Ministry of Electricity & Water (MEW)

Industrial Instrument Training Course

(I & C Department)

Written by: Farooq Ali Chaudhry

SHUWAIKH POWER & WATER STATION KUWAIT

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Dedication

I dedicate this book, with special thanks to my beloved **Parents**, **Wife and Children** with their support I learned to be honest, hardworking and follow the right path in life.

The books published are:

- **Industrial Instrument Training Course**.
- **Standard Calibration Procedures (SCP).**
- **Practical training plan & calibration execution of field instruments & practices in the field.**
- **How to write Technical specifications of spare parts of a Power Plant.**

- Special thanks to **ENG. YAMAMOTO & ENG. HORIGOME** from **YAMATAKE HONEYWELL CO. JAPAN,** who helped my theoretical and practical training of all types of instrumentation including Control Room Instruments, Analog Control system, Interlocks, Safeties & Field Instruments

Eng. Yamamoto / Farooq Ali / Eng. Horigome

- Thanks to **Eng. Ejaz-u-Din Shaikh** (MEW IMD Section Head 1979) who gave me liberty to challenge myself to enhance my knowledge & practical experience in this field.

- Thanks to **Eng. Iqbal Hussain** (Senior Instrument Engineer) who trained me for specialized skills at Boilers, Turbine Interlocks and its safety protections of power Plant.

- Special thanks to **Eng. Ahmad Ashknani** (IMD Superintendent of Doha West Power Station Kuwait) who motivated me to utilize my skill and experience to write in my books.

- Special thanks to **Eng. Salah Al-Mail** (IMD Superintendent of Doha East Power Station & Shuwaikh Power Station Kuwait) whom I worked closely at Boilers, Turbines and Auxiliaries maintenance. In office coordinator providing technical support including spare parts

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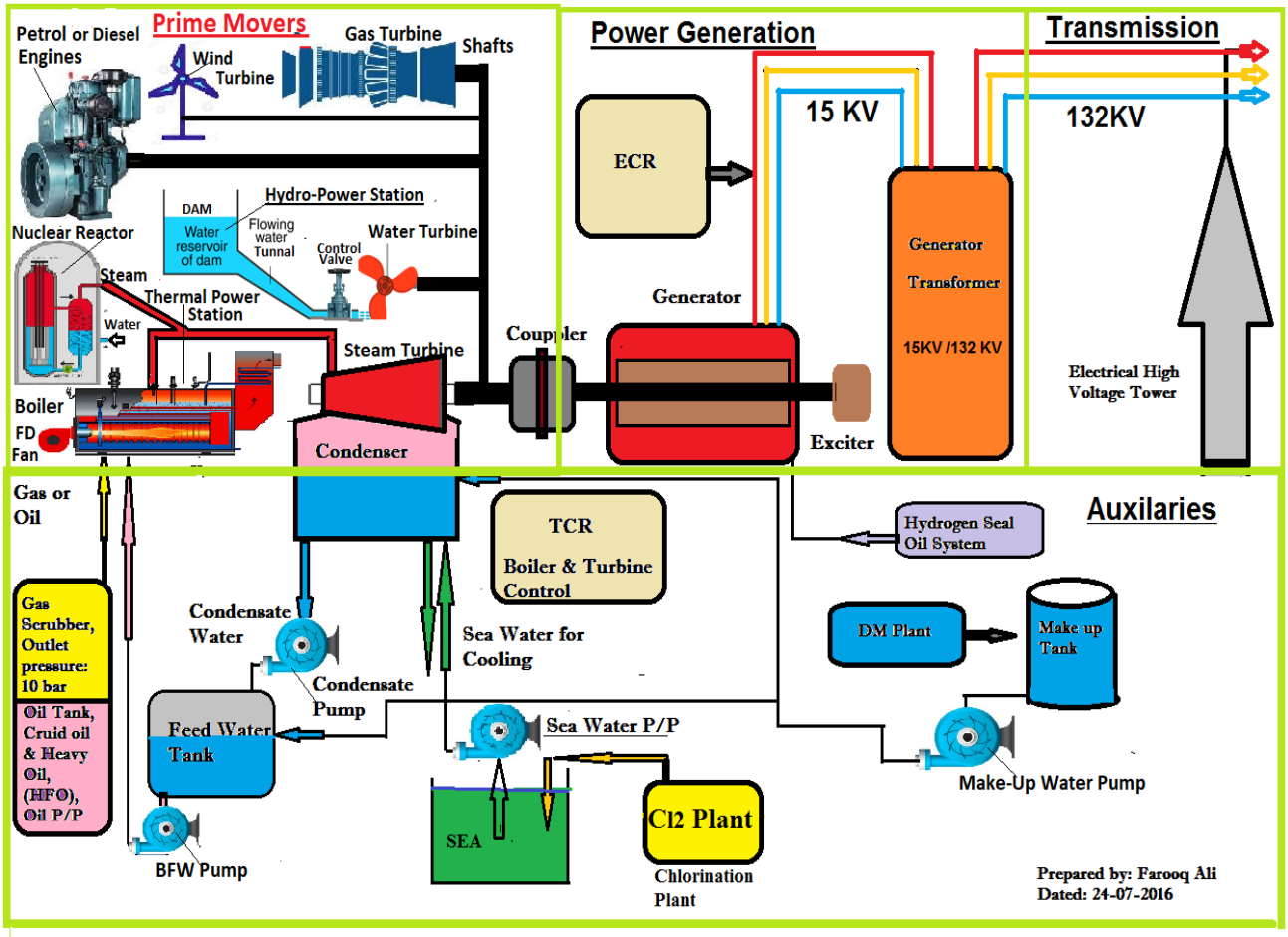
Introduction

Author: **Farooq Ali Chaudhry**

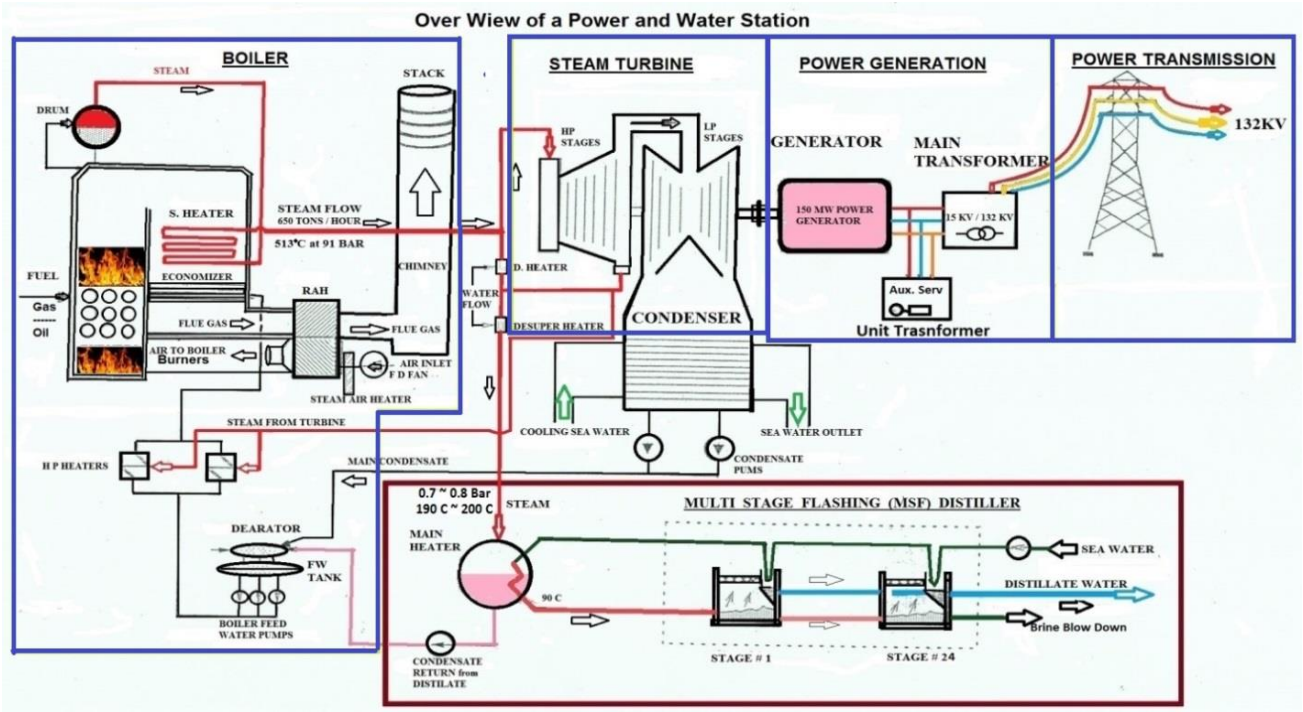
- **Mr. Farooq Ali Chaudhry** has 3 years' diploma of Associate (Assistant) Engineering in Electrical Technology in 1973 from Government collage of technology Lahore Pakistan.
- Experience started from Jan. 1978 to May 1979 at MEW project DEPS for 7 units including common unit of Distillation Plants (MSF) with IHI CO. This was alongside with Japanese engineers of sub. Contractor: YAMATAKE INSTRUMENT CO. Japan – which is one of the well-known industrial instrumentation companies around the globe. Each plant has a capacity of 6 Million Gallons / Day. Calibrated, Configured and installed all field and control room instruments with auxiliaries, commissioned and put in service for production.
- Joined MEW from May 1979 working at Doha East Power & water Station Kuwait, with a total tenure of 39 years and retired January 2019.
- During this period Mr. Farooq Ali Chaudhry has worked on 7 units of Toshiba Turbines with all auxiliaries, each generator having 150 MW capacities.
- Worked on 4 units of FCB Boilers - with all its auxiliaries, each having capacity of 650 Tons/Hr.
- Rejoined as **Senior Instrument Supervisor & Trainer** (for Instrument Technicians and Instrument Engineers) in MEW IMD Section at Shuwaikh Power & Water Station Kuwait as manpower supply through Al-Dhow Contracting Co from January 2019 till Jan. 2022. Here we have 3 Boilers, 3 Distiller Units. Each unit having a capacity of 6 Million Gallons / Day and RO Plant (2 Chains) having a capacity of 30 Million Gallons / Day.
- Engaged with IMD Section Superintendent and Section Engineers by providing technical support in keeping much complex record of spare parts and streamlining spare parts processes in MEW DEPS.
- To spread the knowledge, he has gained throughout his service to MEW DEPS. He decided to pass it on to the coming generation from January 2014 onwards. This included theoretical and practical trainings to new MEW Kuwaiti employee may it be Engineers or Technician.
- Total experience is 44 years in this field at Doha East Power & Water Station and Shuwaikh Power & Water Station Kuwait.
- Mr. Farooq Ali Chaudhry has been rewarded and appreciated "**Twice**" by MEW DEPS Directors, for being internally motivated to training young Instrument Engineers, making an effort to develop several training programs and refining them throughout.

POWER STATION & DISTILLATION PLANTS

INTRODUCTION OF DIFFERENT TYPES OF POWER STATIONS WITH AUXILARIES

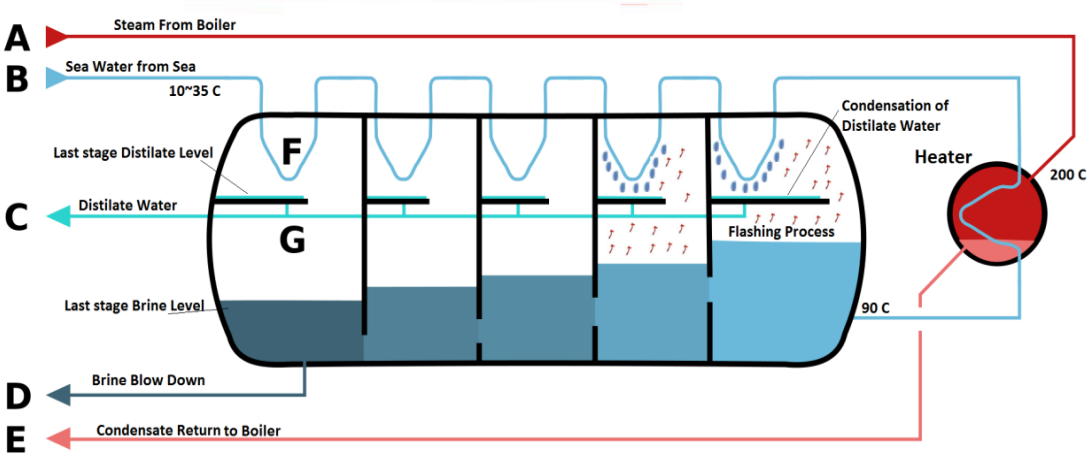


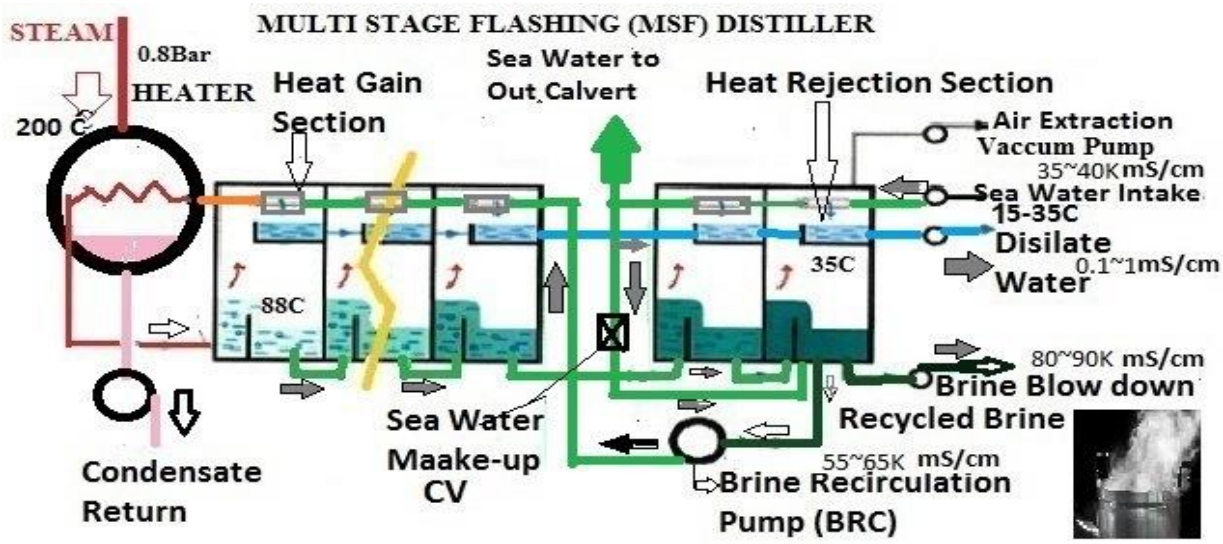
Over View of a Thermal Power Station

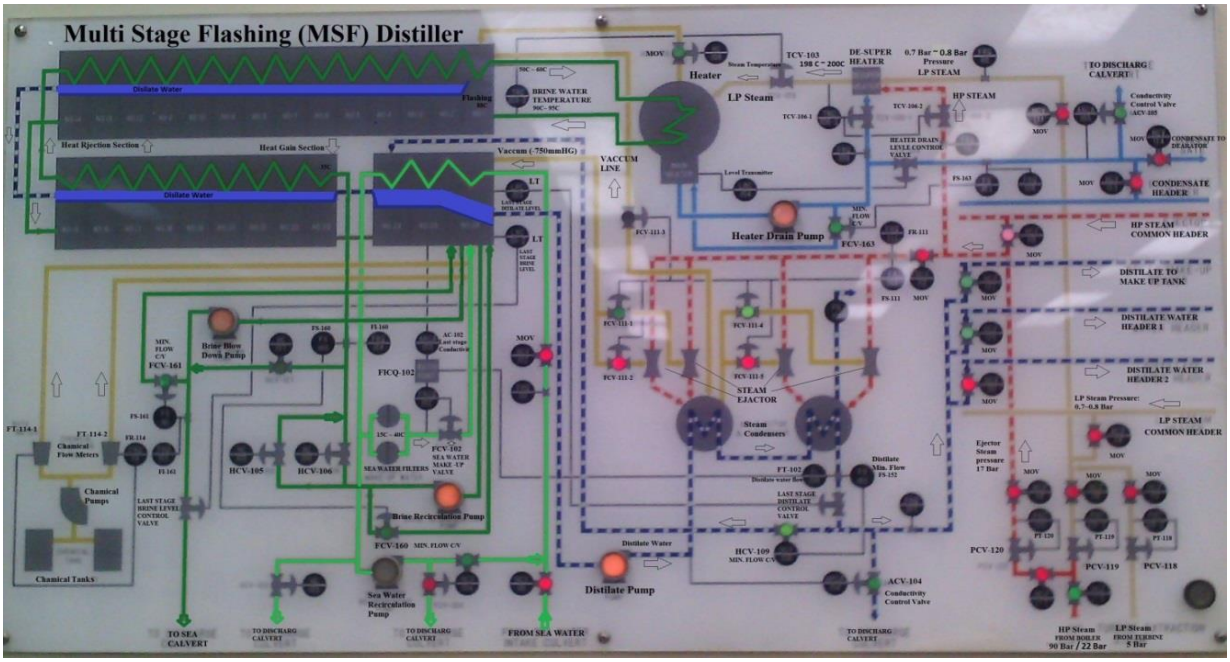


Over View of Distillation Plants

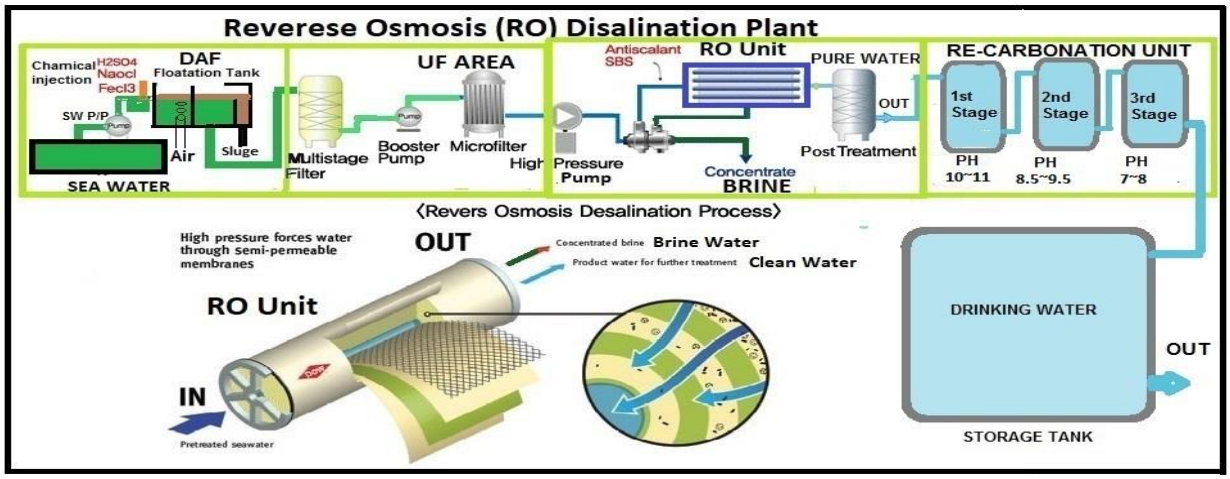
(A) Multi Stage Flashing (MSF)







(B) Reverse Osmosis Plant

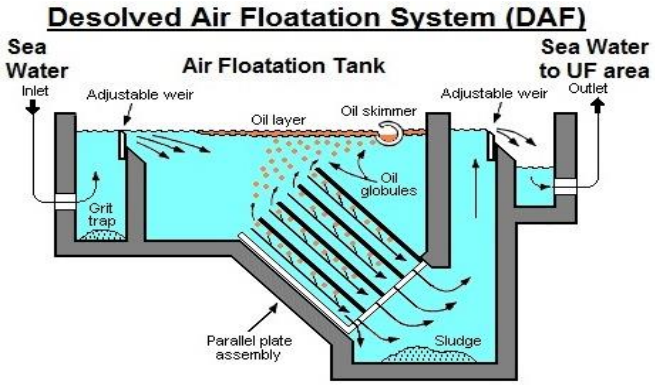


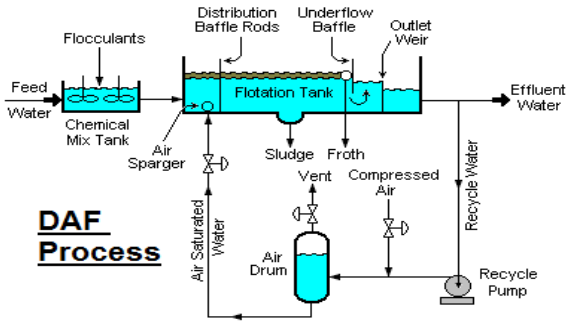
*** Reverse Osmosis plant have 4 main stages.**

(1) DAF (2) UF (3) RO (4) RECARBONATION UNIT

(1) DAF (Dissolved Air Floatation)

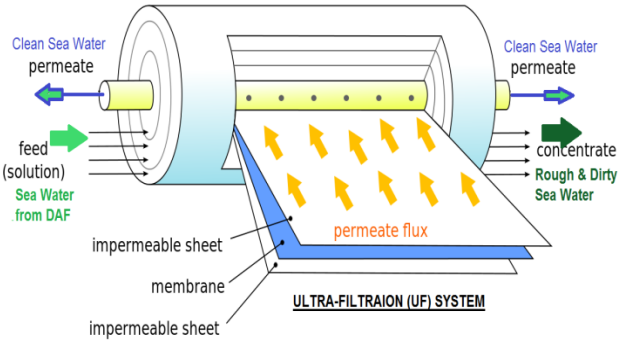
Function: DAF: Removes Grits, Oil, Oil Skimmers & Sludge.





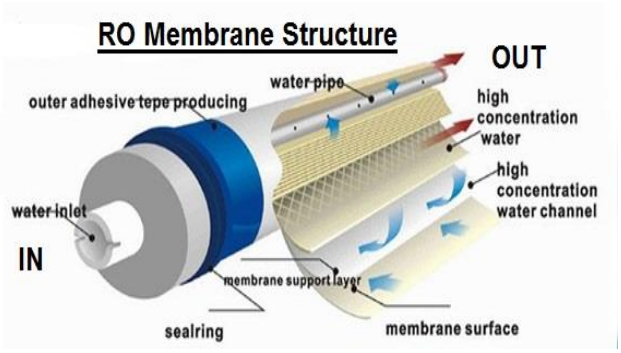
(2) UF (Ultra-filtration)

Function: Removes Solids and Rough & Dirty Sea water.

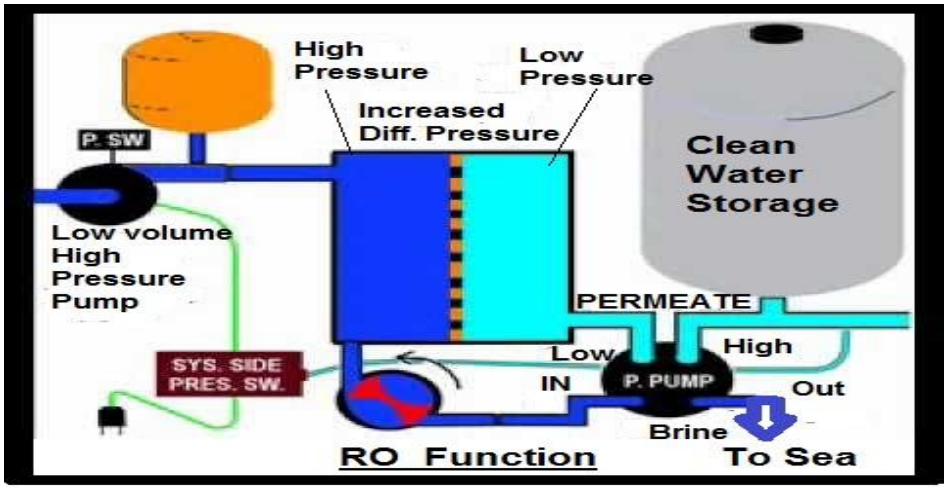


(3) Reverse Osmosis System

Function: Removes un-necessary salts & heavy particles.

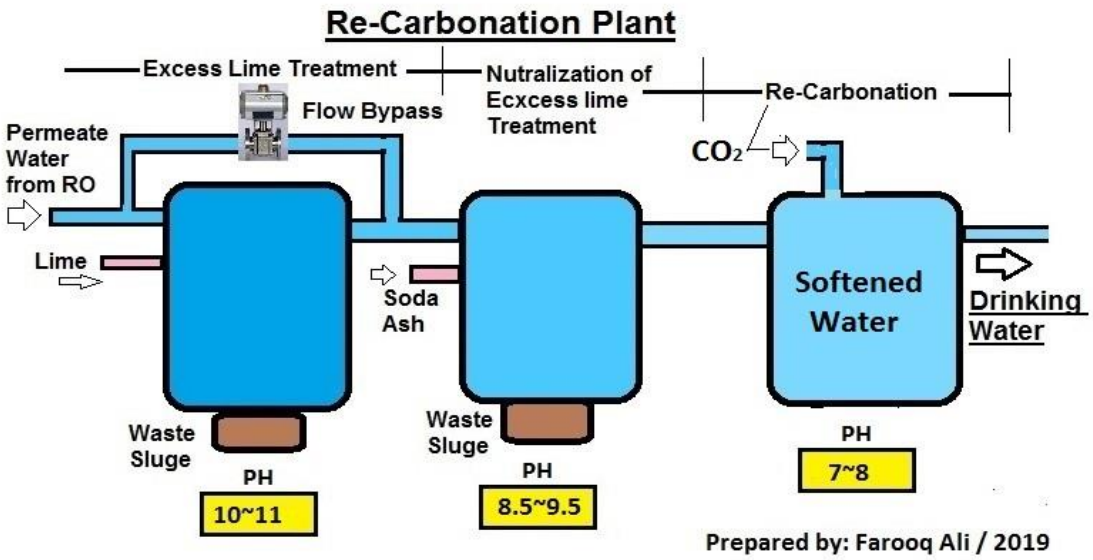


RO Working Principle



(4) Re-Carbonation Plant

Function: Maintaining PH of RO water



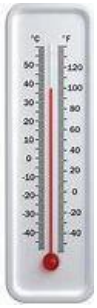
Introduction of

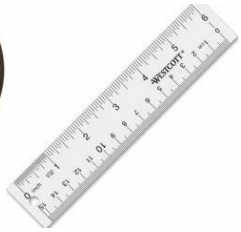
Industrial Instrumentation

Introduction of Industrial Instrumentation

Industrial Instrumentation

(1) Industrial Instrumentation means to Measure a physical quantity (Process Variable "PV") & Control through final control devices (**Control Valves**) to **run the plant in safe condition for better production.**





Instruments may be very simple like:

- **Glass thermometer** to measure heat or cold,
- **Gauge** to measure pressure or temperature etc.
- **Ruler** to measure distance, length or level.

Measuring Systems

There are **many industrial measuring systems available** in the world. Measurement means to **calculate & convert** the **physical quantities** in to **readings** and readings have some units. These are called industrial international systems of measurements.

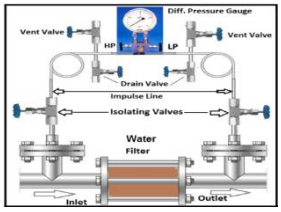
(1) **Imperial System** is a **British System. (FPS System** means **Foot, Pound & Second)**

(2) **Metric System** is a universal measuring system. (Also called **MKS System.)** There are many measuring units are available in this system. Like: **Meter** for Length**, Kilogram** for Weight, **Second** for Time**, Kelvin** for Absolute Temperature**, Ampere, Volt & Watt** for Electrical**, MOL** for Substance / Phenomena **& Candela** for Intensity of Light…etc.

** Most commonly used system in the world is **"MKS"** means **Meter, Kilogram & Second.**

Physical Quantities used in Industries: (Also called Process Variables **"PV")**


Water Pressure



Diff. Pressure


Boiling Water (Temp.)


Water Level


Water Flow

Followings are the most commonly used physical quantities (Process variables) in industrial instrumentations

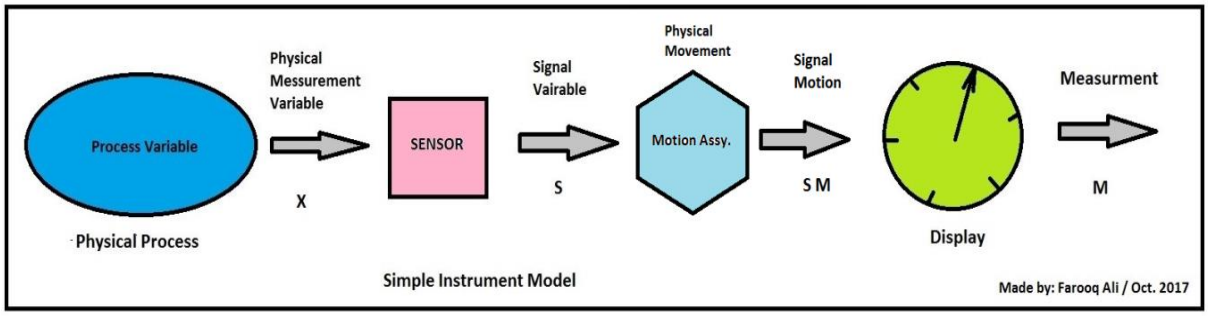
1. **Pressure and differential pressure**
2. **Temperature**
3. **Level**
4. **Flow**

Measurement

Measurement is a **process** to **get reading** on an instrument as shown these Steps.
Any instrument which completes below 5 steps is called **Gauge.**

- 1st step - Physical quantity---------- (Process Variable "PV")
- 2nd step - Sensing element ---------- (Effect on sensor)
- 3rd step - Motion assembly ---------- (Movement assembly)
- 4th step - Pointer movement on a scale ---------- (Needle movement)
- 5th step- Display reading on graduated scale---------- (Showing reading)

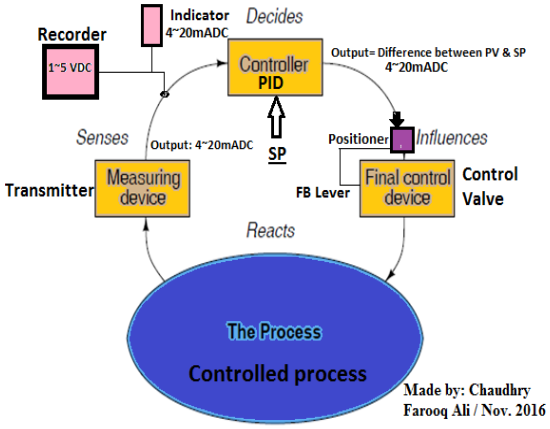
Measuring process by Gauge



Controller & Final Control Devices

Controller is a **device** which senses the **Difference** In between **Process Variable (PV)** **(**Signal received from transmitter) & **Set Point** then send signal to **Control Valve** to maintain the PV in limited value.

Theme of automatic controller

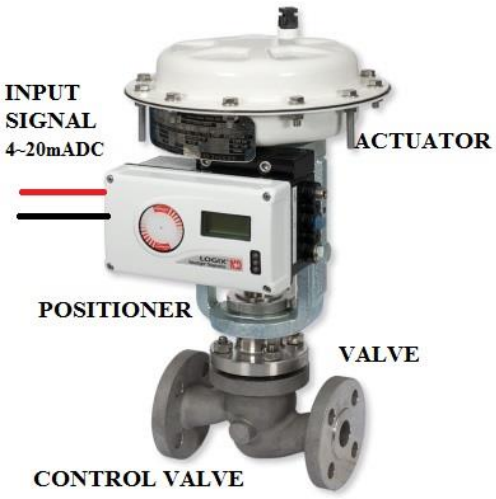


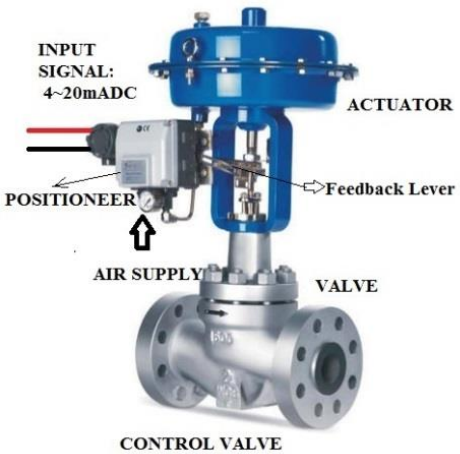
Final Control Devices:

- **ON-OFF Valve Shut-Off valve (OPEN – CLOSE)**



- **Control valves** with positioners





Categories of Industrial Instrumentation

Industrial Instrument Catagories

Field Measuring Instruments

(a) All type of Gauges & Sensors

(b) All type of Transmitters & Sensors

(c) All types of Detectors & Transducers

Controlling system

(a) All types of Controllers & Controlling Modules

(b) All types of Actuators & Control Valves

(c) All types of accessories related to Controlling systems

Supervisory System

(a) All types of Mimics & Indicating Light units

(b) All types of Recorders, & Data Recording System. Including DCS

(c) All types of Analog modules / DCS Analog I/O Cards

(d) All types of Indicators

Annunciation System

(a) All types of Annunciation cards.

(b) All types of Switches related to Annunciators

(c) All types of Auxiliary Relays & Timers.

Protections (Interlocks & Logics)

(a) Protection of pump Motors, Turbines, Generators, Boilers, Generator & Unit Transformers & All Auxiliaries

(b) Interlock and logic Drawings.

(c) Digital I/O cards

Prepared By: Farooq Ali / Jan. 2021

Commonly Used Items

Switch, Relay, Transmitter &

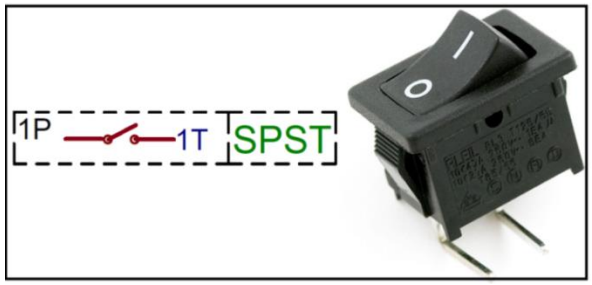
Use of 4~20mADC & Signals

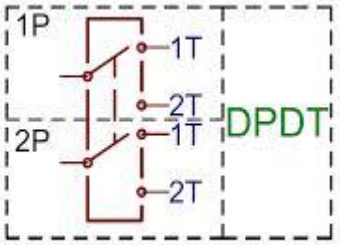
Before we start to understand physical quantities (Process Variables), we should understand basic information of the commonly used items.

1- Switch

Switch is a device which **makes and breaks** the electrical contact or **ON-OFF** contacts. These contacts can be **Normal Open** (**NO**) or **Normal Close** (**NC**).

- **2** Position switch (**ON – OFF)** using two wires is called **SPST** (Single Poll / Single Through) switch. Means 1-Input & 1-Output.
- 4 Position Switch. There is **DPDT** (Double Pole / Double Through) switch having 2-Inputs & 2- Output as shown below.

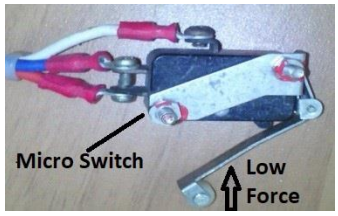


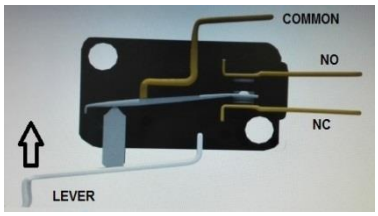


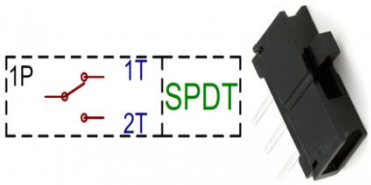
Micro Switch

Micro switch is an electrical **low force operating** switch.

*** 3** Position switch (NO - NC & COMMON). Using 3 wires called **SPDT**. (Single Pole / Double Through) Means 1-Input & 2-Outputs. As shown below.

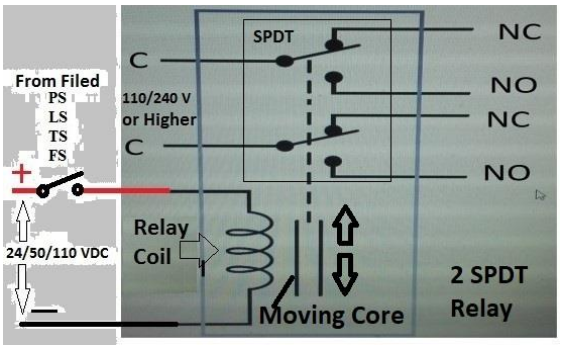


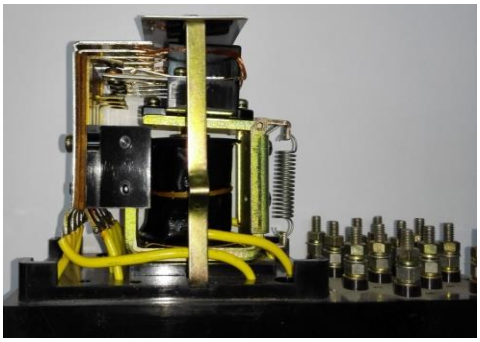




2- Relay

Relay is a device, operating by electrical power supply through **one contact** to energize coil and provides many types of output contacts **(COM. NO, NC = SPDT)**. Relay can be operated by electrical supply either AC or DC.



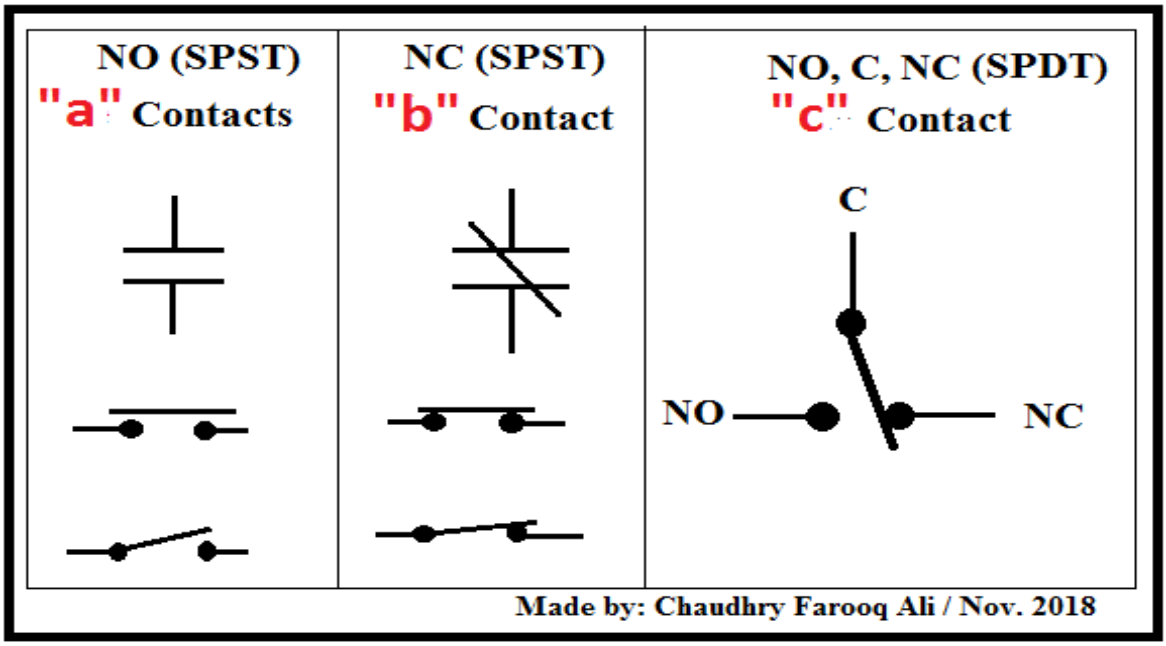


AC means alternate current
DC means direct current.

Use of Different Contacts in Instrument Drawings

When we use SPST / SPDT / DPDT switches in Interlocks drawings, we could not understand that used contacts are closed or open. So some companies used below terms to understand contact conditions used in drawings in rest postion.

a, b & c Contacts



Form "a" contact

"a" Contacts ("Make contacts") Means contacts are open, required to make it. So **"a"** contacts are ***normally open*** **contacts**. This position is in rest condition without external force. To make a contacts need external force. It can be push, energizing magnet or energizing relay. This type of contact is **SPST** contacts.

Form "b" contacts

"b" contacts ("Break contacts") Means contacts are closed required to open it. So **"b" contacts** are **normally closed contacts**. This position is in rest condition without external force. To break the contacts, external force is required. Its operation is logically inverted from Form A. External force can be push, energizing magnet or energizing relay. This type of contact is **SPST** contacts.

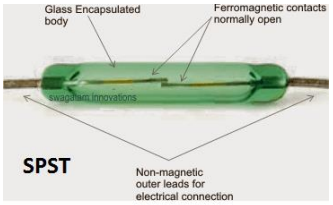
Form "c" contacts

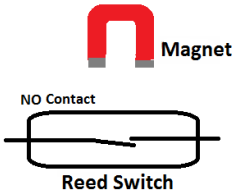
"c" **Contacts** ("Change" or "transfer" contacts) are composed of a normally closed contact pair and a normally open contact pair that are operated by the same device; there is a common electrical connection between a contact of each pair that results in only three connection terminals. These terminals are usually labeled as ***normally open***, ***common***, **and** ***normally closed*** **(*NO-C-NC*).** This type of contact is **SPDT** contacts.

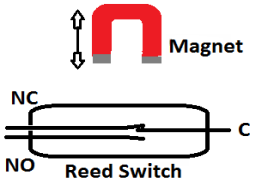
3- REED Switch

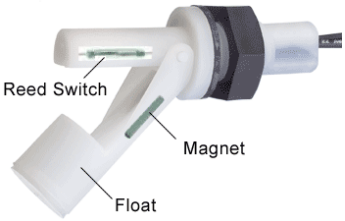
* A reed switch consists of **two or three springy Ferro-magnetic plates** called reeds plated, long-life contacts at the tips and capsulated in a sealed glass tube. The **two-reed** type has normally open (NO) contacts, which close (NC) when permanent magnet comes near it. This is called SPST Reed Switch.

* A **three-reed** type is a changeover switch. It has a pair of normally Open (NO) and a pair of normally Closed (NC) contacts & Common terminal (C) contact. Reed switches are actuated by an external permanent magnet field or electromagnet field placed in close position.









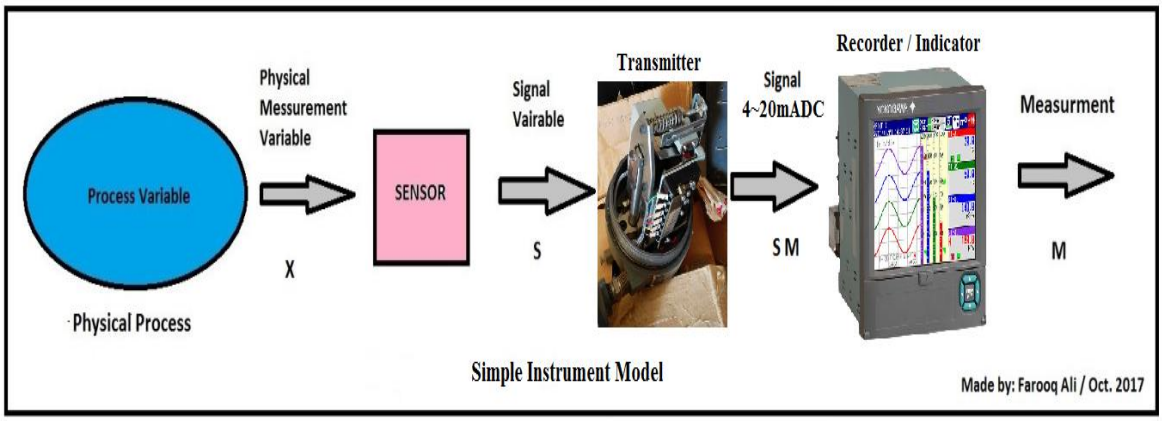
Requirement of a Transmitter

Any gauge is showing reading in local area. We need an instrument which can transmit process variable (PV) values to the control room, where we can record and control all above process variables. That's why we need an instrument which can transmit (PV values) from field to control room. This instrument is called transmitter.

Transmitter: (Steps of Transmitter)

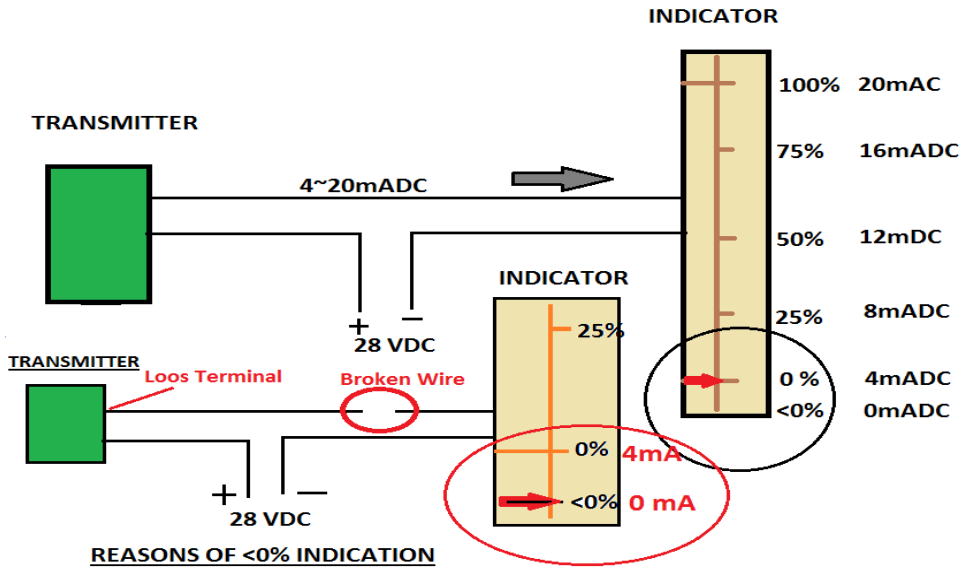
- Transmitter is a device which **senses the process variable** through sensor.
- Sensor transfers his **effects** to motion assembly.
- These motions convert into electrical current **4~20mADC** with the help of electrical power supply and transmit this **4~20mADC** to Indicator or Recorder or controller.
- Then **4~20mADC** converts in **PV** readings and record these values in a recorder. As shown bellow

Measuring process by a Transmitter



- All types of transmitters transmit **4~20mADC** to the control room to record and control the process variable (PV) through the controllers and control valves.

WHY WE USE 4~20 mADC ?, WHY NOT USE 0~16 mADC



REASONS OF <0% INDICATION

1- WIRE BROKEN OR POWER IS OFF
2- WIRE NOT CONECTED WITH TERMINAL
3- ANY SCREW LOOSE IN THIS CONDITION SOME TIME INDICATOR SHOWS 0% AND SOME TIME <0%
4- IF WE USE 0~16mADC, AT 0mADC WE CAN NOT KNOW THAT LOOP IS HEALTHY OR NOT. THAT IS WHY WE USE 4mADC. THE INDICATOR WEILL SHOW US 0% AT 4mADC.

WHY WE USE CURRENT (I) TO TRANASFER PV FROM FIELD TO CNTROL ROOM? WHY NOT VOLTAGE (V)

OHMS LAW

I = V/R (I= CURRENT, V= VOLTAGE, R= RESISTANCE)

ACCOURDING TO OHMS LAW. R IS INVERSLAY PROPORTIONAL TO V
If (R) will increased then (V) will decrease or if (V) will increased then (R) will decrease.

EXAMPLE:

Cable input: 10VDC output: 5vdc
L=10M has R =100 ohms

Cable input= 10Vdc output= 2.5vdc
L: 20M has R=200ohms

Means: if cable Lenght will increase from field to control room, voltage at end will be drop with respect of resistance of cable. Due to this reason we can not use votage (V) to transfer signal from field to control room.

RESULT: Current always will be same at start of cabel till end of cable. Even Lenth of cable is no metter.

THAT IS THE REASON WE USE CURRENT (4~20mA DC) TO TRANSFER SIGNAL OF PROCESS FROM FIELD TO CONTROL ROOM

WHAT IS PROCESS VERIABLE (PV)

PV Means Signal at real time or present time. It changes in each second

NOTE: Any signal in past time will be called history.

Prepared by: Ch. Farooq Ali / 22-08-2016

Commonly used Signals in Industial Instrumentation

1- Signals from Field Instruments to Control Room

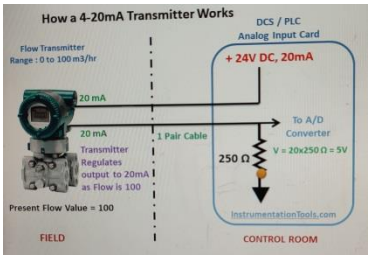
a) **4~20mADC**, Current signal from **All Transmitters** to control room. (Like: Pressure, Differential pressure, Flow, Level, Analyzers Transmitters, Valve position Transmitter & Temperature Transmitter if installed in field.

b) **Milli Volt (mV) & 1~5 V DC:** from all types of Thermocouples to mV / V/I Converter.

c) **Resistance Transducers (Ω)**: From Resistance Temperature Detector (RTD Pt100 Ω at 0C) to Volt Converter (RTD / V/I).

d) **ON / OFF or Binary Nos. / Digital Signal (0-1):** Contacts / Digital Signals from **All types of Switches** to DCS Digital Input Cards / Relays. (Like: Pressure, Differential pressure, Flow, Level, Temperature & Limit Switches installed in field)

e) **1~5 VDC**: 250 **Ω** Resistance is used to convert **4~20mADC in to 1~5 VDC** by using Ohms Law. **V= I x R** (Where **I** = 4~20mADC and **R** = 250 Ohms)



2- From Control Room to Field Instruments

f) **4~20mADC**, Current Signal from **All PI & PID** Controllers to all I/P Converters or SMART positioners to operate the control valves.

g) **0.2 ~ 1.0 Bar / 3~15PSI** Pneumatic Signal from **I/P converter / in SMART Positioner** to operate the control valves.

h) **ON / OFF or Binary Nos. / Digital Signal (0-1)**: Contacts / Digital Signals from **DCS Digital Output Cards / Relays** allow control power supply to the Solenoid Valves installed on Shut-Off Valves & Control Valves.

i) **110 VDC / (24VDC Used in DCS):** Control Power Supply to **All Solenoid valves** installed on Shut-Off valve & Control Valves.

Pressure

&

Differential Pressure

Pressure & Differential Pressure

Pressure: **Pressure** is the **amount of force** applied over the **specific size of the area.** (Per unit area)

$$P = \frac{F}{A}$$

To understand **(Force "F"),** let's understand the followings

Mass: Every Substance / Element / Object / Material on the earth is Mass. Every mass has density.

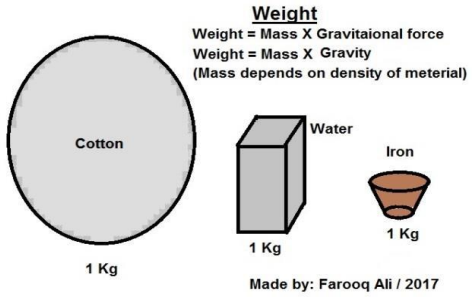
So Mass = Object X Density

Weight: Weight is the **Gravitational force** in between the **Mass (Object) and the Earth**. Object has more weight if it has more mass.

So Weight = Mass X Gravity

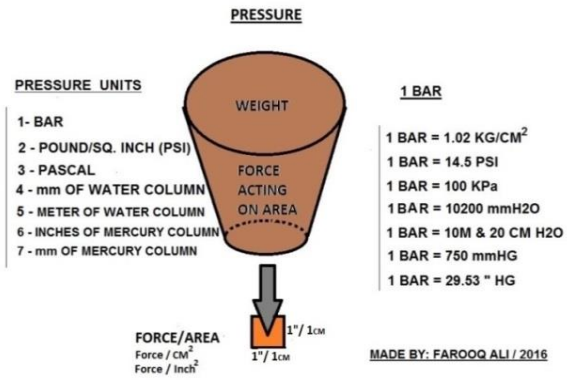
So Weight = Object X Density X Gravity

(This Weight is called Force)



Now we know the Definition of Pressure

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$



Units of Pressure are as follows

(1) PSI (2) Bar (3) mmH2O (4) Pascal

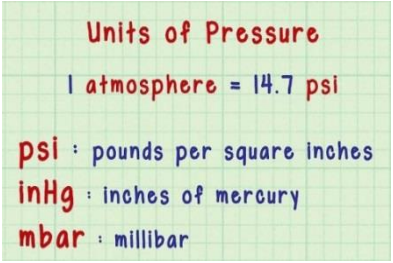
Pressure conversion chart in different pressure units

Pressure Units Conversion Chart

Pressure Units	PSI	atms.	"H_2O	mm H_2O	CM H_2O	oz/in²	Kg/cm²	"Hg	mm Hg (Torr)	cm Hg	mbar	Bar	Pa (N/m²)	kPa	MPa
Psi	1	0.0681	27.71	703.8	70.38	16	0.0704	2.036	51.715	5.17	68.95	0.0689	6,895	6.895	0.0069
Atms	14.7	1	407.2	10,343	103.43	235.1	1.033	29.92	760	76	1013	1.013	101,325	101.3	0.1013
Inch H2O	0.0361	0.00246	1	25.4	2.54	0.5775	0.00254	0.0735	1.866	0.187	2.488	0.00249	248.8	0.249	0.00025
mm H2O	0.001421	0.000097	0.0394	1	0.1	0.0227	0.0001	0.00289	0.0735	0.00735	0.098	0.000098	9.8	0.0098	0.00001
Cm H2O	0.01421	0.000967	0.3937	10	1	0.227	0.001	0.0289	0.735	0.0735	0.98	0.00098	98	0.098	0.0001
Oz/In2	0.0625	0.00425	1.732	43.986	4.4	1	0.0044	0.1273	3.232	0.3232	4.31	0.00431	431	0.431	0.00043
Kg/Cm2	14.22	0.968	394.1	100,010	1,001	227.6	1	28.96	735.6	73.56	980.7	0.981	98,067	98.07	0.0981
Inch Hg	0.4912	0.03342	13.61	345.7	34.57	7.858	0.0345	1	25.4	2.54	33.86	0.0339	3,386	3.386	0.00339
mm Hg	0.01934	0.001316	0.536	13.61	1.361	0.31	0.00136	0.0394	1	0.1	1.333	0.001333	133.3	0.1333	0.000133
Cm Hg	0.1934	0.01316	5.358	136.1	13.61	3.1	0.0136	0.394	10	1	13.33	0.01333	1,333	1.333	0.00133
m Bar	0.0145	0.000987	0.4012	10.21	1.021	0.2321	0.00102	0.0295	0.75	0.075	1	0.001	100	0.1	0.0001
Bar	14.504	0.987	401.9	10,210	1021	232.1	1.02	29.53	750	75	1,000	1	100,000	100	0.1
Pa (N/m2)	0.000145	0.00001	0.00402	0.102	0.0102	0.00232	0.00001	0.000295	0.0075	0.00075	0.01	0.00001	1	0.001	0.000001
Kpa	0.14504	0.00987	4.019	102.07	10.207	2.321	0.0102	0.295	7.5	0.75	10	0.01	1,000	1	0.001
Mpa	145.04	9.869	4019	102,074	10,207	2321	10.2	295.3	7500	750	10,000	10	1,000,000	1,000	1

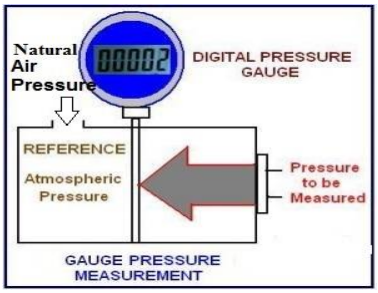
Different Types of Pressure Measurement

There are 4 types of pressure measurement

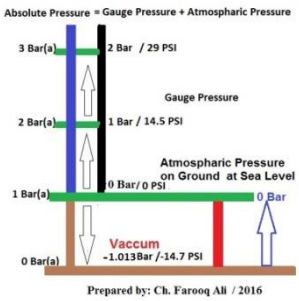


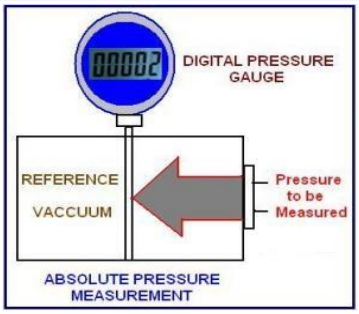
1. **Atmospheric pressure:** The **Mass** of air has weight and this weight is pressing downward to earth causing atmospheric pressure. So air pressure acting on the earth at sea level is called atmospheric pressure.

2. **Gauge Pressure**: Pressure above the atmospheric pressure is called gauge pressure.

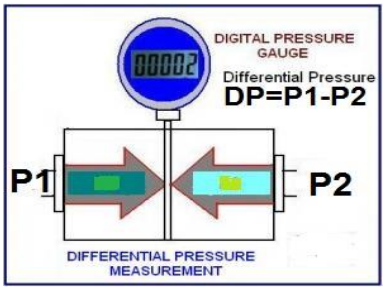


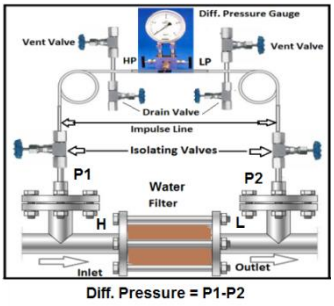
3- Absolute Pressure: Atmospheric pressure + Gauge pressure is called absolute pressure.





4- Differential Pressure: The difference between any two measured pressures is called differential pressure.





Example:

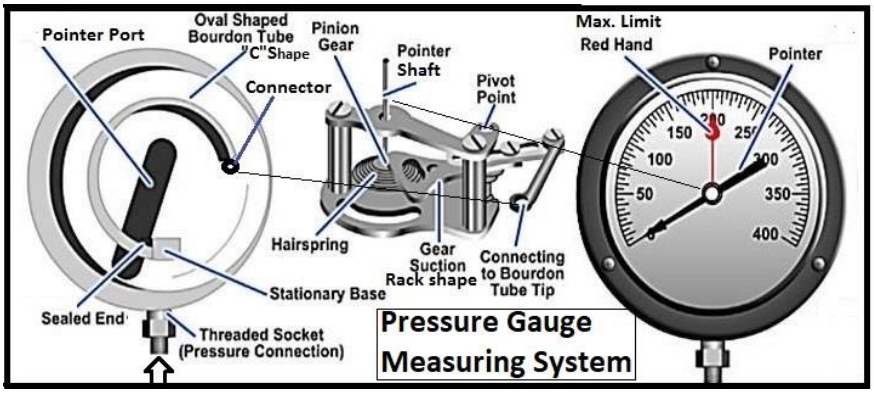
Two pressures act on the wall of the car tyre,

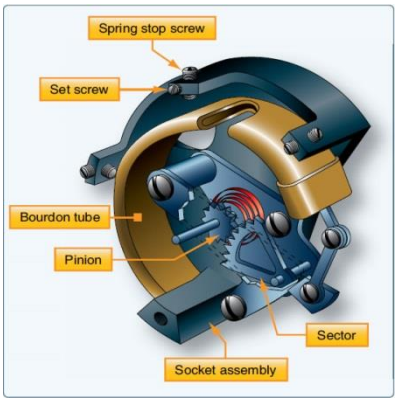
1- The pressure of the atmosphere on the outside of the tyre.
2- The pressure we read on the gauge when air is pumped into tyre.
3- Due to the difference of 2 pressures, car tyre lifts up.

Pressure Gauges & Sensors

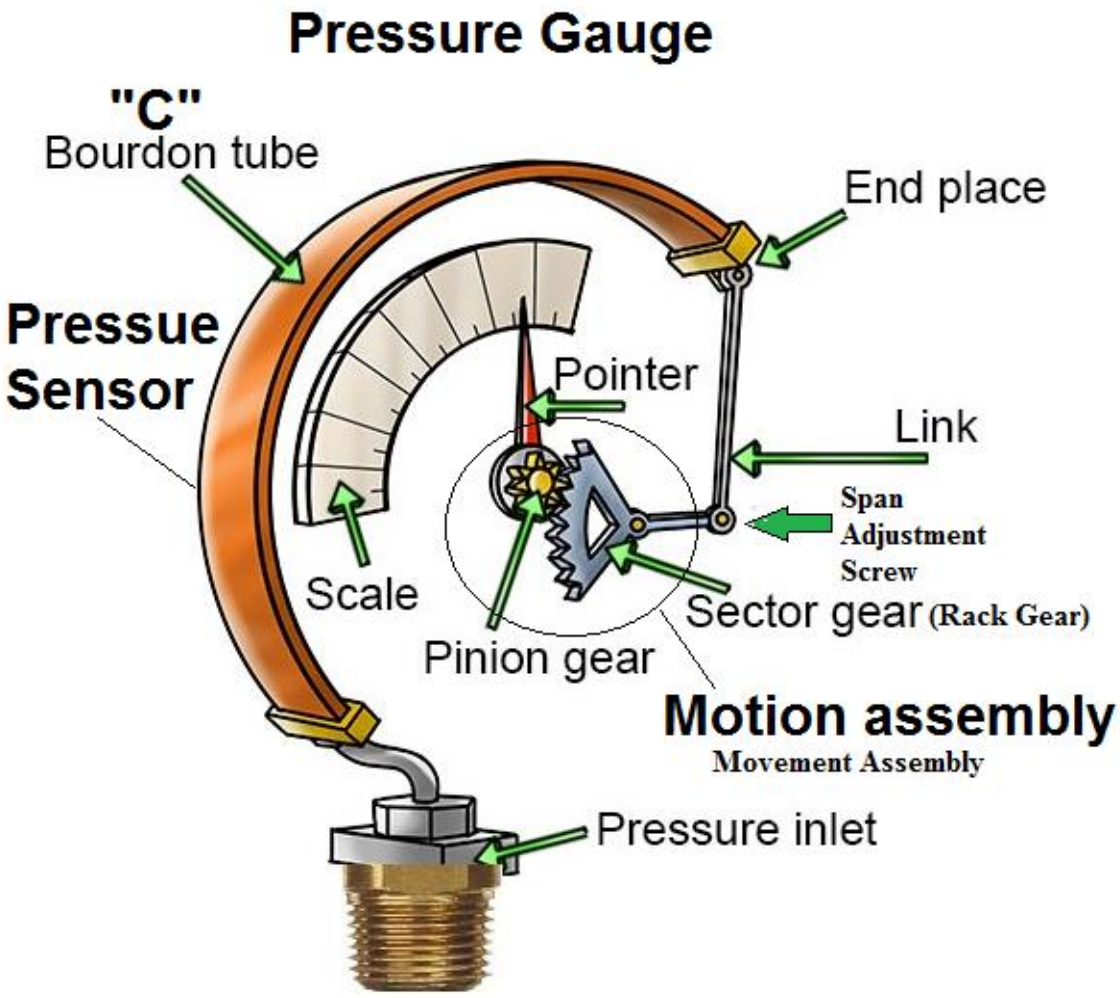
- **Pressure Gauge**

It is a device which takes **process pressure** through the **input port** and expands the **sensing element** and transfer expanding movement through the **movement assembly** to the **pointer** which moves on **scale** of the gauge. This measuring device is called **Pressure Gauge**.





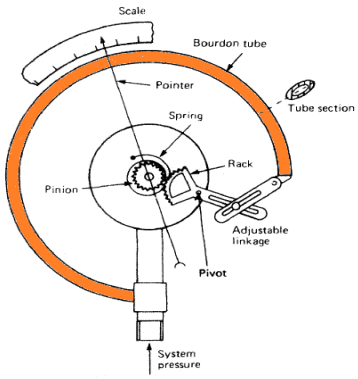
Pressure Gauge and Parts Names:



SENSORS OF PRESSURE & DIFF. PRESSURE

There are many types of pressure sensing elements.

- **C – Bourdon**



The working principle of a "C" bourdon tube

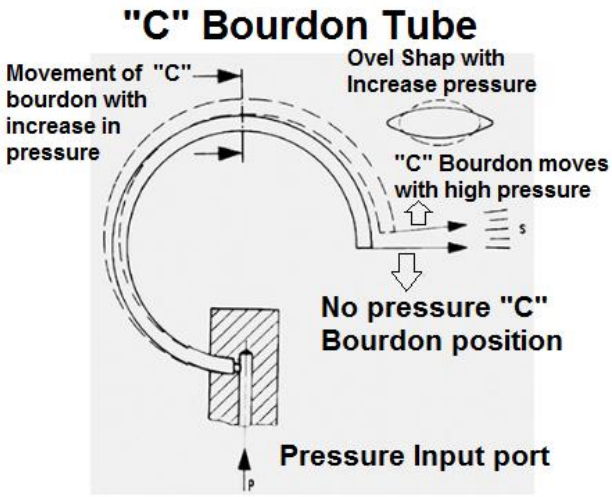
* Outer diameter of "C" bourdon is bigger than the inner diameter of "C" bourdon. Due to the oval shape of "C" bourdon, the area of outer side is bigger than the inner side. So "C" bourdon tries to become in round shape and expands upper side. So movement takes place.

Working principle is called

(Force & Balance Principle)

Spiral

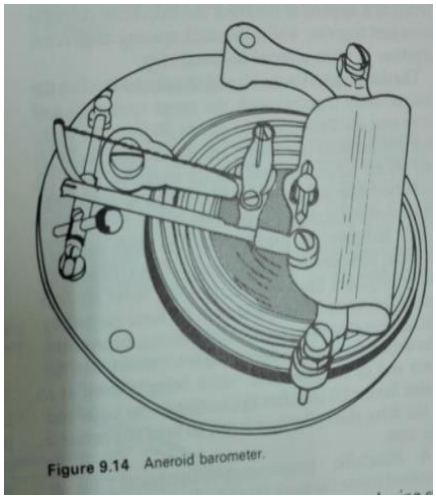
Beloon



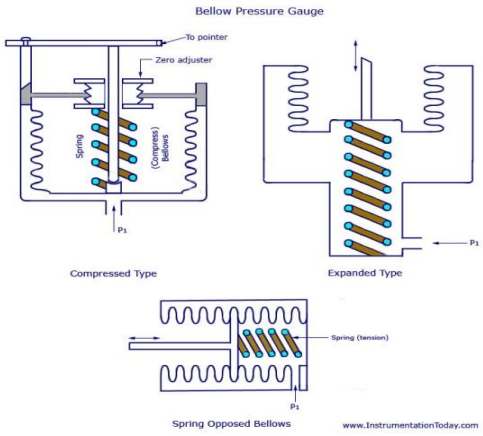
- **Spiral bourdon**

- **Helical spiral bourdon**

- **Diaphragm (Used for very Low pressure in mmH2O water column)**

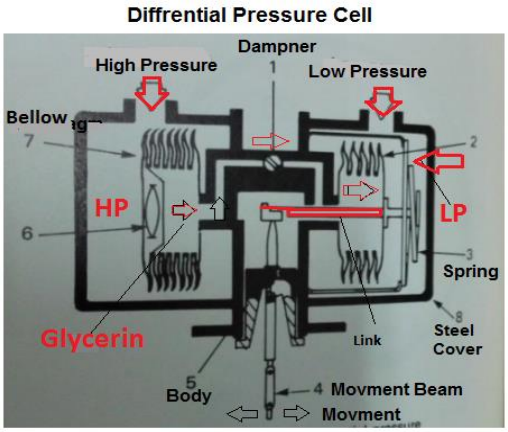


- **Bellow**



Differential Pressure Cell (Diff. Pressure = P1-P2), P1= High & P2 = Low

Conventional DP Cell



SMART DP Cell

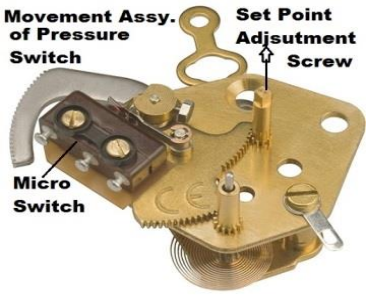
○ Pressure & Differential Pressure Switch

Pressure / Diff. Pressure Switch

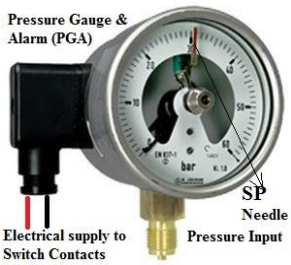
If we use a **Micro Switch** in the pressure / Diff. Pressure Gauge, can **adjust the Set Point** and get **ON – OFF** contacts at required set point value is called **Pressure / Diff. Pressure Switch**.

ON-OFF contact can be used for **ALARM** in control room or **START /STOP** Pump Motor.

There ae two types of pressure & differential pressure witches (1) Indicating type (2) blind type.

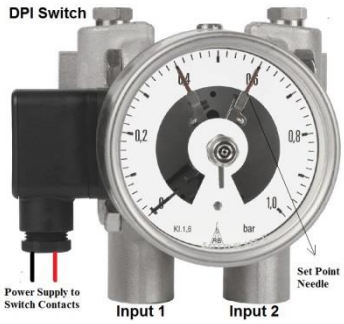


Micro Switch

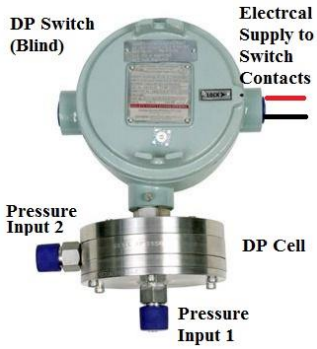


Pressure Switch (Indicating)

Pressure switch (Blind)

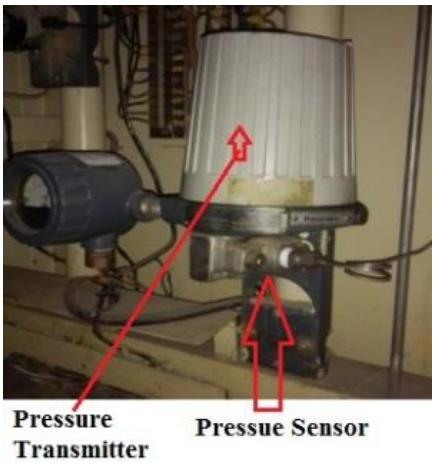


Differential pressure switch (Indicating)



Diff. Pressure Switch (Blind)

- # Pressure / Diff. Pressure Transmitter



Pressure & diff. pressure transmitter is a device, which detects pressure or differential pressure, and regulate the analog output current in to 4~20mADC or regulate Digital output according to the input Process Variable (PV) and transfer to the control room. We can record process values and control the all process variable with help of controllers.

We have 2 types of pressure transmitters.

A- **Analog** Pressure Transmitters.
Output: 4~20mADC

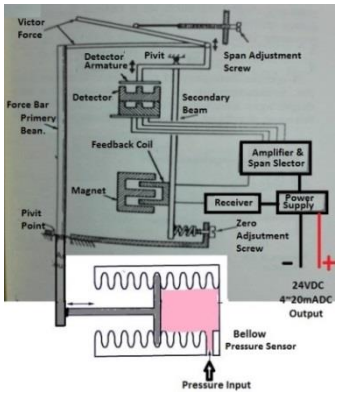
B- **SMART** Pressure & Diff. Pressure Transmitters

(1) Digital Output **(2)** Analog output: 4~20mADC

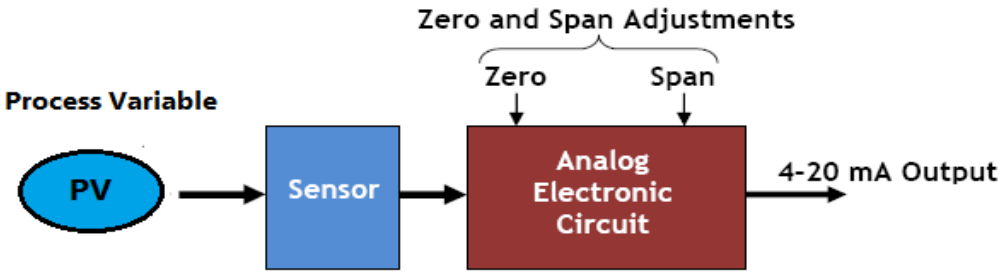
SMART Diff. Pressure Transmitter

1- **Analog Transmitter:** This type of transmitters is blind and duff. Even doesn't know his Tag No. Only have sense to detect effects of PV to Pressure or Diff. Pressure Sensor. Working principle **Force Balance principle.** This type of transmitters only produces current **(4~20 mADC)** and transmit from field to control room.

Draw Back: Analog transmitter cannot remember anything when removed from the field because he doesn't have memory.

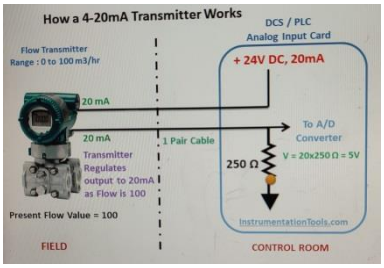


Analog Transmitter Function Block



(A) Formula to convert current in to Voltage is called Ohms Law:

I= V/R or V= I X R (I= mA, R= Ohms)



2- S.M.A.R.T Transmitter: means

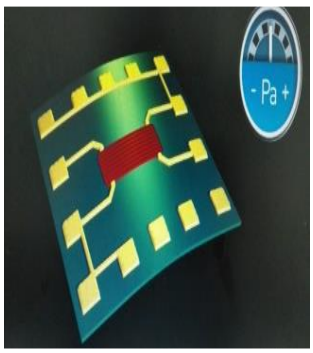
Single, Modular, Auto-ranging, Remote, & Transducer

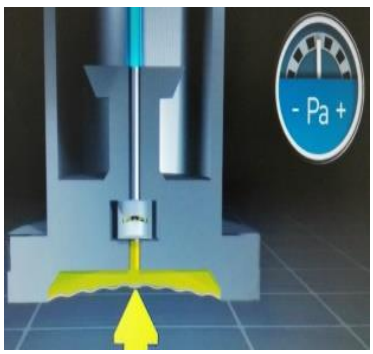
& S.M.A.R.T. (**Self-Monitoring, Analysis, And Reporting Technology**; written as **SMART**)

SMART Transmitter

SMART It is a universal type Transmitters having many functions.

1- **SMART Transmitter has processor and memory**.
2- He can remember everything what we feed any data.
3- He can communicate with communicator from long distance.
4- We can **configure** his Tag No. Process Name, all data to be measured and Unit to be Calibrate according to required Range.
5- It has **Memory unit** we can recall history of transmitter.
6- We can **communicate &** Calibrate (Low & High Range) / **Trim (LRV & HRV)** in different units and ranges through communicator.
7- We can **configure calibration and maintenance schedule** in its memory.
8- It can communicate through communicator in different protocol i.e. **HART, PROFIBUS & BRAIN.** These transmitters can be used with any network and DCS systems.

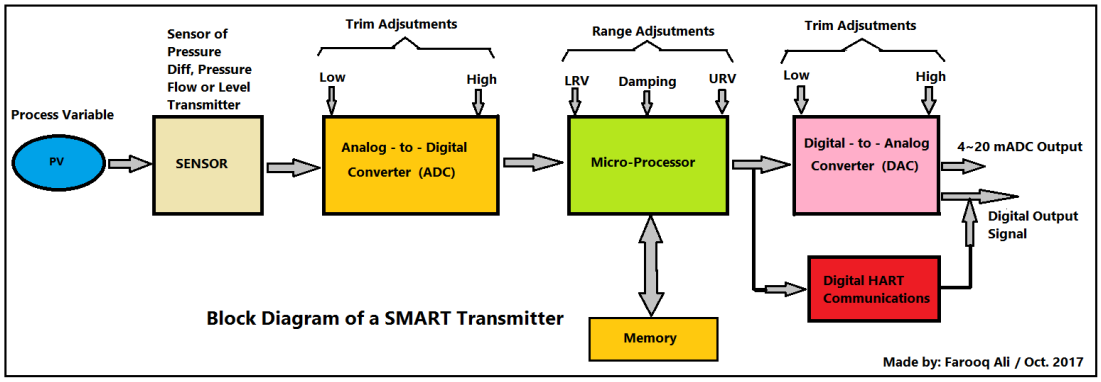




SMART Transmitter Sensors Working Principle:

- **DP HARP (D**ifferential **P**ressure **H**igh **A**ccuracy **R**esonant **P**ressure).
- **Piezo-Resistance:** The **Piezo-Resistive** effect is a change in the Electrical Resistivity of a semiconductor or metal.

SMART Transmitter Function block



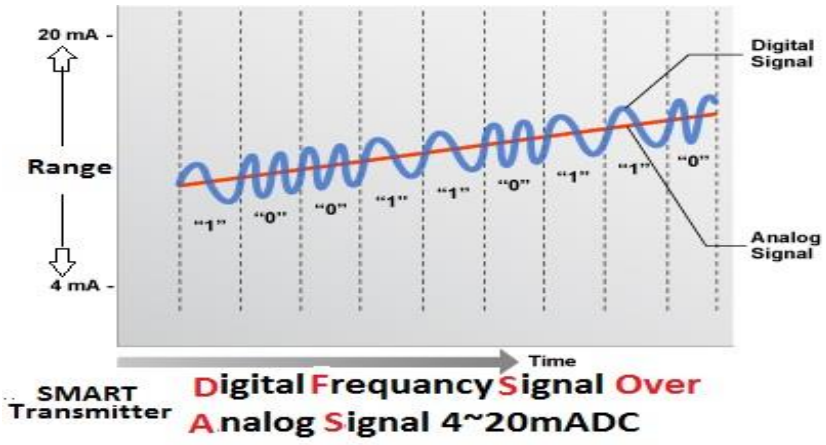
HART Protocol

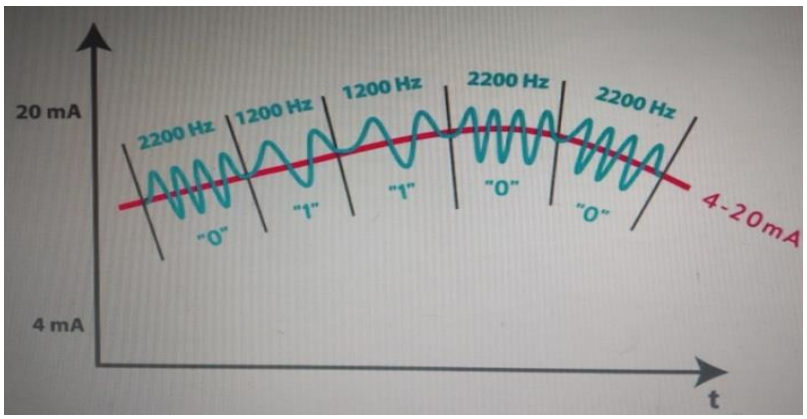
Highway Addressable Remote Transducer

HART is the working protocol of HART instruments

HART Transmitter has 2 out puts.

1- **Analog Current output (4~20 mADC)**
2- **Frequency output as communication signal (0 / 1)**





TEMPERATURE

Temperature

A temperature means **Hot** **or** **Cold** energy, means thermal energy in any object. It is measured by a thermometer.

Temperature is a **physical quantity / conditions** expressing **hot and cold.**

- **Temperature** means intensity of **heat** present in any abject.
- Means any object is how much **hot or cold.**
- Temperature is calibrated in one or more temperature scales.

Temperature Units:

- **The Celsius (**^{o}C**)** scale is known as a Universal System Unit. It is used in most countries.
  Water freezing point is **"0"** degree Celsius **(^{o}C)** and boiling point is **"100"** degree Celsius **(^{o}C).**

- **The Fahrenheit** also commonly used in many countries.
  The freezing point of water is at **"32"** degrees **(F)** and the boiling point are at **"212"** degrees **(F)** as shown below thermometer.

- **The Kelvin** scale is designed to go to **Absolute Zero**. **Means absolute fozen**. The freezing point of kelvin is **"273"** degree **"C"** and boiling point is **"373"** degree "C". This unit is not used in industries instrumentation.
  "0 Kelvin" means stop motion of electrons and molecules in an atom.

Glass Thermometer

Thermometer: It directly measures the temperature of any process. Thermometer is made by glass and graduated in Degree **C** or Degree **F**.

Thermometer can be filed by mercury or any liquid which proportionally expand with heat.

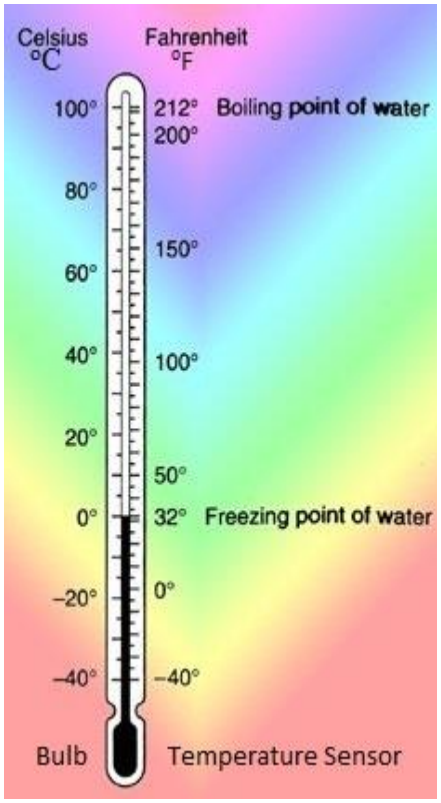
Standard FORMULA of Temperature Convertion.

$$\frac{C}{100} = \frac{\mathrm{F} - 32}{180}$$

Driven Formulas from Standard Formula.

$$\mathrm{C} = \left(\frac{5}{9}\right) X\ (F - 32)$$

$$\mathrm{F} = \left[\left(\frac{9}{5}\right) X\ C\right] + 32$$



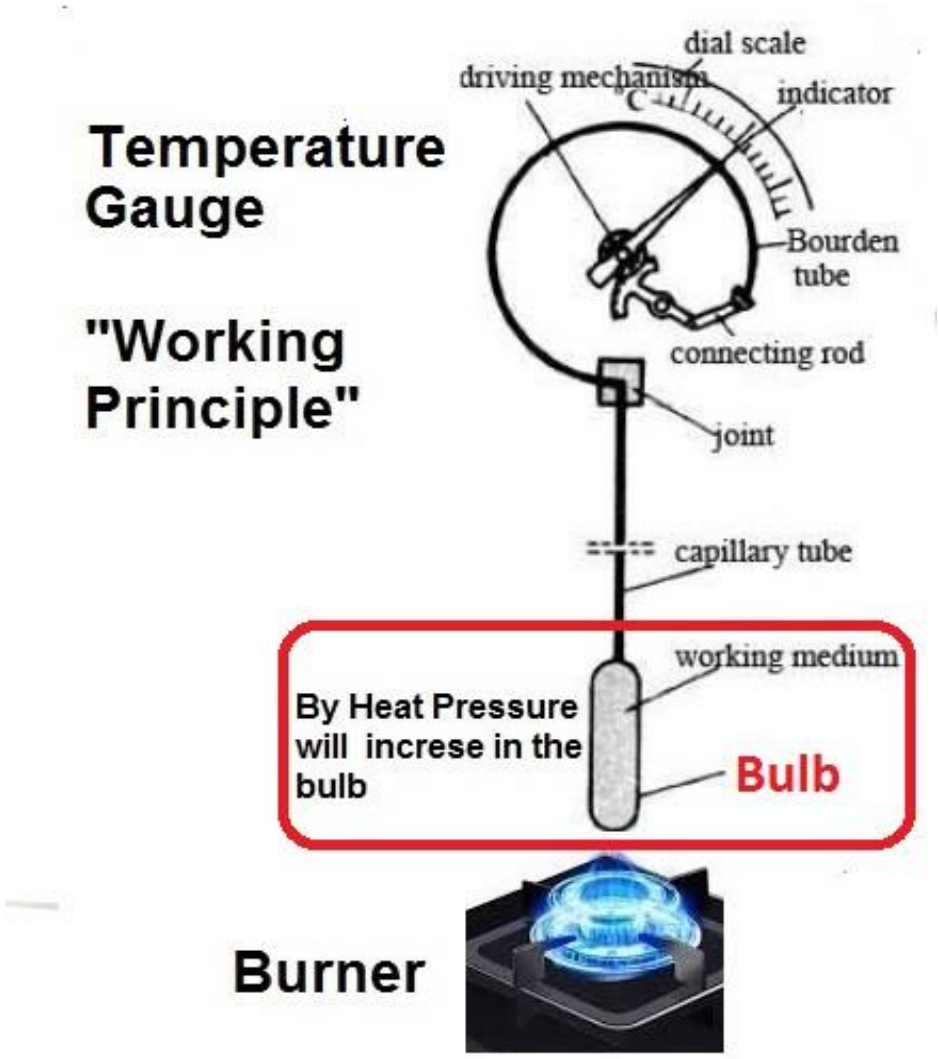
Temperature Measuring Sensors

There are 4 types of sensors of temperature.

1. **Thermometer** (As shown in above page)
2. **Bulb** (Used in Temperature Gauges)
3. **Thermocouple** (T/C)
4. **Resistance Temperature Detector** (RTD)

Temperature Gauge

- It is just like a pressure gauge having **Bulb welded with input port**.
- Filed with mercury or gas. Heat expands the Mercury or Gas in the "C" bourdon.
- This expansion of bourdon is transferred to movement assembly.
- Which moves the pointer on the temperature graduated scale?
- By heating the bulb, we can read the temperature of any process



Note:

All types of pressure sensors also used in all type of Temperature Gauges & Temperature Switches as shown in chapter 3.

Ambient Temperature Compensation in a Temperature Gauge

We have 2 types of temperature gauges used in industrial instrumentation**.**

1- **Direct mount temperature gauge,** which is directly installing in the process pipe under sun shine.
2- **Remotely mount temperature** gauge, which has capillary length from **3 meters to 20 meters** or more. In this system temperature gauge is always away from the Temperature sensor **(Bulb**).

Capillary Tube:

Capillary tube is thin SS tube (Filled with Liquid or Gas. It is covered by metallic and plastics sheath and laid down in the cable trey under sun. Due to the atmospheric heat effects gas or liquid filled in the SS capillary is affected and ambient temperature is adding in the process variable reading.

Temperature Compensation:

A compensation system is installed in the temperature gauge to take actual temperature of process variable. This system removes the ambient temperature effects from the actual reading of process. It works opposite of main sensor in the gauge. That is the reason, we need temperature compensation system in the all temperature gauges.

There are 2 types of temperature compensation in a temperature gauge.

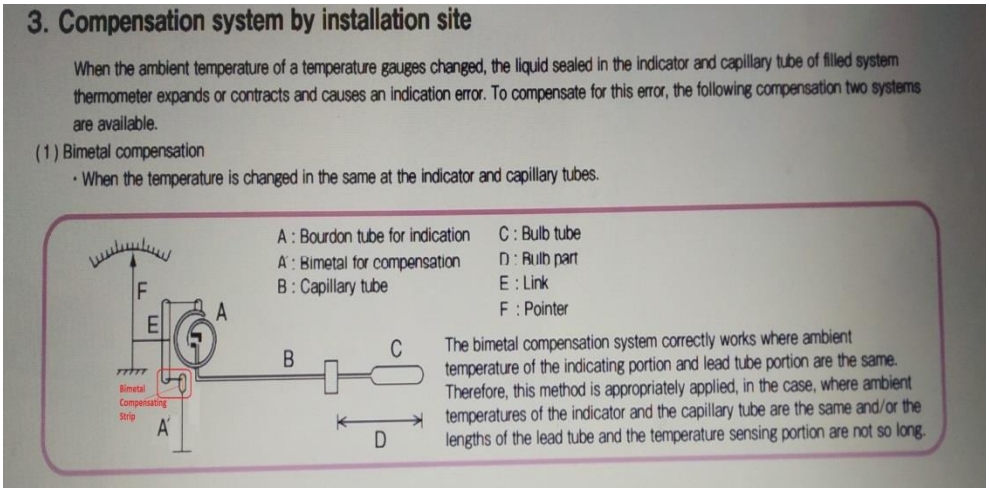
1- **Bimetal compensation**
2- **(2) Lead / Capillary Type Compensation**.

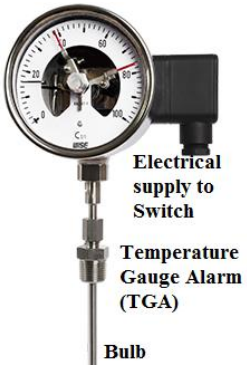
Direct Mount or Capillary L:5 Meter

(1) **Bimetal compensation**.
This type of compensation is always used in direct mount temperature gauges or very short capillary type temperature gauges,

It is **2 different types of metals** (Bimetal plates) fixed before movement assembly which is always opposing the main capillary movement to reduce ambient temperature and true movement will be transfer to the movement assembly to reach the pointer, as shown in these pics.

Direct Mount Temp. Gauge



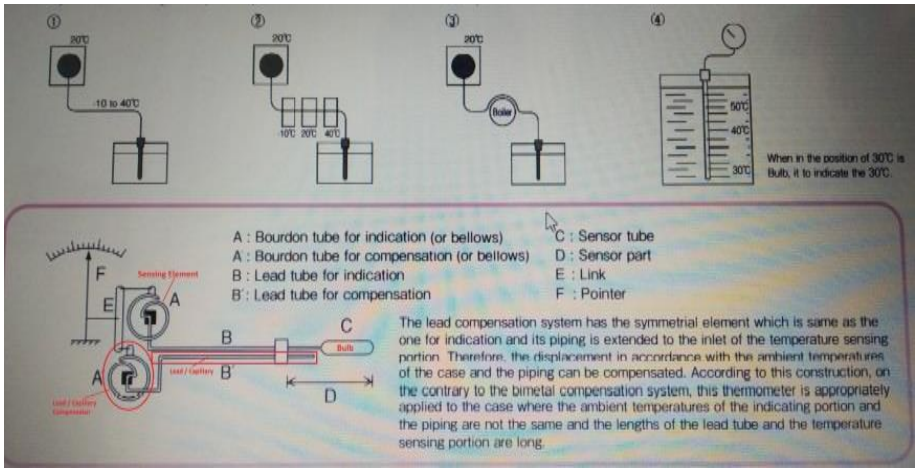


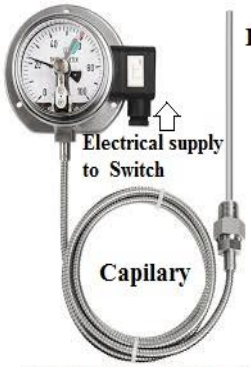
(2) **Lead Type Compensation**:

This type of compensation is always used in remote mount temperature gauges having long capillary. (From 3 Meter to 20 Meter or more)

In this compensation a **2nd Lead / Capillary** is used along with main capillary but don't have sensing bulb and end point is always finished before bulb of main capillary. So ambient temperature effects on both capillaries in same ways and in the gauge a second pressure sensor is installed which is attached with **2nd Lead / Capillary**. This temperature sensor is always fixed to oppose of the movement of main capillary sensor. The difference in between 2 pressure sensors will be transfer to the movement assembly to move the pointer and will show the actual temperature of process variable on the temperature scale. As shown in the fowling pics.

Capillary Length : 5~20 Meter/More

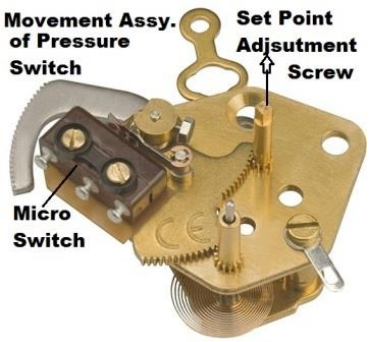


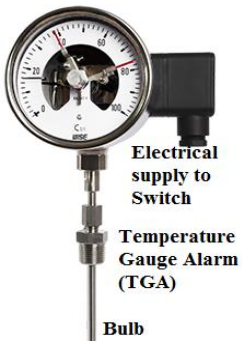


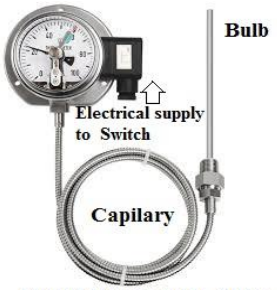
Temperature gauge Alarm (TGA) Remote Type

Temperature Switch

In any temperature gauge, if a **Micro Switch** is installed and can be adjusted the **Set Point** on a certain temperature then gives output **ON-OFF** contacts. It is called a temperature switch. As shown below.







Temperature gauge Alarm (TGA) Remote Type

Draw-back of a Temperature Gauge:

- Temperature gauge is always installed it the field.
- Temperature gauge can't send temperature in control room to record and control.

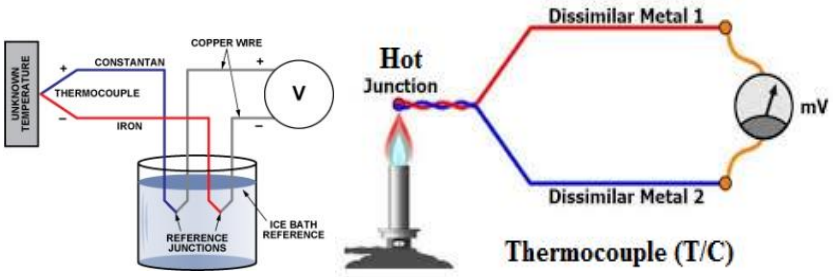
- Whenever we need to know the temperature of any process, an operator should go in the field to take reading.
- Temperature gauge can't control the temperature at required set point.

Note: But we need to know all process temperatures in the control room for recording and controlling purposes.

- So we need some other types of sensors which detect temperatures and transfer these temperatures values in the control room for recording and controlling.
- **We have 2 types of sensors.**
  - **(a) Thermocouple (T/C)**
  - **(b) Resistance Temperature Detectors (RTD)**

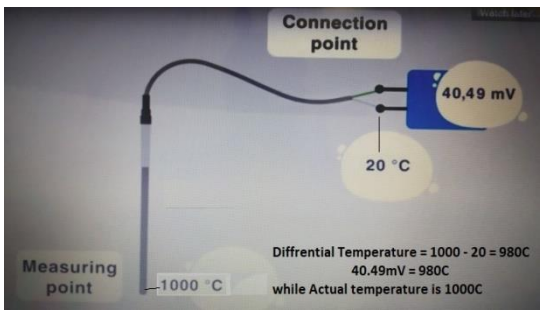
Thermocouple (T/C)

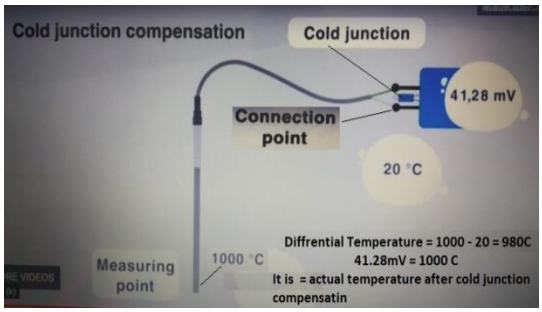
- Thermocouple is a device which is made by two different metals and defused at one end. (Never welded with any other material)
- T/C always used with the measuring bridge which amplify mV signal in to volt (V) or current (I).
- By heating of the defused end (mV) produces. This is called **Hot Junction**.
- Hot junction is using as a sensor to measure the heat in process.
- **Ice pot** can be used as a **Cold Junction** to test the loop of thermocouple.



Ambient Temperature Compensation in Thermocouple

- **Thermocouple** doesn't measure absolute temperature. **("0" Kelvin)**
- **Thermocouples measure the differential temperature between the measuring point (Hot Junction) and the connection point of Transmitter / Converter.** That's why thermocouples also need a **cold junction compensation**, which ensures that the ambient temperature at the connection terminals of the cold junction does not change the measuring result & Showing accurate reading.





There are many types of thermocouples (T/C) available with different ranges of temperatures.

TYPES: K, J, T, E, N, S, R & B, Mostly 3 types are used: **(T)** type, **(J)** type and **(K)** type. Each T/C has different ranges of temperatures with color codes.

ANSI Code	ANSI MC 96.1 Color Coding		Alloy Combination		Maximum T/C Grande temp. range	EMF(mv)Over Max.temp.range	IEC 584-3 Color Coding	IEC Code
	Thermocouple	Extension	+ Lead	- Lead				
K			NICKEL-CHROMIUM Ni-Cr	NICKEL-ALUMINUM Ni-Al	-270 to 1372°C -454 to 2501°F	-6.458 to 54.886		K
J			IRON Fe (magnetic)	CONTANTAN COOPER-NICKEL Cu-Ni	-210 to 1200°C -346 to 2193°F	-8.095 to 69.553		J
T			COPPER Cu	CONTANTAN COOPER-NICKEL Cu-Ni	-270 to 400°C -454 to 752°F	-6.258 to 20.872		T
E			NICKEL-CHROMIUM Ni-Cr	CONTANTAN COOPER-NICKEL Cu-Ni	-270 to 1000°C -454 to 1832°F	-9.835 to 76.373		E
N			NICROSIL Ni-Cr-Si	NISIL Ni-Si-Mg	-270 to 1300°C -450 to 2372°F	-4.345 to 47.513		N
S	NONE ESTABLISHED		PLATINUM-10% RHODIUM Pt-10%Rh	PLATINUM Pt	-50 to 1768°C -58 to 3214°F	-0.236 to 18.693		S
R	NONE ESTABLISHED		PLATINUM-13% RHODIUM Pt-13%Rh	PLATINUM Pt	-50 to 1768°C -58 to 3214°F	-0.226 to 21.101		R
B	NONE ESTABLISHED		PLATINUM-30% RHODIUM Pt-30%Rh	PLATINUM-6% RHODIUM Pt-6%Rh	0 to 1820°C 32 to 3308°F	0 to 13.820		B

Material used in each type of Thermocouple

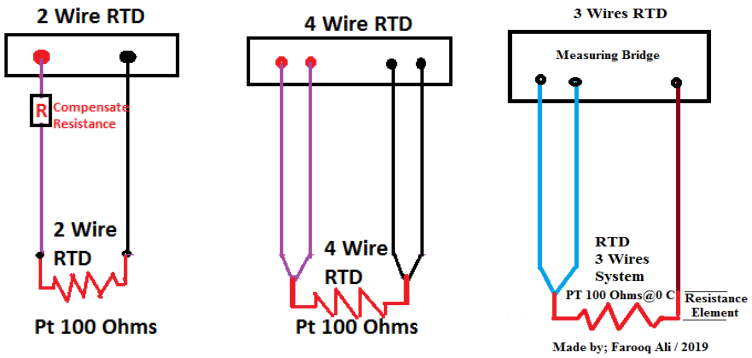
Type	Positive wire	Negative wire
B	70% Platinum 30% Rhodium	96% Platinum 6% Rhodium
E	Chromel	Constantan
J	Iron	Constantan
K	Chromel	Alumel
N	Nicrosil	Nisil
R	87% Platinum 13% Rhodium	Platinum
S	90% Platinum 10% Rhodium	Platinum
T	Copper	Constantan

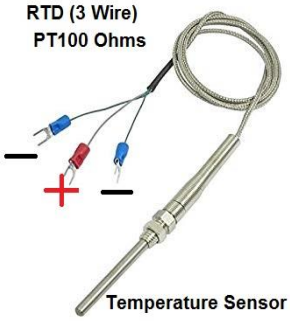
Resistance Temperature Detector (RTD)

- RTD is a device which is made by a **special resistance (Pt100 having resistance 100 ohms at "0" degree C),** whose resistance value changes with the heat. This is good for low temperature. 0 to 260C)
- By heating the resistance of RTD, there is change in resistance which is always proportional to the temperature.
- RTDs are always used with the measuring bridge (RTD to V/I Converter) which converts resistance in to Volt or Current.
- This Signal transmits to indicator or recorder to show accurate temperature.

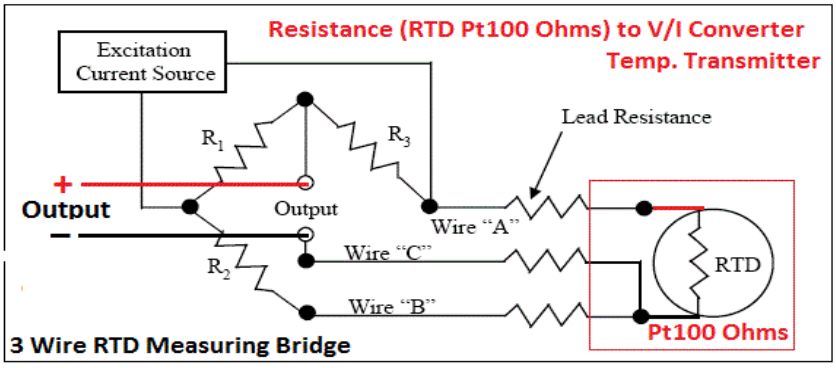
Note: There are 2 wires, 3 wires and 4 wires RTD.

Most commonly used RTD is 3 wires





RTD, **Red wire** showing **Positive** and other two white / blue wires shorted with each other in the sensor used as **Negative** as shown above picture.



Most commonly use of RTD is to measure winding temperature of motors, transformers and generators where thermocouple could not use because of high voltages.

Level

Level

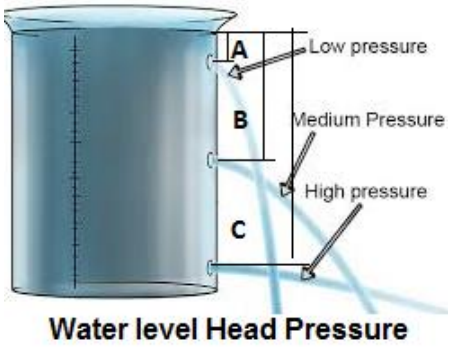
1- A measurement in **between two altitude points** is called level.

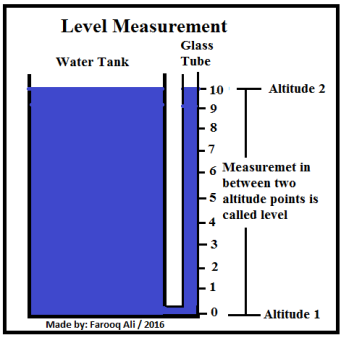
2- Level means any liquid filled in a tank and travelling vertically from **one altitude point to other altitude point** is called level.

3- **Vertical Height** from the **reference point** is called Level

4- Level of any liquid is producing **head pressure** at bottom of the tank. Head pressure at bottom of tank will increase if level in the tank will increase.

5- At zero level head pressure will also be zero. Means there is no water in the tank.



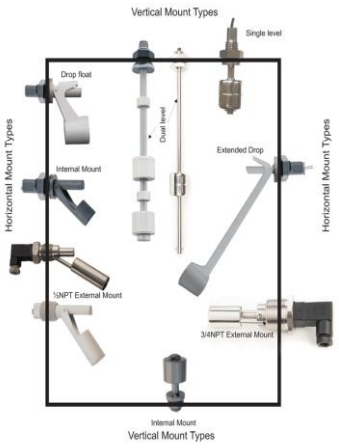


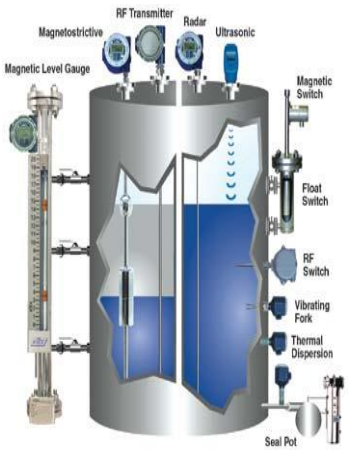
Sensors of level measurement

There are many level sensors available in the market. Basic few level sensors are as follows.

1- **Level glass** with measuring scale or ruler as shown in above picture.
2- **Pressure & Differential Pressure (DP Cell)** measuring water head pressure in the bottom of the tank.
3- **Floats** in different designs and sizes having vacuum in it. Floating along with water level.
4- **Displacer** having specific weight according to the medium. It displaces the liquid and liquid will create bouncy power to lift this weight but it will loss his weight according to the displaced liquid.
5- **Electrodes** type conductivity based contact types level sensors.
6- **Ultrasonic Wave, Magnetic Float, Flat Board and many more sensors used to measure level**

- **Local Level Glass Gauge**: Directly attached with tank. Made by glass and graduated in Meter WC, mm WC or Inches of WC or feet WC. As shown in above & below Pictures.
- **Different Types of Float Sensors:** There are many types of floats and Displacer used for level measuring system.
- **Float moves along with water level.**
- **Pressure and Differential Pressure** sensors can be used as level sensors.

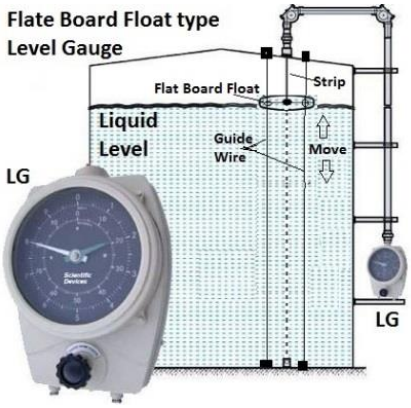




- **Magnetic Float Type Level Gauge:**

Magnetic float is floating in chamber behind the level indicator. It moves up & down along with liquid level. Moving plates are fixed in a trail vertically and panted **one side Red** and **other side Green or White**. When float rises with liquid level, due to the magnetic flux, plates change their position from **Green** to **Red** and when level fall down plates changes their position from **Red** to **Green**.

- **Red** means the Level in the tank.
- **Green** means the empty portion of a Tank.

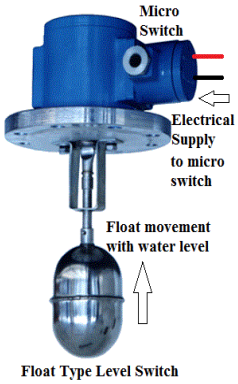


- **Flat Board Float Type Level Gauge:**

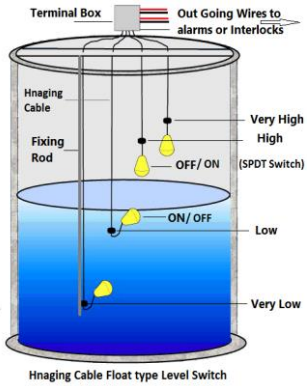
This type of float is used in very large sizes of tanks. Floats moves along with liquid in the tank and hold by 2 guide wires. This float hangs with steel strip and it moves on the 2 rollers. Steel strip roles in a Level Gauge which has 2 needles. Big needle moves on Meter scale and Small needle move on CM scale.

- Level Switches: When **Micro switches** used with, floats and Displacers in level gauges are called level switch, level switches giving alarm to control rooms and also used for interlocks.

- There are many types of Floats and displacers available in the market.



Float Type Level Switch

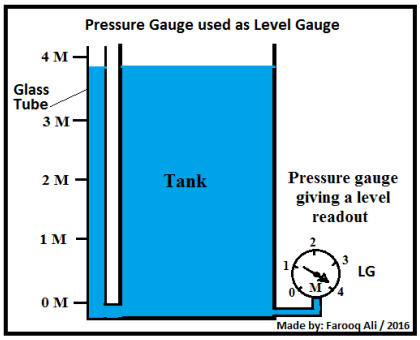


Hnaging Cable Float type Level Switch

How a Pressure Gauge & Pressure Transmitter is used in Level Measurement?

It will only measure liquid level head pressure from one altitude point to 2nd altitude point,

- **Pressure Gauge** scale will be graduated in Meters or mm H2O as shown in this diagram.



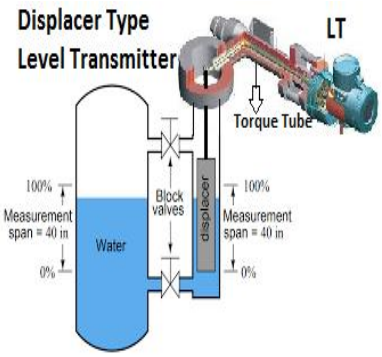
- **Pressure Transmitter** will also measure liquid level head pressure from one altitude point to 2nd altitude point and convert head pressure in to electrical signal 4~20mADC to transfer from field to control room.

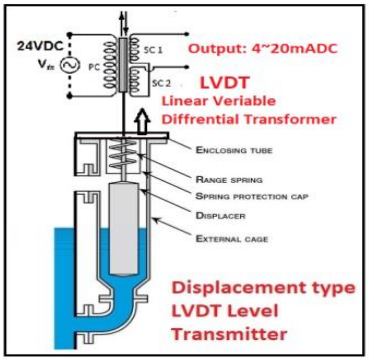
- **Pressure & Differential Pressure** sensors are used as level sensors

Displacer:

- Mostly used in **Level switches & Level Transmitters**.
  It has **specific weight**. **Displacer loses his weight according the principle of Arshmidas.**

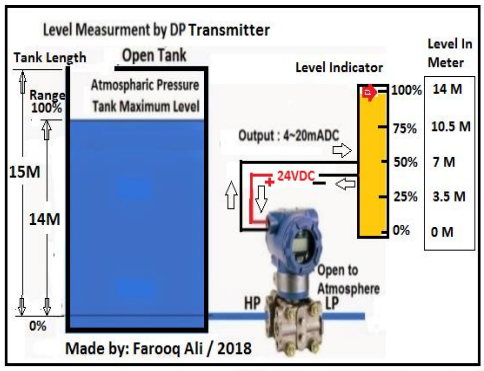
- If water increases, water **bouncy power** will try to move the displacer upward. It **moves few mm** upward because of weight. This movement is transferred through torque tube to transmitter to convert **4~20mADC** and transmitter will transmit this signal to control room to show level on indicator or recorder and control.





DP Cell: (Open Tank Level)

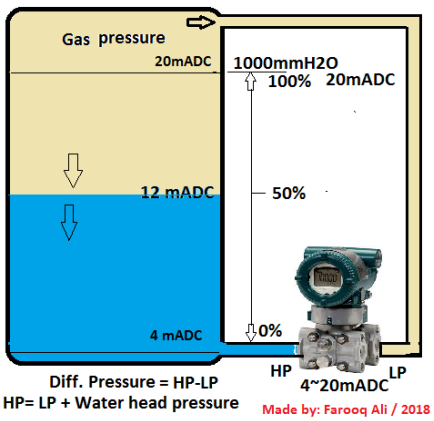
- Differential pressure transmitter high **(HP)** side directly attached at bottom of the tank and low **(LP)** side leave in atmosphere in open tank.
  So Diff. Pressure = **HP - LP**
  While **HP = LP + Water Head Pressure**
  So **HP** will be higher than LP because of water head pressure.



- **Differential Pressure** sensors (DP Cell) can be used as level sensors

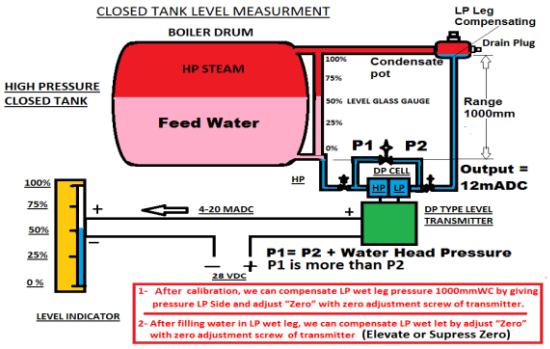
DP Cell: (Closed Tank Level)

- In closed tank High side (HP) attached bottom of the tank and Low side (LP) attached at the top of the tank. It will measure the differential pressure which is graduated on the indicator as level of tank.



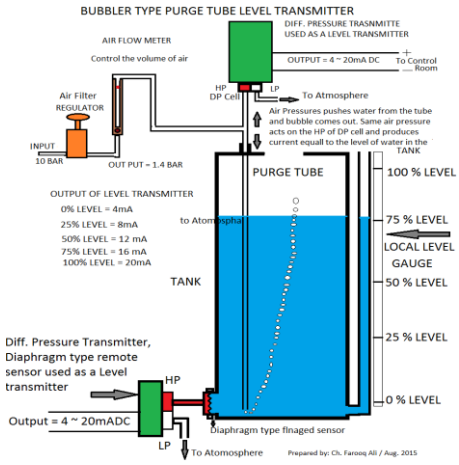
DP Cell: (Closed Tank Level)

- **Like:** Drum Level in Boiler



Level means Diff. Pressure = **HP - LP**.
If **HP** pressure is **P1** & **LP** pressure is **P2**
The Differential Pressure = P1 – P2
Then **P1= P2 + Water Level Head Pressure** in tank.

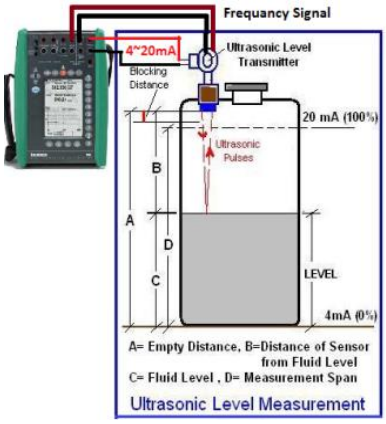
- **Bubbler type Level transmitter:**



Bubbler type purge tube level transmitter works against back pressure of air. When level increase or decrease in a bubble tube.

1- When zero level of water in a tank then back pressure of air will be very less.
2- When water level is full in the tank then pressure in the bubble tube will be maximum and this pressure will act on the pressure or Diff. pressure cell. This pressure will be maximum and used as back pressure to the level sensor.

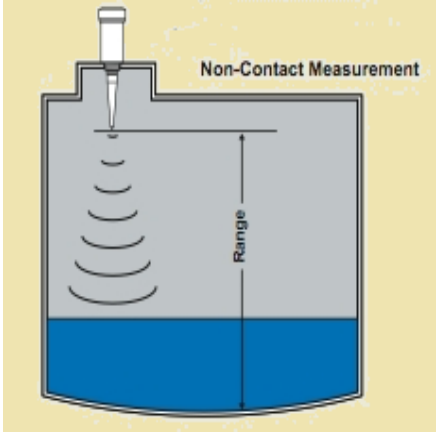
Ultrasonic Level Measurement:



Ultra sonic level transmitter sends ultrasonic frequency signal (Wave) to bottom of the tank. This this signal reaches to the surface of the liquid and return back to the receiver.

Transmitter calculates the **Difference in time of flight (Time sending & receiving wave)**. The time will be taken from transmitter to send and received back to receiver. In case of tank will be empty then time duration will be more and if tank will be full time duration will be very less as shown in this picture.

- **Radar / Microwave Type Level Transmitter.**

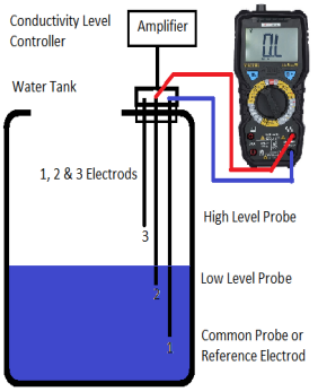


Working principle of Radar / Micro wave transmitter is similar as Ultrasonic type level transmitter. (Measuring flight time of the wave)

Difference in time of flight (Time sending & receiving wave)
Difference is only signal. Instead of ultrasonic it transmits radar waves.

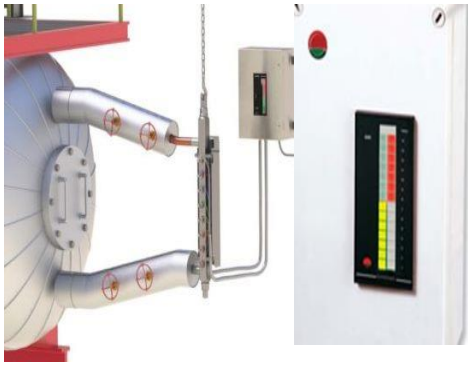
- **Electrode type conductivity based level sensor**

Electrodes (Iron / steel Rods)) are dipped in the water and when level water touch to 2 rods. It connects the circuit and send signal to the controlling system to start / stop the motor / alarm or solenoid valve to open or close.



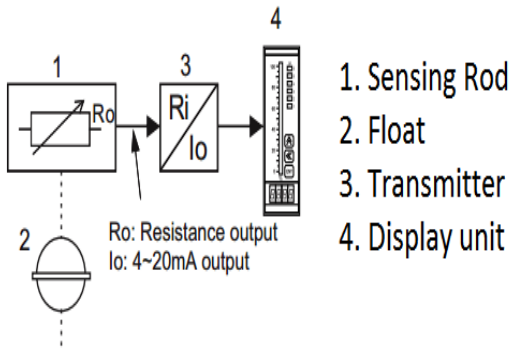
- **Hydra Step Level Transmitter:**

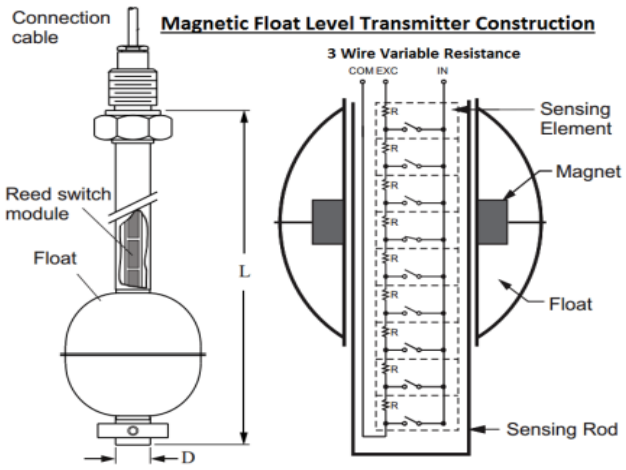
It has many detectors (**Electrodes**, **Conductivity based level sensors**) which detects water and send contact signal to transmitter. Then light on indicator will change from Red to yellow or green.

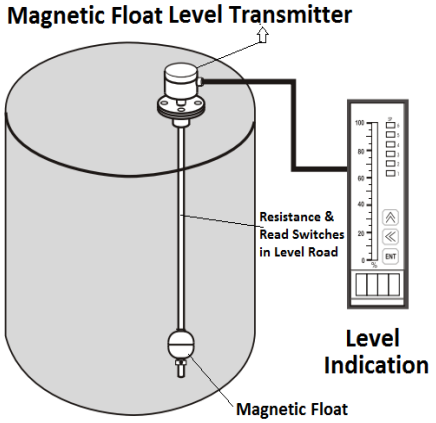


- **Magnetic Float type Level Transmitter Working Principle**

The magnetic float level transmitter devices using the principles of buoyancy and magnetism to generate a changing electrical output in response to the rise and fall of the float on the sensing guide rod.
The magnetic float level transmitter provides a 3-wire resistance output. As the float is raised or lowered by the liquid level, the sensing rod will induce a resistance output, which is directly proportional to the liquid level







There are many more types of level measuring instruments available in the market.

Flow & Flow Calculation

&

Function of Square Root

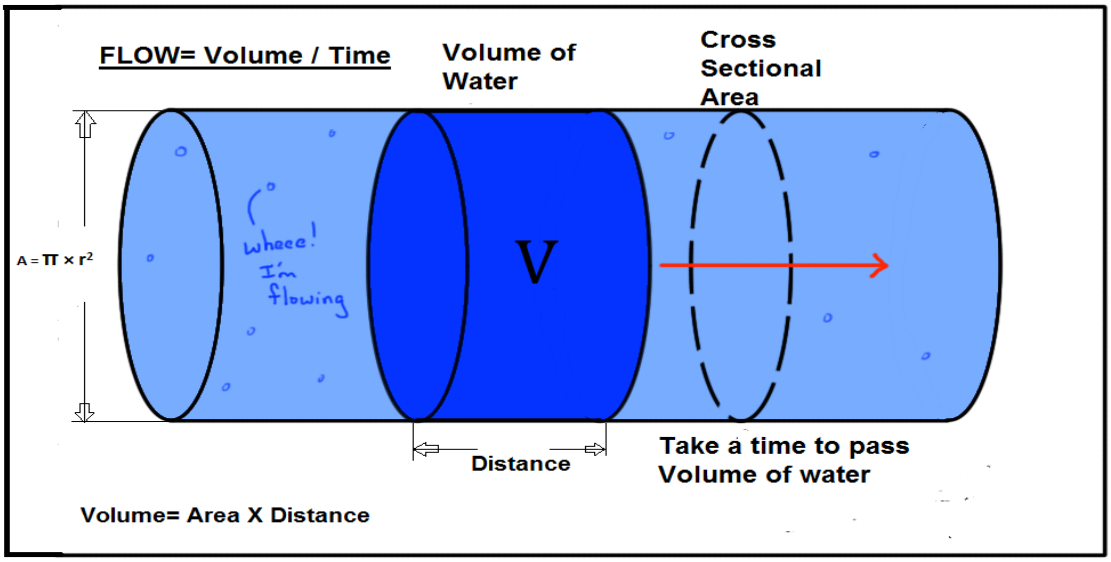
+

Multiplier & Divider

Flow

Flow means the **Volume** of any liquid passes through any pipe, (given cross sectional area) per **Unit Time** is called flow.

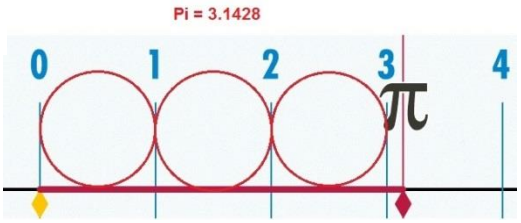
$$\textbf{Flow} = \frac{\boldsymbol{Volume}}{\boldsymbol{Time}} \qquad \textbf{F} = \frac{\boldsymbol{V}}{\boldsymbol{T}}$$



$$\boldsymbol{Volume = Area\ x\ Distance}$$

Calculate the internal area of tank or pipe by formula: $A = \pi \times r^2$

A=Area, π=22/7=3.14, & r = d/2, where "d" is Internal diameter of tank or pipe.



Units of flow:

1- **Solids**: Tons/Hour, Kg/Minute
2- **Liquids**: Liters/Hour, M^3/Hour, Gallons/Hour, Barrels/Hour
3- **Gases:** SM^3/Hour (Standard Meter Cub /Hr.) & NM^3/Hour (Normal Meter Cub / Hr.)
4- **Steam:** Tones /Hour, Kg /Minutes

There are two type of flow:

1. **Volumetric Flow (**Volume / Unit time)
2. **Mass Flow** (Volume X Density / Unit time)

Types of Fluids:

There are two types of fluid:

1. **Liquid** (Non-Compressible) in this case volume will not change while compressed.
2. **Gases** (Compressible) in this case volume will change while compressed.

Measurements of Flow

Flow Meter

Flow meter is a device that measures the **Volume** of a moving fluid through the device / **Unit time**.

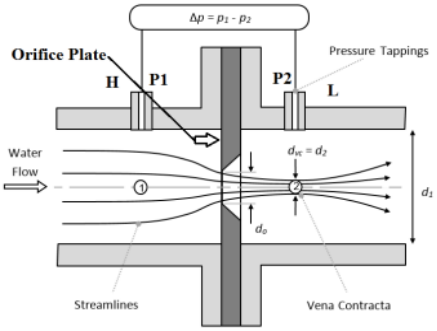
Flow = Volume / Unit Time

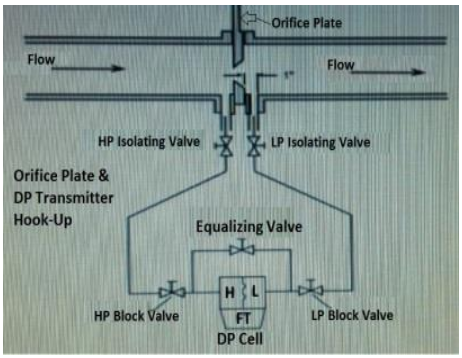
(**Flow meter** tells us that how much quantity of water flows through the flow meter in 1 Hr.)

Flow Meters and Sensors

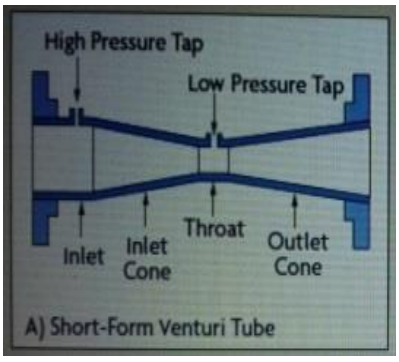
1. **Mechanical type flow sensors:** (These Flow sensor creates Differential Pressure)

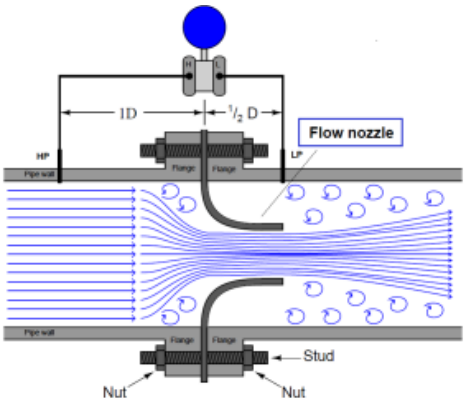
- **Orifice Plates** & Hookup of DP Transmitter



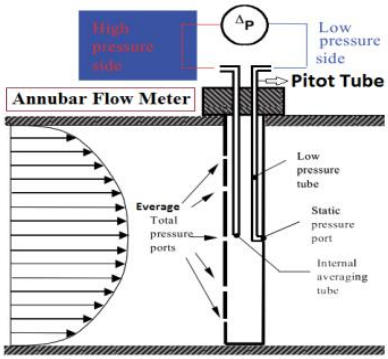


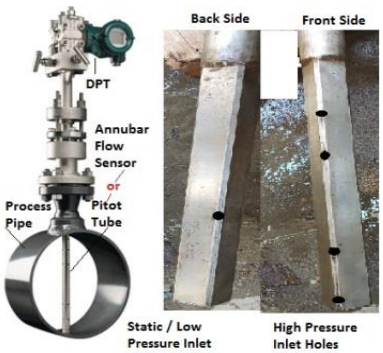
- **Venture Tube & Flow Nozzle,**

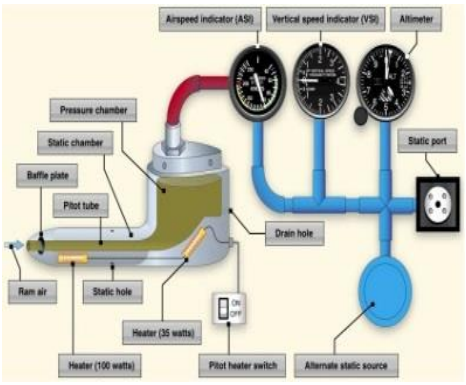




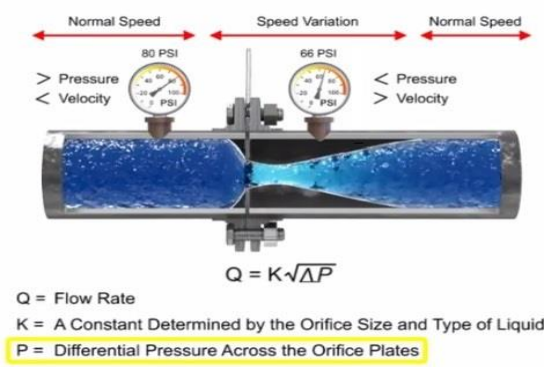
- **Pitot tube** or **Annubar** Flow sensor

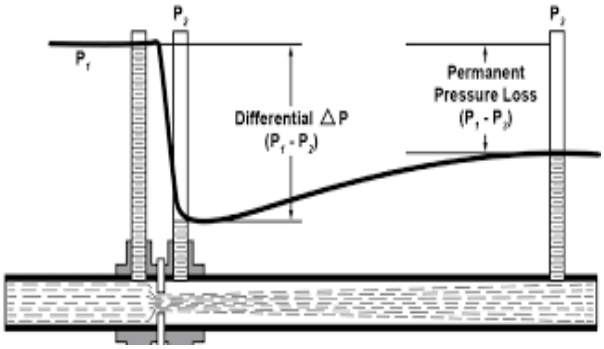






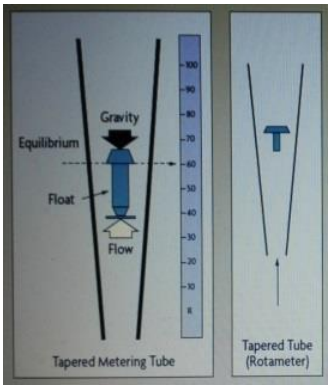
Function of Orifice, Pitot tube, Venture Tube or Nozzle always creates Diff. Pressure. We can see that Pressure before flow sensor is higher than the pressure after Flow sensor on the pressure gauges.



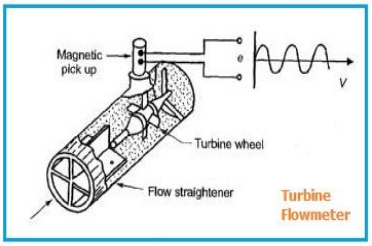


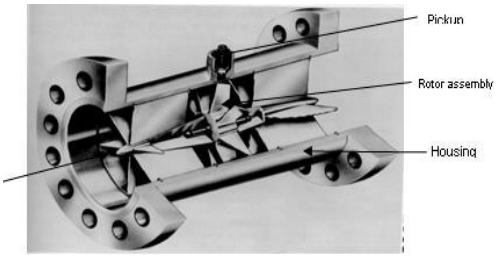
Note: We can use differential pressure transmitters and switches with all above sensors

- **Line Mounted Flow Meters:** * Variable area flow meters (Rota Meter Types)



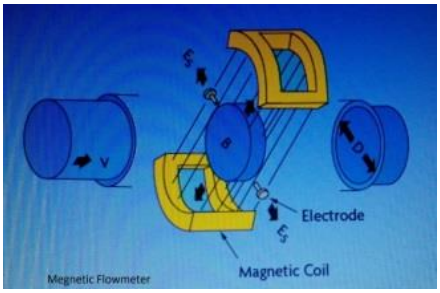
- **Turbine Flow Meter**



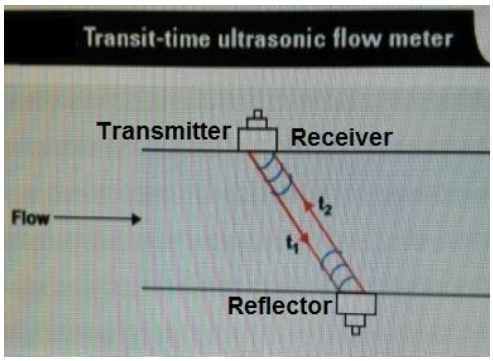


Electrical / Electronic type Flow Meters:

- Electromagnetic flow meter and working principle.

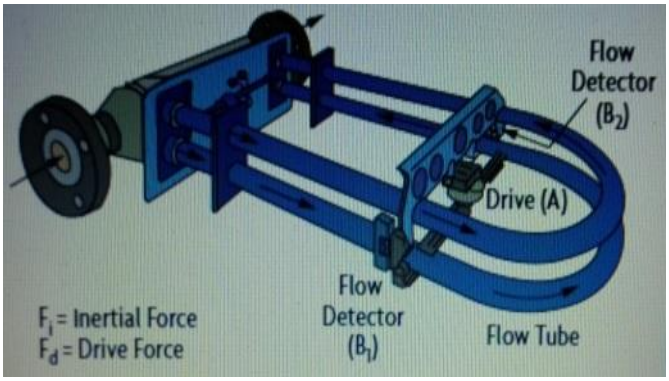


- **Ultrasonic flow meter**, Difference in time of flight (Time between sending & receiving wave) from transmitter to receiver.



- **Coriolis flow meter:** There is an oscillator driver (A) which continuous oscillate the 1 or 2 flow tubes and 1 or 2 flow detectors (B1 & B2) fixed on flow tubes (called Oscillation Detectors). When flow moves from the tubes by the principle of **Coriolis**, tubes oscillates and we can detect the oscillation difference between 2 tubes by 2 flow detectors.

Carioles flow meter



Note: Many more sensors are also available in the market to measure the flow of any process

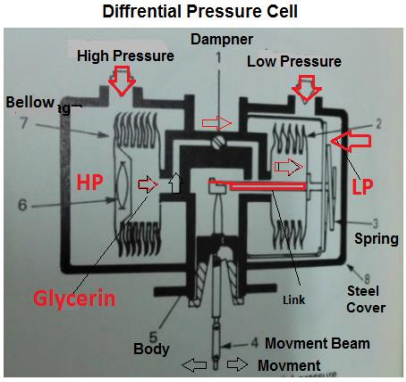
FLOW SWITCHES

1- Differential Pressure Flow Switch.

There are 2 types of differential pressure flow switches.

(a) Indicating type flow switches.

Diff. Pressure Cell



(b) Blind type Diff. Pressure & Flapper type flow switches.



2- Line mounted indicating type Variable area **flow switches**:



Note: Many more flow switches are also available in the market.

Switches SET & RESET Function in the Plant

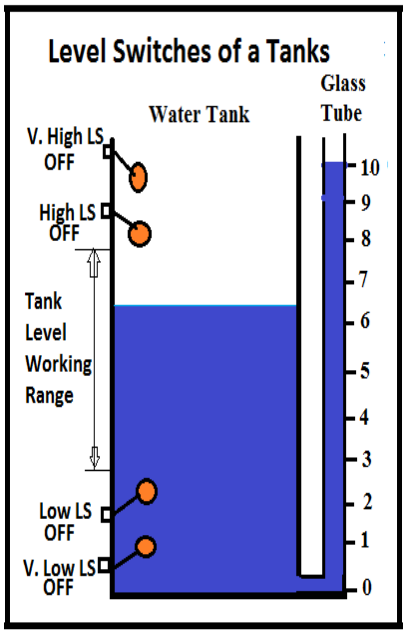
Pressure & Diff. Pressure Switches

1- Level Switches

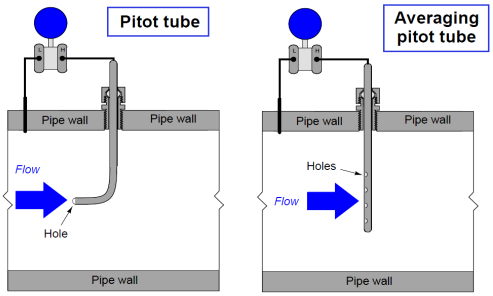
2- Flow Switches

3- Temperature Switches &

4- Others Switches



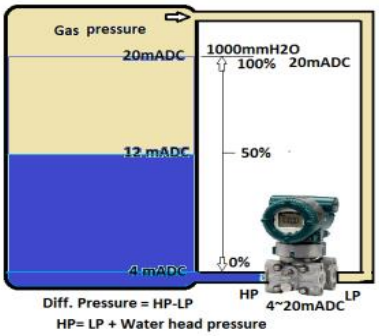
DP cell detects high diff. pressure of different Process variables, in different sensors installed in the flow line.

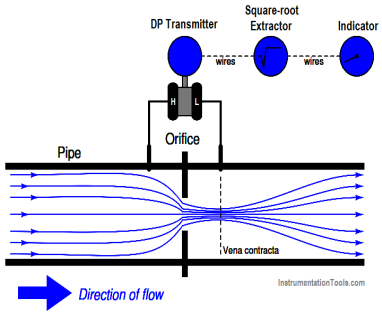


- **DP Sensors:** like Orifice plate, pitot tube or venture, Nozzle and DP type level measurement.
- Differential pressure is directly proportional to the Flow / Level.

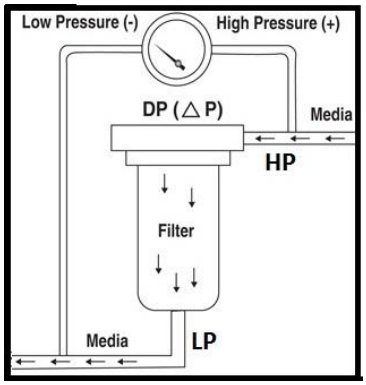
1- If Diff. Pressure Increased by Orifice Plate or Pitot tube, means outlet flow in the pipe line is increased.

2- If Diff. Pressure Increased in a closed tank means liquid Level is increased in the tank.

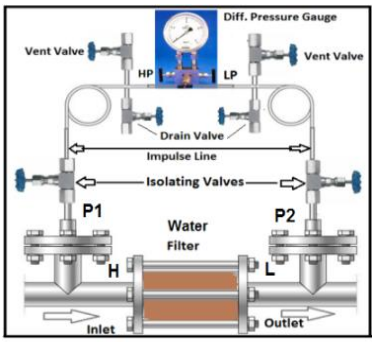




- **Filters:**
- Differential pressure is inversely proportional to the Flow in filters.



3- If Diff. Pressure Increased in any filter, means outlet flow is decreased. It means filter is chocked.



Diff. Pressure = P1-P2

4- If Diff. Pressure Increased against any filter, then outlet flow will be decreased. It means filter is chocked, then DP type Pressure / Flow switch will take action and give alarm / Interlocks.

==========

Flow Calculation

We will study the types of **Flow** in this chapter. That there are 2 types of flow.

(1) **Volumetric Flow:** Means (Volume / Unit time).
(2) **Mass Flow:** {Volume X Density (**Weight**) / Unit time}

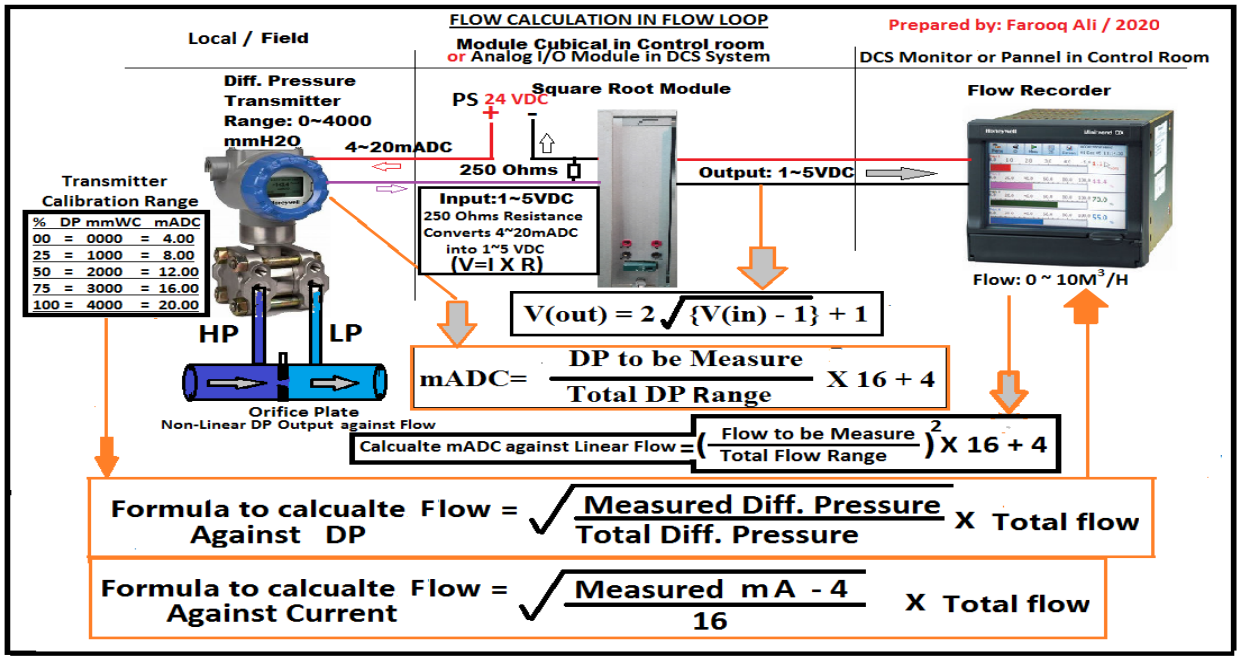
- **Steam is not Pure Gas:** Steam is produced by heating water. It converts in to gas form but it contains water. More heating of water means more steam pressure producing. So it is always Mass Flow & measures in **Ton / Hr.** or **Kg / Minute.**

Behavior of Flow

- Flow is always **Non-Linear** when any liquid flows in a pipe line.
- Flow sensors always creates **Non-Linear** differential pressure.
- DP effects on DP cell will also be **Non-Linear**.
- DP transmitter output signal (4-20mADC) will also be **Non-Linear** Signal.
- **So Square Root Extractor** is always used to convert **Non-Linear Signal** in to **Linear Signal** to Record and Control.

Note: **Square Root Extractor electronic module** is installed in analog cubical. We can check and view all input and output values of module as shown below picture.

- **(Analog Electronic Module system is an old system which is now replace by DCS)**
- **DCS:** In DCS system all Input / Output values are part of analog I/O card. Square root, Multiplier, R/IV or TC/IV and all other analog controlling system input output values are part of configuration of analog I/O cards.
- **Here we will calculate only Volumetric Flow. (like: Water Flow)**
- **Example: Diff. Pressure Transmitter having full Range: 0~4000mmWC**



Calculation of Non-Linear Flow

Note: **Square Root Module always convert Input signal in to Square Root Output Signal.**

(A) If we give Linear Input Signal, then Output Signal will be Non Linear.
(B) If we give Non Linear Input Signal, then Output will be Linear

(A) 1st Option: Behavior of Square Root in case of linear input.

Note: This option is not used in the plant for flow.

When we calibrate a differential pressure transmitter (as a Flow transmitter) in a workshop, **we always calibrate as linear calibration against the differential pressure**. As shown here in chart.

Transmitter Calibration Range

%	DP mmWC	mADC
00	= 0000	= 4.00
25	= 1000	= 8.00
50	= 2000	= 12.00
75	= 3000	= 16.00
100	= 4000	= 20.00

- Diff. Pressure Transmitter range: **0~4000mmH2O**

Let us see the **behavior and calculate** the flow in case of **linear input signal** to **Square Root Extractor**:

- Differential pressure transmitter:
- **D.P. Range: 0~4000mmH2O**
- **Flow Range: 0~10M^3/H**

The standard formula to calculate flow after Sq. Root against differential pressure is as follows.

- **Result will be as below and shown in below diagram.**

$$\text{Output Flow} = \sqrt{\frac{\text{Diff. Pressur to be measure}}{\text{Total Diff. Pressure Range}}} \times \text{Total Flow Range}$$

Let's calculate flow against linear given Diff. Pressure Ranges. The output is always non-linear.

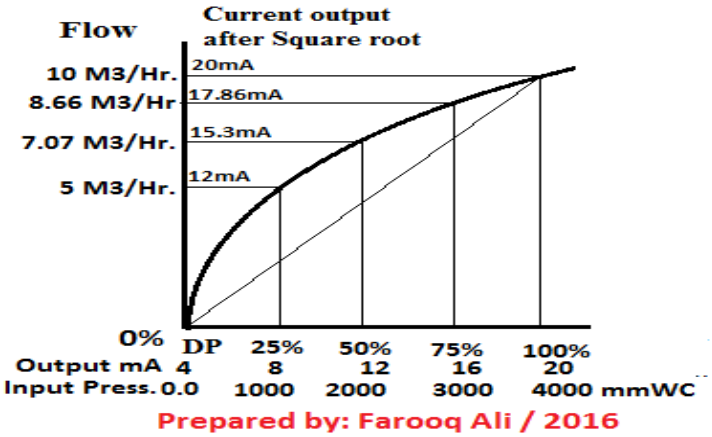
(a) At **25%** input Diff. Pressure = $\sqrt{\frac{1000}{4000}} \times 10 =$ **5M^3/H**

(b) At **50%** input Diff. Pressure= $\sqrt{\frac{2000}{4000}} \times 10 =$ **7.07M^3/H**

(c) At **75**% input Diff. Pressure= $\sqrt{\frac{3000}{4000}} \times 10 =$ **8.66M^3/H**

(d) At **100%** input Diff. Pressure= $\sqrt{\frac{4000}{4000}} \times 10 =$ **10M^3/H**

Behavior of Flow is always Non-Linear (Input Linear)



Prepared by: Farooq Ali / 2016

(a) Formula to convert Linear Current in to Voltage is: V= I X R
(I= mADC & R= Resistance in Ohms)

Note: We are using very precision resistance **250 Ohms** with very less error or no error to convert mADC in to Voltage DC

(1) At 4mADC,	V=4mA X 250=1000mV	**1VDC**	0%
(2) At 8mADC,	V= 8mA X 250=2000 mV	**2VDC**	25%
(3) At 12mADC,	V=12mA X 250=3000 mV	**3VDC**	50%
(4) At 16mADC,	V=16mA X 250=4000 mV	**4VDC**	75%
(5) At 20mADC,	V=20mA X 250=5000mV	**5VDC**	100%

(b) Now we will use the formula of Square Root Extractor to calculate the output voltage against Linear Input.

$$V(out) = 2\sqrt{\{V(in) - 1\}} + 1$$

According to the above formula; if input is linear the answers will be the following.

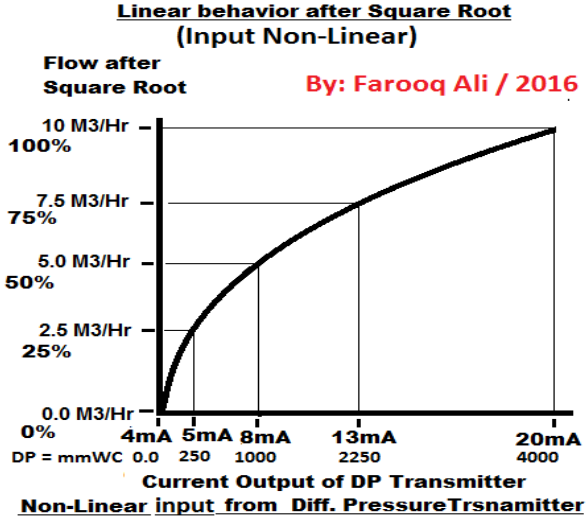
(1) 00% Input signal=1VDC	Output: $2\sqrt{1-1}$ +1=	**1**VDC
(2) 25% input signal=2VDC	Output: $2\sqrt{2-1}$ +1=	**3**VDC
(3) 50% Input signal=3VDC	Output: $2\sqrt{3-1}$ +1=	**3.828**VDC
(4) 75% Input signal=4VDC	Output: $2\sqrt{4-1}$ +1=	**4.464**VDC
(5) 100% Input signal=5VDC	Output: $2\sqrt{5-1}$ +1=	**5**VDC

(B) 2nd Option: Behavior of Square Root in case of Non-Linear input.

Note: This option is used where DP Transmitter is used as Flow Transmitter.
When we install or hook-up the differential pressure transmitter in flow loop then we can see the **linear output flow rate after Square root** on recorder scale / in DCS or HMI.

- In this situation we don't know the following values against flow.

(a) **Differential pressure** against flow.
(b) Output **mADC** of diff. pressure transmitter against flow.
(c) But we know the linear values of output flow. **As shown in this figure**.



(d) **25% Flow = 2.5 M^3/H**

(e) **50% Flow = 5.0 M^3/H**

(f) **75% Flow = 7.5 M^3/H**

(g) **100% Flow = 10M^3/H**

Note: In above situation we have to use the **formula which will be opposite of Sq. Root Extractor** because we have to go back the Square Root Extractor to calculate the followings.

- **Differential Pressure** against known linear flow
- **Current (mADC)** against known linear flow.

The standard formulas to calculate Differential Pressure and Current against linear flow are as follows.

(1) $$\text{Diffrential Pressure} = \left(\frac{\text{Flow to be Measure}}{\text{Total Flow Range}}\right)^2 \text{X Diff. Pressure Range}$$

(2) $$\text{mADC} = \left(\frac{\text{Flow to be Measure}}{\text{Total Flow Range}}\right)^2 \text{X } 16 + 4$$

Let us **calculate** the **Differential Pressure** and **Current (mADC)** in case of Non-Linear input signal to square root extractor.

Differential Pressure Transmitter: **Range: <u>0~4000mmH2O</u>** **&** **Flow Range: <u>0~10M^3/H</u>**

(A) Calculation of Differential Pressure before Sq. Root against linear flow using this formula:

$$\text{Diffrential Pressure} = \left(\frac{\text{Flow to be Measure}}{\text{Total Flow Range}}\right)^2 \text{X Diff. Pressure Range}$$

(a) At **25%** Flow=**2.5 M^3/H,** Differential Pressure = $(\frac{2.5}{10})^2$ X 4000=**250mmH_2O**

(b) At **50%** Flow=**5.0 M^3/H,** Differential Pressure = $(\frac{5}{10})^2$ X 4000=**1000mmH_2O**

(c) At **75%** Flow=**7.5 M^3/H**, Differential Pressure = $(\frac{7.5}{10})^2$ X 4000=**2250mmH_2O**

(d) At **100%** Flow=**10M^3/H,** Differential Pressure = $(\frac{10}{10})^2$ X 400= **4000mmH_2O**

(B) Re- Confirmation of flow against non-Linear differential Pressure using standard formula.

In **(A)** we have calculated **Differential Pressure** against linear flow. Now we can re-confirm the linear flow by the standard formula.

$$\text{Output Flow} = \sqrt{\frac{\text{Diff. Pressur to be measure}}{\text{Total Diff. Pressure Range}}} \text{ X Total Flow Range}$$

(a) At **25%** Input Diff. Pressure = **250**mmWC: **Flow** = $\sqrt{\frac{250}{4000}}$ X 10 = **2.5M³/H**

(b) At **50%** Input Diff. Pressure =**1000**mmWC: **Flow** = $\sqrt{\frac{1000}{4000}}$ X 10 = **5M³/H**

(c) At **75%** Input Diff. Pressure = **2250**mmWC: **Flow** = $\sqrt{\frac{2250}{4000}}$ X 10 = **7.5M³/H**

(d) At **100%** Input Diff. Pressure = **4000**mmWC: **Flow** = $\sqrt{\frac{4000}{4000}}$ X 10 = **10M³/H**

(C) Calculation of Current (mADC) before Sq. Root against linear Flow by this formula.

$$mADC = \left(\frac{\text{Flow to be Measure}}{\text{Total Flow Range}}\right)^2 X\ 16 + 4$$

(a) At **25%** Flow = **2.5M³/H**: Answer: mA = $(\frac{2.5}{10})^2$X16+4 = **5mA**.

(b) At **50%** Flow = **5.0M³/H**: Answer: mA = $(\frac{5}{10})^2$X16+4 = **8mA**

(c) At **75%** Flow = **7.5M³/H**: Answer: mA = $(\frac{7.5}{10})^2$X16+4 = **13mA.**

(d) At **100%** Flow = **10M³/H**: Answer: mA = $(\frac{10}{10})^2$X16+4 = **20mA**

(D) Re- Confirmation of Current (mADC) before Sq. Root Known Differential Pressure.

In **(A)** we have already calculated the differential pressure against linear flow. Now we can calculate the **current** using the basic formula.

$$\text{Output Current of a Transmitter}: mADC = \frac{\text{DP to be Measure}}{\text{Total DP Range}} X\ 16 + 4$$

(a) At **25%** Input pressure **250**mmWC: **Answer:** mA = [$(\frac{250}{4000})$ X16] +4= **5mA**

(b) At **50%** Input pressure **1000**mmWC: **Answer:** mA = [$(\frac{1000}{4000})$ X16] +4= **8mA.**

(c) At **75%** Input pressure **2250**mmWC: **Answer:** mA = [$(\frac{2250}{4000})$ X16] +4= **13mA.**

(d) At **100%** Input pressure **4000**mmWC: **Answer:** mA = [$(\frac{4000}{4000})$ X16] +4= **20mA.**

1- In case of Non-Linear current we can convert in to Voltage.
Ohms law is: I=V/R, So V= **I X R**

Note: We are using precision resistance **250 Ohms** with very less error or no error to convert mADC in to Voltage

(a) At **4**mADC,	V= **4**mA X 250=1000mV	**1.0VDC**	0% Flow
(b) At **5**mADC,	V= **5**mA X 250=1250 mV	**1.25VDC**	25% Flow
(c) At **8**mADC,	V= **8**mA X 250=2000 mV	**2.0VDc**	50% Flow

(d) At **13**mADC, V=**13**mA X 250=3250 mV **3.25VDC** 75% Flow

(e) At **20**mADC, V=**20**mA X 250=5000mV **5.0VDC** 100% Flow

2- **Now we will use the formula of Square Root Extractor against converted voltage (VDC)**

$$V(out) = 2\sqrt{\{V(in) - 1\}} + 1$$

According to the above formula; if input is none linear (As we have seen the flow is always non-linear) the answers will be the following.

(a) At **0%** flow = **0 M^3/H**, Input signal **4mA**= 1.0VDC Output: $2\sqrt{1-1}+1=$ **1**VDC

(b) At **25%** flow= **2.5M^3/H**, Input signal=**5mA**=1.25VDC Output: $2\sqrt{1.25-1}+1=$ **2**VDC

(c) At **50%** flow=5**.0 M^3/H**, Input signal= **8mA**=2.0VDC Output: $2\sqrt{2-1}+1=$ **3**VDC

(d) At **75%** Flow= **7.5M^3/H**, Input signal=**13mA**=3.25VDC Output: $2\sqrt{3.25-1}+1=$ **4**VDC

(e) At **100%** Flow=**10.0 M^3/H**, Input signal **20mA**= 5.0VDC Output: $2\sqrt{5-1}+1=$ **5**VDC

Result of Sq. Root Extractor is as Follows.

Before Square Root Extraxtor

- According the **Non-Linear Flow:**
- Output of **"Orifice Plate**" will create **Non-Linear Differential Pressure.**
- So **input** of Diff. Pressure Transmitter will be **always Non-Linear**.
- Then **Output Current** of Diff. Pressure Transmitter will also be **Non-Linear**.
- When converting into Voltage by **250 Ohms** resistance will be also **Non-Linear**.

- **None - Linear Input Values.**

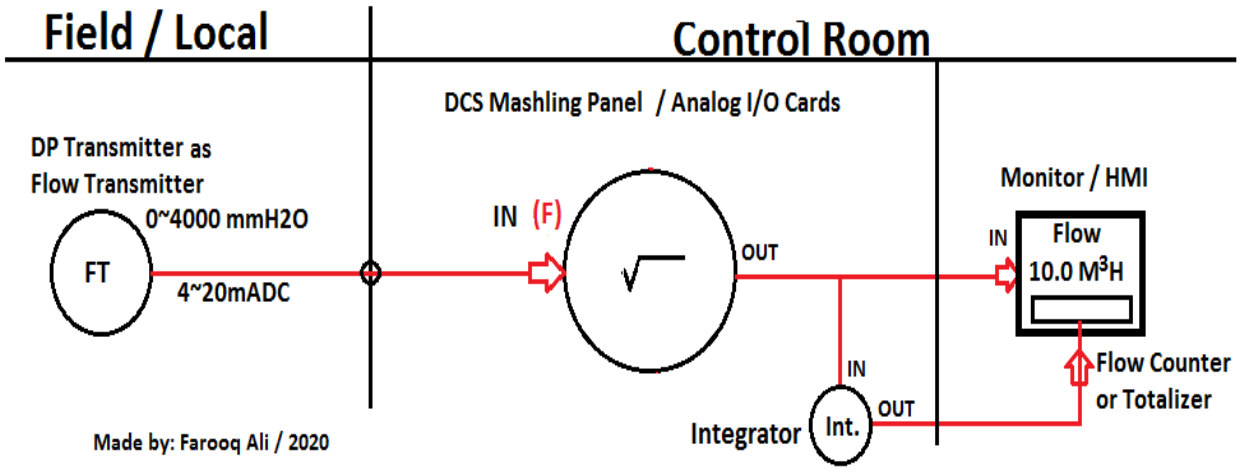
○	**0% =**	**00 mmWC=**	**4.0mADC=**	**1.0VDC,**
○	**25% =**	**250 mmWC =**	**5.0 mADC =**	**1.25 VDC**
○	**50% =**	**1000 mmWC =**	**8.0 mADC =**	**2.0 VDC**
○	**75% =**	**2250 mmWC =**	**13.0 mADC =**	**3.25VDC**
○	**100% =**	**4000 mmWC =**	**20.0 mADC =**	**5.0VDC**

After Square Root Extraxtor

- Square Root Extractor will convert **Non- Linear input signal** (Differential Pressure or Current mADC or VDC) in to **Linear output signal** in to Linear DC Voltage (1, 2, 3, 4 & 5 VDC) which will be converted in to **Linear Flow** to Record and Control.

- **Linear Output Values.**
  - **0% = 1 VDC= 0.0 M^3/H,**
  - **25% = 2 VDC= 2.5 M^3/H,**
  - **50% = 3 VDC= 5.0 M^3/H**
  - **75% = 4 VDC= 7.5 M^3/H**
  - **100% = 5 VDC= 10.0 M^3/H**

Flow Loop in DCS



- **Calculate of Flow from Diff. Pressure at Monitor/ HMI**

1-

$$\text{Output Flow} = \sqrt{\frac{\text{Diff. Pressur to be measure}}{\text{Total Diff. Pressure Range}}} \text{ X Total Flow Range}$$

- **Calculate of mADC from Diff. Pressure after Transmitter.**

2-

$$\text{Output Current of a Transmitter ; mADC} = \frac{\text{DP to be Measure}}{\text{Total DP Range}} \text{X } 16 + 4$$

- **Calculate mADC before Square Root Extractor from Linear Flow.**

3-

$$\text{mADC} = \left(\frac{\text{Flow to be Measure}}{\text{Total Flow Range}}\right)^2 \text{X } 16 + 4$$

- **Calculate Diff. Pressure after Orifice Plate from Flow at Monitor/HMI**

4-

$$\text{Diffrential Pressure} = \left(\frac{\text{Flow to be Measure}}{\text{Total Flow Range}}\right)^2 \text{X Diff. Pressure Range}$$

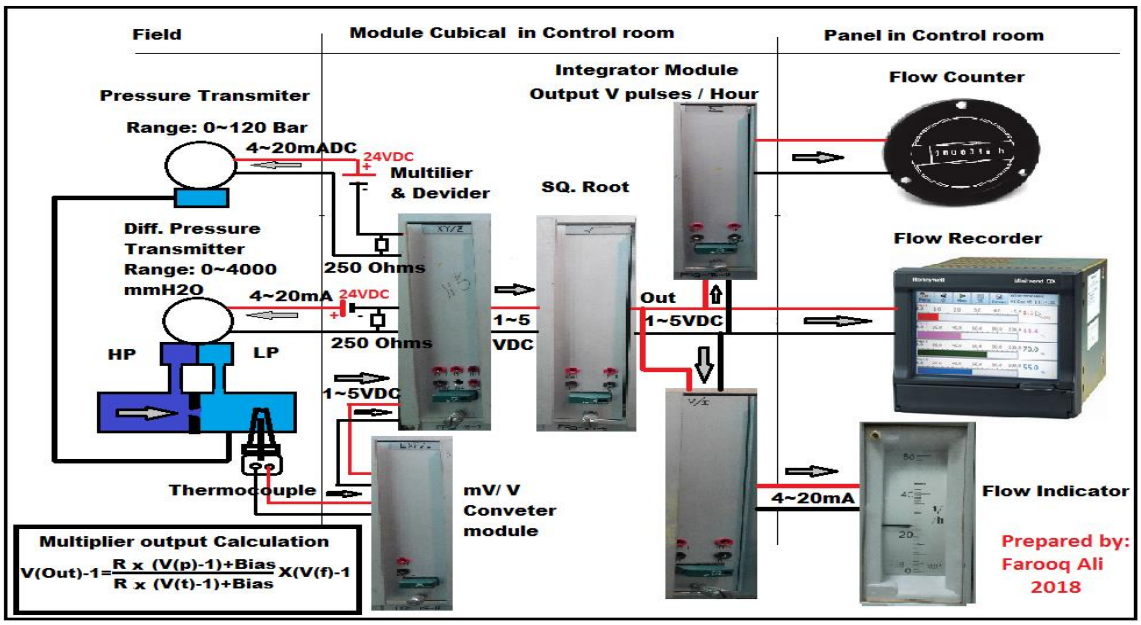
Multiplier & Divider Extractor Function

Steam Flow is a Mass Flow

Here is a Flow Loop Diagram of a Steam flow with pressure and Temperature compensation with Multiplier & Square root extractor module to the steam Flow recorder, Indicator and flow counter as shown below.

In below figure: Multiplier module card receives **3 input signals**, **Pressure, Temperature & Flow**. The **Pressure** & **Temperature** are always constant. (Designer set these values of both inputs; it depends upon pressure and temperature produced by boiler). Only **Flow** input is always variable from 0 to 100%.

- **Pressure is directly proportional to flow**, increasing steam pressure, steam flow will also increase because of velocity of steam will increase in orifice.
- **Temperature is inversely proportional to flow**, means increasing in temperature, it will not increase flow directly but it will increase steam pressure.
- So we are using **Multiplier & Divider Converter** to **compensate steam pressure and temperature**. Then we can calculate actual steam flow.
- **Steam pressure and temperature will be always constant** as input of multiplier and divider. It depends on the design.
- The **unit of steam is always Ton/Hr.** or **KG/M** (Ton or KG is the unit of **Weight**). So it will be mass flow. For accurate flow of steam, we are adding **pressure and temperature compensation** to get accurate flow calculation.
- Any variation in pressure and temperature is effecting on output of multiplier which is the input of Square root extractor.



Multiplier & Divider Extractor Function

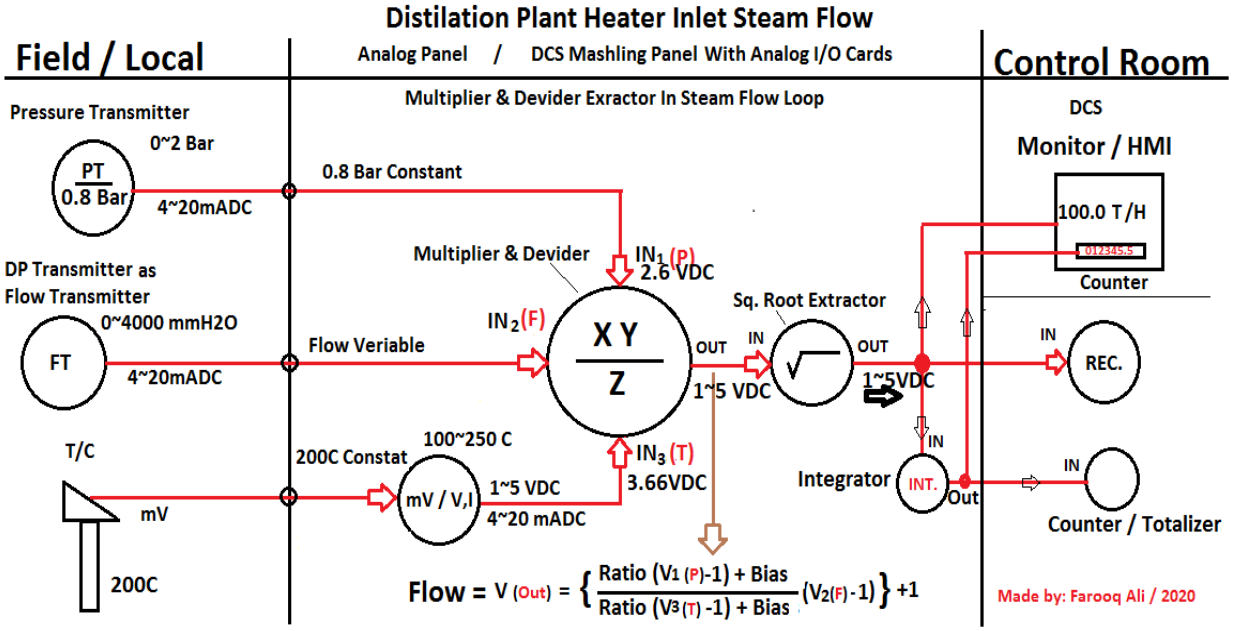
All three field instruments (**Pressure Transmitter**, **Flow Transmitter** and **T/C**) output going to the multiplier module. This module calculates the output Voltage according to the pressure and Temperature and Flow. (Designed values by designer) Output of multiplier can be calculate according to the below formula.

$$V_{(out)} - 1 = \frac{R \times \{V(p) - 1\} + Bias}{R \times \{V(t) - 1\} + Bias} \times \{V(f) - 1\}$$

1- **MSF** Heater Inlet Steam pressure: (**Range of Transmitter: 2 Bar**) **0.8 bar=2.6VDC**,

2- Heater inlet Steam Temperature: **(Range: 100C ~ 250C) 200C = 3.66 VDC.**

3- We should know the **Ratio and Bias values** designer has used in any flow circuit.



Note: If Square root used after multiplier & Divider extractor then output goes to the square root module to convert the non-linear signal in linear values then it goes to flow recorder, Indicator & integrator which send pulses signal to the counter to count Volume of steam.

Use of 2 DP Transmitters in 1 Flow Loop

The Flow is a typical mater. As we can see in behavior of flow in Fig.1, **Flow is Non-Linear.** The error at 25% flow will be very high because the difference is only **1mADC**.

So to measure the accurate flow between 0% to 25%, we are using another Very Low Range DP Transmitter.

Example: High DP Range **=4000mmH2O**, **Total Flow = 10.0 M3/H, (100% Flow)**

Low DP Range **= 250 mmH2O,** **Flow = 2.5 M3/H, (25% Flow)**

Fig. 1

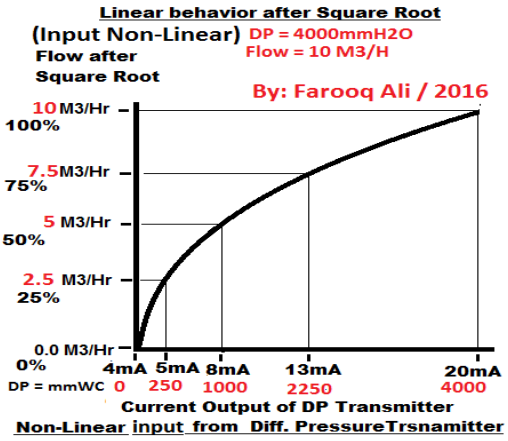
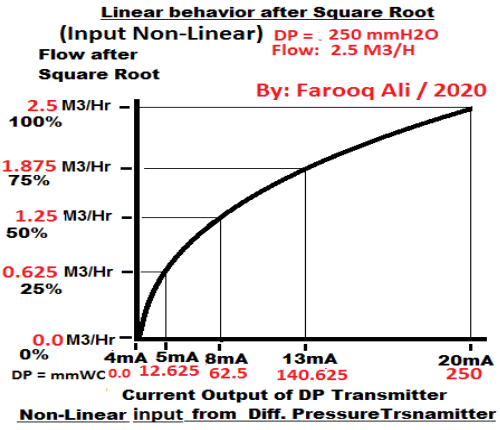
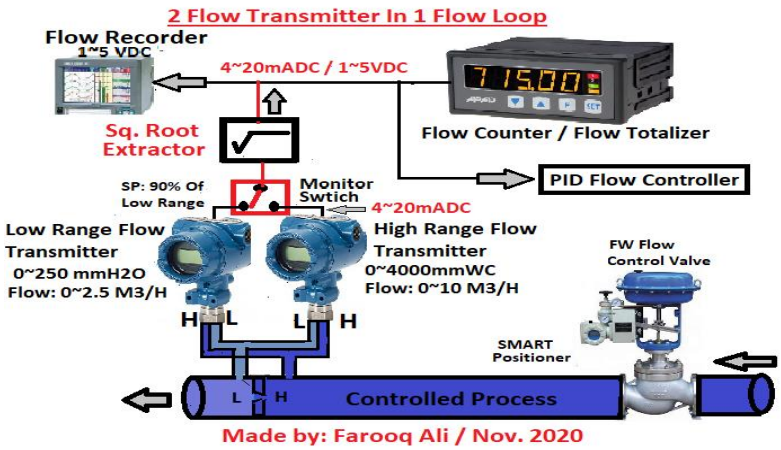
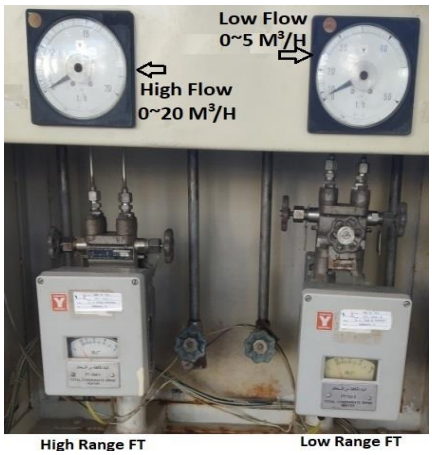
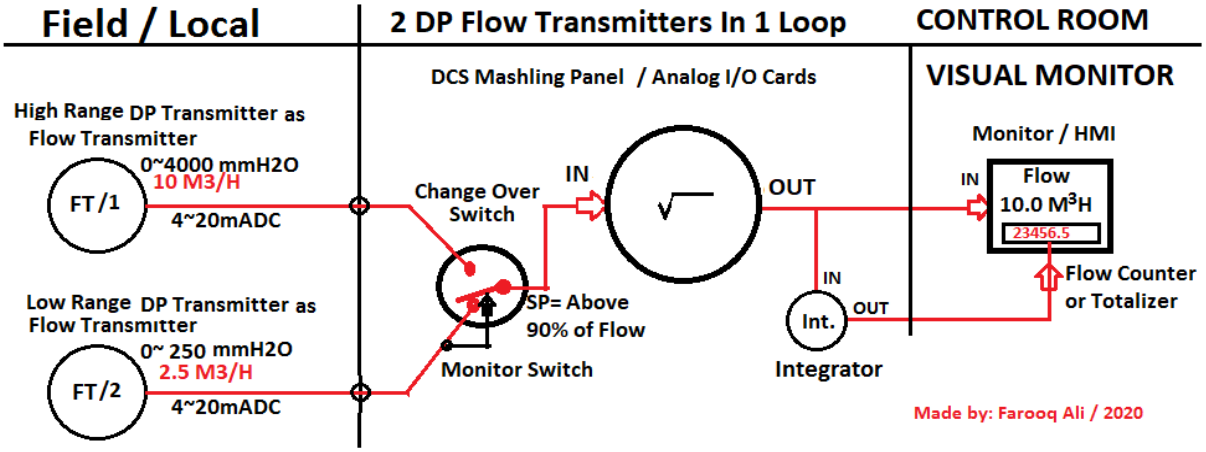


Fig. 2







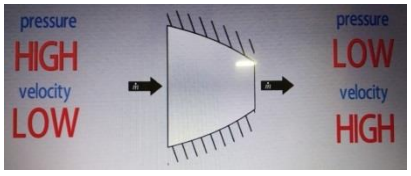


Nozzle / Flapper Mechanism,

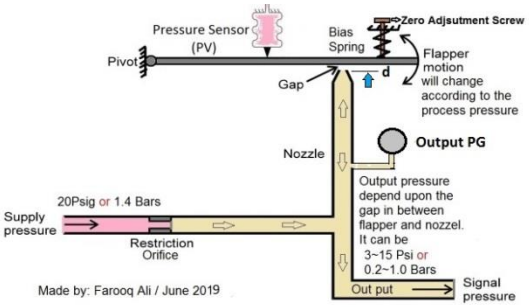
& Actuators

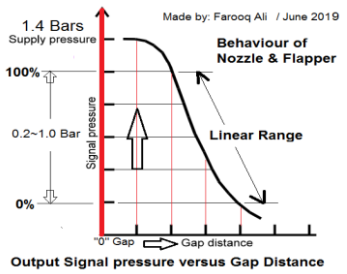
Nozzle / Flapper Mechanism

Nozzle: **Nozzle** is a conical device (with Big Inlet and small Outlet) which converts **High Pressure & Low velocity** into **Low Pressure & High Velocity.**

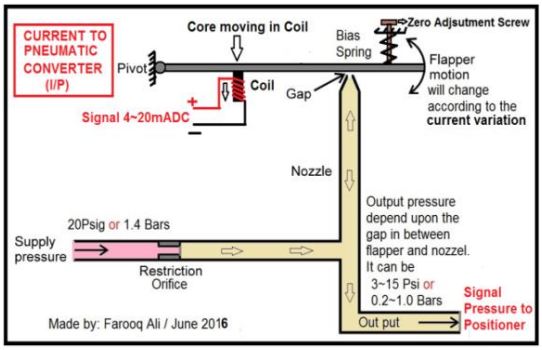


Nozzle & Flapper is the primary device for all pneumatic instruments which **convert a measurement (Process Variable "PV") in to Pneumatic Pressure Signal. (PV / Pneumatic Converter)**





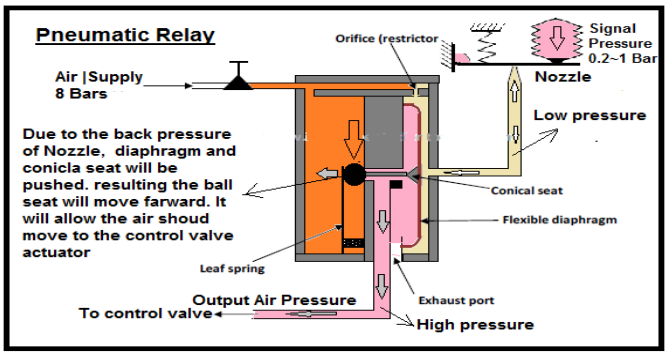
- **Behavior of Nozzle & Flapper:** Output Pn. Pressure is Inversely proportional to the Gap
- **Current to Pneumatic converter (I/P Converter)**

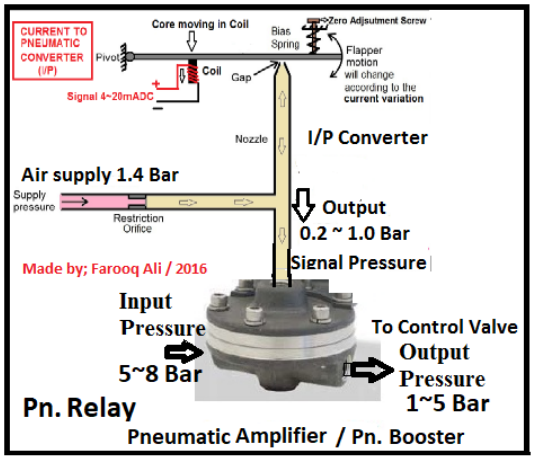


Function of I/P converter: It coverts **4~20mADC in to 0.2~1.0Bar** of air pressure. **So the input current is directly proportional to the output pressure**.

Pneumatic Relay / Pneumatic Amplifier or Pn. Booster Relay

Pneumatic relay is working as **Pneumatic Pressure Amplifier** **or** **Booster**. It takes input signal pressure 0.2 to 1.0 bars from the nozzle and flapper and amplifies output pressure from 1.0 bar to 5 bars accordingly as shown below.





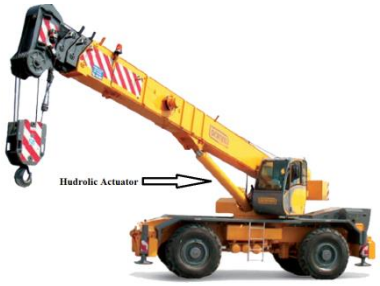
Assembly of I/P Converter + Pneumatic Relay / Pn. Booster (Part of SMART Positioner)
Input current is directly proportional to the output of Pn. Relay or Pn. Booster.

ACTUATORS

Function of Actuator: Actuator moves his own stem with the help of external source. It can be Air Pressure, Hydraulic Pressure or Electrical Motor.

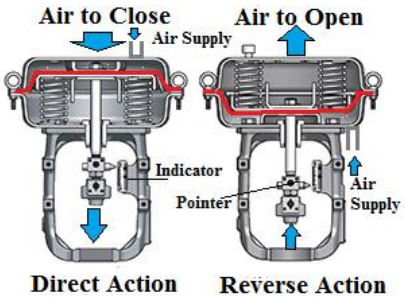
We have 3 categories of actuators.

(1) Hydraulic Actuator
(2) Pneumatic Actuator
(3) Motorized Actuator



(1) Hydraulic Actuators:
Used in lifts, forklifts and cranes. These types of actuators work with hydraulic oil pressure.

(2) Pneumatic Actuators: These types of actuators work with dry instrument air pressure.



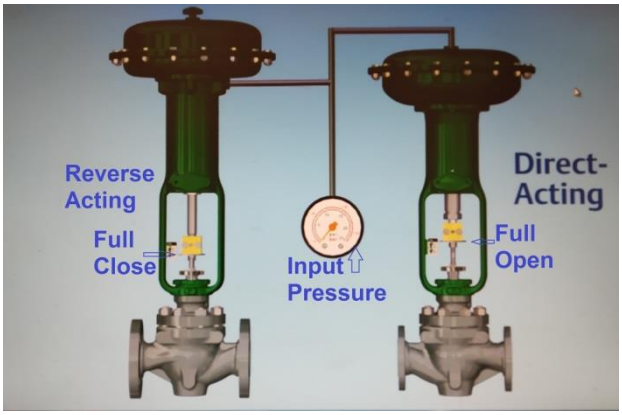
Types of actuator: There are 2 types of pneumatic actuators.

(A) Single Acting Actuator
(B) Double Acting Actuator

(A) Single Acting Actuators

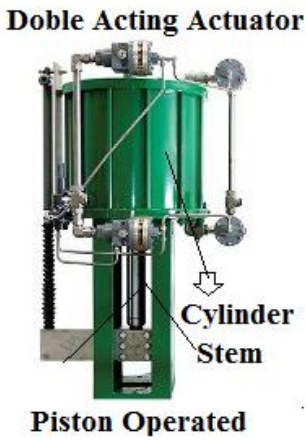
(Diaphragm Operated)
There are two types.

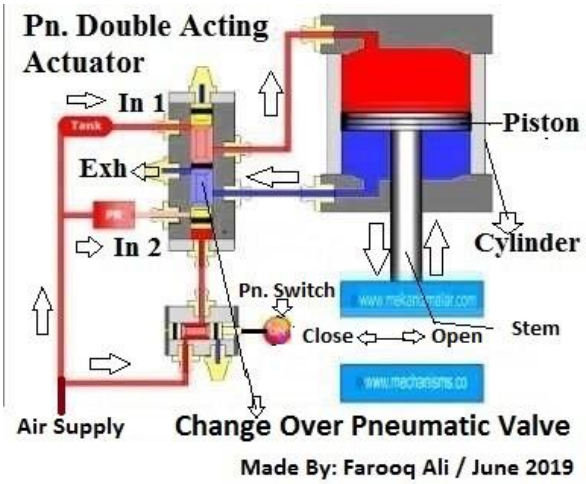
a) **Direct Acting Actuator**
(**Air to Close** / Spring to Open)
b) **Revers Acting Actuator**
(**Air to Open** / Spring to Close)



(B) Double Acting Actuator

(a) Double Acting Pneumatic Actuator: (Cylinder type Piston Operated):
Working principle: Stem with Piston moves **Up & Down** or **Too & Fro** motions with air pressure.





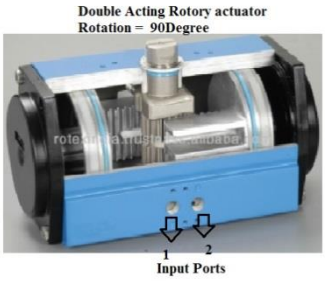
(b) Rotary Type Pneumatic Actuators (Piston Operated):

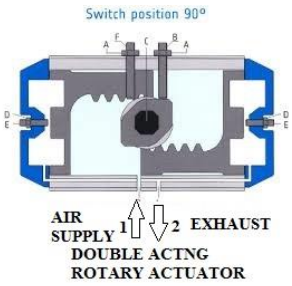
In these actuators, Mostly **Shaft moves in circular motion up to 90 Degree. In some conditions shaft can move up to 180 Degree.**

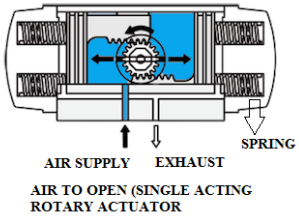
There are 2 types of actuator.

- **Single Acting Rotary Actuator** (Air to move / spring to return) &
- **Double Acting Rotary Actuator** (Air to move / Air to return):

D/A Actuator **S/A Actuator**

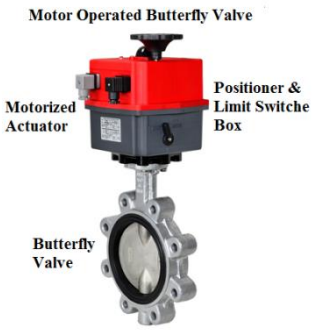






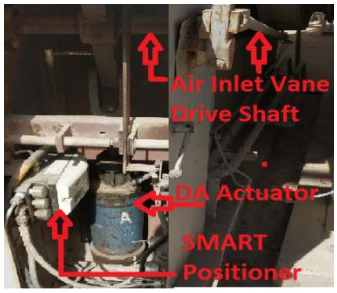
5- Motorized Actuators: (Electrical motor operated actuators)

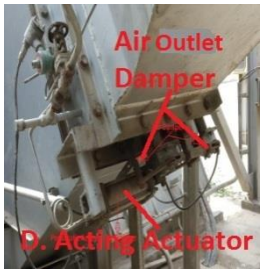
The new standard intelligent quarter-turn actuators (Moves 90 degree)



6- Air Dampers Actuators (Control Drives): Used **Pneumatic Double Acting Actuators or Motorized Actuator** to operate air Dampers (Air Shutters) can install in circular air ducts or rectangular air ducts.

FD Fan Air Inlet Damper & FD Fan Air Outlet Dampers with Double Acting Actuator





Motorized Actuators
Circular & Rectangular Air Damper

Positioner
&
Solenoid Valves

POSITIONERS

Positioner:

- **Positioner** is a **device** which moves the actuator stem **(Up & Down, Too & Fro** or **Rotary motion)** to **open the mechanical valve and stop in between any position (0% to 100%) according to the input signal** (4~20mADC / 0.2 ~ 1.0 Bar) received from the PID controller.
- Every positioner has pneumatic relay, which can amplify the air pressure (1.0 bar to 5 bars) according to the design pressure of Actuator.
- **A feed Back Lever:** Checks the movement of actuator stems (Position of control valve) & gives information to positioner to stop the valve according to the signal receives from PID Controller.

There are 2 types of Positioners.

(A) Pneumatic Positioners
(B) SMART Positioners

(A) Pneumatic Positioner Takes Input pneumatic signal: 0.2~1.0 Bar from I/P converter and amplify output air pressure 1.0 bar to 5.0 Bars.

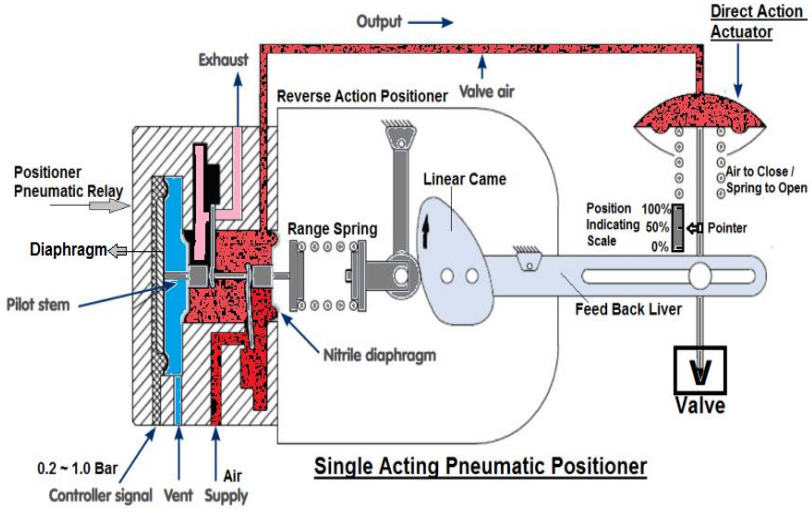
There are 2 types of Pneumatic positioner

1- Single Acting Positioner
2- Double Acting Positioner

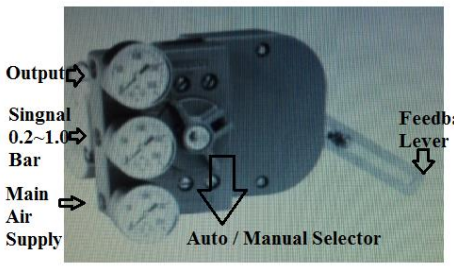
- **Single Acting Pneumatic Positioner:** There two types of single acting positioners.

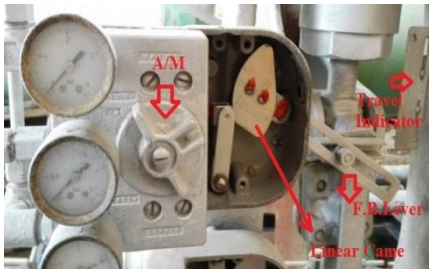
  a) Direct Action Positioner: Input signal is **Directly Proportional** to the output pressure. Means increasing input signal, output pressure will be increasing.

  b) Reverse Action Positioner: Input signal is **Inversely Proportional** to the output pressure. Means increasing Input signal, Output pressure will be decreasing.



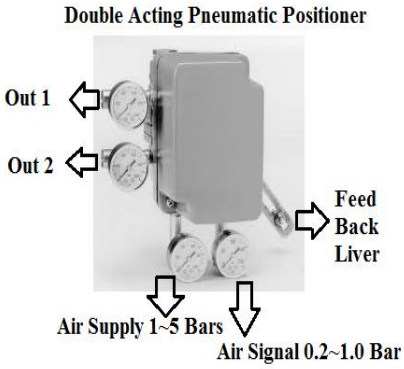
Single Acting Pneumatic positioner

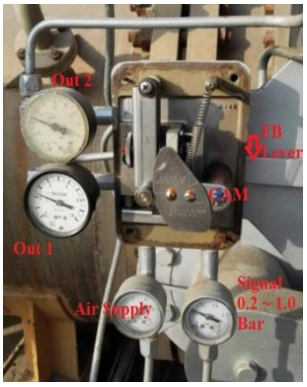


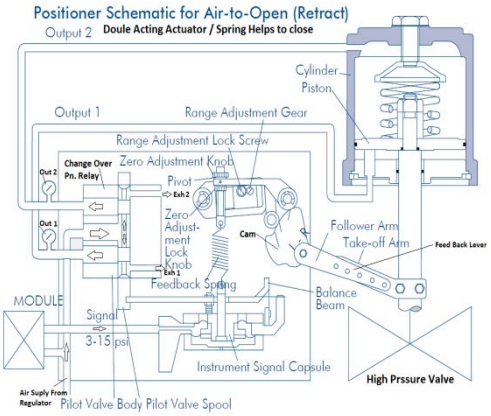


c) Pneumatic Double Acting Positioner.

Input signal: 0.2~1.0 bar, Output pressure: 1 ~ 5 Bar







Note: Drawback of Pneumatic Positioner and Position Transmitter with loop

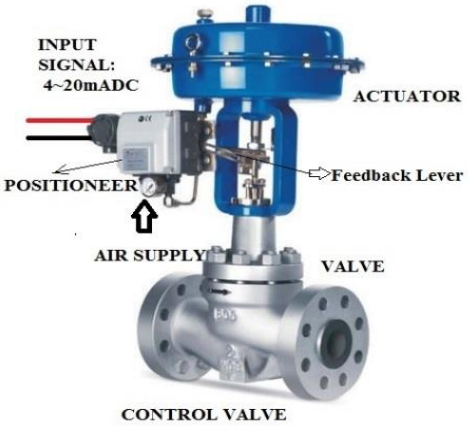
(a)- Need lot of time to calibrate the Control Valve.

(b)- Maintenance is required in every year. Clean the pneumatic relay, nozzle flapper & replace consumable spare parts. (Like diaphragm for pneumatic relay)

(B) SMART Positioner: Takes 4~20mADC signals from PID controller and give output air pressure 1.0 to 5 Bars. It also works like a position transmitter.

Benefits of SMART Positioners:

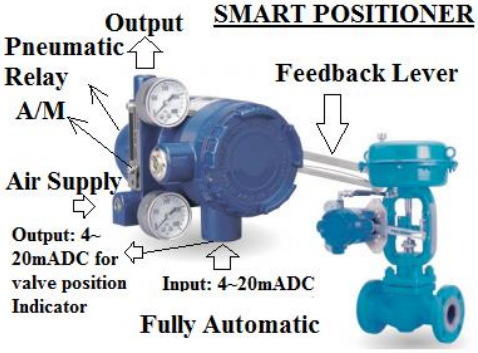
- One touches fully Automatic Calibration of control valve including position transmitter.
- Transmit output current: 4 ~ 20 mADC for remote position indicator.
- SMART Positioner is 4 in 1.
- SMART Positioner eliminates the following.
  - I/P converter;
  - Pneumatic Positioner;
  - Pneumatic Position transmitter
  - P/I converter.
- Very less maintenance is required.
- No maintenance cost is required. (Only need cleaning of nozzle and dust filter).
- Have a Processor & Memory, So we can Configure, Communicate & Calibrate the control valve.



SMART Positioner: There are 2 types.

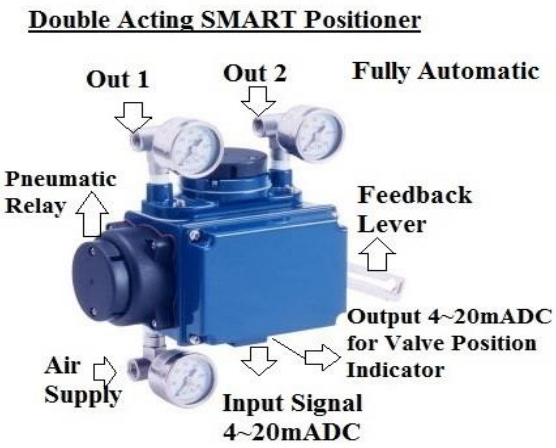
1- **Single Acting SMART Positioner:**
Input: 4~20mADC, with
1 Pneumatic output.

   a) Direct Action
   b) Reverse Action



2- Double Acting SMART Positioner.

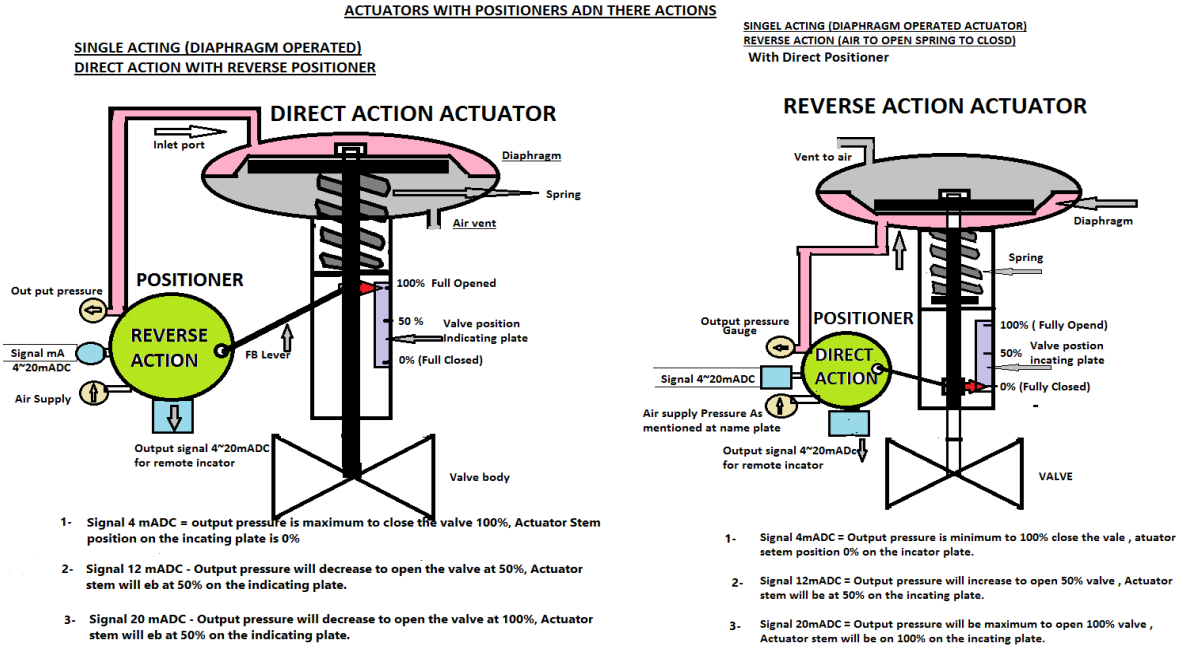
- Input: 4~20mADC with 2 Pneumatic outputs.
- Output current 4~20mADC for valve position Indicator



Use of Single Action Actuators with Single Action Positioners:

- Direct Action Actuator ---------- with Reverse Acting Positioner
- Reverse Action Actuator ---------- with Direct Action Positioner

- **Note: At 4mADC All control valve should be closed**



- ## Accessories used in Control Valves:

There are many accessories used in control valve:

1. **I/P Converter**: Converts **Current** to **Pneumatic Pressure** (4~20mADC into 0.2~1 Bar)
2. **Air Filter Regulator** (To clean the air and adjust the correct air pressure**)**
3. **Air Lock Relay** (for Single Acting Control Valve) used for **Air Failure Safe System**.
4. **Lock-up Relay** (For Double Acting Control Valve) used for **Air Failure Safe System**
5. **Limit switch:** (For OPEN / CLOSE Position of control valve in control room)
6. **Solenoid Valve** (Electrically operates and allows air to operate control valve)

Solenoid Valve and its working

We have seen solenoid valve using on the shut-off valve and also on the control valves in the plant. These solenoid valves are working on control power supply 110 VDC or 24 VDC in DCS.
All solenoid valves have two parts. **(1) Solenoid** (**2) Body, Bonnet or Spool Valve**

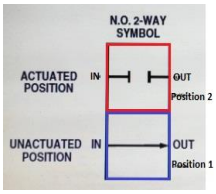
1st part is Solenoid: Single solenoid used with spring return and Double solenoid used with solenoid return. It is working by electrical power supply. It can be operating by any power supply, Like AC or DC with different voltage. It will be "ON" when power supply given to solenoid coil. It is called Energize.

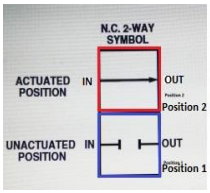
So it has 2 positions. (a) Energized (b) De-Energized.

2nd part is Body, Bonnet or Spool: It works by air**.** It has many ports with 2 positions. Like: 2/2, 3/2, 4/2 & 5/2 (1st digit showing ports and 2nd digit is showing positions of internal rod (Piston) which changes the path of the air).

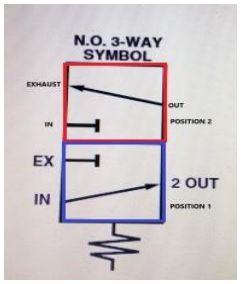
So it has also Positions (a) Normal Close (NC), (b) Normal Open (NO)

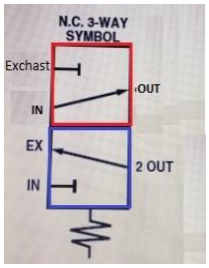
- **2/2** means 2 ports / 2 positions (Two ways) (1 IN & 1 OUT) and used with small pipe lines to open and close the flow of Air. (It works like a ON/OFF switch).



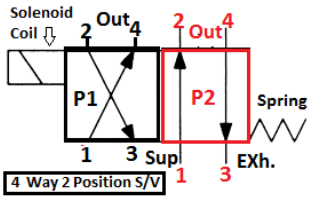


- **3/2** means 3 ports / 2 positions (1 IN & 1 OUT &1 EXHAUST) and mostly used with single acting diaphragm operated control valves.

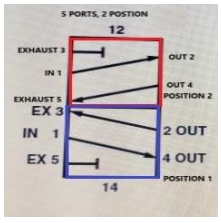


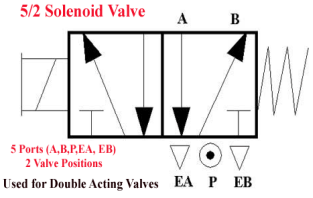


- **4/2** means 4 ports / 2 positions (1 IN & 2 OUT & 1 EXHAUST) used with double acting control valves.

- **5/2** means 5 ports / 2 positions (1 IN & 2 OUT & 2 EXHAUST) used with double acting control valves.





Fail Safe System
In a Plant

Fail Safe System

Main Aim of Fail Safe System are

1- Continuous Production
2- Plant should run safely
3- Should Be No Tripping or Shutdown

So to achieve the above targets there are some instruments used in the power plant.

There are 3 types of failure safe systems using in the plant.

1- **Electrical Control Power Supplies (110 VDC / 24 VDC) Fail Safe Systems**.
2- **Air Fail Safe System**
3- **Positioner Fail Safe System**

Note: All above failure safe systems, using in the plant are very important to save the plant from any trouble, incident or shut down the plant to stop production. There are some instruments used at Shut-Off Valve & Control Valves for all above fail safe features.

1st we will discuss about solenoid valves: Solenoid valve uses with Electrical Control power supplies 110 VDC / 24VDC in DCS.

(1) Electrical Control Power Supplies 110VDC / (24VDC In DCS) Failure Safe System.

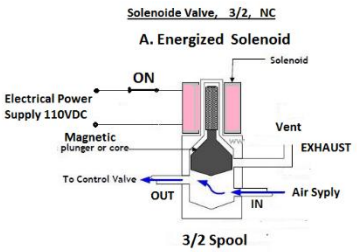
What will happen if control power supply fails of a solenoid valve?

Failure of Control power supply 110 VDC means Solenoid valve will be De-Energized.

Now we have two types of air spool "**NC**" action & **"NO"** action used in solenoid valves.

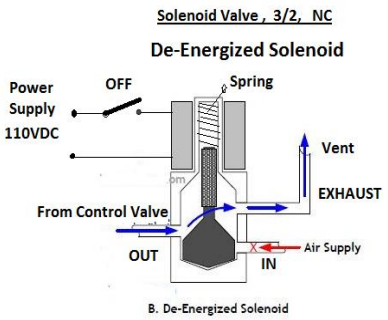
A- Normal Closed "NC" Spool Action, with 3 ports (IN / OUT / EXHAUST) & 2 positions. (OFF / ON)

a) **With 110 VDC, Solenoid is Energized**: When solenoid is energized, the **spool changes the position from NC to NO,** means air supply will open from "IN" to "OUT" and block the "EXHAUST" and control valve will be working with air supply. As shown in this figure.



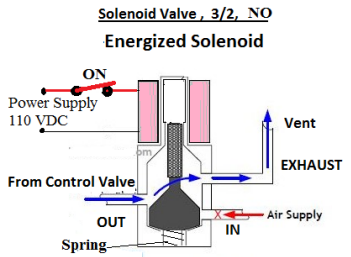
- **Action of the Valve:** Valve will act with **air supply.**

b) **When 110 VDC failed then Solenoid became De-energized:** In this condition solenoid valve will **block the air supply** from "IN" port to "OUT" port and air will move from actuator to "EXHAUST" of the solenoid valve.



- **Action of the Valve:** Valve will work with **Spring Action**.

B- Normal Opened "NO" Spool Action with 3 ports (IN / OUT / EXHAUST) & 2 positions. (ON / OFF) This **action is completely reversed than "NC"**.

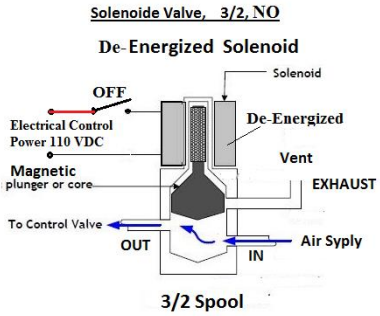


a) **With 110 VDC Solenoid is Energized:** the spool will **change the position from NO to NC**, means air supply will block from "IN" port to "OUT" port. Now trapped actuator air will release from "EXHAUST" port.

Action of the Valve: Valve will work with spring action

b) **110 VDC Failure and Solenoid became De-Energized:** In this condition solenoid valve will **open the air** supply from "IN" port to "OUT" port. **"EXHAUST" port will be blocked.**

- **Action of the Valve: Valve will work with air supply.**



Result: Use of the solenoid valve is depending upon the system and plant requirements. It depends upon the designer how he designs the plant process to save and production & Plant should not stop.

2- Air Failure Safe System.

Lock-up Relay or Air Lock relay & Test Loops (Used for Air Fail Safe System)

- **All these instruments used in Shut-Off valves and Control Valves**

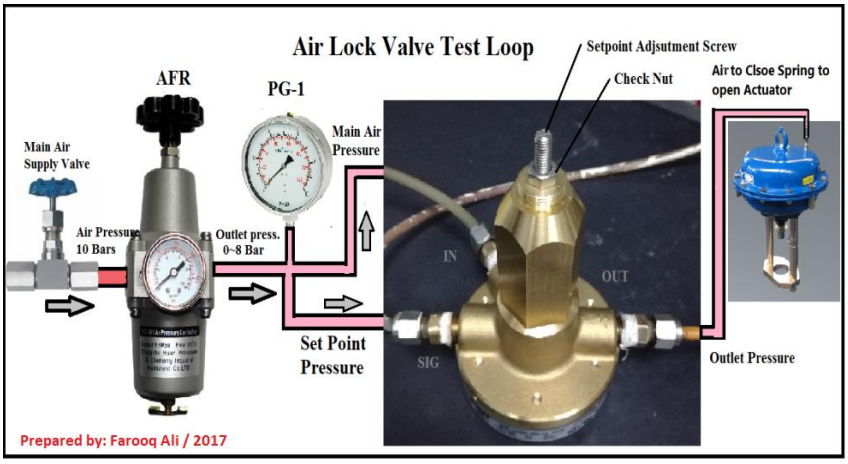
A) **Single Stage: Air Lock Relay or Lock-up Relay used with Single Acting Actuators. Having 3 Ports. (IN, OUT & Signal)**

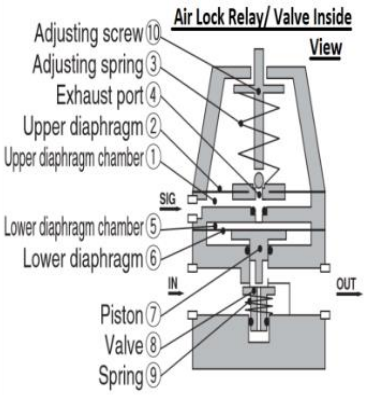
B) **Double Stage: Air Lock Relay used with D/A Actuators. Having 5 Ports. (2 IN / 2 Out & 1 Signal).**

Note: Air lock valve is a pneumatic switch, working as **(ON-OFF)** Having Set and Reset values.

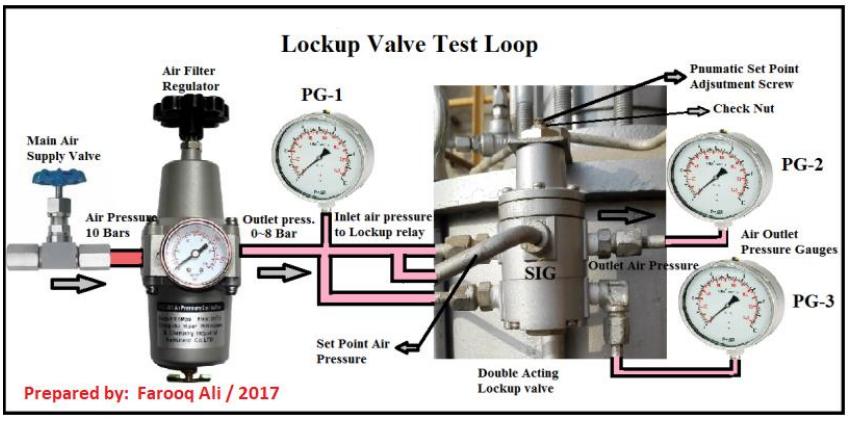
1- **Decreasing Pressure at "SET Point" (Works with Less air pressure or No air supply).**
2- **Increasing Pressure is "Reset" Pressure (Works with More than Set Air Pressure).**

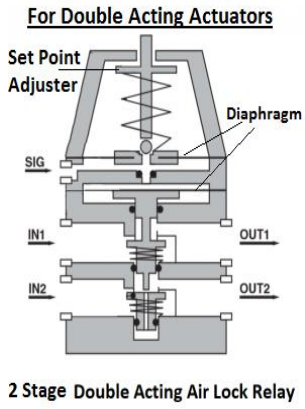
1- **Closed (OFF/NC) at No Air or Low Air Pressure at signal port & Open (ON) at more than SET Pressure as shown in below test Loop.**





C) **Double Stage Lock-Up Relay Used with Double Acting Actuators.**





2 Stage Double Acting Air Lock Relay

3-Positioner Failure Safe System

We have different types of positioners which are controlling the control valves to control the process variable.

1- **Single Acting Direct / Reverse Pneumatic Positioner.**
2- **Double Acting Direct / Reverse Pneumatic Positioner.**
3- **SMART Positioner, Single Acting / Double Acting, Direct & Reverse.**

All positioner has **Feedback Lever** to control the position (0%~100%) of the control valve according to the **signal 4~20mADC** receiving from the controller directly to SMART positioner or converted from I/P converter in to pneumatic signal 0.2 ~ 1.0 Bar for pneumatic positioners.

In case of Feedback Lever Broken or attachment of lever disconnect from the stem, Then Positioner will take Action by itself as configured by designer.

Best Choices of Designer:

(1) Designer have many options to configure the control valve action through I/P converter (Direct / Reverse), Positioner (Direct / Reverse) Actuators (Direct action / Reverse action). These all options should save the plant. The production should not be stop or nothing have to waist from the process variables.

(2) Keep in mind that any Instrument Technician or Instrument Engineer is **always not available in the plant**. According to the situation, positioner has to decide action to be taken**.**

(3) Designer always keep in his mind all above reasons then he selects the best Control Valves & Best Positioners and configures the best choices of control valve actions, which is suitable for the plant. (Either Control Valve should be open or close or hold in same position when positioner failed)

If Feedback liver broken or positioner fails, then Positioner can take the following actions.

a) **Liver can fall down or rise up**. (It is depending on the cam and spring which is used in the positioner to change output of pneumatic relay) We have many types of cams. Linear / Non-Linear. Mostly linear cam is used. Here is given some examples of cams shapes & positions used with different types of positioners.

To understand the strategy of designer what he can choose the best choice of positioner's action to save the production. **We have to understand the close and open loops of the power station. As shown below diagram**.

Mostly designer has only 3 choices.

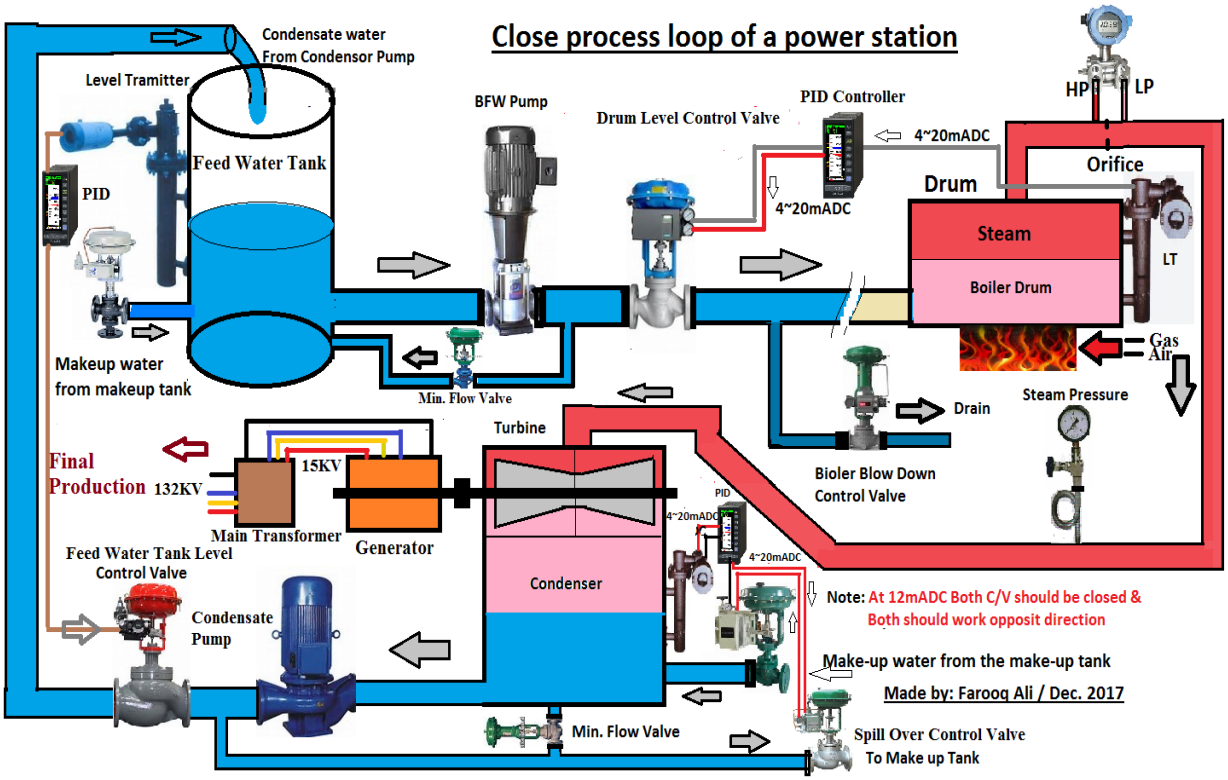
(1) Full open the control valve.
(2) Full close the control valve.
(3) Hold in Same position
(4) In SMART Positioner, we can configure any above choice.

Fail Safe System in a Closed Loop Process

In a power plant, steam is main process in closed loop to run Turbo Generator. So in case of any above 3 failures, we have only 3 options.

(1) <u>In closed process loop</u> all control valves or shut-off valves in the process line should **not be closed,** to stop production. Either valve **should Locked on same position** or **Full Open. In case of full open valves, process will be disturbed, then operator should control by manual.**

(2) <u>In open process loop</u> all valves **should be closed, not to waist DM Water** as shown in Boiler Blow Down control valve in below flow loop.



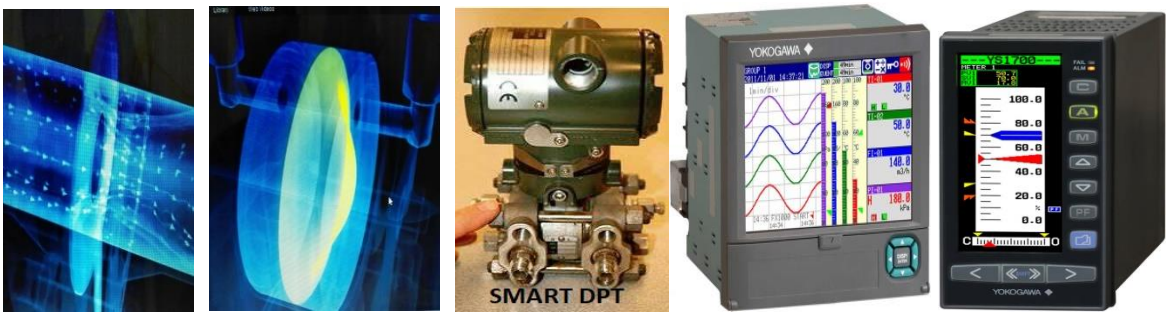
Controllers

Controllers

Measurement:

- Process variable (PV) is detecting by sensing element,
- Sensing Element Transfer effects to movement process assembly, which converts physical change in to electrical current output signal 4~20 mADC.
- Transmitter transmits 4~20mADC to control room to record the value of process on recorder is called measurement.
- Measuring signal 4~20mADC (PV) is converted in to 1~5 V DC & connected to controller to operate final control element (Control valve).

Process | Sensor | Transmitter | Recorder | PID Controller



Controller:

- Controller is a device, which **calculates the difference** (error) in between **Measuring Value** & **Set Point (SP)** value then decides to send a signal to move **final control device** to open or close the control valve and bring back process near to the set point.

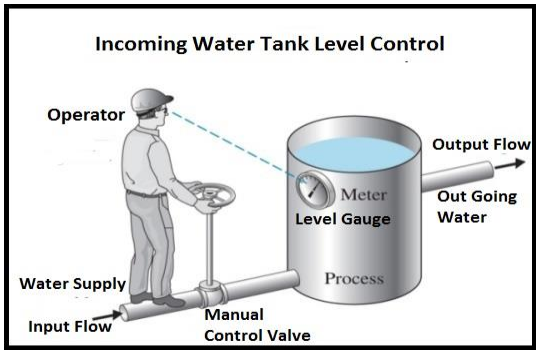
Types of Controllers:

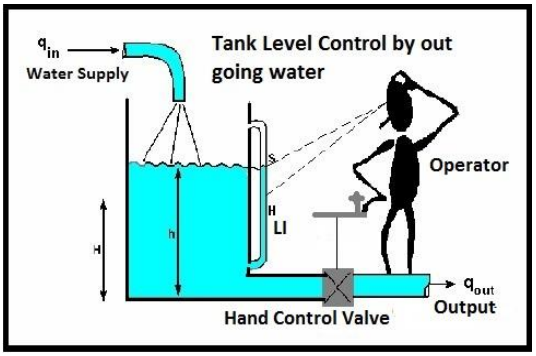
1. Manual control
2. Automatic Controllers
    a. ON-OFF Automatic Controller
    b. P - Controller (Proportional Controller)
    c. PI - Controller (Proportional + Integral Controllers)
    d. PID - Controller (Proportional + integral + derivative Controllers)

Controlling Systems:

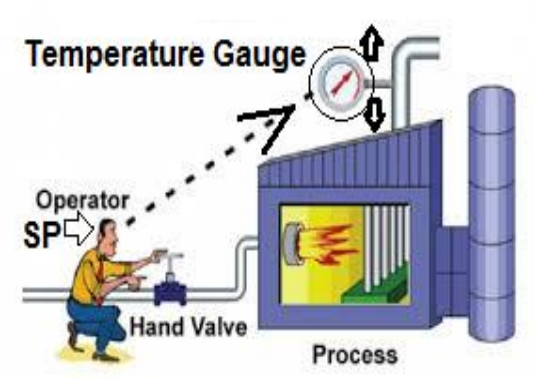
1- **Manual Control System,** Water level controlled by an operator. We have 2 options of water level control system.

- **Incoming water level control**: Operator will **open the valve** when level will **decrease** from the set value and close the valve when level will increase.
- **Outgoing water level control**: **Her operator action is opposite to the above action**. Operator will **open the valve** when level will **increase** and close the valve when level will decrease.





1- An operator tries to control the temperature of boiler manually near the set point.
2- A driver of car is trying to control the speed and lane of the road manually.



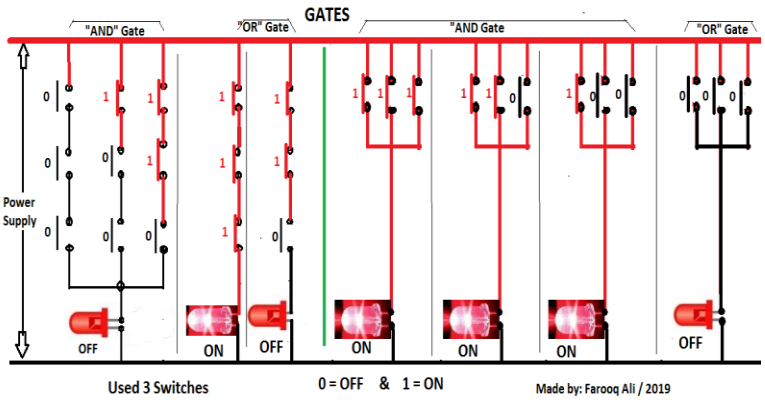
1- Brain is a Controller with SP
2- Eyes are input device
3- Hands and Feet are Final Control Devices to control the Stairing, Accelator and Break.

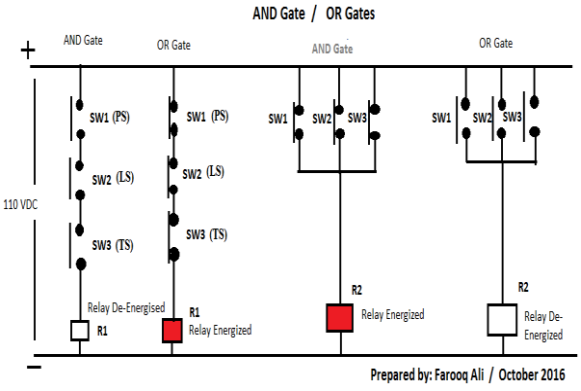
Drawback of manual control:

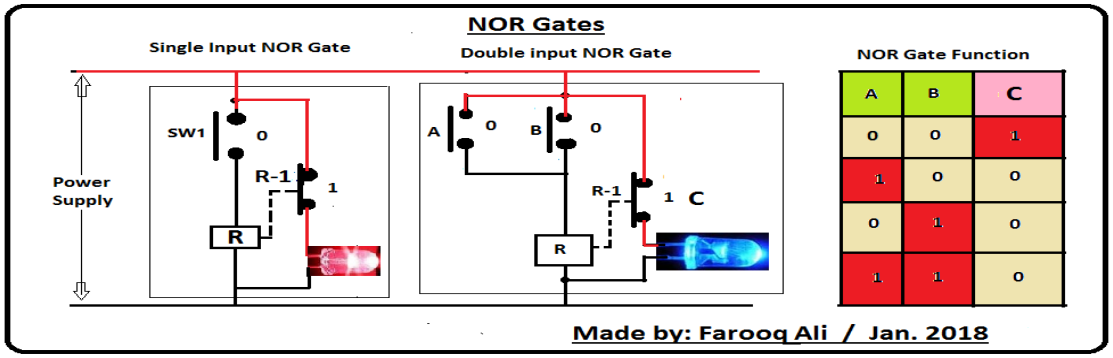
a) It requires **full attention** of an operator to control the level or temperature at set point.
b) There are many controlling systems of flow, level, temperature or pressure in a plant. It is **impossible to keep many operators** for each controlling system.
c) It will 'take **long time to stabilize the temperature or level, flow or pressure** as required by operator.
d) It is **impossible for an operator to keep full attention** on the temperature gauge each & every second.

To understand ON-OFF Logics and Automatic Controller, first we should understand the "Gates" in the control circuit.

Gates: "**AND**" Gate & "**OR**" Gate & "**NOR**" Gate. Used for "ON & OFF" Automatic Controllers. (Gates are used in interlocks and as ON-OFF controller)

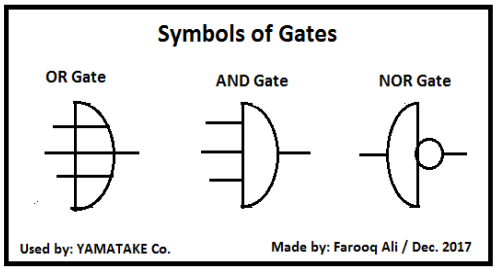


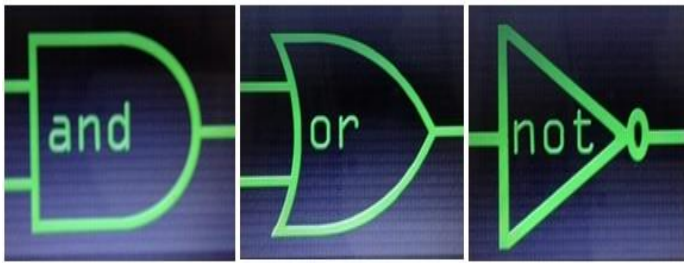




A	B	C
0	0	1
1	0	0
0	1	0
1	1	0

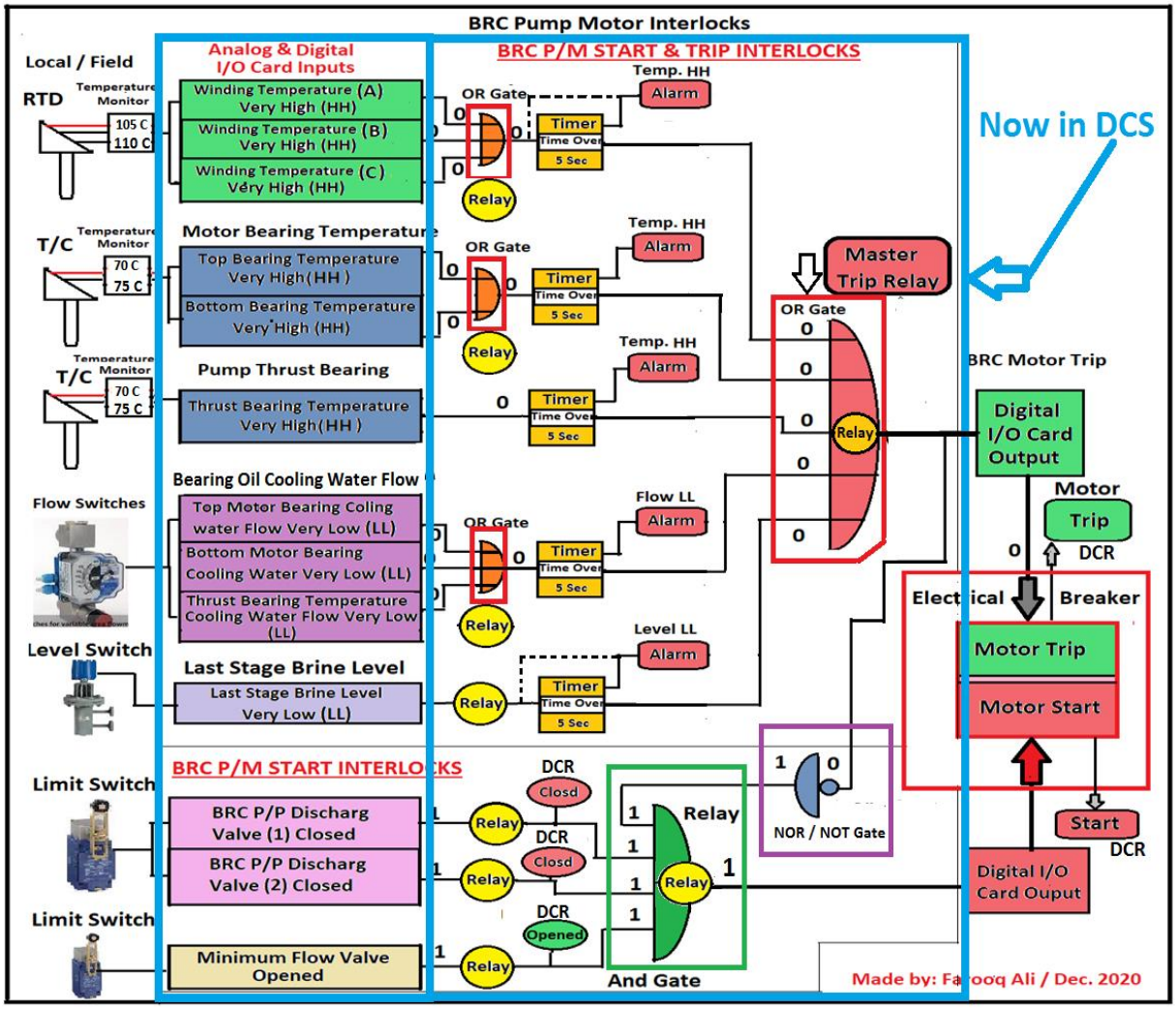
There are many symbols used by designer companies in logic interlocks.
Let us use YAMATAKE Co. gates in a BRC Pump Motor Logic Circuit.





Warning Alarms: **Before Tripping of any Pump Motor, we will receive following alarms.**

1. **Winding Temperature (HIGH) Alarm (SP= 105C).**
2. **Bearing Temperature (HIGH) Alarm (SP= 70C).**
3. **Cooling Water Flow (LOW) Alarm at Low Flow.**
4. **Last Stage Brine Level (LOW) Alarm at low Level.**



Note: In any other Pump Motor we can add 2 more permissive to start /Trip interlocks.
(1) Inlet valve should be **open.**
(2) Inlet Pressure should **not be Very Low**.
(3) Some time there is **No Min. Flow Valve** is designed. In this situation **Motorized Discharge** valve starts to open when Pump Motor starts to protect Pump.

Gates (Symbols) used in a Pump Motor Protection System.
Vertical Mounted Pump Motor Interlocks

(1) Warning Alarms (Annunciation System):

BRC P/M is vertically Mounted in a (MSF) Distillation Plant.
Before **Tripping Action** of any Pump Motor, we will receive the following alarms on windows in the control room for the operator to take action to save a plant. These windows are called "**Normal Alarms"** having YELLOW color windows.

1. Winding Temperature (**HIGH**) Alarm (**SP= 105C**).
2. Bearing Temperature (**HIGH**) Alarm (**SP= 70C**).
3. Cooling Water Flow (**LOW**) Alarm at **Low Flow**.
4. Last Stage Brine Level (**LOW**) Alarm at **Low Level**.
5. Thrust bearing Oil Level **(Low)** Alarm at **Low Level in Oil Tank.**

(2) Brine Recirculation Pump Motor (BRC Pump/Motor) Interlocks.

BRC Pump Motor is **Vertical mounted** in the Distillation Plant (MSF), having 4100KW electrical power. It is the biggest pump motor in the Plant.
We have **3 types of interlocks** used in any pump motor protection system as shown in above Logic Drawing.

(a) Tripping interlocks used with **"OR" Gates**.
(b) **Starting interlocks** used with "**AND" Gates**
(c) Both gates are used as **Permissive to Start** a P/M with **"NOR / NOT" Gate.**

(a) Tripping interlocks used with "OR" Gates.

Any one of these switches is active. It will **Trip the P/M.** These window are called "**First Out"** alarm windows. These window are in **RED** colors.
Alarm will receive 5~10 Second (As set Timer) before tripping Pump Motor.
Output of "**OR"** gates should be OFF digit **(0)** when all reading will be less than the set point values.

1. **Winding Temperature** (3 Nos) Very High or High High **(HH**) Trip at **110 ºC**.
2. **Thrust Bearing Temperatures** (1/2 Nos) Very High or High High **(HH)** Trip at **75 ºC.**
3. **Motor bearing Temperatures** (2 Nos) Very High or High High **(HH)** Trip at **75 ºC.**
4. **Cooling Water** for bearing temperatures (3 / 4 Nos) Flow Very Low /or Low Low **(LL). Trip** at specific set point of flow switch**.**
5. **Last stag Brine Level** Vey Low or Low Low **(LL) Trip** at specific Set Point of Level Switch.

(b) Starting Interlocks used with "AND" Gates.

BRC Pump / Motor have **4 starting interlocks** as shown in **above diagram.** Output of gates are used with digit **(1)** when active **(ON).**

1. **Pump Discharge Valves** (2 Nos) **Fully Closed (1).**
2. **Minimum Flow Valve Full Open (1).**
3. **All Tripping interlocks not active (0).** Ued with **"NOR / NOT"** gate**. (1)**

(c) "OR / AND or NOR / NOT Gates "are used as permissive to start Pump Motor.

In Permissive to Start Interlocks, we are using **both gates** (**OR gates & AND gates**). **"OR"** gate is used through **another gate** is called **"NOR / NOT Gate".** This gate will convert **"OR**" gate in to "**AND"** gate.

1. When **"OR"** gate will not active **(0),** then output of all **"OR"** gates will be **(0)**
2. So **"NOR / NOT"** gate will receive inputs from **"OR" Gates (0),** NOR / NOT Gate will convert it in to **"AND"** Gate to give output **(1)** when all "**AND"** gates will be **ON (1)** then **we can start a pump motor**.
3. In case of any one of **"OR"** gate will be **active (1),** means **RED Alarm** then **"NOR / NOT"** gate input will be **(1)** and output of **"NOR / NOT"** Gate will be **(0)**
4. Then from **4 "AND "gates**, only **3 "AND"** gates will be **ON (1)** but **1 "AND" gate** will be **OFF (0)**
5. **So we cannot start a Pump Motor until that one RED alarm will not be cleared or normalized from the tripping interlocks.**

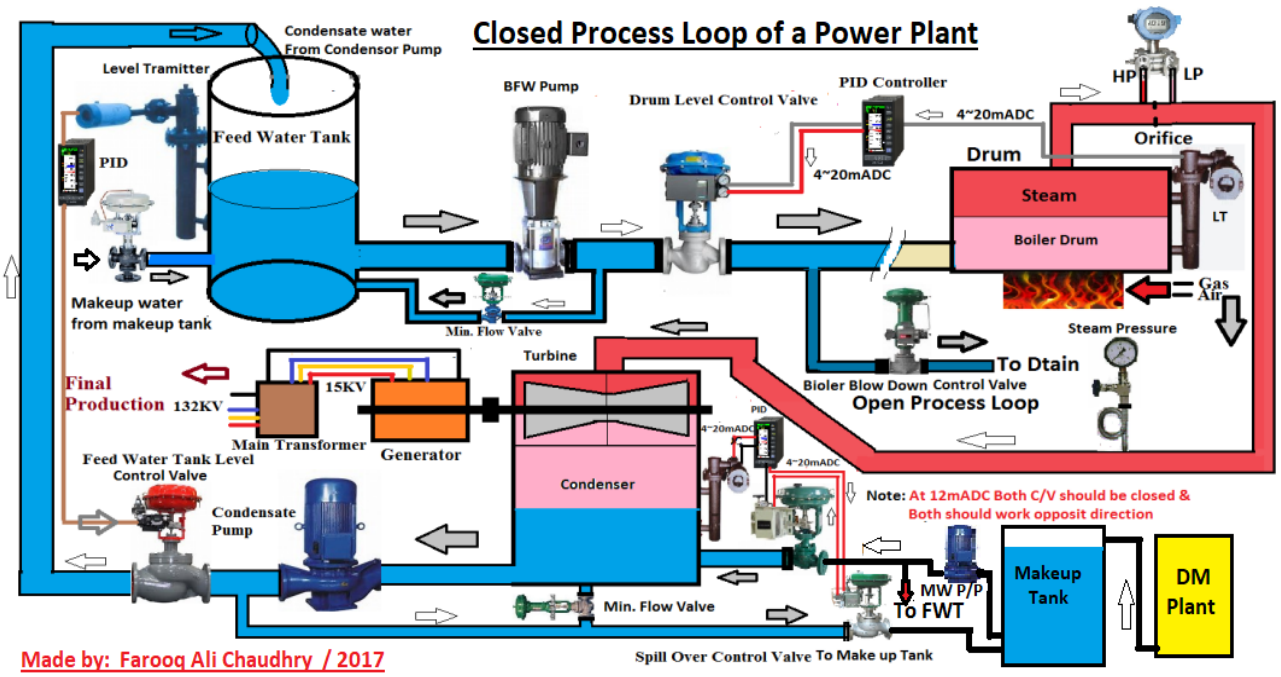
Horizontal Mounted Pump / Motor

In case of a **Horizontal installed Pump Motor** or any other Pump Motor, we can add 2 more permissive to start /Trip interlocks.

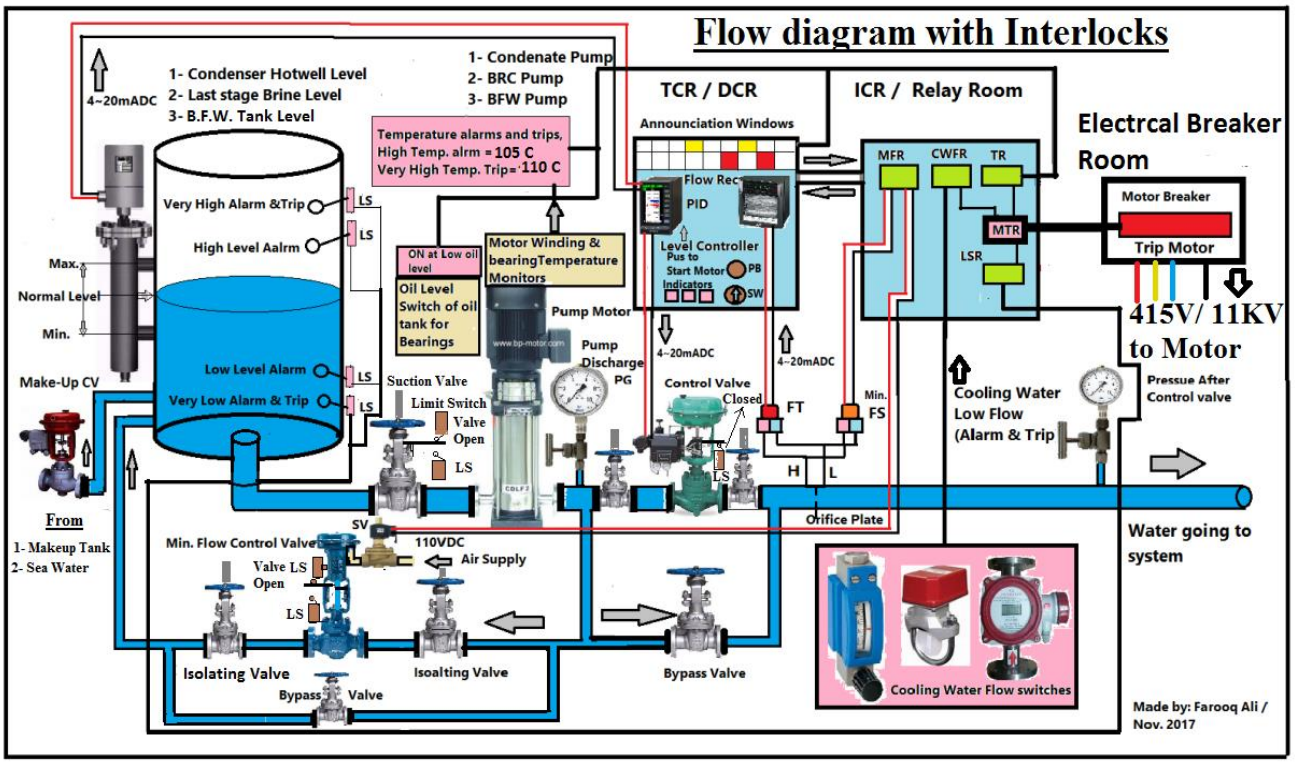
1. The Inlet valve should be **open**.
2. Inlet Pressure should **not be Low or Very Low**.
3. Sometimes **No Minimum Flow Valve** is designed in the process control. In this situation, a **Motorized Discharge valve** is provided. The motorized discharge valve will open as soon as we start the Pump Motor. It is a safety of pump.

Motorized discharge valve must be open, **minimum 20% to 30%** in **1st 10~15** Sec to keep the pump motor running. If it **fails to open within 10~15 Sec,** then Pump Motor should trip for its safety of Pump.

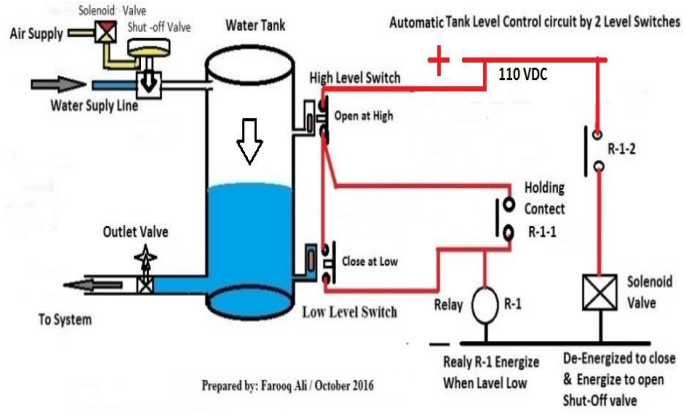
Process of Condensate Water & Steam in a Power Plant (Closed Loop)

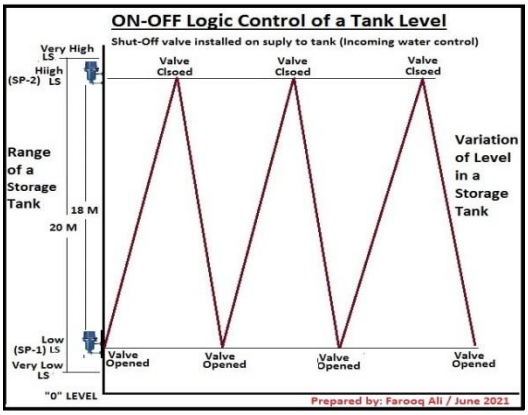


Below Flow Loop Diagram used to understand Interlocks (Protections) of a Pump Motor & Automatic Process Control System.

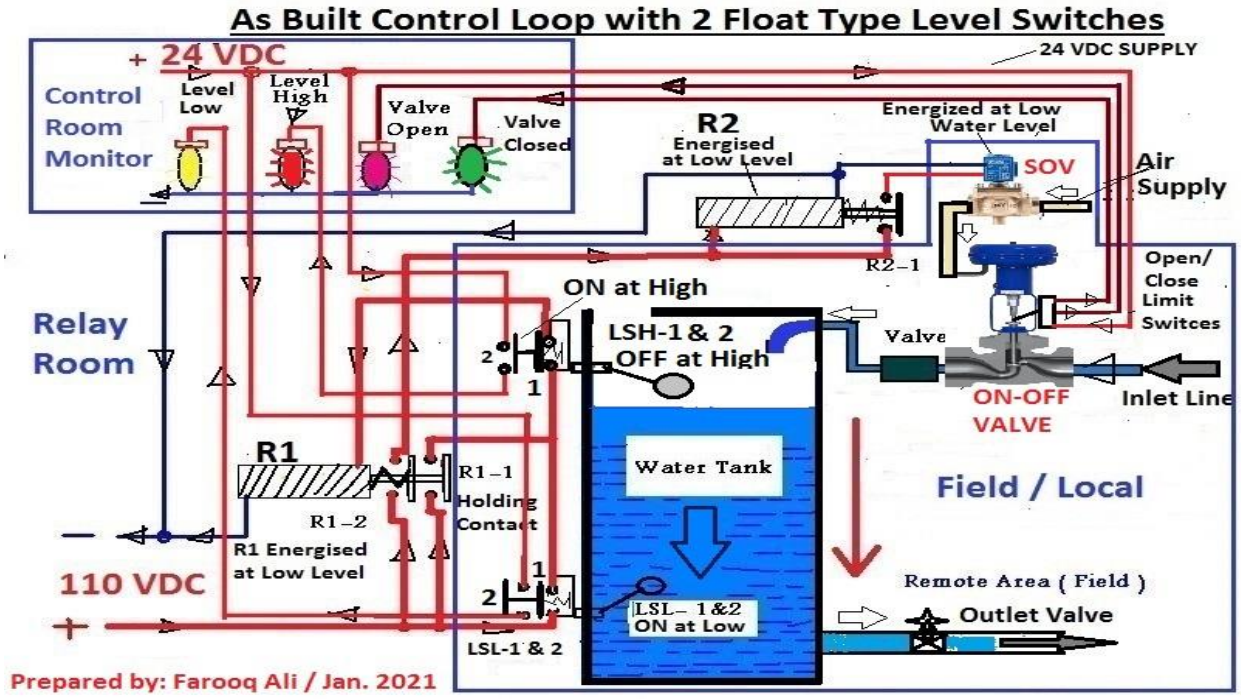


(a) ON - OFF Automatic Controller using " AND " " OR "gates

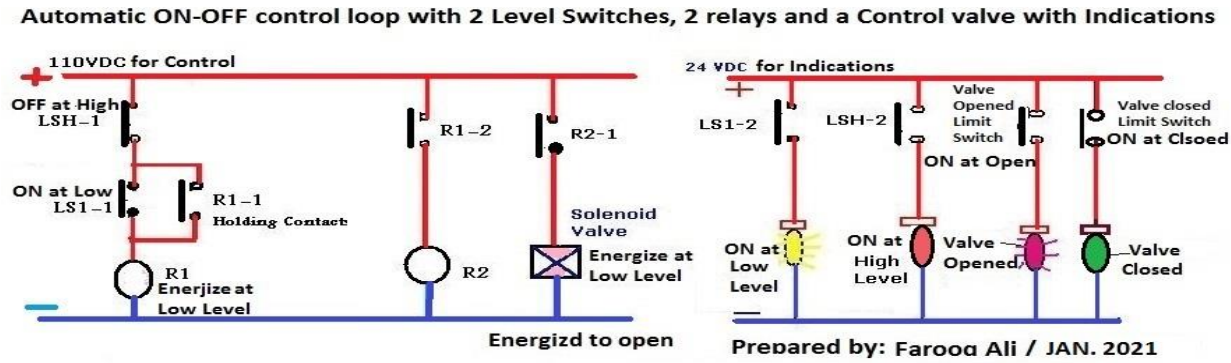




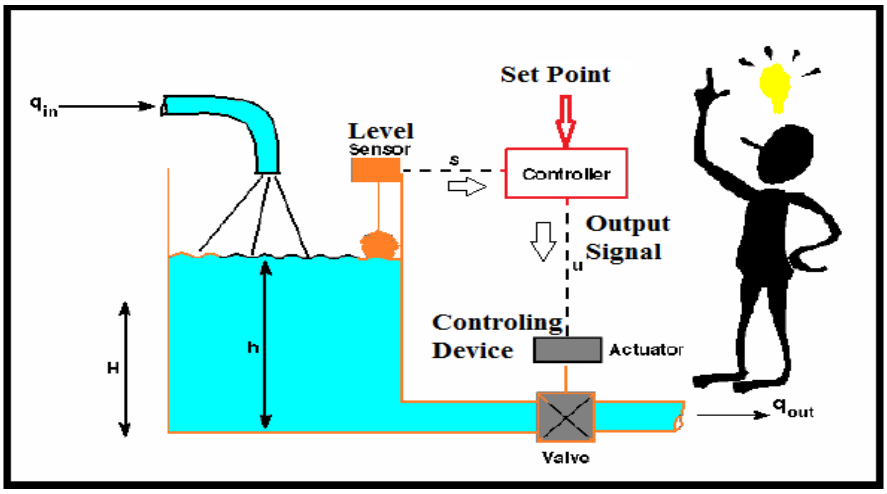
- **Actual / As built Automatic water tank Level Control System with indications. 2 Float type Level switches (DPDT contacts) and 2 relays and different types of power supplies (24VDC for indications and 110 VDC for interlocks) with a Solenoid valve & a Shut-OFF valve.**



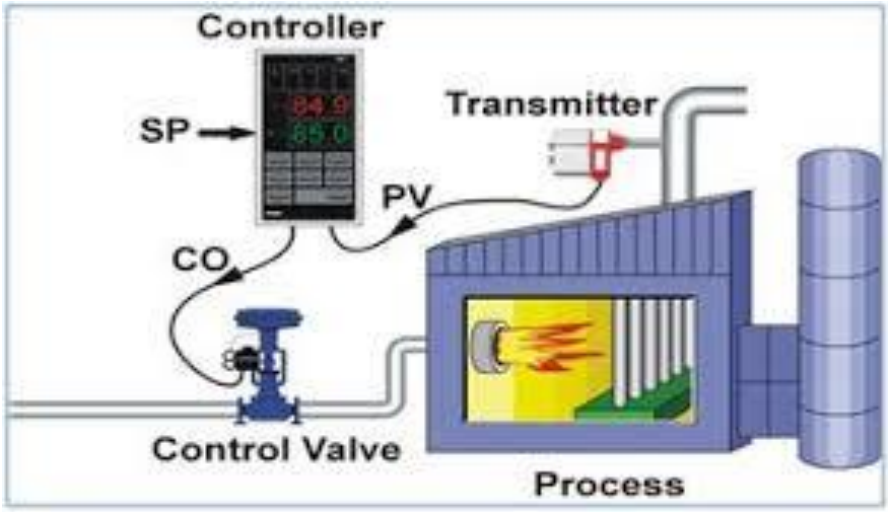
- **ON - OFF Control Loop of as built water tank level control system.**



(b) **Automatic Water Level Controller:** Level transmitter is measuring the tank level. Automatic Controller controls level maar the Set Point with help of control valve installed on outgoing water line**.** Automatic controller will **open the valve when level increases & Close when level decrease**.



- **Automatic steam temperature control:** Temperature transmitter is measuring the steam temperature. Automatic Controller controls the temperature near the Set Point with help of control valve installed on incoming gas line. Automatic controller will **open the valve when temperature decreases & Close when temperature increases.**

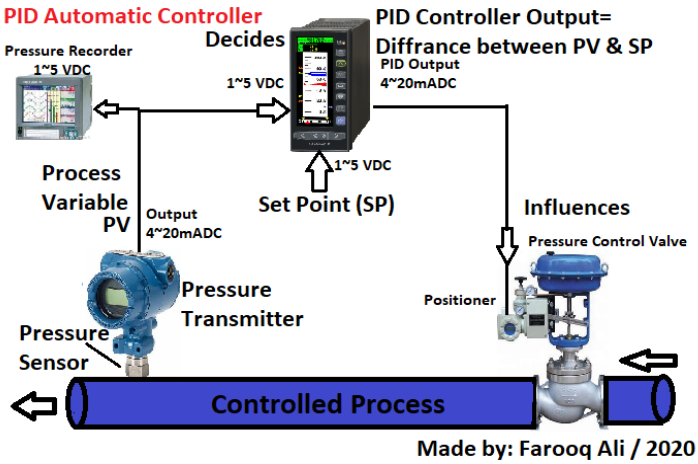


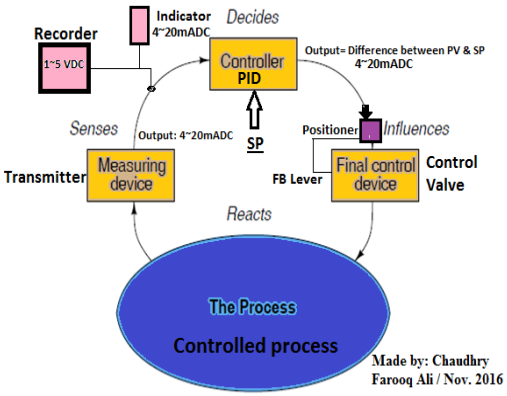
- **Benefits of Automatic Control System**

5. It eliminates the **operator**. (Means operator is not required on any control loop).
6. Automatic Controller **it-self decides** by calculates the error and operates the control valve to correct process.
7. It is **accurate and safe**,
8. It required **very short time to stabilize** PV along with SP.
9. It can be **using in one control loop or multiple controlling** systems like cascade control system used in boilers.
10. It will **eliminate the OFFSET** between PV & SP.

Automatic Controller

- ## Automatic PID Control Loop:

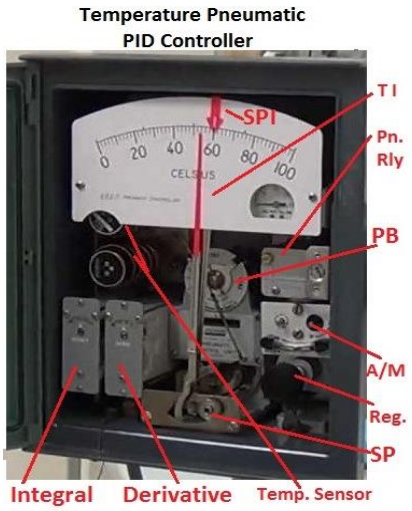


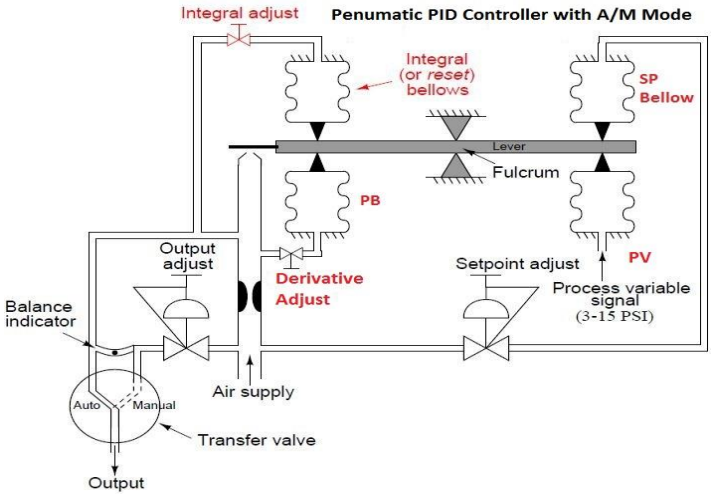


(c) PID Controller: There are 2 types of PID Controllers

- Pneumatic type PID Controller
- Electronic type PID Controller

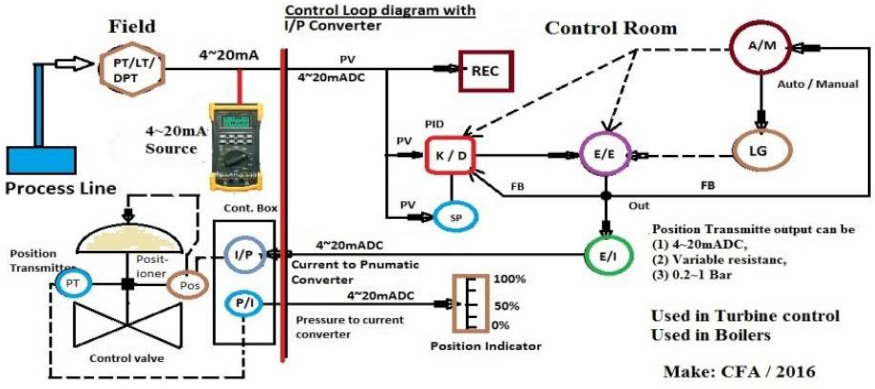
- ## PID Pneumatic Controller & Function



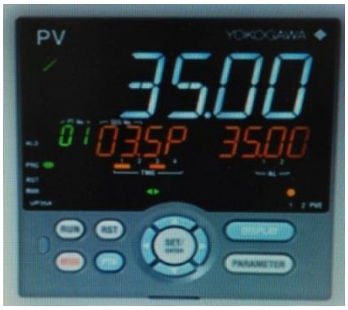


- ## PID Electronic Controller

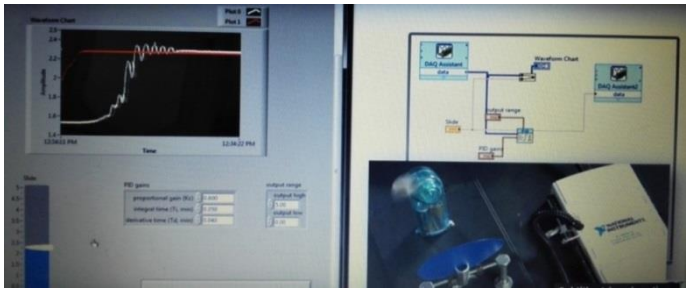
(a) PID Module based controller & Function

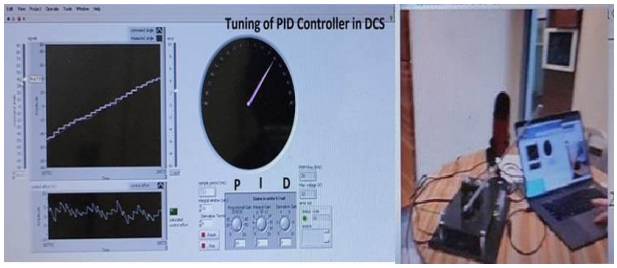


- **PID Compact universal type Controller** (Panel Mount):

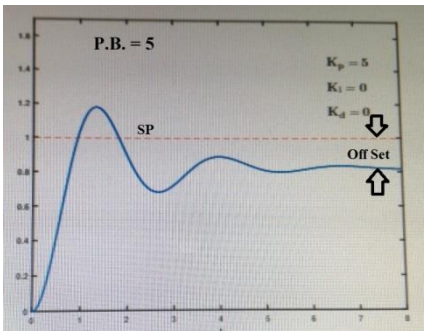


- **PID, PC Based Controller (**DCS Controller),
  This type of controller works by DCS software made with function blocks:

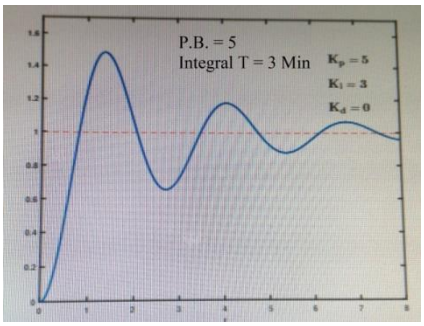




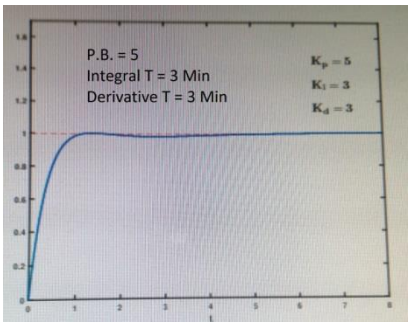
Process behavior of "P" Controller, "PI" Controller & "PID" Controller



"P" Controller Function



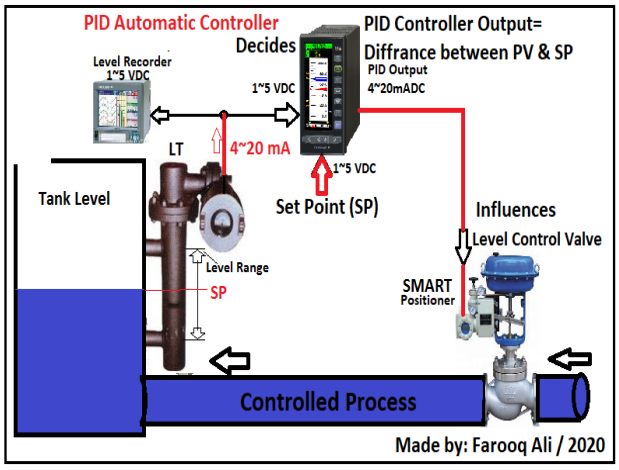
"PI" Controller Function

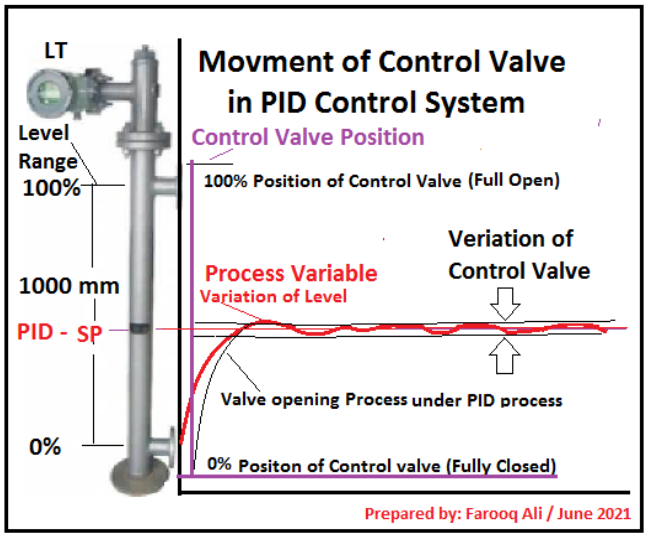


"PID" controller Function

Behavior of Control Valve under PID Level Control PID Process.

Function of PID Control & its Behavior





PID Controllers

P Controller - Proportional Controller.
PI Controller - Proportional + Integral Controllers.
PID Controller - Proportional + integral + derivative Controllers.

(a) Proportional "P" in (%) (Means Damping)

Proportional "P" is denoted as Proportional Band **(PB). PB** is controlling the **Sensitivity** of control valve, that **how much and how fast control valve will operate**. Increasing the PB means increasing the damping. Decreasing the PB means decreasing damping.

"PB" is always inversely proportional to the Gain Output of a controller.

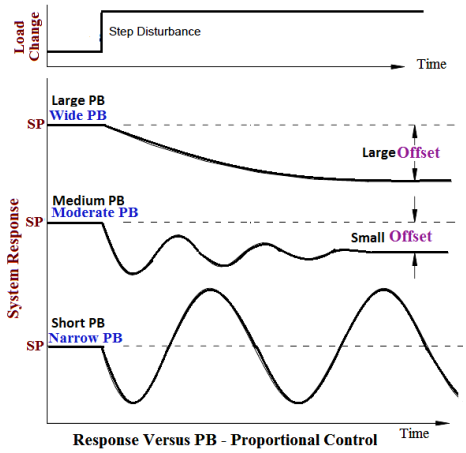
PB ∝ 1 / Gain Output,

(Gain = 100% / PB in %)

(1) If **"PB" is "0%"** then controller output will be max. Means 100% output **(20 mADC)** of controller will reach to the positioner to operate the control valve. **(Means there is no damping).**

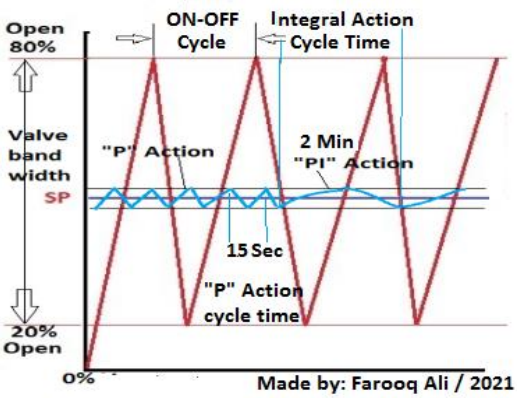
(2) If **"PB"** will be **"100%"** then output of controller will be minimum (**"0%"**) **m**eans **(4 mADC).** So there will be **0%** output signal will reach to positioner to operate the control valve because at **(4 mADC)** valve must be closed. **(Means there is 100% damping)**

(3) If "**PB"** will be **"50%"** then **"50%** signal" will reach to the positioner to operate the control valve and so on as shown in this picture.



Response Versus PB - Proportional Control

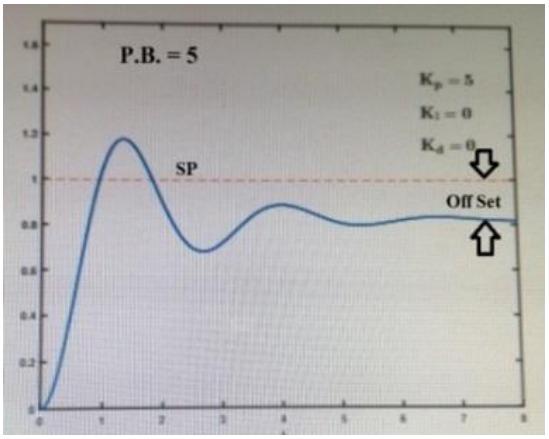
Result: So Proportional **(P)** works like **Dampener.** **If we increase (PB) damping will be increased & if we decrease "PB" damping will be decreased**. So it will control **sensitivity** of Control Valve.

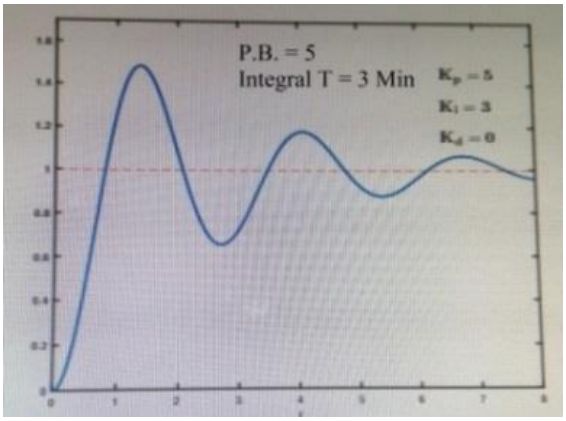


- **(a)** It will **reduce the movement** of control valve in **limited band**.
- **(b)** It will **stabilize** Process Variable in limited band but it will **take long time to stabilize**.
- **(c)** It will create **difference** between **Set Point "SP"** and **Process variable "PV"** which is called **"OFF SET"**
- **(d)** Tune the **PB%** (**Increase / Decrease the Damping**) in such a way that in trend / history we can see very small variation in process variable.
- **(e)** **This will be best PB**.

(b) Integral / Reset time "I" in (Minutes)

Unit of integral is (**Repeat / Minute or Minute/ Repeat**). **Time is involved to open and close the control valve.** **How much time control valve will take to complete a cycle?**



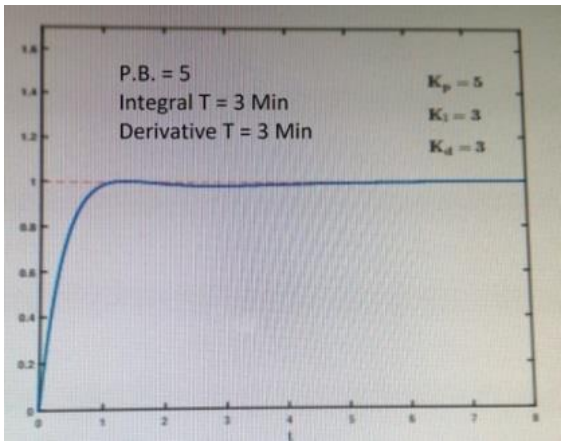


There is a repeat of cycles to open and close of a control valve in limited band. To increase the cycle time, we are adding **integral time** in the controller.

Result: (1) It will **increase opening and closing cycle time** of a control valve. **(2)** It eliminate **"OFF-SET**. So it will make "**Alignment"** in between of Process Variable (PV) and Set Point (SP)

(c) Derivative / Rate / Pre-act time "D" in (Minutes)

Adding derivative time in controller, derivative action is an **automatic control over correction. It corrects the controller output, based on the rate of change of the input. It re-acts before PB action.**



Result:

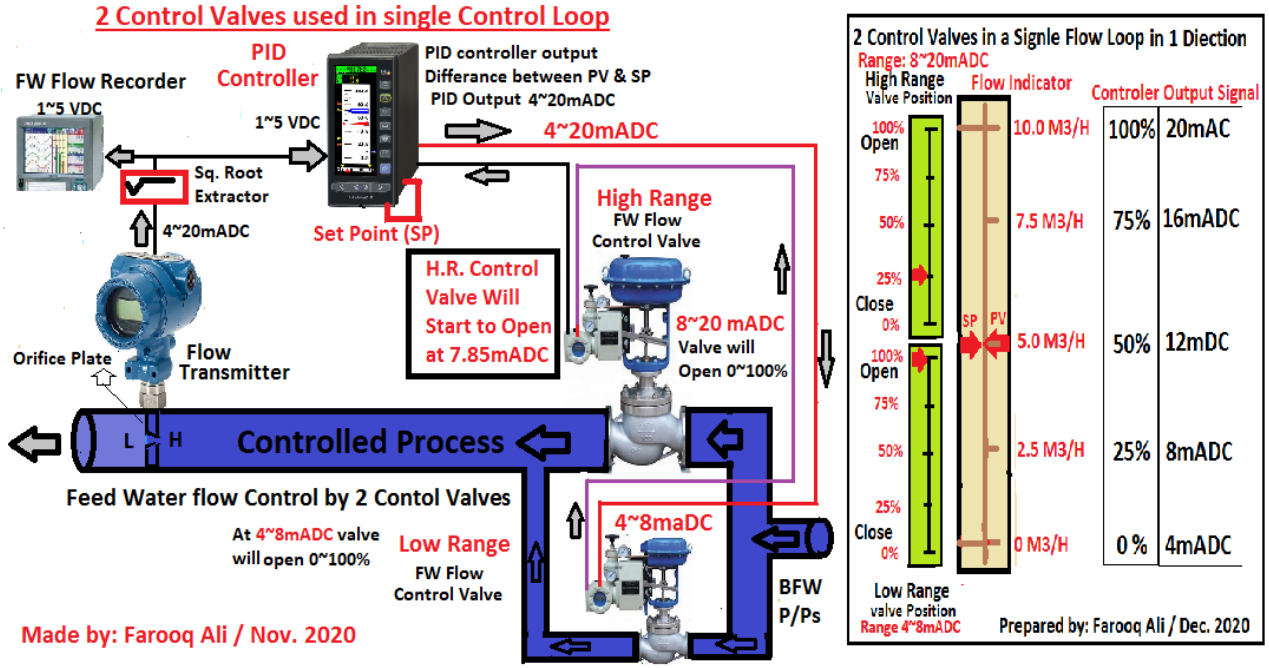
(1) It works like **"Fine Tuning"** of a controller.

(2) Also it works to reduce stabilizing time of the process.

2 Control Valves
With (1) PID Controller
In a Single Control loop

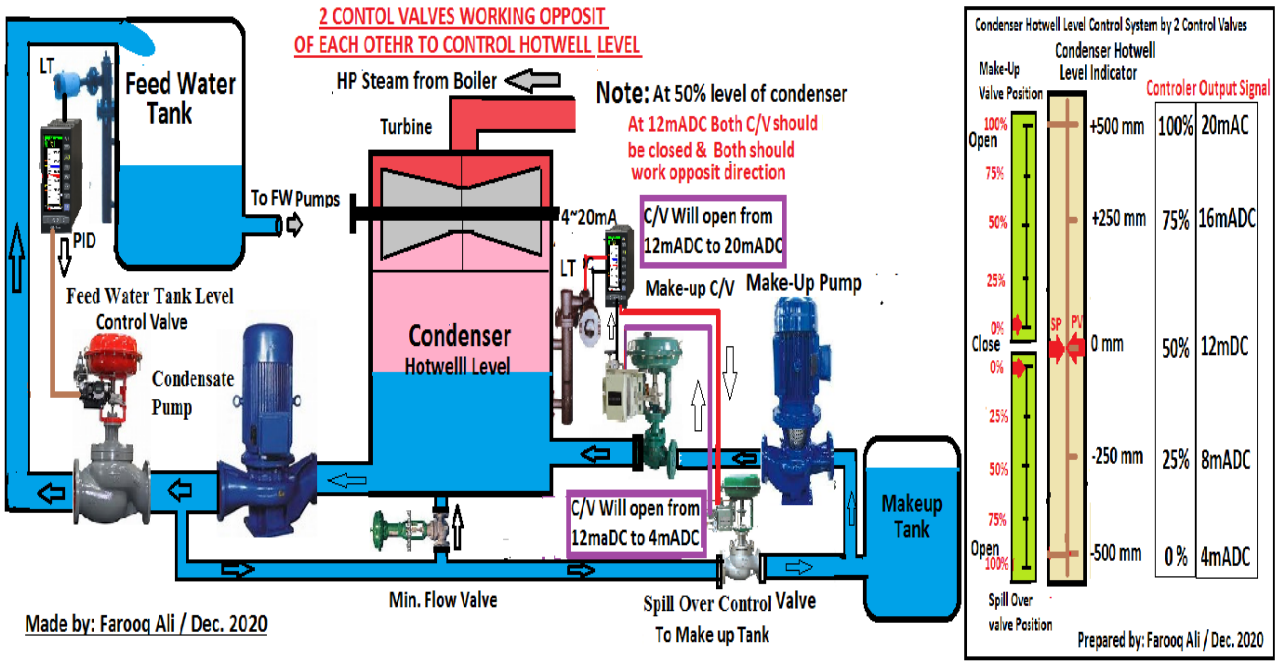
2- Control Valves working in parallel with (1) PID Controller in a single Control loop.

- As we know the flow is non-linear. In same way when we open a control valve up to 25% then water flow moves up to 50% of the total flow.
- It is very difficult to control the accurate flow in between 0~25% opening of the control valve. Very small movement of control valve, huge flow moves from the valve.
- According to the 2 flow transmitters (Low & High Range), in the same ways 2 control valve (Low & High Range). Low Range control valve is very necessary to control the flow in narrow band in 0% to 25%.
- So 2 Control Valves are used to **control the accurate flow** in narrow band**.**
- To control accurate flow up to 25%, we are using **Low Range** control valve.
- **Low Range** control valve will open 0% to 100% from **4 mADC ~ 8 mADC**.
- **High Range** valve will start to open 05 to 100% from **8 mADC ~ 20 mADC**.
- **Note:** For smooth parallel operation of High Range control valve should be set to take off at **7.8 mADC** as shown in below figure.



2 Control Valves working opposite direction in a single control loop with (1) PID controller.

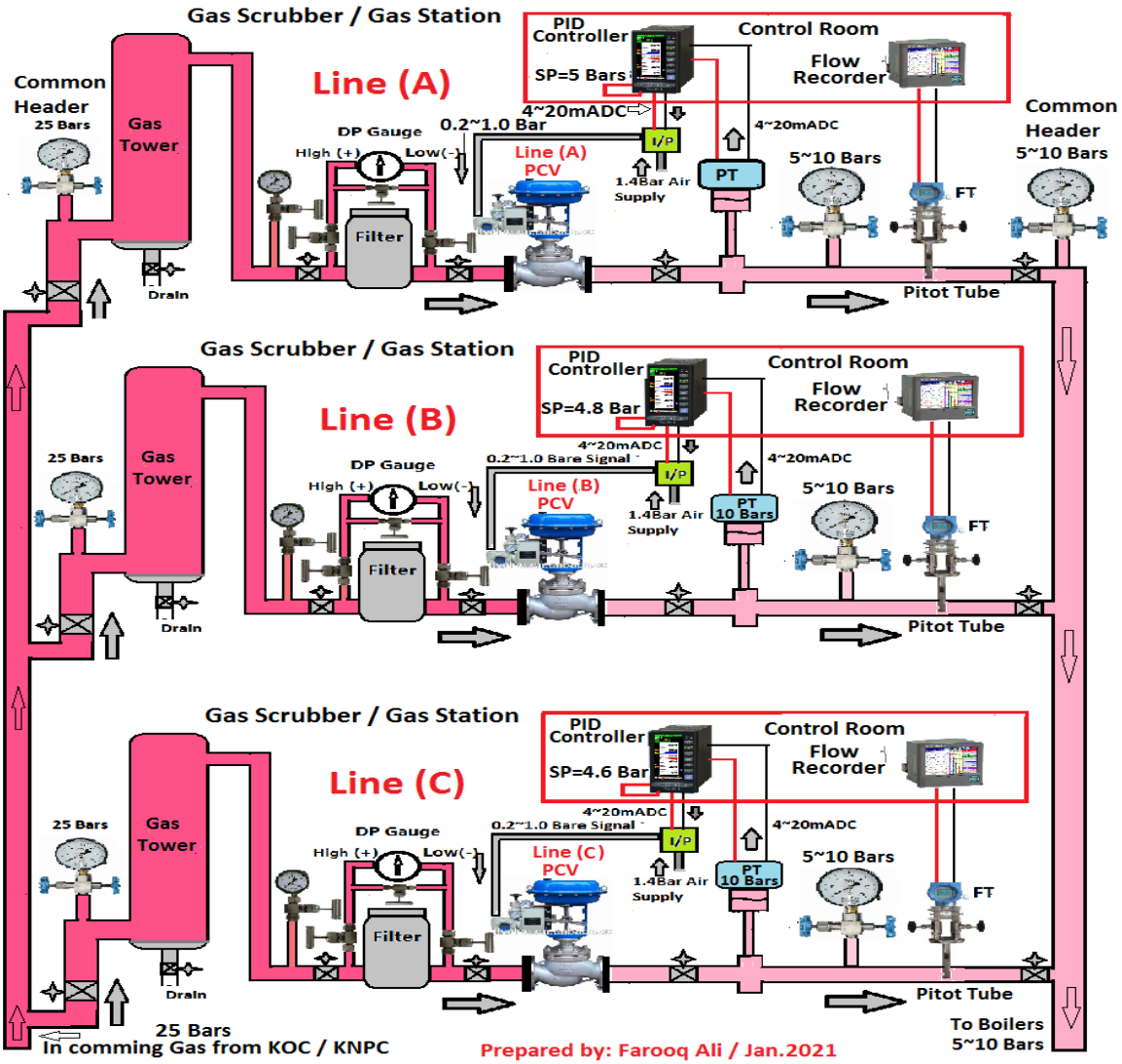
- This is **Condenser Hot-Well** level control loop (under the turbine) where we have to control the level by **2 control valves**.
- We have **Make-up Control Valve** taking water from the make-up tank to fill the **Condenser Hot-Well** and maintain the level.
- Condensate pump always transfer condensate water from the condenser hot-well to boiler feed water tank and feed water tank has own level controlling system.
- In this situation some time feed water level controller not allows the water to be received from the hot well to the feed water tank.
- So access water in the hot well should be removing to maintain the hot well level.
- For this reason, we need another control valve which can remove the access water and send back to the make-up tank. This control valve is called **Spill Over Control Valve.**
- **So Make-up control valve and Spill over control valve are working opposite from each other.**
- **When hot-well level will be 50%, then Controller output should be 50% (12mADC). So both control valves position should be fully closed (100% Closed).**
- **More than 12mADC, Make-up valve should start to open to fill the hot-well. So Range of makeup water hot well level control valve will be 12 mA (Full Closed) to 20 mA DC (Full Opened)**
- **Less than 12mADC, Spill over valve should be open to send back the water to make-up tank to maintain the hot-well level. So Range of spill over hot well level control valve will be 12 mA (Full Closed) to 4.0 mA DC (Full Opened).**



Gas Scrubber

Fuel Gas Pressure Controlling System

1- Fuel Gas is very important for any boilers.
2- There should be No & Never disturbance to supply fuel gas to the boilers.
3- **Priority** of gas is depending upon the **Set Point** of each pressure controller.
4- **Higher Set Point** will the **1st priority** then **lower** will be the **2nd priority** then **lowest** will be the **3rd priority** and so on.
5- **If 1st priority controlling system fails, then 2nd priority controller will pick the all load automatically.**
6- If we want to **change the duty** of lines from **(Line A)** **to** **(Line C)** then increase the Set Point of **(Line C)** controller same as **(Line A)** controller and reduce the set point slowly of **(Line A)** controller same as **(Line C)** controller.
7- Keep an eye on **(Line C).** The control valve should be opened slowly and maintain the gas pressure equal to adjusted SP and line A control valve should be closed slowly and work as standby.
8- So automatically **(Line C)** will be come in service and pick the load and **(Line A)** will be closed and work as standby.



Commissioning of a Plant:

Commissioning is the Procedure to line up all the systems of the pant like: Pump Motors Including each & every equipment related to **mechanical Section**, each and every equipment related to **Electrical Section** & each and every Instrument related to **Instrument Section** including all shut-off valves and control valves, used to run the system safely without any trouble is called **Commissioning**.

It means to check, line-up & test of all systems including Safeties of a plant through some procedures, before start-up is called Commissioning.

As we know any newly installed plant or after annual maintenance of any plant, every section **(IMD, EMD, MMD and OPERATION)** prepares and test of their work done.

Operation Section prepares the process loop and line up the all isolating valves including sequence test of logic control circuits & analog control loops with the help of all sections through some written procedure.

Electrical Section test and prepare their breakers, complete all connections of motors and field equipment and all other electrical equipments after repair and cancel the annual maintenance work permit.

Mechanical Section test and prepare their equipment Like: After repair, assembling of all pump motors, installing of all mechanical devices, removed during annual maintenance and cancels the annual maintenance work permit.

Instrument Section Also checks and line up their field instrument after repair and calibration all instuments. Power supplies of supervisory & logic instruments should be ON. All instrument loops should be healthy. All instruments should be ready to put in service without any trouble.

Interlocks and Sequence tests of all pump motors, operation of all control valves, shut-off valves and other systems, line–up all isolating valves of all analog instruments & control loops to be tested with co-ordination of all sections.

All type of annunciation window should ne normalized and canceled the annual maintenance work permit.

Above mentioned process is called commissioning.

P & I D

Piping & Instrument Drawing

Piping & Instrument Drawing (P&ID)

It is graphically presentation of Process system of a plant.

It is a complex drawing using different types of symbols to show the following.

- All types of mechanical equipment used in process lines.
- All type of field instruments including control valves shut-off valves and motorized valves.
- All types & size of piping, Vessels, equipment and other components.

Symbols

There are many types of symbols used in P&ID to identify each and every equipment and instrument used in piping process lines.

These symbols further labeled with Words, Letters and Numbers.

Each word and Letter is identifying the process, measurement, and controlling equipment and instrument.

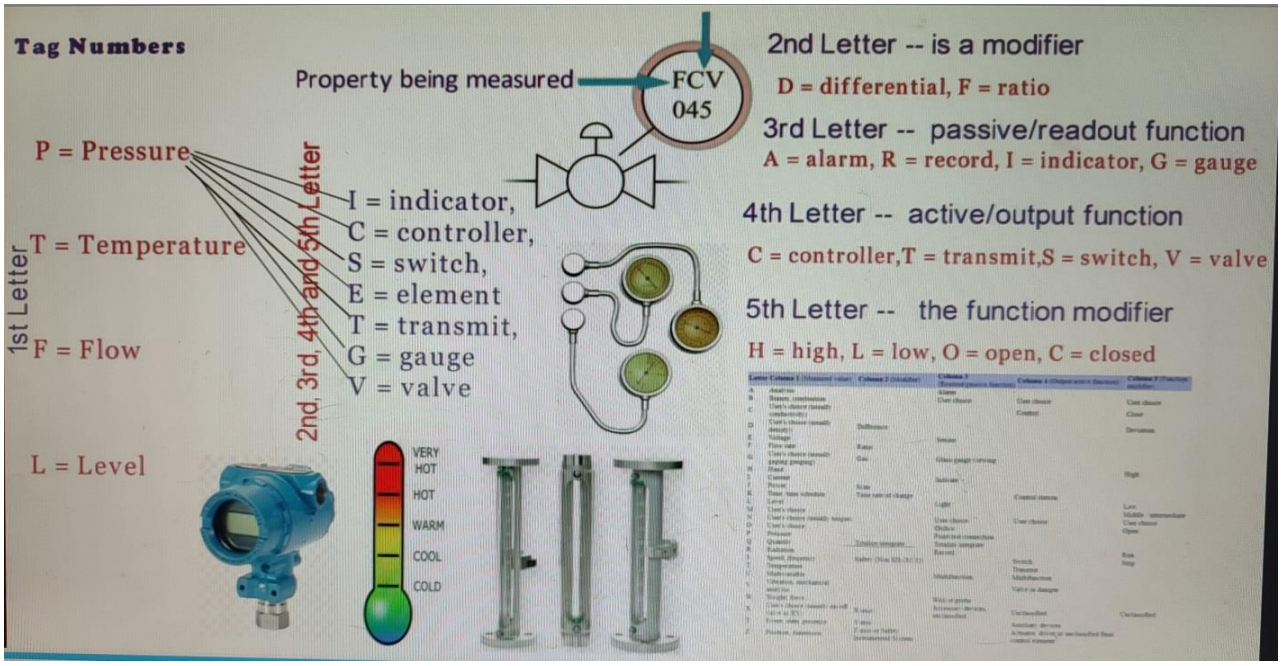
Most commonly used Words Letters and symbols in instruments are as follows

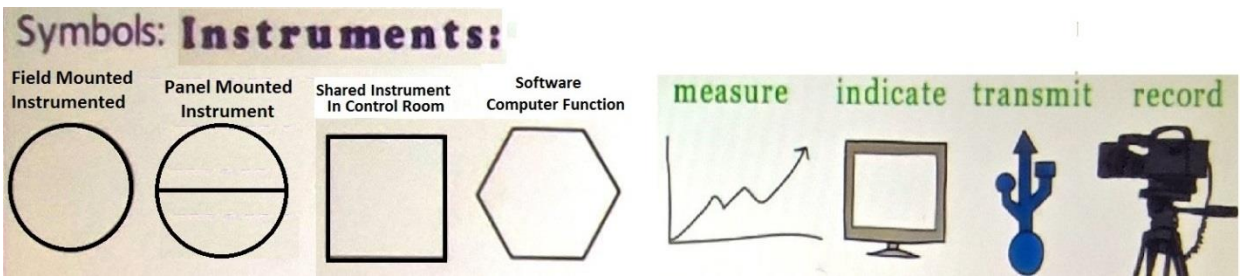
Abbreviation letters using in Piping & Instrument Drawings (P&ID) as an Instrument Tag Nos.

First Letter	Initiating or Measured Variable	Controllers				Read Out Devices	
		Recording	Indicating	Blind	Self-Actuated Control VALVE	Recording	Indicating
A	Analysis	ARC	AIC	AC		AR	AI
B	Burner/ Combustion	BRC	BIC	BC		BR	BI
C	User's Choice						
D	User's Choice						
E	Voltage	ERC	EIC	EC		ER	EI
F	Flow Rate	FRC	FIC	FC	**FCV / FICV**	FR	FI
FQ	Flow Quantity	FQRC	FQIC			FQR	FQI
K	Time	KRC	KIC	KC		KR	KI
L	Level	LRC	LIC	LC	**LCV**	LR	LI
M	User's Choice						
N	User's Choice						
O	User's Choice						
P	Pressure/ Vacuum	PRC	PIC	PC	**PCV**	PR	PI
PD	Pressure, Differential	PDRC	PDIC	PDC	**PDCV**	PDR	PDI
Q	Quantity	QRC	QIC			QR	QI
R	Radiation	RRC	RIC		**RIC**		RC

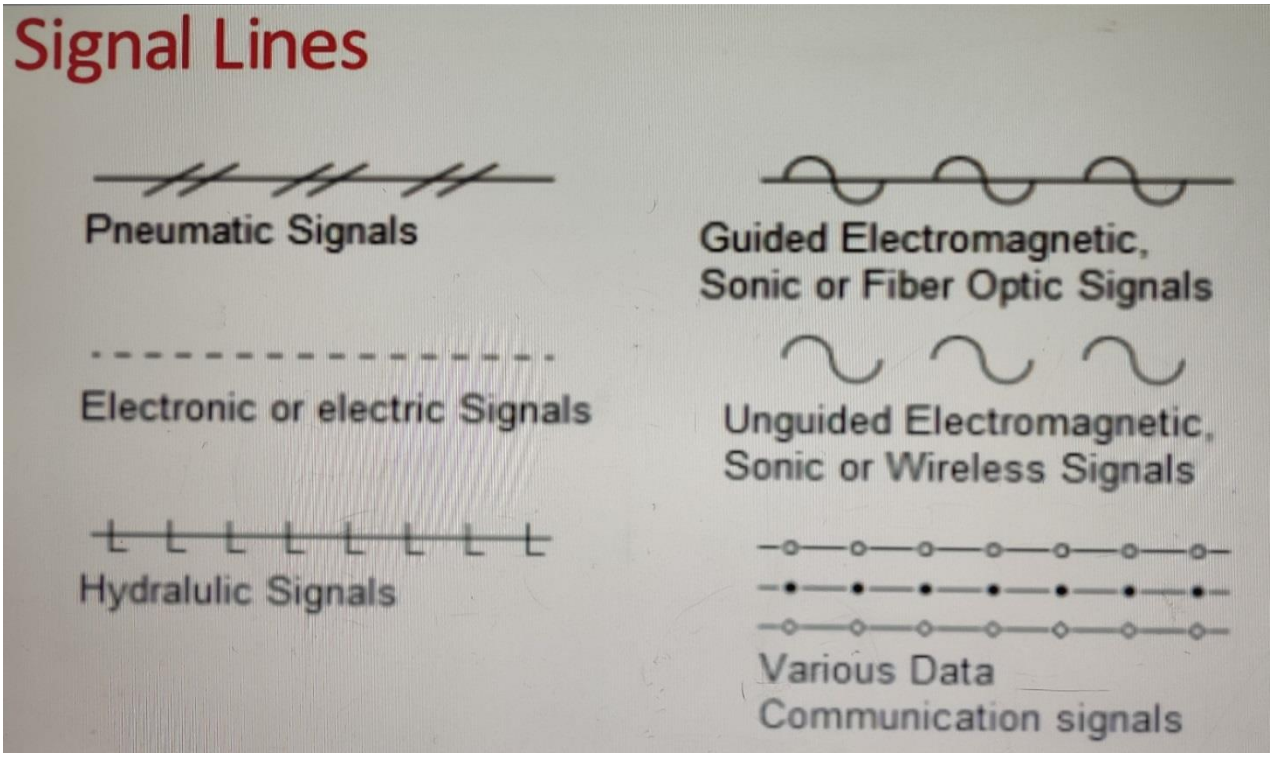
S	Speed/ Frequency	SRC		SIC	**RC**	RR	RI
T	Temperature	TRC	TIC	TC	**TCV**	TR	TI
TD	Temp. Differential	TDRC	TDIC	TDC	**TDCVT**	TDR	TDI
U	Multivariable						
V	Vibration/ Machinery Analysis						
W	Weight/ Force	WRC	WIC	WC		WR	WI
WD	Weight/ Force, Differential	WDRC	WDIC	WDC	**WDCV**	WDR	WDI
X	Unclassified	CELL	CELL	CELL		CELL	CELL
Y	Event/State/ Presence		YIC	YC			
Z	Position/ Dimension	ZRC	ZIC	ZC	**ZCV**	ZR	ZI
ZD	Gauging/ Deviation	ZDRC	ZDIC	ZDC	**ZDCV**	ZDR	ZDI

Leters used in Tages

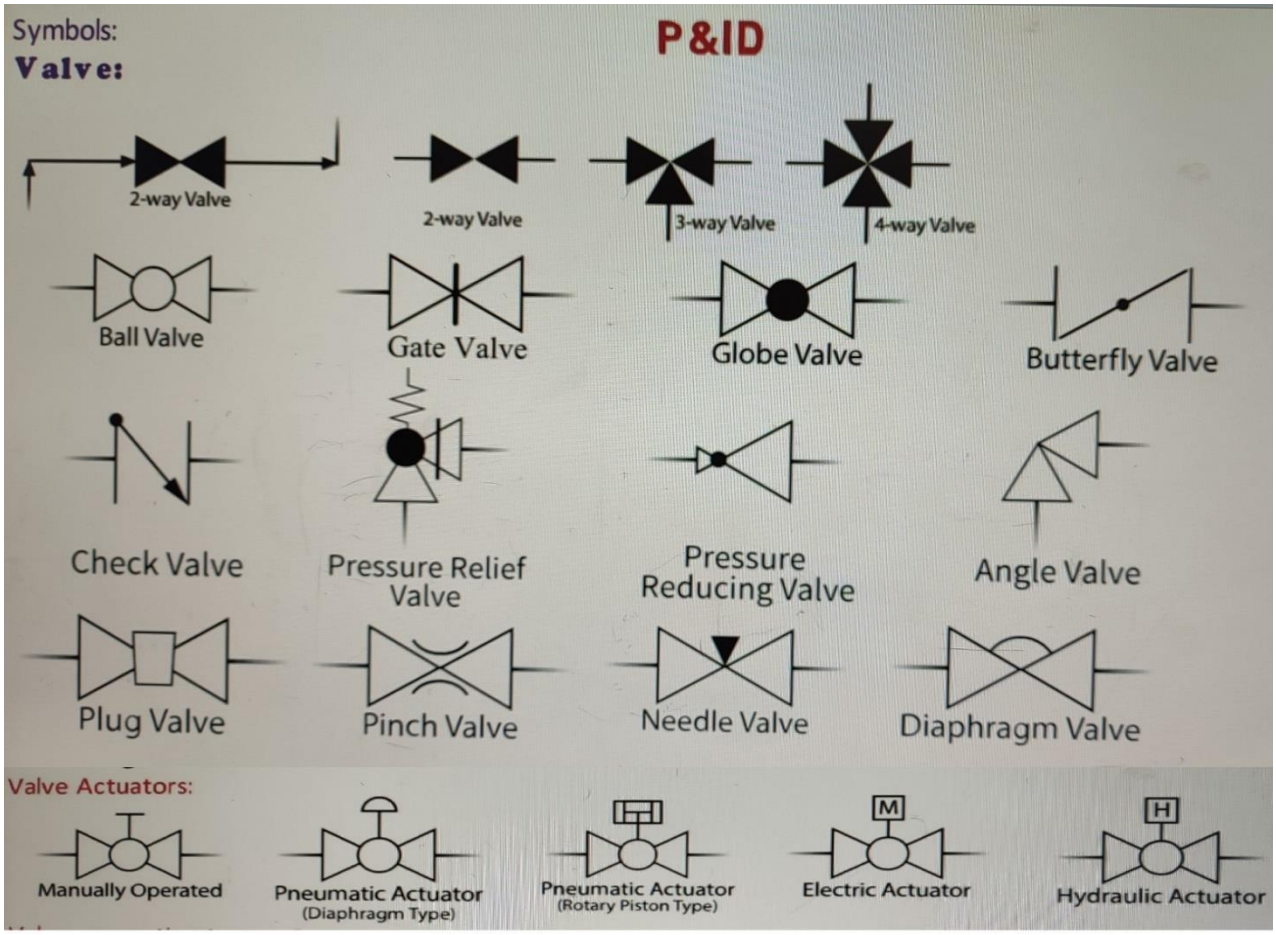




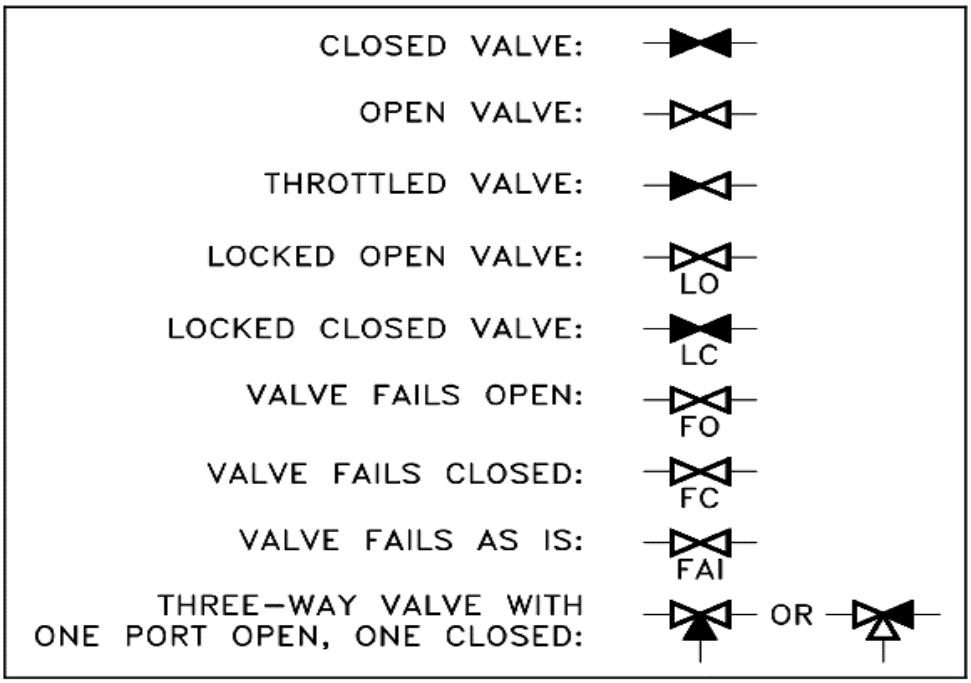
Signals symbols used in P&ID



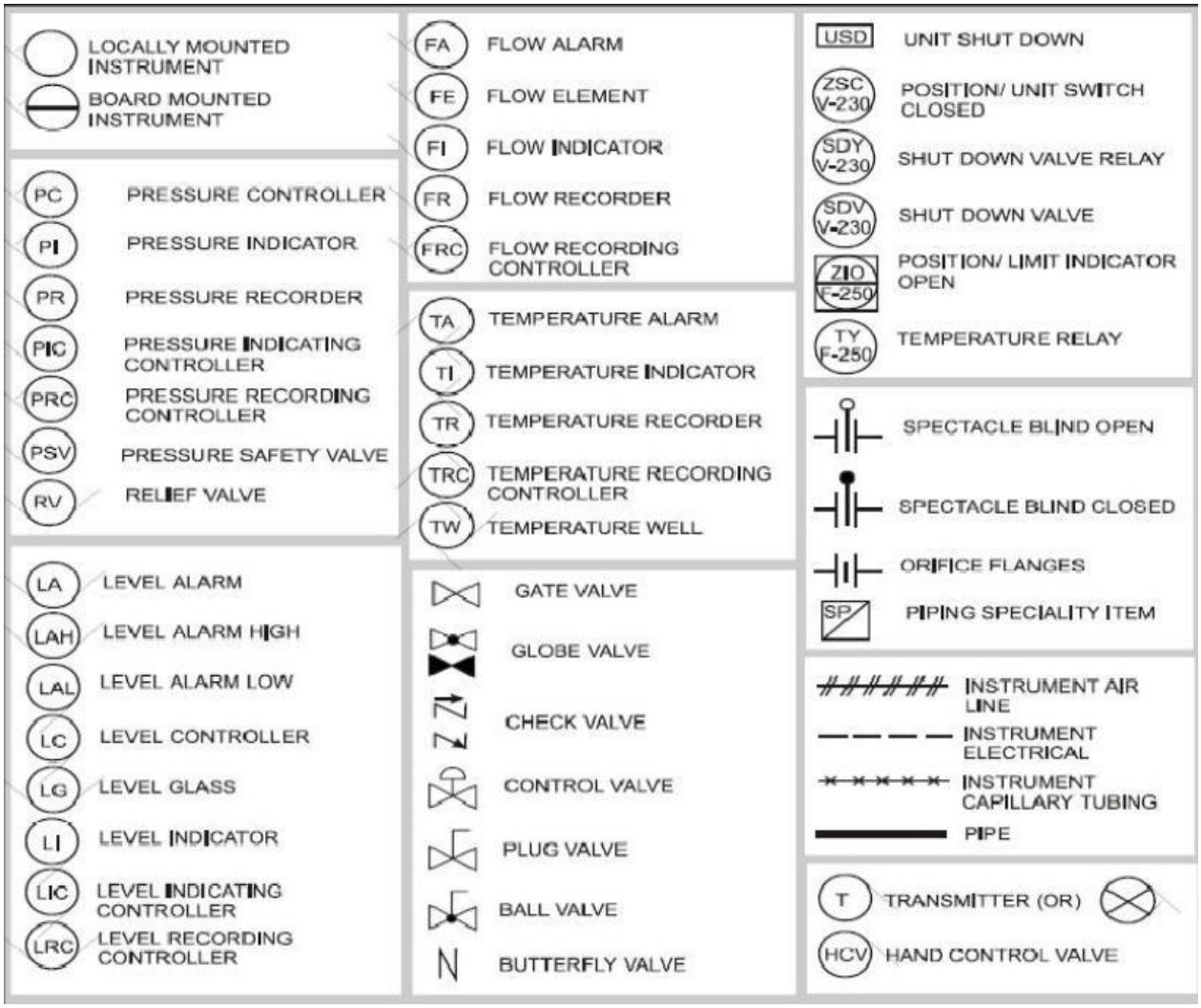
Valves symbols used in P&ID



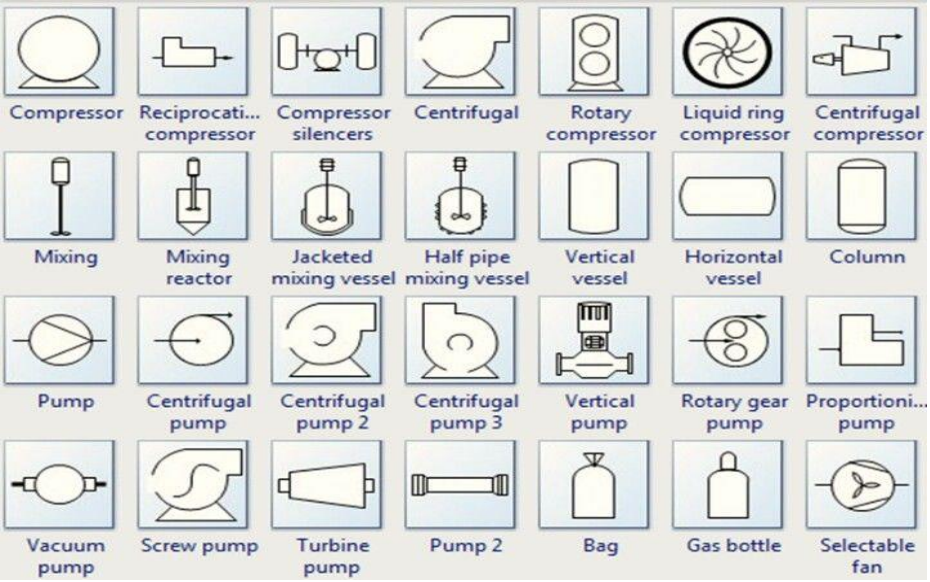
Valve Positions used in P&ID



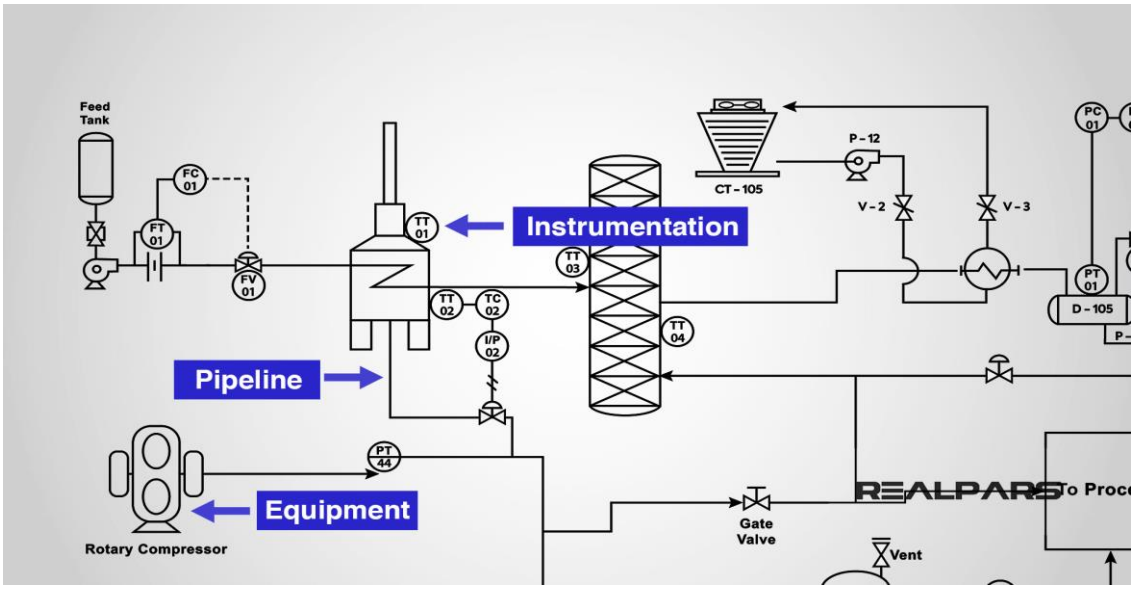
Most Commonly used Symbols

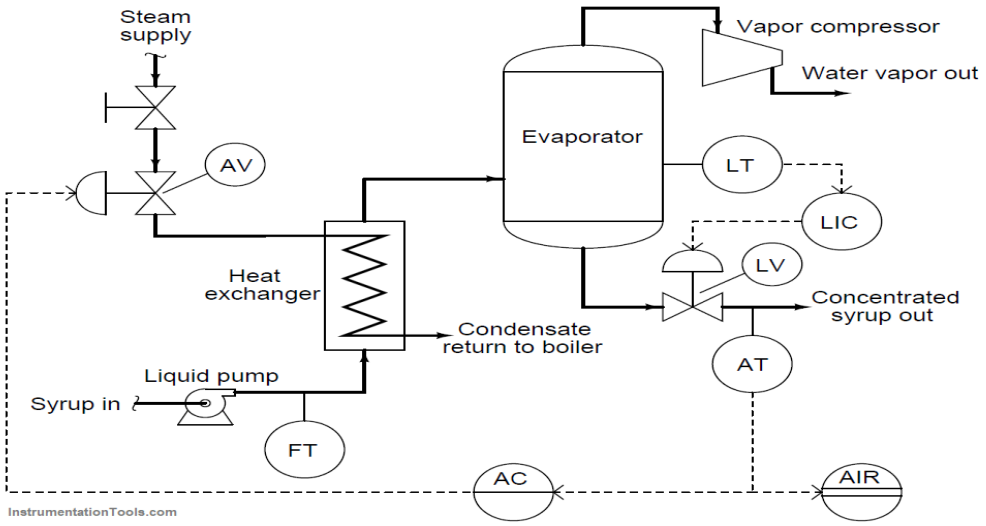


Pump Symbols used in P&ID



Examples of P&ID





Difference between

Fail Safe System (FSS),

Basic Process Control System (BPCS)
&
Safety Instrumented System (SIS)

Difference between Fail Safe System, BPCS (Analog), & SIs

- There are many protection and safety systems used in different plants.
- **Most commonly 3 systems are used in plants.**

1- Fail Safe System is **Individual Process Safety system**.
2- Basic Process Control System (BPCS), Mostly called **Analog Control system**
3- Safety Instrumented System (SIS). It is a **Plant Protection System**.

1- Fail Safe System:

- **Fail Safe System is an individual process safety system used for continuous production.**
- **In case of failure of these 3 systems as studied in early chapter.**
- **(A) Continuous Production B- Plant should run safely. C- Should Be No Tripping**

- **Note: There is no link of Fail Safe System with BPCS & Safety Instrumented System (SIS)**

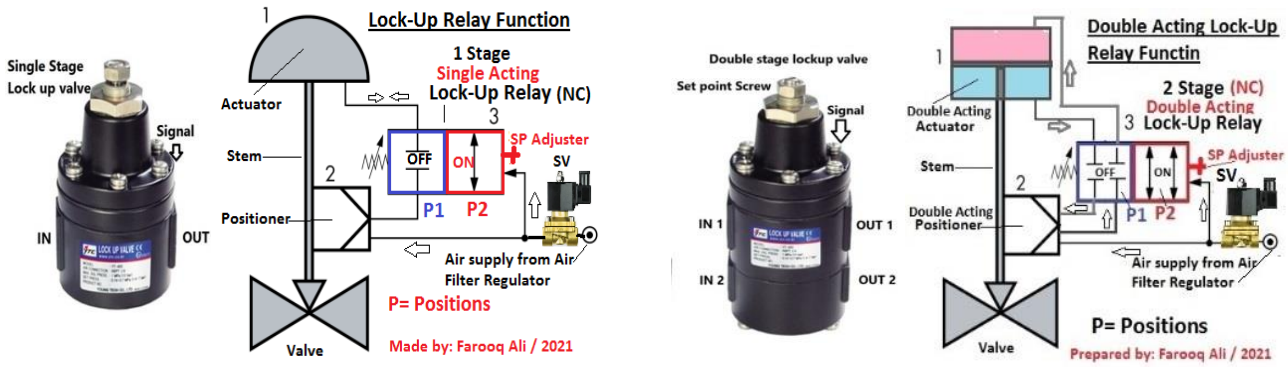
  - **These are 3 Failure Safe System:** (Solenoid Vales, Airlock relays and Positioner are installed in the field on Shut-Off valves and Control Valves)

(1) **Control Power 110 VDC / 24 VDC Fail**. (Means Solenoid Valves will be De-energized)

(2) **Air Fail Safe system** (Means there is **No Air supply** on Control valves & Shut-off valves). In this system, single acting or Double Acting Air Lock Relays or Lock-up Relays to hold the valves in same position.

(3) **Positioner Fail Safe System**. (Means Feedback Lever broken or Positioner malfunction)

Air Lock Relay / Lockup Relay used at Diff. Actuators in Air Fail Safe System



- **Loss of Air Supply or Electrical supply in single acting & Double acting actuators, all valves should have holed in same position as shown in above pictures.**

Result: In above pictures we can see that all three instruments used with single acting and double acting actuators. (Positioner, Solenoid Valve and Lockup Relay)

Option: 1: In this situation, if **Solenoid Valve De-Energized** then it will close the air supply to the position and lockup relay. **Therefore, at low air pressure lockup relay will block the air supply to hold the control vale in same position. (If valve opened, it should remain opened and if it is closed then it should remain closed or if it is in middle position it should remain hold in same position).**

Option: 2: In this situation if **Air Supply Lost** by any reasoned (It can be all air compressor tripped or not in service or air filter regulator chocked), Then air lock relay will block the air supply and hold the valve in same position.

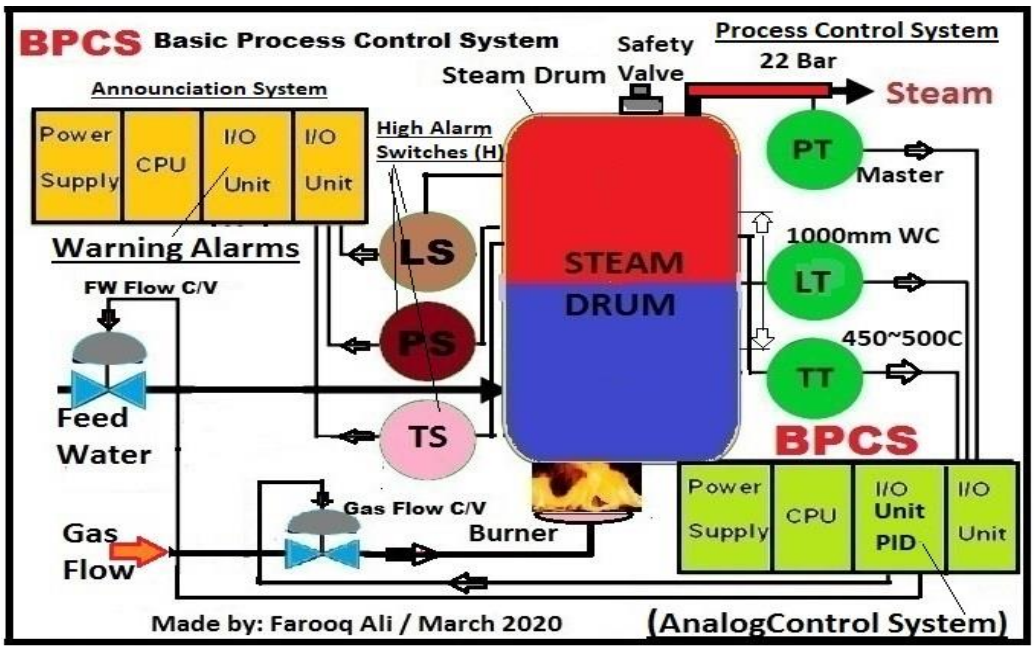
Option: 3: In case of **Positioner Failed**, the positioner has to decide that valve should be hold at same position or open the valve or closed the valve.

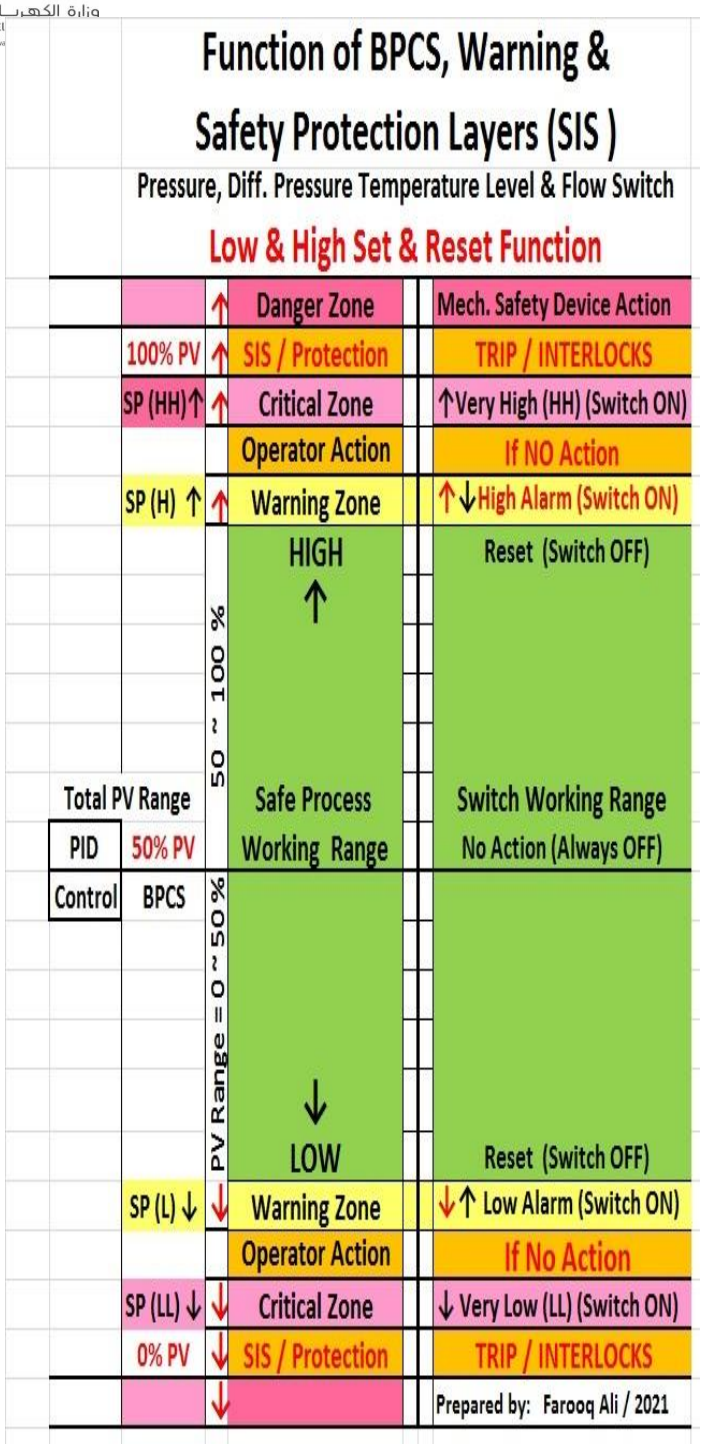
2- Basic Process Contort System (BPCS):

It is an Analog Control System, which controls Pressure, Level, Temperature, flow and any other process variables.

This system is a Flexible Analog Process Control System.

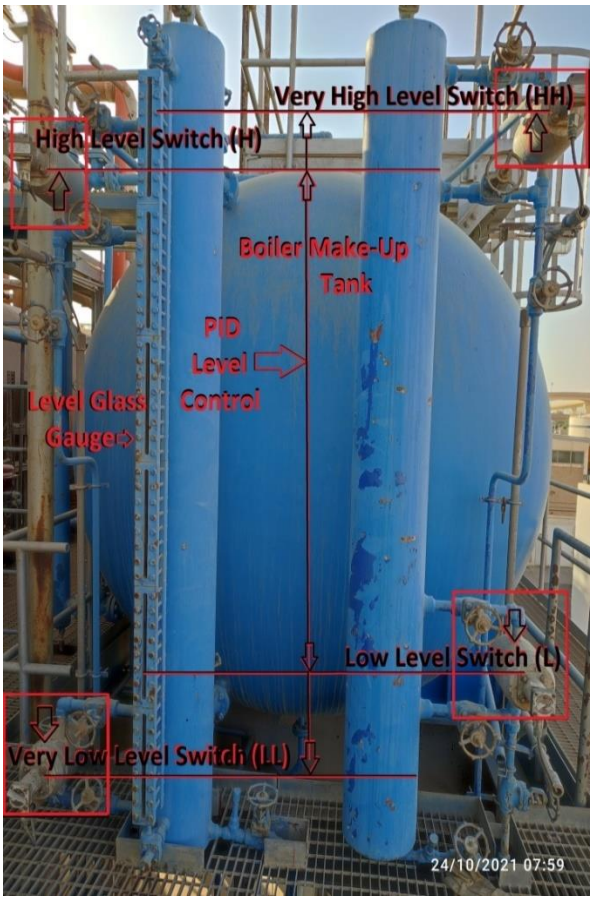
- This system allows changing the process conditions frequently. This system controls the basic parameter. It will control all types of analog process **(Like: Pressure, Temperature, flow & Level)** in safe limitation areas. It can give best performance from minimum to maximum limitations in safe conditions.
- **BPCS** must be so flexible to like: PID controlling system can be easy to change the conditions of control system from **AUTO** to **MANUAL** to control the process manually or **MANUAL** to **AUTO to** control he process on **AUTO**, also can change the **SET POINT (SP)** or **BYPASS** the PID system.
- Most chances of failure of the BPCS is malfunction of any controller or control valve.
- Also possible human error
- This system not built with safety features also not given safety tasks.
- This system runs all the time to control the process and has no fault diagnostic provision.
- **BPCS** works normal and controlling plant in normal flexible limitations all the time. It has flexibility to control the process variables. **As shown in this picture**





Example

Boiler Make-Up Tank Level Control (BPCS) & (SIS) Level Switches for Alarms and Interlocks (Actual Hook-up of level switches) in Shuwaikh Power Station Kuwait



3- Safety Instrumented System (SIS):

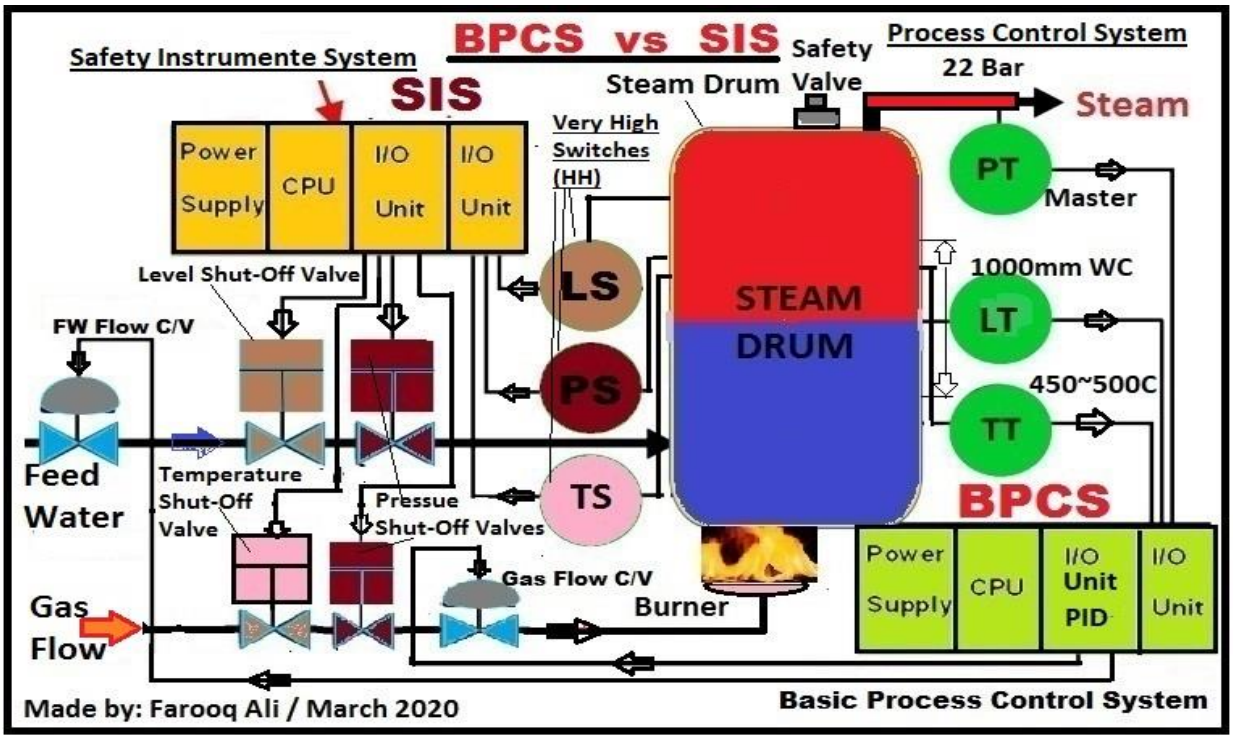
The **Safety Instrumented Systems (SIS)** continuously monitors the plant's safety devices' status and diagnoses the health of the entire safety loop–dramatically reducing the risk.

SIS works Opposite of BPCS & Fail Safe Sysem.

- **SIS** deals critical condition of the plant while it has no flexibility. It is always there, not doing anything to plant and waiting for any critical situation. **It will act when critical conditions create.**

- If **BPCS** not controlling the plant in limits and going to critical conditions. Even there is no action by operator when receiving warning alarms by annunciation system.

- **Then SIS will be in action to save the plant or human life.**



Here are shown safety layers of a power plant.

For Examples:

There are some stages of Safety Layers.

1- **Basic Plant Infrastructure**
2- **Analog Control System of a Plant, Called Basic Process Control System (BPCS)**
3- **Warning Alarm System**
4- **Safety Instrumented System (SIS) This system has many layers.**

- **Layers of Safety Instrumented System (SIS)**
  - **A- SIL-1 ---------- (Safety Instrumented Level - 1)**
  - **b- SIL-2 ---------- (Safety Instrumented Level - 2)**
  - **c- SIL-3 ---------- (Safety Instrumented Level - 3)**
  - **d- SIL-4 ---------- (Safety Instrumented Level - 4)**

5- **Mechanical safety (Mechanical Relief Valves)**
6- **Fire Fitting System (Fire Sensors and Sprinkling &Deluge System)**

BPCS and SIS with Mechanical Safety System

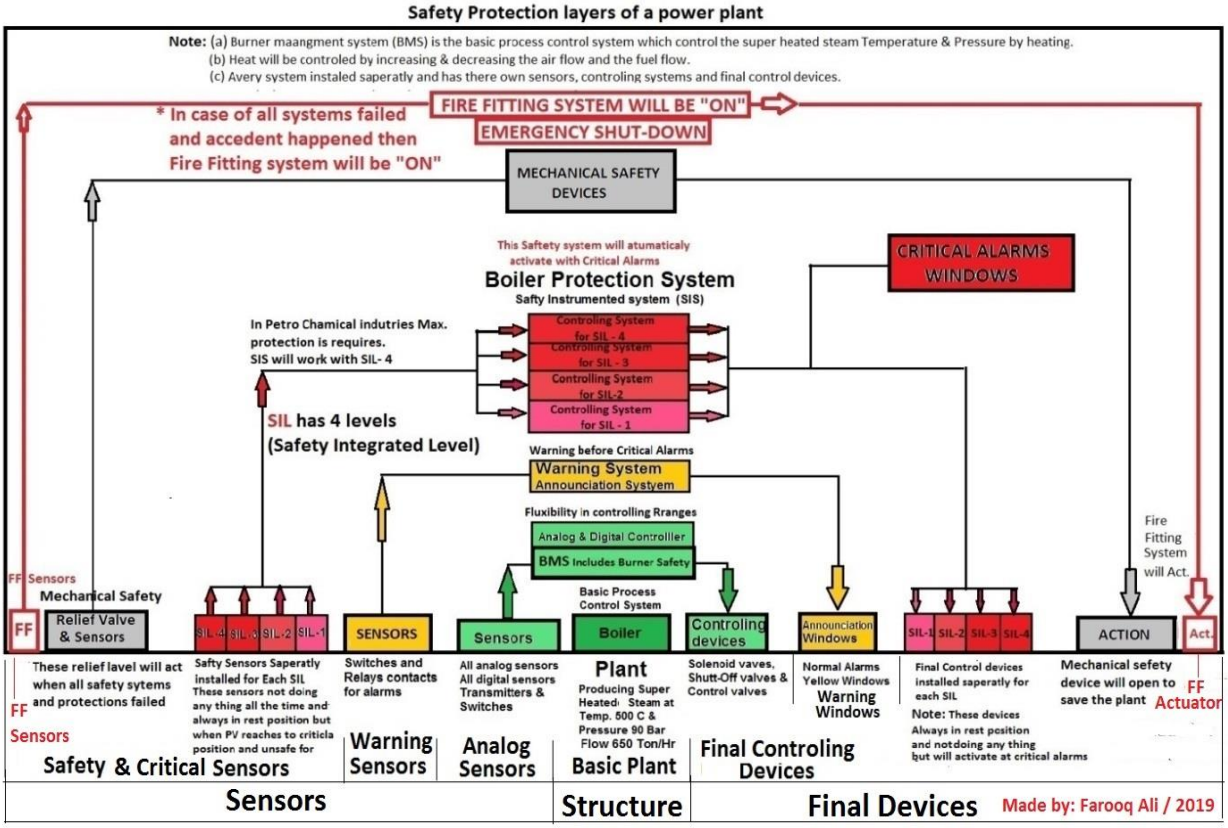
A- Level of a Boiler Drum: It is controlling by **BPCS** in safe limitations all the time. However, as soon as level reaches to high limits or low limits it will give alarm in control room. If it is still out of control and reaches to very high / very low limits, **SIS** will **trip the boiler** to save the plant.

B- **Boiler steam Temperature:** Steam temperature will be control by **BPCS** in safe limitations all the time. But as soon as temperature reaches to **high limits**, it will give high temperature alarm in Control room. If steam temperature is still out of control and reaches to **very high** limits, **SIS** will **trip some burners or boiler** to save the plant.

C- **Boiler steam pressure:** Steam pressure will be control by **BPCS** in safe limitations all the time. But as soon as pressure reaches to **high limits**, it will give high pressure alarm in Control room. If steam pressure is still out of control and reaches to **very high** limits, **SIS** will **trip some burners or boiler** also **stop he feed water** to save the plant.

D- **Mechanical safety device:** If **SIS** not act and still steam pressure is out of control and reaches the set value of safety valve then mechanical **safety valve will act** and **open the safety relief valve** to vent the steam pressure in the air to save the plant.

E- **Mechanical failure:** Many failures can be happening in the plant and may not be self-diagnostic. In case of **mechanical relief valve stuck-up and not function** from long time or safety **/ Relief valves never be tested also not checked its operation periodically**, then **incident / accident can be happened and haram full for human life**.



NOTE: Always Use of Safety Instrumented System (SIS):

It is very important for any plant to work in safe conditions to save the plant & human lives.

Cascade Control System

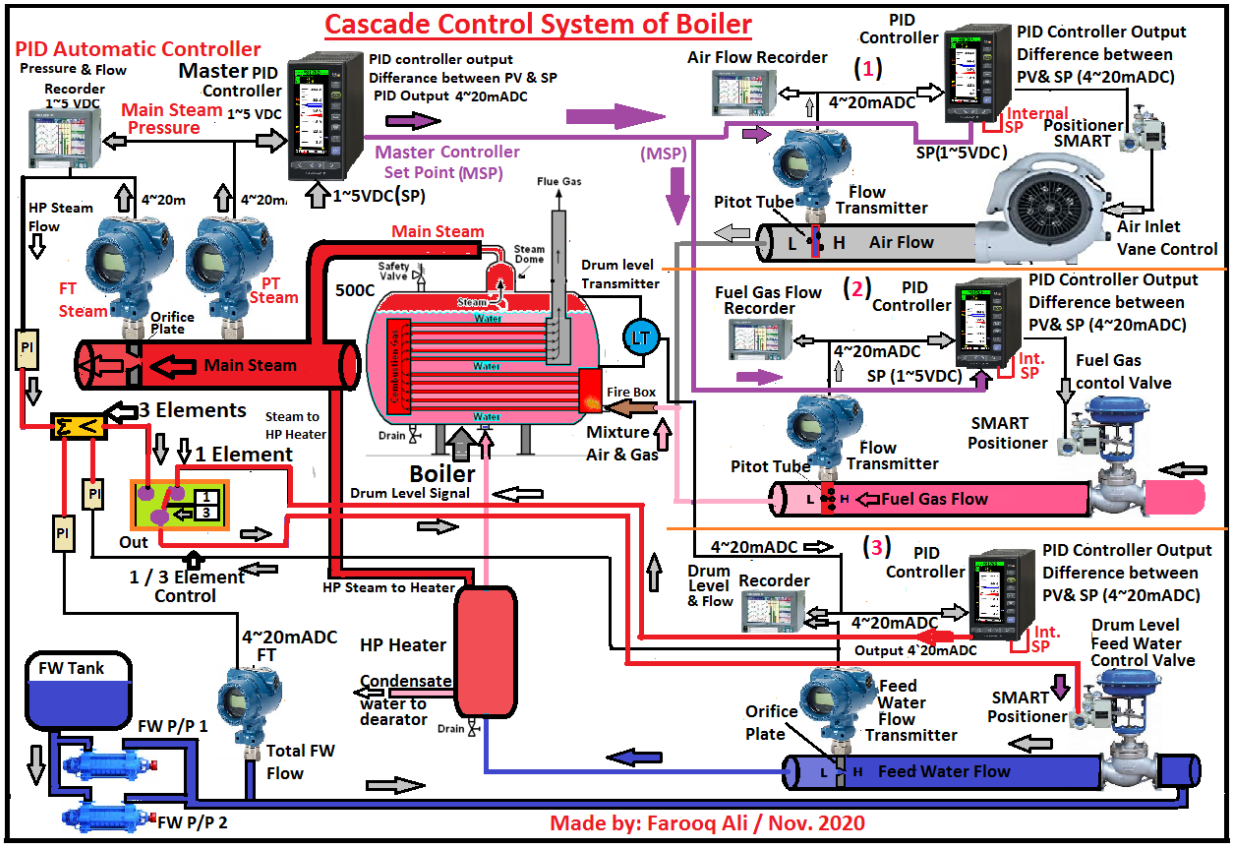
Cascade Control System

Cascade Control System: In this system **main steam pressure** is the **Master Controller**. Output of steam pressure controller is the set point for Air **flow** & **Fuel Gas flow** controllers, related to the boiler to produce steam when demand is required, **so these controllers will work as a slave controller** of main steam pressure controller.

(A) Whenever any change in steam pressure the **main steam pressure controller** sending output signal as a **Master Set Point (MSP)** to **Air Flow Controller** and **Fuel Gas Flow Controller** to increase or decrease the process to comply the demand of master controller as shown in below diagram.

(B) There is also **1 or 3** Element control system is used to control the total steam flow produced by boiler.

(**1**) **One** Element control system means only **Drum Level Controller.**
(**2**) **Three** Element control system means 3 Control systems. (**1- Total Steam Flow. 2- Total FW P/P Discharge Flow & 3- Feed Water Flow after control valve**) as shown in below figure.



If Electrical Load demand increases in the electrical ring system, then automatically all cascade controllers will increase their demand (Increase the Air Flow, Fuel Gas Flow & Feed Water Flow same time) to maintain the steam pressure and increase steam flow to run the Turbine Generator at constant speed (3000RPM) as required by central command of electricity.

Burner Management System

(BMS)

Burner Management System (BMS)

Starting Procedure of a Burner

Burner Management System (BMS)

- **BMS is a Flame Safe Guard system.**
- **Based on Events in sequence.**
- There are many steps in systematic way to start a burner.
- It is compulsory that **any step should not be missed or by-passed**. It will be harmful.
- Burner safety instruments will ensure that gas should be available with required pressure to establish good flame.

Protection of Boiler

- There are many protections systems are in boiler. All protections should be completed.
- **It is very important to purge the boiler properly before start 1st burner**. If any un-burnt fuel accumulated in the gas line or furnace, then suddenly blast can be happened when burner will start. To save the boiler this step is very important to complete**.**
- **(Never bypass purging step)**
- **Note:** If any shut-off valve is passing and during leak test gas pressure will not be hold at certain pressure. Then gas will be accumulating in the furnace which is very dangerous for plant.

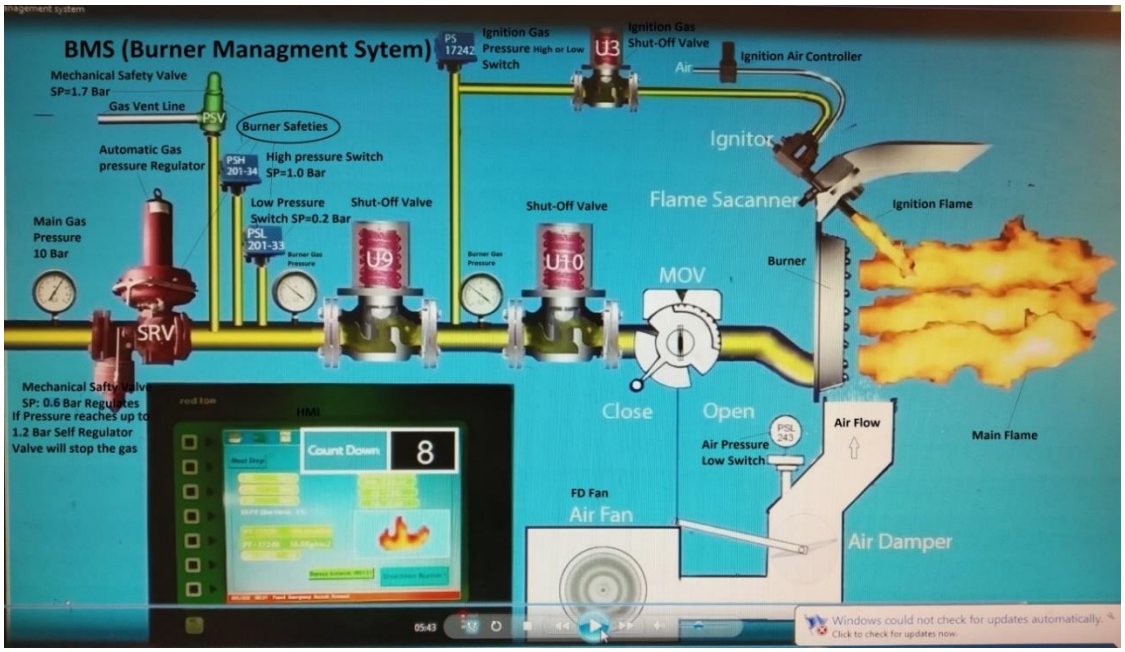
Steps Before start a Burner

- After Start of FD fans. Complete all steps till reach to start 1st burner.
- **BFW P/P** should be in service at minimum flow.
- **Drum Level** should be normal.
- **Boiler / Furnace Purge** should be completed before start 1st burner.

  Note: Above step is most important for safety of boiler. If any fuel gas is accumulated in boiler, there can be serious accident can happen.
- **Boiler protections** & Safety system should be completed**.**
- **Main Fuel Gas Lines and Main Fuel Oil protection & safeties should be completed**.

Gas Burner Protection & Safety Features

- Main Inlet Gas Pressure before control valve from gas scrubber = **5 ~ 10 Bar.**
- Pressure Regulating valve / Self Regulating valve regulates **0.5 ~ 0.6 Bar** (Best pressure for good flame for 1 Burner)



- **Note:** Main Gas pressure can be controlled between **(1.5 ~ 2.5 Bar or more**) according to the No. of Burners, Wind Box Pressure and Air Flow.
- **Best ratio of Gas and Air is required for best Flame**.
- f Pressure Regulating valve or Self-regulating valve fails to control the pressure **0.5 ~ 0.6 Bar** and pressure reaches **1.2 Bar**, it will stop the gas to burner.
- If still pressure increases, then safety vent valve will open at **1.7 Bar** and vent the gas in the air.
- There are **High** and **Low Gas Pressure** switches installed in the burner gas lien and set at **1.2 Bar** & **0.2 Bar**. If pressures reach these values, then these switches not allow to starting burner.
- There is **Low / High Gas pressure switch** in ignition line. In case of low or high gas pressure Ignition will not start.
- There is **Low Air pressure** switch in the air line. If air pressure is Low, then burner will not start

1- **Gas Leak test:** To ensure that there is no leakage in between 2 main gas shut-off valves and ignition gas shut-off valves. Also there is no gas passing from ignition and main gas shut off valves.

When leak test completed indication received then ------ Go to next step.

2- Burner Purging: It is very important to purge ignition and main gas lines to remove all un-burnt gases.

When Purging completed indication received then ------- Go to next step

Note: (a) - If any un-burnt fuel accumulated in the burner line, suddenly blast can be happened when burner will start. To save the burner line this step is very important to complete**.**

(Never bypass this step)

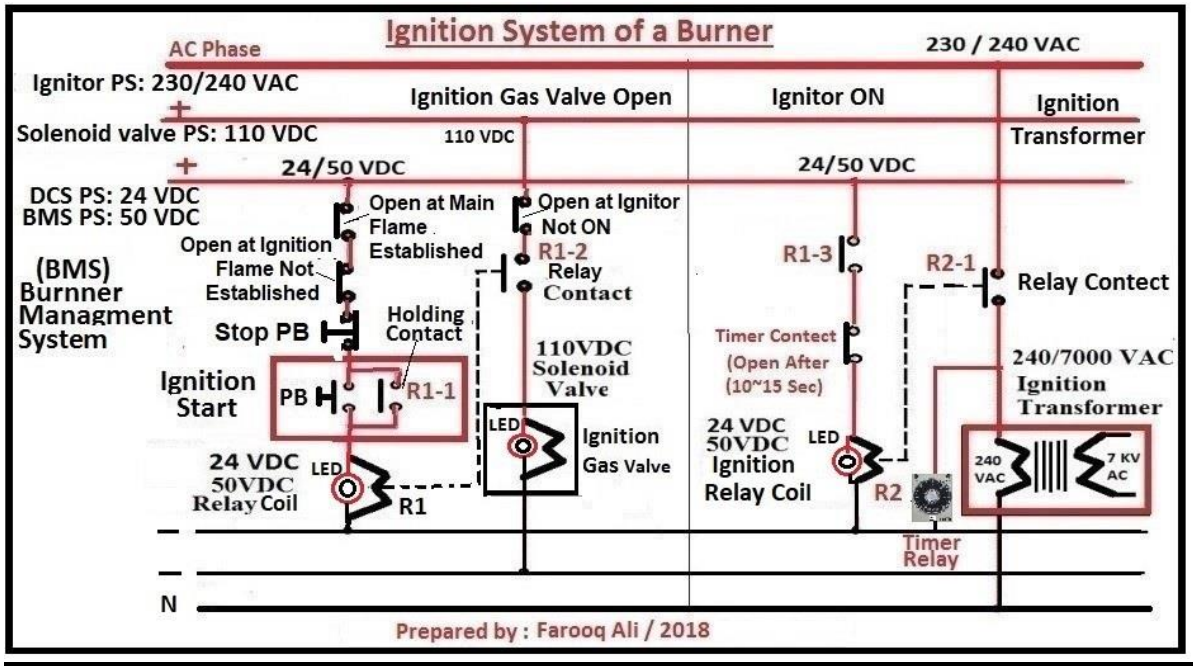
(b)- After purge completion, shut-off valves will open for **5 to 10** seconds to fill the main and ignition gas lines.

Startup of a Burner

3- Start Pilot Ignition System: Ignition transformer will be **ON** for **10~15** Seconds, Ignition Gas shut-off valve will open and ignition burner will be **ON,** & will establish ignition flame.

Note: Confirm the ignition flame is established and indication received on indicator or HMI

How an Ignition system works?



4- Start Main Burner: Main gas shut-off valve will open and main flame will be **ON**.

After main flame established, Main flame scanner will show the main flame on the indicator or HMI.

Note: Confirm that Main Flame is established and indication received on indicator or HMI

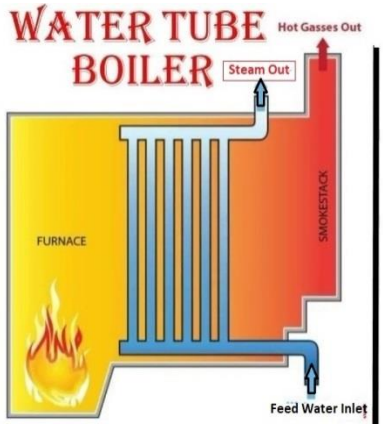
5- To **Increase the Temperature** in the boiler, increase the **Air flow** and **Fuel gas flow**
(With proper ratio) for very good flame in the boiler to produce steam at specific Temperature and pressure

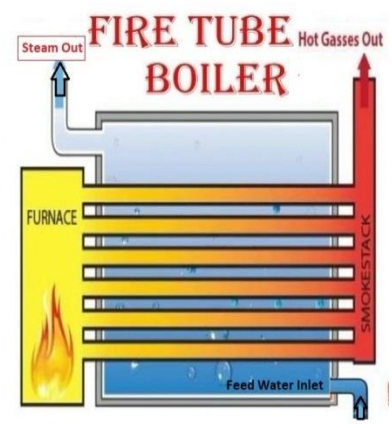
- To maintain the **Temperature & Pressure** of steam put Master PID controller on **AUTO.**
- It will automatically increase or decrease air flow and gas flow according the set points.

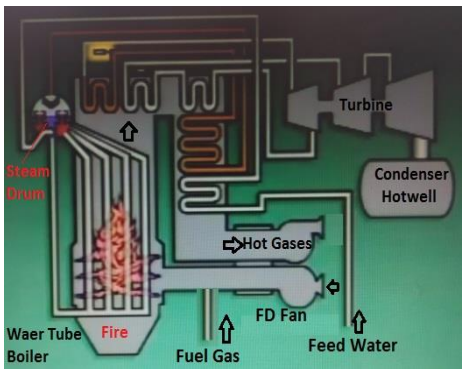
De-Mineralized Plant
(DM Plant)
&
Chlorination Plant

De-Mineralized Plant

To run the **Turbo Generator and Distiller Plant**, we need to produce steam from boiler.
We have 2 types of Boilers .
(1) **Fire Tube Boiler** means Fire will be in side of tubes & water will be outside of tubes.
(2) **Water Tube boiler** means water will be in side of the tubes. As shown in picture.







Requirement of a De-Mineralized Plant:

The main task from Boiler, Turbine and MSF is to exchange of HEAT from one section to other section through some metallic tubes, but there are some factors which reduces the heat transfer process from one area to other area. That factor name is called **SALTS** in the normal water.

Drawback of Salt layer in the tubes:

1- These salts make a layer on the metallic tubes. Due to this layer a big loss of heat energy produces.
2- To comply this loss, more fuel is required and with respect to time, thickness of salts layers will increase and fuel requirement also will increase.
3- So every place, where heat exchange is required, heat losses will be increased. So fuel cost will also be increased.
4- More maintenance is required to remove these salts layers from the tube so cost of repair will also be very high.

Solution: To overcome these losses, we need to remove all types of salts from the water, which are producing layers in the tubes. So this free of salt water will be used in the boiler to produce steam. Steam is the main media to transfer heat from one section to other section of plants.

Result: This is the main reason that we need a plant which can remove all salts from the water. The name of this plant is **De-Mineralized plant means DM Plant**.

DM Plant & Working Principle:

Note: The water used for DM plant is the product of **MSF plant or RO plant,** already water is cleaned and conductivity is very low nearly 1~2 mS/cm. **So DM plant is just polishing this water till conductivity reaches 0.05 ~0.2mS/cm.** But Normal water has nearly 300mS/cm.

A demineralizer / DM plant is a system, which uses an **ion exchange chemical process** to remove dissolved ionic compounds (different types of salts) from water.

It is also known as **De-Ionized Water System, Demineralizer or DM Plant**.

Demineralization Plant consists of Minimum **2 vessels** (Tanks) Sometime **3 / 4 vessels**.

Mostly using **2 chains** of DM plant**, "1st" chain** will be in service while **"2nd" chain** will be in regeneration mode. After regeneration will be standby until **1st** chain will be exhausts.

1st stage: Cat-ion Tank. The feed water or raw water (Water from MSF or RO plant) is passed through first vessel which contains **strong base cation resin** in the form of **Hydrogen (H+),** whereupon all the positively charged ions **(sodium, calcium, iron and copper etc.)** are **exchanged for Hydrogen ions**.

So (H+) Ions are removed in 1st stage (From Cat-Ion Tank)

Means these salts are removed from water. **(Sodium, calcium, iron and copper. etc**)

2nd Stage: An-ion Tank: The outgoing water from Cat-ion tank (after 1st stage) passed through another vessel) containing **strong base anion resin** in the form of **Hydroxyl (OH-),** where upon all the negatively charged ions **(chloride, sulphate, nitrate, etc)** are **exchanged for hydroxide ions** which then combine with the hydrogen ions to form water

So (OH-) Ions are removed in 2nd stage (From AN-Ion Tank)

Means these salts are removed from water **(chloride, sulphate, nitrate, etc)**

3rd Stage: Mixed Bed: Mixed Bed is a single vessel unit, which combines **Cat-ion resin and An-ion resin / exchangers in a single column**. When it comes to require high-purity Demineralized Water, mixed bed demineralizer is considered more efficient in many ways. It is **used as polishing** unit to purify water to higher levels, which is treated through 2 Beds of ions (Cation & **Anion**).

So both ions (H+ ions & OH- ions) removed in 3rd Stage

Result: Finally, "0%" Salt water comes out from DM Plant having conductivity 0.05~0.2 mS/cm.

DM Plant Regeneration

Regeneration is a process of restoring the power of Cat-Ion resin & An-Ion or enhancing active ion concentration level is called Regeneration.

Depending upon frequency of use and DI Water (De-Ionized water) output condition. In this situation DM plant can't maintain conductivity of water less than 1mS/cm.

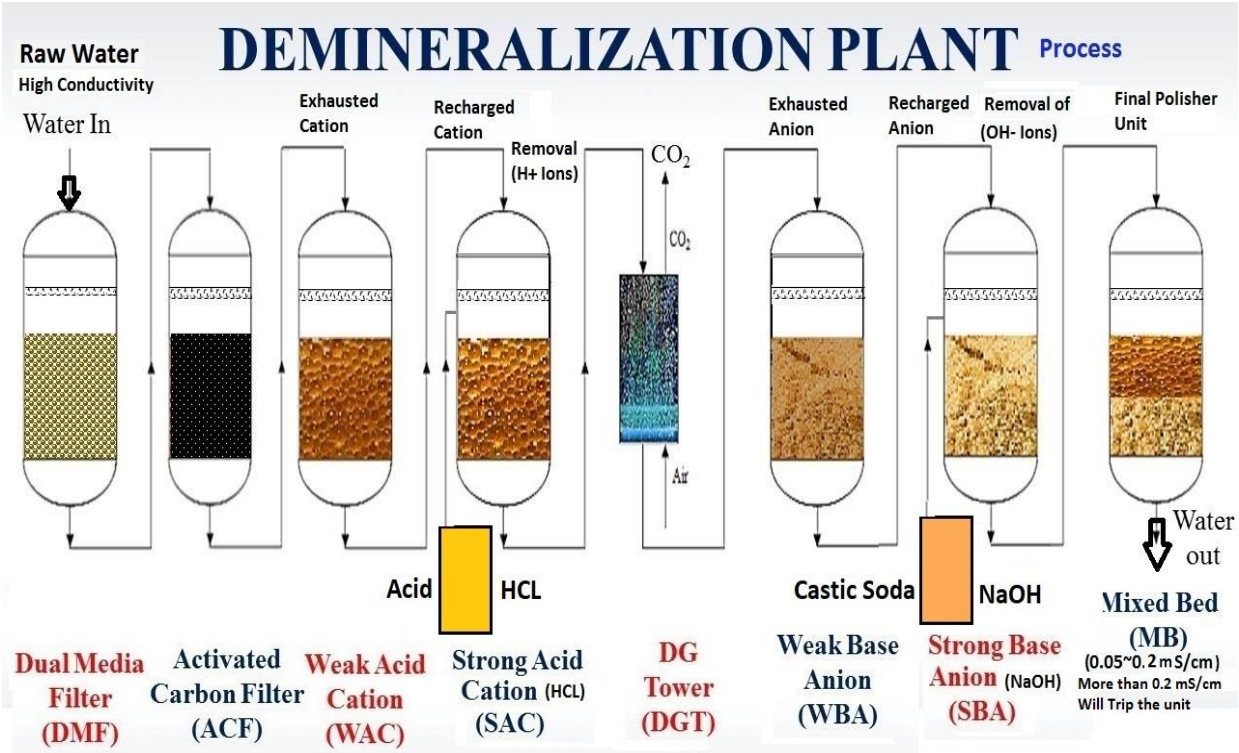
The resin becomes exhausted and does not capable to de-ionize the raw water, in other words, their power of removing ionic materials reduces and active ion concentration reaches a low level.

So Restoring their process power (Cat-ion, An-ion and Mixed Bed) or enhancing active ion concentration level is called Regeneration.

In this process exhausted (Cat-ion and An-ion) ions are recharged **with Hydrogen (H+) means Hydrochloric Acid (HCL) & Hydroxyl (OH-) ions means Alkali -Caustic Soda (NaOH).**

Note: Never use Pure Acid and Pure Alkali in regeneration process. During regenerations **Diluted Acid and Diluted Alkaline** should be used to maintain PH & Conductivity that Cat-ion Resin and An-ion Raisin should not be damaged.

Demineralizing Process of DM Plant



Chlorination Plant

Purpose of Chlorine Injection in Sea Water for Power Plants

Mostly Thermal Power plants located near the seashore require massive amounts of water for cooling purposes.

Many slow moving marine organisms, such as **barnacles**, **Shells**, **oysters** & **bryozoan etc.** expands and stuck on the inner wall of cooling water intake pipelines.

The growth of these marine organisms can reduce the rate of thermal exchange, restrict water movement, clog the pipeline, or erode and perforate the wall of the pipeline.

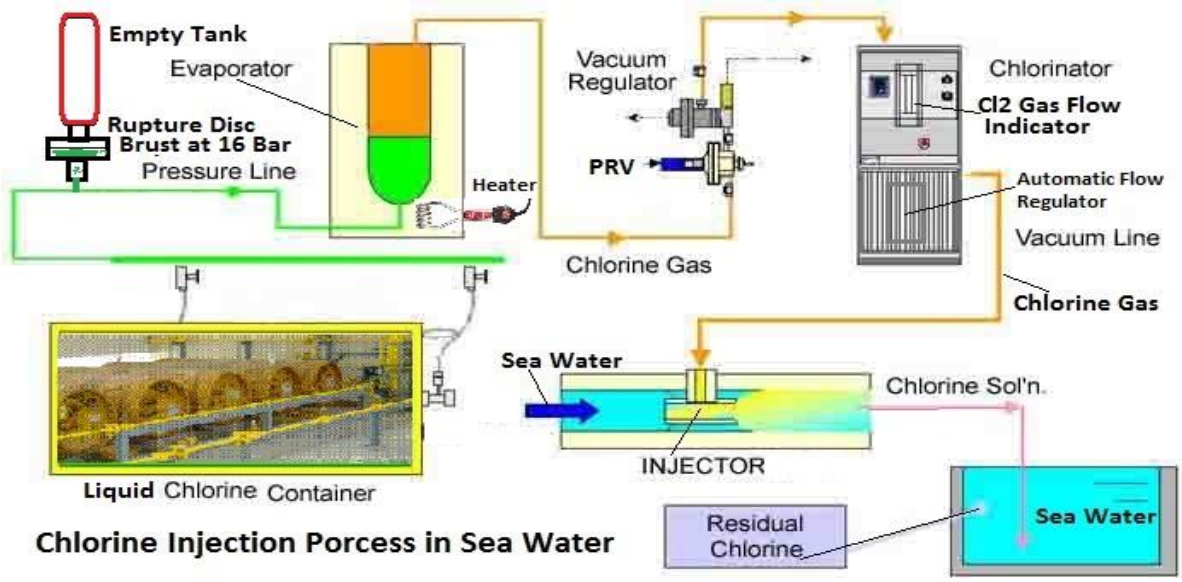
Under extreme circumstances, power plant may have to shut down to clean and repair the pipeline system. On such case many tons of marine organisms had to be removed from the pipeline during a single cleaning process.

Many techniques have been developed in the world. One of them is adding chlorine in sea water is a widely accepted method to simply and efficiently prohibit fouling. The use of chlorine to avoid fouling occurrence has the supposed benefit of rapid decay of chlorine toxicity.

One major drawback of chlorine is that interactions between chlorine and seawater can induce complex chemical reactions that produce compounds with higher toxicity.

So chlorine is used as an anti-fouling reagent in sea water in power plants. The outgoing sea water from Power Plant has residual chlorine 0.2mg/l which is acceptable.

Injection of Chlorine in Sea Water

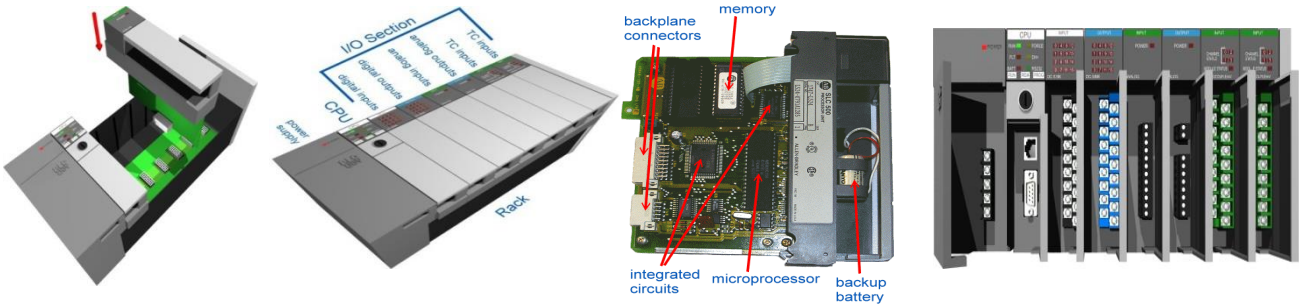


Process of injection chlorine: Liquid chlorine drums are attached with 2 headers, so liquid chlorine is transferred to evaporators. A bursting disc is provided with an empty tank with high pressure switch. If pressure increased in any header it will burst and alarm will appear in the control room. By heating the water in evaporator liquid chlorine will convert in to gas form. This chlorine gas will be transferred through the Pressure and Vacuum regulator to the chlorinator. Manual or automatic flow controller will transfer this chlorine gas to the sea water pipeline through the injector which is creating vacuum to suck the Chlorine gas from chlorinator. Then this chlorine solution injects to the sea where Sea Water Supply Pump are located in sea bay. In case of chlorine Gas leakage, automatic sensing system is installed. It will suck all gas and send to neutralization tank to neutralize the chlorine gas.

PLC / SCADA
&
DCS

PLC (Programmable Logic Control)

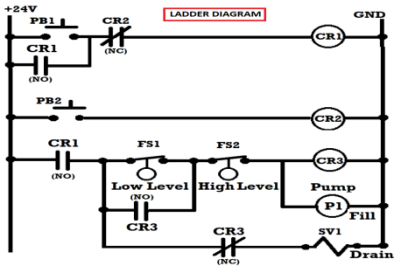
Programmable logic controller (PLC) is a small, modular plug & play type rack based Solid State Computer with customized instructions for performing a particular task.



PLC have largely replaced electro mechanical type relays, drum sequencers, large size of solenoid valves, big size of micro switches, electro mechanical type timers and large size of step programmer (cam switch type) etc. As shown these pictures.

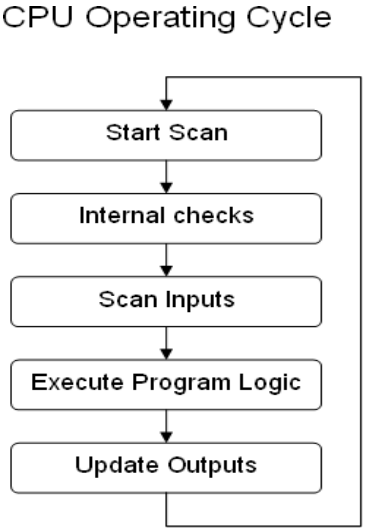
PLC is a useful tool for repeatable processes of small units Like:

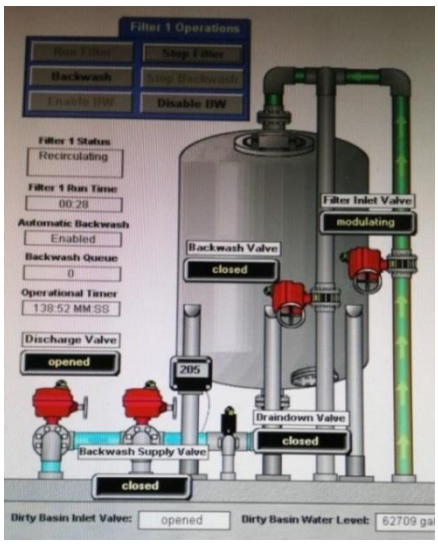
DM plant for regeneration, **Chlorination plant** for shock chlorine injection is sea water.
HMI is friendly useful tool to operate a small unit.
PLC has no mechanical part and they can gather information through the I/O cards. **The most common language is used in PLC is LADDER. It is very simple like electrical diagram.** As shown here.



Repeatable Process

It will only process one Program over and over by the interval of time.





SCADA

SCADA is a Supervisory control and data acquisition system. SCADA systems are used by industrial organizations and companies in the public and private sectors to control and maintain efficiency, distribute data for smarter decisions, and communicate system issues to help operators and other employees, analyze the data and make important decisions.

The basically SCADA system begins with programmable logic controllers (PLCs) or remote terminal units (RTUs). PLCs and RTUs are microcomputers that communicate with a trail of objects such as factory machine process sensors, control devices, I/O sensors with HMIs, and then route the information from those objects to computers with SCADA software. The SCADA software processes, distributes, and displays the data, to help operators and other employees, analyze the data and make important decisions.

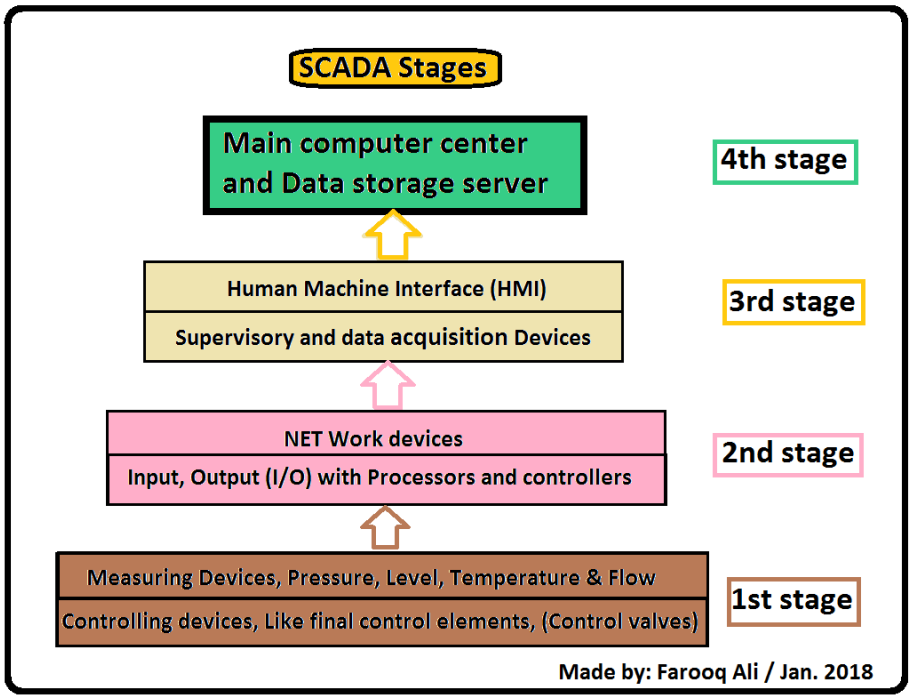
SCADA have 4 stages.

1st stage: Contains the field measuring devices such as flow, level, pressure and temperature, sensors, and controlling the all processes through the final control elements, such as control valves.

2nd stage: Contains the input/output (I/O) modules, and their associated distributed electronic processors and controllers.

3rd stage: Contains the supervisory computers, which collects information from processor, controllers through the network station, and provide the all information to HMI for operator.

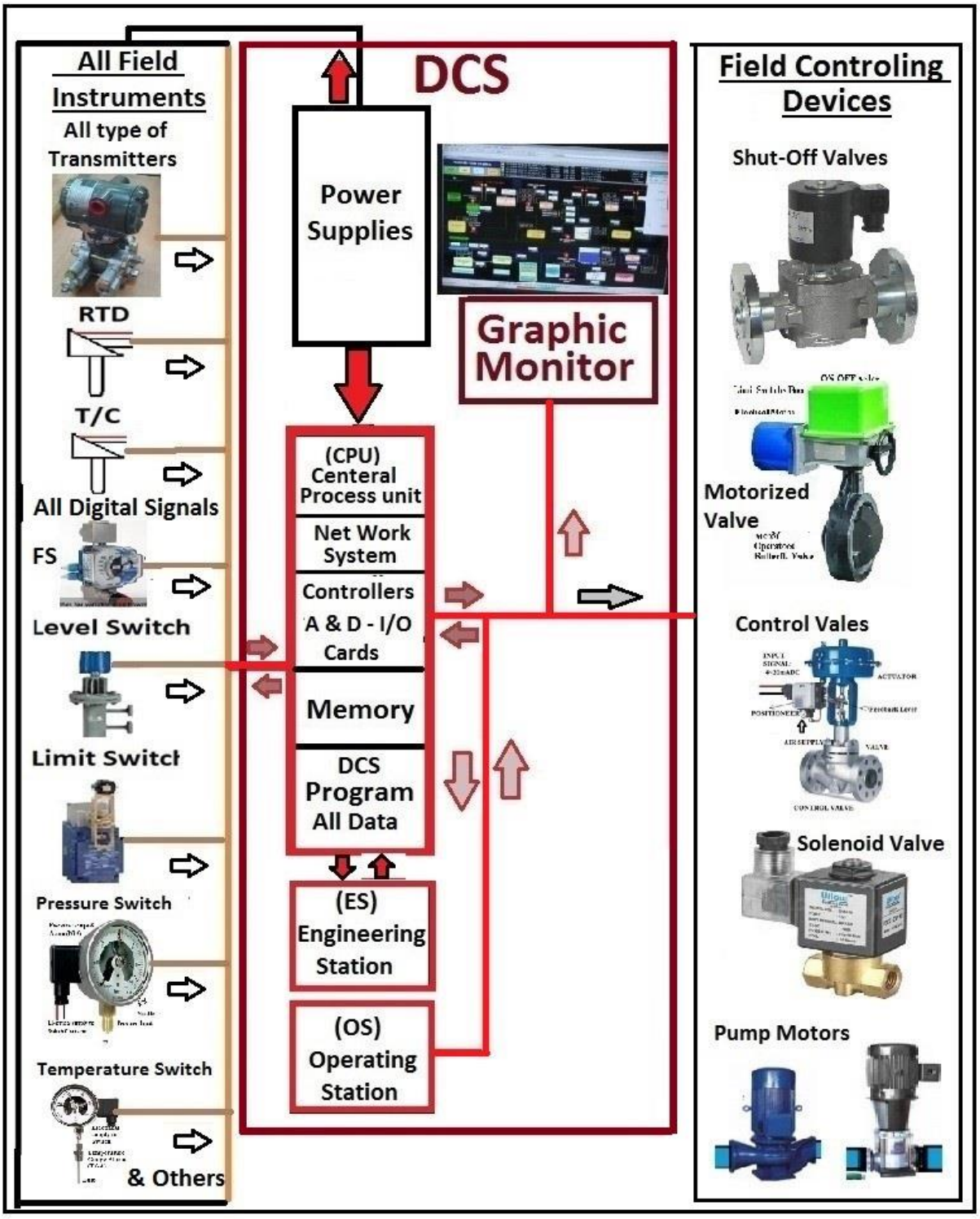
4th stage: is the production control stage, that does not directly control the process, but it is related with data logging, monitoring production and targets.

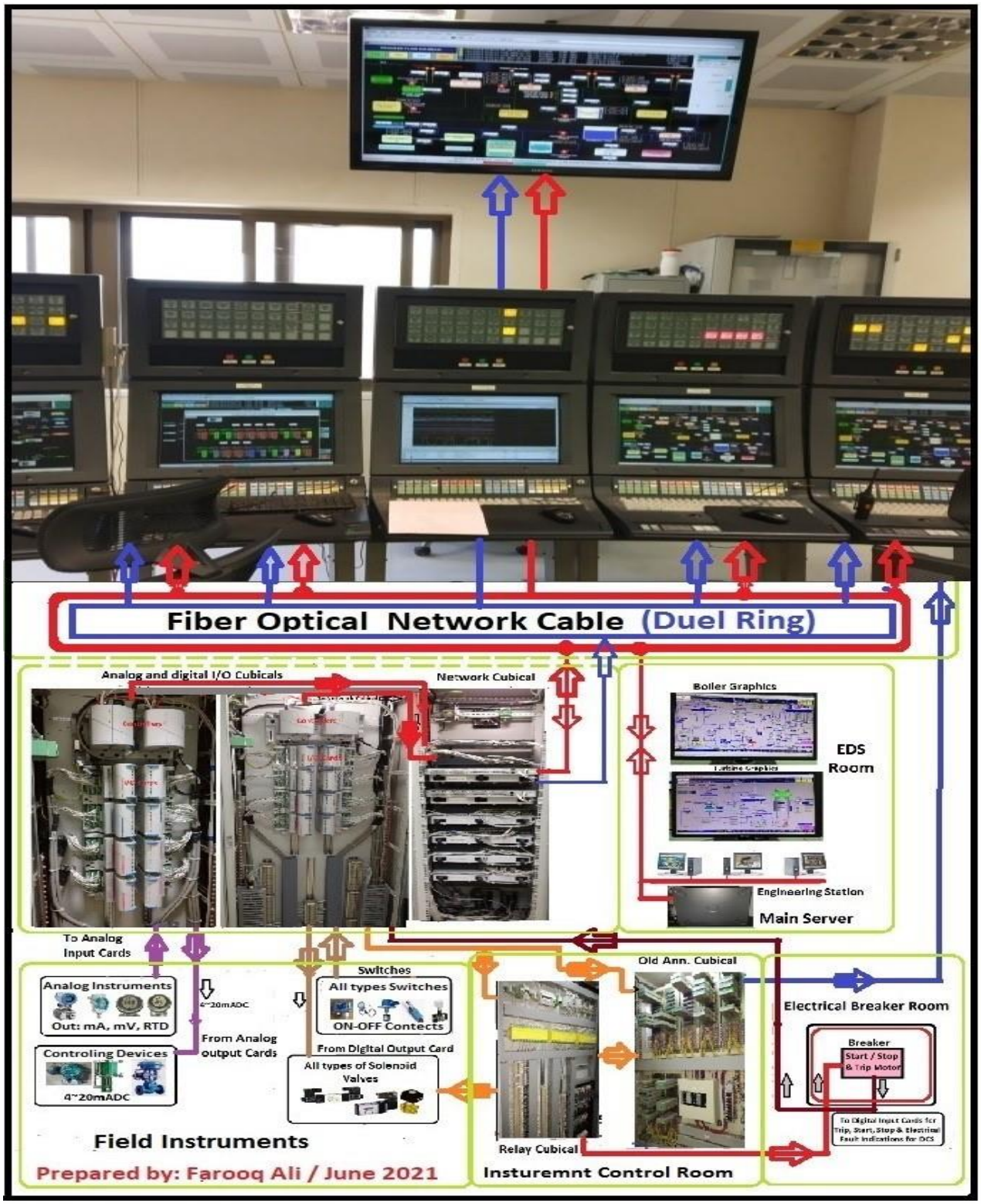


Distribute Control System "DCS"

1- **DCS instrumentations:** (**DCS means Distributed Control System.** This is the 4th generation of industrial technology, designed with software & computer based technology. This technology can eliminate all types of conventional control systems.

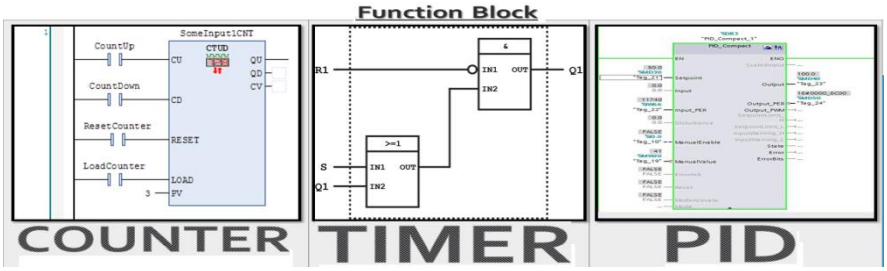
2- A **Distributed Control System (DCS)** is a specially designed automated control system that consists of geographically distributed control elements over the plant or control area.





3- It differs from the centralized control system where in a single controller at central location handles the control function, but in DCS each process, element, machine or group of machines are controlled by a dedicated controller. DCS consists of a large number of local controllers in various sections of plant control area and are connected via a high speed communication network**.**

4- DCS creates new world of technology. DCS control systems using different languages through the PC. Most commonly used language in DCS is **Function Block**.



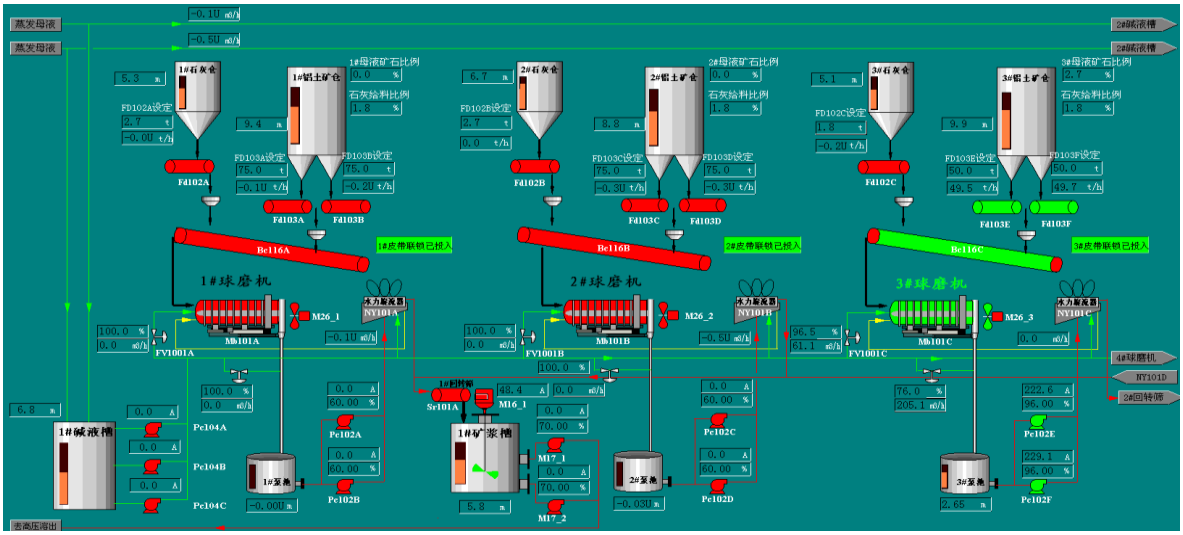
5- **Plant Operating Stations (POS)** is the PC through which an operator can operate a big Power Plant or all types of Plants.

6- **DCS** takes less space, perform more complex tasks and are more customizable than the electro-mechanical technologies they have replaced.

7- Analog input cards receive analog input signals **(All types of analog signals like: 4~20mADC, from transmitters, T/C, RTD and all types of Transducers)** from the field and transfer all information through the network controllers and fiber optical cables to the **POS DCS Server**, which saves & transfers the data to **POS (Operator)** or **HMI**. These analog readings can be viewed on the LED monitor. The process variable (PV) can be control through the analog output cards from the **Plant Operating Station (POS)** or **HMI** to the field controlling instruments.

8- Same ways digital input / output signal also transfers through the digital input / output cards. So the digital output signal transfers through the network controllers to the **DCS Server & POS (Operator**) So We Can **Open / Close** any shut-off valve and safety protection systems from the **HMI** through the **DCS Server**, also we can **Start / Stop** any pump motor through the same way.

9- So all graphic and readings can be viewed on the **LED Monitor** and also can be control **PV** from the **POS (Operator)** or **HMI.**



10- **DCS Server:** has all the technical software belonged to the plant. It is used to store all type of data of the all DCS system of a plant**.**

11- Engineering Station (ES) is used to create graphic, change in any configuration of any system, diagnostic of troubles and any modification in the DCS system.

12- Plant Operating Station (POS) Operator: is used for operators to control and operate a big plant like a Power Plant / or any heavy industry, having multiple controlling systems with many I/O cards. (Analog input / Output cards & Digital input / Output cards).

13- Each I/O card has 8 channels up to 64 Channels. (Depend upon the design & use of the system requirements)

HMI (Human Machine Interface)

HMI (**H**uman **M**achine **I**nterface): This is user interface in a manufacturing or process control system. It provides a graphics-based visualization of an industrial control and monitoring system. HMI typically resides in an office-based Windows computer that communicates with a specialized computer in the plant such as a programmable automation controller (PAC), programmable logic controller (PLC) or part of (DCS).

HMI (Human Machine Interface) is used to control a small plant like chlorination plants or DM plant.

Benefits of DCS

* All manufacturing companies design their own software for DCS.
* We can configure all loops of analog, interlocks, alarms & trips in the DCS.
* It can control complete production unit of power station from 1 PC only.
* We can install a big monitor screen and we can see all parameters and graphics on it, including Process loops, process values & mimics.
* We can create graphic in the system through ES station.
* It is easy to trace the fault in the circuit.
* This is cheapest and long life control system with low cost maintenance.
* Only field instruments required calibration and maintenance periodically.

Note: DCS eliminates the following from the conventional Relay Room & Control room.

* Conventional Desk / Panels and all types of switches installed on the desk and panel.
* All analog Cables (Module based analog cubical)
* Different types and size of Indicators
* Different types and size of Recorders
* All types of Flow Counters
* TPL Switches (Start/ Stop motors)
* Big size of annunciation panels.
* Big sizes of analog Controllers & set point stations.
* Electro mechanical Relays & timers.

* Different types of alarm cards.
* Mimics and many more instruments installed on desk and panel.

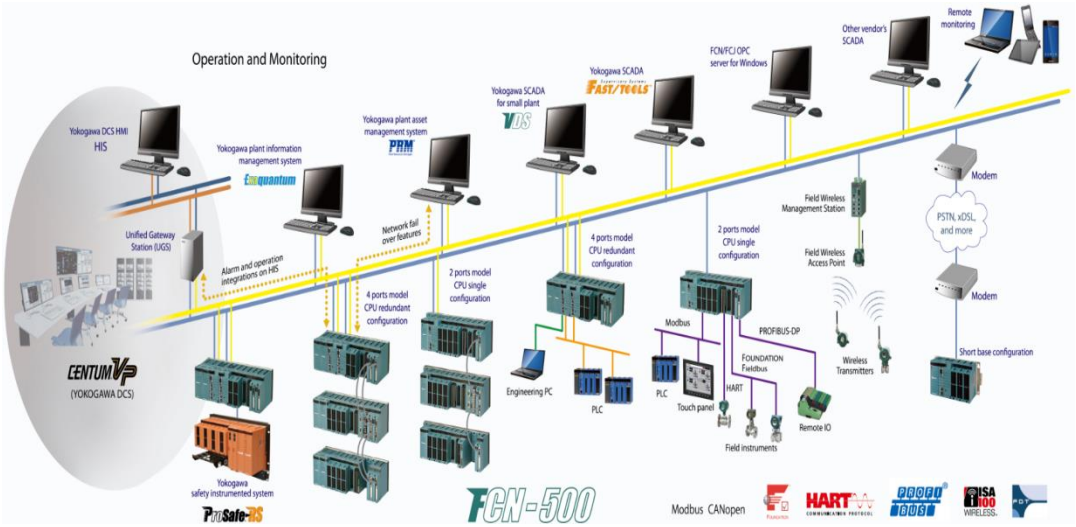
So all above instruments are configured and available in DCS software so not required as hardware.

Old look of Conventional Control Room,
Where every instrument installed on the Desk & panel

New Look of DCS Control Room,
Here everything in the software of DCS

DCS is a De-Centralized system means there are many systems but not controlling from one centralized computer control system.

DCS Controls different types of systems / Loops / sections of a Plant Including PLC & SCADA System with Wireless facilities.



Trouble Shootings

Trouble Shootings:

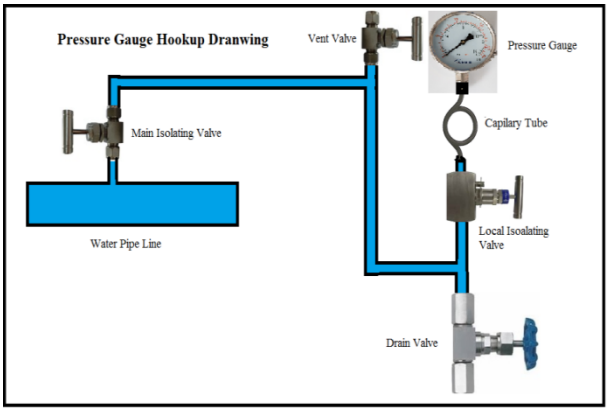
Common problem in any instrument:

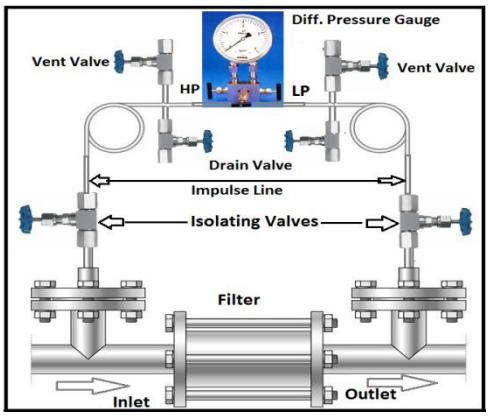
1- **Any measuring instrument cannot measure 2 mediums simultaneously, such as measuring water pressure and air pressure at the same time. Instrument will give always wrong reading.**
2- To measure water pressure, **purge the air** from the impulse lines and instruments sensors.
3- To measure air pressure, **drain the water** from the impulse line & instrument sensors.
4- Instrument working on Sea water, **Impulse lines should be cleaned** in every A/M.
5- Capillary tubes, Gauge savers, Instrument **sensors & input ports** should be clean.
6- All isolating valve should be free to open and close easily.
7- During commissioning check all valves are inline and no leakage in process loop.

In case of the trouble in any process, what action to be taken to get correct results

1- PRESSURE & DIFF. PRESSURE GAUGE:

TROUBLE: Pressure & Diff. pressure gauge shows wrong reading or no reading:





- Check whether the main isolating valves of impulse lines are open.
- Check whether the impulse line and damping capillary tube / dampener / gauge saver is not chocked.
- Check whether the process input port of gauge is not chocked. (Salt block the port)
- Check the internal physical condition of gauge. Bourdon tube, movement assy. hair spring and pointer are ok. If any of them is damaged, replace it with a new spare part.
- Open the vent valve and remove the air or open the drain valve and drain the water from impulse line.
- Check the equalizing valve of diff. pressure gauge. It should be closed.
- Differential pressure, (DP cell) long time in service. Generally, when high side diaphragm is pushed at one side for long time.
- Check filling sealant in DP Cell is leaked.
- If calibration is required, then calibrate with the calibration procedure as approved by MEW.

2- PRESSURE / DIFF. PRESSURE & FLOW SWITCH (High or Low alarms):

TROUBLE: Not giving any alarm in control room:

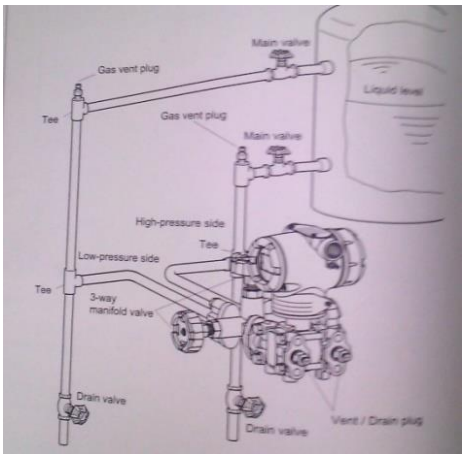

Line Mounted Varable Area Flow Switch

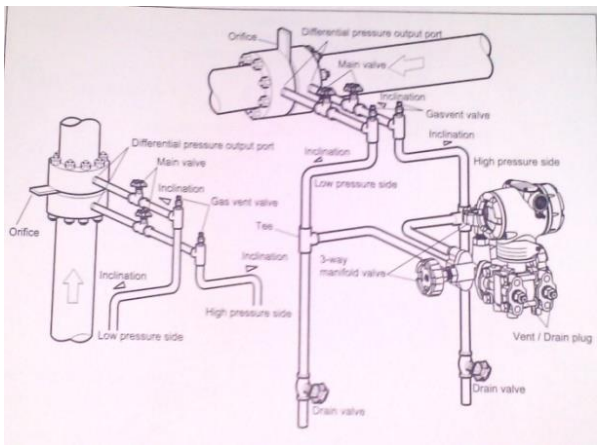

Line Mounted Variable Area Flow Switch

- Check the isolating valves are open.
- Vent the air in case air in the impulse line.
- Check the impulse line and capillary / dampener / saver is not chocked.
- Check the micro switch is working effectively.
- Check the process input port of switch is not chocked.
- Check the physical condition of internal parts of the switch. If any spare is damaged replace it with a new spare part.
- Check the wires and terminals on both ends should be tight.
- Check the annunciation lamps are working on the annunciation window
- Differential pressure, (DP cell) long time in service. Generally, when high side diaphragm is pushed at one side for long time and stuck or filling sealant is leaked.
- In case no alarm is received in control room, check the loop of switch for annunciation. If any PCB card or relay does not work, then replace it.
- Line mounted variable flow meter; Rota meter should not be stuck.
- There may be a chance that set point is out, in such situations calibrate and adjust set points with the calibration procedure as approved by MEW.

3- PRESSURE, DIFF. PRESSURE, LEVEL & FLOW TRANSMITTER:

TROUBLE: Transmitter has no reading or wrong reading in control room.

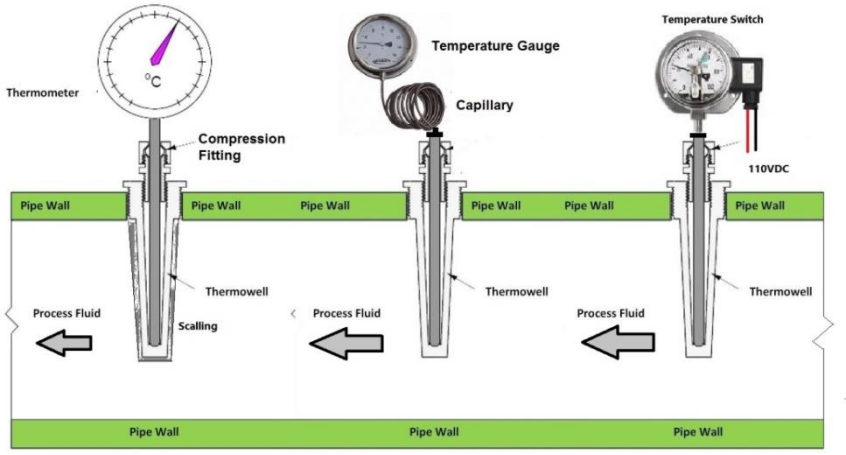




- Check the isolating valves are in line. For DP transmitter the balance valve should be closed.
- Check the impulse lines are not chocked.
- Differential pressure, (DP cell) long time in service. Generally, when high side diaphragm is pushed at one side for long time or filling sealant is leaked.
- If the transmitter is working on:
  - **Water process** then vent the air from impulse line;
  - **Air or gas** then drain the water from impulse line;
  - **Steam line** then vent the air from the impulse line and wait for it to cool down the steam in to water and fill the condensate pot for correct reading.
- Check the zero of transmitter (4mADC) by closing the high and low side isolating valve and open the balance valve. If it is shows value other than zero, then adjust zero at 4 mADC before working.
- Check the calibration of indicator or recorder is correct.
- In case of flow measurement, it is required to check the complete loop from field to control room. All modules should be properly calibrated. If calibration is required, then calibrate with the calibration procedure as approved by MEW.

4- TEMPERATURE GAUGES AND SWITCHES:

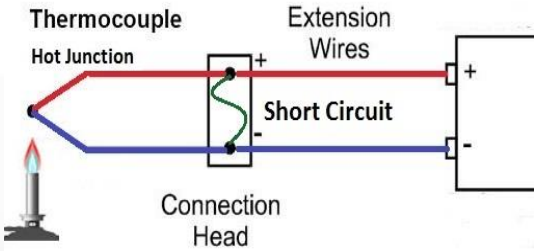
TROUBLE: Temperature gauge is giving wrong reading or no alarm in control room.

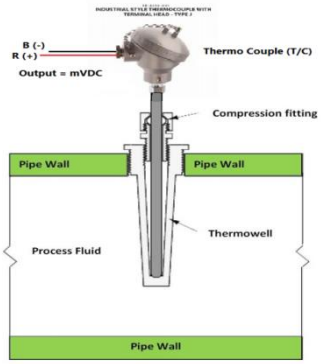


- Ensure the bulb of temperature gauge fixed properly.
- Check the scaling on the thermos-well. (If possible)
- Ensure physically the capillary tube is not damaged.
- Check the physical condition of internal parts of temperature gauge. If any spare is damaged replace it with a new spare part.
- Ensure the micro switch of temperature switch is working effectively.
- Check the wires and terminals on both ends should be tight.
- Check the annunciation lamps are working on the annunciation window.
- In case no alarm is received in control room, check the loop of temperature switch for annunciation. If any PCB card or relay does not work, then replace it.
- If calibration is required, then calibrate with the calibration procedure as approved by MEW.

5- THERMOCOUPLES (T/C)

TROUBLE: showing wrong reading, or is out of scale or showing ambient temperature.





a- Check the cover of the T/C to be air tight. If Cover is left loose water vapors may enter in the terminal making it a semiconductor and therefore giving inaccurate readings.

b- Ensure the terminal polarity is right. In case of wrong connection, it will show wrong readings.

c- All terminals should be properly tight.

d- Check the terminal lugs not loose with wire.

e- If there is any short circuit in terminal box, it will make new T/C which will always show the ambient temperature.

f- Temperature compensation resistance might not be functioning.

g- Check the ground test by using multi meter, if T/C being used is un-grounded.

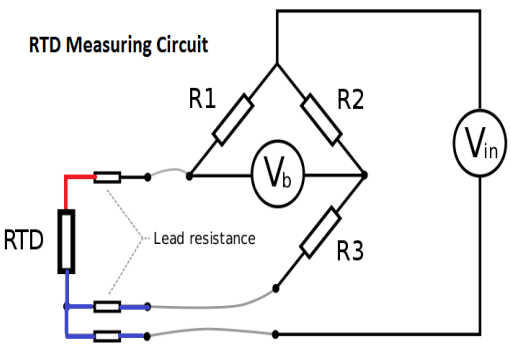
h- In case if water vapors are accumulated in the capillary of T/C, it can give wrong reading and trip the motor. Therefore, it is mandatory to remove water and dry the capillary of T/C and protect from humidity or rain.

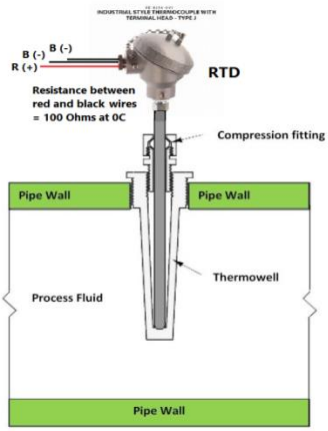
i- T/C connection can be opened from sensing point.

j- Remove T/C from the well and test it by giving heat at sensing point and check mV output by multi meter.

6- RESISTANCE TEMPERATURE DETECTOR (RTD):

TROUBLE: Gives wrong reading, or is out of scale or showing ambient temperature.

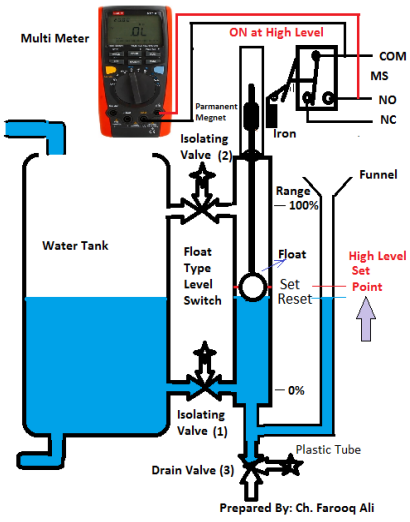


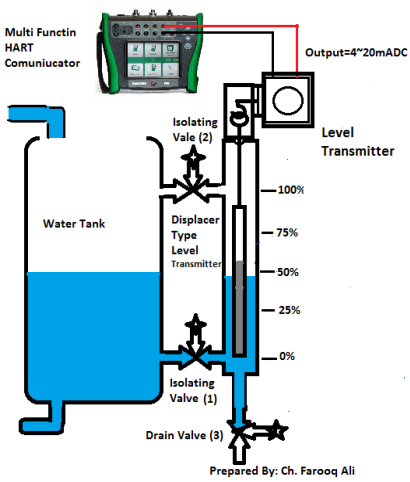


- Check the cover of the RTD to be air tight. In case of loose cover, water vapors may enter in the terminals \& generating nearly short circuit and therefore giving inaccurate readings.
- Ensure the terminal polarity is right. In case of wrong connection, it will show wrong readings.
- All terminals should be properly tight according to the core identifications.
- From 3 wires of RTD, any wire can be opened from sensing point. Continuity should be checked of each wire.
- RTD is made by platinum PT100 ohms (100 Ohms at 0C) and at ambient temperatures resistance can be nearly 110 ohms at 25 C, in case if reading is zero ohms or open circuit then replace it with new RTD.
- Remove the RTD from the well and heat the sensor. Check the output resistance increasing on multi meter. If it varies according to the temperature, then RTD is considered to be in a good condition.

7- FLOAT TYPE LEVEL SWITCHES AND LEVEL TRANSMITTERS:

TROUBLE: No level alarm or no level reading in control room.



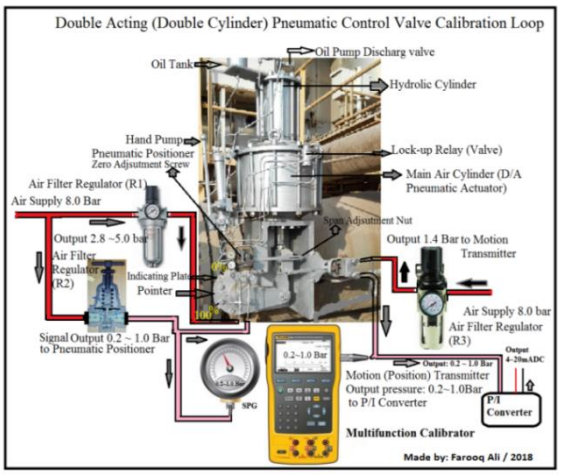


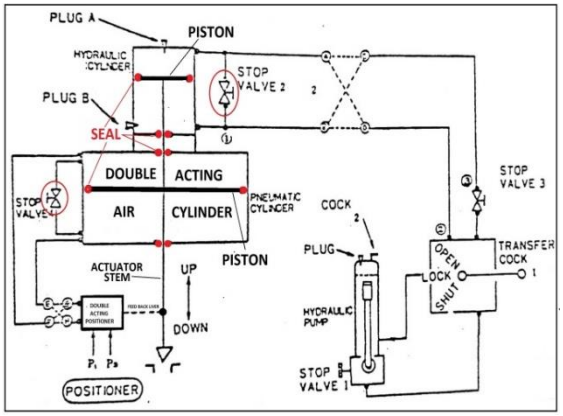
- Check the micro switch of level switch is working.
- Check the magnet of float is working. If damaged change with new.
- Check the adjustment of micro Switch, may be it is out of set point.
- Check the main isolating valves should be opened and drain valve closed. (Some time upper valve is closed)
- Open the chamber and check the float and displacer. May be float and displacer is leaked and water filled in it.
- If there is water in the float or in displacer, then change with new.
- May be chamber is dirty and rusty, due to that float is stuck, if used on sea water.
- If calibration is required, then calibrate with the calibration procedure as approved by MEW.

8- ACTUATORS, POSITIONERS AND ACCESSORIES:

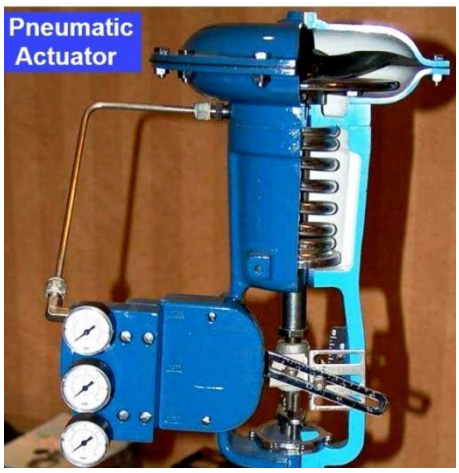
TROUBLE: D/A Control valve is not opening full / working very slow or Hunting.

We can check the folloing points to solve the trouble.





- Check the output of I/P converter is 0.2 ~ 1.0 Bar is correct.
- Ensure that air filter regulator output pressure is equal to max. Pressure of designed actuator. If it is less, then adjusting the air pressure according to the designed pressure.
- Clean the filter regulator if air filter is chocked. In case it is damaged then replace with a new one.
- In case of double acting actuator, check the equalizing valve of air cylinder is in line / closed.
- Equalizing valve of hydraulic actuator should be fully opened.
- Check or clean the positioner pneumatic relays and nozzle and flapper.
- Ensure the feedback lever is attached with stem.
- Check the signal 0.2 ~ 1.0 bar is receiving to the positioner.
- In case of SMART positioner 4~20mADC input signal should reach to positioner.
- Apply leak test procedure to ensure that there is no air leakage in the actuator. In case of air is leaking then open the actuator and check the internal diaphragm (may be punctured) / seals (may be damaged), replace with the new spare parts if required.



- Ensure the current output of position transmitter is correct (4~20mADC).
- Check the solenoid valve is working properly if not then repair or replace it.
- Ensure air lock valve or lock-up valve are working effectively.
- If any speed controllers or dampener are using, then check the setting of both.
- If any pneumatic directional valve and lock-up valves are used, then check their operation.
- If control valve calibration is required, then calibrate with the calibration procedure as approved by MEW.
- If all above points are cleared and Ok, then Re-Tuning of PID Controller is required to stop hunting.

Hazards / Dangers

&

Personal Safety

Hazards / Dangers & Personal Safeties

Hazards / Dangers

For human there are many hazards / dangers in the power station. Most common hazards /dangers are as follows.

1- **Electrical (High voltage in Electrical panels)**
2- **Heights**
3- **Stairs**
4- **Heat and Steam**
5- **Fire & Smoke**
6- **Chlorine gas (Chlorination Plant)**
7- **Natural Gas (Gas scrubber and gas lines near boilers)**
8- **Oil (Oil Tank area) (Gas oil /Crude Oil, Heavy fuel Oil, Oil pump house, Oil pipe lines near boilers).**
9- **Welding**
10- **Sea area (Pumping plant)**

For Plant there are some hazards

1- **Less knowledge**
2- **Untrained persons**
3- **Less practical experience**
4- **Not understand logic & interlock drawings**

Common Personal Safeties

1- Take personal safety training and get knowledge about dangers in power plant.
2- Use personal protective cloths (PPE) before starting of work. (Such as: (Uniform, Helmet & Non slippery / shockproof safety shoes).
3- Identify the work place & Location.
4- Identify the nature of trouble.
5- Complete focus on work.
6- Issue a work permit with isolation (if required).
7- Practical knowledge of actual work to solve the trouble
8- Identify the danger.
9- Take safety clearance certificate from safety department if required.
10- Proper tool kit.
11- Neat and clean tidy place of work.
12- Cordon off the work area if necessary.

Reduction of Hazards / Danger

Note: When working in danger area where danger can harm the person, should be **calculate the risk and fill the risk assessment form to reduce the danger** and take approval from safety department.

1- Electrical (Working in electrical panel)

(a) Identification of work place (Nature of work and location).
(b) High voltage resistance tools.
(c) Check proper grounding of the panel.
(d) Use insulated gloves.
(e) Use proper test equipment.

2- Heights (Works on height)

(a) Full attention.
(b) Use safety belt at danger work place.
(c) Don't move on loos plate form.

3- Stairs (While using stairs)

(a) Full Attention and see the stairs.
(b) Catch realigns.
(c) Don't use mobile when using stairs.

4- Heat & Steam Leakage

(a) Face protector.
(b) Heat Resistance Gloves.

5- Fire & Smoke leakage

(a) Keep distance from fire.
(b) Use mask in smoke area.
(c) Keep away all other burning material.
(d) Try to vanish /eliminate the fire according to the proper safety procedures.

6- Chlorine gas leakage (Chlorination Plant)

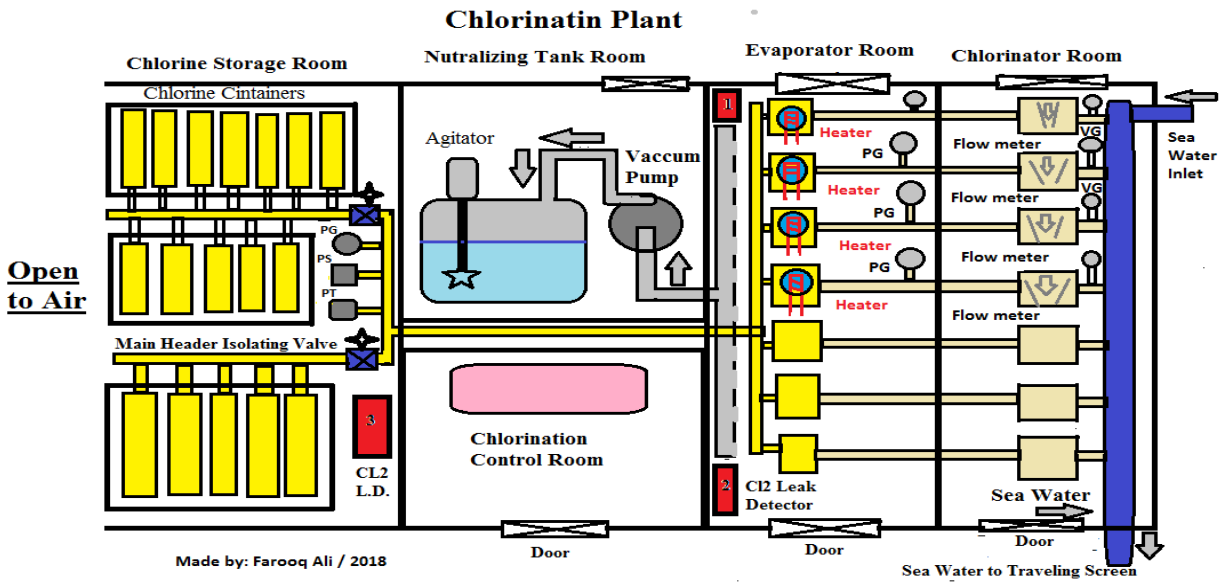
This gas is very toxic, have a **yellow color** and heavier than air. We can see it near the ground level because of its color. It suddenly effects on throat.

(a) Always keep all the doors open.
(b) Wear PPE (Personal Protecting Clothes)

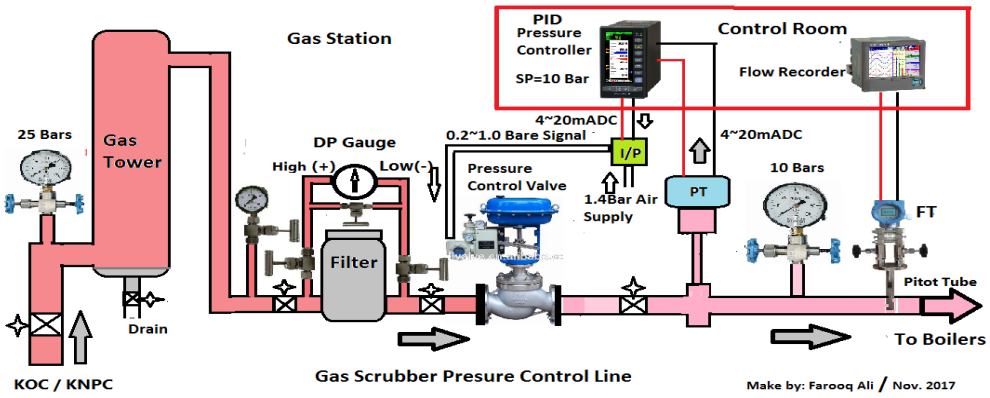
(c) Vacuum pump should be run automatically by leak detectors. (If not start then run manually from control room or locally).

(d) Always use proper Gas Mask and never stay long time in leakage area.

(e) Always use eyes protecting goggle in chlorine gas plant.



Natural Gas leakage (Gas scrubber, and gas lines near boilers)



It is lighter than air, not visible, mix in the air very soon, only we can smell.

(a) Use gas leak tester.
(b) Keep your mobile off & away from gas station and gas lines.
(c) Use proper gas mask and never stay long time in leakage area.
(d) Isolate instrument properly from where gas is leaking.
(e) Use non-sparking tools in gas scrubber and gas lines near the boiler.
(f) If gas enters in the rooms then **Never Electrical Switch ON or OFF** any thing.
(g) Keep electrical appliances in same condition.
(h) Open windows very carefully.
(i) Never use cigarette lighter in gas area.
(j) Never use iron chipping hammer to remove the rust.

7- Oil (Gas oil /Crude Oil Leakage) {Oil tank area, Oil pump house, Heavy fuel Oil station (HFO), Oil pipe lines near boilers}

(a) Isolate instrument properly.
(b) Drain oil to the oil drain system before work.
(c) Keep always sand near work area.
(d) Keep extra container in case of oil drain system is not installed.
(e) Use non-slippery tools in oily and greasy areas.
(f) Never use cigarette lighter in oil area.
(g) Use waist cotton during work.
(h) Sand can also to be used to clean the oil.

8- Chemicals

a. Use PPE
b. Use face protector shield
c. Use proper Gloves (Anti- Chemical)
d. Always away from drained /spilled / splashed chemical on ground.
e. Use suction pump to collect splashed chemical.
f. Spray water facility should be provided to wash effected body from chemical.

9- Welding

(a) Use safety goggles during welding.
(b) Never see directly during welding (Arc light is dangerous for eyes).
(c) Never use welding near gas lines, oil lines.

10- Sea (Pumping Plant)

(a) Don't go near the sea. (Sea bay is very deep and very huge suction).
(b) Don't move around the trash rack.
(c) Don't catch the reeling near the sea.
(d) Care full from the traveling screen.
(e) Don't use slippery shoes.

Preparation of work:

1- At the initiation stage take approval from operation engineer and request for WP to work on the desired instrument.
2- If any instrument is working on PID controller, then request to transfer control from Auto to Manual in case of running unit.
3- In case of alarm not receiving in control room then check the annunciation lamps are working on the annunciation window.
4- Check the complete loop of switch is healthy.
5- If any switch is working with interlock, then take approval to bypass interlock if possible.

Risk
&
Risk Assessment

Risk

Risk is the probability / possibility of an event accruing in some circumstances.

Risk is exposure to hazard.

Risk= Probability of an event and severity

Risk Assessment:

An assessment of risk is a careful examination of your work area with regards to what could cause harm to peoples and what precaution to be applied. The aim is to eliminate or reduce the risk of hazard.

Probability (Possibility) / Likely Hood (A)

Description of Likely Hood	Examples
Not Likely (1)	Very little risk present, Only under exceptional conditions would there by an accident or incident.
Possible (2)	Several factors probably need to be present for an accident or incident.
Quite Possible (3)	Under normal conditions an accident of incident will not occur. Some fault or abnormality is necessary to cause it.
Likely (4)	Under prevailing conditions an accident or incident will either occur or will be difficult to avoid.
Very likely (5)	If abnormal condition continues, an accident or incident is almost occurring.

Severity (B)

Hazard Severity	**Example of Type of Injury**
Very Low (1)	Scratch, minor cut, Injury allows normal work after First Aid treatment, Typical there is no lost time
Low (2)	More severe, sprain, strain, minor burns, normal work may not be immediately possible following treatment. There may be some loss of time.
Medium (3)	Burns severe fractures, minor amputations, temporarily, disabling back injuries. Accident almost definitely reportable loss of time or Serious injury.
High (4)	**Permanent disability, serious loss of body part.**
Very High (5)	**One or more fatalities**

Risk description in matrix (Calculation of Risk)

Risk = Probability (Likely Hood) X Severity, (A X B = Risk)

Severity (B)	Probability / Likely Hood (A)				
	Not Likely (1)	Possible (2)	Quiet Possible (3)	Likely (4)	Very Likely (5)
Very Low (1)	Very Low (1)	Very Low (2)	Low (3)	Medium (4)	Medium (5)
Low (2)	Very Low (2)	Very Low (4)	Medium (6)	Medium (8)	High (10)
Medium (3)	Low (3)	Medium (6)	Medium (9)	High (12)	High (15)
High (4)	Medium (4)	Medium (8)	High (12)	Very High (16)	Very High (20)
Very High (5)	Medium (5)	High (10)	High (15)	Very High (20)	Very High (25)

Risk Assessment Record sheet

Power Station ----------

Process / activity ……. Location / Area ……

Department ……. Employ Affected …….

Assessment No…… Assessment date: …….

Hazard Description	Initial Risk			Control Measures to minimize Risk	Calculated Risk			Final Risk / Remarks
	Prob. (A1)	Sev. (B1)	Risk (A1 x B1)		Prob. (A2)	Sev. (B2)	Risk (A2 x B2)	

Risk Assessment by: …… Checked by (Section Head) …….

Reviewed by Safety Engineer: …… **Risk= Probability (A) X Severity (B)**

Example ----- Risk Assessment Record sheet

Power Station: …SWPS……

Process / activity …Cl2 Gas Isolation / Natural Gas Leakage Location / Area …Cl2 Plant / Gas Scrubber

Department ……IMD…… No. of Employ … 2

Assessment No: … Cl2 – 01 / N. Gas - 01 Assessment date: … 15 / 09 / 020…….

Hazard Description	Initial Risk			Control Measures to minimize Risk	Calculated Risk			Final Risk / Remarks
	Prob. (A1)	Sev. (B1)	Risk (A1 x B1)		Prob. (A2)	Sev. (B2)	Risk (A2 x B2)	
Chlorine Gas Leakage in Chlorine storage Room / Evaporator Room	**4**	**4**	**16**	1- Use PPE 2- Use Cl2 Mask 3- Spend short time	**2**	**2**	**4**	Very Low Risk Much Safer
Natural Gas leakage in Gas Scrubber Area **or** Boiler Main Gas Line Burner Area	**4**	**5**	**20**	1- Use PPE 2- Spend short time 3- Keep Mob. Away 4- Don't use Lighter 5- Use Gas detector 6- Use Non-Sparking tools. 7- Never Switch **ON or OFF** Lights. **Note: All Switches Keep in same position.**	**1**	**2**	**3**	Very Low Risk Much Safer

Risk Assessment by: …… Checked by (Section Head) …….

Reviewed by Safety Engineer: …… **Risk= Probability (A) X Severity (B)**

The End