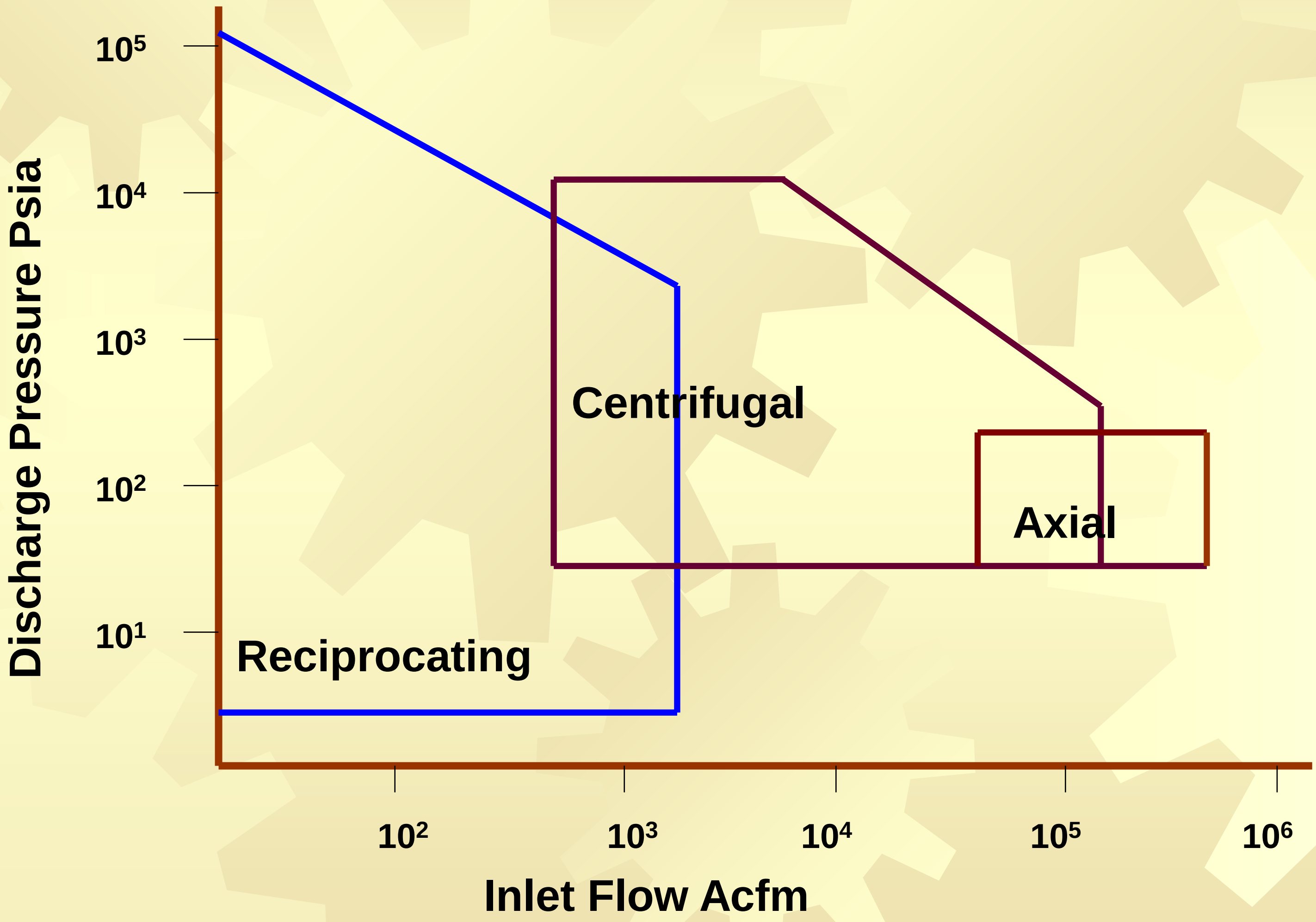
Centrifugal

Compressors

Types of Compressors

- COMPRESSORS
  - POSITIVE DISPLACEMENT (COMPRESSING FLUID BY REDUCING VOLUME OF COPRESSION CHAMBER)
    - RECIPROCATING
    - ROTARY TYPE
      - HELICAL SCREW
      - SPIRAL AXIAL
      - STRAIGHT LOBE
      - SLIDE VANE
  - DYNAMIC TYPE (ACCELERATING AND DECLERATING OF FLUID)
    - CENTRIFUGAL COMPRESSORS
    - AXIAL COMPRESSORS

Application Range



Centrifugal Compressors

Design	:	To international standards like API and customer specs.
Flow	:	Up to 350000 m^3/hr.
Disch. pr.	:	Up to 700 kg/cm^2

Advantages of Centrifugal Compressors

- High degree of balancing
- Pulsation free delivery
- Obviates the use of surge tank receivers
- Easy maintenance
- Best suited for part load operations
- Lower noise level
- Compact

Types of Centrifugal Compressors

Horizontally split compressor

- Model types

  MCL /2MCL /3MCL /DMCL

- Cast casing
- Pressure up to 40 ata
- Services : Air / Ammonia / Propylene / Wet gas

Vertically split compressor

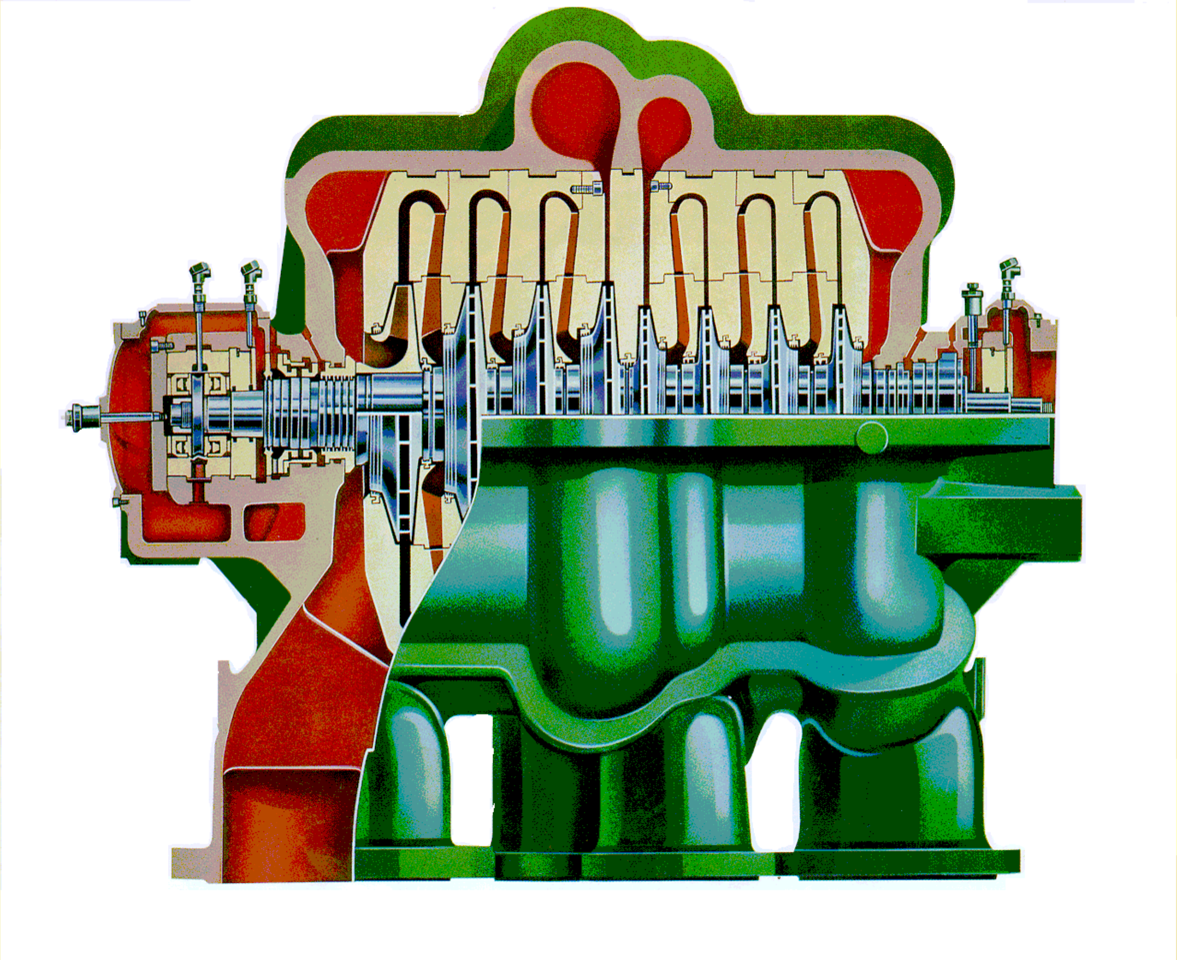
- Model types

  BCL /2BCL /DBCL /

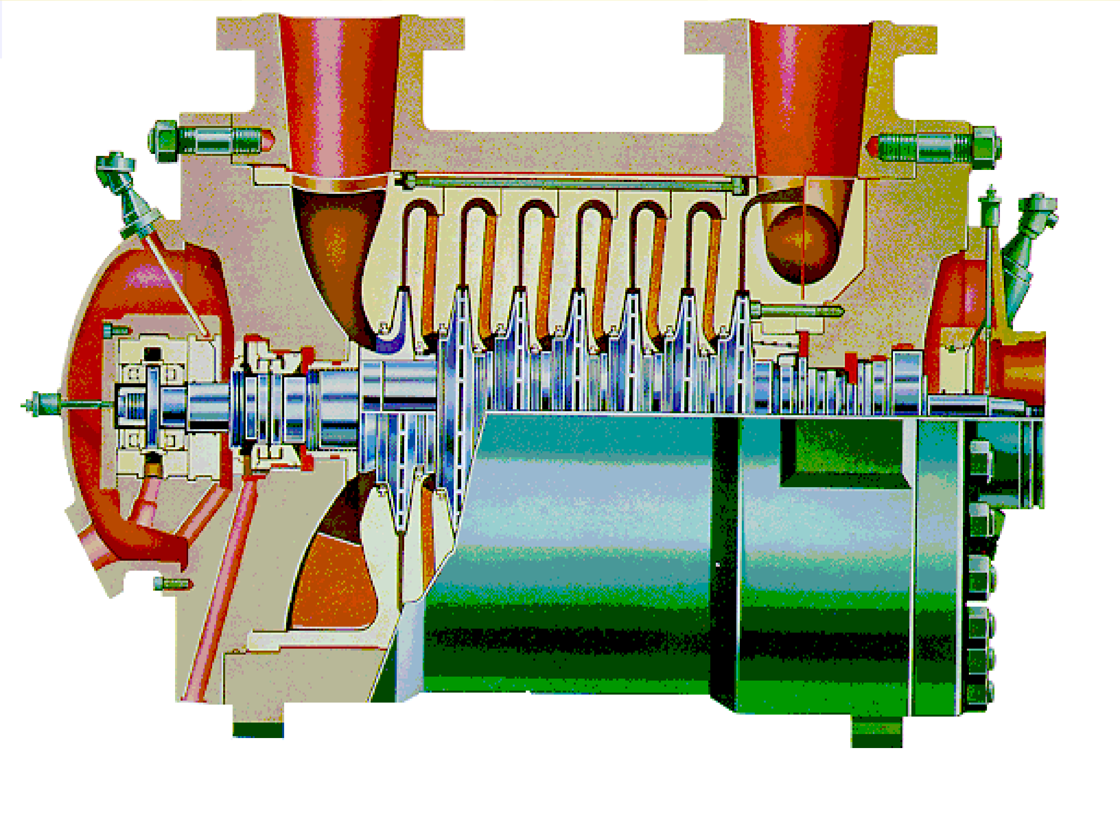
  BCLa /BCLb /BCLc /BCLd

- Forged Casing (barrel type)
- Pressure up to 700 ata
- Services : Syn gas / Nat gas / H_2 recycle /

2MCL Compressor



BCL Compressor



Type / Size Designation

Example : 2BCL407/b

2 BCL 40 7 / b

- **b** – **Pr rating (up to 350 ata)**
- **7** – **No. Of impellers (7 impellers on rotor)**
- **40** – **Nominal dia of impeller (Impeller dia of 40 cms appx.)**
- **BCL** – **Constructional feature (Barrel design)**
- **2** – **Functional feature (Compressor stages in series)**

Industrial Applications of Centrifugal Compressors

Type of Plant	Gas Compressed
Fertilisers	Syn Gas, NH_3, Air, Nat gas, CO_2, Nitrogen
Refineries	Air, Wet Gas, Hydrogen
Petrochemical Plants	Propane, Propylene,Ethylene.
Metallurgical Plants	O_2, Air, Gas

Industrial Applications of Centrifugal Compressors....contd

Chemical Plants

- Melamine
- Oxo Alcohols

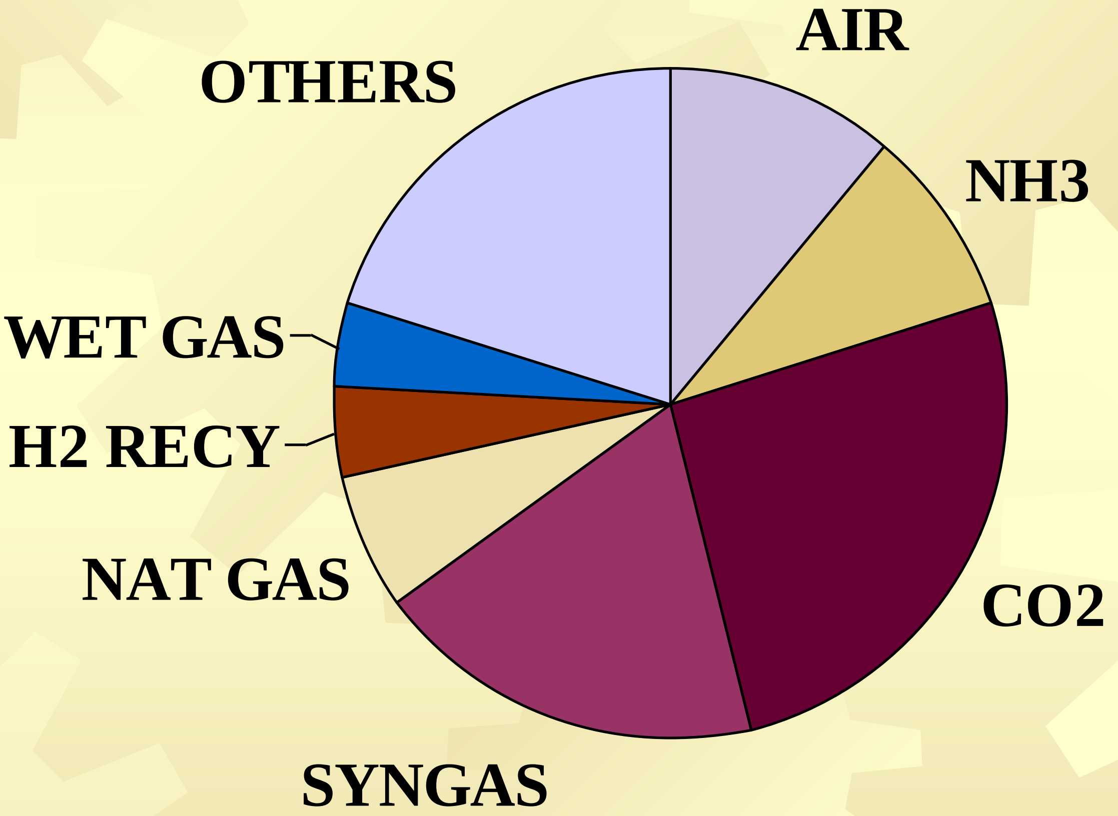
Refrigeration System

- Ammonia
- Ethylene
- Propylene

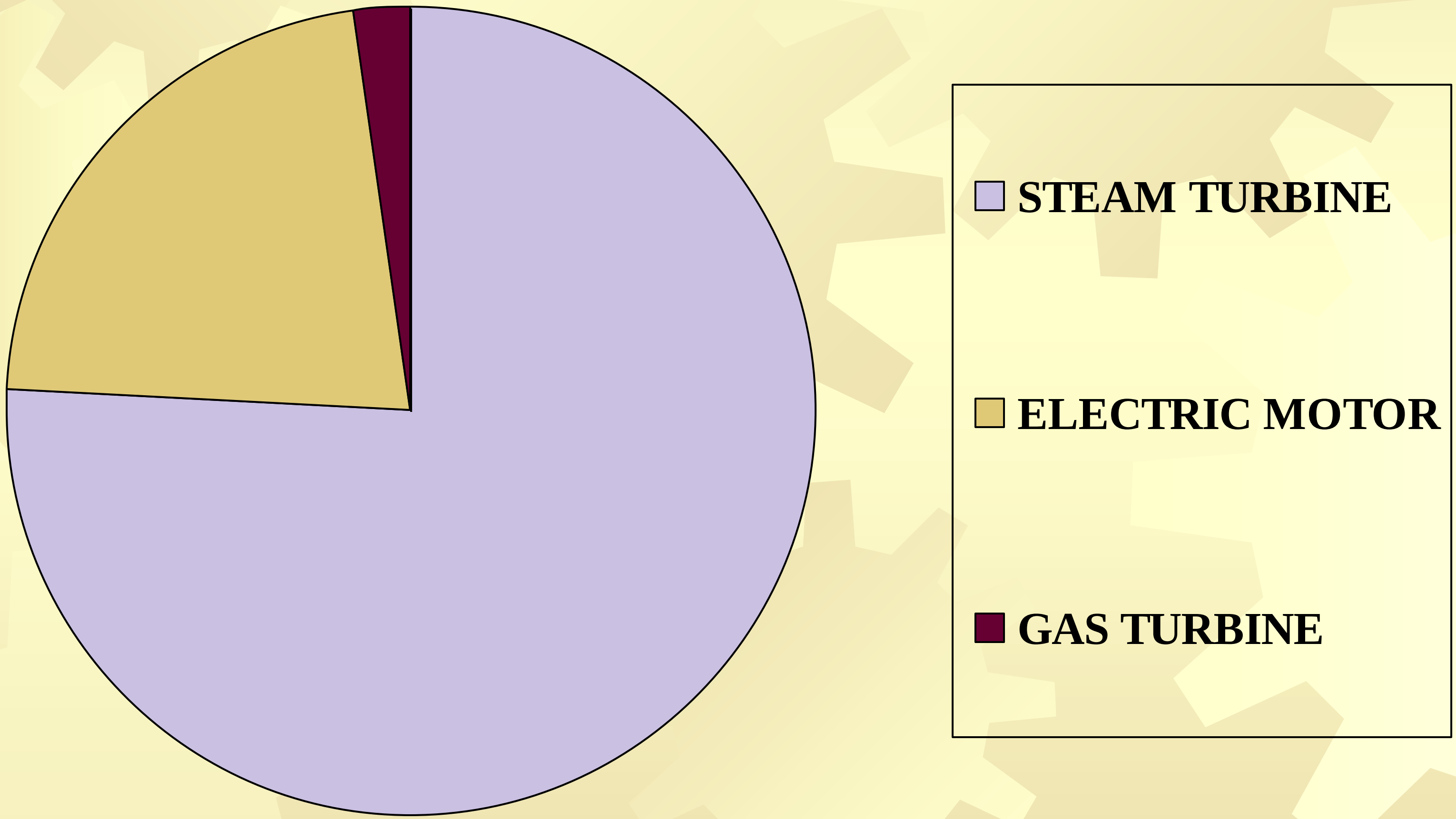
General Industrial Application

- Instrumentation Air
- Freon Compressor For R & D Labs
- Gas Booster Compressors For Gas Turbines, CCCP

Service Wise Break up of Centrifugal Compressors



Drive Wise Break up of Centrifugal Compressors



Operating Parameters

Service	Suct Press (ata)	Disch Press (ata)	Flow (Nm^3/hr)
Process Air	1.03	40	60000
Natural Gas	2.00	40	40000
Synthesis Gas	25.0	140 / 250	165000 (Make up) 590000 (Recycle)
Ammonia Feed	1 to 4.5	17 to 20	40000
Urea Synthesis (CO_2)	1 to 3	150 / 220	32000

Applicable Standards

- API 610 Centrifugal Pumps
- API 611 Auxiliary Steam Turbines
- API 612 Drive Steam Turbines
- API 613 Gearbox
- API 614 Oil Systems
- API 616 Drive Gas turbines
- API 617 Centrifugal Compressors

Applicable Standards

- API 670 Instrumentation
- API 671 Couplings
- API 672 Packaged, Integrally Geared Compressors
- API 676 Positive Displacement Pumps
- IS 325 Auxiliary Electric Motors
- ASME PTC 10 Performance Test
- ASME Sec. VIII & IX Heat Exchangers

Compressor Modernization

Additional test facilities

- Helium leak test facility
- Rotor insensitivity test
- Full load / full speed / full pressure test set up
- Performance test as per ASME PTC Class II & III
- Performance test bed for large air compressors
- 30 T/hr boiler & condenser for tests up to 5 MW

Modernization of test facilities

- Additional test equipment
- Additional analysis software

5 - Axis milling machine from RIGID-STARRAG

- Designed & manufactured more than 50 3D impellers

What to Specify

to

ensure optimum selection

for a

Compressor

Basic Data Required for Selection of Compressor

- Capacity and side streams, if any
- Suction pressure
- Suction temperature
- Discharge pressure
- Gas composition (presence of moisture)
- Off-design performance requirements
- Type of driver
- Utilities like cooling water, steam, N2, Electricity

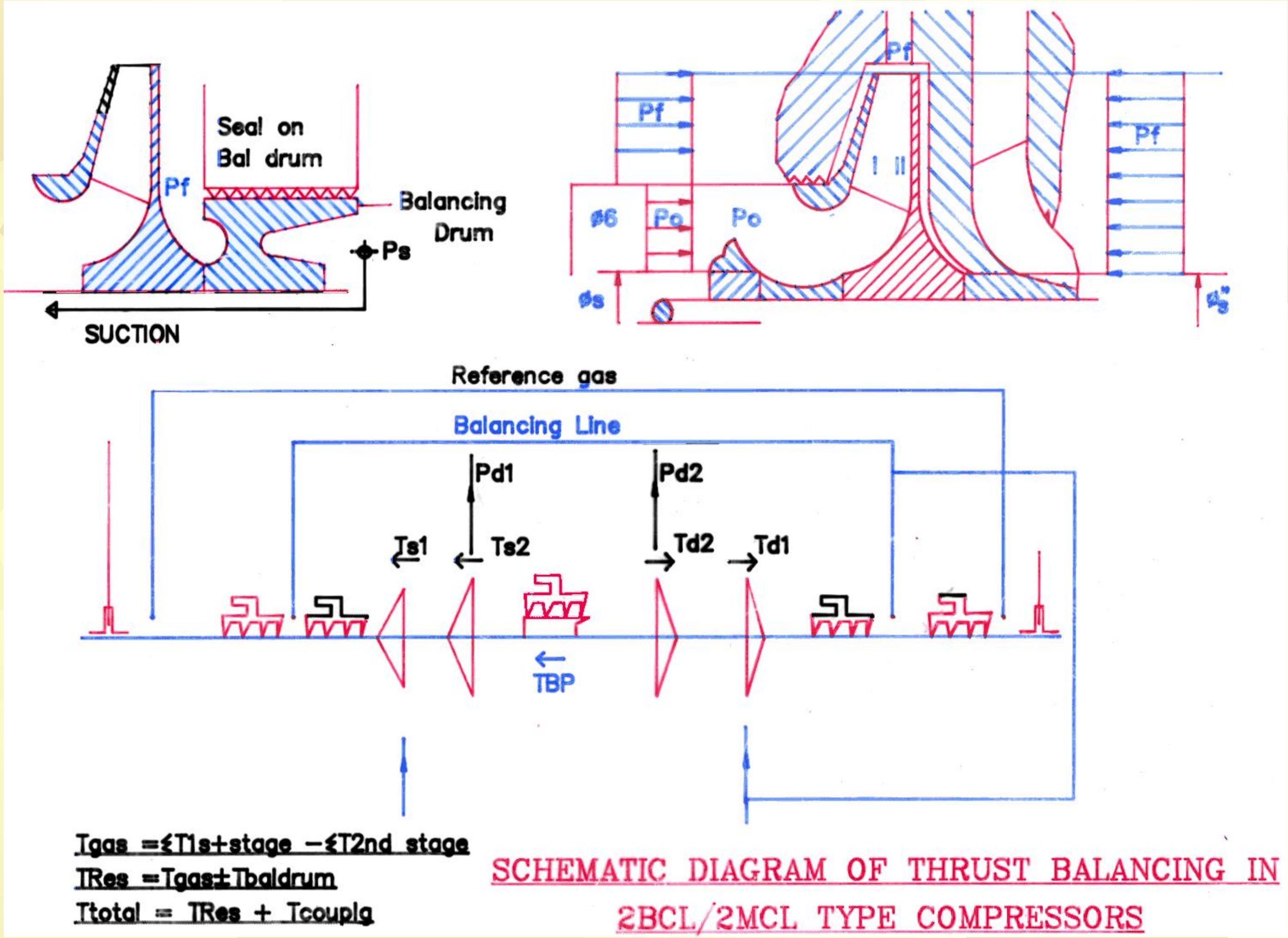
Selection of Compressor stages

- Number of phases
- Number, type and size of impellers in each phase
- Number of casings
- Speed
- Power consumption
- Operating range

Compressor Design Calculations

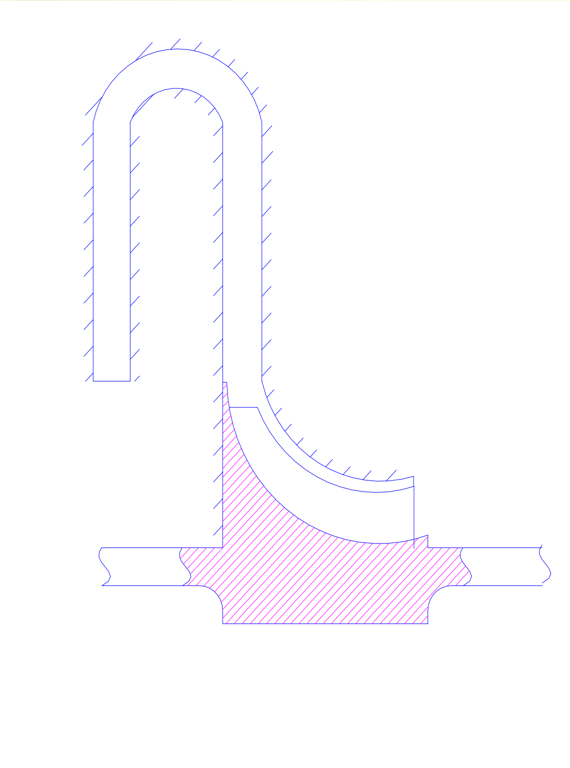
- Study of operating points
- Selection of standard stages
- Thermodynamic properties of gas mixture
- Graphical generation of performance curves
- Axial thrust
- Un-damped critical speed
- Stability and rotor response analysis
- Torsional critical speed analysis

Thrust balancing of back to back Compressors

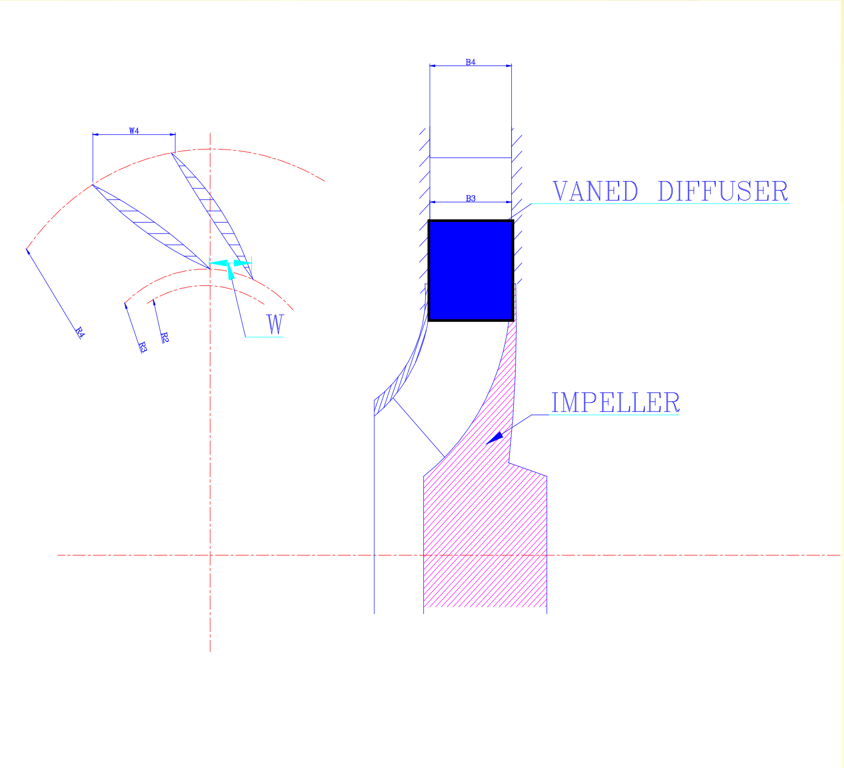


Diffuser

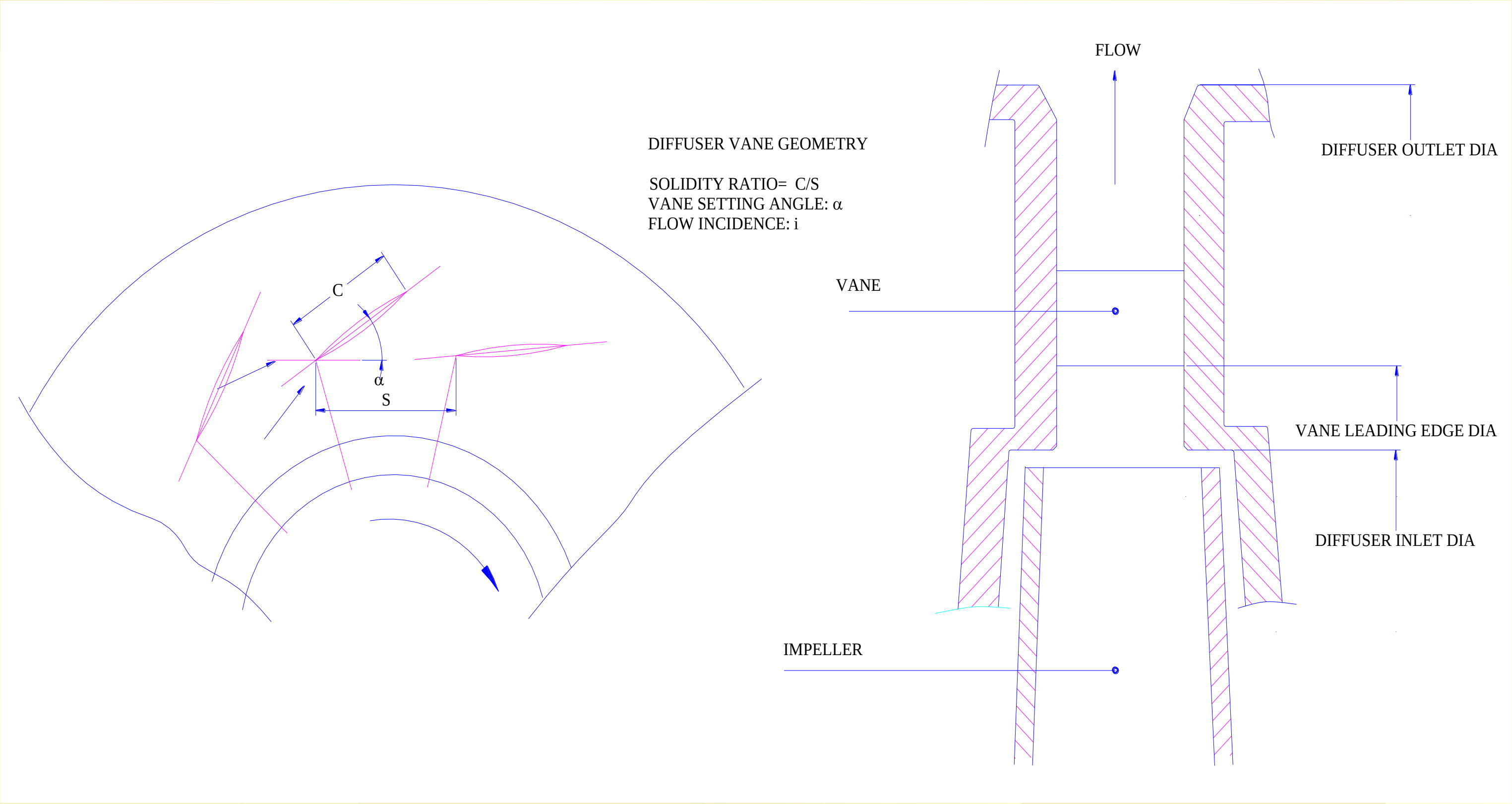
Vane Less



Full Vane



Low Solidity Vaned Diffuser



Rotor Dynamics

Rotor dynamics is the study of vibrations in the rotor system of turbo machinery, and allied phenomena.

a) Lateral

b) Torsional

Design should ensure acceptable rotor dynamic behaviour of machinery so as to ensure compatibility with API 617:

- Low shaft vibration levels.
- Safe speeding up and coast down.
- Optimum performance by preventing seal rubs etc.
- Preventing undue loading of rotor, couplings, piping etc.

Rotor Dynamics

Following calculations are performed:

- Rotor response to unbalance
- Stability analysis
- Torsional analysis

Rotor dynamic behaviour can be optimised by:

- Selection of couplings and bearings
- Deciding the rotor span & speed of operation

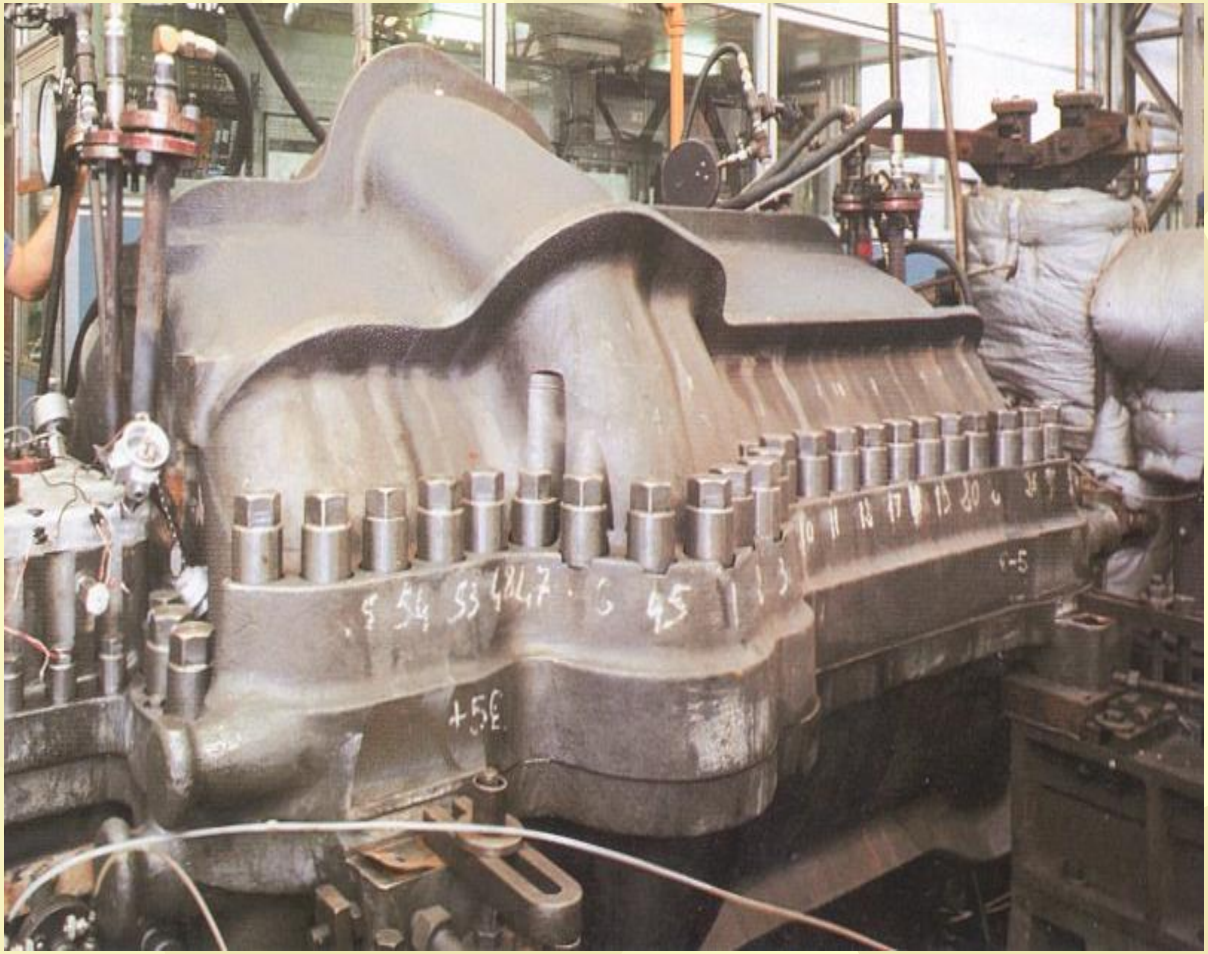
Constructional Aspects

of

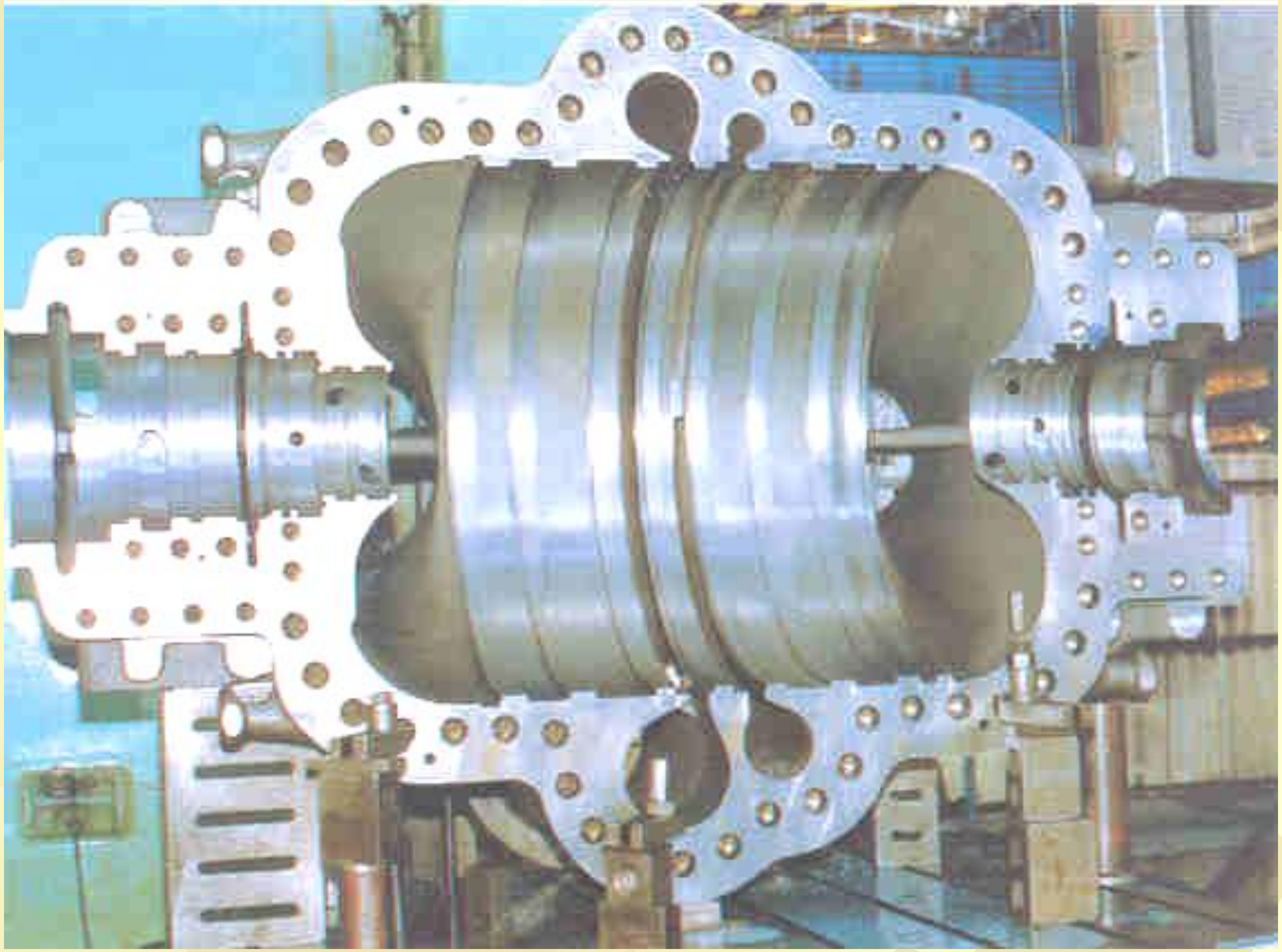
<u>Centrifugal</u>

<u>Compressors</u>

2MCL Compressor Assembly

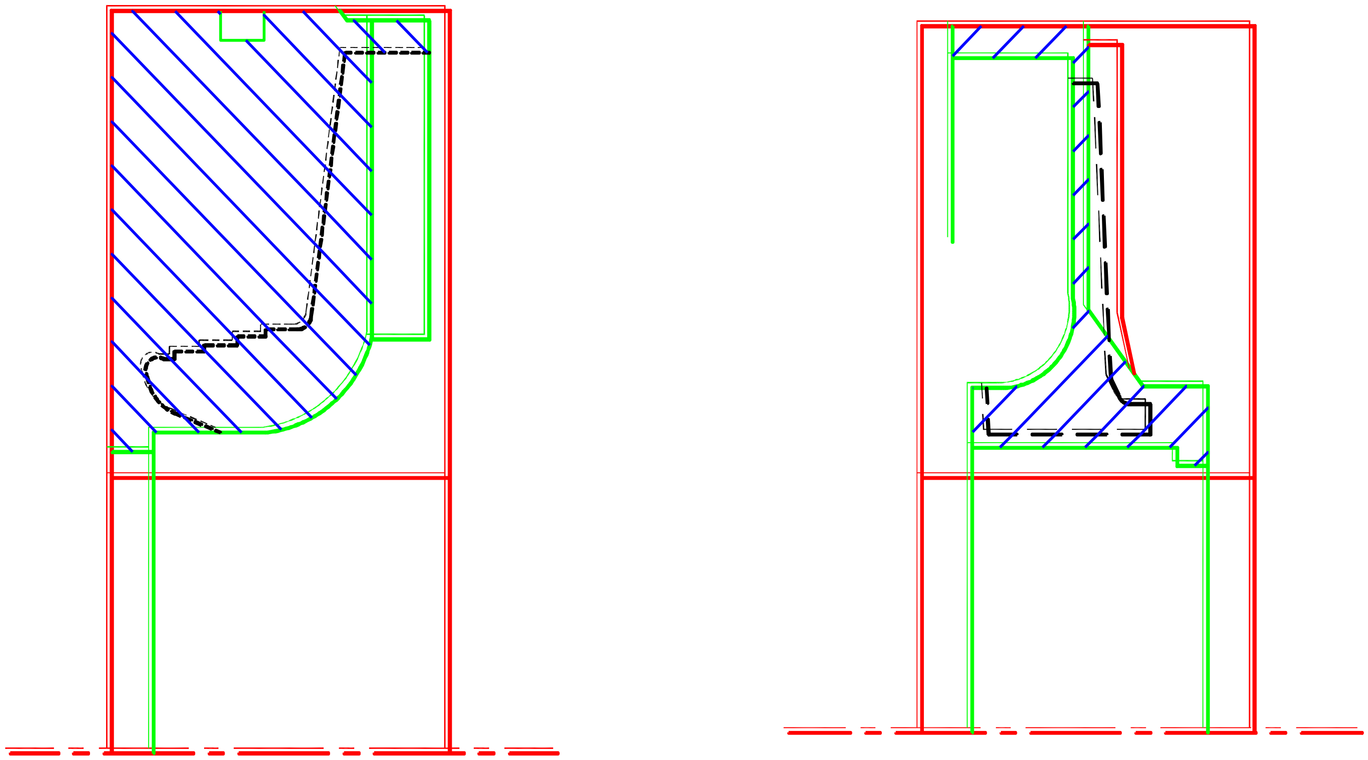


Parting plane view of MCL Casing



BCL Compressor Assembly

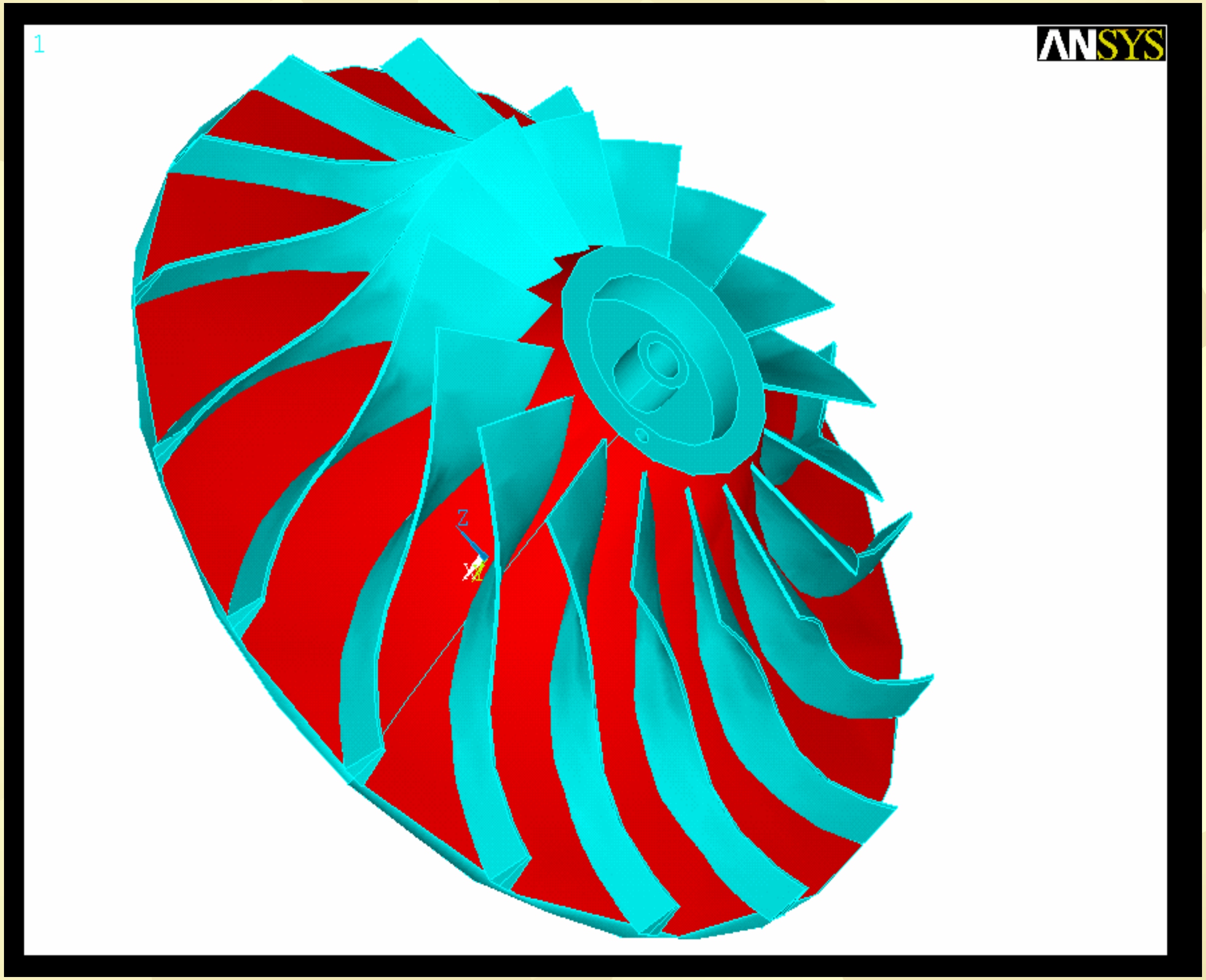
Externally Welded Impeller



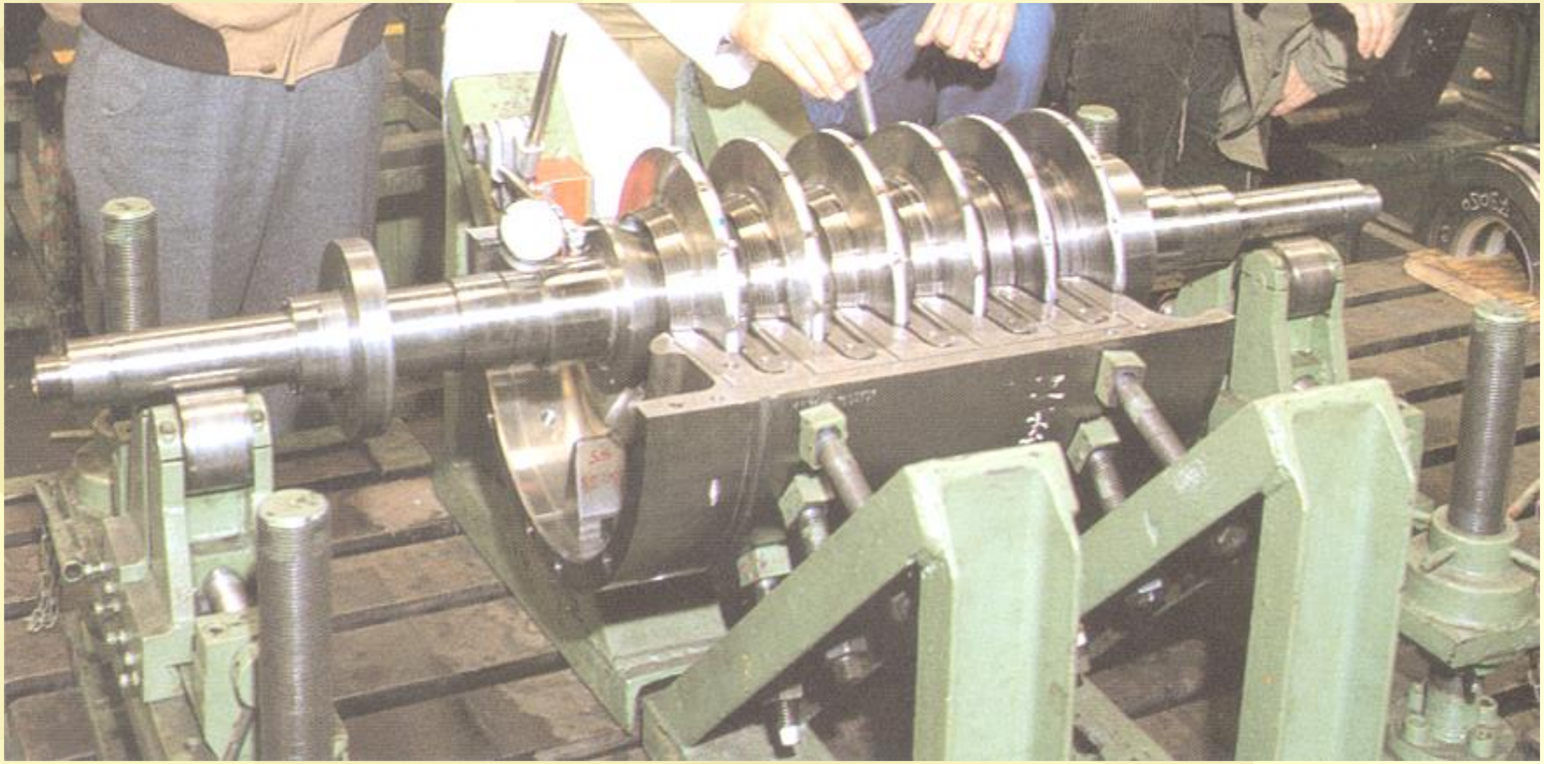
C.DISC MILLING

DISC MILLING

3D Impeller

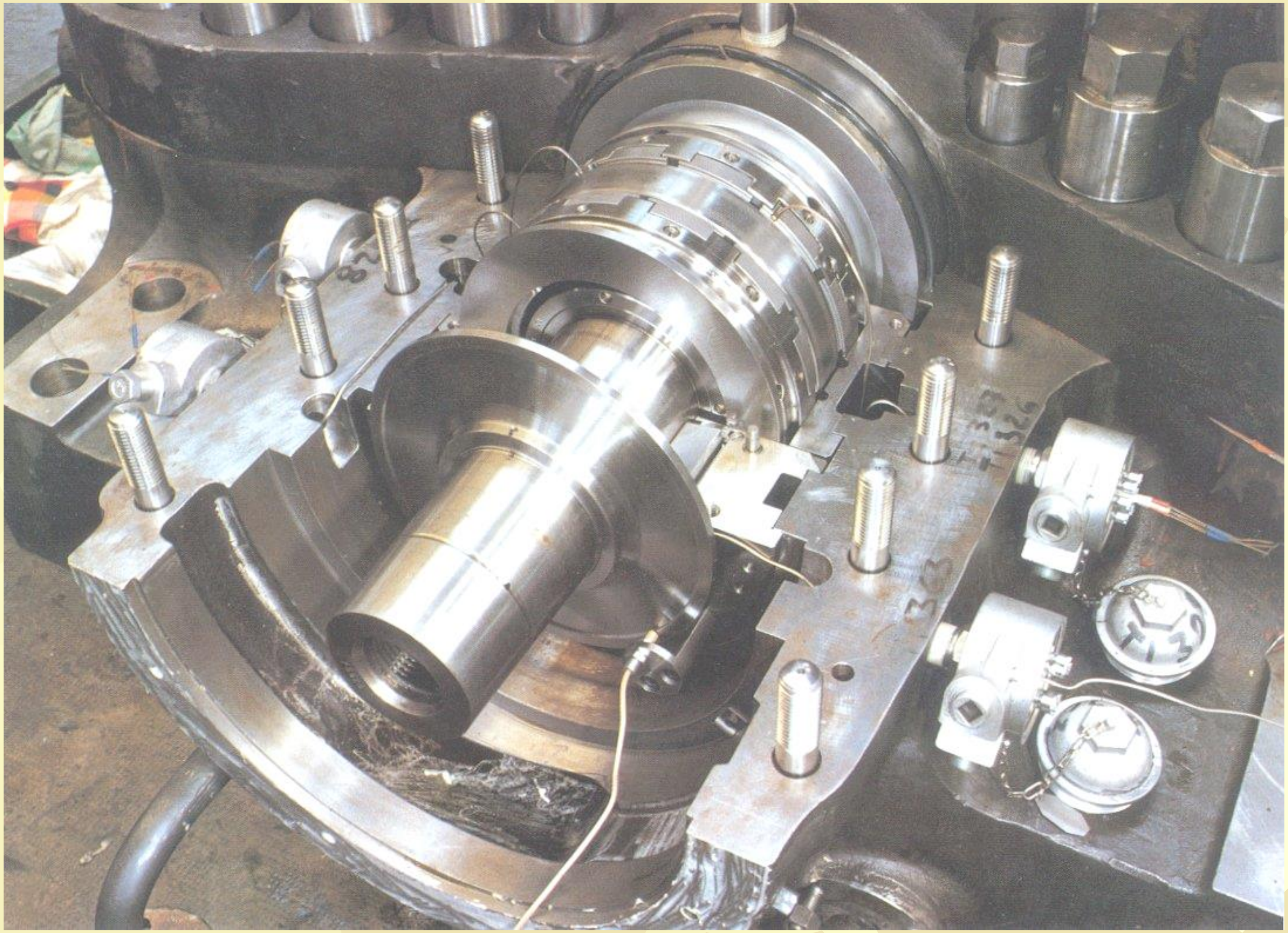


Rotor Assembly

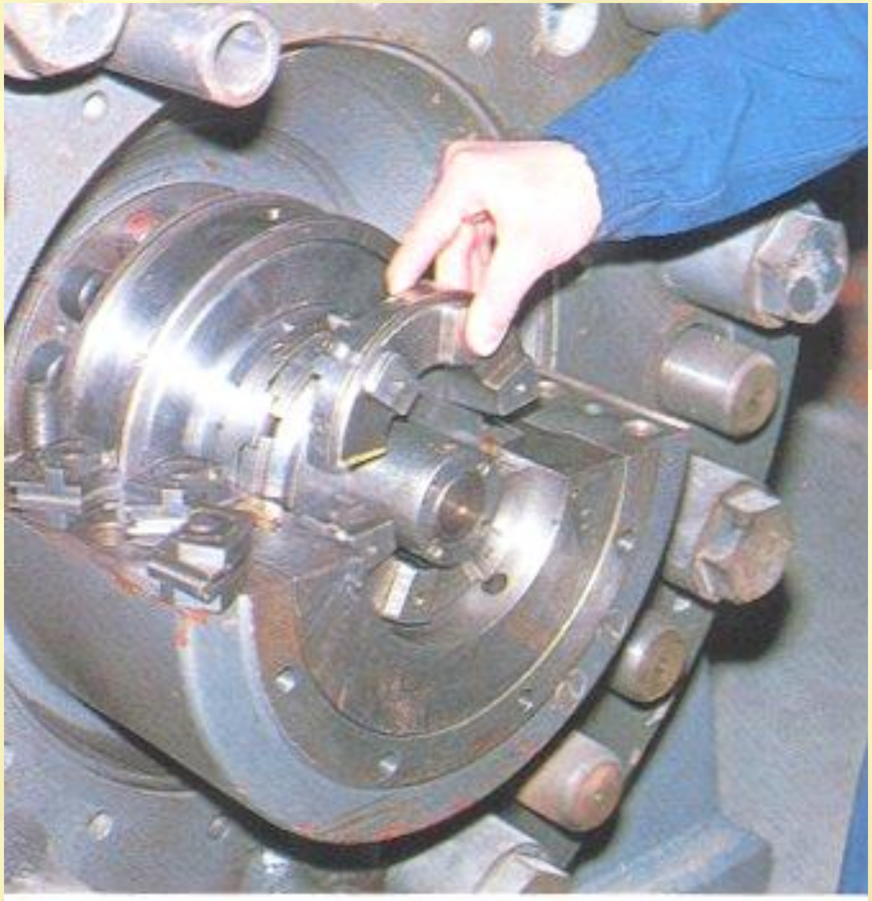


Assembly of Diaphragms in Counter Casing of BCL Compressor

Assembly of Journal Bearing



Assembly of Thrust Bearing



Shop Tests

Mandatory tests

- Dynamic balancing of impellers and over speeding at 115% of max. Cont. Speed.
- Stage by stage dynamic balancing of complete rotor.
- Mechanical run test from 0 - 110% of Max. Cont. Speed to check performance of bearings, mechanical performance and vibration.
- Gas leak test for compressors handling toxic/ explosive gasses.
- Performance of liquid film shaft seals (static/ dynamic).
- Hydrostatic testing of compressor casing.
- Performance checking of lube and seal oil system

Shop Tests

Optional tests

- Helium leak test for low MW gasses
- String test of compressor and its drive
- Performance test of compressor as per PTC-10
- Full pressure full-load test

Augmentation of Test Facilities

Additional test facilities installed

- ✓ Use of job lube oil system for complete unit test
- ✓ Augmentation of test bed for performance testing of large Syn gas and air compressors
- ✓ Installation of computerized data acquisition system
- ✓ On-line vibration monitoring and analysis with ADRE
- ✓ On-line gas analysis using gas chromatograph during performance test
- ✓ Use of dual drive involving double end drive steam turbine and shop electric motor

Auxiliaries & Subsystems

Compressors require the following sub-systems for their reliable, safe and efficient operation;

- Lube oil
- Anti-surge and performance control system
- Sealing (oil, DGS, ejector etc.) system
- Instrumentation and monitoring system
- Coolers and separators.

SURGE

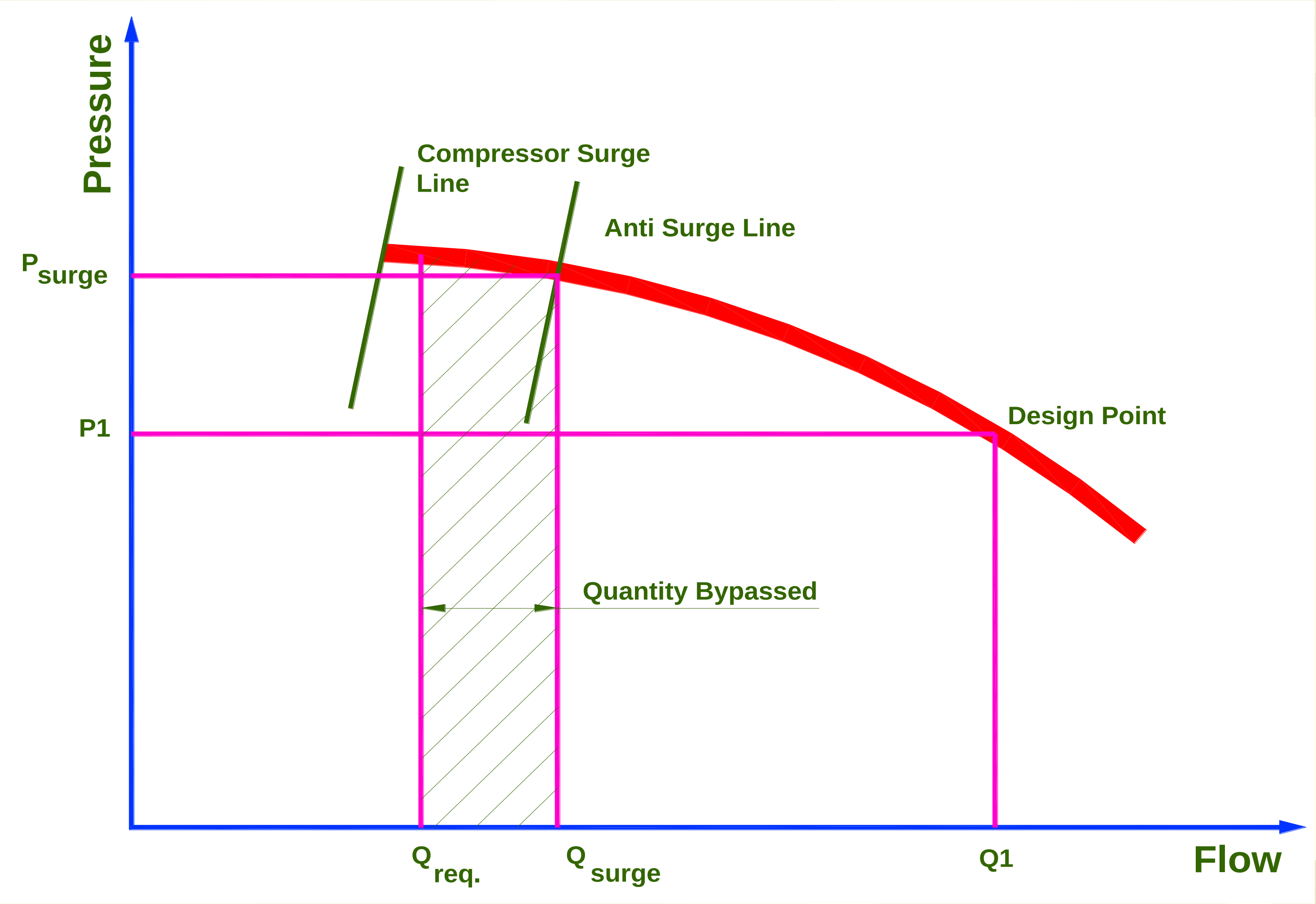
AND

CONTROLS

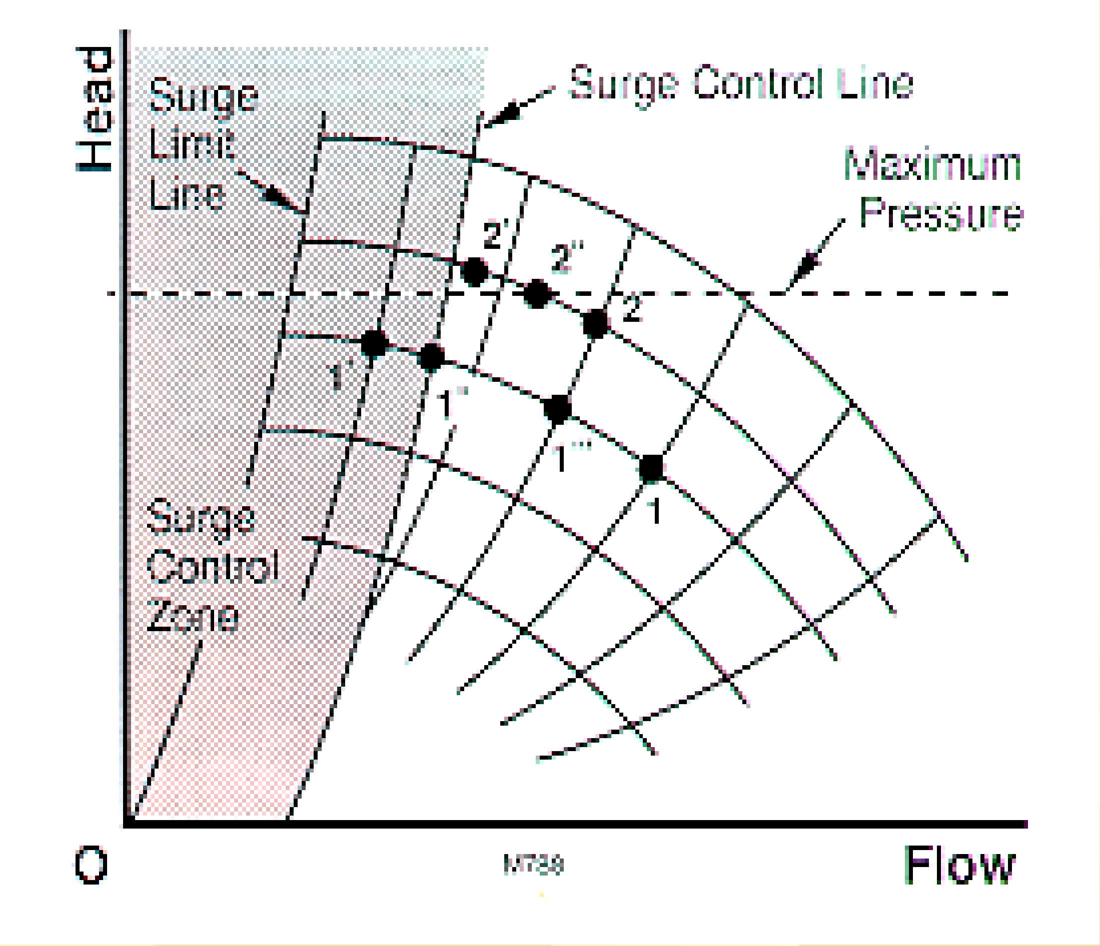
WHAT IS SURGING

Surge can be defined as the capacity below which the centrifugal compressor performance becomes unstable. The surging conditions occur when the inlet capacity approaches the surge capacity. At a given speed, as the inlet capacity is reduced, the discharge pressure of the machine goes on increasing. This happens because of the collapse of the pressure developing capability of the machine at surge point. The percentage flow at which the surge occurs in a centrifugal compressor depends upon the aerodynamic design, gas properties, stability of flow, system characteristics, stage components design etc.

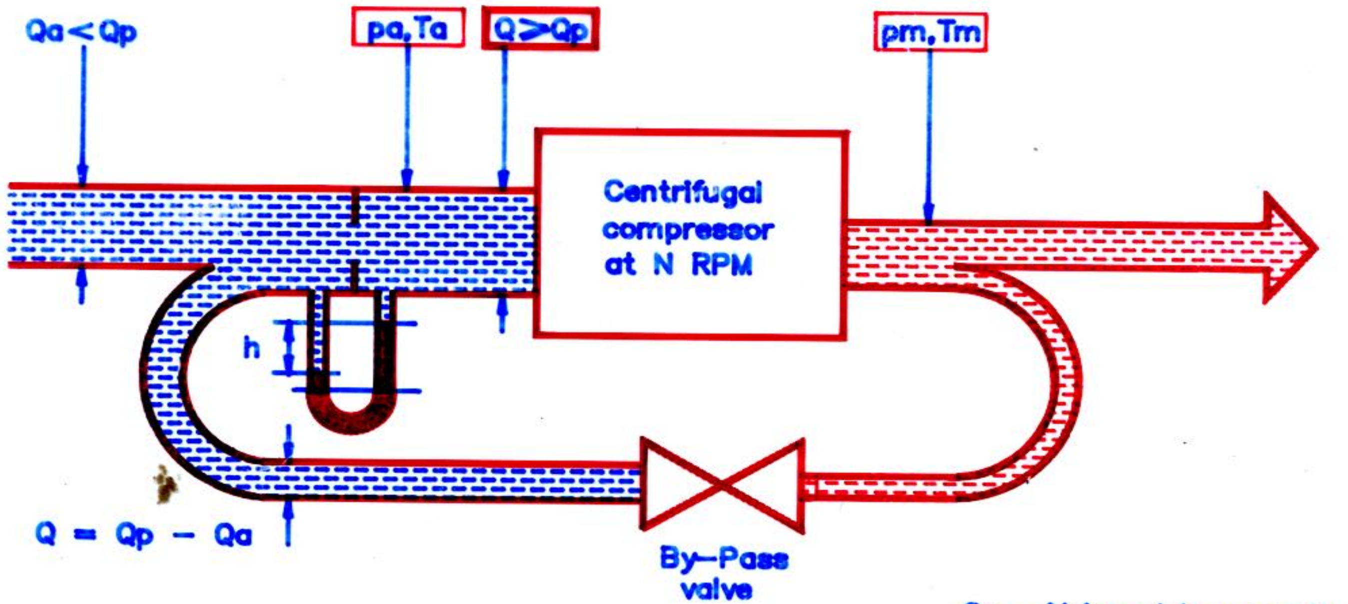
Compressor Performance Curve



Typical Compressor Performance Map And Surge Control



Typical Bypass Anti Surge System



Schematic diagram of using a by–pass valve to avoid surge

PROCESS OF SURGING

When surging occurs, the high-pressure gas at the discharge of the machine flows back through the compressor in a complete reversal of the normal direction of flow. Once the discharge pressure is dissipated sufficiently, the conditions causing the collapse of pressure no longer exist and the compressor resumes normal flow and discharge pressure. If the discharge conditions on the machine have not changed, the collapse of pressure producing ability will repeat and cycle through the same sequence.

PROTECTION FROM SURGING

The protection of compressor from surge is to provide an anti-surge control system. The basic idea in the antisurge control system is to provide the minimum flow through the compressor suction at all speeds which is higher than the surge limit either by re-circulating back the required quantity from the discharge of the machine after cooler or by venting. Generally the anti surge control is effected based on the flow differential at suction or discharge. But for certain applications, this is not an adequate function and hence the control is obtained by modulating the control with pressure, temperature flow and combination of those parameters.

Anti-surge controller

The use of sophisticated anti-surge control systems has the following advantages:

- Increase in safety and reliability
- Better operational flexibility and efficiency
- Provision for Load sharing & Parallel operation
- Performance and speed control
- Fast response
- Redundancy

PROTECTION FROM SURGING

On any control system, the system shall be also designed to prevent surging during starting and stopping. The trip out of the driver shall be interlocked to immediately open the antisurge valve and allow the machine to coast to a stop with antisurge line open. Otherwise the machine could be surging constantly while coasting down.

PRECAUTIONS TO BE TAKEN

One of the most potentially damaging occurrences for compressor is the ingestion of liquids with the process gas. The following precautions are to be taken.

PRECAUTIONS TO BE TAKEN

a) Trim cooling water or other process conditions to keep the compressor inlet conditions above the liquifation points for any gas constituent.

b) Heat trace or purge normally stagnant lines when liquids are collected due to stagnant gas cooling down to ambient temperatures. This is normally the case with the Urea synthesis machines. This avoids the problems of erosion of valve stems.

c) Recycle lines should re-enter main gas stream upstream or at inlet of knockout drums.

PRECAUTIONS TO BE TAKEN

d. If there is any possibility of liquid formation exists upstream or downstream of compressor, drains and level indications should be provided at all low spots of piping, vessels, etc. This allows routine checking for liquids and draining as required.

e. During a start-up after a shut down, ensure that all the liquids formed by cooling of the stagnant process gas are drained away. Heavy flow variations during surging can pick up large slugs of liquid and can damage the compressor.

f. Prevent sub-cooling of gases to temperatures below liquid line, after expansions across valve openings. Some liquids or even solids may be formed from this effect.

LUBE AND SEAL OIL SYSTEMS

Every centrifugal compressor has a lube oil system. But seal oil systems, however, are not always provided, depending on the type of gas such as air where simple labyrinth seals are used .

The other sealing systems includes injection of an external medium such as Nitrogen and / or extraction of compressed gas (e.g. CO2 compressors). Inert gas injection is provided to prevent leakage of process gas.

LUBE OIL SYSTEMS

Lube oil is used to create a rotor lift by forming a hydrodynamic film of oil between the shaft and bearing, and to cool the bearings.

Twin oil cooler is provided in the lube oil console to cool the return lube and seal oil in order to maintain a constant temperature, good viscosity. Oil viscosity is a very important parameter, which along with the geometrical characteristics of the bearings considerably influences rotor dynamic behaviour and consequently vibrations. A lubricant may have sufficient damping to allow operation at near critical speeds.

LUBE OIL SYSTEMS

Low viscosity due to high bearing temperatures would make operation unsafe, if the weight of the rotor is not supported by sufficient lift of oil film , the film could break and make the shaft and working surfaces come in to contact, thus increasing temperatures and the risk of the bearing damages.

LUBE OIL SYSTEMS

It should be stressed that the oil flow has to be sufficient to dispose of the heat generated by the bearings. Hence, there is need for the bearing temperature to be always kept under control, it is regulated by varying the inlet oil pressure with the pressure control valve (PCV). Also the drain oil temperature should be kept under control to ensure a proper exchange of heat between the bearings and oil.

Components of Lube Oil system

- Tank
- Pumps
- Coolers
- Filters
- Pressure Control Valve

Pressure Control Valve

After the filters, there is a self-actuated pressure control valve (PCV), which keeps the oil pressure to the bearings constant between 1.5 and 2.5 kg/cm2.

All the Oil inlet lines to the bearings are fitted with adjustable orifices and pressure gauges for regulating the pressure to the individual bearings.

The oil should be able to easily drain without foaming or evaporating, which would make lubrication difficult. It is therefore drained by gravity by providing adequate size drain chambers and oil return lines with a suitable slope and to the main oil tank.

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INSTRUMENTATION

OF

CONTROL

&

PROTECTION SYSTEMS

INSTRUMENTATION & CONTROL SYSTEM

For the safe operation of the plant as well as the machines themselves a sizable number of instruments and controls are necessary. The selection and sizing of these instruments and controls are in turn co-related with the driver and gas circuits

CONTROL SYSTEMS

The following methods are employed for maintaining the capacity, the suction or the discharge pressures constant under varying process conditions.

Variation of compressor speed - This method is employed when steam turbine or any other variable speed driver drives the compressor.

CONTROL SYSTEMS

Suction throttling - This method is frequently used and is achieved by providing a throttling valve in the suction piping. The minimum obtainable capacity is dictated by the surge limit of the compressor.

Adjustable inlet guide vanes - This vanes induces a pre-rotation of the gas by altering the direction of flow there by varying the compression ratio and capacity of the compressor. This feature is mostly available on axial flow compressors.

PROTECTIVE DEVICE

The protective devices of a turbine - compressor group consist of emergency stop devices, alarm devices and safety valves to prevent dangerous over pressures, in case of faulty operation.

The conditions causing the emergency stop are following:

a) Low lube oil pressure

b) Low level in seal oil header tanks

c) Over speed

PROTECTIVE ALARMS

The following are the events causing the alarms:

- Low lube oil pressure
- High lube oil temperature
- Low lube oil level in the reservoir
- High and low level in the reservoir
- High seal oil level in the drain tanks of the last two compressor casings.
- High bearing temperature.
- High axial thrust.

Necessary safety valves are provided at the gas suction and delivery as well as at each interstage cooler. All the safety valves are sized for the design capacity of the compressor, except the one on the by pass line from the delivery of the last casing. This valve is sized for other maximum capacity that can flow back through this line assuming the anti-surge valve to be completely open and with up-stream pressure fixed at normal value.

Sealing Systems

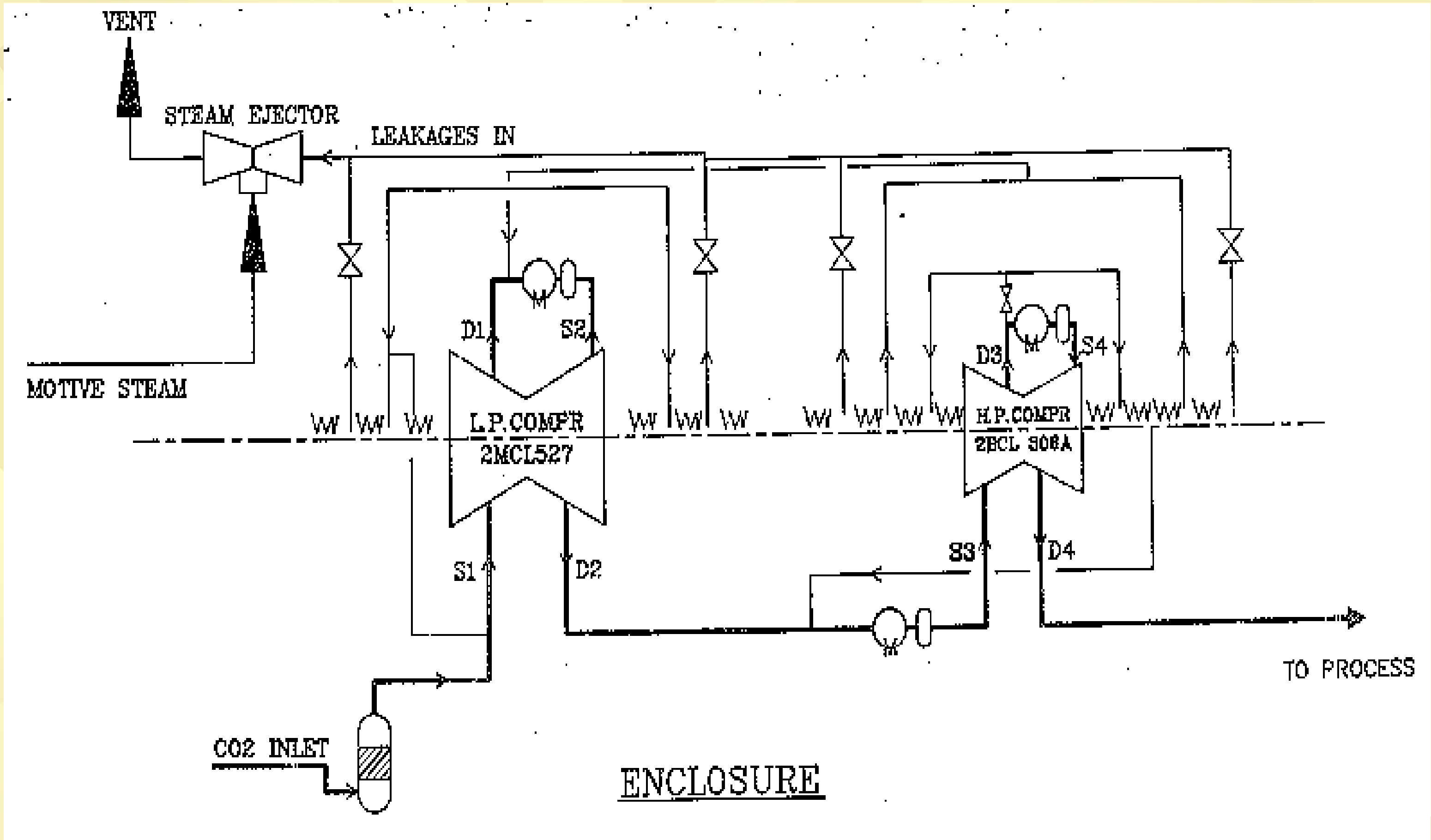
Used in

Compressors

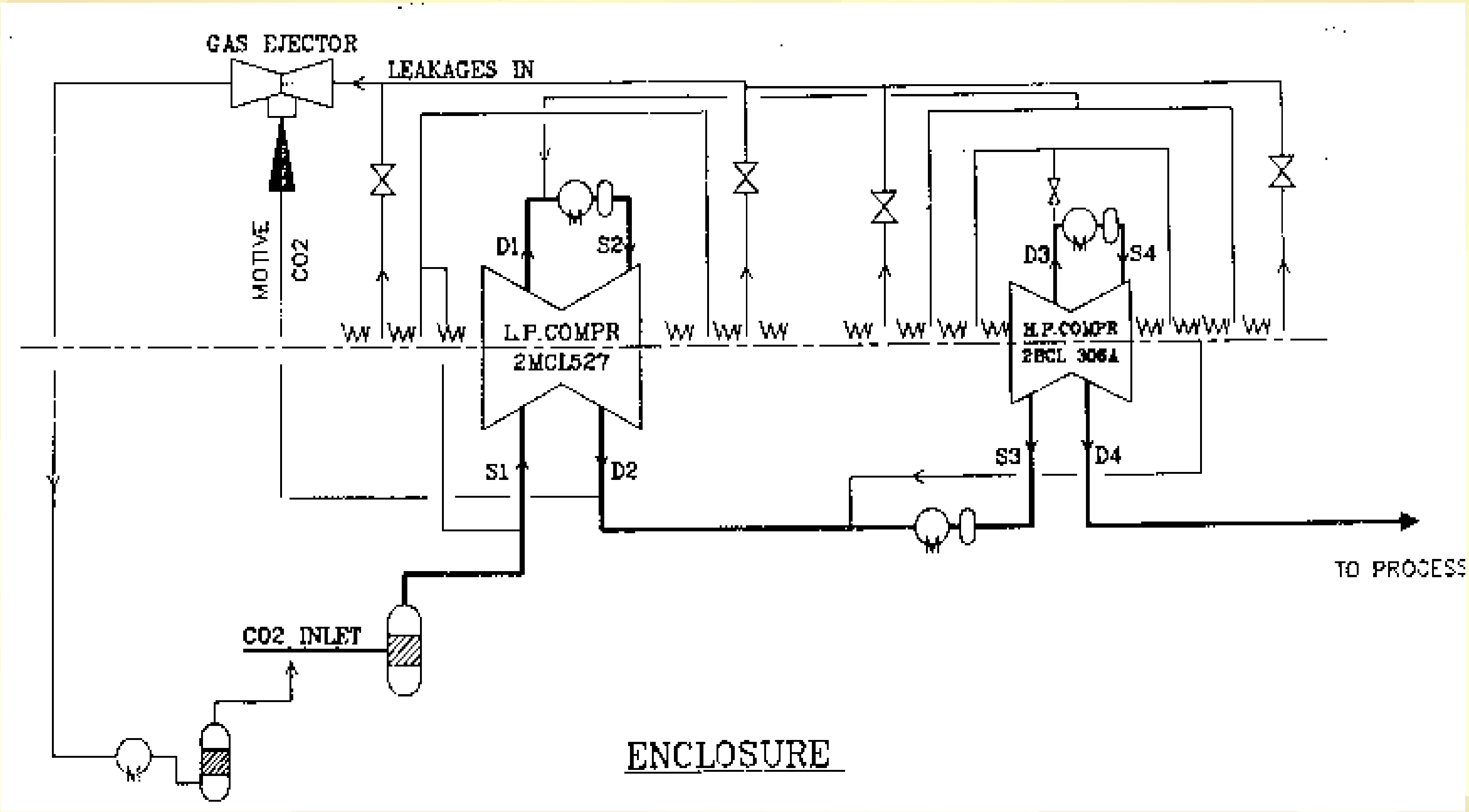
Types of Compressor End Sealing Systems

- Labyrinth Sealing
- Floating Oil Seals
- Oil Mechanical Seals
- Air Injection Sealing System
- Injection / Extraction Sealing
- Dry Gas Seals

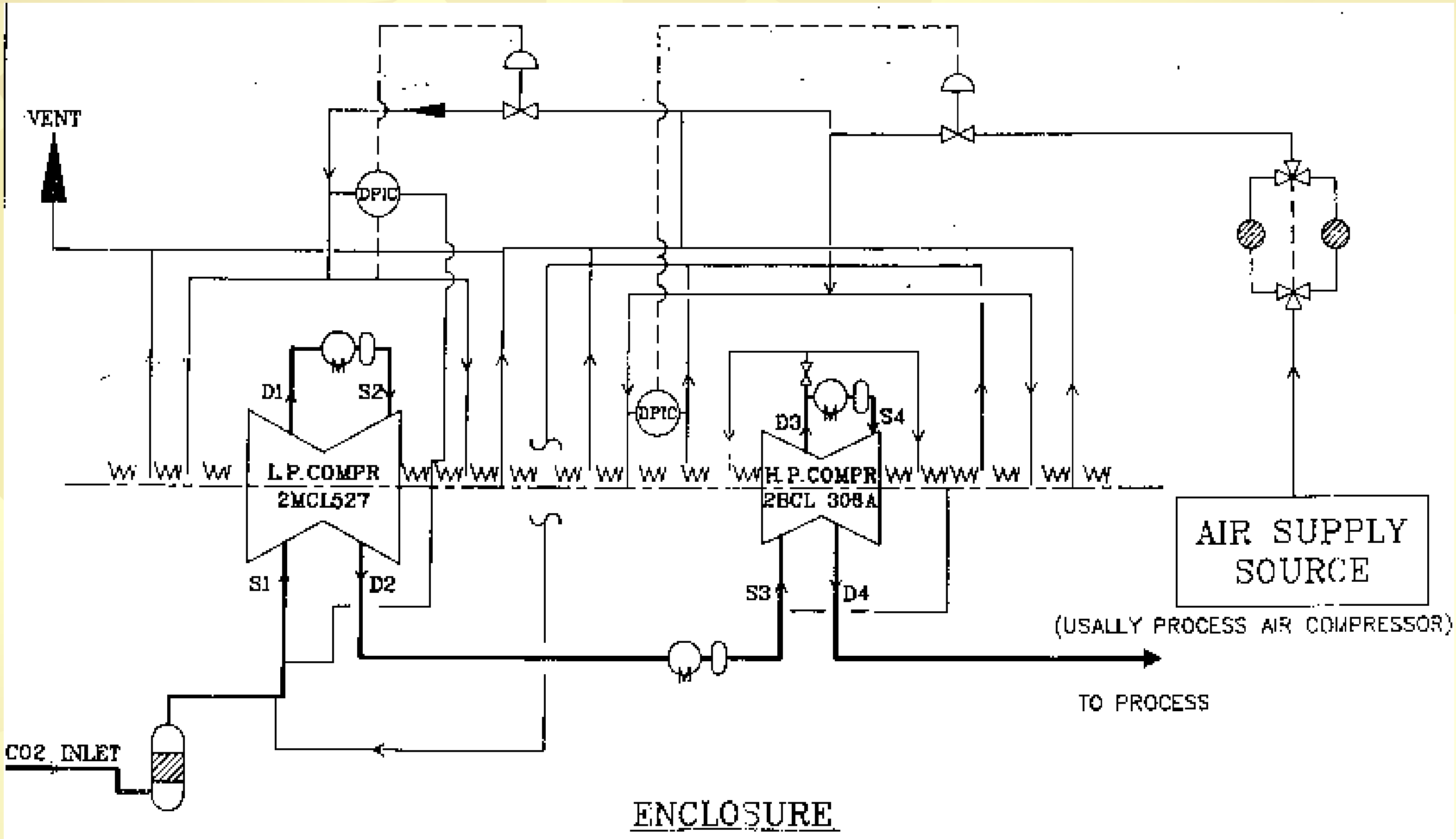
Labyrinth Sealing With Steam Ejector



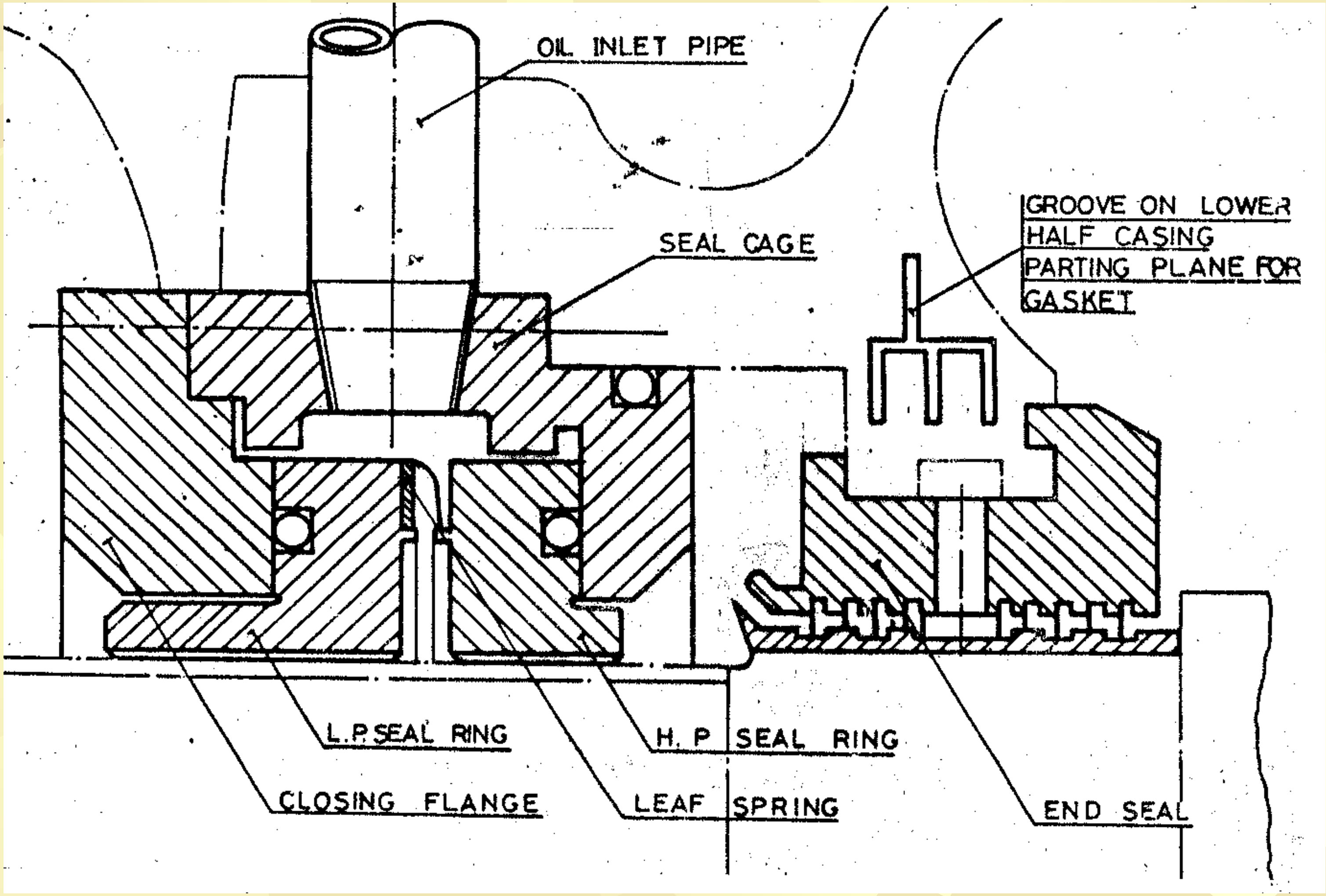
Labyrinth Sealing With Gas Ejector Recovery System



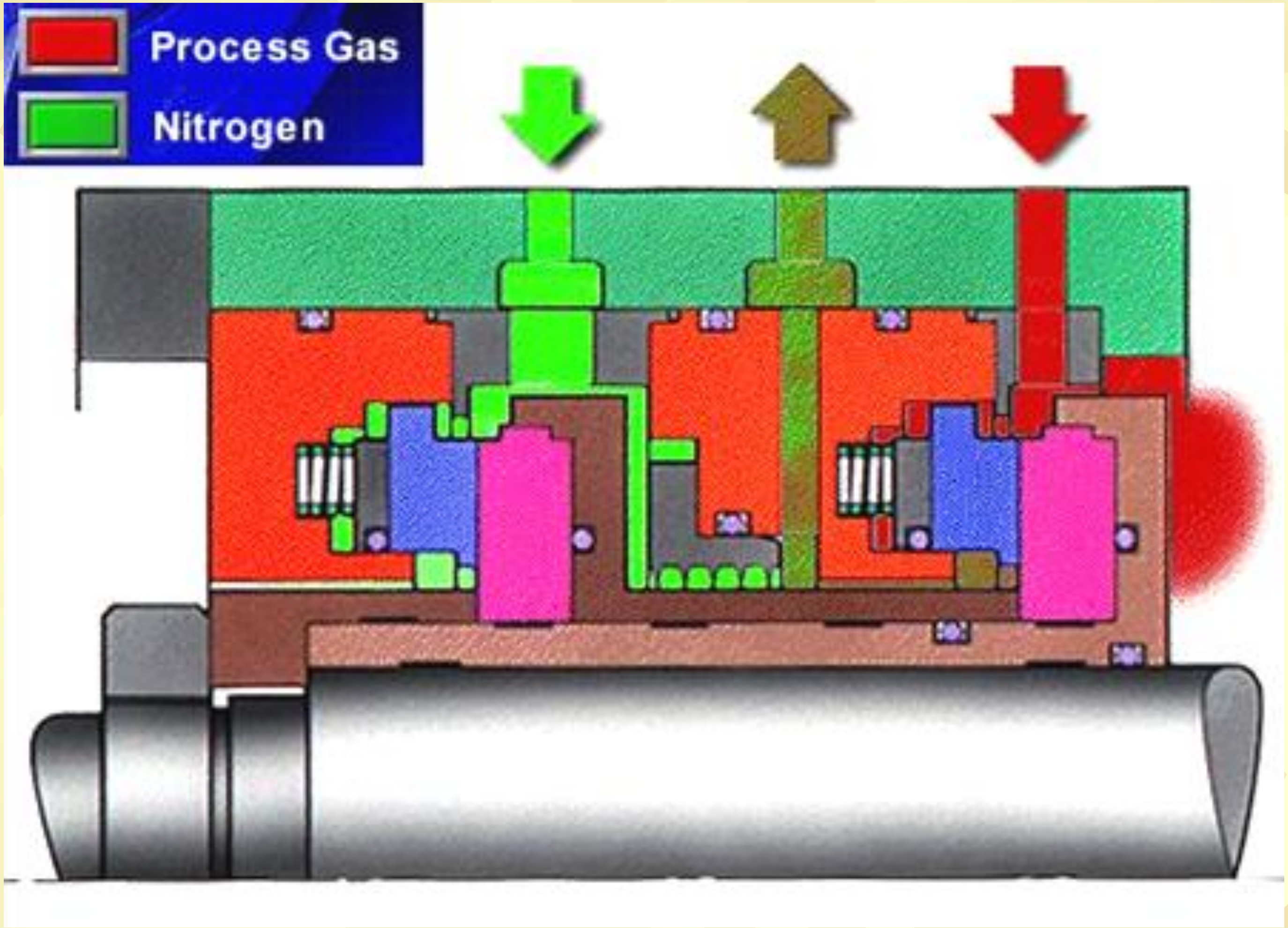
Labyrinth Sealing With Air Injection



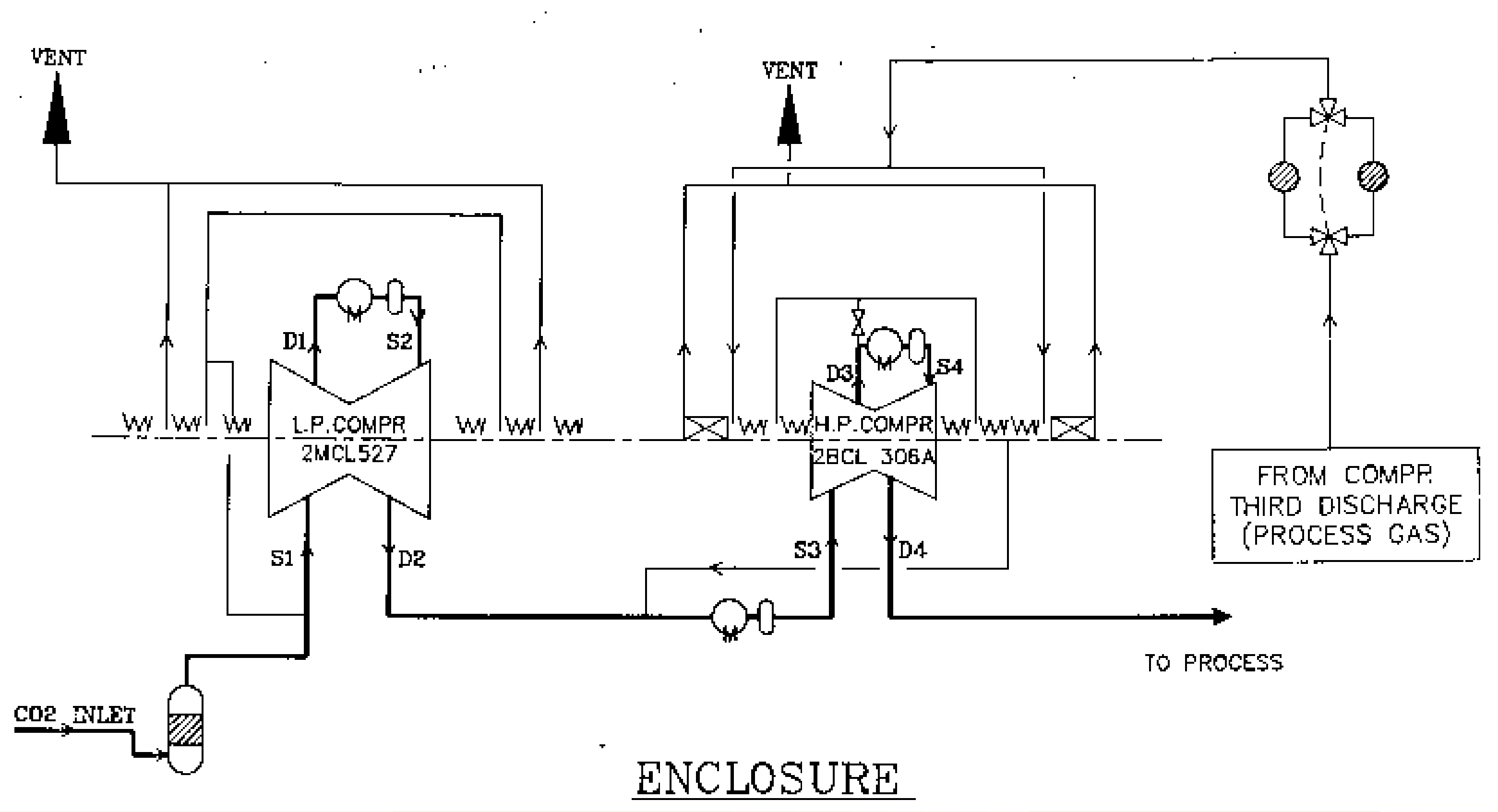
FLOATING OIL SEALS



Cross-section of Typical Dry Gas Seal



Gas Mechanical Sealing System

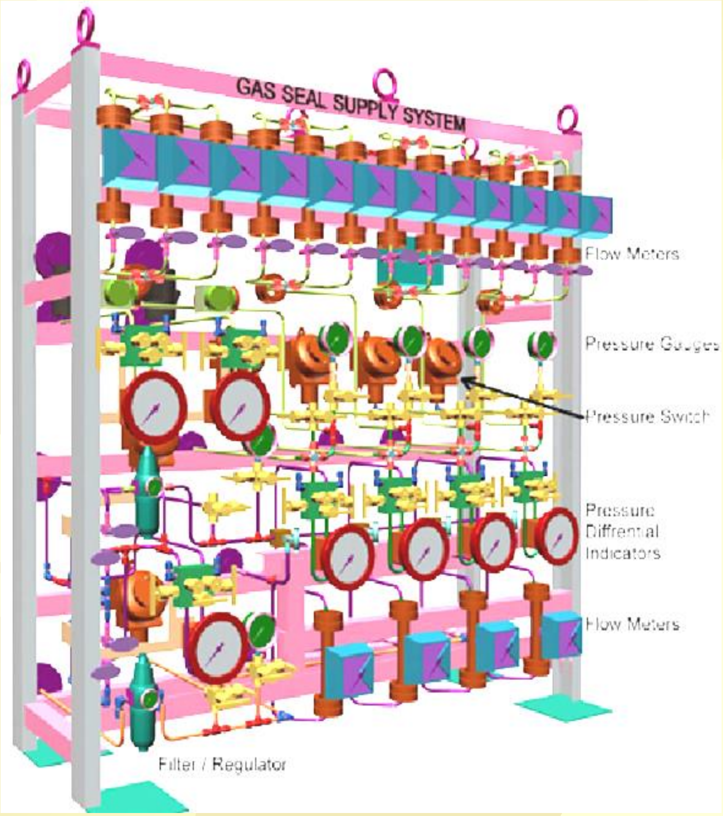


Advantages of Dry Gas Seal

- Atmospheric leakages are very low
- Oil free operation hence no oil contamination to process gas
- Minimum auxiliary equipment
- Reduction in power loss
- Extremely compact and trouble free

Seal Gas Skid System for Dry Gas Seals

- Supply Clean gas
- Monitor Seal Leakage
- Supply Buffer Gas
- Initiate alarms & shutdowns when necessary



Dry Flexible Coupling

Advantages of Dry Flexible Coupling

- High misalignment handling capability
- No oil required for lubrication
- Improved rotor dynamics
- Safer and more reliable operation

Pii Learning

PII

Operational & Maintenance

Aspects of

Centrifugal Compressor

Compressor – Check Lists for startup

Important aspects of Compressor needing attention:

- Healthiness of m/c in respects of alignment (machine to machine & machine to gas piping), bearings and coupling assembly.
- Status of clearances of :
  - Journal Bearing
  - Oil Seals
  - Lab Seals
  - Balance Drum Seal

- Proper functioning of LO/SO/seal gas systems.
- Suction conditions of Gas handled, pressure, temperature, molecular weight, flow etc.
- Proper functioning of instrumentation and controls.

Compressor – Operational Problems

Factors influencing normal operation:

CAUSE	**EFFECT**
a) Unbalance, misalignment, looseness b) Higher bearing clearances c) Operating close to critical speeds d) Scoring on journals/Th. collar e) Worn out couplings f) Surging of machines g) Improper lubrication h) External piping forces I) Flow induced excitations	Vibrations

Shaft Vibrations

Component of Vibration	Likely Causes
Synchronous (1x)	Unbalance, bent shaft, Misalignment
Sub-Synchronous (<1x)	Oil whirl, bearing damage, piping forces
Super-Synchronous (nx)	Rubs, loose parts, gear teeth error

Compressor – Operational Problems

Factors influencing normal operation:

CAUSE	EFFECT
II a) Increase in seal clearances/ damaged 'O' rings b) Blockage at suction strainer c) Blockage of impeller/diaphragm passages. d) Varied suction operating conditions e) Malfunctioning of valves (suction /discharge/ASV)	Reduction of throughput/ surging

Compressor – Operational Problems

Factors influencing normal operation:

CAUSE	**EFFECT**
III a) Low bearing oil pressures b) High oil inlet temperatures c) Unclean oil d) Wear out of pads e) Scoring of journal / misalignment f) Bypassing of oil flow to drain	High bearing temperatures

Compressor – Operational Problems

Factors influencing normal operation:

CAUSE		**EFFECT**
IV a)	Change in operating parameters	High axial thrust
b)	Incorrect lubrication/ Worn out gear coupling and seal clearance in balance drum/seal Axial displacement	
c)	Blockage in thrust balance gas line	
d)	Worn out thrust pads	

Compressor – Operational Problems

Factors influencing normal operation:

CAUSE		**EFFECT**
V a)	Low differential pressure between seal oil & reference gas lines	oil carry over / gas leakage
b)	Damaged seals/springs/ 'o' rings	
c)	Seal oil contamination	
d)	Increased seal clearances	
e)	Orifice (vent line) diameter very small	
f)	Seal oil traps not working	
g)	LCV/DPCV not working	

Off Design Operation of Compressors

Effect on performance with the variation in the following parameters;

- Molecular Weight
- Inlet temperature
- Inlet pressure
- Increase in internal leakage
- Fouling of internals

Control & Instrumentation systems

- Turbo supervisory system
- Compressor Capacity control
- PLC's
- Improved Anti Surge Controllers
- Dry gas seal control system

Integrated control philosophy

A totally integrated control system can be offered for Performance control, load sharing and parallel operation and surge control of compressors

Case Studies

<u>Compressor – Case Studies</u>

Problem	Site	Cause / Solution
Thrust bearing failure	CFCL, Kota	Thrust balancing pipe was too small which resulted in reduced ΔP across the balancing drum. <u>Pipe size increased</u>
Seal rings damage due to drop in ΔP across seal oil & Ref. Gas	IOC, Baroda	Oil was contaminated with VGO & block the inlet seal oil pipes & ports resulting in reduced Δ P. <u>Oil change, system clean up prevention of entry of VGO into the compressor has resolved the Δ P problem</u>.

Compressor – Case Studies

Problem	Site	Cause / Solution
High vibrations at 4th Discharge pipe.	CO_2 Compr. at TCL, CFCL, NFCL	High pipe line vibrations are flow induced. Rotating stall caused by high gas density high discharge pressure. Resolved by modified diffuser passage in 4th phase.
Frequent tripping of Coker gas compressor during start up	BRPL	Motor was tripping due to high amperage due to higher mass flow handled by m/c because of high suction pressure. Suction butterfly valve replaced with control valve to drop suction pressure

Compressor – Case Studies

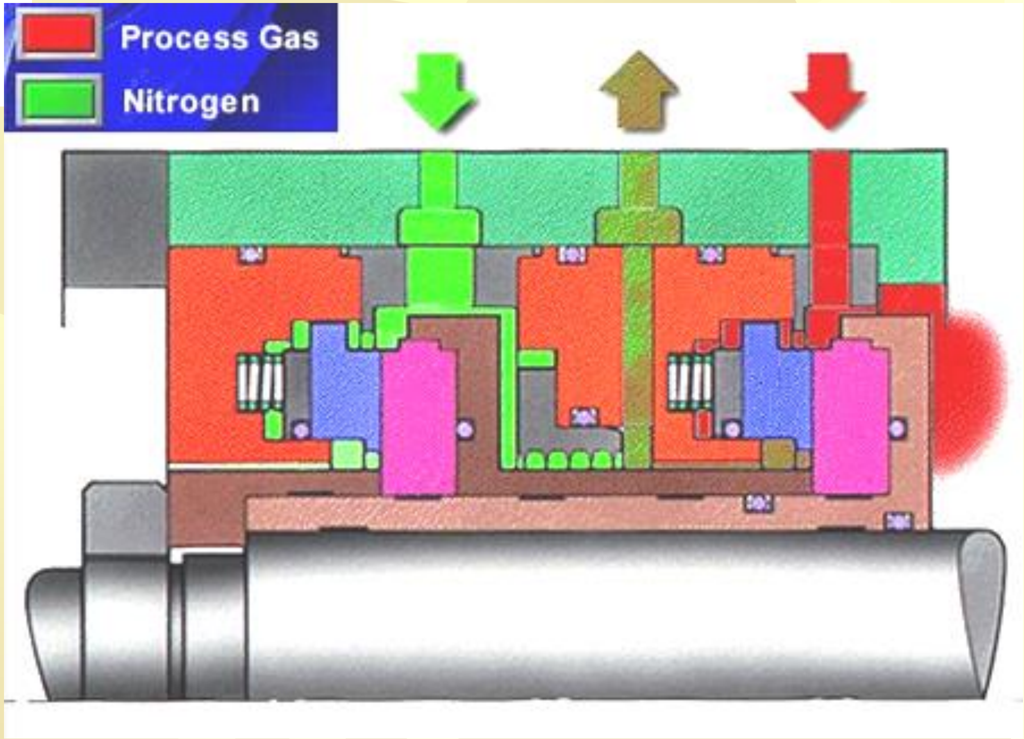
Problem	Site	Cause / Solution
Drop in capacity of wet gas Compressor	MRL, Madras	Due to blockage of suction strainer, impeller and diaphragm passages with black dust, the machine capacity and discharge pressures dropped. Machine was cleaned, overhauled to restore its normal capacity.

Compressor – Case Studies

Problem	Site	Cause / Solution
Surging of Compressor during tripping on load	GNFC, Bharuch	The Compressor was run with higher load and reduced pressure drops between 2nd & 3rd stages. This caused severe mismatch and resulted in surging of LP Barrel during trip. <u>Modified vent valve opening & recommend to install additional vent to resolve the surging problem.</u>

Compressor – Case Studies

Problem	Site	Cause / Solution
Improper functioning of dry gas seals	NFCL, Kakinada CFCL, Kota	Seals were frequently getting damaged during initial commissioning period. The failure was analysed to be due to entry of liquid/dirt/ corrosion into the seal. Clean gas injection line is connected by throttling from 3rd discharge instead of from 4th discharge. This prevented liquid entry into seal.


Process Gas
Nitrogen

Compressor – Case Studies

Problem	Site	Cause / Solution
Anti surge controller becoming ineffective	TCL,NFCL	Due to change in suction temperature the machine operates away from normal operating point. The surge point also shifts making the anti surge controller ineffective. Improvement in suction temperature has restored normal operation.

Compressor – Case Studies

Problem	Cause / Solution
Abnormal Behaviour of Machine can be due to Not following of recommended start up procedure Abnormal variation of suction parameters Exceeding design capacities Running with damaged bearings, seals, couplings Bypassing of alarms and trip	By not maintaining the design parameters and increasing Compressor flow rates can cause severe mismatches for a multistage, multiphase centrifugal compressor. This can cause choking/surging of subsequent stages. <u>Maintain compressor operating parameters and recommended procedures.</u>