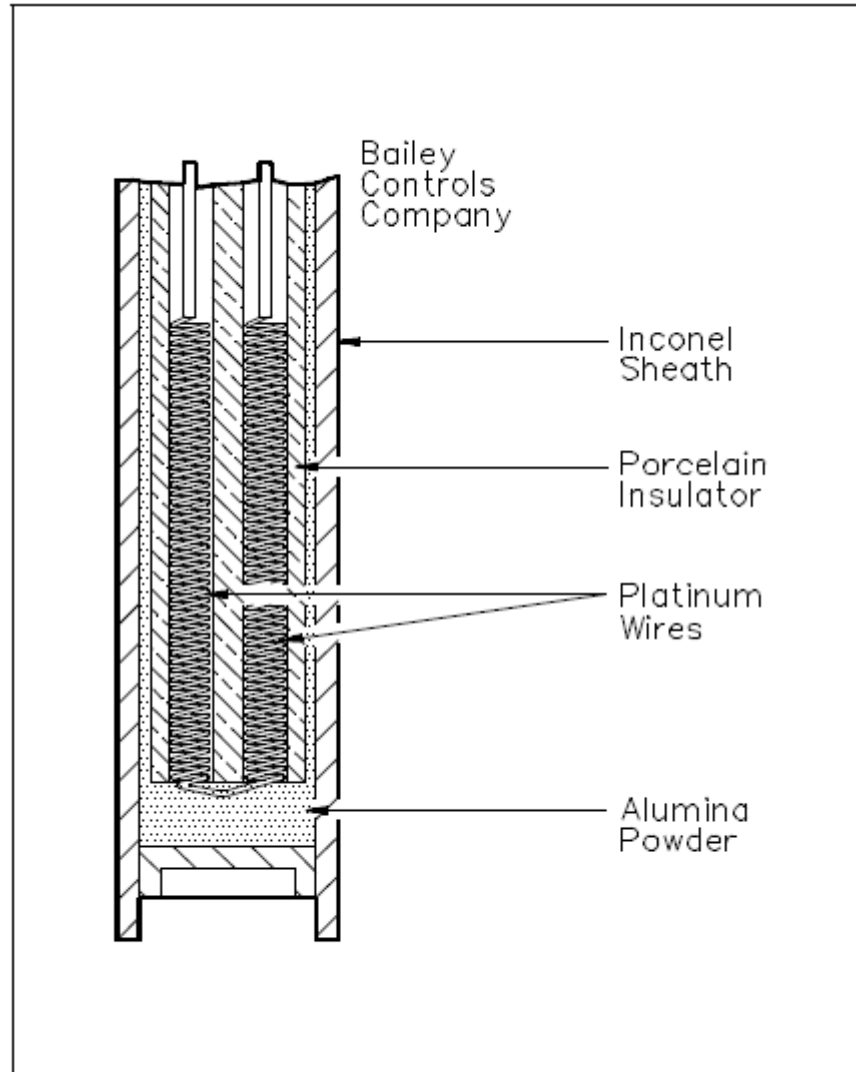
1.6.2.4 RTD/TC

RTD Construction

The RTD incorporates pure metals or certain alloys that increase in resistance as temperature increases and, conversely, decrease in resistance as temperature decreases. RTDs act somewhat like an electrical transducer, converting changes in temperature to voltage signals by the measurement of resistance. The metals that are best suited for use as RTD sensors are pure, of uniform quality, stable within a given range of temperature, and able to give reproducible resistance-temperature readings. Only a few metals have the properties necessary for use in RTD elements. RTD elements are normally constructed of platinum, copper, or nickel. These metals are best suited for RTD applications because of their linear resistance-temperature characteristics, their high coefficient of resistance, and their ability to withstand repeated temperature cycles. The coefficient of resistance is the change in resistance per degree change in temperature, usually expressed as a percentage per degree of temperature. The material used must be capable of being drawn into fine wire so that the element can be easily constructed.

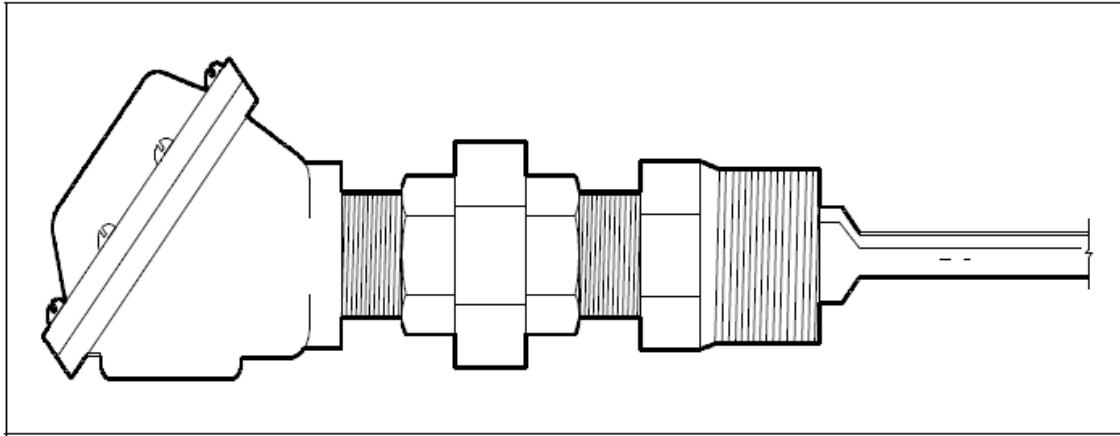


RTD elements are usually long, spring-like wires surrounded by an insulator and enclosed in a sheath of metal.



This particular design has a platinum element that is surrounded by a porcelain insulator. The insulator prevents a short circuit between the wire and the metal sheath. Inconel, a nickel-iron-chromium alloy, is normally used in manufacturing the RTD sheath because of its inherent corrosion resistance. When placed in a liquid or gas medium, the Inconel sheath quickly reaches the temperature of the medium. The change in temperature will cause the platinum wire to heat or cool, resulting in a proportional change in resistance. This change in resistance is then measured by a precision resistance measuring device that is calibrated to give the proper temperature reading. This device is normally a bridge circuit.

Module 1: DCS Architecture



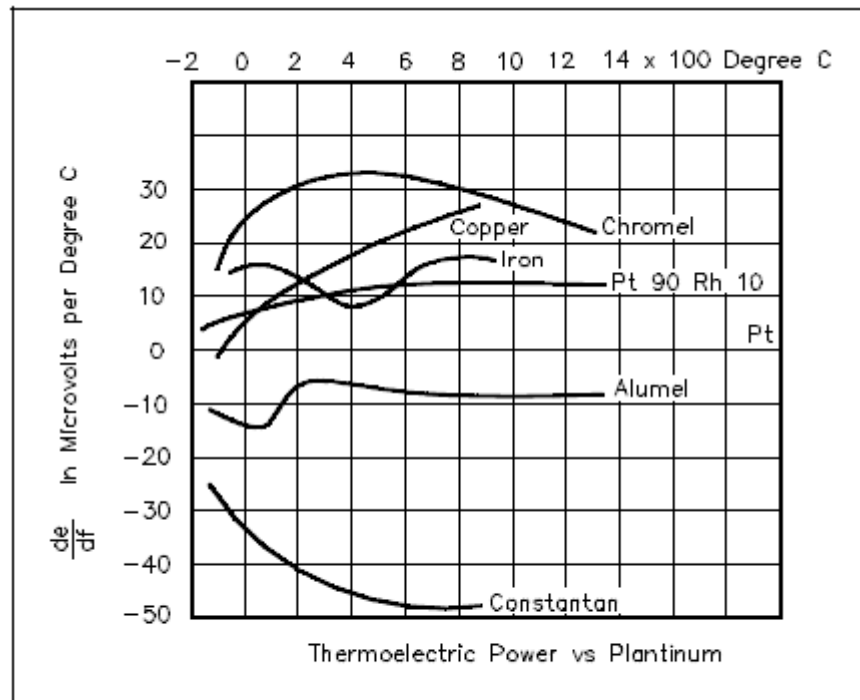
The Figure above shows an RTD protective well and terminal head. The well protects the RTD from damage by the gas or liquid being measured. Protecting wells are normally made of stainless steel, carbon steel, Inconel, or cast iron, and they are used for temperatures up to 1100°C.

Temperature Compensation

Because of changes in ambient temperature, the resistance thermometer circuitry must be compensated. The resistors that are used in the measuring circuitry are selected so that their resistance will remain constant over the range of temperature expected. Temperature compensation is also accomplished through the design of the electronic circuitry to compensate for ambient changes in the equipment cabinet. It is also possible for the resistance of the detector leads to change due to a change in ambient temperature. To compensate for this change, three and four wire RTD circuits are used. In this way, the same amount of lead wire is used in both branches of the bridge circuit, and the change in resistance will be felt on both branches, negating the effects of the change in temperature.

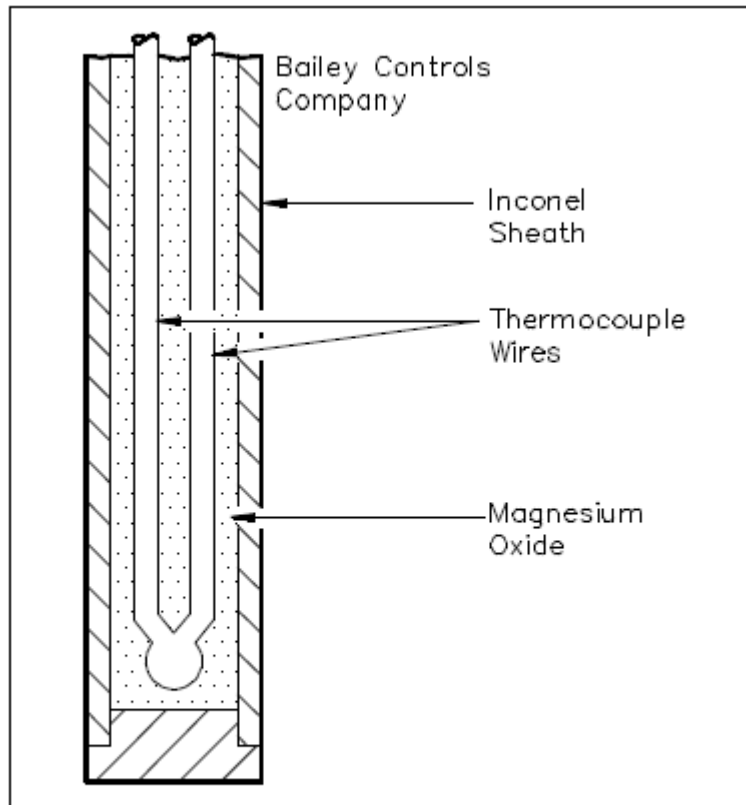
Thermocouple Construction

A thermocouple is constructed of two dissimilar metal wires joined at one end. When one end of each wire is connected to a measuring instrument, the thermocouple becomes a sensitive and highly accurate measuring device. Thermocouples may be constructed of several different combinations of materials. The performance of a thermocouple material is generally determined by using that material with platinum. The most important factor to be considered when selecting a pair of materials is the "thermoelectric difference" between the two materials. A significant difference between the two materials will result in better thermocouple performance. The Figure illustrates the characteristics of the more commonly used materials when used with platinum. Other materials may be used in addition to those shown. For example: Chromel-Constantan is excellent for temperatures up to 2000°F; Nickel/Nickel-Molybdenum sometimes replaces Chromel-Alumel; and Tungsten-Rhenium is used for temperatures up to 5000°F. Some combinations used for specialized applications are Chromel-White Gold, Molybdenum-Tungsten, Tungsten-Iridium, and Iridium/Iridium-Rhodium.



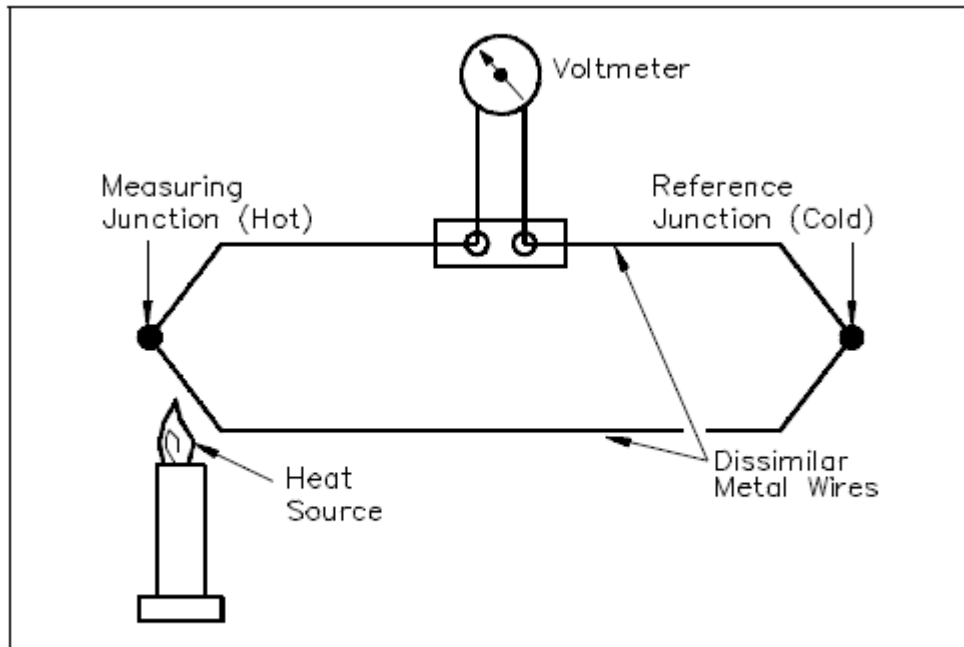
The leads of the thermocouple are encased in a rigid metal sheath. The measuring junction is normally formed at the bottom of the thermocouple housing. Magnesium oxide surrounds the thermocouple wires to prevent vibration that could damage the fine wires and to enhance heat transfer between the measuring junction and the medium surrounding the thermocouple.

Module 1: DCS Architecture



Thermocouple Operation

Thermocouples will cause an electric current to flow in the attached circuit when subjected to changes in temperature. The amount of current that will be produced is dependent on the temperature difference between the measurement and reference junction; the characteristics of the two metals used; and the characteristics of the attached circuit. Heating the measuring junction of the thermocouple produces a voltage which is greater than the voltage across the reference junction. The difference between the two voltages is proportional to the difference in temperature and can be measured on the voltmeter (in millivolts). For ease of operator use, some voltmeters are set up to read out directly in temperature through use of electronic circuitry. Other applications provide only the millivolt readout.



In order to convert the millivolt reading to its corresponding temperature, you must refer to tables like the shown. These tables can be obtained from the thermocouple manufacturer, and they list the specific temperature corresponding to a series of millivolt readings.

Temperatures (°C) (ITS 1968).											Reference Junction 0°C.	
°C	0	10	20	30	40	50	60	70	80	90	100	°C
Thermoelectric Voltage in Absolute Millivolts												
- 0	0.000	-0.053	-0.103	-0.150	-0.194	-0.236						- 0
+ 0	0.000	0.055	0.113	0.173	0.235	0.299	0.365	0.432	0.502	0.573	0.645	+ 0
100	0.645	0.719	0.795	0.872	0.950	1.029	1.109	1.190	1.273	1.356	1.440	100
200	1.440	1.525	1.611	1.698	1.785	1.873	1.962	2.051	2.141	2.232	2.323	200
300	2.323	2.414	2.506	2.599	2.692	2.786	2.880	2.974	3.069	3.164	3.260	300
400	3.260	3.356	3.452	3.549	3.645	3.743	3.840	3.938	4.036	4.135	4.234	400
500	4.234	4.333	4.432	4.532	4.632	4.732	4.832	4.933	5.034	5.136	5.237	500
600	5.237	5.339	5.442	5.544	5.648	5.751	5.855	5.960	6.064	6.169	6.274	600
700	6.274	6.380	6.486	6.592	6.699	6.805	6.913	7.020	7.128	7.236	7.345	700
800	7.345	7.454	7.563	7.672	7.782	7.892	8.003	8.114	8.225	8.336	8.448	800
900	8.448	8.560	8.673	8.786	8.899	9.012	9.126	9.240	9.355	9.470	9.585	900
1,000	9.585	9.700	9.816	9.932	10.048	10.165	10.282	10.400	10.517	10.635	10.754	1,000
1,100	10.754	10.872	10.991	11.110	11.229	11.348	11.467	11.587	11.707	11.827	11.947	1,100
1,200	11.947	12.067	12.188	12.308	12.429	12.550	12.671	12.792	12.913	13.034	13.155	1,200
1,300	13.155	13.276	13.397	13.519	13.640	13.761	13.883	14.004	14.125	14.247	14.368	1,300
1,400	14.368	14.489	14.610	14.731	14.852	14.973	15.094	15.215	15.336	15.456	15.576	1,400
1,500	15.576	15.697	15.817	15.937	16.057	16.176	16.296	16.415	16.534	16.653	16.771	1,500
1,600	16.771	16.890	17.008	17.125	17.243	17.360	17.477	17.594	17.711	17.826	17.942	1,600
1,700	17.942	18.058	18.170	18.282	18.394	18.504	18.612					1,700
°C	0	10	20	30	40	50	60	70	80	90	100	°C

Module Outcome : Upon successful completion of this learning outcome guide, you will be able to differentiate between the control valve types

Learning Objectives: To successfully complete this learning outcome guide you should be able to:

1. To list the different types of linear motion valves and its application
2. To list the different types of rotary motion valves and its application
3. To list the different types of special valves and its application
4. To categorize the different flow characteristic curves

Let's have some Fun

يوميّات عتريس و مراته (الحلقة الثانية)
تخيل عتريس و مراته في محل ملابس حدد الأسس و الطرق و المعايير التي ستختار
بها مدام عتريس فستان السهرة لحضور زفاف بنت عمها مع مراعاة الحجم الضخم
للزوجة و فقر الزوج المدقع

Pre-Assessment

1. State 8 types of control valve
2. Categories them into (on- off valve or control valves)
3. Define flow characteristics & shut-off class
4. State the types of the flow control valve

Objective 1: Linear-Motion Valves.

The designation "**globe**" is a generic term encompassing a number of related valve varieties. The common features are a *plug* attached to a *stem* that is moved linearly in a somewhat globular cavity. Figure. 1 is one-ported globe valve. The following illustrations show some of the varieties available.

Figure 2 is a double-ported globe valve. The illustration shows a post-guided plug, also known as "top and bottom guided." The two plugs are arranged so that the flow tends to open one plug and close the other. The opposing fluid forces across the plug area tend to balance each other, so that

a less powerful actuator is required. When fluid flows through the valve at a high velocity, the dynamic forces may defeat this objective

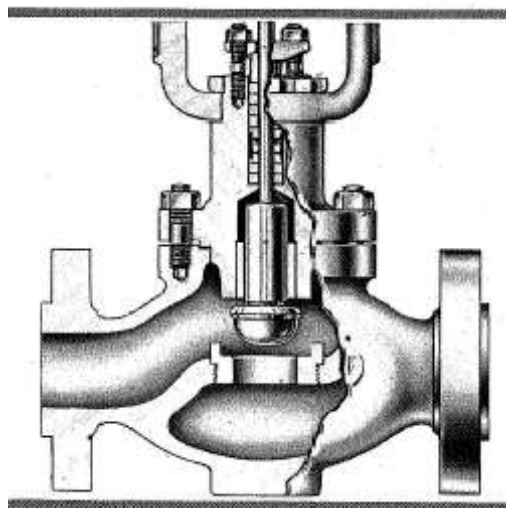


Fig.1 Single-Ported Globe Valve

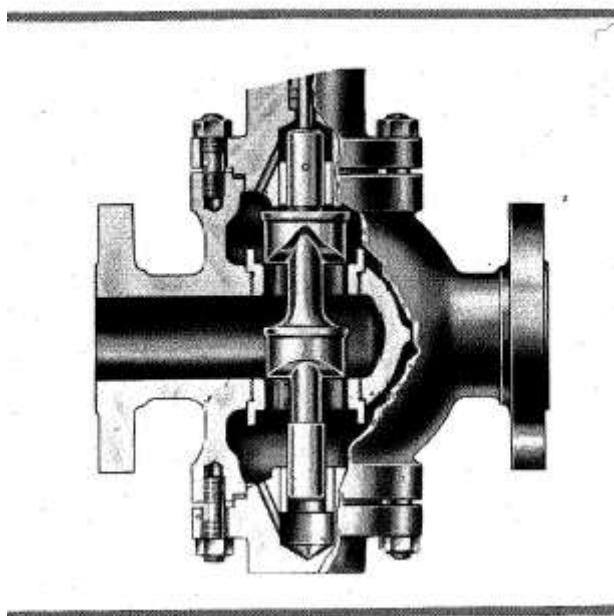


Fig.2 Double-Ported Globe Valve

Figure 3 is an angle valve. An angle valve differs from the standard globe valve in that the connections are at 90°. The illustration shows a split-body construction, made for easy seat and plug removal. The separable flanges shown permit the use of flanges made of a different material than the body. The split body and separable flange features also are available in other valve patterns

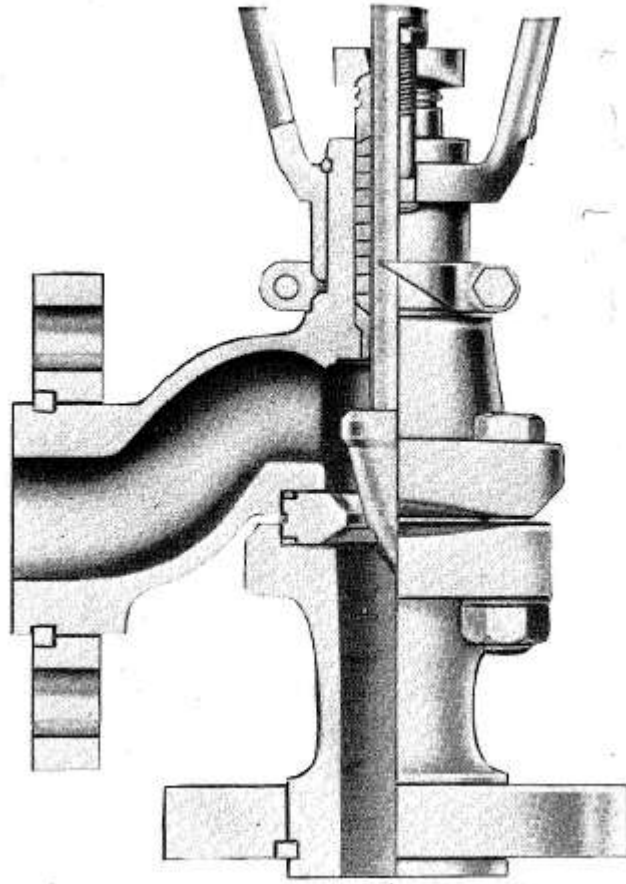


Fig.3 Angle Type Split Body

Figure 4 is a Y-pattern valve. This style valve minimizes the change in direction of the flow path, and can be mounted so that it is self-draining. The one shown here is a special vacuum-jacketed design for use in cryogenic service

Figures 5 and 6 show two forms of *three-way* bodies. One is designed for diverging flows and the other for converging flows. The difference in construction is that the fluid force is made to act in a direction tending to open both valve plugs in each case. The objective here is to get dynamic stability without using a more powerful and stiffer actuator. These valves are also known as "diverting" and "combining" types.

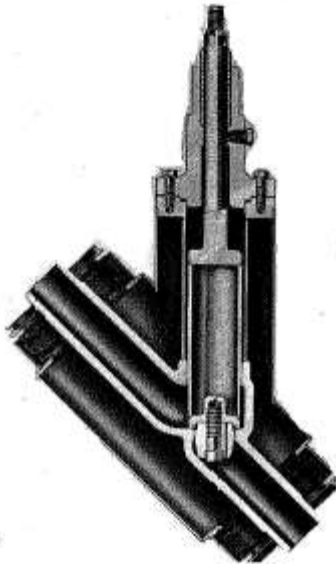


Fig.4 Y-Pattern Valve

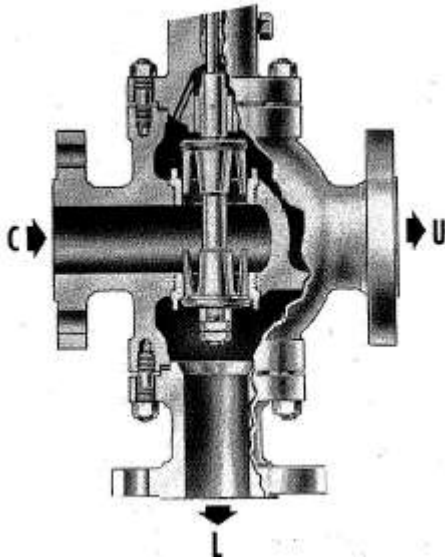


Fig.5 Three-Way Diverging Flows

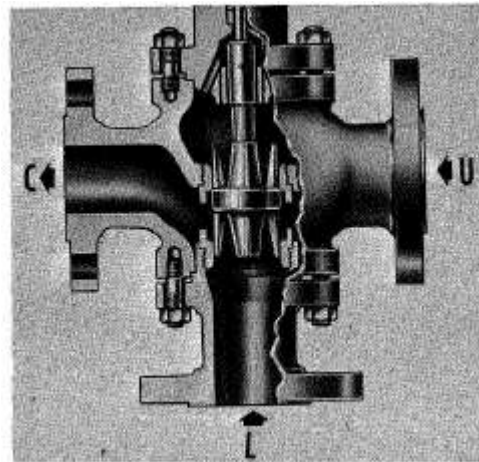


Fig.6 Three-Way Converging Flows

The gate valve is distinguished by a flat or wedge-shaped plate that is moved into or out of the flow path. Gate valves are widely used for hand valves and for on-off services. There are only a few designs that are intended for throttling service. Figure 7 shows a multi-orifice gate valve. The hard, polished faces of the gate and the stationary plate provide a self-cleaning, tight closure. The long, narrow orifices provide good throttling characteristics for gas, liquid, and steam services. Figure 8 shows a gate valve with a vee orifice. This shape is intended to linearize the flow capacity versus gate movement. It is used chiefly on solids flow and may be polyurethane lined for this purpose. Gate valves are made with a bonnet to keep the gate enclosed when it is withdrawn from the flow path. They are

also made bonnetless, in which case the packing is around the entire rectangular cross section of the gate instead of around the stem only. The gate in this case extends outside the pressure boundary when the valve is opened. This style finds little use as a control valve.

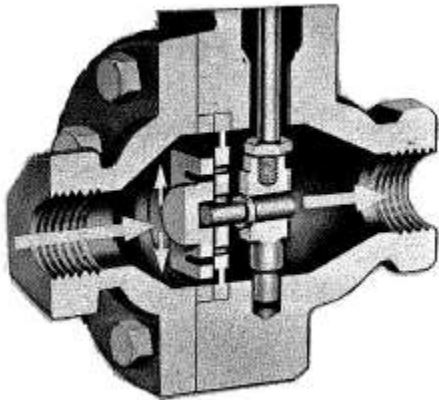


Fig.7 Multi-orifice Gate Valve



Fig.8 V-orifice Gate Valve

Diaphragm valves are linear-motion valves with flexible diaphragms to act as flow closure members, Fig. 9. The illustration shows a weir-type Saunders patent valve. The center weir provides a contoured seating surface for the diaphragm. The actuator forces the diaphragm against the weir by means of a compressor, a solid metal shape backing up the diaphragm. Some designs have a finger plate to restrict the upward motion of the diaphragm and prevent its extrusion into the bonnet cavity when the valve is fully opened. One variation is the *Dual-range* designed to provide better throttling characteristics at small openings. The compressor is made in two parts, so that a small central area of the diaphragm is raised off the weir before the entire diaphragm is lifted. Another variation is the Straightway. The weir is eliminated and the diaphragm is elongated to the shape of a bag that can be extended to completely fill the flow passage. This construction permits the passage of large particles, but restricts the choice of diaphragm materials to elastomers with high degrees of resilience.

Diaphragm valves find use with "difficult fluids" such as corrosive

liquids or slurries. The body can be lined with glass, plastics, or TFE. The diaphragm can also be TFE at the expense of greater closure force. They are inexpensive, but are limited to low pressure and temperature service. When diaphragm valves carry hazardous or valuable materials these valves should be specified with a special bonnet with a suitable packing box for the service, rather than the standard O-ring seal. This will serve as a back-up for diaphragm failure.

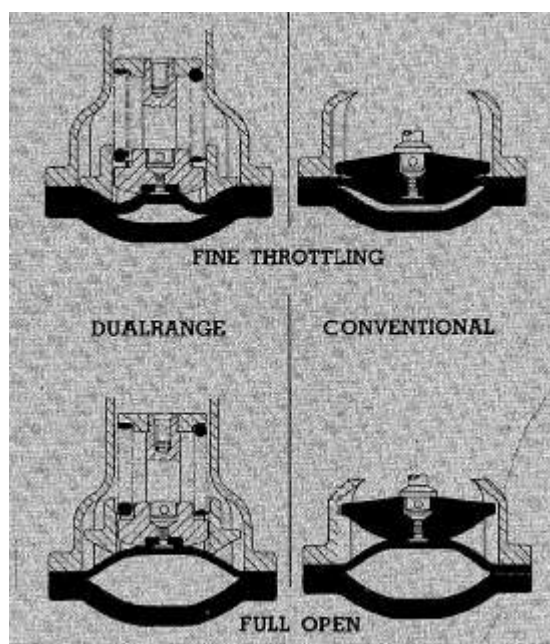


Fig.9 Diaphragm Valve

The basic pinch valve is a variation of the old familiar laboratory hose clamp. It may be enclosed in a pressure-tight housing, or it may merely consist of a flanged-end hose supported by a metal frame with an actuator and compressor bars. The housing, or body, may have a packing box to prevent leakage on tube failure. The hose may be squeezed together by compressor bars moved by a lever system from a single actuator, or there may be two separate actuators acting in concert, one pushing from either side of the hose. The variation designated as a *clamp valve*, Fig. 10, has positive clamps to grip the tube and shaped inserts to prevent over-stress at the creases of the closed tube. Clamping the tube rigidly checks fluttering and consequent vibration. Other variations omit the actuator, levers, and compressors, and cause the tube to collapse by pressurizing a surrounding jacket by an external source of fluid power. The pressurizing fluid may be gas or liquid, but the pressure required to close the tube must be substantially higher than the pressure of the fluid inside the tube. Clamp valves with the actuating mechanisms attached to the tube walls will work on vacuum

service. Other forms depend on the process pressure to return the tubes to open position. Clamp valves are available with TFE liners rated to 350°F (175°C). All of these valves will handle corrosive slurries. Some styles are severely limited as to pressure differential, particularly those which depend on jacket pressure to collapse the tube.

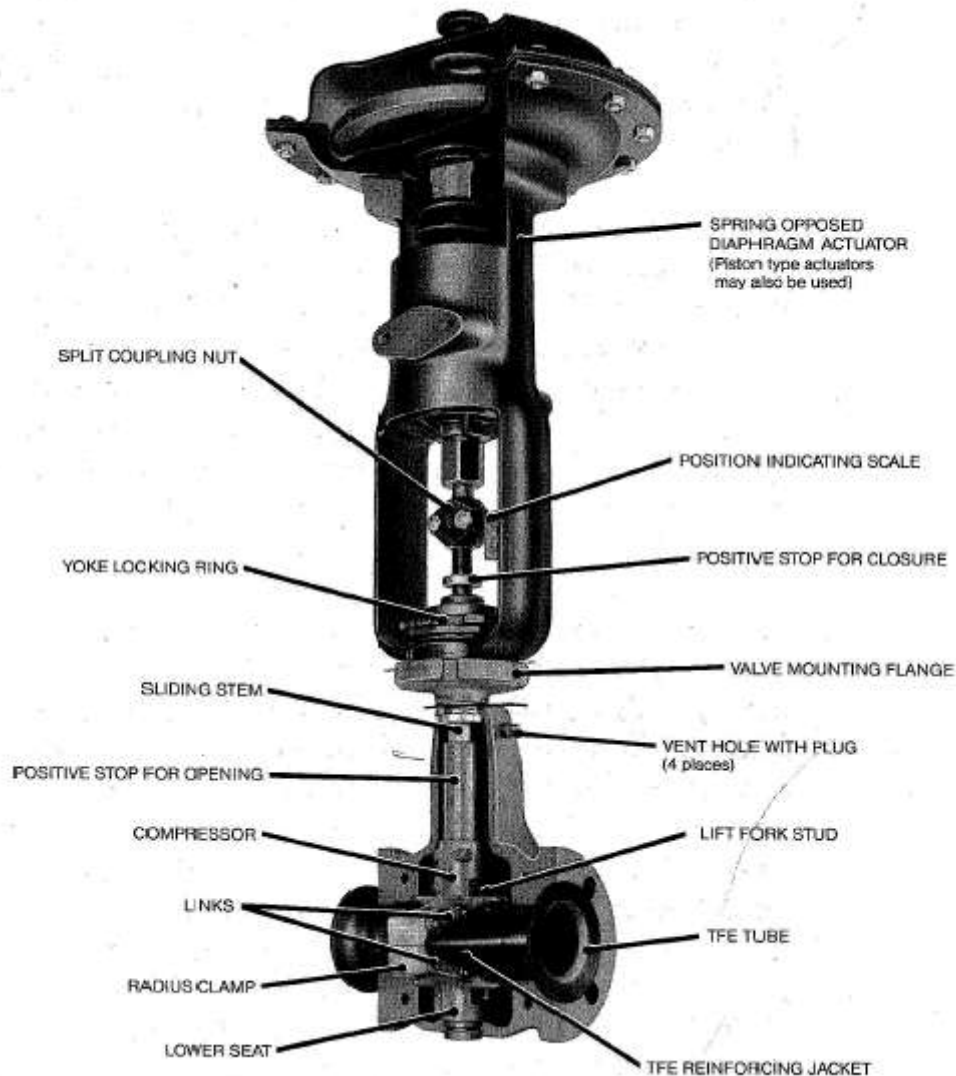


Fig.10 Clamp Valve

Objective 2: Rotary-Motion Valves.

The butterfly valve has a rotary motion. All the preceding types of valves used linear motion to change the valve opening. The butterfly valve is by far the most common rotary-motion control valve, Fig. 11. Variations in designs of butterfly valves are enormous. It is probably for this

reason that butterfly valves so often are vilified. It is so easy, by preparing a poor specification, to get a valve that is entirely inadequate for its intended service. The purchaser, naturally, blames the valve rather than himself for the poor results.

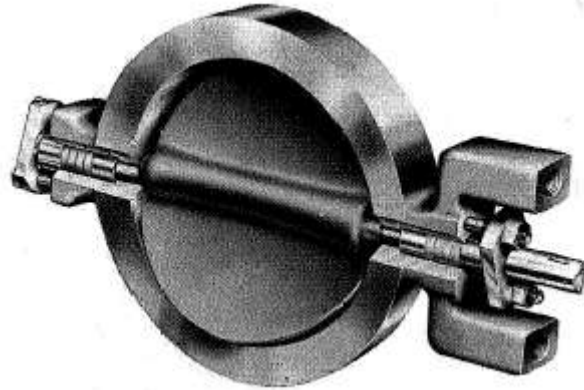


Fig.11 Butterfly Valve

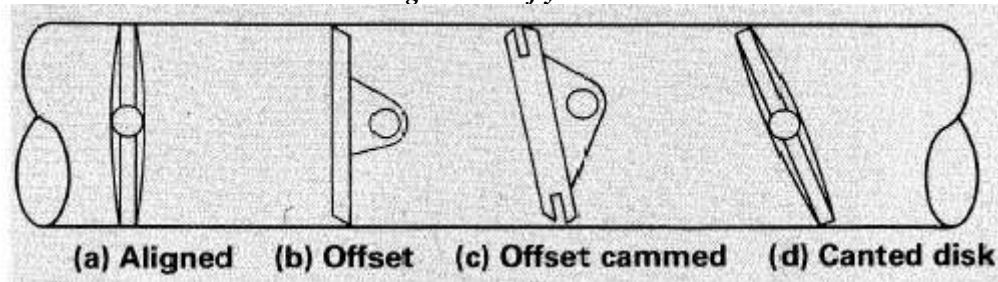


Fig.12 Disk Orientations

Sizes of butterfly valves range from 1/2 inch to over 200 inches. Materials run the gamut from cast iron, to plastics, to ceramics, to most anything. Body types include the following:

Wafer body-also called "flangeless." This fits between the piping flanges like a sandwich, with long studs holding the assembly together.

Lugged body types have metal completely surrounding the studs. The holes may be tapped so that the companion-flanges can be bolted on separately to avoid the use of long studs. This style protects the joints from the effects of differential thermal expansion especially under fire conditions.

Flanged body valves with two separate integral flanges are used infrequently. The body must be long enough to provide room for flange bolting. All this extra metal serves little purpose compared to the lugged style.

Lined or encapsulated bodies may be constructed in any of the forms described above, but the bodies are lined with elastomers to provide an interference fit and achieve a tight seat. For corrosion resistance, the disk as well as the body is protected by an elastomer or a fluorocarbon encapsulant. The linings may be bonded to the body or they may be slip-in or locked-in. The latter is positively retained by a key ring or other means. The linings may be wraparound or flange retained. They may even be pressure energized from an external source to force the liner into tight contact with the disk after closure. This arrangement avoids rubbing between the disk and the liner while the valve is throttling. The entirely encapsulated type may have a soft elastomer behind the encapsulant at the seating area to get resilience. for sealing.

The butterfly disk can have all sorts of things done to it. For one, there is the orientation of the disk and stem, Fig. 12. The four types illustrated are representative of many variations available. All of these variations are attempts to get better sealing or different torque relationships. Some disks are equipped with metal piston rings to get better sealing at temperatures above the limits of TFE liners. Others have TFE rings on the disks to get leak-tight sealing at temperatures up to about 350°F (175°C). These designs, as well as lined and encapsulated types, are apt to present a problem on some control applications because of the high "break-away" torque that is due to the interference fit.

The ball valve is also a rotary-motion valve; the flow closure member is a sphere with an internal passageway. The ball valve has assumed a prominent position as a control valve in the last decade or two. Technological advances in seals and sealing materials enable the ball valve to offer tight shutoff. This quality has gained the ball valve a prominent place in batch processes in on-and-off service where they are frequently operated by programmable controllers. The *full ball* valve uses a complete sphere with a hole through it for flow passage. Full ball valves are constructed in several ways. The one-piece body is made so that the ball can be installed through an opening in the top of the body. A three-piece body has a central section holding the ball and stem, and two end pieces holding the seals. In a two-piece body the ball is installed through one of the ends, and is retained by the end piece, Fig. 13. The full ball valve throttles the stream at two points in series, both at the inlet of the passageway through the ball and at the exit. This two-stage pressure reduction results in a lower velocity than would exist with single-stage reduction.

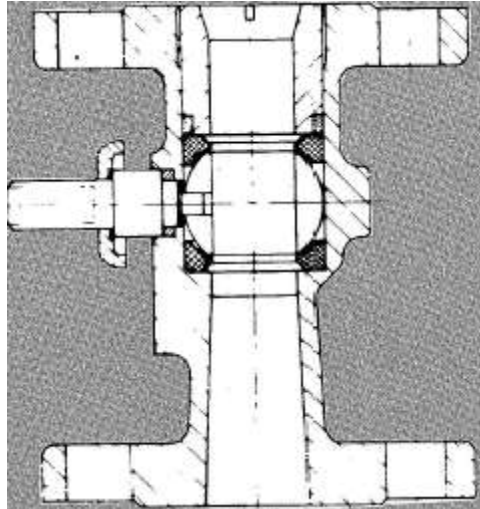


Fig.13 Full Ball Valve

Lower velocity reduces the tendency toward cavitation. Unfortunately, quantitative test information is not always available to permit adequate engineering utilization of this property. Full ball valves also may be categorized by the manner in which the ball is supported. Trunion-mounted balls are 'supported by integral or rigidly connected stub shafts running in bearings. Floating balls are totally supported by the seat rings, upstream and downstream. On the floating ball, the stem-to-ball connection must be designed to permit movement of the ball into the downstream seat ring to seal in the closed position. This construction creates an additional' design problem, since any backlash in the connections between, the ball and the actuator creates dead band, and thereby degrades the quality of control. Minimizing the dead band in linkages is problem enough while trying to get motion from the actuator to the rotating valve stem. The seating means used with these designs is then either: *upstream* seating, where the pressure differential forces the upstream seat against the ball; downstream seating, where the pressure differential across the closed ball forces the ball into tighter contact with the downstream seat; or *spring-loaded* seating, where a spring or compressed elastomer is used to increase the seating force. The standard ball valve has a port diameter that is about 80% of the pipe diameter. This reduction in area means less metal, less seat friction, and a much smaller actuator. It has a negligible effect on the useable capacity for control purposes. *Full-port* ball valves have flow passages as large as the pipes' internal diameters. This design permits "pigging," and may have other special uses.

Three-way ball valves have flow passages that make turns within the ball, Fig. 14. They require only a 90° turn and can be used on both diverging

and converging streams. They can be designed as "transflow" valves where the ports are arranged so that even in intermediate positions the valve capacity is not restricted. In other words, the flow capacity is the same with the flow through either port or with the flow divided between the two ports.

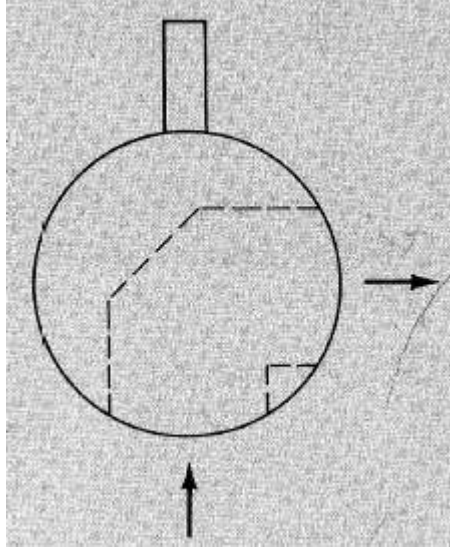


Fig.14 Three Way Ball Valve

The segmented ball valve, instead of being a full sphere, uses a segment of sphere to close off the flow. The leading edge of the spherical surface that closes the port is usually shaped to create a certain flow characteristic (capacity versus valve travel), or to yield an opening shaped to minimize the tendency of the orifice to be plugged by particulate matter or fibers, Figs. 15 and 16.

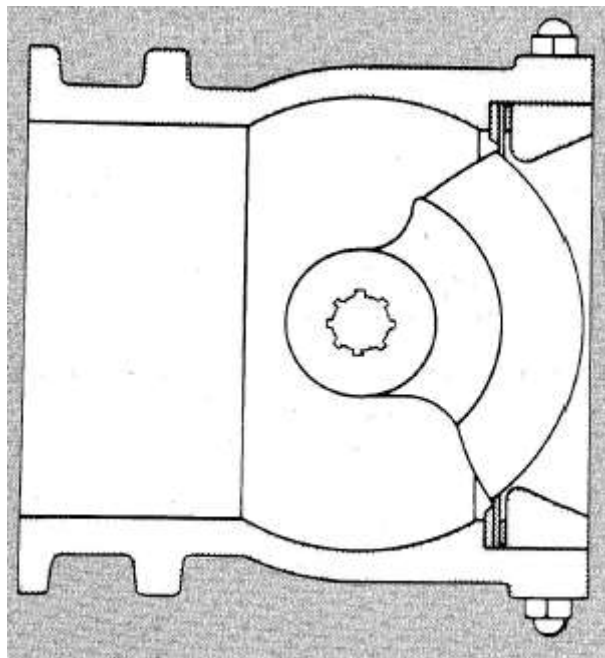


Fig.15 Contoured Edge Ball Valve

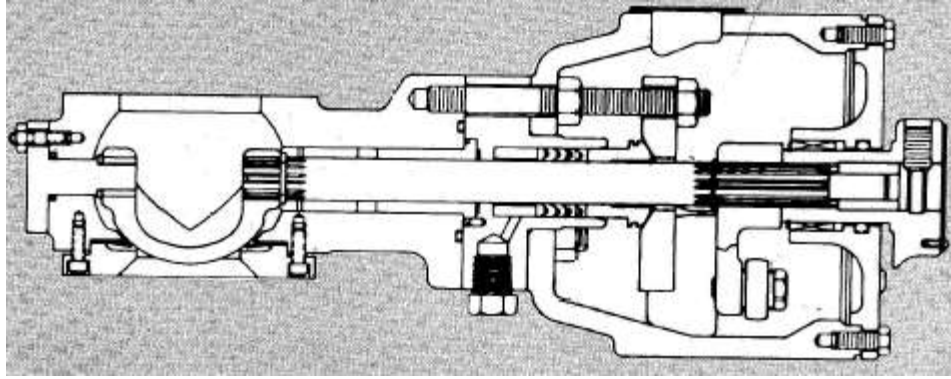


Fig.16 V-Notched Ball Valve

The plug valve is an ancient device. Probably the first one was whittled out of wood to use as a spigot in a wine cask, Fig. 17. The plug may be conical, cylindrical, or a segment of a sphere, all operated with rotary motion. In the conical or cylindrical styles the flow passage may be elongated in cross section to minimize the weight with little effect on capacity. Other forms use only parts of cylinders for closure, to enlarge flow passage, lower the weight, and decrease the friction. Some valves use eccentric plugs to get high seating force yet minimize friction through most of the valve travel, Figs. 18 and 19. The eccentric cylindrical plug valve also can be elastomer faced for tight seating. Some valves are characterized by either shaping the passage through the plug or by shaping the orifice in a sleeve that is surrounded by the hollow plug, Fig. 20. There are many techniques for encapsulating plug valves with TFE so that all wetted parts are protected from corrosion. Another advantage to this is that the friction of the rotating plug is reduced to manageable levels by the natural lubricity of TFE

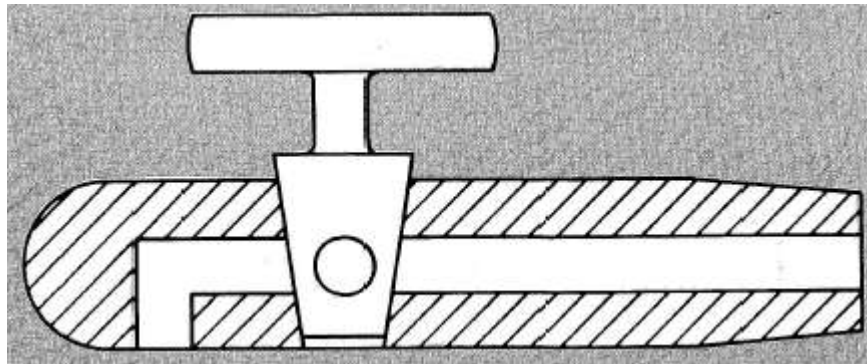


Fig.17 An Early Plug Valve

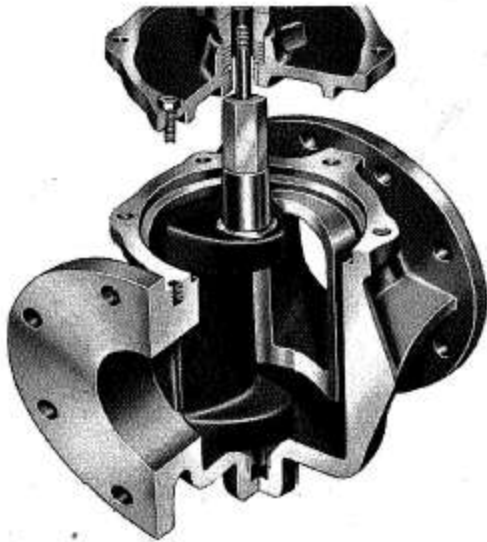


Fig.18 Eccentric Cylindrical Plug

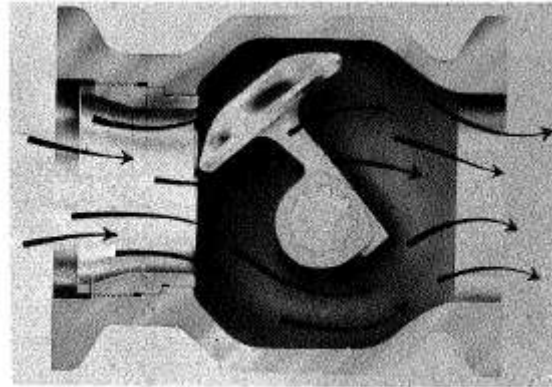


Fig.19 Eccentric Spherical Plug

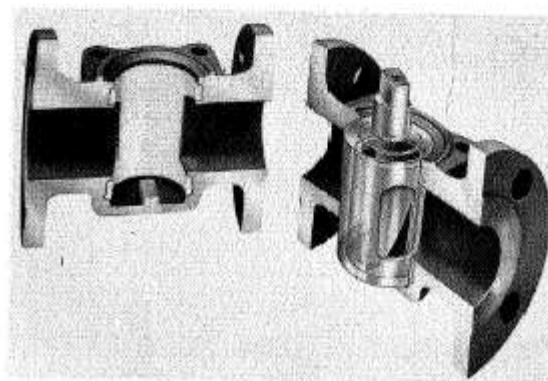


Fig.20 Plug with Characterized Sleeve

Objective 3: Special Valves

High Capacity Control Valves globe-style valves larger than 12-inch, ball valves over 24-inch, and high performance butterfly valves larger than 48-inch fall in the special valve category. As valve sizes increase arithmetically, static pressure loads at shutoff increase geometrically. Consequently, shaft strength, bearing loads, unbalance forces, and available actuator thrust all become more significant with increasing valve size. Normally maximum allowable pressure drop is reduced on large valves to keep design and actuator requirements within reasonable limits. Even with lowered working pressure ratings, the flow capacity of some large-flow valves remains tremendous. Noise levels must be carefully considered in all large-flow installations because sound pressure levels increase in direct proportion to flow magnitude. To keep valve-originated noise within tolerable limits, large cast or fabricated valve body designs (figure 21) have been developed. These bodies, normally cage-style construction, use unusually long valve plug travel, a great number of small flow openings through the wall of the cage and an expanded outlet line connection to minimize noise output and reduce fluid velocity. Naturally, actuator requirements are severe, and long-stroke, double acting pneumatic pistons are typically specified for large-flow applications. The physical size and weight of the valve and actuator components complicate installation and maintenance procedures. Installation of the valve body assembly into the pipeline and removal of major trim parts require heavy-duty hoists.



Fig.21 Large Flow Valve Body

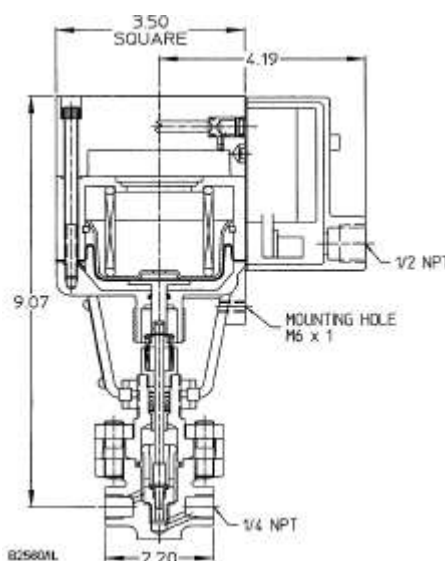


Fig.22 Special Control Valve for Very Low Flow Rates

Low Flow Control Valves are used in Many applications which exist in laboratories and pilot plants in addition to the general processing industries where control of extremely low flow rates is required. These applications are commonly handled in one of two ways. First, special trims are often available in standard control valve bodies. The special trim is typically made up of a seat ring and valve plug that have been designed and machined to very close tolerances to allow accurate control of very small flows. These types of constructions can often handle Cv's as low as 0.03. Using these special trims in standard control valves provides economy by reducing the need for spare parts inventory for special valves and actuators. Using this approach also makes future flow expansions easy by simply replacing the trim components in the standard control valve body. Control valves specifically designed for very low flow rates (figure 22) also handle these applications. These valves often handle Cv's as low as 0.000001. In addition to the very low flows, these specialty control valves are compact and light weight because they are often used in laboratory environments where very light schedule piping/tubing is used. These types of control valves are specially designed for the accurate control of very low flowing liquid or gaseous fluid applications.

High-Temperature Control valves for service at temperatures above 450°F (232°C) must be designed and specified with the temperature conditions in mind. At elevated temperatures, such as may be encountered in boiler feed-water systems and super-heater bypass systems, the standard materials of control valve construction might be inadequate. For instance, plastics, elastomers, and standard gaskets generally prove unsuitable and must be replaced by more durable materials. Metal-to-metal seating materials are always used. Semi-metallic or laminated flexible graphite packing materials are commonly used, and spiral-wound stainless steel and flexible graphite gaskets are necessary. Cr-Mo steels are often used for the valve body castings for temperatures above 1000°F (538°C). ASTM A217 Grade WC9 is used up to 1100°F (593°C). For temperatures on up to 1500°F (816°C) the material usually selected is ASTM A351 Grade CF8M, Type 316 stainless steel. For temperatures between 1000°F (538°C) and 1500°F (816°C), the carbon content must be controlled to the upper end of the range, 0.04 to 0.08%. Extension bonnets help protect packing box parts from extremely high temperatures. Typical trim materials include cobalt based Alloy 6, 316 with alloy 6 hard-facing and nitrided 422 SST.

Cryogenics Service Valves is the science dealing with materials and processes at temperatures below minus 150°F (−101°C). For control valve applications in cryogenic services, many of the same issues need consideration as with high– temperature control valves. Plastic and elastomeric components often cease to function appropriately at temperatures below 0°F (−18°C). In these temperature ranges, components such as packing and plug seals require special consideration. For plug seals, a standard soft seal will become very hard and less pliable thus not providing the shut-off required from a soft seat. Special elastomers have been applied in these temperatures but require special loading to achieve a tight seal. Packing is a concern in cryogenic applications because of the frost that may form on valves in cryogenic applications. Moisture from the atmosphere condensates on colder surfaces and where the temperature of the surface is below freezing, the moisture will freeze into a layer of frost. As this frost and ice forms on the bonnet and stem areas of control valves and as the stem is stroked by the actuator, the layer of frost on the stem is drawn through the packing causing tears and thus loss of seal. The solution is to use extension bonnets (figure 23) which allow the packing box area of the control valve to be warmed by ambient temperatures, thus preventing frost from forming on the stem and packing box areas. The length of the extension bonnet depends on the application temperature and insulation requirements. The colder the application, the longer the extension bonnet required. Materials of construction for cryogenic applications are generally CF8M body and bonnet material with 300 series stainless steel trim material. In flashing applications, hard facing might be required to combat erosion.

Axial flow valves can be represented by the pneumo-hydraulically actuated one shown in fig 24. Here a pneumatically powered diaphragm moves a piston that causes hydraulic fluid to compress an elastomeric plug. The plug expands to throttle the annular flow passageway. These valves are used for gas flows and are said to be especially quiet. The *sleeve valve*, Fig. 25, is also an axial valve used for gas flows. It is actuated by pressurizing the outer side of the sleeve with a pressure greater than the upstream pressure. A minimum pressure drop, depending on size, is needed to fully open the valve. If a gas regulator is used as a pilot, the sleeve valve can be used as a main line regulator



Figure 23. Typical Extension Bonnet

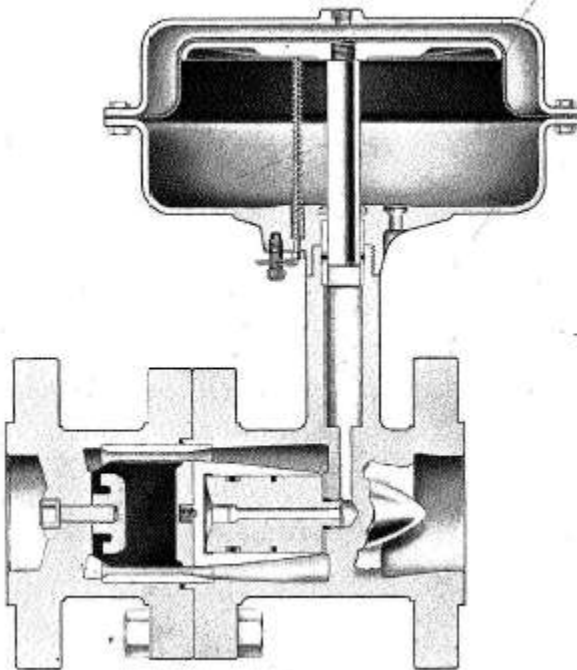


Figure 24. Axial Flow Valve

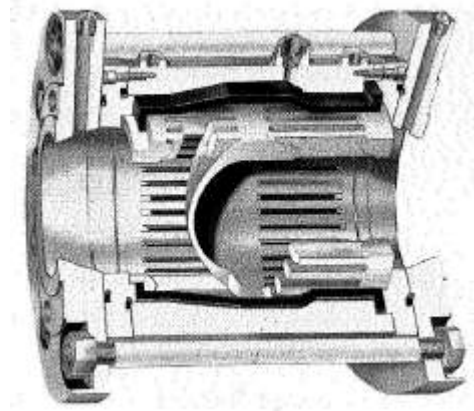


Figure 25. Sleeve Valve

Digital valves have been developed to be controlled directly from a computer or microprocessor. A digital valve is made up of a group of on-off valve elements installed in a common body. Each valve element has a different capacity, so that the sequence of sizes form a binary series. Binary

signals from a digital control device can actuate any combination of valve elements. For example, if there are eight valve elements in a digital valve their capacity ratios will be 1, 2, 4, . . . 128. Each incremental step will vary by one part in 255, and the ratio of maximum to minimum capacity will be 255: 1. These valves have the capability to change from one capacity to another instantaneously. Consider a valve whose smallest element has a 4 of 0.20. It would have a rated capacity of 255×0.20 , or 51. It would be able to change from a 4 of 45 to a 4 of 2 just as rapidly as it would be able to change from 45 to 44. Because of their construction, however, these valves are limited to clean fluids and moderate temperatures. Their ability to handle corrosive fluids also is very limited. This is an area in which there is a great deal of interest because of the digital revolution. Certainly substantial research and development money is being spent on digital valves. But it is difficult to foresee the market potential at this time.

Objective 4: Control Valve Flow Characteristics

The relationship between capacity and valve travel is intrinsic to the form of some valve types. This relationship expressed graphically is known as the *flow* characteristic of the valve, Fig. 26. The quick-opening globe valve is simply a flat-disk plug and a circular orifice. It is effectively fully open when the disk is opened a distance of one-fourth the orifice diameter, where the area of the annulus is equal to the area of the orifice. The curve shown in the illustration is for an opening 50% greater than that. The butterfly valve also loses its effectiveness as it approaches the fully open position (90°). Used as control valves, both of these types are normally limited to travel that avoids the areas where flow becomes insensitive to travel. The curves shown are based on the valve's water capacity with a constant pressure drop. This flow characteristic curve is known as the inherent flow characteristic of the valve. When valves are installed with pumps, pipes, fittings, and so on, the pressure drop across the valve will vary with the travel. When the actual flow in a system is plotted against valve opening the curve is known as the *installed* flow characteristic

Some valves are characterized by shaping the plugs, orifices, or cages to produce a particular curve. The curves that are commonly sought are:

Linear, where flow capacity (C_v) increases linearly with valve travel

Equal percentage, where flow capacity increases exponentially with valve travel—that is, equal increments of valve travel will produce equal percentage changes in the existing C_v .

Modified parabolic, a curve lying approximately midway between linear- and equal-percentage curves. It provides fine throttling action at low flow capacity and an approximately linear characteristic at higher flow capacities

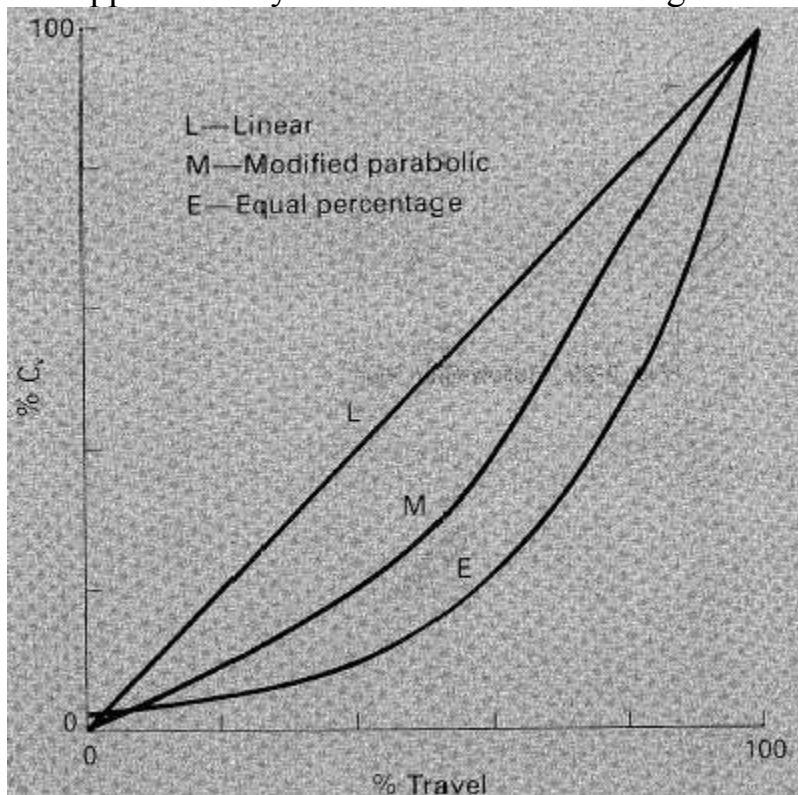


Figure 26. Ideal Flow Characteristics

Figure 27 illustrates these curves as they would appear if the ideal could be attained. The reason for wanting a particular flow characteristic is to introduce non-linearity into the control valve in a manner to compensate for other non-linearities in the control loop. Of course, if there is no substantial non-linearity a linear valve flow characteristic is indicated. Figure 28 shows several techniques for characterizing globe valves.

Selection of Flow Characteristic

Some guidelines will help in the selection of the proper flow characteristic. Remember, however, that there will be occasional exceptions to most of these guidelines, and that a positive recommendation is possible only by means of a complete dynamic analysis. Where a linear characteristic is recommended, a quick opening valve plug could be used, and while the

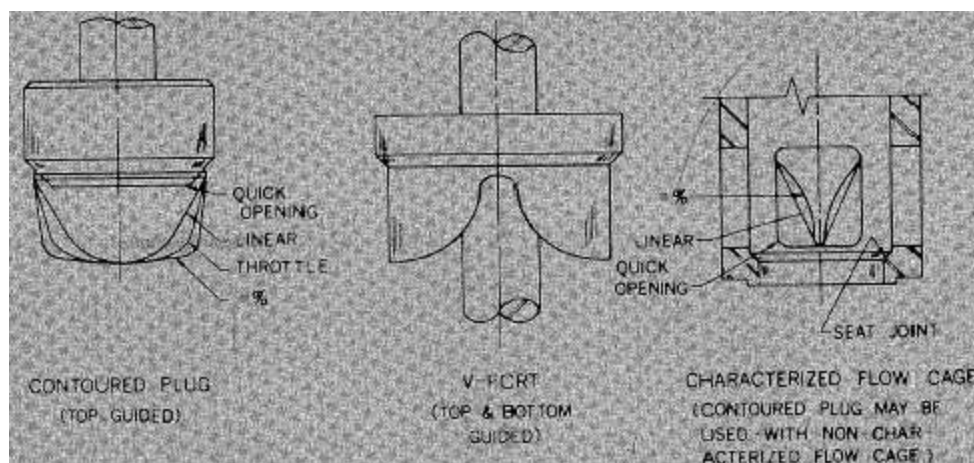


Figure 27 Characterized Plugs and Cages

controller will have to operate on a wider proportional band setting, the same degree of control accuracy may be expected. The tables below give useful guidelines for selecting valve characteristics.

Liquid Level Systems

Control Valve Pressure Drop	Best Inherent Characteristic
Constant ΔP	Linear
Decreasing ΔP with Increasing Load, ΔP at Maximum Load > 20% of Minimum Load ΔP	Linear
Decreasing ΔP with Increasing Load, ΔP at Maximum Load < 20% of Minimum Load ΔP	Equal Percentage
Increasing ΔP with Increasing Load, ΔP at Maximum Load < 200% of Minimum Load ΔP	Linear
Increasing ΔP with Increasing Load, ΔP at Maximum Load > 200% of Minimum Load ΔP	Quick Opening

Flow Control Processes

FLOW MEASURE- MENT SIGNAL TO CONTROLLER	LOCATION OF CONTROL VALVE IN RELATION TO MEASURING ELEMENT	BEST INHERENT CHARACTERISTIC	
		Wide Range of Flow Set Point	Small Range of Flow but Large ΔP Change at Valve with Increasing Load
Proportional To Flow	In Series	Linear	Equal Percentage
	In Bypass ⁽¹⁾	Linear	Equal Percentage
Proportional To Flow Squared	In Series	Linear	Equal Percentage
	In Bypass ⁽¹⁾	Equal Percentage	Equal Percentage

1. When control valve closes, flow rate increases in measuring element.

Post-Assessment

1. State the application of
 - a. Quick opening control valve
 - b. Liner control valve
2. In mixing operation, Which is better to use two way control valves in parallel or 1 three way control valve
3. Can the butterfly or ball valve be used as control valves
4. Draw in sketch the port of the following valves
 - Y-globe valves
 - Multi- orifice gate valves
 - Butterfly valve
 - Gate valve



Module 2

Analogue Control Strategies

2.1. Function Blocks - General Information

The following sections provide detailed information on all of the function blocks. This includes schematic diagrams, block executions, application information, parameters, modes, status handling, and alarms.

2.1.1. Function Blocks

The system utilizes modular configuration for developing a control strategy. The control modules are treated as unique, named control entities in the system. The function block is the basic component of a control module, that is, it is the building block of the control module. Each function block contains standard process control algorithms (such as PID, Analog Out, and Analog In) and parameters that customize the algorithm.

Function block algorithms range from simple input conversions to complex control strategies. The function block uses parameter data supplied by the user, by the function block itself, or by other function blocks to perform its calculations and logic functions and to supply an output value to other function blocks or to field devices. Some function blocks also detect alarm conditions.

You can connect function blocks together in a control module so that data can be transmitted between blocks. This data can be used in the control algorithm, mathematical or logical calculation, or status determination of the block. This capability helps you implement a variety of process control strategies, including advanced control, shutdown sequences, and process reactions to quality control information.

2.1.2. Function Block Types

There are six categories of function blocks in the system:

- **Input/Output (I/O) Blocks** – Scale, convert, and filter input and output signals for use in other function blocks or field devices
- **Math Blocks** – Perform mathematical functions for conversion, integration, and totalizing
- **Timer/Counter Blocks** – Perform timing and counting functions for control and sequencing
- **Logical Blocks** – Perform logic functions for sequencing, scheduling, and interlocking
- **Analog Control Blocks** – Perform simple and complex algorithms for comprehensive analog control
- **Energy Metering Blocks** – Perform mathematical flow calculations for natural gases, steam, and other fluids
- **Advanced Control Blocks** – Perform complex algorithms for advanced process control

In addition, there is a collection of special items that contains input and output parameters, internal read and write parameters, and custom and physical block tools.

2.2. Guide to Function Blocks

The following table includes the analogue function block and a brief description of the capabilities of each block:

Standard analogue Function Blocks

Icon	Function Block	Palette Category	Description
	Absolute Value	Math Blocks	Provides the absolute value of an integer or floating-point input value.
	Add (ADD)	Math Blocks	Sums the values of two to sixteen inputs and generates an output value. The block supports signal status propagation.
	Alarm Detection (ALARM)	Analog Control Blocks	Provides the ability to easily specify alarms on parameters that are obtained from I/O or from the results of other function block calculations.
	Analog Input (AI)	I/O Blocks	Accesses a single analog measurement value and status from an I/O channel. The input value can be a transmitter's 4 to 20 mA signal or the digitally communicated primary or non-primary variable from a HART transmitter. The block supports mode control, block alarming, signal scaling, signal filtering, signal status calculation, and simulation.
	Analog Output (AO)	I/O Blocks	Assigns an analog output value to a field device through a specified I/O channel. The block supports mode control, signal status calculation, and simulation.
	Arithmetic	Math Blocks	Provides the ability to configure a range extension function for a primary input and applies the nine different arithmetic types as compensation to or augmentation of the range extended input.
	Bias/Gain (BG)	Analog Control Blocks	Provides adjustable gain capability by computing an output value from a bias setpoint, an input, and a gain value. The block supports output tracking.
	Calculation/Logic	Analog Control Blocks	Allows you to specify an expression that

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	(CALC)		determines the block's output. Mathematical functions, logical operators, constants, parameter references, and I/O reference values can be used in the expression.
	Comparator (CMP)	Math Blocks	Compares two values and sets a Boolean output based on that comparison.
	Control Selector (CTLSEL)	Analog Control Blocks	Selects one of three control signals to perform override control to a PID function block. The block supports mode control.
	Deadtime (DT)	Analog Control Blocks	Introduces a pure time delay in the value and status used in a signal path between two function blocks. The block supports signal status propagation and mode control.
	Diagnostic (DIAG)	Advanced Control Blocks	Provides a method to monitor device alerts from non-fieldbus assets. Wire parameters or block outputs that indicate device health for non-fieldbus blocks to the Diagnostic block. These alerts from these diagnostic blocks are monitored by Inspect.
	Divide (DIV)	Math Blocks	Divides one input value by another input value and generates an output value. The block supports signal status propagation.
	Fieldbus Input Selector Extended (ISELX)	Analog Control Blocks	A mathematical and logical input calculation block that chooses an output based on up to 8 inputs.
	Fieldbus Multiple Discrete Input (FFMDI)	I/O Blocks	Combines the eight channels of a Discrete Input card and makes them available as an 8-bit input to other function blocks.
	Fieldbus Multiple Discrete Output (FFMDO)	I/O Blocks	Takes an 8-bit setpoint and writes it to the I/O channels of a Discrete Output card on an H1 Carrier device.
	Filter (FLTR)	Analog Control Blocks	Applies an equation to filter changes in the input signal and generates a smooth output signal. The block supports signal status propagation.
	Flow Metering (AGA_SI and AGA_US)	Energy Metering Blocks	Implements the American Gas Association flow calculation standards for natural gases, namely AGA-3 (American Gas Association, Report No.3), AGA-7, and AGA-8.

	Fuzzy Logic Control (FLC)	Advanced Control Blocks	Provides all the logic to perform standard PID control with the added benefit of superior response for both set point changes and external load disturbances.
	Input Selector (INSEL)	Analog Control Blocks	A mathematical and logical input calculation block that chooses an output based on up to 4 inputs.
	Inspect	Advanced Control Blocks	A block that receives statistics data so that you can view, plot, and add to history, the performance values in the system.
	Integrator (INT)	Math Blocks	Integrates a variable over time. The block compares the integrated or accumulated value to pre-trip and trip limits and generates discrete output signals when the limits are reached. The integrated value can increment from zero or decrement from the trip value. The block has two inputs and can calculate and integrate net flow, as well as handling negative flow. The block supports mode control.
	Isentropic Expansion (ISE)	Energy Metering Blocks	Calculates the final enthalpy for isentropic expansion of steam to a given pressure for a given entropy.
	Lab Entry (LE)	Advanced Control Blocks	Provides for operator input of offline lab analysis results.
	Lead/Lag (LL)	Analog Control Blocks	Provides dynamic compensation for an input value. The block can apply a lead time function, a lag time function, or a combination of the two. A specified gain is applied to the compensated value, and the value is high/low-limited based on the block mode. The block supports mode control and signal status propagation.
	Limit (LIM)	Analog Control Blocks	Limits an input value between two reference values. The block supports signal status propagation.
	Manual Loader (MANLD)	Analog Control Blocks	Allows the block output to be set by an operator. The block supports output tracking and alarm detection.
	Model Predictive Control (MPC)	Advanced Control Blocks	Allows interactive processes to be controlled within measurable operating constraints while automatically accounting for process interaction and measurable

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			disturbances.
	Model Predictive Control Professional (MPCPro)	Advanced Control Blocks	Allows large interactive processes (as large as 20 x20) to be controlled within measurable operating constraints while accounting for process interaction and measurable disturbances. An embedded optimizer is included with the MPCPro block that can be used to effectively provide maximum profit or lowest cost production with the process constraints and limits on process inputs.
	MPC Process Simulator	Advanced Control Blocks	Simulates the actual process for use with the MPC function block for operator training.
	Multiplexed Analog Input (MAI)	I/O Blocks	Connects higher density transmitters to a Fieldbus segment.
	Multiply (MLTY)	Math Blocks	Multiplies two to sixteen input values and generates an output value. The block supports signal status propagation.
	Neural Network (NN)	Advanced Control Blocks	Uses a neural network to predict a process output based on measured process inputs.
	PID (PID)	Analog Control Blocks	Combines all the necessary logic to perform analog input channel processing, proportional-integral-derivative (PID) control, and analog output channel processing within one function block. The block supports mode control, signal scaling and limiting, feedforward control, override tracking, alarm limit detection, and signal status propagation.
	Pulse Input (PIN)	I/O Blocks	Provides analog input values from Pulse Input channels on the Multifunction I/O card.
	Ramp (RAMP)	Analog Control Blocks	Creates a ramping output signal to increase or decrease a variable toward a specified target value at a defined rate. The block supports signal status propagation.
	Rate Limit (RTL)	Analog Control Blocks	Limits the rate of change of the output value to specified limits. The block supports signal status propagation.

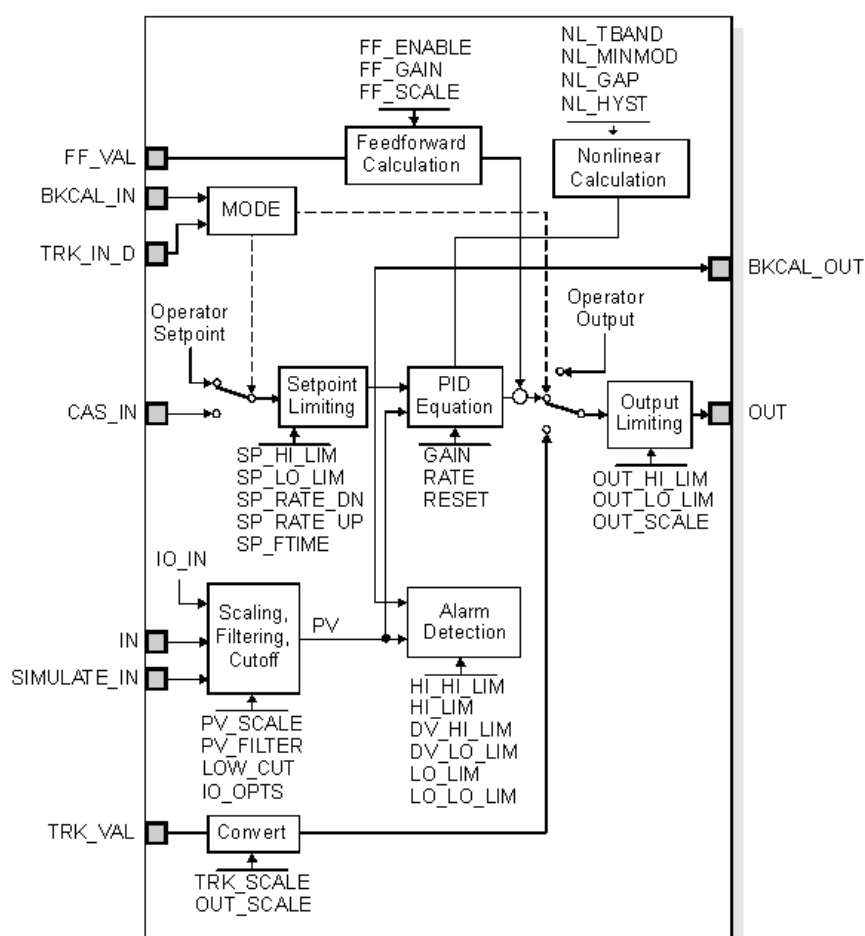
	Ratio (RTO)	Analog Control Blocks	Applies an adjustable ratio setpoint to achieve a desired input/output relationship. The block supports signal filtering, mode control, output tracking, and alarm detection.
	Scaler (SCLR)	Analog Control Blocks	Provides scaling and dimensional consistency between two values of different engineering units. The block converts the input value to the specified scale and generates an output value. The block supports signal status propagation.
	Signal Characterizer (SGCR)	Analog Control Blocks	Characterizes or approximates any function that defines an input/output relationship. The block interpolates an output value for a given input value using the curve defined by the configured coordinates. Two separate analog input signals can be processed simultaneously to give two corresponding separate output values using the same defined curve. The block supports signal status propagation.
	Signal Generator (SGGN)	Analog Control Blocks	Produces an output signal used to simulate a process signal. The block uses a specified combination of a sine wave, a square wave, a bias value, and a random value to generate the output signal.
	Signal Selector (SGSL)	Analog Control Blocks	Selects the maximum, minimum, or average of as many as sixteen input values and places it at the output. The block supports signal status propagation.
	Splitter (SPLTR)	Analog Control Blocks	Takes a single input and calculates two outputs based on specified coordinate values. The block supports mode control and signal status propagation.
	Subtract (SUB)	Math Blocks	Subtracts one input value from another input value and generates an output value. The block supports signal status propagation.
	Steam Density Ratio (SDR)	Energy Metering Blocks	Calculates the square root of the ratio of steam density to the density of steam corresponding to a flow meter calibration pressure and temperature.
	Saturated Steam Properties at	Energy Metering Blocks	Calculates steam enthalpy, entropy, specific volume, and pressure for

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	Temperature (SST)		saturation conditions specified by a given temperature.
	Steam Properties (STM)	Energy Metering Blocks	Calculates steam enthalpy, entropy, and specific volume for a given gauge pressure.
	Saturated Temperature (TSS)	Energy Metering Blocks	Calculates the steam temperature at saturation given the steam pressure.
	Transfer (XFR)	Logical Blocks	Selects one of two analog input signals and transfers the selected input to the output after a specified time. The transfer from one input to another is smoothed with a linear ramp. The block supports signal status propagation.
	Water Enthalpy (WTH)	Energy Metering Blocks	Calculates the enthalpy of water for a specific temperature.
	Water Entropy (WTS)	Energy Metering Blocks	Calculates the entropy of water for a specified temperature.

2.3. PID Function Block

The following diagram shows the internal components of the PID function block.



2.3.1 Block Execution

The PID function block provides proportional (P) + integral (I) + derivative (D) control. Two PID equation forms are supported in the block, both forms supporting external reset and feedforward:

The standard form is a discrete implementation of:

$$\text{OUT}(s) = \pm \text{GAIN}_a \cdot \left(\text{KNL} \cdot \left(\frac{P(s) \cdot T_r s}{(T_r s + 1)} + \frac{E(s)}{(T_r s + 1)} \right) + \frac{D(s) \cdot T_r s \cdot T_d s}{(T_r s + 1)(\alpha T_d s + 1)} \right) + \frac{L(s) - F(s)}{(T_r s + 1)} + F(s)$$

The series form is a discrete implementation of:

$$\text{OUT}(s) = \pm \text{GAIN}_a \cdot \left(\frac{P(s) \cdot T_r s}{(T_r s + 1)} + \frac{E(s)}{(T_r s + 1)} + \frac{D(s) \cdot T_d s}{(\alpha T_d s + 1)} \right) + \frac{L(s) - F(s)}{(T_r s + 1)} + F(s)$$

For $L = \text{OUT}$ (which is the same as OUT being unconstrained) and $P = D = E$ the equations reduce to:

A conventional Standard PID with feedforward,

$$\text{OUT}(s) = \text{GAIN}_a \cdot \left(1 + \frac{1}{T_r s} + \frac{T_d s}{(\alpha T_d s + 1)} \right) \cdot E(s) + F(s)$$

and Series PID with derivative filter applied only to derivative action, with feedforward

$$\text{OUT}(s) = \text{GAIN}_a \cdot \left(1 + \frac{T_d s}{(\alpha T_d s + 1)} \right) \left(\frac{T_r s + 1}{T_r s} \right) \cdot E(s) + F(s)$$

Where:

$E(s)$ is error (SP-PV)

$\pm$ is + for reverse acting and – for direct acting (Direct_Acting in CONTROL_OPTS)

KNL is nonlinear gain applied to P + I terms but not to D term. Nonlinear action is activated in FRSIPID_OPTS by selecting Use_Nonlinear_Gain_Modification.

$P(s)$ is the variable to which proportional action is applied. $P(s)$ is determined by parameters STRUCTURE and BETA (which sets the weighting factor for proportional action applied to SP change).

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$D(s)$ is the variable to which derivative action is applied. $D(s)$ is determined by parameters **STRUCTURE** and **GAMMA** (which sets the weighting factor derivative action on SP change).

$L(s)$ is the external reset input which is either from **BKCAL_IN** or **OUT**.

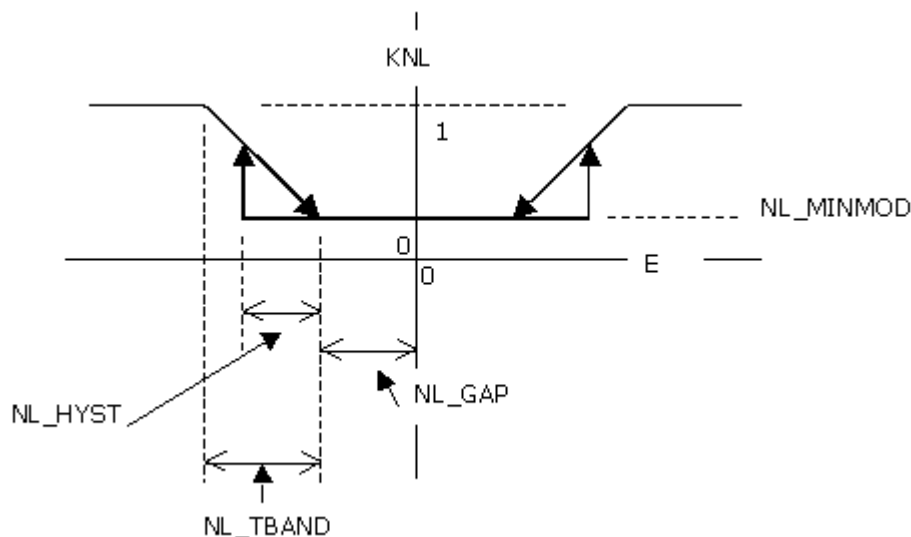
T_r is reset time (parameter **RESET**) in seconds.

T_d is derivative time (parameter **RATE**) in seconds

$GAIN_a$ is normalized gain after scaling the parameter **GAIN** from PV to OUT (DeltaV works in engineering units so it is necessary that the parameter **GAIN** be scaled to maintain the meaning of the normalized entry).

$F(s)$ is the feedforward contribution.

The following diagram illustrates how the nonlinear tuning parameters are used in the calculation of **KNL**.



KNL Calculation

where:

NL_MINMOD is the gain applied when the absolute value of error is less than **NL_GAP**. To get deadband behavior, set **NL_MINMOD** to 0.

NL_GAP is the control gap. When the absolute value of error is less than **NL_GAP**, $KNL = NL_MINMOD$.

NL_TBAND is the transition band over which **KNL** is linearly adjusted as a function of error.

NL_HYST is a hysteresis value. Until absolute value of error exceeds NL_GAP + NL_HYST, KNL = NL_MINMOD. Once absolute value of error has exceeded NL_GAP + NL_HYST, absolute value of error must return to a value less than NL_GAP before KNL returns to a value of NL_MINMOD. If NL_GAP is 0, then the value of NL_HYST has no meaning (effectively assumed to be 0).

You can select the specifics of block execution by configuring I/O selection, signal conversion and filtering, feedforward calculations, tracking variables, setpoint and output limiting, PID equation structures, and block output action. The mode of the block determines setpoint and output selection.

2.3.2. I/O Selection

When you configure the PID function block, you select whether the source of the input value is a wired function block connection or a process input channel.

Input from Another Block – When you want the source to be an input from another function block, the input source (usually another block's output value) is connected to the IN connector on the PID function block. With a fieldbus extension, the connection to IN must be from another function block.

Input from a Process Input Channel – When you want the source to be an input from a process input channel, you configure the Device Signal Tag (DST) of the desired channel in the IO_IN parameter. There is no IO_IN parameter in the fieldbus extension.

Note When IO_IN is configured and IN is connected, the I/O input channel referenced by IO_IN takes precedence and IN is ignored.

You can configure anti-aliasing filtering, NAMUR limit detection, and overrange/underrange detection for the channel parameters. For information on these capabilities, refer to the [I/O Configuration](#) topics.

2.3.3. Simulation

To support testing, you can enable simulation. This allows the measurement value and status to be supplied manually or from another block.

During configuration, decide whether you want the simulated value/status to be entered manually into the function block or whether it will be supplied by another block.

When the value is entered manually:

- The operator first enables simulation by selecting the SIMULATE parameter and setting the Simulate Enabled box in the Simulate Enabled/Disabled field.
- When SIMULATE_IN is not connected (status = Bad: NotConnected), the operator enters the value to be used in the SIMULATE parameter Simulate

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Value field. In online operation, the operator can enter a simulated status value in the Simulate Status field.

Note Make sure SIMULATE_IN is not connected if you want to enter the value or status manually. When SIMULATE_IN is connected, the value entered in the SIMULATE_IN Simulate Value field is used as the simulated value.

When the value/status from another block is used:

- During configuration, connect SIMULATE_IN to the desired block output or parameter. Do not enter a value in the Simulate Value field of the SIMULATE_IN input; the block uses the connected value automatically.
- During operation, the operator enables simulation by selecting the SIMULATE parameter and setting the Simulate Enabled box in the Simulate Enabled/Disabled field.

Note Do not enter a value for the SIMULATE_IN parameter. If you enter a value and the status of SIMULATE_IN is not Bad: NotConnected, the value entered for SIMULATE_IN overrides any value you enter in SIMULATE.

There is no SIMULATE_IN in fieldbus.

2.3.4. Signal Conversion

Choose direct, indirect, or indirect square root signal conversion with the linearization type (L_TYPE) parameter:

Direct signal conditioning – simply passes through the value accessed from the I/O channel (or the simulated value when simulation is enabled).

Indirect signal conditioning – converts the accessed channel input value (or the simulated value when simulation is enabled) to the range and units of the PV parameter (PV_SCALE).

Indirect square root signal conditioning – converts the accessed channel input value (or the simulated value when simulation is enabled) by taking the square root of the value and scaling it to the range and units of the PV parameter (PV_SCALE).

You can view the accessed value (in percent) through the FIELD_VAL parameter.

When the converted input value is below the limit specified by the LOW_CUT parameter and the Low Cutoff I/O option (IO_OPTS) is enabled (True), a value of 0.0 is used for the converted value (PV). This option can be useful with zero-based measurement devices such as flowmeters.

You can choose to reverse the range for conversion to account for fail-open actuators by selecting the following I/O option:

Increase to Close – This option has an impact when a device signal tag is configured in IO_OUT. Increase to Close causes the milliamp signal on the analog output channel to be inverted in Man mode (and in Auto mode). That is, a full scale value on OUT will result in 4 mA on the channel. When IO_OUT is configured, the OUT value is the implied valve position and is not inverted when Increase to Close is true.

Note You can set I/O options in Out of Service mode only.

For complete descriptions of the supported I/O options, refer to the [I/O Options](#) topic.

2.3.5. Feedforward Calculation

You can activate the feedforward function with the FF_ENABLE parameter. When FF_ENABLE is True, the feedforward value (FF_VAL) is scaled (FF_SCALE) to a common range for compatibility with the output scale (OUT_SCALE). A gain value (FF_GAIN) is applied to achieve the total feedforward contribution.

2.3.6. Tracking

You can specify output tracking with control options and parameters. You can set control options in Out of Service mode only.

The Track Enable control option ([CONTROL_OPTS](#)) must be True for the track function to operate. When the Track in Manual control option is True, tracking can be activated and maintained when the block is in Man mode. When Track in Manual is False, tracking is disabled in Manual mode. Activating the track function causes the block's actual mode to go to Local Override (LO).

The tracking value parameter (TRK_VAL) specifies the value to be converted and tracked into the output when the track function is operating. The track scale parameter (TRK_SCALE) specifies the range of TRK_VAL.

When the track control parameter (TRK_IN_D) is True and the Track Enable control option is True, the TRK_VAL input is converted to the appropriate value and output in units of OUT_SCALE.

2.3.7. Setpoint and Output Limit Constraints

As part of download the output high and low limits are set to the configured values. If these limits have not been configured OUT_HI_LIM will be set to OUT_SCALE_HI and OUT_LO_LIM will be set to OUT_SCALE_LO.

The following constraints apply to download or direct entry:

- SP_HI_LIM is restricted to $PV_SCALE_HI + 1 * (PV_SCALE_HI - PV_SCALE_LO)$.

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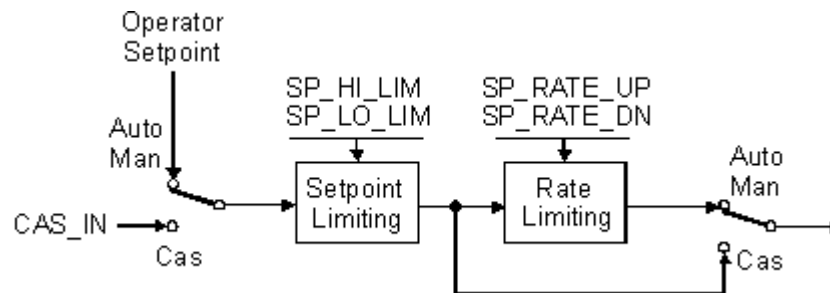
- SP_LO_LIM is restricted to $PV_SCALE_LO - 1 * (PV_SCALE_HI - PV_SCALE_LO)$.
- OUT_HI_LIM is restricted to $OUT_SCALE_HI + 1 * (OUT_SCALE_HI - OUT_SCALE_LO)$.
- OUT_LO_LIM is restricted to $OUT_SCALE_LO - 1 * (OUT_SCALE_HI - OUT_SCALE_LO)$.

If the new scale causes a limit to be outside of these rules, DeltaV software forces the limit within the rules.

The SP or OUT parameters are not changed as a result of changing the scale or limits. However, if OUT violates the new limits OUT will be forced within the limits on the next pass.

Setpoint Selection and Limiting

Setpoint selection is determined by the mode. The following diagram shows the method for setpoint selection:



PID Function Block Setpoint Selection

You can limit the setpoint by configuring the SP_HI_LIM and SP_LO_LIM parameters. In Cas mode, the setpoint comes from the CAS_IN input. In Auto mode, the setpoint is adjusted by the operator. You can limit the setpoint rate of change by configuring the SP_RATE_UP and SP_RATE_DN parameters.

Output Selection and Limiting

Output selection is determined by mode. In Auto, Cas, and RCas modes, the output is computed by the PID control equation. In Man and ROut modes, the output can be entered manually.

Note If the IO_OUT parameter is defined for direct output, use any connection to OUT for calculation purposes only (for example, an input to a calculation block).

You can limit the output by configuring the OUT_HI_LIM and OUT_LO_LIM parameters.

2.3.8 Bumpless Transfer and Setpoint Tracking

You can select setpoint tracking by configuring the following control options (CONTROL_OPTS):

SP-PV Track in LO or IMan

SP-PV Track in Man

SP-PV Track in ROut

When one of these options is set, the SP value is set to the PV value while in the specified mode.

You can select the value that an upstream controller uses for bumpless transfer and reset limiting by configuring the following control option:

Use PV for BKCAL_OUT

When this option is not selected, the working setpoint (SP_WRK) is used for BKCAL_OUT.

With the Use PV for BKCAL_OUT control option, the BKCAL_OUT value tracks the PV value. A master controller whose BKCAL_IN parameter receives the slave PID block's BKCAL_OUT in an open cascade strategy forces its OUT to match BKCAL_IN, thus tracking the PV from the slave PID block. If the master is another PID, then if the master PID has selected Dynamic Reset Limit in FRSIPID_OPTS the external reset portion of the master PID now uses the PV of the secondary as its input. This provides an automatic adjustment of reset action in the master based on the performance of the slave.

You can set control options in Out of Service mode only.

2.3.9 PID Equation Structures

Parameter STRUCTURE in the PID is used to select which of the three PID actions (Proportional, Integral and Derivative) are active and how the actions are applied.

You can select the PID equation structure to apply controller action by configuring the STRUCTURE parameter. Select one of the following choices:

PID Action on Error — Proportional, integral and derivative action are applied to the error (SP - PV). If RATE is non-zero, a setpoint change will exhibit both a proportional and derivative kick. This structure is typically used to get fastest possible setpoint response when derivative action is used (RATE>0) and RATE is not so large as to make the resultant kick too great. A small SPFILTER value or SP RATE limiting can be used to reduce the worst case kick.

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PI Action on Error, D Action on PV — Proportional and integral action are applied to error; derivative action is applied to PV. A setpoint change will exhibit a proportional kick.

I Action on Error, PD Action on PV — Integral action is applied to error; proportional and derivative action are applied to PV. There is no proportional or derivative kick on a setpoint change.

PD Action Error — Proportional and derivative actions are applied to error; there is no integral action. This structure will result in a steady state offset of PV from SP; the size of the offset will be determined by GAIN of the PID and the process gain. Offset is typically adjusted with BIAS of the PID. A setpoint change will exhibit a proportional and derivative (if RATE>0) kick.

P Action on Error, D Action on PV — Proportional action is applied to error; derivative action is applied to PV; there is no integral action. This structure will result in a steady state offset of PV from SP; the size of the offset will be determined by GAIN of the PID and the process gain. Offset is typically adjusted with BIAS of the PID. A setpoint change will exhibit a proportional kick.

ID Action on Error — Integral and derivative action are applied to error; there is no proportional action. This structure is typically selected for use in integral-only applications (RATE=0). It is also used in cases where the process exhibits the tendency to first move in the opposite direction from its final steady state value. There is a derivative kick on an SP change.

I Action on Error, D Action on PV — Integral action applied to error; derivative action applied to PV; there is no proportional action. This structure is typically selected for use in integral-only applications (RATE=0). It is also used in cases where the process exhibits the tendency to first move in the opposite direction from its final steady state value. There is no derivative kick on an SP change.

Two Degrees of Freedom Controller — Two parameters (BETA and GAMMA) can be adjusted to determine the degree of proportional (BETA) action and derivative (GAMMA) that will be applied to SP changes. The range for BETA and GAMMA is 0-1. BETA=0 means no proportional action is applied to SP change. BETA=1 means full proportional action is applied to SP change. GAMMA=0 means no derivative action applied to SP change. GAMMA=1 means full derivative action is applied to SP change. For values greater than 0 and less than 1, the number represents the decimal fraction of the action applied to SP change. This structure then can be used to get any of the structures that include all three (actions) with adjustable action on SP changes for proportional and derivative action.

If a structure other than Two Degrees of Freedom Controller are used, the block automatically uses values as follows for BETA and GAMMA.

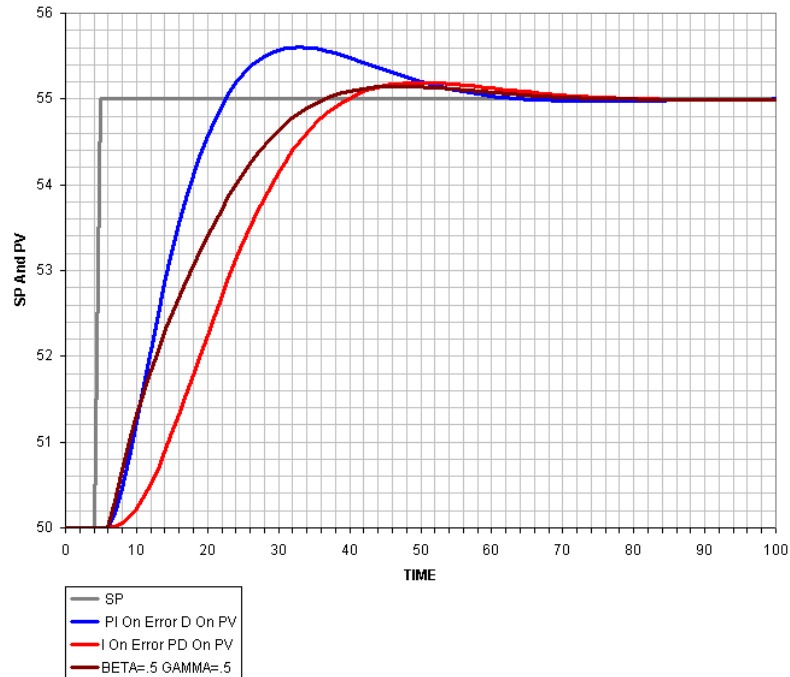
Value of STRUCTURE	Value used by the block for BETA	Value used by the block for GAMMA
PID action on error	1	1

PI action on error, D action on PV	1	0
I action on error, PD action on PV	0	0
PD action on error	1	1
P action on error, D action on PV	1	0
ID action on error	Na	1
I action on error, D action on PV	Na	0
Two Degrees of freedom	(uses configured value)	(uses configured value)

Often, when tuning a control loop for disturbance rejection, the setpoint response exhibits considerable overshoot. This is particularly true when there is derivative action required and the derivative action is taken only on PV (to avoid large bumps in output as the result of modest setpoint changes). The Two Degrees of Freedom structure provided by DeltaV software allows shaping of the setpoint response by adjusting the proportional and derivative action applied to setpoint. The adjustment parameters are BETA (for proportional) and GAMMA (for derivative). Tuning range is from no action to full action (0 to 1).

Two Degrees of Freedom is selected with the STRUCTURE parameter. The following figure illustrates the setpoint response for a loop tuned for good disturbance rejection with little or no overshoot in the disturbance response. Adjustment of BETA and GAMMA can significantly reshape the setpoint response and drastically reduce the overshoot from that of a PID that has full proportional and no derivative action on setpoint.

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When Use Nonlinear Gain Modification is selected in FRSIPID_OPTS, proportional action (if called for by STRUCTURE) is applied to error and standard form equation is applied.

Reverse and Direct Action

You can select the block output action by configuring the Direct Acting control option.

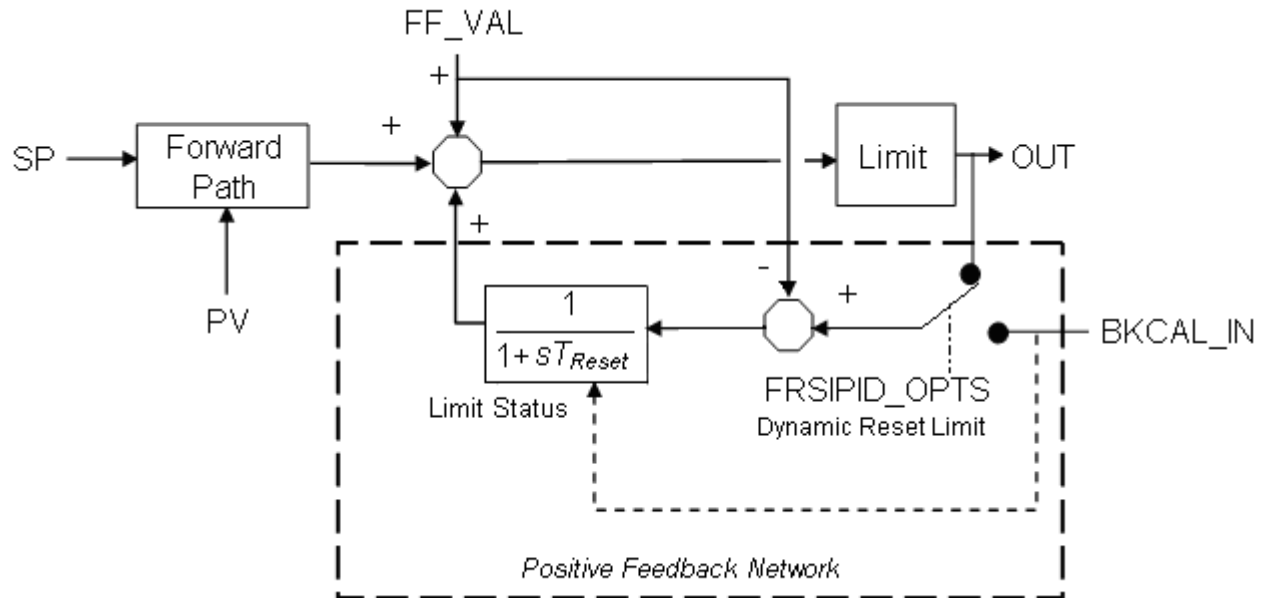
Note You can set control options in Out of Service mode only.

Reset Limiting

The PID function block provides a selection between clamped integral action or dynamic reset limiting (external reset) that prevents windup when a change in output cannot be acted on because of a downstream limit. By selecting Dynamic Reset Limit in FRSIPID_OPTS a master PID in a cascade uses the BKCAL_OUT of the slave block. If the slave block passes back PV then the reset action dynamically uses the PV of the slave.

Reset Implementation

The reset component of the PID block is implemented with a positive feedback network as shown in the following figure.



The behavior of the reset component depends on the FRSIPID_OPTS option Dynamic Reset Limit. If this option is selected, the BKCAL_OUT value of a downstream block is input to the reset calculation. Thus, if the downstream block(s) cannot act on the PID block output, the reset contribution is automatically limited, eliminating windup. If the option is not selected (the default) the reset contribution is clamped if a limit condition is indicated by the BKCAL_IN status and the calculated change in output will drive the output further into the limit.

2.3.10. Modes

The PID function block supports eight modes:

Out of Service (OOS)

Initialization Manual (IMan)

Local Override (LO)

Manual (Man)

Automatic (Auto)

Cascade (Cas)

Remote Cascade (RCas)

Remote Out (ROut)

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You can configure the OOS, Man, Auto, Cas, RCas and ROut modes as permitted modes for operator entry.

For complete descriptions of the supported modes, refer to the [Function Block Modes](#) topic.

2.3.11. Alarm Detection

Block alarm detection is based on the PV and SP values. You can configure the following alarm limits to compare to the PV value for alarm detection:

- High (HI_LIM)
- High high (HI_HI_LIM)
- Low (LO_LIM)
- Low low (LO_LO_LIM)

You can configure the following alarm limits to compare to the difference between the SP and PV values (process error) for deviation alarm detection:

- Deviation high (DV_HI_LIM)
- Deviation low (DV_LO_LIM)

Note Deviation alarms are suppressed on SP changes. When the PV comes within the deviation limits or if the status of OUT or BKCAL_IN becomes limited, the deviation alarm is enabled again.

This block supports conditional alarming. Enabling conditional alarming makes additional parameters available for this block. For more information about conditional alarming and for a description of the additional parameters, refer to the topic [Conditional Alarming](#).

2.3.12. Application Information

The PID function block is a powerful, flexible control algorithm that is designed to work properly in a variety of control strategies. The PID block is configured differently for different applications. The following examples describe how to use the PID block for closed loop control: basic PID loop, feedforward control, cascade control with master and slave, complex cascade control with override, and PID control with tracking.

2.3.12.1 Closed Loop Control

Implement basic closed loop control by taking the error difference between the setpoint (SP) and the process variable (PV) and calculating a control output signal using a PID (Proportional Integral Derivative) function block.

Proportional control responds immediately and directly to a change in the PV or SP. The proportional term (GAIN) applies a change in the loop output based on the

current magnitude of the error. With only the proportional term (GAIN), the control loop will likely have a steady state error.

Integral control eliminates steady state error. It integrates the error until it is negligible. The integral term (RESET) applies a correction based on the magnitude and duration of the error. Lowering RESET increases integral action.

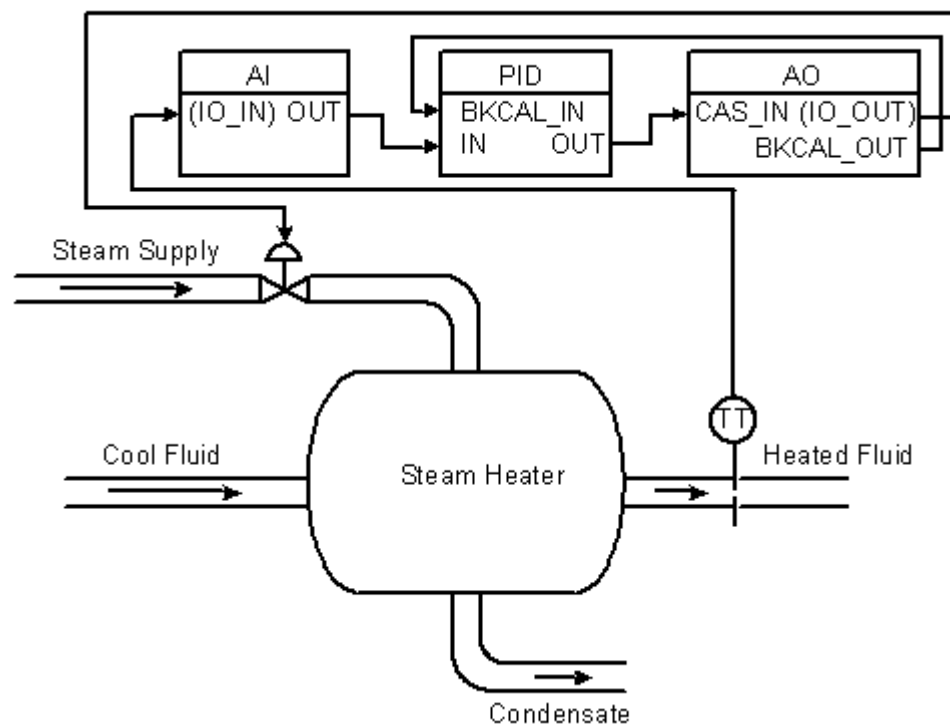
The derivative term (RATE) applies a correction based on the rate of change of error. Use derivative control where large measurement lags exist, which is typically temperature control.

The MODE parameter is a switch that indicates the target and actual mode of operation. Mode selection has a large impact on the operation of the PID block.

For complete descriptions of the supported modes, refer to the [Function Block Modes](#) topic.

2.3.12.2 Application Example: Basic PID Block for Steam Heater Control

A process fluid is heated by steam in a heat exchanger, as in the following example:



Basic Setup for PID Steam Heater Control

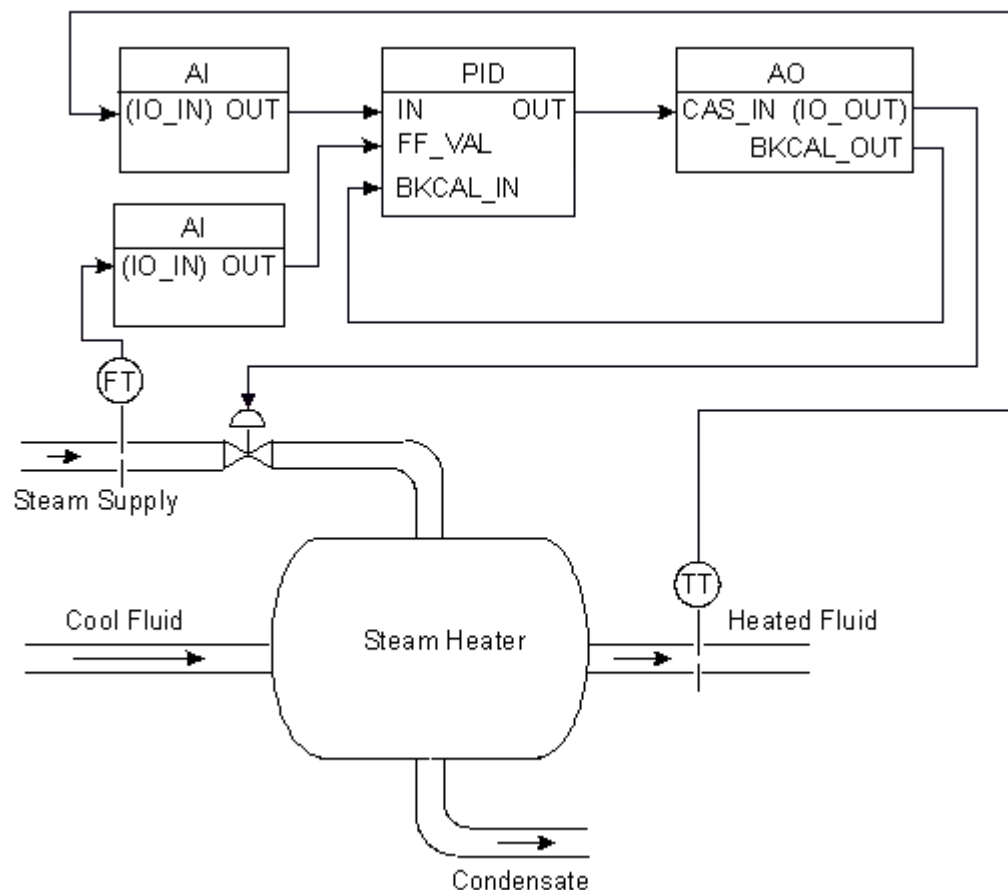
In this example, the PID controller accepts the heated fluid temperatures as an input and provides a signal to the AO block, which sends the control signal to the steam feed valve.

2.3.12.3 Application Example: Feedforward Control

In the above example, control problems can arise because of a time delay caused by thermal inertia between the two flow streams. If, for example, steam flow declines, it can take some time for this disturbance to cause a drop in the heated fluid's temperature.

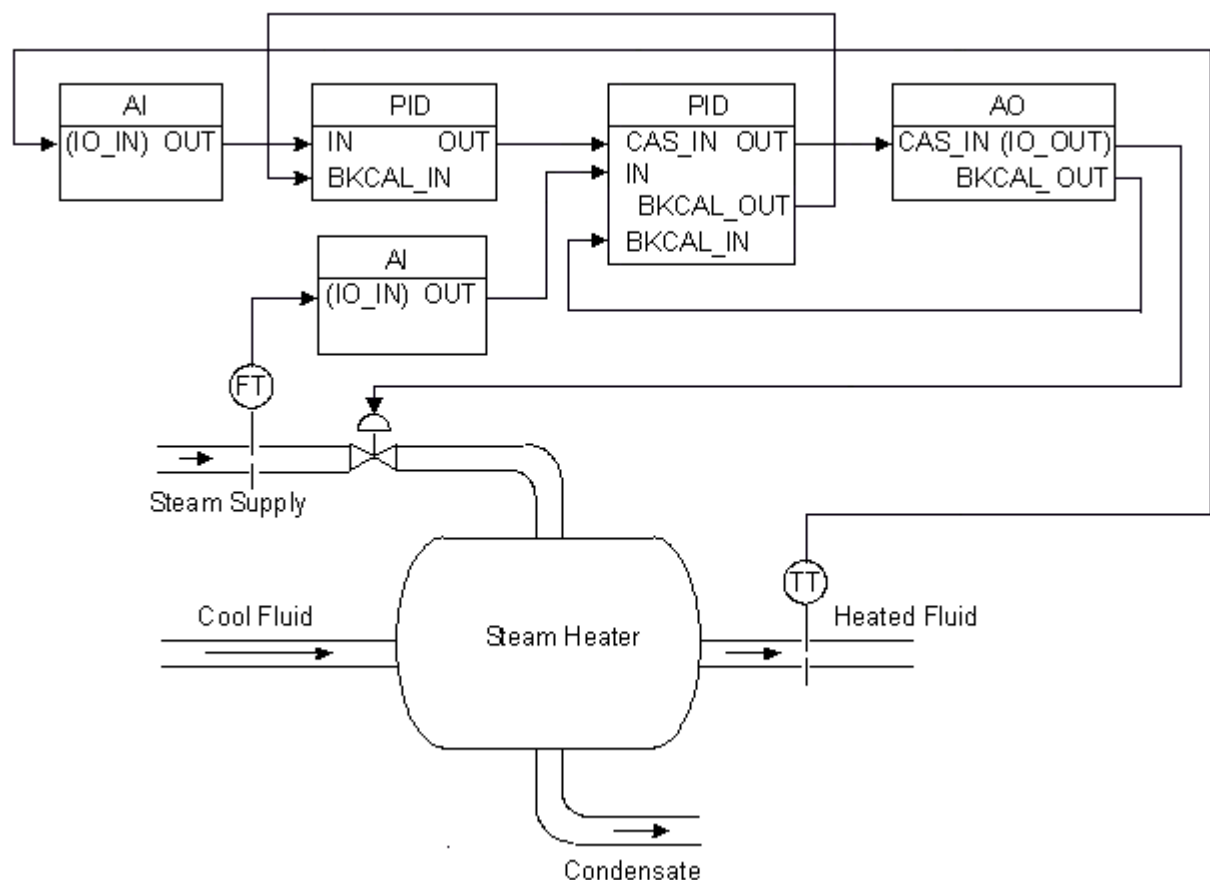
Control can be improved by measuring this disturbance and reacting to it before it manifests itself at the temperature transmitter. In the following figure, steam flow is measured (FT). A feedforward signal is sent to the controller to augment the signal to the valve if flow drops or to lower this signal if steam flow rises. (This applies to a configuration where the higher the signal, the greater the valve opening.)

In this steam heater system, adding feedforward control improves the process outlet temperature response. The inlet steam flow is input to an AI function block and is connected to the FF_VAL connector on the PID block. Enable feedforward control (FF_ENABLE), scale the feedforward value (FF_SCALE), and apply a gain determined by tuning (FF_GAIN). The following figure shows the process and function block configuration for feedforward control:



2.3.12.4 Application Example: Cascade Control with Master and Slave Loops

The feedforward scheme in the above example requires that some correlation be predetermined between steam flow changes and the steam valve opening adjustments they make. Another way to deal with the time delay problem is to use cascaded controllers. This approach does not require finding a correlation between steam flow changes and their steam valve opening adjustments. In the cascade loop in the following figure, the output from the master temperature loop is used as the setpoint for the slave steam flow loop. The following diagram shows the process instrumentation for this example:



The cascaded blocks shown can all be installed in a single module. Another method of configuring function blocks for this example is to put the temperature AI block and the master loop PID block in one module. The flow, slave PID block, and AO block are in a second module. Choose this method when you want to reference faceplates and alarms separately.

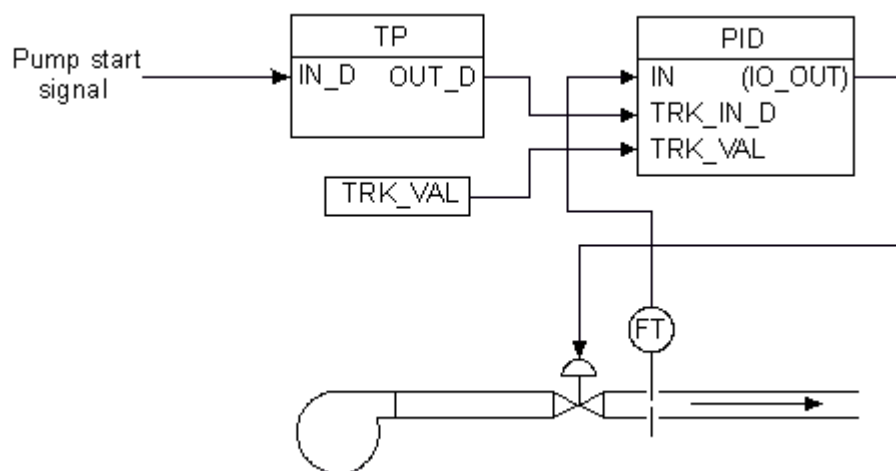
In the PID function block, BYPASS is used when the control function block is a slave block in a cascade. If a transmitter failure or some other problem occurs that causes the slave controller to see a Bad input signal, BYPASS can be activated so that the signal coming from the master controller passes through the slave to the

field. In this manner, the loop still has some control; however, dynamic performance will suffer because a cascaded loop has effectively been replaced with a single PID.

2.3.12.5 Application Example: PID Control with Tracking

An example where tracking is useful is a process operating outside of its normal operating range (for example, during a process startup).

In the following figure, a flow control valve is used to regulate the flow rate supplied by a pump. When the pump is started, the output flow from the pump is low for a short period while the pump is coming up to speed. The flow control valve and controller do not operate effectively at this low flow.



Tracking can be used in this situation to set the valve at a predetermined opening for a given amount of time. The signal to start the pump is also directed through a timed pulse block to turn tracking on for the time duration specified in the timed pulse block. The tracking value is set at the needed valve opening. When the pump starts, tracking starts. The valve opens to the specified value for the duration of the timed pulse. At the end of the pulse, tracking is turned off, and the PID can initiate its normal control, regulating the valve to adjust the output flow.

2.4 Flow Metering (AGA_SI) Function Block

The AGA_SI function block is one of two flow metering function blocks on the Energy Metering palette. It is designed to calculate the flow of natural gas through orifice and turbine meters, but can be used for other gases and liquids (virtually any single phase, Newtonian fluid under turbulent flow).

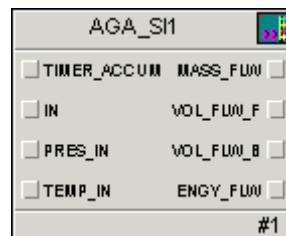
The AGA_SI function block is identical to the AGA_US block, except for the engineering units used. Each applicable parameter in the AGA_SI block has a particular SI engineering unit. If input or output parameters require other engineering units, conversion should be done upstream or downstream of the block. The other flow metering block, AGA_US, uses U.S. units.

The AGA_SI block calculates instantaneous mass flow, volumetric flow, and energy flow for natural gas using equations defined in AGA (American Gas Association) reports and ISO standards.

- Mass flow calculation for orifice metering per AGA3/1995 and ISO5167/1998
- Limits of use for orifice metering per AGA3/1995
- Calculation of densities and compressibility factors per AGA8/1994 (detail characterization method)
- Turbine metering calculations per AGA7/1996
- Calculation of gas heating value per ISO6976/1999 (real gas superior calorific value using 15/15 data)

The block calculates density for natural gases and other related hydrocarbon gases. For other fluids, the density can be entered manually.

In addition to calculating instantaneous flow rates the block provides totalization parameters for base volumetric flow and energy flow that can be reset.



IN is the differential pressure for an orifice meter in kPa (kilo Pascals) or volumetric flow from a PIN function block for a turbine meter in m³/hr (cubic meters per hour).

PRES_IN is the static pressure in kPa (kilo Pascals absolute).

TEMP_IN is the fluid temperature in °C.

TIMER_ACCUM is the input to reset totalization parameters typically wired from OUT_D of a DTE (Date Time Event) function block.

MASS_FLW is the instantaneous mass flow rate in kg/hr (kilograms per hour).

VOL_FLW_F is the volumetric flow rate at flowing conditions in m³/hr (cubic meters per hour).

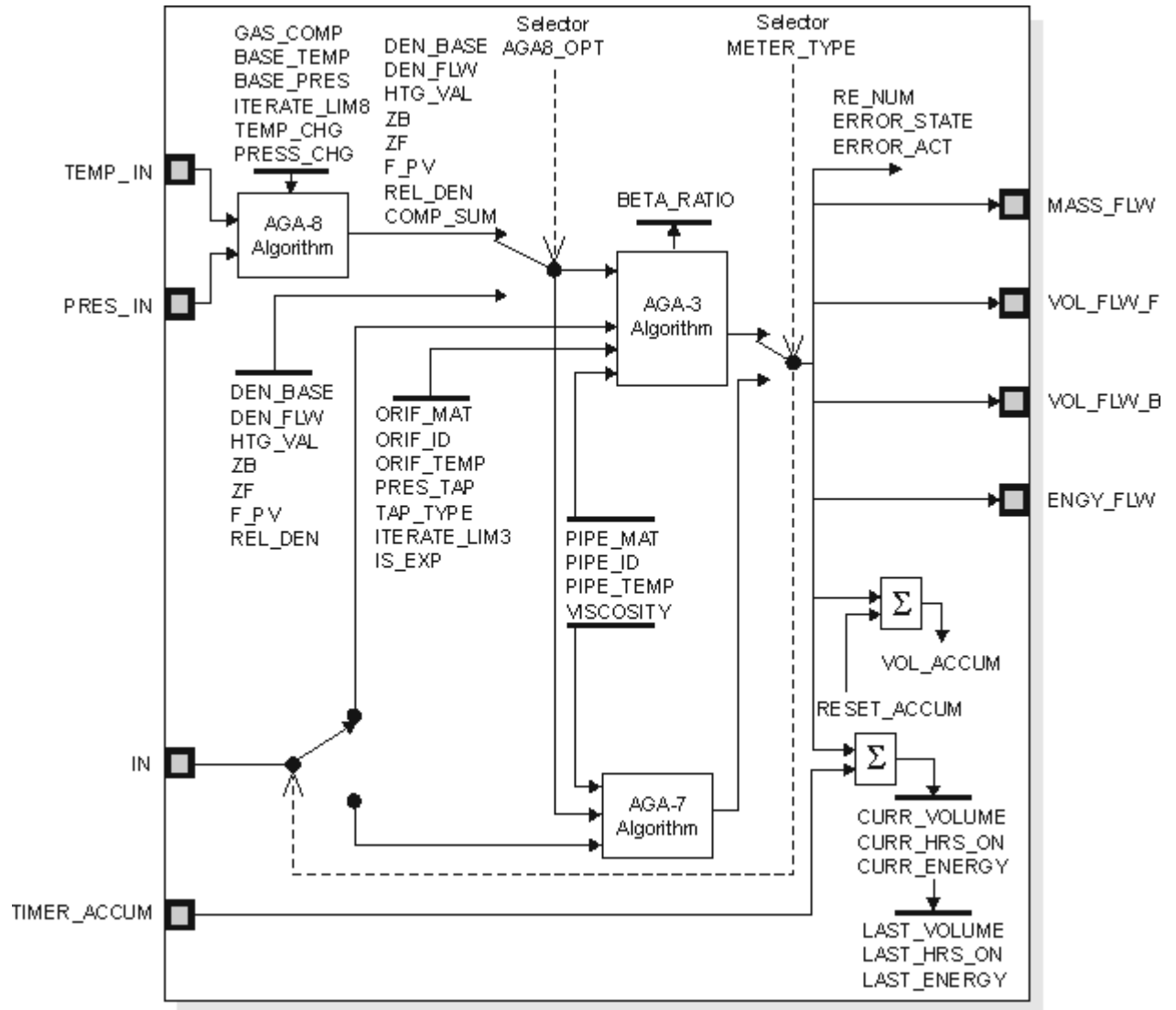
VOL_FLW_B is the volumetric flow rate at base conditions in m³/hr (cubic meters per hour).

ENGY_FLW is the energy flow in GJ/hr (gigajoules per hour).

Note The ranges of valid block input values mentioned in this section are guidelines, not absolute limits. If your inputs are outside the guidelines, block calculations lose accuracy, losing more accuracy the farther you are outside the guidelines.

Schematic Diagram - AGA_SI Function Block

The following figure shows the internal components of the AGA function block:



2.4.1 Block Execution - AGA_SI Function Block

The configuration determines the algorithms used by the block by means of the following parameters:

METER_TYPE specifies whether an orifice (differential pressure) or turbine (pulse) meter is being used.

AGA8_OPT determines whether the AGA8 parameters are to be calculated by the block or manually entered. The AGA8 parameters include DEN_BASE and DEN_FLW (base and flowing density) and the report parameters ZB, ZF, F_PV, and REL_DEN (compressibility factors, supercompressibility, and relative density).

When manual entry is chosen, the block does not calculate HTG_VAL (gas volumetric heating value), which otherwise is calculated using the ISO6976 technique, not AGA8.

The AGA8 parameters are calculated using the mole fractions for the 21 components in GAS_COMP and the base and flowing temperatures and pressures using the detail characterization method. The AGA8 parameters are calculated whenever PRES_IN or TEMP_IN changes from the last AGA8 calculation value by the amount specified in the tunable PRES_CHNG and TEMP_CHNG parameters (but at a minimum of every 60 seconds). The AGA8 parameters are calculated whenever GAS_COMP changes. If the fluid is not a natural gas or other hydrocarbon gas whose components are included in GAS_COMP, choose to manually enter the AGA8 parameters.

For orifice meters TAP_TYPE specifies the type of differential pressure tap, either Flange, Radius (D-D/2), or Corner taps. The block does not calculate flow rates for pipe taps (2.5D-8D).

PRES_TAP specifies the location of the static pressure tap, either Upstream or Downstream of the orifice plate.

The AGA3/ISO5167 algorithm calculates the mass flow rate when METER_TYPE is Differential Pressure. The coefficient of discharge is a function of pipe Reynolds number, which is a function of mass flow. Therefore the calculation of mass flow is an iterative one. The parameter ITERATE_LIM3 specifies the maximum number of iterations allowed. The default value is generally sufficient, but may need to be increased for viscous liquids. The entire flow equation is calculated each block execution, so averaging techniques are not necessary. From the mass flow the block uses the base and flowing densities from AGA8 to determine volumetric flow rates at base and flowing conditions. Like AGA3, the AGA8 algorithms are iterative. ITERATE_LIM8 specifies the maximum iterations allowed. If an iteration limit is violated, the condition is indicated in ERROR_STATE, as are any violations of the limits of use for orifice metering (see Status Handling).

When METER_TYPE is Turbine, the value on IN is the volumetric flow rate at flowing conditions (expected to be wired from the output of a Pulse Input function block). AGA_SI converts this flow to volumetric flow at base conditions and mass flow using the two density values.

Energy flow rate is determined from volumetric flow at base conditions and the volumetric heating value per ISO6976. In the AGA_SI block this is the superior heating value (not inferior) and is for the real gas (not ideal gas). It is based on the mole fractions in GAS_COMP and I5/I5 data from ISO6976, which corresponds to a base temperature of 15 °C and base pressure of 0.101325 kPa.

2.4.2 Totalization Parameters

The block accumulates base volumetric flow each scan into two parameters, CURR_VOLUME (reset by TIMER_ACCUM) and VOL_ACCUM (reset by RESET_ACCUM). CURR_VOLUME is intended for daily or shift totals.

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VOL_ACCUM is intended for ad hoc totals to monitor short-term contract usage. The block accumulates energy flow in CURR_ENERGY and flow hours in CURR_HRS_ON. *Flow hours* is the number of hours of flow through the pipe where VOL_FLW_B is greater than zero.

The reset parameter TIMER_ACCUM is intended to be wired from OUT_D of a Date Time Event (DTE) function block, which allows resetting at regular intervals. When TIMER_ACCUM is 0, the block allows the accumulation of CURR_VOLUME, CURR_ENERGY, and CURR_HRS_ON. When greater than 0, the block copies the three CURR_ parameters to the three LAST_ parameters and resets the CURR_ parameters. CURR implies today or this shift or whatever the current period represents.

If the *Restore parameter values after restart* checkbox is selected in the module properties dialog, all of the accumulation parameters retain their current value during a module (partial) download and a controller restart. The accumulation parameters have status (see [Status Handling](#)).

2.4.3 Status Handling - AGA_SI Function Block

The block determines the status of the output parameters and the internal accumulation parameters.

The status of the output parameters is a function of the status of the input parameters and the value of ERROR_STATE.

When ERROR_STATE is other than *Clear*, it impacts the status of output parameters. The error states include:

- **Gas Composition Sum Not 100%** - The sum of the mole percents in GAS_COMP does not equal 100.00 and AGA8_OPT is *Calculate AGA-8 parameters using Detail Method*. Contributes to Bad status on the output parameters.
- **Invalid Pipe or Orifice Size** – Actual beta ratio is less than 0.1 or greater than 0.75, or orifice ID is less than 11.43 mm, or pipe ID is less than 48.26 mm. Applicable when METER_TYPE is *Differential Pressure*. Contributes to Uncertain status on the output parameters.
- **Reynolds Number Out of Range** – Calculated pipe Reynolds number is less than 4000. Applicable when METER_TYPE is *Differential Pressure*. Contributes to Uncertain status on the output parameters.
- **AGA-8 Algo Not Convergent** – The required iterations exceeded ITERATE_LIM8, thus the AGA8 algorithm did not converge. Applicable when AGA8_OPT is *Calculate AGA-8 parameters using Detail Method*. Contributes to Bad status on the output parameters (does not affect VOL_FLW_F when METER_TYPE is Turbine).
- **AGA-3 Algo Not Convergent** – The required iterations exceeded ITERATE_LIM3, thus the AGA3 algorithm did not converge. Contributes to Bad status on the output parameters.

The status of the output parameters is set to the worst of the status of the input parameters and the status based on ERROR_STATE.

The status of the accumulation parameters is Good until a value accumulated has Bad or Uncertain status. At that point the accumulation parameter has Uncertain status until it is reset.

There is a corresponding PCT_ parameter for each accumulation parameter. For example, CURR_VOLUME has PCT_CURR_VOLUME. The PCT_ parameter contains the percentage of the total in the corresponding parameter where the value being accumulated had Good status.

2.5 Splitter Function Block

The Splitter (SPLTR) function block takes a single input and calculates two outputs based on specified coordinate values. This allows an integrating controller to drive two outputs without winding up when either or both outputs are constrained.

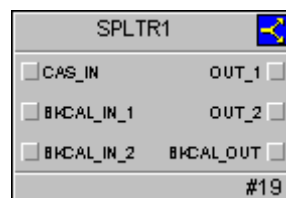
The Splitter function block supports mode control and signal status propagation. There are no standard alarms in this function block. Custom alarms are supported.

The transfer function for each output is a straight slope described by its endpoints. The control regions defined by the slopes can be separate or can overlap, but the low input limit is determined by the first output (OUT_1) and the high input limit is determined by the second output (OUT_2).

The block's normal mode is Cascade (Cas). You can isolate the block for testing by using Automatic (Auto) mode and adjusting the setpoint. Manual (Man) is not a permitted mode.

When a block attached to an output requests initialization, one of the following actions might occur:

- When the other output is not in Cas mode, the block attached to the input is initialized.
- When the other output is in Cas mode, this output returns to the value calculated from its slope in a specified time period.



CAS_IN is the remote setpoint from another block.

BKCAL_IN_1 is the value and status reflecting the BKCAL_OUT of the lower block associated with OUT_1. It is used for initialization and to prevent windup in upstream blocks.

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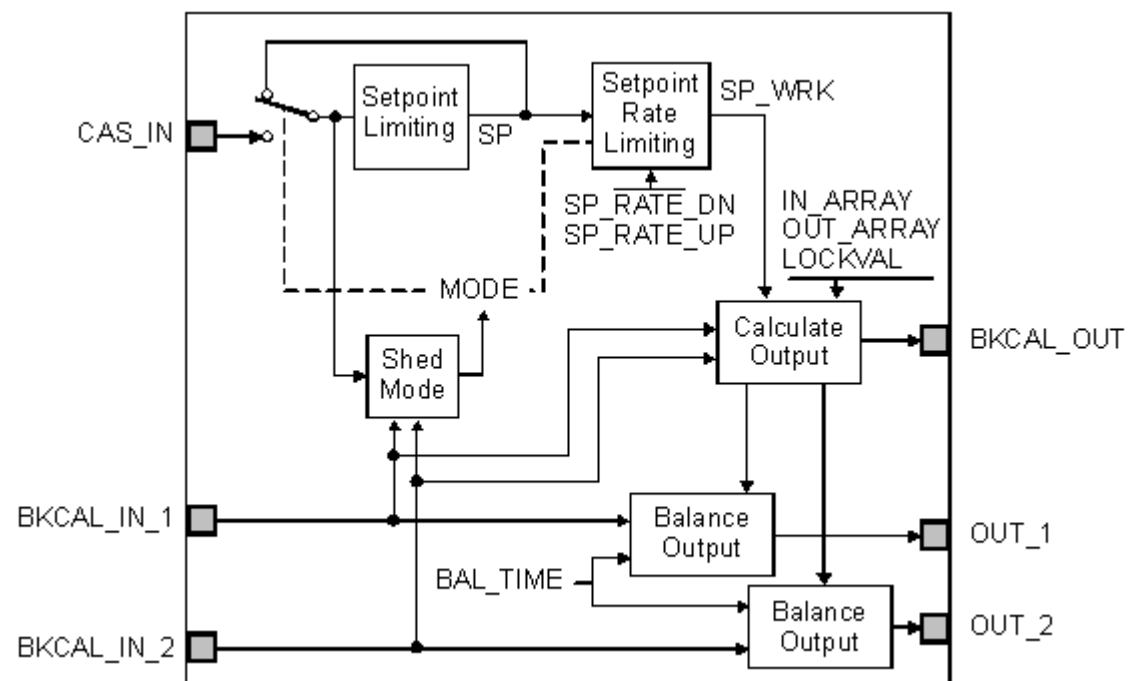
BKCAL_IN_2 is the value and status reflecting the BKCAL_OUT of the lower block associated with OUT_2. It is used for initialization and to prevent windup in upstream blocks.

OUT_1 is the first output value and status.

OUT_2 is the second output value and status.

BKCAL_OUT is the value and status required by the BKCAL_IN input of the upstream block to prevent reset windup and to provide bumpless transfer to closed loop control.

The following figure shows the internal components of the Splitter function block:



You select how the outputs are calculated with parameter configuration. The inputs wired to the block determine the outputs.

2.5.1 Calculating Outputs

The block outputs (OUT_1 and OUT_2) are calculated from the block setpoint (SP) using the slope and limits established by the IN_ARRAY and OUT_ARRAY parameters. The four values of the IN_ARRAY determine the SP range used to calculate outputs based on the four values of the OUT_ARRAY output range. The following table illustrates the relationship between the block outputs and the array elements:

Block Output	IN_ARRAY Element		OUT_ARRAY Element	
	Starting SP Value	Ending SP Value	Output Value for Starting SP Value	Output Value for Ending SP Value
OUT_1	X11	X12	Y11	Y12
OUT_2	X21	X22	Y21	Y22

Some constraints are enforced by the controller to guarantee useful output values:

- X12 must be greater than X11
- X22 must be greater than X21
- X21 must be greater than or equal to X11

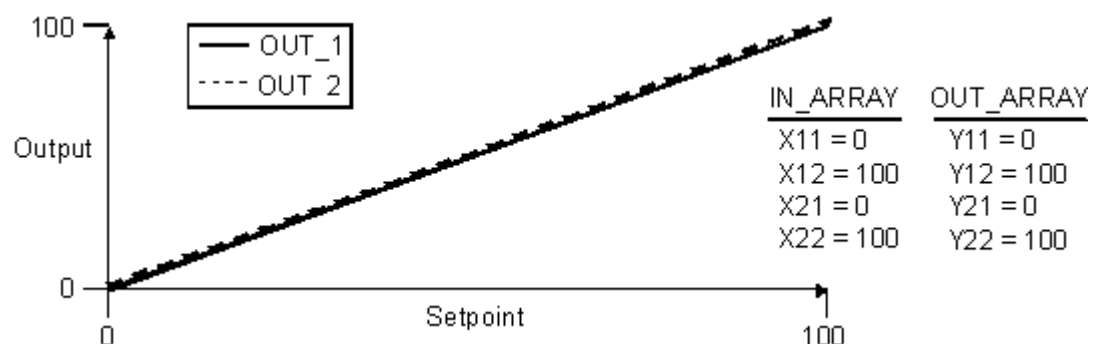
Violation of any of these constraints locks the block into OOS mode and sets the BLOCK_ERR parameter to Configuration Error.

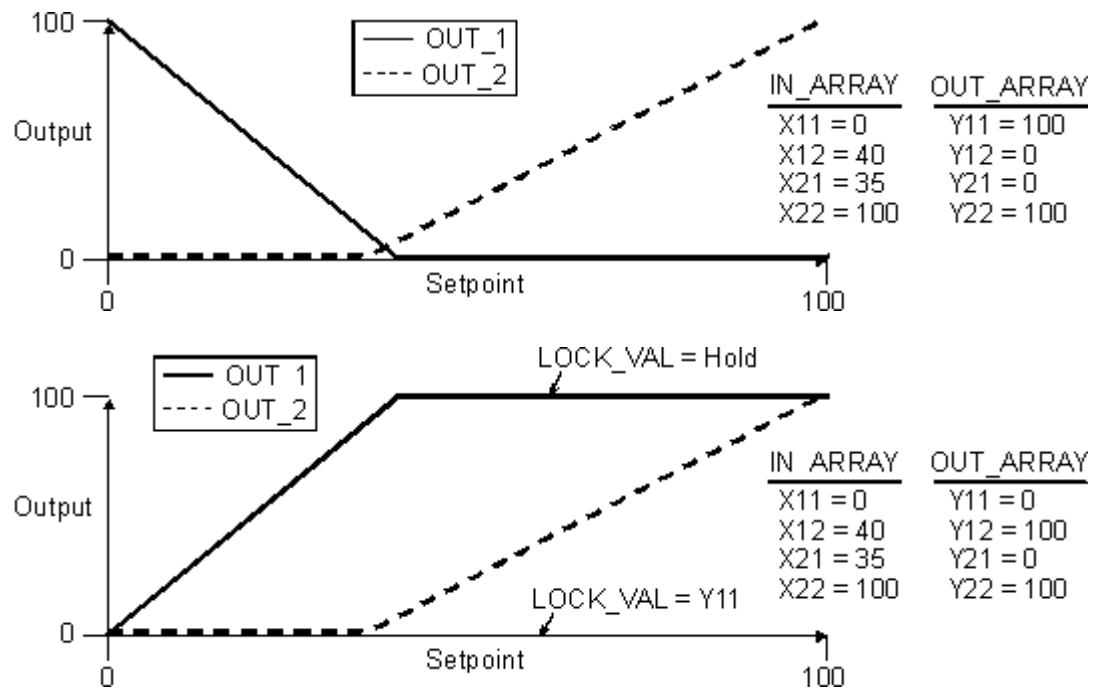
The OUT_1 parameter is set to Y11 when the SP value exceeds X12 when the LOCKVAL parameter is defined as follows:

OUT_1 is Y11 when $SP > X12$

Hysteresis equal to five percent of the X11-to-X12 span is used to prevent OUT_1 from jumping between Y11 and Y12 at X12.

The following figure shows the output values for three examples of IN_ARRAY and OUT_ARRAY elements:

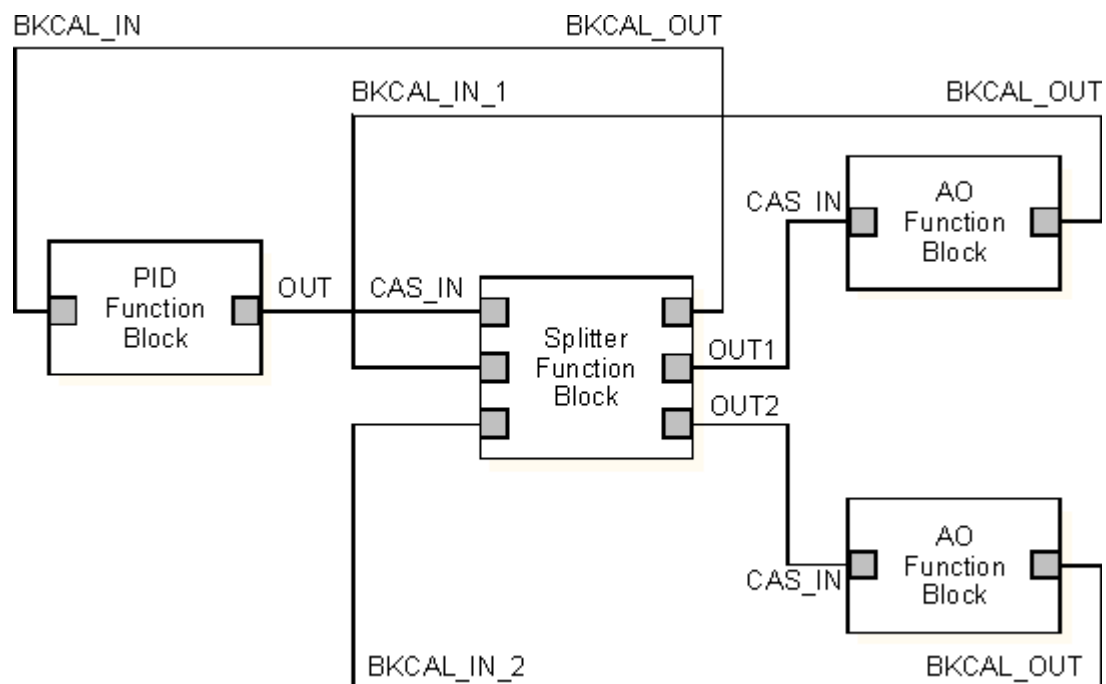




Splitter Function Block Execution Example

2.5.2 Application Information

You can use the Splitter function block to regulate multiple control loops or outputs. The following figure shows a function block diagram example when the output from a PID function block is split into two signals that are sent to Analog Output (AO) function blocks:



The following examples illustrate typical uses for the Splitter function block.

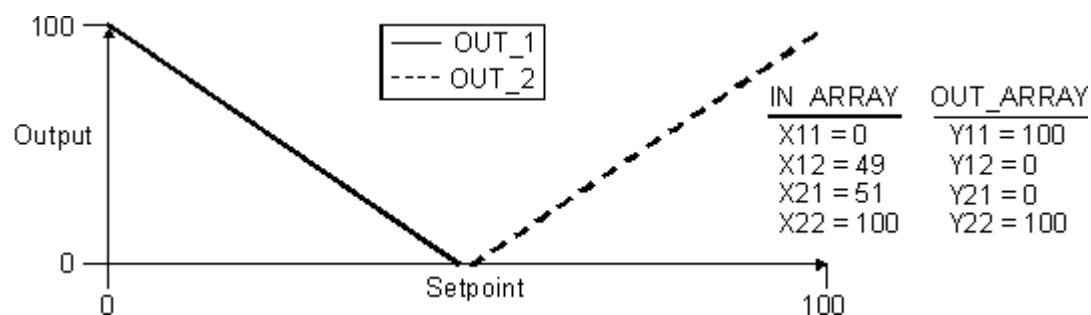
2.5.2.1 Application Example: Split Range Control

Assume two valves (one for heating and one for cooling) are driven by a single temperature controller. You use the Splitter function block between the controller and two Analog Output (AO) function blocks. When the controller requires heat, the AO block action for the cooling valve does not matter. When the AO block for the heating valve goes to Bad status, the controller is prevented from calling for more heat, but is allowed to call for cooling if required. For this example, you can set up the splitter characterization in the following manner:

Splitter Function Block Split Range Control Example Settings

Parameter	Setting
IN_ARRAY[1][1]	0
IN_ARRAY[2][1]	49
IN_ARRAY[3][1]	51
IN_ARRAY[4][1]	100
LOCKVAL	Hold
OUT_ARRAY[1][1]	100
OUT_ARRAY[2][1]	0
OUT_ARRAY[3][1]	0
OUT_ARRAY[4][1]	100

This allows the controller to call for maximum cooling (negative heat) at 0 output and maximum heat at 100 output, with a gap of 2 around 50 to make sure that the heating and cooling valves are not both open at the same time. The following figure graphically represents the settings for this example:



2.5.2.2 Application Example: Sequencing Control

Assume you must use two valves for control because one valve does not provide enough range for a nonlinear control problem, such as pH control. The small valve controls an expensive reagent in the pH region near neutral; therefore, it must be

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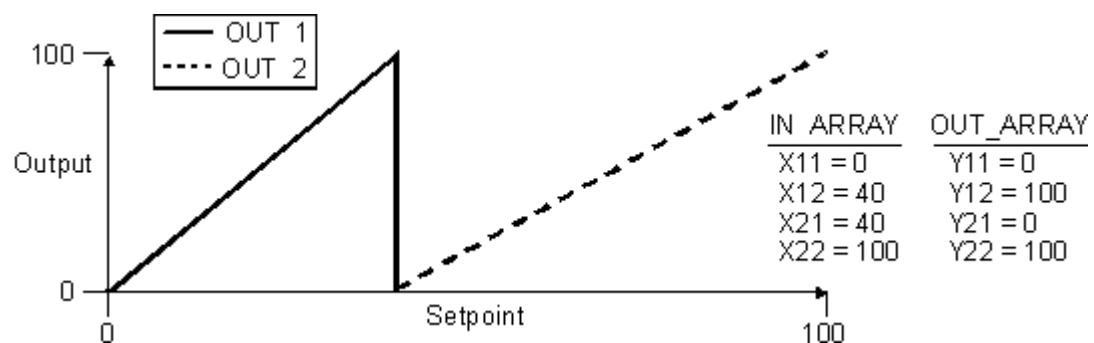
closed when the pH is away from neutral. The big valve adds caustic, which is too strong to use near a neutral pH.

You can use the Splitter function block between the controller and two Analog Output (AO) blocks. As in the preceding example, one AO block can have Bad status without disturbing control when it is not the block required by the pH controller. For this example, you can set up the splitter characterization in the following manner:

Splitter Function Block Sequencing Control Example Settings

Parameter	Setting
IN_ARRAY[1][1]	0
IN_ARRAY[2][1]	40
IN_ARRAY[3][1]	40
IN_ARRAY[4][1]	100
LOCKVAL	OUT_ARRAY[1][1]
OUT_ARRAY[1][1]	0
OUT_ARRAY[2][1]	100
OUT_ARRAY[3][1]	0
OUT_ARRAY[4][1]	100

The following figure graphically represents the settings for this example:



Splitter Function Block Sequencing Control Example

2.5.2.3 Application Example: Cascade Fan-out

The cascade fan-out scheme is used when a cascade control strategy includes multiple secondary controllers. For example, assume a header pressure controller interacts with two secondary boiler controllers. You use the Splitter function block between the pressure controller and the two boiler master controllers. Header

pressure control is maintained when one or both secondary Bias/Gain blocks are in Auto mode. When both secondary blocks are not in Auto mode, the pressure controller output is frozen and initializes to balance the first secondary block that is put into Auto mode.

For this example, you can set up the splitter characterization in the following manner:

Splitter Function Block Cascade Fan-out Example Settings

Parameter	Setting
IN_ARRAY[1][1]	0
IN_ARRAY[2][1]	100
IN_ARRAY[3][1]	0
IN_ARRAY[4][1]	100
LOCKVAL	Hold
OUT_ARRAY[1][1]	0
OUT_ARRAY[2][1]	100
OUT_ARRAY[3][1]	0
OUT_ARRAY[4][1]	100
BAL_TIME	Four times the pressure controller integral time

2.6 Analog Input (AI) Function Block

The Analog Input (AI) function block accesses a single analog measurement value and status from an I/O channel. You can configure the channel type for each I/O channel to be the transmitter's 4 to 20 mA signal or the digitally communicated primary or non-primary variable from a HART transmitter.

The AI function block supports block alarming, signal scaling, signal filtering, signal status calculation, mode control, and simulation.

In Automatic mode, the block's output parameter (OUT) reflects the process variable (PV) value and status. In Manual mode, OUT can be set manually.

To support testing, you can enable simulation. This allows the measurement value and status to be supplied manually or from another block through the SIMULATE_IN input.

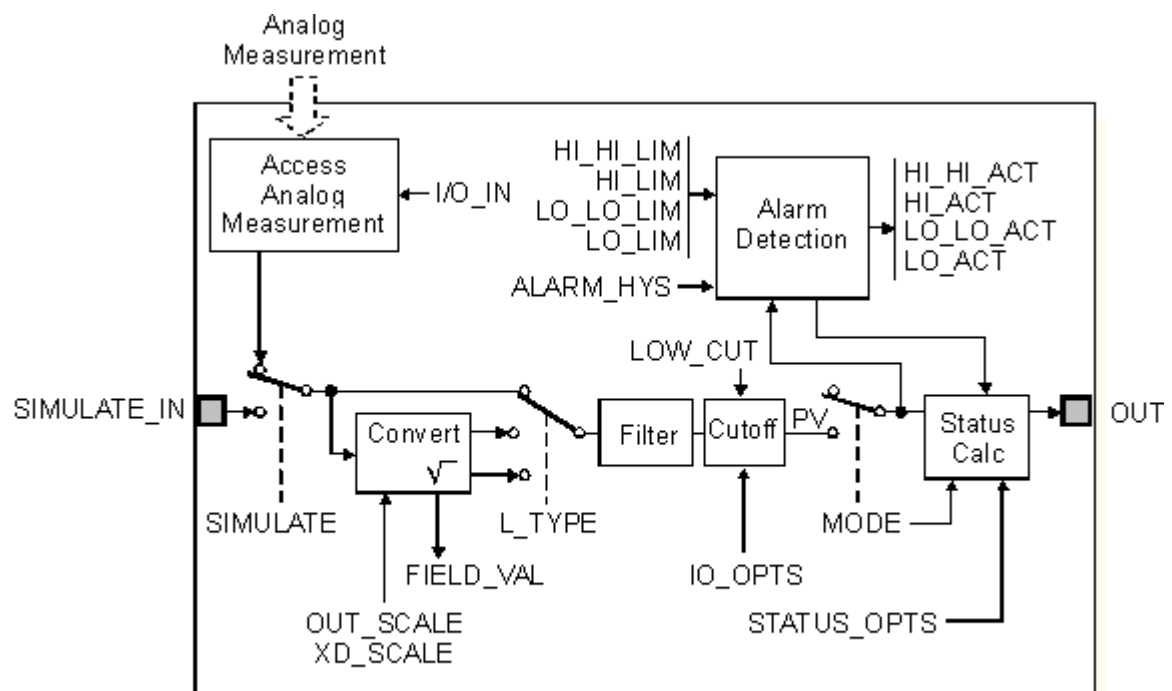
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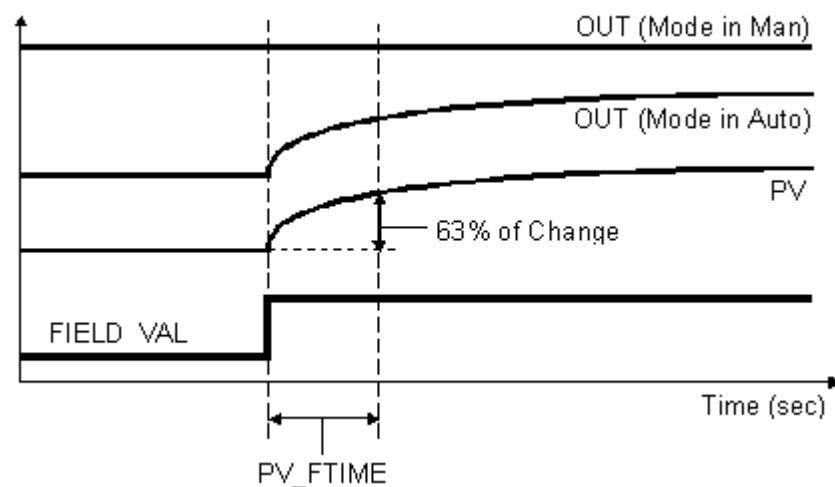
SIMULATE_IN is the simulated value from another block that is used by the Analog Input function block when simulation is enabled.

OUT is the block output value and status.

The following diagram shows the internal components of the Analog Input function block. The parameters may vary slightly for extended blocks.



The following diagram shows the timed response of the Analog Input function block:



You select the manner of processing the analog measurement value by configuring the I/O selection, signal conversion, and filtering parameters.

2.7. Analog Output (AO) Function Block

The Analog Output (AO) function block assigns an output value to a field device through a specified I/O channel. The block supports mode control, signal status calculation, and simulation.

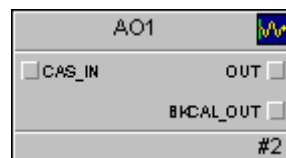
In Manual mode, the value of the output parameter (OUT) is set manually.

In Automatic mode, OUT is set automatically based on the value specified by the setpoint (SP) in engineering units and the I/O options parameter (IO_OPTS). In addition, you can limit the SP value and the rate at which a change in the SP is passed to OUT.

In Cascade mode, the cascade input connection (CAS_IN) is used to update the SP. The back calculation output (BKCAL_OUT) is wired to the back calculation input (BKCAL_IN) of the upstream block that provides CAS_IN. This provides bumpless transfer on mode changes and windup protection in the upstream block. The OUT parameter or an analog read-back value, such as valve position, is shown by the process value (PV) parameter in engineering units.

To support testing, you can enable simulation. This allows the channel feedback to be set manually.

There are no standard alarms in the Analog Output function block. Custom alarms are supported in this function block.



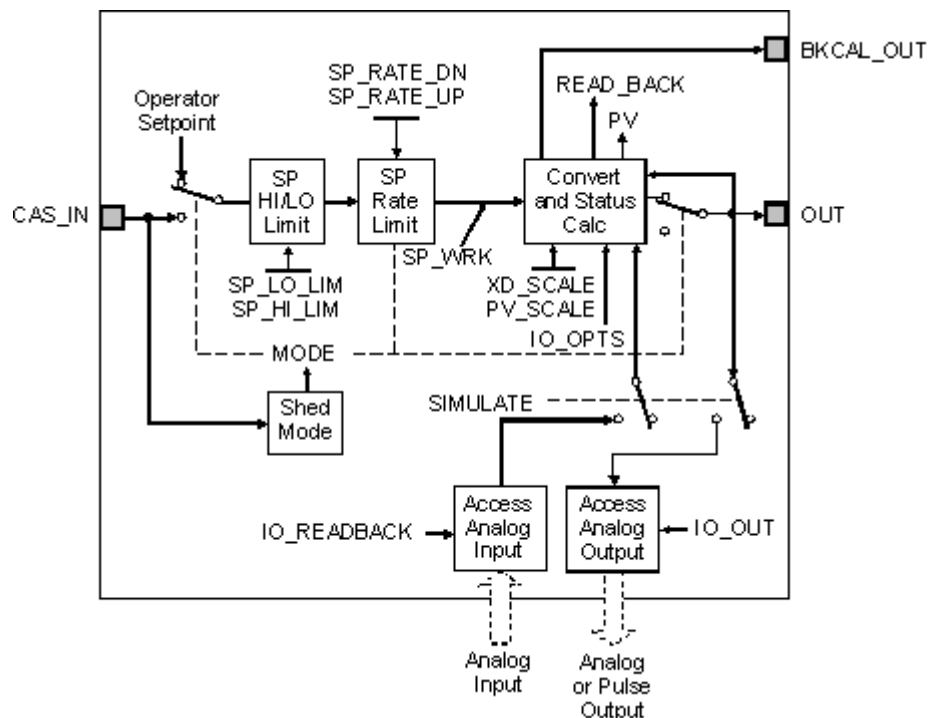
CAS_IN is the remote setpoint value from another function block.

BKCAL_OUT is the value and status required by the BKCAL_IN input of another block to prevent reset windup and to provide bumpless transfer to closed loop control.

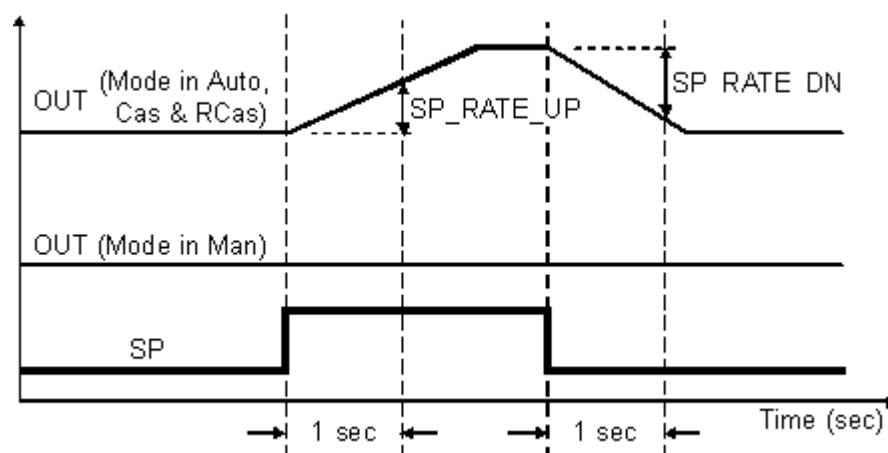
OUT is the block output and status.

The following diagram shows the internal components of the Analog Output function block. The parameters may vary slightly for extended blocks.

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The following diagram shows the timed response of the Analog Output function block.

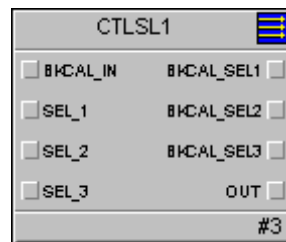


You select the manner of processing the SP and the channel output value by configuring setpoint limiting options, tracking options, and conversion and status calculations.

2.8. Control Selector Function Block

The Control Selector (CTLSEL) function block selects one of three control signals to perform override control to a PID function block. The block supports mode control. The outputs are calculated based on the actual operation mode, which is determined by parameter values and input value statuses.

There are no standard alarms in this function block. Custom alarms are supported.



BKCAL_IN is the analog input value and status from a downstream block's BKCAL_OUT output that is used for backward output tracking for bumpless transfer.

SEL_1 is the first input value to the selector.

SEL_2 is the second input value to the selector.

SEL_3 is the third input value to the selector.

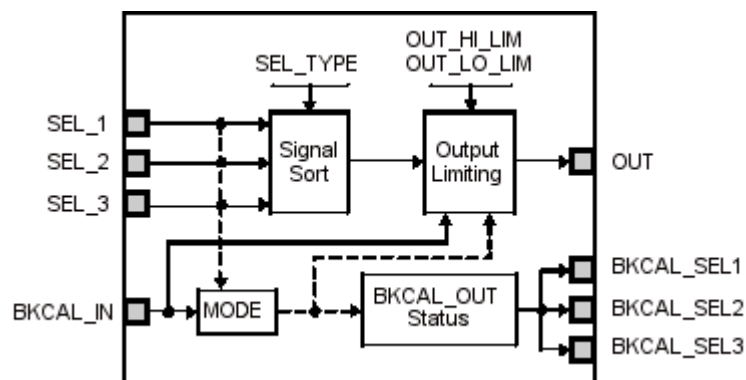
BKCAL_SEL1 is the selector output value associated with SEL_1 for backward output tracking to an upstream PID function block.

BKCAL_SEL2 is the selector output value associated with SEL_2 for backward output tracking to an upstream PID function block.

BKCAL_SEL3 is the selector output value associated with SEL_3 for backward output tracking to an upstream PID function block.

OUT is the output value and status.

The following diagram shows the internal components of the Control Selector function block:



The Control Selector function block picks the high, low, or middle control signal from two or three PID function block primary outputs and places it at the Control Selector block's primary output. Three back calculation outputs are sent to upstream PID function blocks.

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At the beginning of each scan period, the block calculates the actual mode according to the input status, target mode, and configured parameter settings. The block steps into the calculated actual mode or stays in the original mode.

Next, the block calculates the forward path primary output:

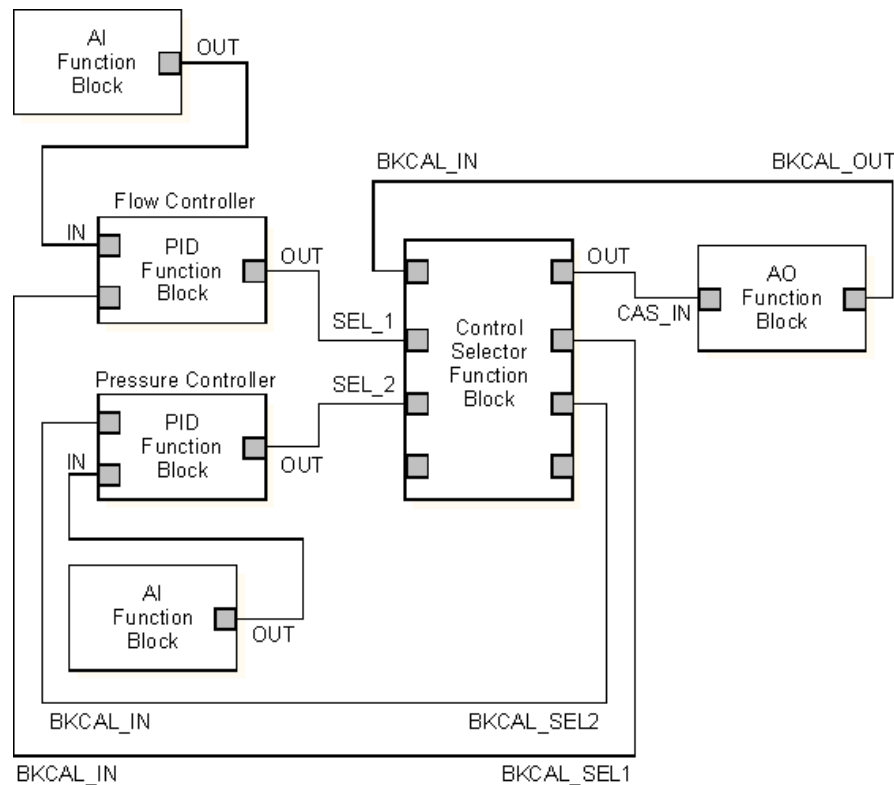
- In Initialization Manual (IMan) mode, the primary output is unchanged. The BKCAL_SEL1, BKCAL_SEL2, and BKCAL_SEL3 parameter values are passed to the upstream function blocks.
- In Manual (Man) mode, OUT can be set manually.
- In Automatic (Auto) mode, the block selects SEL_1, SEL_2, or SEL_3 as the primary output based on the selection type parameter (SEL_TYPE). The output value is sent back to all the upstream blocks.

Note In Auto mode, when any of the connected SEL_1, SEL_2 or SEL_3 inputs have Bad status during block execution, the block transitions its actual mode to Man. When the Bad SEL_1, SEL_2 or SEL_3 input transitions back to Good status, the block resumes Auto operation.

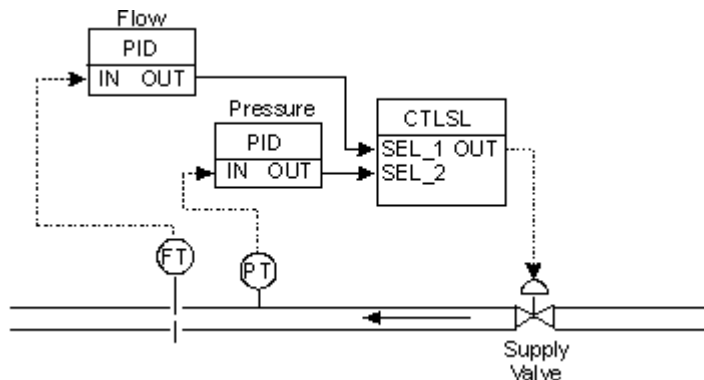
All the output parameter status values are set to indicate the status of the block and the status of the corresponding parameter.

2.8.1 Application Information

The Control Selector function block is ideal for providing automatic override control. This function block can take three control signals as input. The user can select SEL_TYPE = Low, Medium, or High for various control configurations.



Use the Control Selector function block in a situation where flow is the primary control variable but pressure must be controlled in the event that it rises to a dangerous level. The following figure illustrates this example:



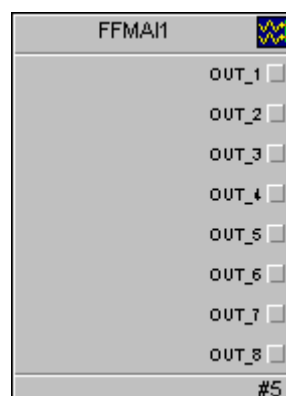
In this example, both the flow and pressure PID blocks control a supply valve. The flow PID operates in a pressure regime below a safety limit. Since this is a low pressure for the pressure PID, it sends a high output signal to the supply valve, telling it to open more to increase the pressure.

At normal operating pressures, the pressure PID's high SP requests a maximum valve opening to increase pressure. The flow PID's signal is lower than that of the pressure PID. In this case, SEL_TYPE is set to Low so that the Control Selector function block sends the flow PID's signal on to the supply valve and blocks the pressure PID's signal.

If the flow stream's pressure rises to a dangerous level, the pressure PID sends a low signal to the supply valve, telling it to close. When this output signal falls below that from the flow PID, the Control Selector function block begins to pass the pressure PID's signal and block the flow PID's signal.

2.9. Fieldbus Multiplexed Analog Input Function Block

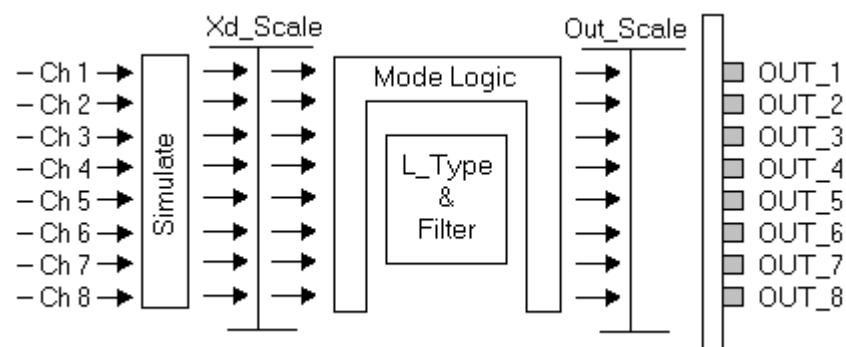
The MAI function block can process up to eight fieldbus device measurements from a single device. This function block is for fieldbus applications where the sensor types are the same. The MAI block can optimize the communications on an H1 segment by providing all of the information for up to 8 measurements in a single function block.



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Note that the MAI block uses many of the same parameters to support all eight inputs. One consequence of this is that the RTD's or thermocouples connected to an MAI block must all have the same range. In a similar way, the simulation value and mode handling applies to all outputs as well. The MAI block is ideal for higher density fieldbus transmitters, such as the Rosemount Model 848T transmitter.

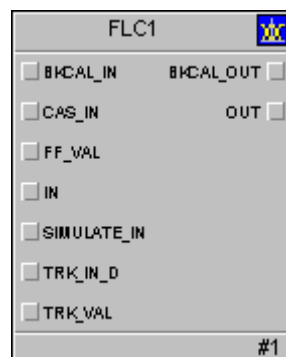
The following diagram shows the internal components of the Multiplexed Analog Input function block:



2.10. Fuzzy Logic Control (FLC) Function Block

The Fuzzy Logic Control (FLC) function block provides the control capability of the PID block with the added benefit of superior response for both setpoint changes and external load disturbances. By using fuzzy logic, the FLC function block minimizes overshoot and provides good load disturbance rejection. The scaling factors of the FLC function block can be automatically established using Tune with InSight.

The FLC function block operates by using predefined fuzzy rules, membership functions, and adjustable parameters known as scaling factors. The FLC function block translates the loop's absolute values into fuzzy values by calculating the scaled error (e) and scaled change in error (Δe) in addition to the degree of membership in each of the predefined membership functions. It then applies the fuzzy rules and, finally, retranslates the values into a control move.



This function block supports mode control, signal scaling and limiting, feedforward control, override tracking, alarm limit detection, and signal status propagation.

This block supports conditional alarming. Enabling conditional alarming makes additional parameters available for this block. For more information about conditional alarming and for a description of the additional parameters, refer to the topic Conditional Alarming.

In Cascade (Cas) mode, the setpoint (SP) is adjusted by a master controller. In Remote Cascade mode (RCas), the setpoint is written by an application. In Automatic (Auto) mode, the SP can be adjusted by the operator. In RCas, Cas and Auto modes, the output is calculated to maintain setpoint. In Manual (Man) mode, the block's output is set by the operator. In Remote Output (ROut) mode, the block's output is written by an application.

The FLC function block can be connected directly to process I/O, can receive its input from another block at the input connection (IN), or can provide an output value to another block through the output connection (OUT).

You can connect BKCAL_OUT to a master controller and BKCAL_IN to a slave controller to compensate for downstream limits and to provide bumpless transfer to closed loop control.

You connect the tracking inputs (TRK_IN_D and TRK_VAL) for externally controlled output tracking.

BKCAL_IN is the analog input value and status from another block's BKCAL_OUT output that is used for backward output tracking for bumpless transfer and to pass limit status.

CAS_IN is the remote setpoint (SP) value from another block.

FF_VAL is the feedforward control input value and status.

IN is the connection for the process variable (PV) from another function block.

SIMULATE_IN is the input value and status used by the block instead of the analog measurement when simulation is enabled.

TRK_IN_D initiates the external tracking function.

TRK_VAL is the value after scaling applied to OUT in Local Override mode.

BKCAL_OUT is the value and status required by the BKCAL_IN input of another block to compensate for downstream limits and to provide bumpless transfer to closed loop control.

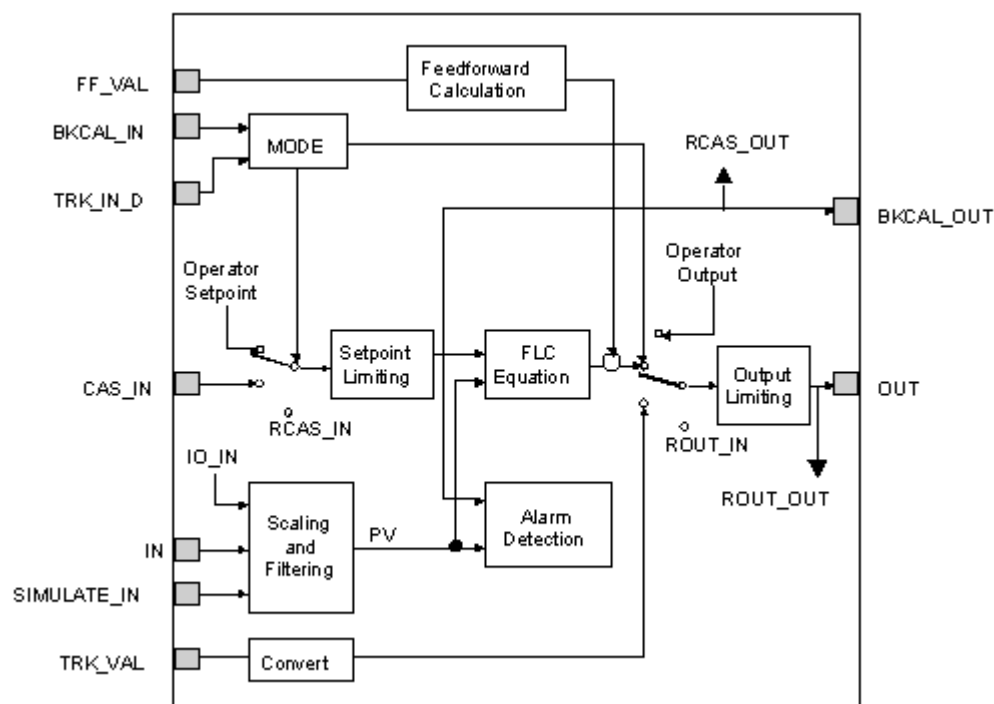
OUT is the block output value and status.

2.10.1 Other FLC Function Block Features

Many of the following features of the FLC function block are identical to those provided for the PID function block.

- alarm detection
- status handling
- I/O Selection
- simulation
- signal Conversion
- filtering
- feedforward Calculation
- tracking
- setpoint selection and limiting
- output selection and limiting
- bumpless transfer and setpoint tracking
- reverse and direct action
- block errors

The following diagram shows the internal components of the Fuzzy Logic Control function block:



Fuzzy Logic Control Function Block Schematic Diagram

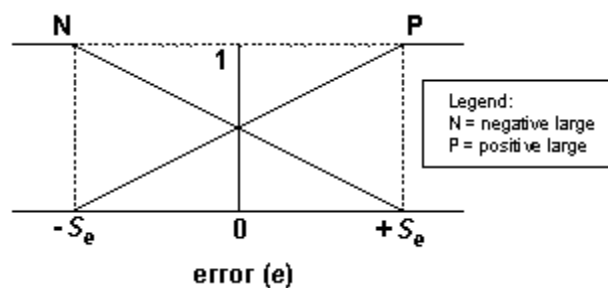
The nonlinearity built into the FLC function block reduces overshoot and settling time, achieving tighter control of the process loop. Specifically, the FLC function block treats small control errors differently from large control errors and penalizes large overshoots more severely. It also severely penalizes large changes in the error, helping to reduce oscillation.

This section describes how the Fuzzy Logic Control block functions.

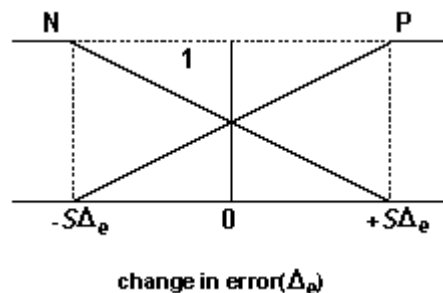
Two Membership Functions

The FLC function block uses two membership functions: the input signals are error and change in error, and the output signal is the change in control action. The relations among these three variables represent a nonlinear controller. The nonlinearity results from a translation of process variables to a fuzzy set (fuzzification), rule inference, and retranslation of a fuzzy set to a continuous signal (defuzzification).

The two membership functions for error, change in error and change in output are **negative** and **positive**. The membership scaling (S_e and $S_{\Delta e}$) and the error value and change in error, respectively, determine the degree of membership.

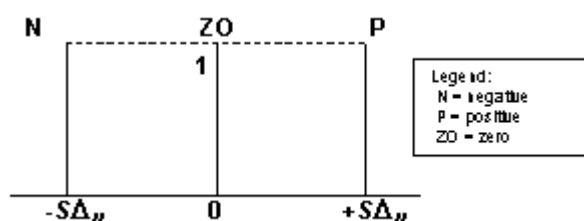


Error Membership Functions



Change in Error Membership Functions

The change in output membership functions are called **singletons**. They represent fuzzy sets whose support is a single point with a membership function of one. The membership scaling ($S_{\Delta u}$) determines the magnitude of output change for a given error and change in error.



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Change in Output Singleton Membership Functions

Four Fuzzy Logic Rules

There are four fuzzy logic rules that the FLC function block uses for a reverse acting controller.

DeltaV Fuzzy Logic Rules

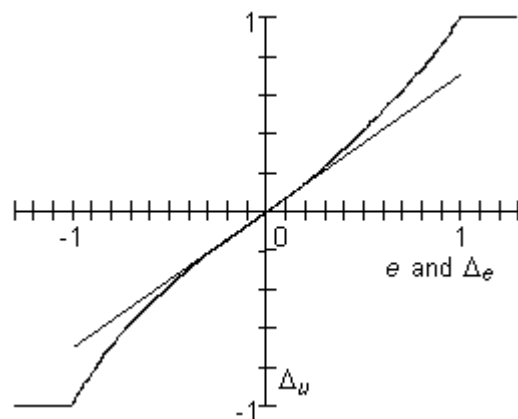
Number	Rule
Rule 1	If error is N and change in error is N, make change in output P.
Rule 2	If error is N and change in error is P, make change in output ZO.
Rule 3	If error is P and change in error is N, make change in output ZO.
Rule 4	If error is P and change in error is P, make change in output N.

Refer to the [Fuzzy Logic Evaluation](#) topic for an explanation and example of how the fuzzy membership functions and rules are used in fuzzy logic evaluation.

Fuzzy Logic Control Nonlinear PI Relationship

The two membership functions associated with each input variable and three membership functions for the output variable makes the FLC function block nonlinear in its response.

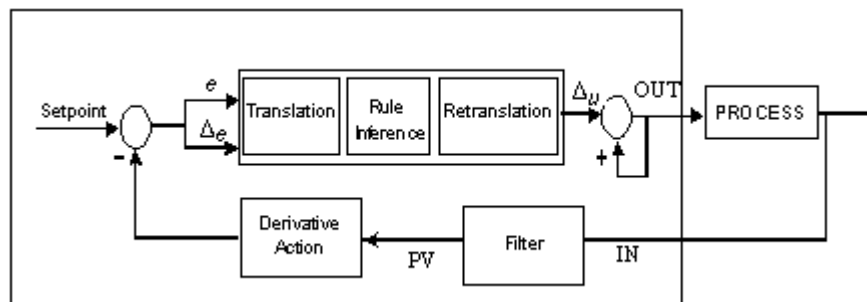
For regions where the absolute error is greater than the error scaling factor or the absolute change in error is greater than the change in error scaling factor, the values for error and change in error are clipped at the error scaling factor and change in error scaling factor, respectively. The following figure shows an example FLC curve that illustrates how the change in controller gain is smooth and continuous using only two input membership functions and three output membership functions.



FLC Function Block's Nonlinear Relationship

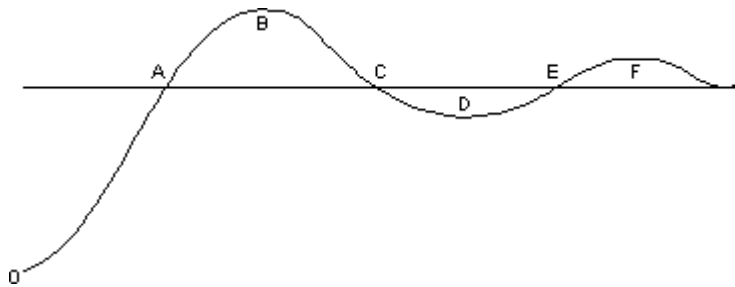
The dark line shows the FLC function block's nonlinear relationship when the error is equal to the change in error. The straight line through the origin shows the linear relationship of a standard PI controller. As the error and change in error increase, the change in output of a standard PI controller increases linearly. Note that the gain of the FLC function block is similar to the gain of the PI controller when the error and change in error are small. The gain of the FLC function block increases gradually as the error and change in error increase.

The nonlinearity built into the FLC function block reduces overshoot and settling time, achieving tighter control of the process loop. To help anticipate a rapid change in the process with the FLC function block, derivative action is provided in the feedback path of the loop, as shown in the following figure.



Fuzzy Logic Control with Derivative Action

The FLC function block treats small control errors differently from large control errors and penalizes large overshoots more severely. It also severely penalizes large changes in the error, helping to reduce the oscillation.



Process Variable Oscillation Example

The above figure depicts how an FLC function block reacts to overshoot and oscillation. At points B, D, and F, where overshoot occurs, the FLC function block applies stronger control actions to bring the variable back to the setpoint. At points A, C, and E, where large changes in error occur and are dominant, the FLC function block applies stronger corrective actions to reduce oscillation.

This type of nonlinearity allows the FLC function block to provide better control performance than standard PID control.

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Establishing Scaling Factors

Tune can be used to establish the scaling factors (S_e , S_{Δ_e} , and S_{Δ_u}). For a small control error and setpoint change less than a nominal value (ΔY_{sp}), the FLC function block scaling factors are related to the proportional gain (Kp) and reset (Ti), which would be used in a PI block executing at a one (1) second scan rate (Δt) to control the same process. Refer to the following equations:

$$S_{\Delta_e} = \beta \Delta Y_{sp}$$

$$S_{\Delta_u} = 2 S_{\Delta_e} K_p$$

$$S_e = S_{e0} = T_i S_{\Delta_e}$$

where:

S_{Δ_e} = change of error scaling

S_e = error scaling

S_{Δ_u} = change of controller output scaling

S_{e0} = error scaling for a one (1) second scan rate

Beta is a function of process deadtime (DT) and ultimate period or time constant (TC) and has values in the following range:

$$.2 < \beta < .5$$

The approximate formula for calculating beta is as follows:

$$\beta = .2 + \frac{DT}{TC}$$

The Fuzzy Logic Control function block accounts for the scan rate and recalculates the error scaling factor (S_e), which depends on the scan rate appropriate to the function block scan (Δt).

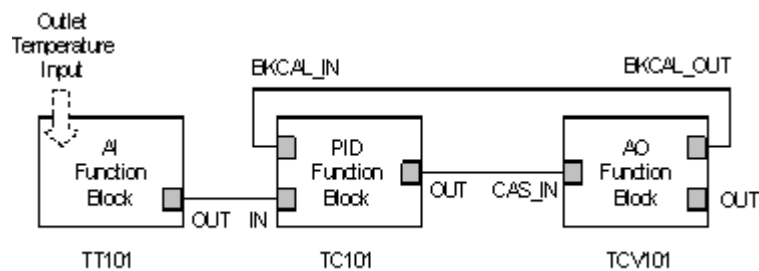
$$S_e = \frac{S_{e0}}{\Delta t} = \frac{T_i S_{\Delta_e}}{\Delta t}$$

The Fuzzy Logic Control function block is designed to be set up by Tune. However, if you choose to set up scaling factors manually, it is important to note that, in such a case, Tune will **not** set up derivative time for the FLC block, and you will **not** have manual access to the derivative term. In such a situation, the FLC block, effectively, becomes the PI controller. This can affect block performance significantly.

2.10.2 Application Information

The Fuzzy Logic Control function block is designed for use in any situation where you need less oscillation and overshoot than is possible with the PID block. Therefore, you can use the FLC function block in any continuous process with significant disturbances or nonlinearities. For example, use the FLC function block to minimize overshoot when fast response to a setpoint or load disturbance is required.

To implement an FLC function block, replace the existing PID with the FLC function block in your control strategy. For example, the blocks and connections required for a single loop using PID and using FLC are shown below:



Valve Selection **and Sizing**

Valve Selection and Sizing

Module Outcome: Upon successful completion of this learning outcome guide, you will be able to select and size the control valve

Learning Objectives: To successfully complete this learning outcome guide you should be able to:

1. To practice valve selection procedure
2. To practice the sizing calculations

Let's have some Fun

يوميات عتريس و مرآة (الحلقة السابعة)

حلم عتريس بالأمس ان زوجة ماتت فى حادث قطار . ساعده على وضع الأسس التى يمكنه بها اختيار الزوجة الجديدة من بين النساء التى أعجب بهم وكانت زوجته تقف حائلا بينه و بينهم مع مراعاة الاختيار المناسب للمقاس

Pre-Assessment

1. Define the parameters affecting the valve size in liquid operation
2. Define the parameters affecting the valve size in gas operation
3. List the factors of the valve selection

Objective 1: Control Valve Selection

Control valves handle all kinds of fluids at temperatures from the cryogenic range to well over 1000°F (538°C). Selection of a control valve body assembly requires particular consideration to provide the best available combination of valve body style, material, and trim construction design for the intended service. Capacity requirements and system operating pressure ranges also must be considered in selecting a control valve to ensure satisfactory operation without undue initial expense.

Reputable control valve manufacturers and their representatives are dedicated to helping select the control valve most appropriate for the existing service conditions. Because there are frequently several possible correct choices for an application, it is important that all the following information be provided:

- ★ Type of fluid to be controlled
- ★ Temperature of fluid
- ★ Viscosity of fluid
- ★ Specific gravity of fluid
- ★ Flow capacity required (maximum and minimum)

- ★ Inlet pressure at valve (maximum and minimum)
- ★ Outlet pressure (maximum and minimum)
- ★ Pressure drop during normal flowing conditions
- ★ Pressure drop at shutoff
- ★ Maximum permissible noise level, if pertinent, and the measurement reference point
- ★ Degrees of superheat or existence of flashing, if known
- ★ Inlet and outlet pipeline size and schedule
- ★ Special tagging information required
- ★ Body Material (ASTM A216 grade WCC, ASTM A217 grade WC9, ASTM A351 CF8M, etc.)
- ★ End connections and valve rating (screwed, Class 600 RF flanged, Class 1500 RTJ flanges, etc.)
- ★ Action desired on air failure (valve to open, close, or retain last controlled position)
- ★ Instrument air supply available
- ★ Instrument signal (3 to 15 psig, 4 to 20 mA, Hart, etc.)

In addition the following information will require the agreement of the user and the manufacturer depending on the purchasing and engineering practices being followed.

- ★ Valve type number
- ★ Valve size
- ★ Valve body construction (angle, double-port, butterfly, etc.)
- ★ Valves plug guiding (cage-style, port-guided, etc.)
- ★ Valve plug action (push down to close or push down to open)
- ★ Port size (full or restricted)
- ★ Valve trim materials required
- ★ Flow action (flow tends to open valve or flow tends to close valve)
- ★ Actuator size required
- ★ Bonnet style (plain, extension, etc.)
- ★ Packing material (PTFE V-ring, laminated graphite, environmental sealing systems, etc.)
- ★ Accessories required (positioner, handwheel, etc.)

Valve Selection and Sizing

Objective 2: Valve Sizing

Definitions and Abbreviations

A) calculations parameters and coefficients

Symbol	Description
C_v	Valve flow coefficient
d	Valve inlet diameter
D	Internal diameter of the pipe
F_d	Valve style modifier
F_F	Liquid critical pressure ratio factor, dimensionless
F_k	Ratio of specific heats factor, dimensionless
F_L	Liquid pressure recovery factor of a valve without attached fittings, dimensionless
F_{LP}	Product of the liquid pressure recovery factor of a valve with attached fittings (no symbol has been identified) and the piping geometry factor, dimensionless
F_P	Piping geometry factor, dimensionless
F_R	Reynolds number factor, dimensionless
F_s	Laminar, or streamline, flow factor, dimensionless
g	Local acceleration of gravity
k	Ratio of specific heats, dimensionless
K	Head loss coefficient of a device, dimensionless
K_B	Bernoulli coefficient, dimensionless
K_i	Velocity head factors for an inlet fitting, dimensionless
$N_1, N_2, \text{etc.}$	Numerical constants for units of measurement used
Re_v	Valve Reynolds number, dimensionless
X	Ratio of pressure drop to absolute inlet pressure ($\Delta P / P_1$), dimensionless
X_T	Pressure drop ratio factor, dimensionless
X_{TP}	Value of X_T for valve-fitting assembly, dimensionless

B) Process conditions

Symbol	Description
G_f	Liquid specific gravity at upstream conditions [ratio of density of liquid at flowing temperature to density of water at 60°F (15.6°C)], dimensionless
G_g	Gas specific gravity (ratio of density of flowing gas to density of air with both at standard conditions, which is equal to the

ratio of the molecular weight of gas to the molecular weight of air), dimensionless

M Molecular weight, atomic mass units

P_1 Upstream absolute static pressure, measured two nominal pipe diameters upstream of valve-fitting assembly

P_2 Downstream absolute static pressure, measured six nominal pipe diameters downstream of valve-fitting assembly

ΔP Pressure differential, $P_1 - P_2$

Note : Critical Point: That state at which the densities of the gas and liquid phase

and all other properties become identical. It is an important correlating parameter

for predicting fluid behavior.

P_c Absolute thermodynamic critical pressure, The pressure at which the critical point occurs.

P_r Reduced pressure, dimensionless

P_v Absolute vapor pressure of liquid at inlet temperature

P_{vc} Apparent absolute pressure at vena contracta

q Volumetric flow rate

q_{max} Maximum flow rate (choked flow conditions) at a given upstream condition

T_r Reduced temperature, dimensionless

T_c Absolute thermodynamic critical temperature The critical-point temperature above which the fluid cannot exist as a liquid.

T_1 Absolute upstream temperature (in degrees K or R)

U_1 Velocity at valve inlet

w Weight or mass flow rate

Y Expansion factor, ratio of flow coefficient for a gas to that for a liquid at the same Reynolds number, dimensionless

Z Compressibility factor, dimensionless The change in volume per unit of volume of a fluid caused by a change in pressure at constant temperature.

γ_1 (gamma) Specific weight, upstream conditions The force (weight/unit area) with which a body at specified conditions is attracted by gravity.

μ Viscosity, absolute The absolute viscosity (μ) is the measure of a fluid's intermolecular cohesive force's resistance to shear per unit of time.

Valve Selection and Sizing

- ν Kinematic viscosity, centistokes A fluid's property that measures the shearing stress that depends on flow velocity, density, area, and temperature. which in turn affects the flow pattern to a meter and hence measurement results.
- ρ Density The density of a quantity of homogenous fluid is the ratio of its mass to its volume. The density varies with temperature and pressure changes, and is therefore generally expressed as mass per unit volume at a specified temperature and pressure.

Subscripts

- 1 Upstream conditions
2 Downstream conditions
s Nonturbulent
t Turbulent

Sizing Valves for Liquids

The sizing of control valves for liquid flow can be performed using the following four steps procedure.

STEP 1: Specify the variables required to size the valve as follows:

- _ Desired valve type: refer to the appropriate valve flow coefficient table.
- _ Process fluid (water, oil, etc.)
- _ Appropriate service conditions q or w , P_1 , P_2 or ΔP , T_1 , G_f , P_v , P_c , and γ_1

STEP 2: Determine F_p , the piping geometry factor.

F_p is a correction factor that accounts for pressure losses due to piping fittings such as reducers, elbows, or tees that might be attached directly to the inlet and outlet connections of the control valve to be sized.

If such fittings are attached to the valve, the F_p factor must be considered in the sizing procedure. If, however, no fittings are attached to the valve, F_p has a value of 1.0 and simply drops out of the sizing equation.

When possible, it is recommended that F_p factors be determined experimentally by using the specified valve in actual tests. The F_p

factors for rotary valves used with reducers have all been determined in this manner, and their values are listed in the flow coefficient tables. For F_p values not listed in the flow coefficient tables, calculate the F_p factor using the following equation.

$$F_p = \left[1 + \frac{SK}{N_2} \left(\frac{C_v}{d^2} \right)^2 \right]^{-1/2}$$

where:

$$N_2 = \begin{matrix} 0.00214 & d, D \text{ in mm} \\ 890 & d, D \text{ in inch} \end{matrix}$$

C_v = Valve sizing coefficient at 100-percent travel

In the above equation, the SK term is the algebraic sum of the velocity head loss coefficients of all of the fittings that are attached to the control valve.

$$SK = K_1 + K_2 + K_{B1} - K_{B2}$$

where,

K_1 = Resistance coefficient of upstream fittings

K_2 = Resistance coefficient of downstream fittings

K_{B1} = Inlet Bernoulli coefficient

K_{B2} = Outlet Bernoulli coefficient

The Bernoulli coefficients, K_{B1} and K_{B2} , are used only when the diameter of the piping approaching the valve is different from the diameter of the piping leaving the valve, whereby:

$$K_{B1} \text{ or } K_{B2} = 1 - \left(\frac{d}{D} \right)^4$$

If the inlet and outlet piping are of equal size, then the Bernoulli coefficients are also equal, $K_{B1} = K_{B2}$, and therefore they are dropped from the equation.

The most commonly used fitting in control valve installations is the short length concentric reducer. The equations for this fitting are as follows:

For an inlet reducer

$$K_1 = 0.5 \left(1 - \frac{d^2}{D^2} \right)^2$$

Valve Selection and Sizing

For an outlet reducer

$$K_2 = 1.0 \left(1 - \frac{d^2}{D^2} \right)^2$$

For a valve installed between identical reducers

$$K_1 + K_2 = 1.5 \left(1 - \frac{d^2}{D^2} \right)^2$$

STEP 3: $\Delta P_{\max}$ (the allowable sizing pressure drop).

The maximum or limiting flow rate ($q_{\max}$), commonly called choked flow, is manifested by no additional increase in flow rate with increasing pressure differential with fixed upstream conditions. In liquids, choking occurs as a result of vaporization of the liquid when the static pressure within the valve drops below the vapor pressure of the liquid (Cavitation).

The IEC standard requires the calculation of an allowable sizing pressure drop ($\Delta P_{\max}$), to account for the possibility of choked flow conditions within the valve. The calculated $\Delta P_{\max}$ value is compared with the actual pressure drop specified in the service conditions, and the lesser of these two values is used in the sizing equation.

$\Delta P_{\max}$ (the allowable sizing pressure drop) can be determined from the following relationships:

For valves installed without fittings

$$\Delta P_{\max(L)} = F_L^2 (P_1 - F_F P_V)$$

Values for F_F , the liquid critical pressure ratio factor, can be obtained from the following equation:

$$F_F = 0.96 - 0.28 \sqrt{\frac{P_V}{P_c}}$$

Values of F_L , the recovery factor for valves installed without fittings attached, can be found in the flow coefficient tables.

For valves installed with fittings attached

$$\Delta P_{\max(LP)} = \left(\frac{F_{LP}}{F_P} \right)^2 (P_1 - F_F P_V)$$

where

$$F_{LP} = \left[\frac{K_1}{N_2} \left(\frac{C_v}{d^2} \right)^2 + \frac{1}{F_L^2} \right]^{-1/2}$$

where:

$N_2 = 0.00214$ d, D in mm
 890 d, D in inch
 C_v = Valve sizing coefficient at 100-percent travel

STEP 4: Solve for required C_v , using the appropriate equation:

I) ΔP_{max} is greater than ΔP

For volumetric flow rate units

$$C_v = \frac{q}{N_1 F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

For mass flow rate units

$$C_v = \frac{W}{N_6 F_p \sqrt{(P_1 - P_2)g}}$$

Equation Constants⁽¹⁾

	N	w	q	p ⁽²⁾	g	T	d, D
N_1	0.0865	---	m ³ /h	kPa	---	---	---
	0.865	---	m ³ /h	bar	---	---	---
	1.00	---	gpm	psia	---	---	---
N_6	2.73	kg/h	---	kPa	kg/m ³	---	---
	27.3	kg/h	---	bar	kg/m ³	---	---
	63.3	lb/h	---	psia	lb/ft ³	---	---

II) ΔP_{max} is less than ΔP

this is an indication that choked flow conditions will exist under the service conditions specified. If choked flow conditions do exist, then the above equations must be modified by replacing the actual service pressure differential ($P_1 - P_2$) with the calculated ΔP_{max} value.

Note

Once it is known that choked flow conditions will develop within the specified valve design (ΔP_{max} is calculated to be less than ΔP), a further distinction can be made to determine whether the

Valve Selection and Sizing

choked flow is caused by cavitation or flashing. The choked flow conditions are caused by flashing if the outlet pressure of the given valve is less than the vapor pressure of the flowing liquid. The choked flow conditions are caused by cavitation if the outlet pressure of the valve is greater than the vapor pressure of the flowing liquid.

Sizing Valves for Compressible Fluids

The sizing of control valves for gas flow can be performed using the following four steps procedure.

STEP 1: Specify the variables required to size the valve as follows:

- _ Desired valve type: refer to the appropriate valve flow coefficient table.
- _ Process fluid (air, natural gas, steam, etc.)
- _ Appropriate service conditions q or w , P_1 , P_2 or ΔP , T_1 , G_g , M , K , Z , and γ_1

STEP 2: Determine F_p , the piping geometry factor.

Determining F_p the Piping Geometry Factor, which is located in the section for Sizing Valves for Liquids.

STEP 3: Determine Y , the expansion factor, as follows

$$Y = 1 - \frac{x}{3F_k x_T}$$

where,

$F_k = k/1.4$, the ratio of specific heats factor

k = Ratio of specific heats

$x = \Delta P/P_1$, the pressure drop ratio

x_T = The pressure drop ratio factor for valves installed without attached fittings. More definitively, x_T is the pressure drop ratio required to produce critical, or maximum, flow through the valve when $F_k = 1.0$

If the control valve to be installed has fittings such as reducers or elbows attached to it, then their effect is accounted for in the

expansion factor equation by replacing the x_T term with a new factor x_{TP} .

$$x_{TP} = \frac{x_T}{F_p^2} \left[1 + \frac{x_T K_i}{N_5} \left(\frac{C_v}{d^2} \right)^2 \right]^{-1}$$

where,

$$N_5 = \frac{0.00241}{1000} \quad \begin{array}{l} d, D \text{ in mm} \\ d, D \text{ in inch} \end{array}$$

C_v = Valve sizing coefficient from flow coefficient table at 100 percent travel

K_i , is the inlet head loss coefficient, which is defined as:

$$K_i = K_1 + K_{B1}$$

Conditions of critical pressure drop are realized when the value of x becomes equal to or exceeds the appropriate value of the product of either $F_k x_T$ or $F_k x_{TP}$ at which point:

$$y = 1 - \frac{x}{3F_k x_T} = 1 - 1/3 = 0.667$$

Although in actual service, pressure drop ratios can, and often will, exceed the indicated critical values, this is the point where critical flow conditions develop. Thus, for a constant P_1 , decreasing P_2 (i.e., increasing ΔP) will not result in an increase in the flow rate through the valve. Values of x , therefore, greater than the product of either $F_k x_T$ or $F_k x_{TP}$ must never be substituted in the expression for Y . This means that Y can never be less than 0.667. This same limit on values of x also applies to the flow equations that are introduced in the next step.

STEP 4: Solve for required C_v , using the appropriate equation:

For standard volumetric flow rate units

If the specific gravity, G_g , of the gas has been specified:

$$C_v = \frac{q}{N_7 F_p P_1 Y \sqrt{\frac{x}{G_g T_1 Z}}}$$

If the molecular weight, M , of the gas has been specified:

Valve Selection and Sizing

$$C_v = \frac{q}{N_7 F_p P_1 Y \sqrt{\frac{x}{M T_1 Z}}}$$

For mass flow rate units

If the specific weight, γ_1 , of the gas has been specified:

$$C_v = \frac{w}{N_6 F_p Y \sqrt{x P_1 g_1}}$$

If the molecular weight, M , of the gas has been specified:

$$C_v = \frac{w}{N_8 F_p P_1 Y \sqrt{\frac{x M}{T_1 Z}}}$$

Post-Assessment

1. Which is the main factor that drive the flow to be choked
2. How the followings affect the valve
 - a. Cavitation
 - b. Low temperature
 - c. High differential pressure
 - d. Low size

Practical Application

Solve with your class the hand-out examples and problems

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8**

Testing and Installation

Module Outcome : Upon successful completion of this learning outcome guide, you will be able to test and install the control valve properly

Learning Objectives: To successfully complete this learning outcome guide you should be able to:

- 1- To judge the valve performance
- 2- To test and inspect the control valve
- 3- To list the valve installation procedure

Let's have some Fun

يوميّات عتريس و مرّاة (الحلقة الثامنة)
هل ترى جدوى لاختبار عتريس لزوجته في محاولة لكشف عيوبها و العمل على اصلاحها

Pre-Assessment

- 1- List the factors affecting the valve performance
- 2- Describe the test of the valve
 - a. online
 - b. offline
- 3- List the valve installation procedures in a safe manner

Objective 1: Control Valve Performance

In today's dynamic business environment, manufacturers are under extreme economic pressures. Market globalization is resulting in intense pressures to reduce manufacturing costs to compete with lower wages and raw material costs of emerging countries. Competition exists between international companies to provide the highest quality products and to maximize plant throughputs with fewer resources, although meeting ever changing customer needs. These marketing challenges must be met although fully complying with public and regulatory policies.

Process Variability

To deliver acceptable returns to their shareholders, international industry leaders are realizing they must reduce raw material and scrap costs while increasing productivity. Reducing process variability in the manufacturing processes through the application of process control technology is recognized as

Testing and Installation

an effective method to improve financial returns and meet global competitive pressures.

The basic objective of a company is to make a profit through the production of a quality product. A quality product conforms to a set of specifications. Any deviation from the established specification means lost profit due to excessive material use, reprocessing costs, or wasted product. Thus, a large financial impact is obtained through improving process control. Reducing process variability through better process control allows optimization of the process and the production of products right the first time.

The non-uniformity inherent in the raw materials and processes of production are common causes of variation that produce a variation of the process variable both above and below the set point. A process that is in control, with only the common causes of variation present, typically follows a bell-shaped normal distribution (figure 1).

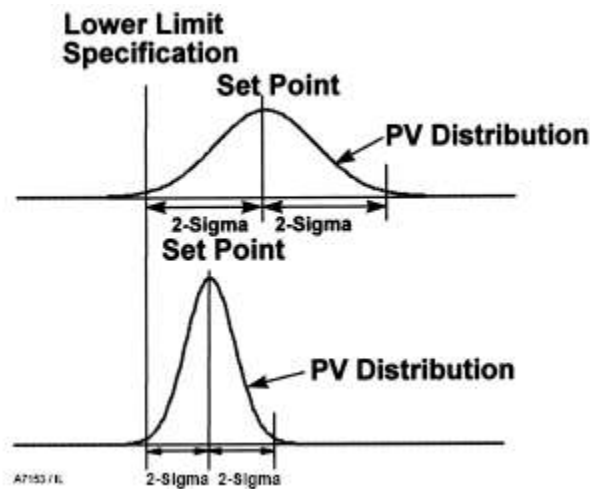


Figure 1. Process Variability

A statistically derived band of values on this distribution, called the ± 2 sigma band, describes the spread of process variable deviations from the set point. This band is the variability of the process. It is a measure of how tightly the process is being controlled. Process Variability is a precise measure of tightness of control and is expressed as a percentage of the set point.

If a product must meet a certain lower- limit specification, for example, the set point needs to be established at a 2 sigma value above this lower limit. Doing so will ensure that all the product produced at values to the right of the lower limit will meet the quality specification.

The problem, however, is that money and resources are being wasted by making a large percentage of the product to a level much greater than required by the specification (see upper distribution in figure 1).

The most desirable solution is to reduce the spread of the deviation about the set point by going to a control valve that can produce a smaller sigma (see lower distribution in figure 1).

Reducing process variability is a key to achieving business goals. Most companies realize this, and it is not uncommon for them to spend hundreds of thousands of dollars on instrumentation to address the problem of process variability reduction.

Unfortunately, the control valve is often overlooked in this effort because its impact on dynamic performance is not realized. Extensive studies of control loops indicate as many as 80% of the loops did not do an adequate job of reducing process variability. Furthermore, the control valve was found to be a major contributor to this problem for a variety of reasons.

To verify performance, manufacturers must test their products under dynamic process conditions. These are typically performed in a flow lab in actual closed-loop control. Evaluating control valve assemblies under closed-loop conditions provides the only true measure of variability performance. Closed-loop performance data proves significant reductions in process variability can be achieved by choosing the right control valve for the application.

The ability of control valves to reduce process variability depends upon many factors. More than one isolated parameter must be considered. Research within the industry has found the particular design features of the final control element, including the valve, actuator, and positioner, are very important in achieving good process control under dynamic conditions. Most importantly, the control valve assembly must be optimized or developed as a unit. Valve components not designed as a complete assembly typically do not yield the best dynamic performance.

Some of the most important design considerations include:

- Dead band
- Actuator/positioner design
- Valve response time
- Valve type and sizing

Each of these design features will be considered in this chapter to provide insight into what constitutes a superior valve design.

Dead Band

Testing and Installation

Dead band is a major contributor to excess process variability, and control valve assemblies can be a primary source of dead band in an instrumentation loop due to a variety of causes such as friction, backlash, shaft windup, relay or spool valve dead zone, etc..

Dead band is a general phenomenon where a range or band of controller output (CO) values fails to produce a change in the measured process variable (PV) when the input signal reverses direction. When a load disturbance occurs, the process variable (PV) deviates from the set point. This deviation initiates a corrective action through the controller and back through the process. However, an initial change in controller output can produce no corresponding corrective change in the process variable. Only when the controller output has changed enough to progress through the dead band does a corresponding change in the process variable occur.

Any time the controller output reverses direction, the controller signal must pass through the dead band before any corrective change in the process variable will occur. The presence of dead band in the process ensures the process variable deviation from the set point will have to increase until it is big enough to get through the dead band. Only then can a corrective action occur.

Dead band has many causes, but friction and backlash in the control valve, along with shaft wind-up in rotary valves, and relay dead zone are some of the more common forms. Because most control actions for regulatory control consist of small changes (1% or less), a control valve with excessive dead band might not even respond to many of these small changes. A wellengineered valve should respond to signals of 1% or less to provide effective reduction in process variability. However, it is not uncommon for some valves to exhibit dead band as great as 5% or more. In a recent plant audit, 30% of the valves had dead bands in excess of 4%. Over 65% of the loops audited had dead bands greater than 2%.

Figure 2 shows just how dramatic the combined effects of dead band can be. This diagram represents an open-loop test of three different control valves under normal process conditions. The valves are subjected to a series of step inputs which range from 0.5% to 10%. Step tests under flowing conditions such as these are essential because they allow the performance of the entire valve assembly to be evaluated, rather than just the valve actuator assembly as would be the case under most bench test conditions.

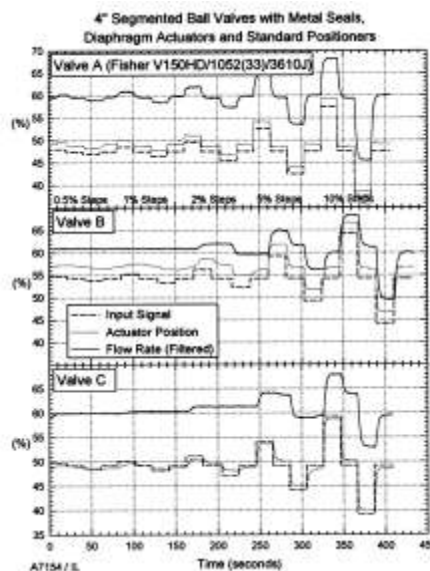


Figure2. Effect of Dead Band on Valve Performance

Some performance tests on a valve assembly compare only the actuator stem travel versus the input signal. This is misleading because it ignores the performance of the valve itself.

It is critical to measure dynamic performance of a valve under flowing conditions so the change in process variable can be compared to the change in valve assembly input signal. It matters little if only the valve stem changes in response to a change in valve input because if there is no corresponding change in the controlled variable, there will be no correction to the process variable.

In all three valve tests (figure 2) the actuator stem motion changes fairly faithfully in response to the input signal changes. On the other hand, there is a dramatic difference in each of these valve's ability to change the flow in response to an input signal change.

For Valve A the process variable (flow rate) responds well to input signals as low as 0.5. Valve B requires input signal changes as great as 5% before it begins responding faithfully to each of the input signal steps. Valve C is considerably worse, requiring signal changes as great as 10% before it begins to respond faithfully to each of the input signal steps. The ability of either Valve B or C to improve process variability is very poor.

Friction is a major cause of dead band in control valves. Rotary valves are often very susceptible to friction caused by the high seat loads required to obtain shut-off with some seal designs. Because of the high seal friction and poor drive train stiffness, the valve shaft winds up and does not translate motion to the control element. As a result, an improperly designed rotary valve can exhibit significant dead band that clearly has a detrimental effect on process variability.

Testing and Installation

Manufacturers usually lubricate rotary valve seals during manufacture, but after only a few hundred cycles this lubrication wears off. In addition, pressure- induced loads also cause seal wear. As a result, the valve friction can increase by 400% or more for some valve designs. This illustrates the misleading performance conclusions that can result from evaluating products using bench type data before the torque has stabilized. Valves B and C (figure 2) show the devastating effect these higher friction torque factors can have on a valve's performance.

Packing friction is the primary source of friction in sliding stem valves. In these types of valves, the measured friction can vary significantly between valve styles and packing arrangements.

Actuator style also has a profound impact on control valve assembly friction. Generally, spring-and-diaphragm actuators contribute less friction to the control valve assembly than piston actuators. An additional advantage of spring-and-diaphragm actuators is that their frictional characteristics are more uniform with age. Piston actuator friction probably will increase significantly with use as guide surfaces and the O-rings wear, lubrication fails, and the elastomer degrades. Thus, to ensure continued good performance, maintenance is required more often for piston actuators than for spring and- diaphragm actuators. If that maintenance is not performed, process variability can suffer dramatically without the operator's knowledge.

Backlash is the name given to slack, or looseness of a mechanical connection. This slack results in a discontinuity of motion when the device changes direction. Backlash commonly occurs in gear drives of various configurations. Rack-and-pinion actuators are particularly prone to dead band due to backlash. Some valve shaft connections also exhibit dead band effects. Spline connections generally have much less dead band than keyed shafts or double-D designs.

While friction can be reduced significantly through good valve design, it is a difficult phenomenon to eliminate entirely. A well-engineered control valve should be able to virtually eliminate dead band due to backlash and shaft wind-up.

For best performance in reducing process variability, the total dead band for the entire valve assembly should be 1% or less. Ideally, it should be as low as 0.25%.

Actuator-Positioner Design

Actuator and positioner design must be considered together. The combination of these two pieces of equipment greatly affects the static performance (dead band), as well as the dynamic response of the control valve assembly and the overall air consumption of the valve instrumentation.

Positioners are used with the majority of control valve applications specified today. Positioners allow for precise positioning accuracy and faster response to process upsets when used with a conventional digital control system. With the increasing emphasis upon economic performance of process control, positioners should be considered for every valve application where process optimization is important.

The most important characteristic of a good positioner for process variability reduction is that it be a high gain device. Positioner gain is composed of two parts: the static gain and the dynamic gain.

Static gain is related to the sensitivity of the device to the detection of small (0.125% or less) changes of the input signal. Unless the device is sensitive to these small signal changes, it cannot respond to minor upsets in the process variable. This high static gain of the positioner is obtained through a preamplifier, similar in function to the preamplifier contained in high fidelity sound systems. In many pneumatic positioners, a nozzle-flapper or similar device serves as this high static gain preamplifier.

Once a change in the process variable has been detected by the high static gain positioner preamplifier, the positioner must then be capable of making the valve closure member move rapidly to provide a timely corrective action to the process variable. This requires much power to make the actuator and valve assembly move quickly to a new position. In other words, the positioner must rapidly supply a large volume of air to the actuator to make it respond promptly. The ability to do this comes from the high dynamic gain of the positioner. Although the positioner preamplifier can have high static gain, it typically has little ability to supply the power needed. Thus, the preamplifier function must be supplemented by a high dynamic gain power amplifier that supplies the required air flow as rapidly as needed. This power amplifier function is typically provided by a relay or a spool valve.

Spool valve positioners are relatively popular because of their simplicity. Unfortunately, many spool valve positioners achieve this simplicity by omitting the high gain preamplifier from the design. The input stage of these positioners is often a low static gain transducer module that changes the input signal (electric or pneumatic) into movement of the spool valve, but this type of device generally has low sensitivity to small signal changes. The result is increased dead time and overall response time of the control valve assembly.

Testing and Installation

Some manufacturers attempt to compensate for the lower performance of these devices by using spool valves with enlarged ports and reduced overlap of the ports. This increases the dynamic power gain of the device, which helps performance to some extent if it is well matched to the actuator, but it also dramatically increases the air consumption of these high gain spool valves. Many high gain spool valve positioners have static instrument air consumption five times greater than typical high performance two-stage positioners.

Typical two-stage positioners use pneumatic relays at the power amplifier stage. Relays are preferred because they can provide high power gain that gives excellent dynamic performance with minimal steady-state air consumption. In addition, they are less subject to fluid contamination. Positioner designs are changing dramatically, with microprocessor devices becoming increasingly popular. These microprocessor-based positioners provide dynamic performance equal to the best conventional two-stage pneumatic positioners. They also provide valve monitoring and diagnostic capabilities to help ensure that initial good performance does not degrade with use.

In summary, high-performance positioners with both high static and dynamic gain provide the best overall process variability performance for any given valve assembly.

Valve Response Time

For optimum control of many processes, it is important that the valve reach a specific position quickly. A quick response to small signal changes (1% or less) is one of the most important factors in providing optimum process control. In automatic, regulatory control, the bulk of the signal changes received from the controller are for small changes in position. If a control valve assembly can quickly respond to these small changes, process variability will be improved.

Valve response time is measured by a parameter called T_{63} (Tee-63); T_{63} is the time measured from initiation of the input signal change to when the output reaches 63% of the corresponding change. It includes both the valve assembly dead time, which is a static time, and the dynamic time of the valve assembly. The dynamic time is a measure of how long the actuator takes to get to the 63% point once it starts moving.

Dead band, whether it comes from friction in the valve body and actuator or from the positioner, can significantly affect the dead time of the valve assembly. It is important to keep the dead time as small as possible. Generally dead time should be no more than one-third of the overall valve response time. However, the relative relationship between the dead time and the process time constant is critical. If the valve assembly is in a fast loop where the process time constant approaches the dead time, the dead time can dramatically affect loop

performance. On these fast loops, it is critical to select control equipment with dead time as small as possible.

Also, from a loop tuning point of view, it is important that the dead time be relatively consistent in both stroking directions of the valve. Some valve assembly designs can have dead times that are three to five times longer in one stroking direction than the other. This type of behavior is typically induced by the asymmetric behavior of the positioner design, and it can severely limit the ability to tune the loop for best overall performance.

Once the dead time has passed and the valve begins to respond, the remainder of the valve response time comes from the dynamic time of the valve assembly. This dynamic time will be determined primarily by the dynamic characteristics of the positioner and actuator combination. These two components must be carefully matched to minimize the total valve response time. In a pneumatic valve assembly, for example, the positioner must have a high dynamic gain to minimize the dynamic time of the valve assembly. This dynamic gain comes mainly from the power amplifier stage in the positioner. In other words, the faster the positioner relay or spool valve can supply a large volume of air to the actuator, the faster the valve response time will be. However, this high dynamic gain power amplifier will have little effect on the dead time unless it has some intentional dead band designed into it to reduce static air consumption. Of course, the design of the actuator significantly affects the dynamic time. For example, the greater the volume of the actuator air chamber to be filled, the slower the valve response time.

At first, it might appear that the solution would be to minimize the actuator volume and maximize the positioner dynamic power gain, but it is really not that easy. This can be a dangerous combination of factors from a stability point of view. Recognizing that the positioner/ actuator combination is its own feedback loop, it is possible to make the positioner/actuator loop gain too high for the actuator design being used, causing the valve assembly to go into an unstable oscillation. In addition, reducing the actuator volume has an adverse affect on the thrust-to-friction ratio, which increases the valve assembly dead band resulting in increased dead time.

If the overall thrust-to-friction ratio is not adequate for a given application, one option is to increase the thrust capability of the actuator by using the next size actuator or by increasing the pressure to the actuator. This higher thrust-to-friction ratio reduces dead band, which should help to reduce the dead time of the assembly. However, both of these alternatives mean that a greater volume of air needs to be supplied to the actuator. The tradeoff is a possible detrimental effect on the valve response time through increased dynamic time.

Testing and Installation

One way to reduce the actuator air chamber volume is to use a piston actuator rather than a spring-and-diaphragm actuator, but this is not a panacea. Piston actuators usually have higher thrust capability than spring-and-diaphragm actuators, but they also have higher friction, which can contribute to problems with valve response time. To obtain the required thrust with a piston actuator, it is usually necessary to use a higher air pressure than with a diaphragm actuator, because the piston typically has a smaller area. This means that a larger volume of air needs to be supplied with its attendant ill effects on the dynamic time. In addition, piston actuators, with their greater number of guide surfaces, tend to have higher friction due to inherent difficulties in alignment, as well as friction from the O-ring. These friction problems also tend to increase over time. Regardless of how good the O-rings are initially, these elastomeric materials will degrade with time due to wear and other environmental conditions. Likewise wear on the guide surfaces will increase the friction, and depletion of the lubrication will occur. These friction problems result in a greater piston actuator dead band, which will increase the valve response time through increased dead time.

Instrument supply pressure can also have a significant impact on dynamic performance of the valve assembly. For example, it can dramatically affect the positioner gain, as well as overall air consumption.

Fixed-gain positioners have generally been optimized for a particular supply pressure. This gain, however, can vary by a factor of two or more over a small range of supply pressures. For example, a positioner that has been optimized for a supply pressure of 20 psig might find its gain cut in half when the supply pressure is boosted to 35 psig. Supply pressure also affects the volume of air delivered to the actuator, which in turn determines stroking speed. It is also directly linked to air consumption. Again, high-gain spool valve positioners can consume up to five times the amount of air required for more efficient high-performance, two-stage positioners that use relays for the power amplification stage.

To minimize the valve assembly dead time, minimize the dead band of the valve assembly, whether it comes from friction in the valve seal design, packing friction, shaft wind-up, actuator, or positioner design. As indicated, friction is a major cause of dead band in control valves. On rotary valve styles, shaft wind-up can also contribute significantly to dead band. Actuator style also has a profound impact on control valve assembly friction. Generally, spring-and-diaphragm actuators contribute less friction to the control valve assembly than piston actuators over an extended time. As mentioned, this is caused by the increasing friction from the piston O-ring, misalignment problems, and failed lubrication. Having a positioner design with a high static gain preamplifier can

make a significant difference in reducing dead band. This can also make a significant improvement in the valve assembly resolution. Valve assemblies with dead band and resolution of 1% or less are no longer adequate for many process variability reduction needs. Many processes require the valve assembly to have dead band and resolution as low as 0.25%, especially where the valve assembly is installed in a fast process loop.

One of the surprising things to come out of many industry studies on valve response time has been the change in thinking about spring-and-diaphragm actuators versus piston actuators. It has long been a misconception in the process industry that piston actuators are faster than spring-and-diaphragm actuators. Research has shown this to be untrue for small signal changes. This mistaken belief arose from many years of experience with testing valves for stroking time. A stroking time test is normally conducted by subjecting the valve assembly to a 100% step change in the input signal and measuring the time it takes the valve assembly to complete its full stroke in either direction.

Although piston-actuated valves usually do have faster stroking times than most spring-and-diaphragm actuated valves, this test does not indicate valve performance in an actual process control situation. In normal process control applications, the valve is rarely required to stroke through its full operating range. Typically, the valve is only required to respond within a range of 0.25% to 2% change in valve position. Extensive testing of valves has shown that spring-and-diaphragm valve assemblies consistently outperform piston actuated valves on small signal changes, which are more representative of regulatory process control applications. Higher friction in the piston actuator is one factor that plays a role in making them less responsive to small signals than spring-and-diaphragm actuators. Selecting the proper valve, actuator, positioner combination is not easy. It is not simply a matter of finding a combination that is physically compatible. Good engineering judgment must go into the practice of valve assembly sizing and selection to achieve the best dynamic performance from the loop.

Table 1 shows the dramatic differences in dead time and overall T_{63} response time caused by differences in valve assembly design.

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VALVE RESPONSE TIME			
	STEP SIZE	T(d) SEC.	T63 SEC.
ENTECH SPEC. 4" VALVE SIZE	%	≤ 0.2	≤ 0.6
Valve A (Fisher V150HD/1052(33)/3610J)			
VALVE ACTION / OPENING	2	0.25	0.34
VALVE ACTION / CLOSING	-2	0.50	0.74
VALVE ACTION / OPENING	5	0.16	0.26
VALVE ACTION / CLOSING	-5	0.22	0.42
VALVE ACTION / OPENING	10	0.19	0.33
VALVE ACTION / CLOSING	-10	0.23	0.46
Valve B			
VALVE ACTION / OPENING	2	5.61	7.74
VALVE ACTION / CLOSING	-2	0.46	1.67
VALVE ACTION / OPENING	5	1.14	2.31
VALVE ACTION / CLOSING	-5	1.04	2
VALVE ACTION / OPENING	10	0.42	1.14
VALVE ACTION / CLOSING	-10	0.41	1.14
Valve C			
VALVE ACTION / OPENING	2	4.4	5.49
VALVE ACTION / CLOSING	-2	NR	NR
VALVE ACTION / OPENING	5	5.58	7.06
VALVE ACTION / CLOSING	-5	2.16	3.9
VALVE ACTION / OPENING	10	0.69	1.63
VALVE ACTION / CLOSING	-10	0.53	1.25
NR = No Response			

Table.1 Valve Response Time Summary

Objective 2: Control Valve Test

The conventional solution

Estimates indicate that as much as 40 to 50% of loop operating problems are caused by final control elements. Therefore it is imperative that these valves be tested frequently in order to reduce the PFD and meet the target SIL. The more frequently the valves are tested, the less likely they will be to fail. The only sure way to test a final control element completely is with an in-line test that strokes the valve from 0–100% (full open/full close).

Unfortunately, to stroke a shutdown valve completely often requires a total shutdown of the process, causing a significant loss in production. Operations managers usually wait to test the valves until a scheduled plant shutdown. In the past, plant turnarounds were scheduled every two to three years. However, with increased system reliability and more inclusive preventive maintenance programmes, plant turn- arounds now are being scheduled to occur every five to six years.

Although extended periods between turnarounds improve economic returns by increasing production, they also mean that safety system final control elements are tested less frequently. This has a dramatic impact on the PFD of the system, which often prevents it from meeting the target SIL. In an attempt to get around this problem, many companies have devised methods for testing SIS valves online so they do not have to shut down the process. The typical approach is to install a bypass around each safety valve.

Although bypassing the safety valve during testing is done to improve the PFD, not all of this testing approach goes to that benefit. The fraction of time that the system remains in bypass must be taken into account in the PFD calculation. For long bypass periods or frequent testing, the negative impact on PFD can be significant to where it could negate much of the benefit obtained by the testing. Safety engineers recognize that the most likely failure mode of a discrete shutoff valve is that it remains stuck in its normal standby position.

Testing for this type of failure requires stroking the valve only a small amount to verify that the valve is not stuck. This partial-stroke technique can detect a large percentage of covert valve failures. Furthermore, performing this type of test online without shutting down the process could improve the PFD without a loss of production. Over the years, a variety of partial testing methods have been developed. While all of them have a definite risk of spurious shutdown trips, limiting valve travel using a mechanical device seems to be the most popular.

Mechanical limiting methods may involve a pin, a valve stem collar, a valve handjack, or some other apparatus that restricts valve travel to 15% or less of full stroke. While these mechanical limiting devices themselves are inexpensive, the pneumatic test panels used to conduct the test are complex and costly. The testing process must be manually initiated in the field, and the tests themselves are manpower-intensive and subject to error. In addition, a major drawback is that the safety shutdown function is not available during the test period.

Likewise, there is always the possibility that the safety valve will be left inadvertently in a mechanically-limited condition. Worse yet, this situation cannot always be determined by a casual inspection. This means that the valve potentially could be out of service for an extended period of time with the operators being unaware of the situation.

Smart positioners

So-called “smart” positioners have grown in great popularity in recent years. These are microprocessor-based, current-to-pneumatic digital valve controllers that are communicating instruments with internal logic capability. In

Testing and Installation

In addition to the traditional function of converting a current signal to a pressure signal to operate the valve, these smart positioners use the HART communications protocol to give easy access to information that is critical to process operation. In addition to this, the smart positioner receives feedback about valve travel position plus existing supply and actuator pneumatic pressures, which allows it to diagnose not only itself, but also the valve and actuator to which it is mounted.

Including a smart positioner as part of the final control element facilitates on-line, partial-stroke testing without the need for special mechanical limiting devices or other special test apparatus. Because the positioner communicates via HART protocol, the partial-stroke test can be initiated from a HART hand-held communicator, from a personal computer running the positioner companion software, or from a panelmounted pushbutton hardwired to the positioner terminals. Since the testing sequence is completely automatic, it eliminates errors and possible nuisance trips.

For safety reasons, the operator is required to initiate the test sequence. The partial-stroke technique along with the automated routine provided by the smart positioner allows testing to be done more frequently. Typically the partial-stroke test moves the valve 10% from its original position, but it can be up to 30% if allowed by plant safety guidelines. Even though partial-stroke testing does not eliminate the need for full-stroke testing, which is required to check valve seating etc, it does reduce the required full-stroke testing frequency to the point where it can most likely be tested during plant turnaround.

The smart positioner provides diagnostic as well as positioning information, allowing the valve status and response time to be monitored during the test. Valve performance trends can be monitored and analysed after each partial-stroke test so that potentially failing valves can be identified long before they become unavailable. The results of a signature test (Figure 1) can identify packing problems (through friction data), leakage in the pneumatic path to the actuator, valve sticking, actuator spring rate and bench set. The smart positioner stores this data for subsequent use.

For instance, overlaying the results of a current signature test with those of previous tests can indicate if valve response has degraded. Corrective action can be scheduled, which ultimately increases valve availability and ensures that the valve responds upon demand. Some smart positioners can alert the operator if a valve is stuck. As the positioner begins the partial-stroke test, it continually checks valve travel to see if the valve is responding properly. If it is not, the positioner will abort the test and alert the operator that the valve is stuck.

This prevents the valve from slamming shut, should it eventually break loose. As an added safety advantage, should an emergency shutdown

demand occur during testing the smart positioner will override the test, moving the valve to its safe position.

Installation

A smart positioner can be used with any control valve style, including sliding-stem, rotary, quarter-turn etc, with spring-and diaphragm actuators, spring-return piston actuators, or double-acting piston actuators. Two types of installation are possible. Both use a solenoid valve and provide a redundant pneumatic path (the actuator pressure will always exhaust to allow the valve to move to the safe position). If the solenoid valve fails, the actuator pressure exhausts through the pneumatic path in the smart positioner.

If the smart positioner fails, the actuator pressure exhausts through the solenoid valve. Figure 2 shows a smart positioner installed in a four-wire system. In this installation the logic solver provides two separate outputs: a 4 to 20mA dc signal for the smart positioner and a 24V dc signal for the solenoid valve. The 4 to 20 mA output serves as the primary valve position control signal. It also is used to control the valve position during remote online partial-stroke testing.

The HART digital information is superimposed on the analogue signal, which means the same wire pair provides both the means to control the valve through the SIS and to monitor valve diagnostic information contained in the HART signal. The second output from the logic solver, the 24V dc signal, is connected to the solenoid valve. It serves as an independent means of sending a SIS command to the safety valve. Consequently, two separate SIS signals are provided to the valve, permitting a one-out-of-two, fail-safe command.

The four-wire system requires an additional pair of wires, but it does permit the smart positioner to continue communicating even during “Safety Demand” conditions. Because the positioner continues to communicate, it can provide valuable trending information through its companion software. Being able to record the valve action during the emergency shutdown is very important for insurance or plant environment authorities since it provides evidence that the valve did stroke upon demand. Figure 3 shows a smart positioner installed in a two-wire system.

The logic solver powers both the solenoid valve and the smart positioner, which reduces wiring costs in new installations and requires no additional wiring in existing installations. It also saves an I/O card in the control room. The installation, however, does require a line conditioner and a low-power solenoid valve. Because power is removed from the positioner during a demand, it will be unable to continue to communicate.

Conclusion

Testing and Installation

While the smart positioner provides performance and safety benefits through automated, online partial-stroke testing, many additional benefits can be realized. These include eliminating expensive pneumatic test panels, reducing manpower requirements, lowering base equipment cost and shortening testing time. In addition, remote testing results in fewer maintenance trips to the field as well as the establishment of an automated test routine that can produce great time savings.

Smart positioners allow partial-stroke testing while the process is running with no threat of missing an emergency demand. This type of test applies a small ramp signal to the valve that is too small to disrupt the process, but is large enough to confirm that the valve is working properly. Installing the smart positioner along with a solenoid valve provides an inherently redundant pneumatic path. Should an emergency condition arise, the actuator pressure will always exhaust, either through the solenoid valve or through the smart positioner itself, thus ensuring that the valve will always go to the safe position.

The smart positioner can be designed so that it does not completely exhaust the actuator pressure should the valve become stuck during a partial-stroke test. This ensures that if the valve then becomes unstuck, it will not slam shut. The smart positioners would then abort the test and send an alert to the operator warning that the valve was stuck. Smart positioners prove to be a great aid to predictive maintenance by providing a valve degradation analysis, which is important for critical valves in safety-related systems.

This also reduces the amount of scheduled maintenance. The smart positioner provides a time and date stamp on all tests and reports, which is very important for complying with the requirements of statutory authorities. It also provides the capability for comparing and interpreting diagnostic data. All in all, considering these unique benefits, the use of smart positioners in safety instrumented systems is a sensible and economical pathway to enhanced SIS reliability.

Objective 3: Control Valve Installation

Proper Storage and Protection

Proper storage and protection should be considered early in the selection process, before the valve is shipped. Typically, manufacturers have packaging standards that are dependent upon the destination and intended length of storage before installation. Because most valves arrive on site some time before installation, many problems can be averted by making sure the details of the installation schedule are known and discussed with the manufacturer at the

time of valve selection. In addition, special precautions should be taken upon receipt of the valve at the final destination. For example, the valve must be stored in a clean, dry place away from any traffic or other activity that could damage the valve.

Proper Installation Techniques

Always follow the control valve manufacturer's installation instructions and cautions. Typical instructions are summarized here.

Read the Instruction Manual

Before installing the valve, read the instruction manual. Instruction manuals describe the product and review safety issues and precautions to be taken before and during installation. Following the guidelines in the manual helps ensure an easy and successful installation.

Be Sure the Pipeline Is Clean

Foreign material in the pipeline could damage the seating surface of the valve or even obstruct the movement of the valve plug, ball, or disk so that the valve does not shut off properly. To help reduce the possibility of a dangerous situation from occurring, clean all pipelines before installing.



Fig.3 Install the Valve with the Flow Arrow Pointing in the Direction of the Process Flow

Make sure pipe scale, metal chips, welding slag, and other foreign materials are removed. In addition, inspect pipe flanges to ensure a smooth gasket surface. If the valve has screwed end connections, apply a good grade of pipe sealant compound to the male pipeline threads. Do not use sealant *Figure 3. Install the Valve with the Flow Arrow Pointing in the Direction of the Process Flow* W1916/IL on the female threads because excess compound on the female threads could be forced into the valve body. Excess compound could cause

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sticking in the valve plug or accumulation of dirt, which could prevent good valve shutoff.

Inspect the Control Valve

Although valve manufacturers take steps to prevent shipment damage, such damage is possible and should be discovered and reported before the valve is installed. Do not install a control valve known to have been damaged in shipment or while in storage. Before installing, check for and remove all shipping stops and protective plugs or gasket surface covers. Check inside the valve body to make sure no foreign objects are present.

Use Good Piping Practices

Most control valves can be installed in any position. However, the most common method is with the actuator vertical and above the valve body. If horizontal actuator mounting is necessary, consider additional vertical support for the actuator. Be sure the body is installed so that fluid flow will be in the direction indicated by the flow arrow (figure 3) or instruction manual. Be sure to allow ample space above and below the valve to permit easy removal of the actuator or valve plug for inspection and maintenance. Clearance distances are normally available from the valve manufacturer as certified dimension drawings.

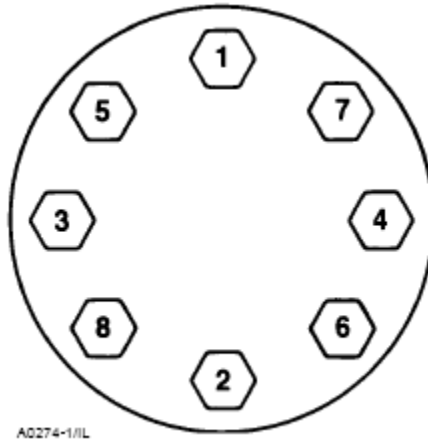


Fig.4 Tighten Bolts in a Crisscross Pattern

For flanged valve bodies, be sure the flanges are properly aligned to provide uniform contact of the gasket surfaces. Snug up the bolts gently after establishing proper flange alignment. Finish tightening them in a criss-cross pattern (figure 4). Proper tightening will avoid uneven gasket loading and will help prevent leaks. It also will avoid the possibility of damaging, or even breaking, the flange. This precaution is particularly important when connecting to flanges that are not the same material as the valve flanges. Pressure taps installed upstream and downstream of the control valve are useful for checking flow capacity or pressure drop. Locate such taps in straight runs of pipe away from

elbows, reducers, or expanders. This location minimizes inaccuracies resulting from fluid turbulence. Use 1/4- or 3/8-inch (6-10 millimeters) tubing or pipe from the pressure connection on the actuator to the controller. Keep this distance relatively short and minimize the number of fittings and elbows to reduce system time lag. If the distance must be long, use a valve positioner or a booster with the control valve.

Post-Assessment

Try to solve Pre-assessment, and feel the difference in your knowledge