

# Steam Turbine



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- **Module –III : Steam Turbine Topics:**
- Functioning of steam turbines and their constructional features
- Governing and control, HP-LP bypass valve
- Gland sealing, control oil, seal oil, lubricating oil systems

# CONTENTS

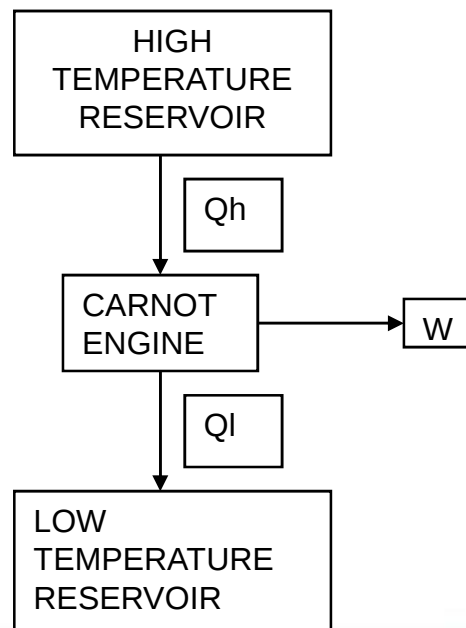
- PRINCIPLE OF OPERATION OF STEAM TURBINES
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# STEAM TURBINE

A **steam turbine** is a mechanical device that extracts thermal energy from pressurized steam, and converts it into rotary motion. Its modern manifestation was invented by **Sir Charles Parsons** in 1884.

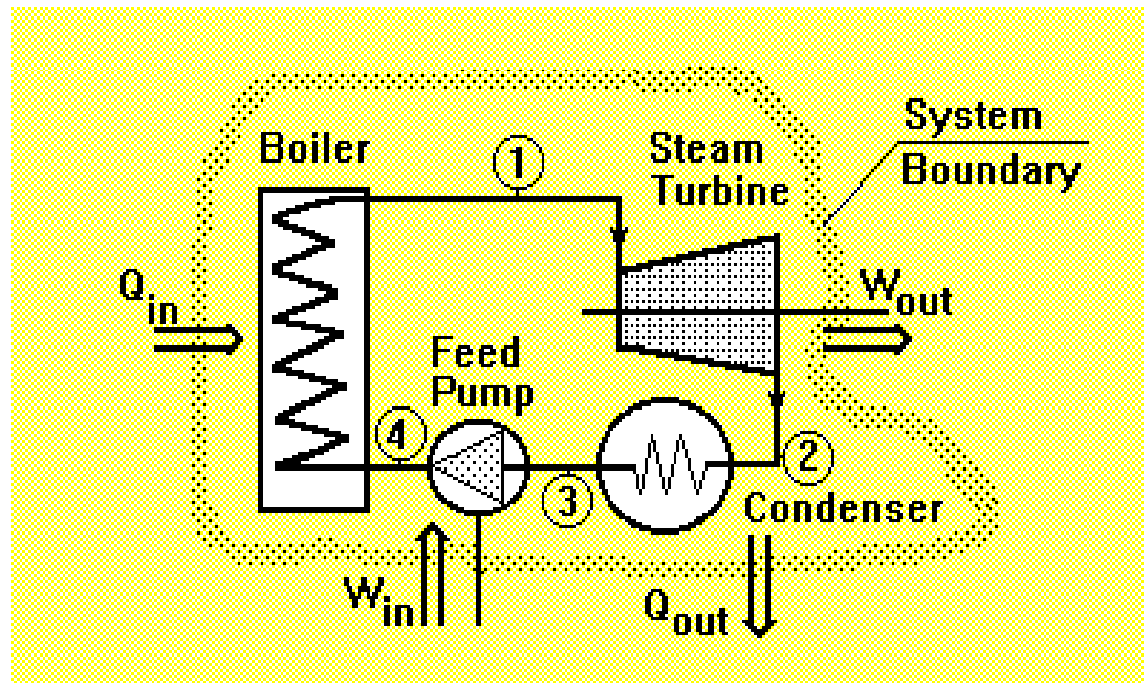
# VAPOUR POWER CYCLE

- To convert heat into work, two thermal reservoirs are required, one high temperature and another low temperature.
- As the thermal reservoir is a very large system in stable equilibrium, the temperature of both the reservoirs remain constant.
- Nicolas Leonard Carnot was the first to introduce the concept of reversible cycle where heat can be converted to work



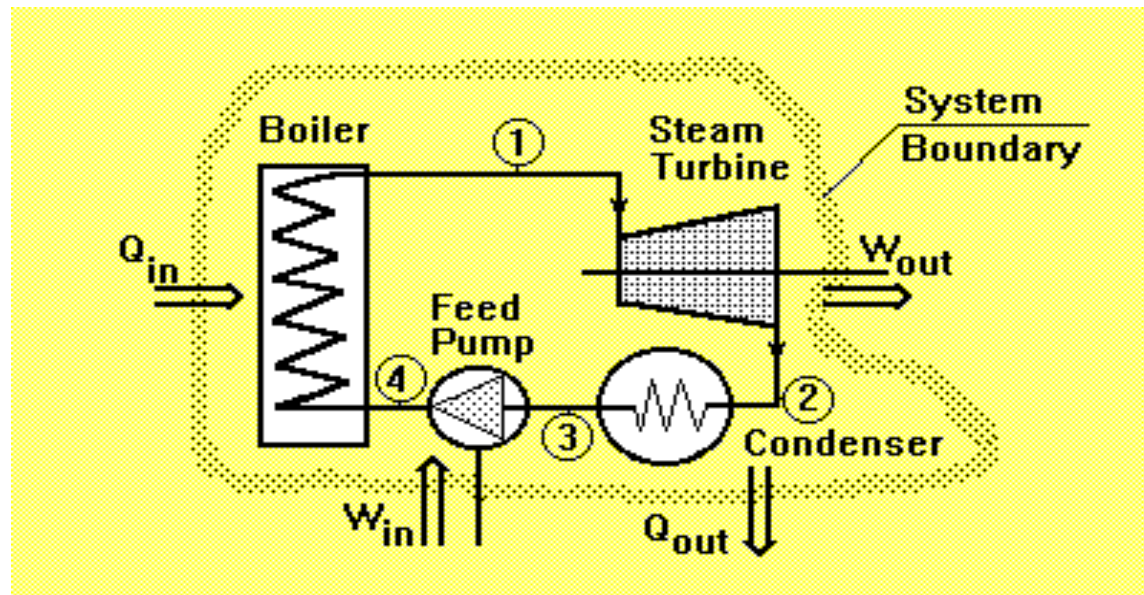
# Rankine Cycle

- Rankine cycle is the practical vapor power cycle. The common working fluid is water.

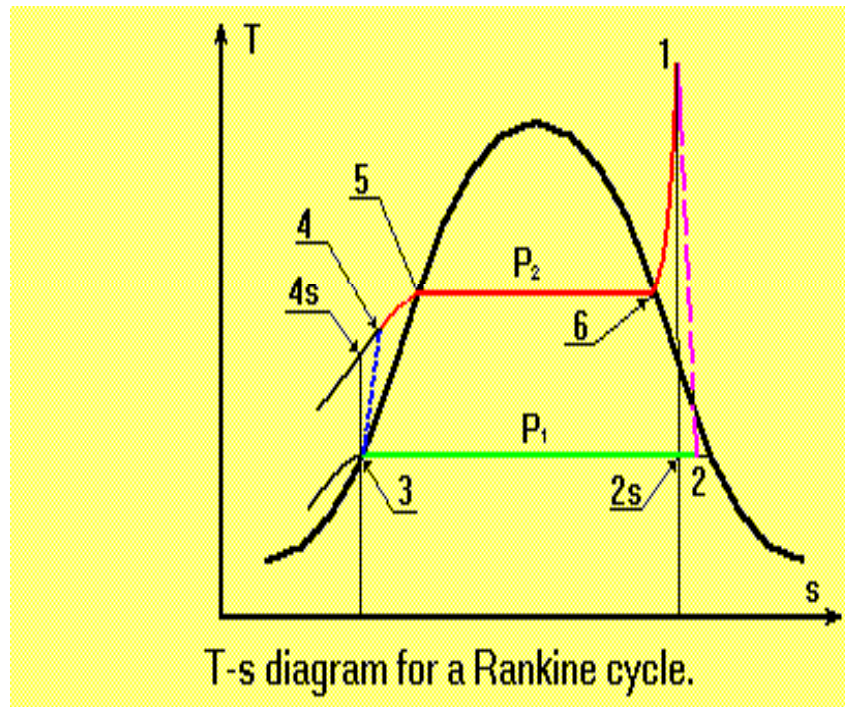


# Rankine Cycle

- The cycle consists of four processes:
  - 1 to 2: Isentropic expansion (Steam turbine)
  - 2 to 3: Isobaric heat rejection (Condenser)
  - 3 to 4: Isentropic compression (Pump)
  - 4 to 1: Isobaric heat supply (Boiler)



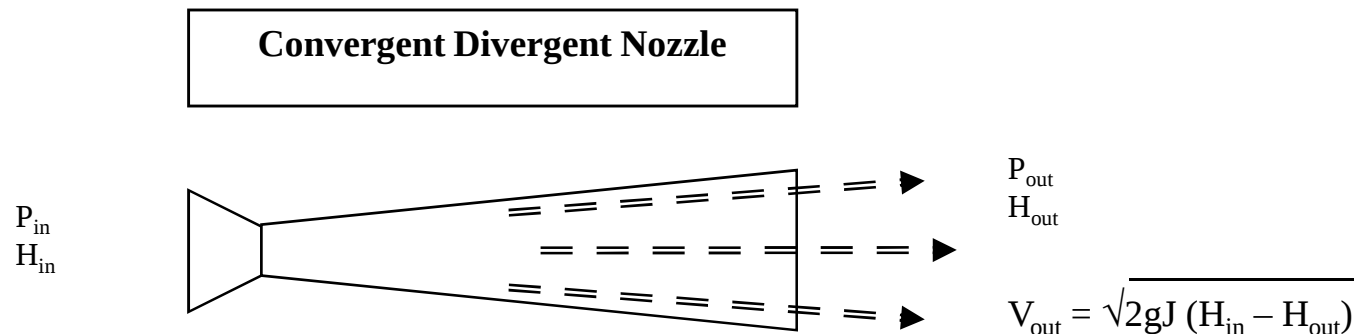
# Rankine Cycle



- Work output of the cycle (Steam turbine),  $W_1 = m (h_1 - h_2)$  and
- Work input to the cycle (Pump),  $W_2 = m (h_4 - h_3)$
- Heat supplied to the cycle (boiler),  $Q_1 = m (h_1 - h_4)$  and
- Heat rejected from the cycle (condenser),  $Q_2 = m (h_2 - h_3)$
- The net work output of the cycle  $W = W_1 - W_2$
- The thermal efficiency of a Rankine cycle  $\eta = W/Q_1$   
( $m$  is mass flow of steam)

# Principle of operation

- Steam at high pressure and temperature expands through nozzles forming high velocity jets



In the above process the entropy of steam do not change, hence it is called “Isentropic”

# Principle of operation

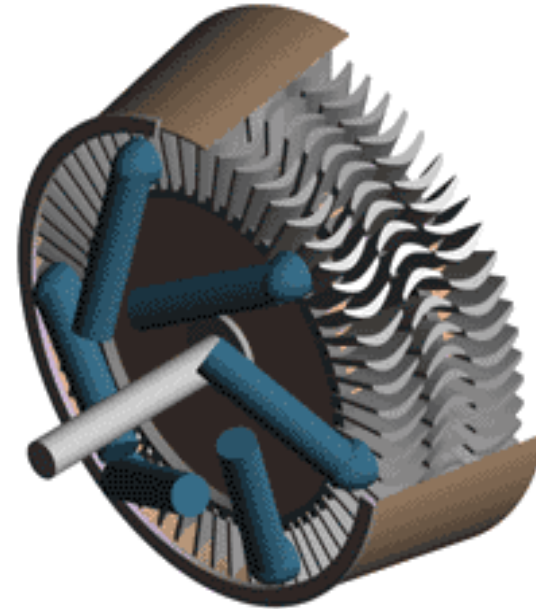
- Many such nozzles are mounted on inner wall of cylinder or stator casing
- The rotor of the turbine have blades fitted around in circular array
- Steam jet from static nozzles impinges and impart its momentum on to rotor blades
- This make the rotor to rotate

# Principle of operation

- A set of one array of stator and rotor blade is called a 'stage'
- Number of stages are arranged one after another and thus thermodynamic energy is converted into kinetic energy

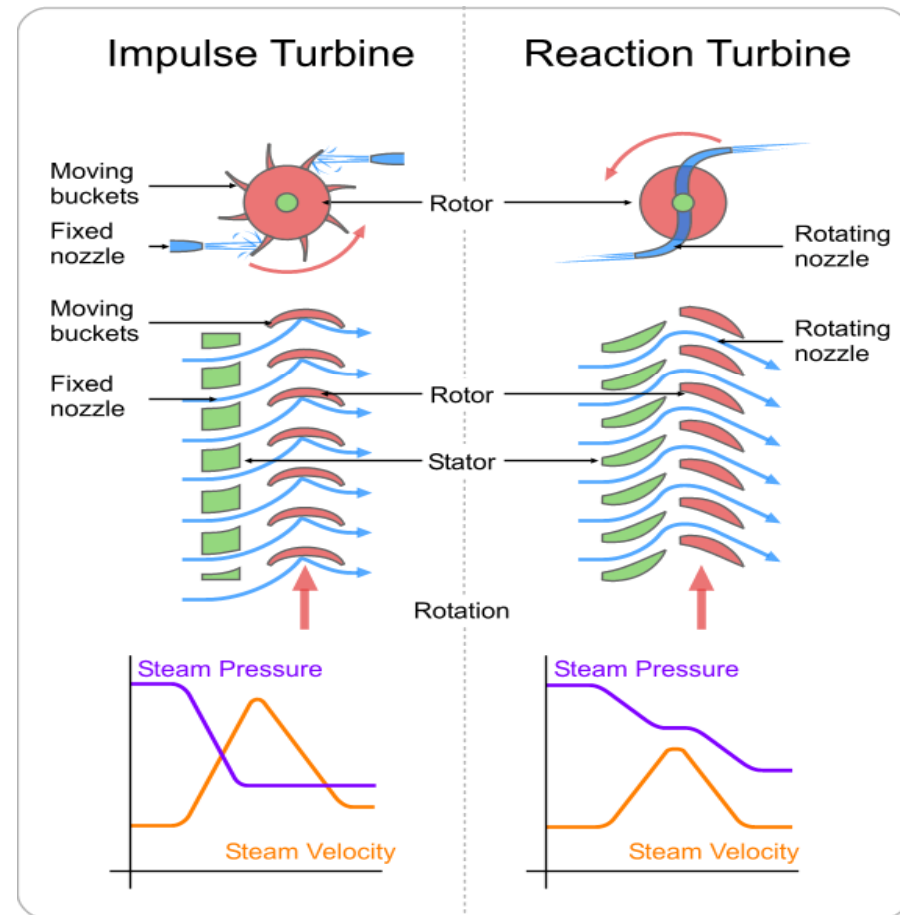
# Turbine Blades

- Number of rows of static and rotating blades (stages) produce the requisite torque
- Type of turbine are classified according to the arrangement and shape of these blades



# Turbine Classification

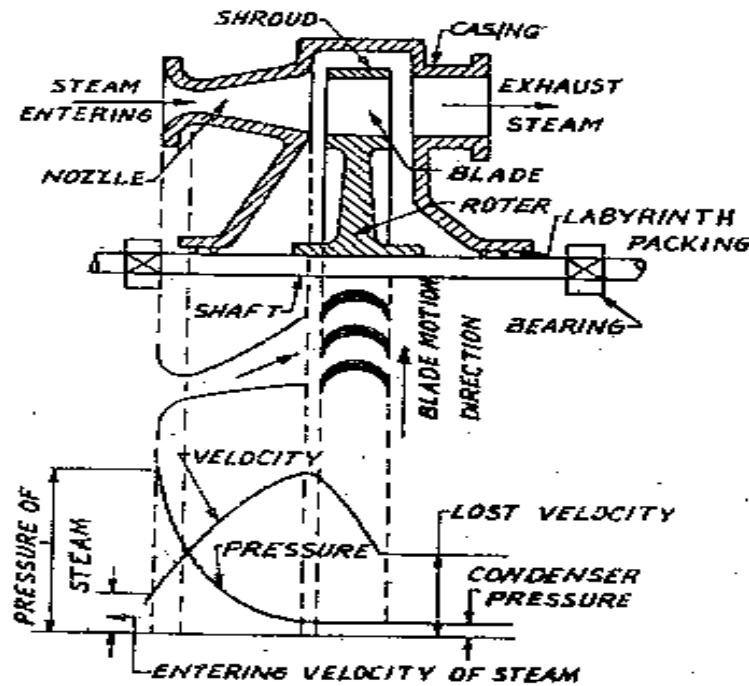
- Based on the nature of blade profile, steam perform work on the blades differently.
- Accordingly there are two types of turbine
  - Impulse
  - Reaction



# IMPULSE TURBINE

- Simple impulse turbine consists of a nozzle or a set of nozzles and one set of moving blades attached to a rotor, and a casing.
- Here, complete expansion of steam from steam chest pressure to exhaust or condenser pressure takes place only in one set of nozzles. Pressure drop takes place only in nozzles.
- The steam at condenser pressure enters the blade and comes out at the same pressure. There is no pressure drop in the moving blades.
- Steam enters the blade at a very high velocity (supersonic: 1100m/s) and reduces along the passage of the blade. But the exit velocity also remains considerably high, which results into high leaving velocity loss. This loss may be 11% of the initial kinetic energy. Example of this type of turbine is de-Laval turbine.
- If steam velocity at entry is 1100m/s, for good economy blade speed will be 500m/s. This results into a rotational speed of 30000rpm. This requires large gearing arrangement to drive the generator.

# IMPULSE TURBINE



**Fig. 4.12 Diagrammatic Arrangement of a simple Impulse Turbine**

# COMPOUNDING OF IMPULSE TURBINE

- This is a method of reducing rotational speed of the simple impulse turbine to practical limit. This also reduces the exit loss. Compounding is done by making use of more than one set of nozzles and blades in series so that either the steam pressure or the jet velocity is absorbed by the turbine in stages. There are three main types of compounding:
- Pressure compounded impulse turbine
- Velocity compounded impulse turbine
- Pressure and velocity compounded impulse turbine

## PRESSURE COMPOUNDED IMPULSE TURBINE

- In this turbine compounding is done for pressure of steam only to reduce the high rotational speed of the turbine.
- This is done by arranging a no. of simple impulse turbines in a series on the same shaft, each having a set of nozzles and a set of moving blades.
- This results splitting up the whole pressure drop from the steam chest pressure to the condenser pressure into a series of smaller pressure drops across the several stages.

# PRESSURE COMPOUNDED IMPULSE TURBINE

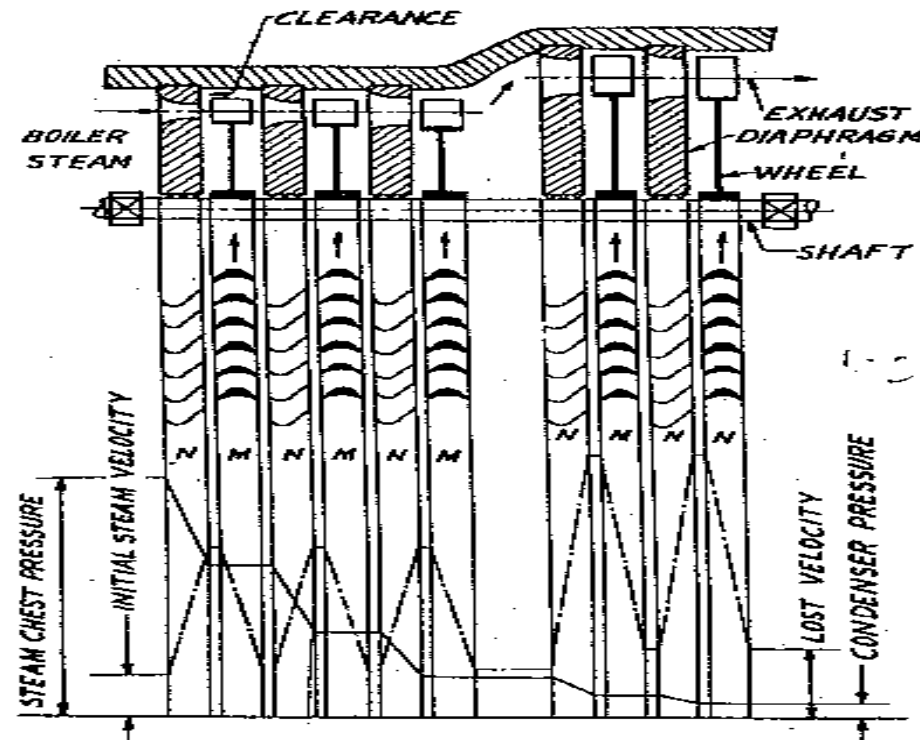
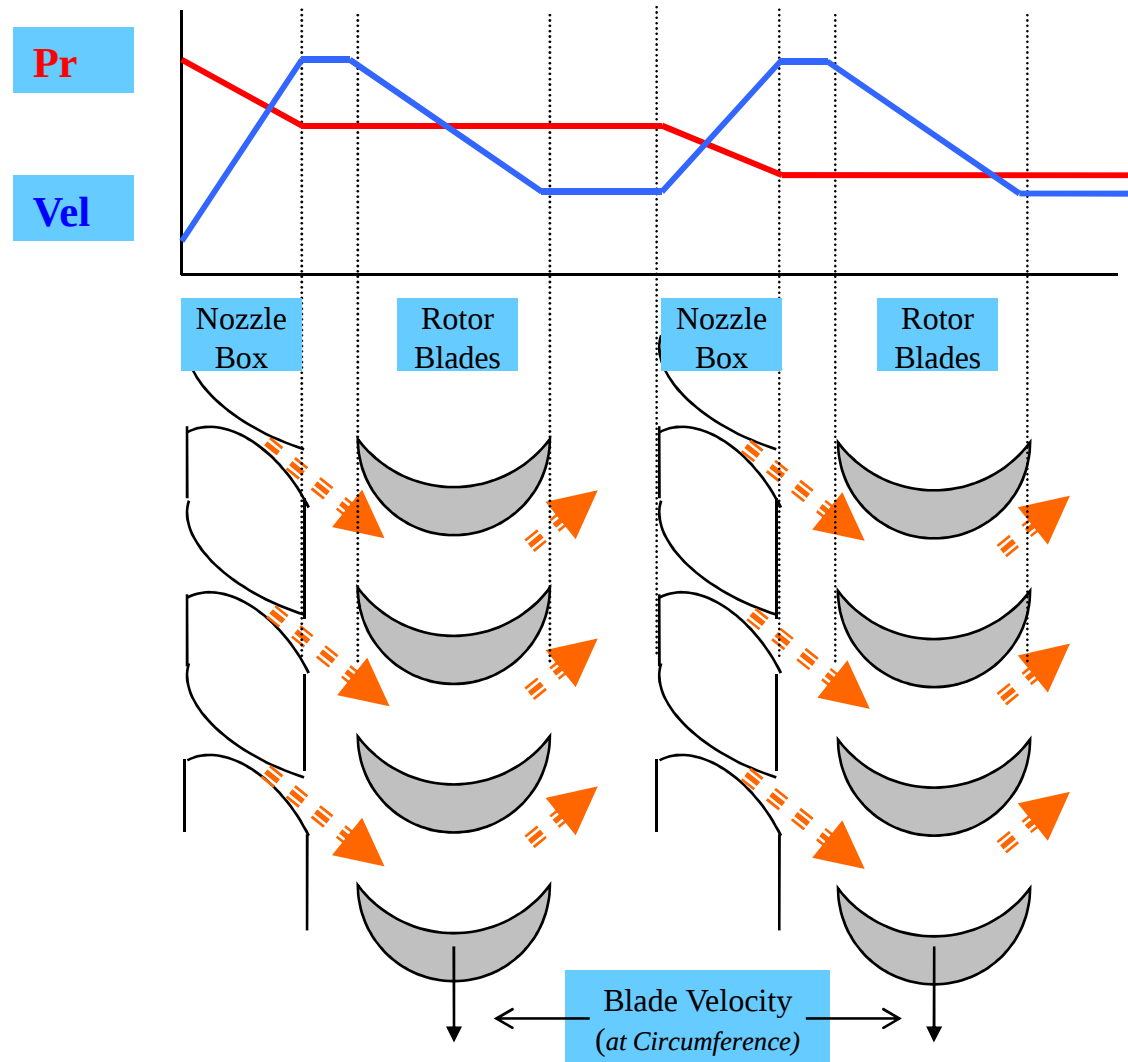


Fig. 4.13. Diagrammatic Arrangement of Pressure Compounded Impulse Turbine.

# Simple Pressure Com- pounded Turbine

- High rotational speed can be avoided
- The total pressure drop takes place in number of stages in small steps
- Steam expands only in the nozzles
- Leaving loss of steam is very small (1-2%)



# VELOCITY COMPOUNDED IMPULSE TURBINE

- In this turbine compounding is done for velocity of steam only. Velocity drop is arranged in many small drops through many rows of moving blades.
- It consists of a set of nozzles and many rows of moving blades attached to rotor and many rows of fixed blades attached to casing arranged alternatively.
- The whole expansion of steam from steam chest pressure to condenser pressure takes place in nozzles only. No pressure drop takes place either in moving or fixed blades.
- Steam velocity drops gradually at every stage of moving blades. There is only a negligible velocity drop in fixed blades due to friction.

# VELOCITY COMPOUNDED STEAM TURBINE

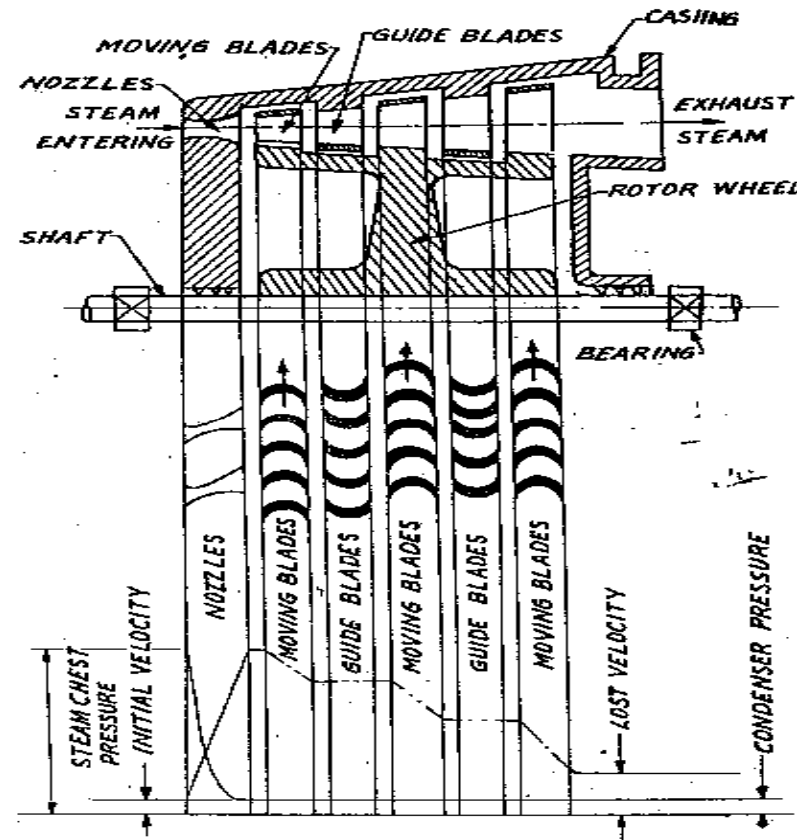
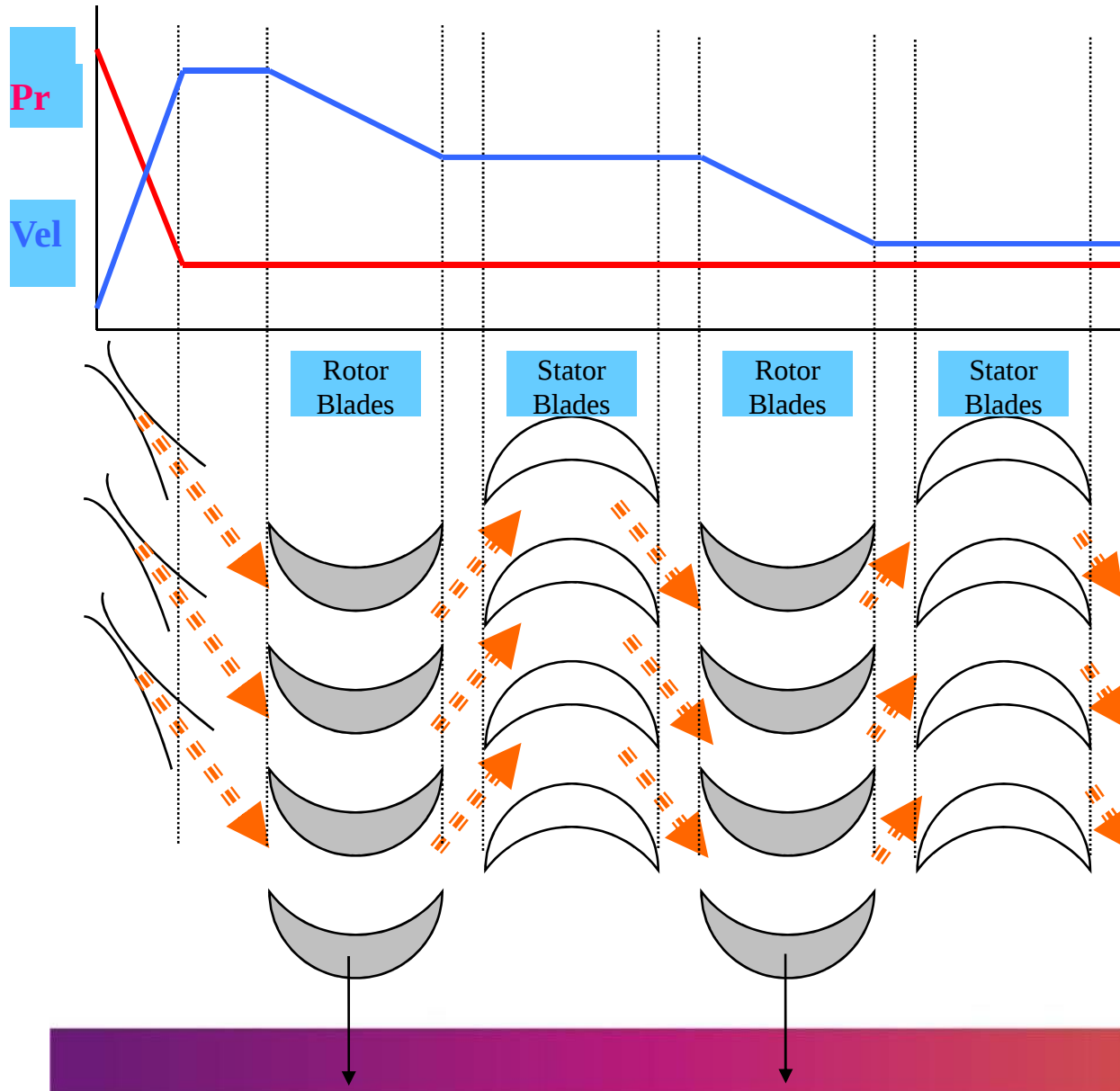


Fig. 4.14 Diagrammatic arrangement of Velocity Compounded Impulse Turbine.

# Simple velocity Compounded Turbine



- Velocity compounding helps to reduce high rotational speed
- Enthalpy drop occurs totally across nozzles
- Stator blades only guide the exhaust steam from one rotor blade to the next

## PRESSURE AND VELOCITY COMPOUNDED IMPULSE TURBINE

- This is a combination of pressure and velocity compounding.
- There are two sets of nozzles where the whole pressure drop takes place.
- After each set of nozzles, there are more than one moving and fixed blade rows arranged alternatively.
- Hence velocity drop also takes place in steps.

# PRESSURE AND VELOCITY COMPOUNDED IMPULSE TURBINE

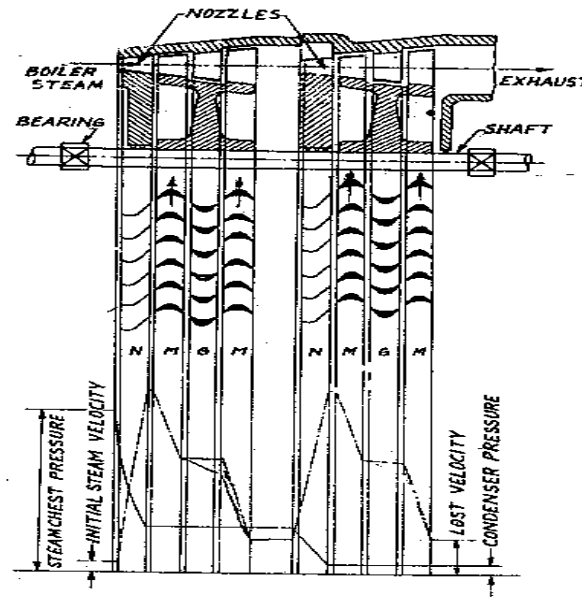
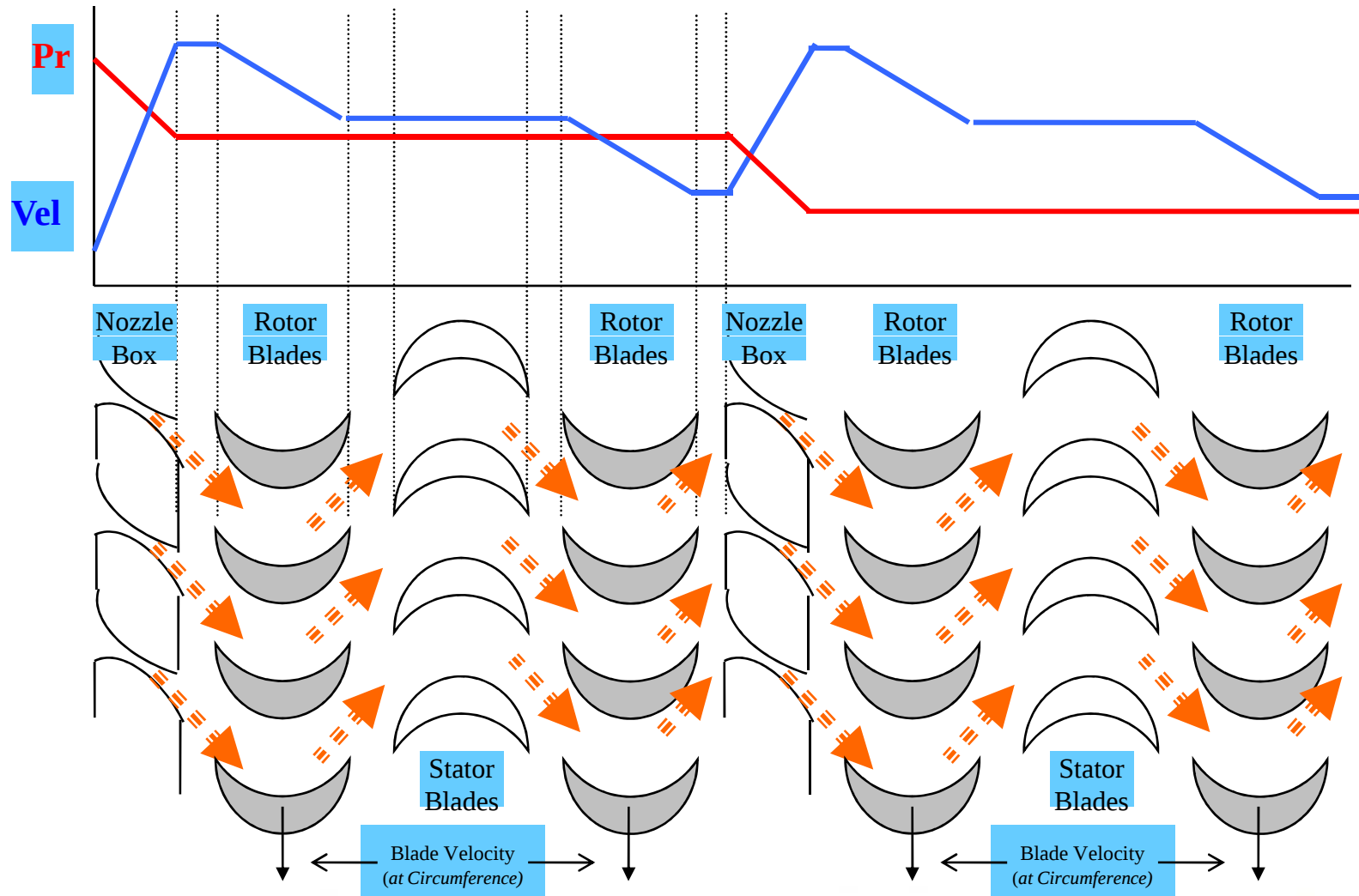


Fig. 4.16. Diagrammatic Arrangement of Pressure-Velocity Compounded Impulse Turbine.

# Velocity & Pressure Compounded Turbine



# IMPULSE – REACTION TURBINE

- This utilizes principle of both impulse and reaction.
- There are a no. of moving blade rows attached to the rotor and equal no. of fixed blades attached to the casing.
- While passing through the first row of fixed blades, steam undergoes a small drop in pressure and hence its velocity increases a bit.
- Then it enters the first row of moving blades and like impulse turbine, suffers a change in direction and momentum. This momentum gives rise to impulse on blades.
- Additionally there is also a drop in pressure while passing through the moving blades which results in an increase in kinetic energy of steam. This kinetic energy gives rise to reaction in the direction opposite to that of the added velocity.
- Thus the gross driving force is the vector sum of impulse and reaction forces. This turbine is also known as Reaction turbine.

# IMPULSE – REACTION TURBINE

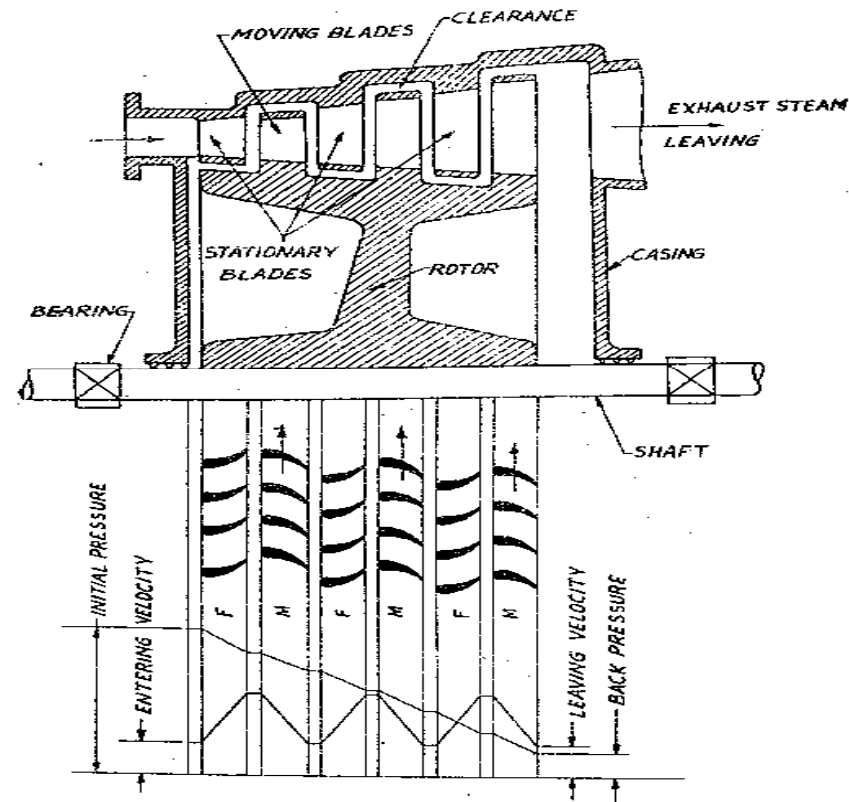
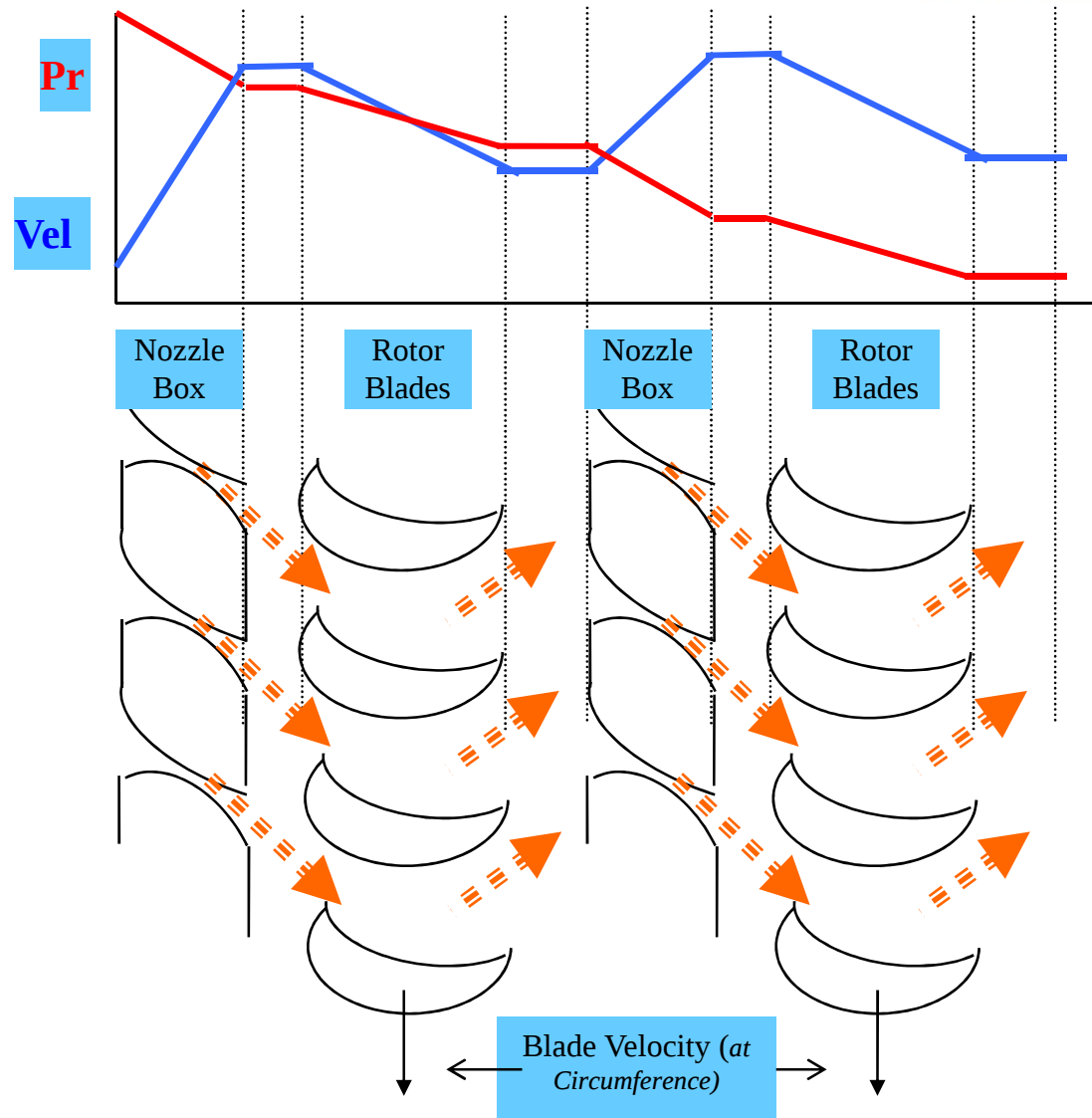


Fig 4.17 Diagrammatic Arrangement of Impulse-Reaction Turbine

# Reaction Turbine

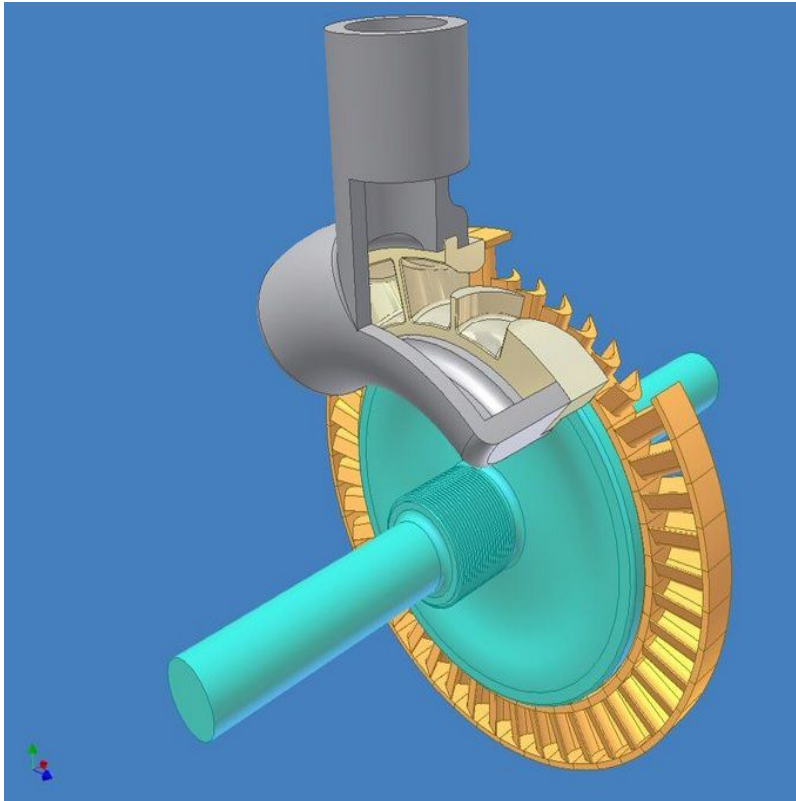
The term “degree of reaction” in a reaction turbine implies the ratio of drop of enthalpy in moving blades to the combined drop in moving blade (rotor) and fixed blade (stator)



# DIFFERENCE BETWEEN IMPULSE AND REACTION TURBINE

| S.No. | Impulse Turbine                                          | Reaction Turbine                                                                             |
|-------|----------------------------------------------------------|----------------------------------------------------------------------------------------------|
| 1     | Pressure drops only in nozzles                           | Pressure drops in fixed blades (nozzles) as well as moving blades                            |
| 2     | Constant blade channel area                              | Varying blade channel area (converging type)                                                 |
| 3     | Profile type blade                                       | Aerofoil type blade                                                                          |
| 4     | Not all round or complete admission of steam             | All round or complete admission of steam                                                     |
| 5     | Diaphragm contains the nozzles                           | Fixed blades similar to moving blades attached to casing serve as nozzle and guide the steam |
| 6     | Occupies less space for same power                       | Occupies more space for same power                                                           |
| 7     | Lesser efficiency                                        | Higher efficiency                                                                            |
| 8     | Blade manufacturing is not difficult and thus not costly | Blade manufacturing process is difficult compared to impulse and hence costly                |
| 9     | Velocity of steam is higher                              | Reduced velocity of steam                                                                    |

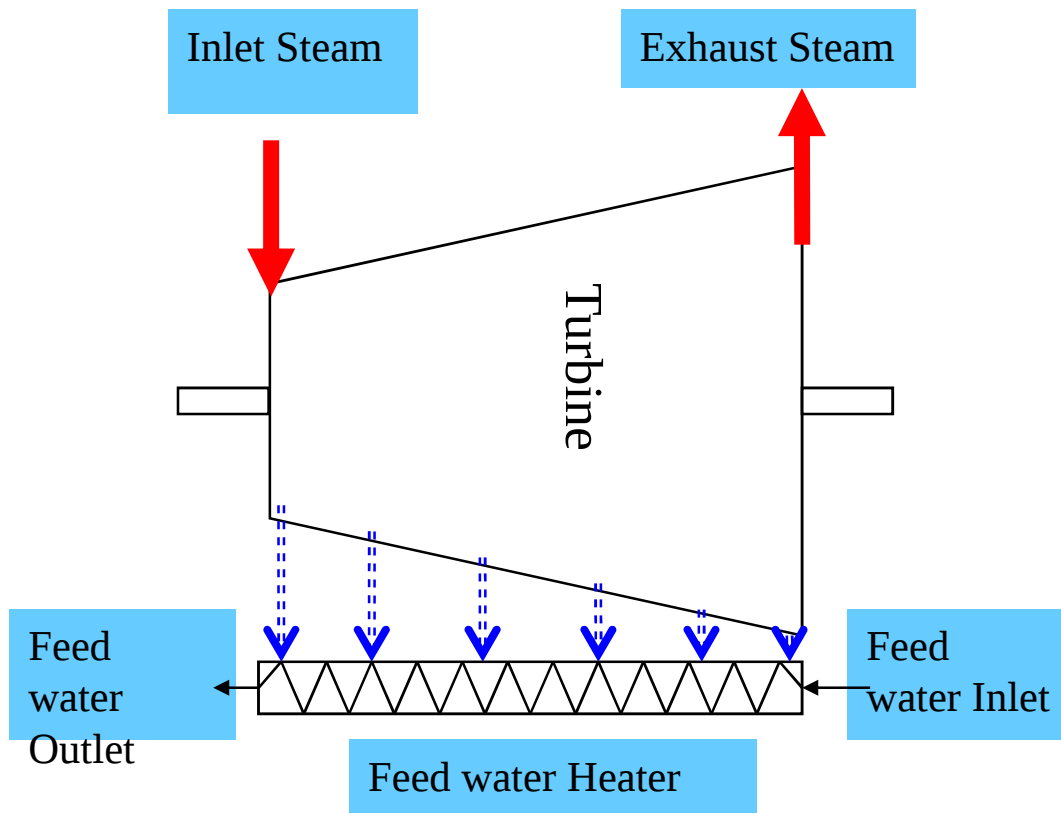
# Example of Velocity Compounded Stage



- The figure on left is of “Curtis Wheel”
- This is a common name of Velocity compounded stage
- First one or two row of most steam turbines are “Curtis Wheel”

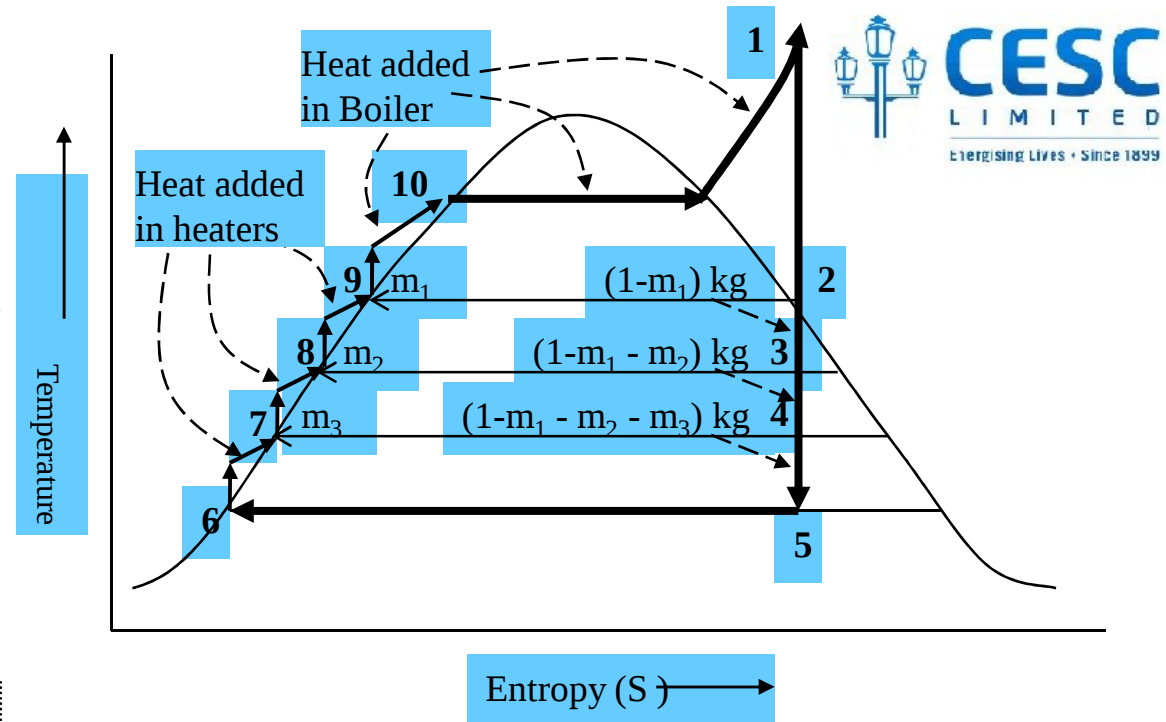
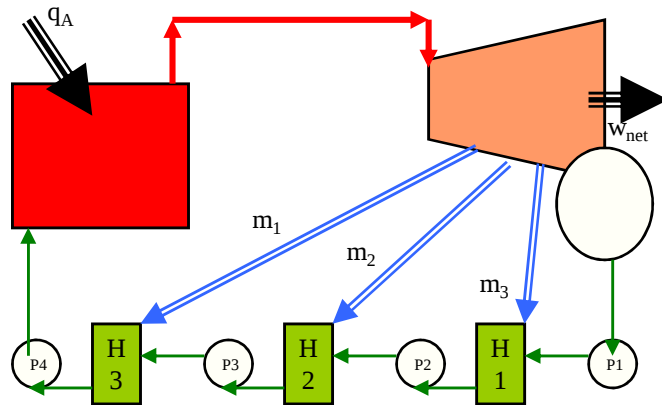
# EXTRACTIONS OF STEAM TURBINE

# Regenerative Cycle



- Regenerative Cycle helps to optimize overall Carnot Cycle Efficiency
- Temperature of water feeding to the boilers is gradually raised
- Steam extracted from the turbine is used for heating gradually
- Steam is suitably extracted so that the degree of superheat is minimum
- Heat exchange is isothermal

# Cycle $\eta_{reg}$



- The work output of the turbine is the sum of outputs of *Rankine Cycles*

-1-2-9-10  
 -2-3-8-9  
 -3-4-7-8  
 -4-5-6-7

- Net work output from all the *Rankine Cycles*

$w_{net}$  = see calculation

- Heat added in boiler  $q_A = h_1 - h_9$

- $\eta_{reg} = w_{net} / q_A$

**Theoretical regeneration cycle is** a) Not possible to construct  
b) Steam gets too wet to expand

In **practical regeneration cycle** limited number of heaters are used (*The above is an example T-S diagram is for 3 such regenerative heaters, of open heating type*)

**Heat gained by water equals to the heat lost** by bled steam so that in:

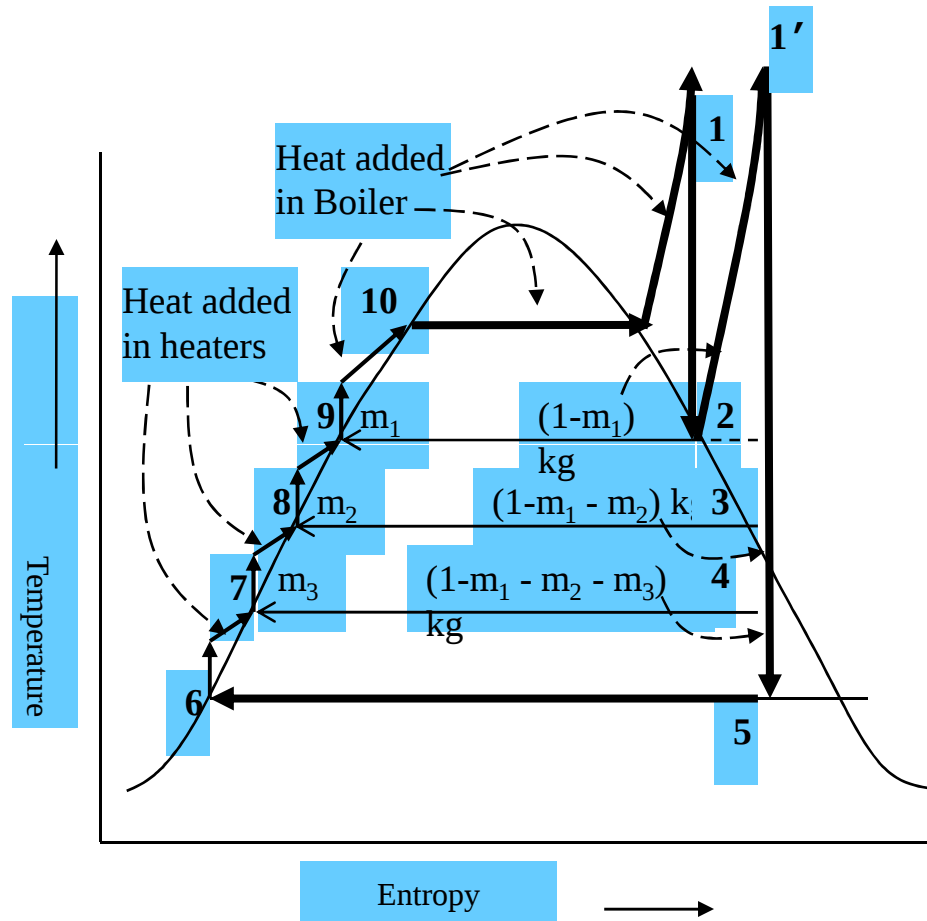
Heater 1:-  $(1-m_1 - m_2 - m_3) (h_7 - h_6^*) = m_3 (h_4 - h_7)$

Heater 2:-  $(1-m_1 - m_2) (h_8 - h_7^*) = m_2 (h_3 - h_8)$

Heater 3:-  $(1-m_1) (h_9 - h_8^*) = m_1 (h_2 - h_9)$

**Work output**  $w_{nt} = (h_1 - h_2) + (1 - m_1) (h_2 - h_3) + (1 - m_1 - m_2) (h_3 - h_4) + (1 - m_1 - m_2 - m_3) (h_4 - h_5)$ ; [*\*if we neglect pumping power*]

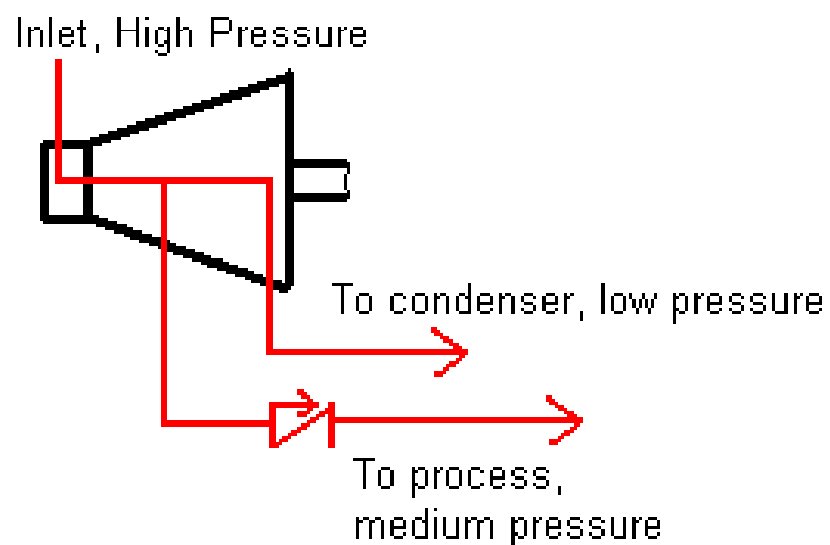
# Reheat Cycle



- In Rankine Cycle the exhaust steam has low dryness fraction after complete expansion
- Higher the pressure more wet is the steam after isentropic expansion
- In Reheat Cycle the exhaust steam from Turbine is sent to the boiler (re-heater) and superheated
- The re-heated steam is again admitted into the turbine for further expansion
- There can be more than one Reheat stage

# Extractions for feed and condensate heating

## Extracting Turbine



# Extractions

- Steam working inside the turbine are bled off for the purpose of heating
- Extractions are tapped off suitably from turbine cylinders
- Process plants use this heat for various heating processes
- In a power cycle this is mainly for regenerative heating as well as de-aeration of condensate and feed water

# Extractions

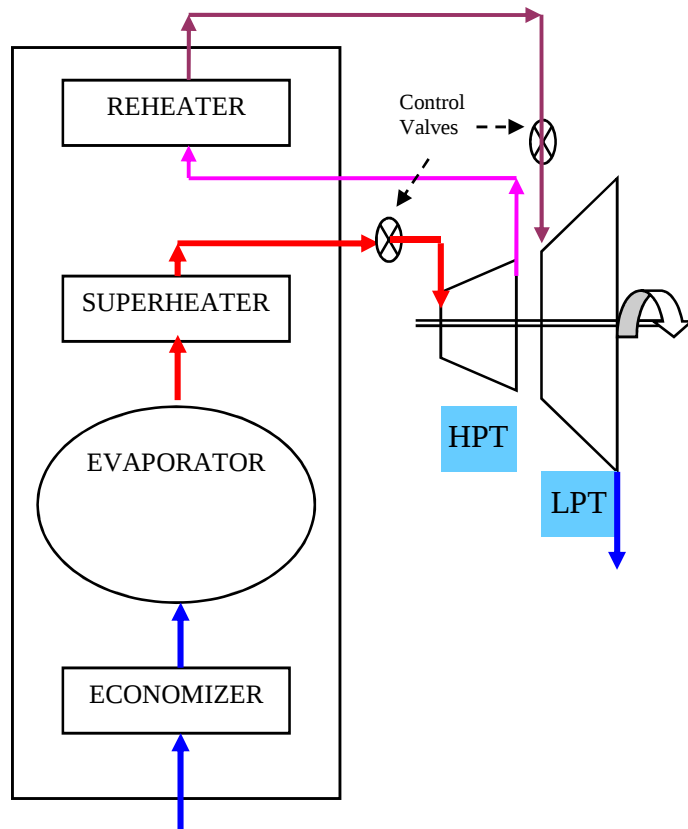
- The extraction lines are provided with non return and isolating (optional) valves
- The non return valves are either simple or power assisted
- Backflow of steam into the turbine is prevented in the event of 'trip'
- Dual extraction for high and low loads is a requirement for de-aerator heaters

# Extractions

- Usually extractions are avoided from HP stage because
  1. The casing will be weakened if tap offs are constructed in it
  2. There will be additional stress originated from thermal mass
  3. Feed heating, using HP steam having high degree of super-heat will be uneconomical
- In 250 MW set of Budge Budge seven extractions are tapped offs from CRH, IPT (3 nos) & LPT (3 nos)

# Reheat Cycle

- Steam path figure in a common reheat cycle



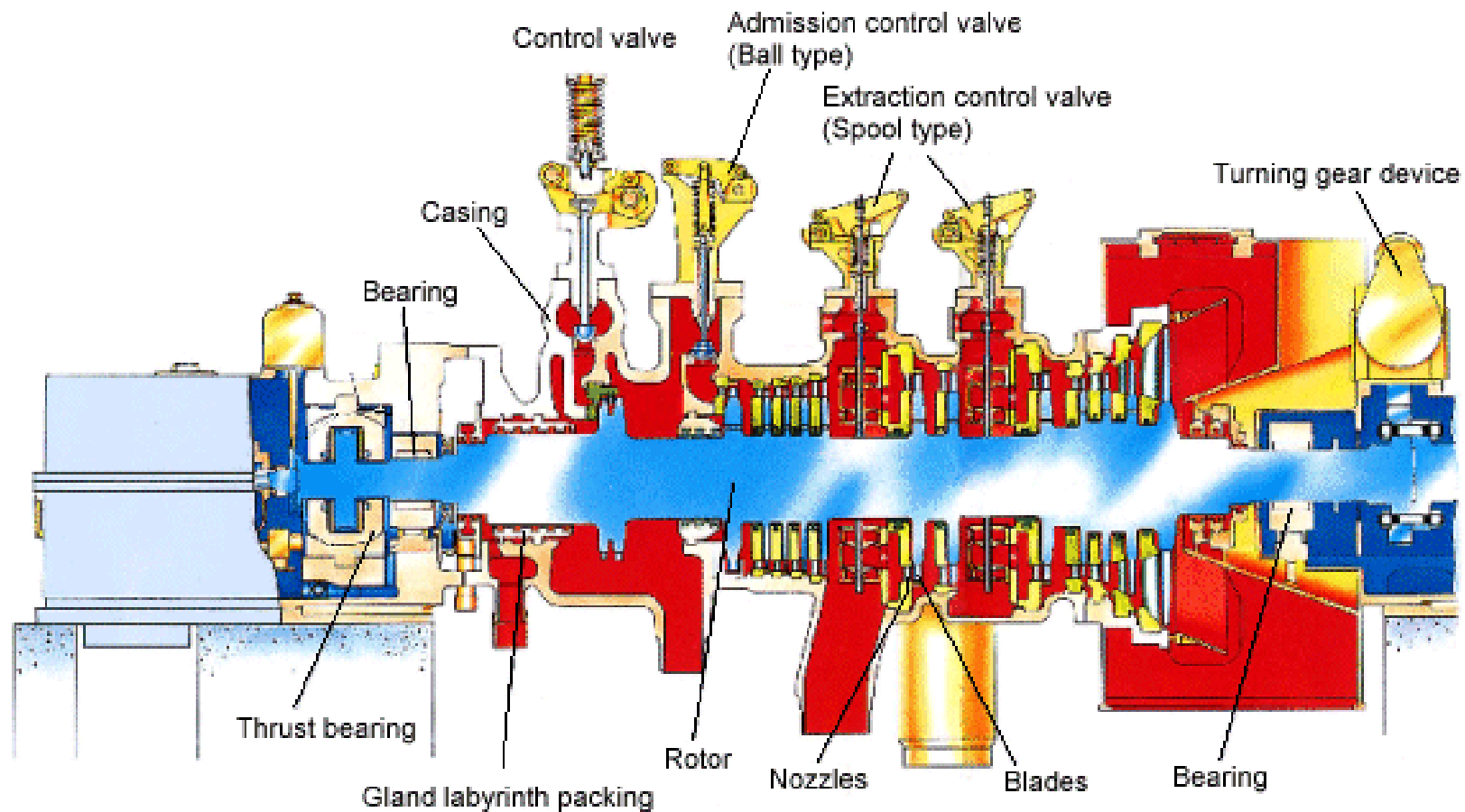
- Steam from final super-heater of the boiler is known as Main Steam
- Main Steam enters the HP turbine through control valves
- The exhaust of HP turbine (cold reheat) is reheated in the boiler
- Steam from re-heater of the boiler is known as Hot Reheat
- Hot Reheat steam enters the IP/LP turbine (through control valves)

# Reheat System

- Introduction of re-heater results in pressure drop in the steam expansion path of turbine
- Therefore the number of reheat stages can not be many as the pressure drop will reduce efficiency of thermal cycle
- The steam pipes and re-heater coils are to be so designed to limit the drop to 2-3%
- The control valves in reheat steam path is not desirable, Systems using HPLP bypass require these valves to control steam flow during bypass operation

# Constructional feature of steam turbine

# Typical Steam Turbine

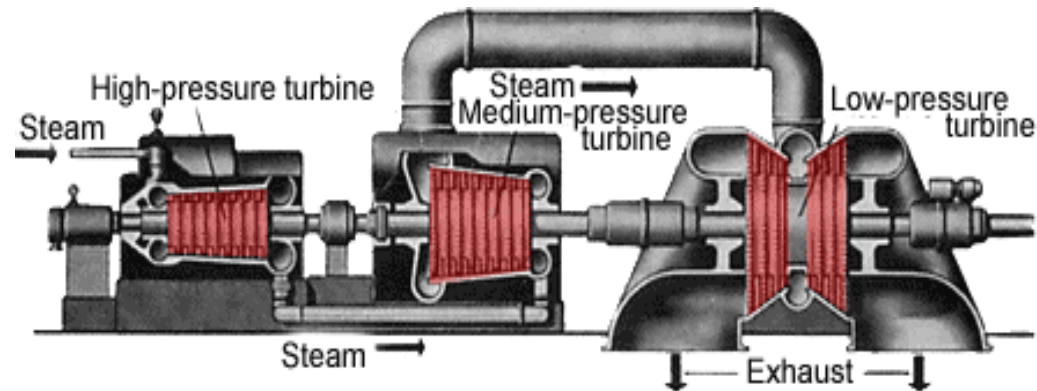


# Turbine types

- Large steam turbines have,
  - many number of stages
  - very high pressure & temperature of inlet steam
  - large volume expansion of steam
- Therefore instead of single turbine cylinder multiple turbines are used
- Steam flow cascade from one turbine cylinder to another arranged in series &/or parallel
- Depending on inlet pressure of these multiple turbine cylinders, they are termed as HP, IP, LP



# Turbine Construction Features



Major Constructional features of a Turbine include:

- Cylinders (HP, IP, LP) and their assembly
- Steam admission valves and interconnecting pipes
- Gland Sealing Arrangements
- Bearings Thrusts and their lubrication system
- Expansion, locking and guide
- Barring arrangements
- Governing system

# Turbine Construction Features

Cycle Efficiency increase with temperature as well as pressure of inlet steam

With the advancements of material science  
Turbine construction have also advanced over the past

In older turbine design casing walls were very thick to cope with higher pressure

Modern turbines are of double casing, which did away with many problems of older design



# Turbine Construction Features

In older turbine rotors construction were heavy and large bearings were needed to support them

Modern turbine rotors are much lighter in comparison so are the bearings

In some of the design one common bearing support two successive rotors



# Turbine of BBGS

Below is a sectional view of Budge Budge  
Turbine Of Unit 1,2

Different features of this turbine will be  
discussed

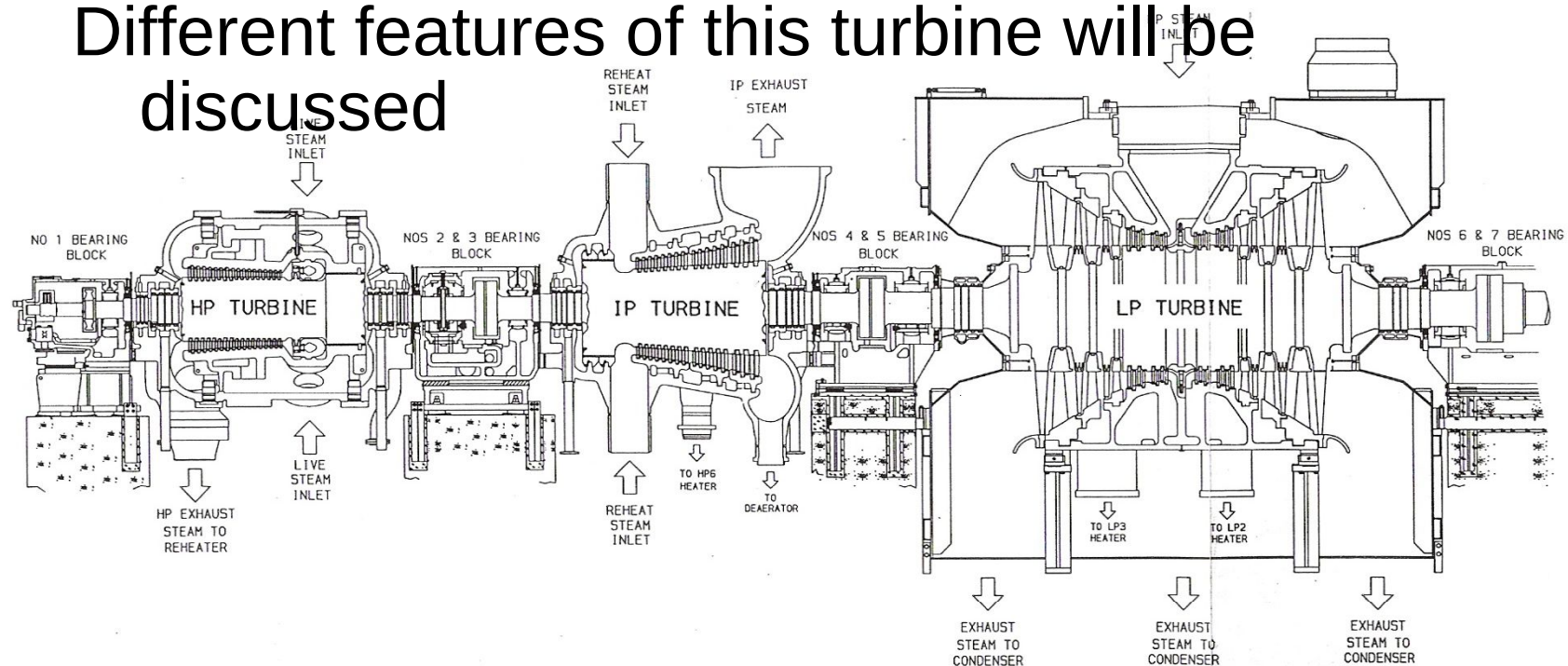


FIG 1 THE TURBINE  
SM0747

# HP Turbine - BBGS

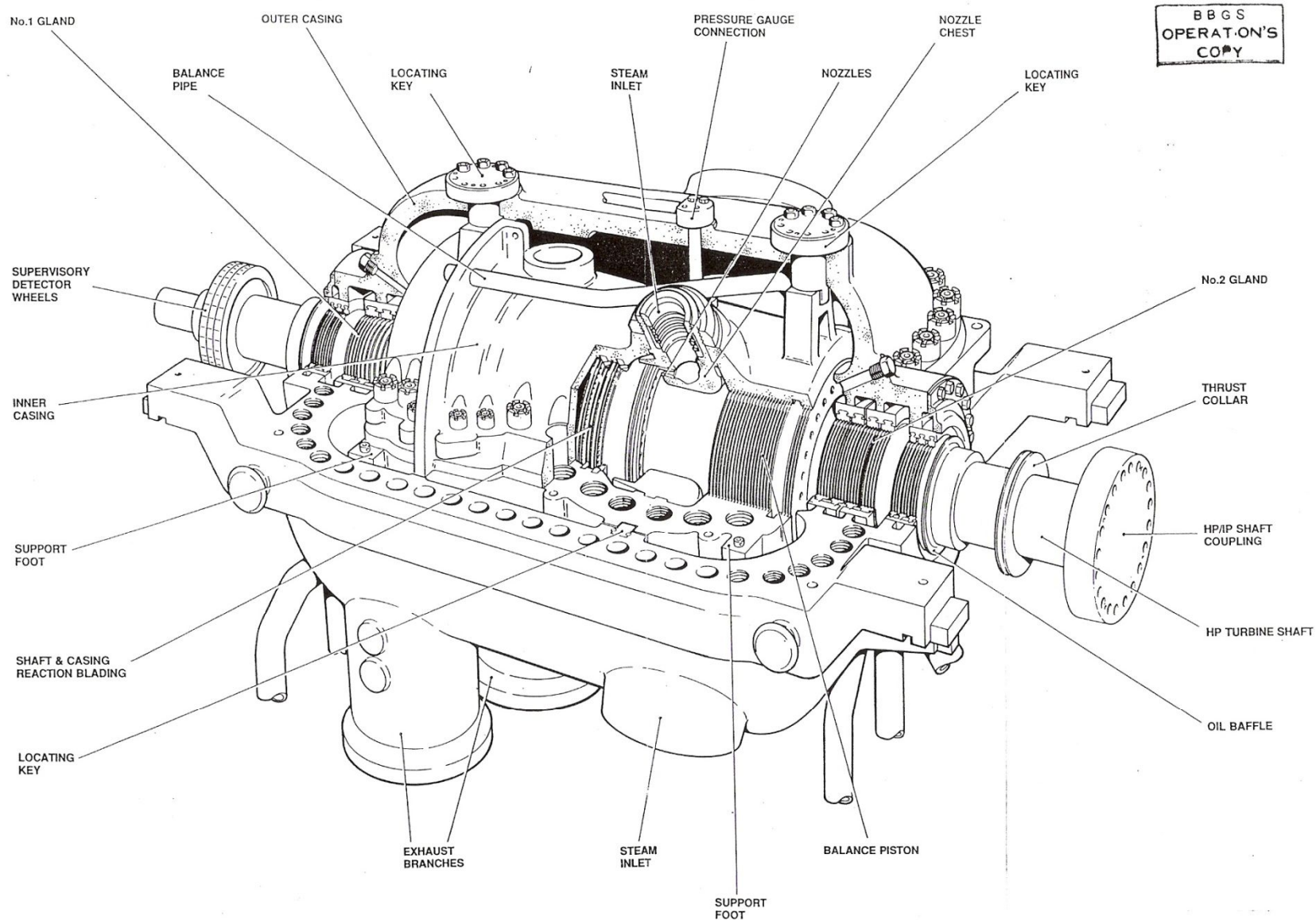
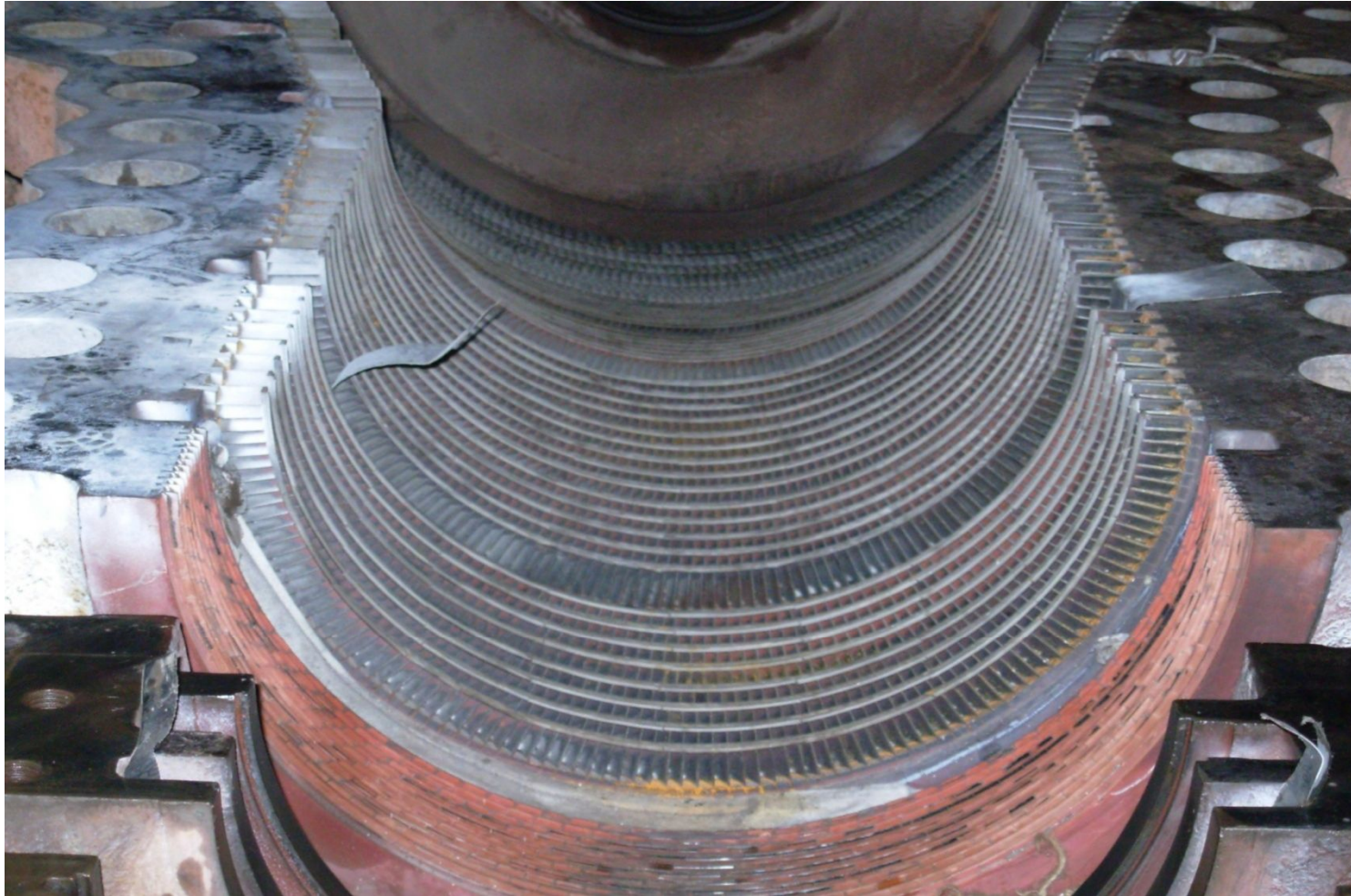
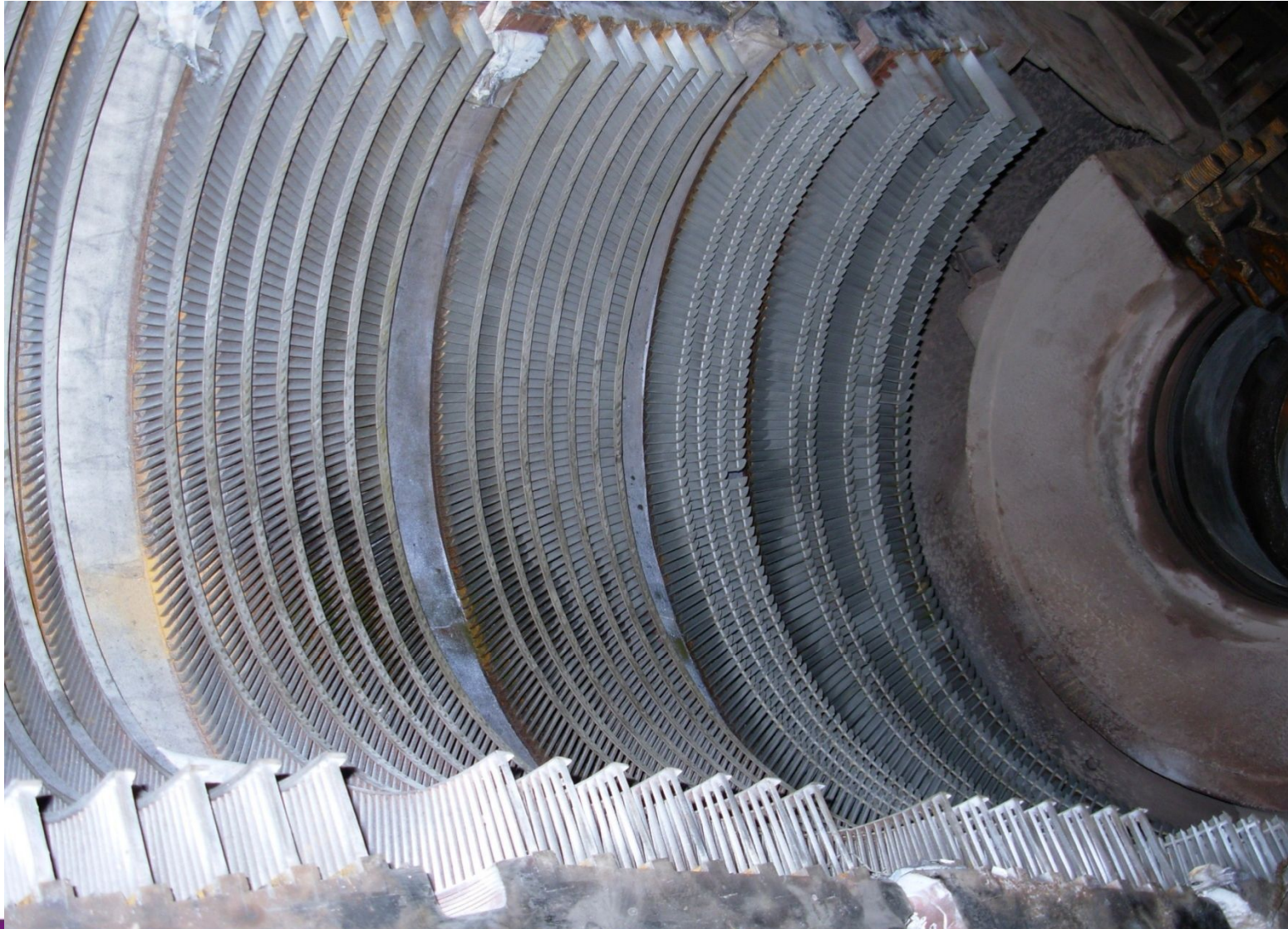


FIG.2 HP TURBINE

# NCGS 2 HP CASING BOTTOM



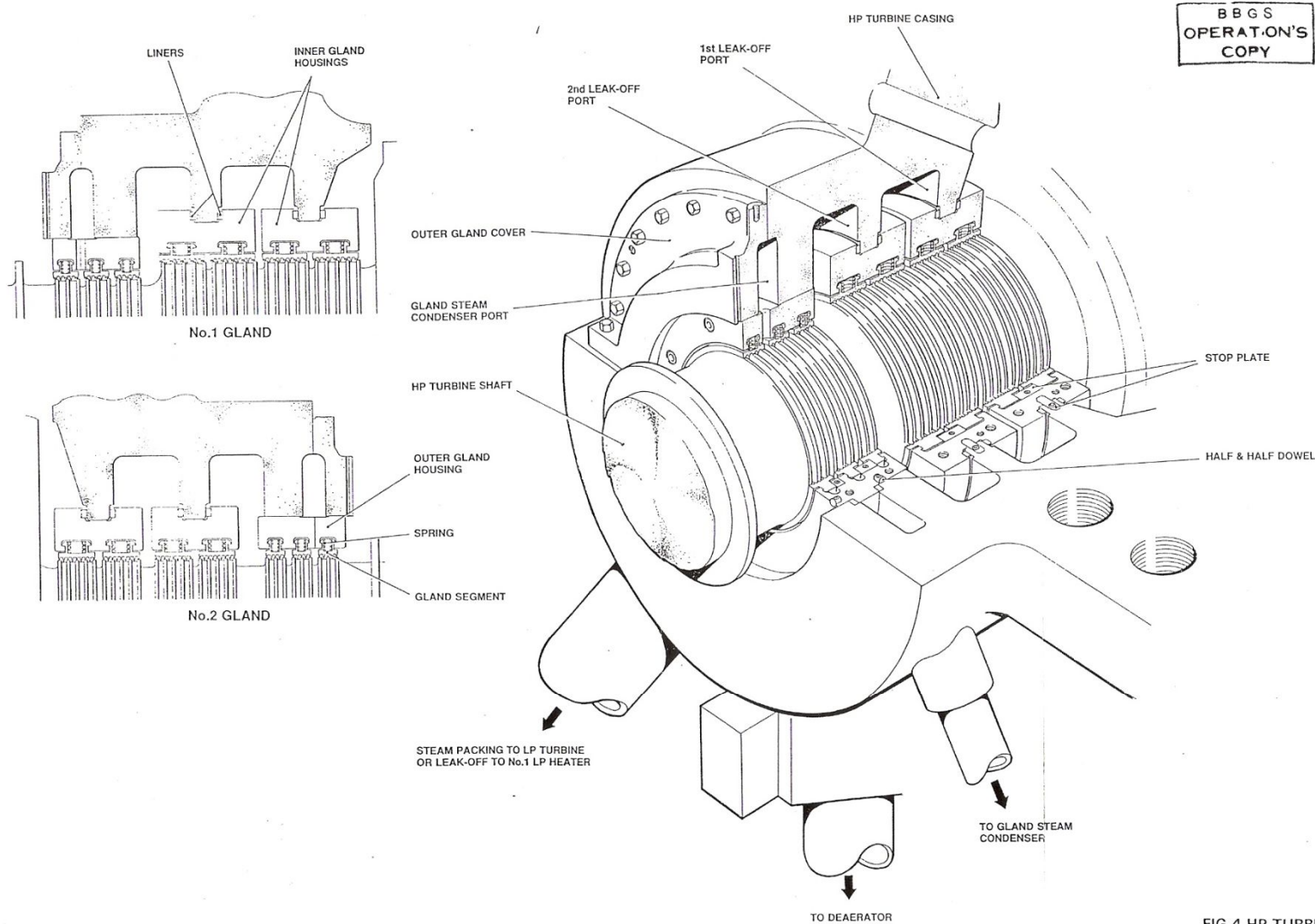
# NCGS 2 HP CASING BOTTOM



# BBGS HP CASING



# HP Turbine Glands - BBGS



BBGS  
OPERATION'S  
COPY

FIG.4 HP TURBINE GLAND

SM01

# IP Turbine - BBGS

BBGS  
OPERATION'S  
COPY

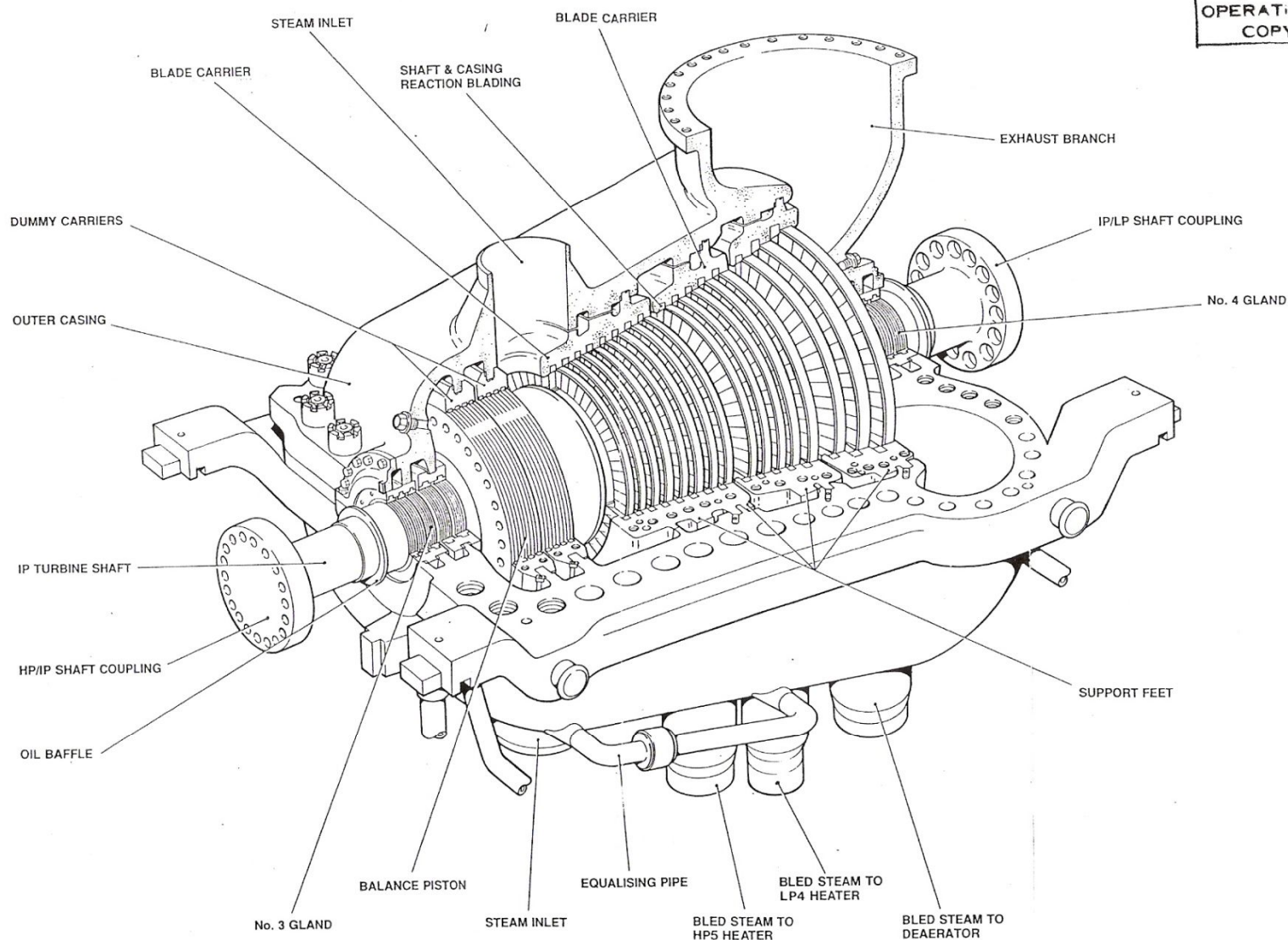


FIG.5 IP TURBINE

SM059

# BBGS IP CASING



# IP Turbine Glands- BBGS

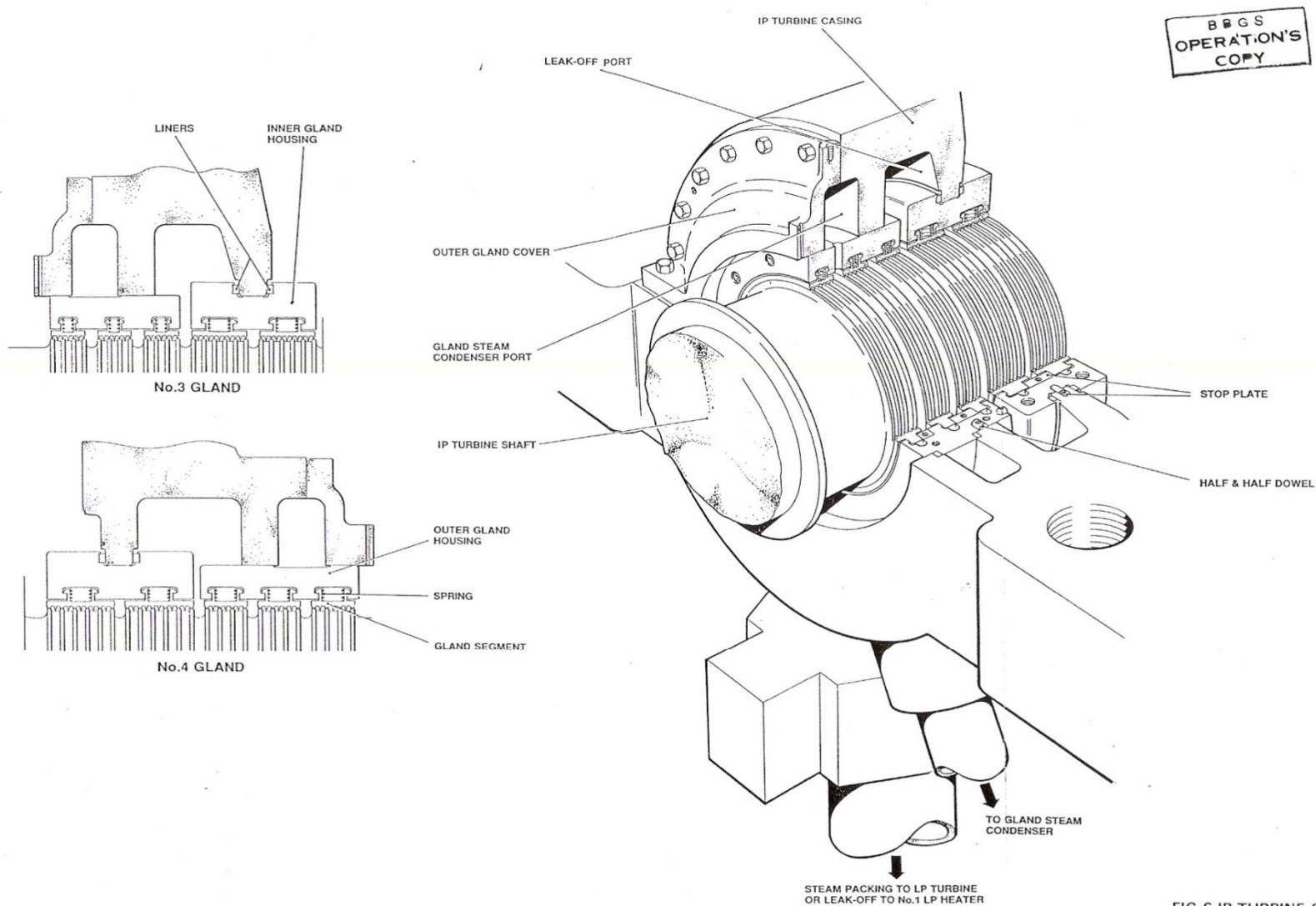


FIG.6 IP TURBINE GLAND  
SM01

# LP Turbine - BBGS

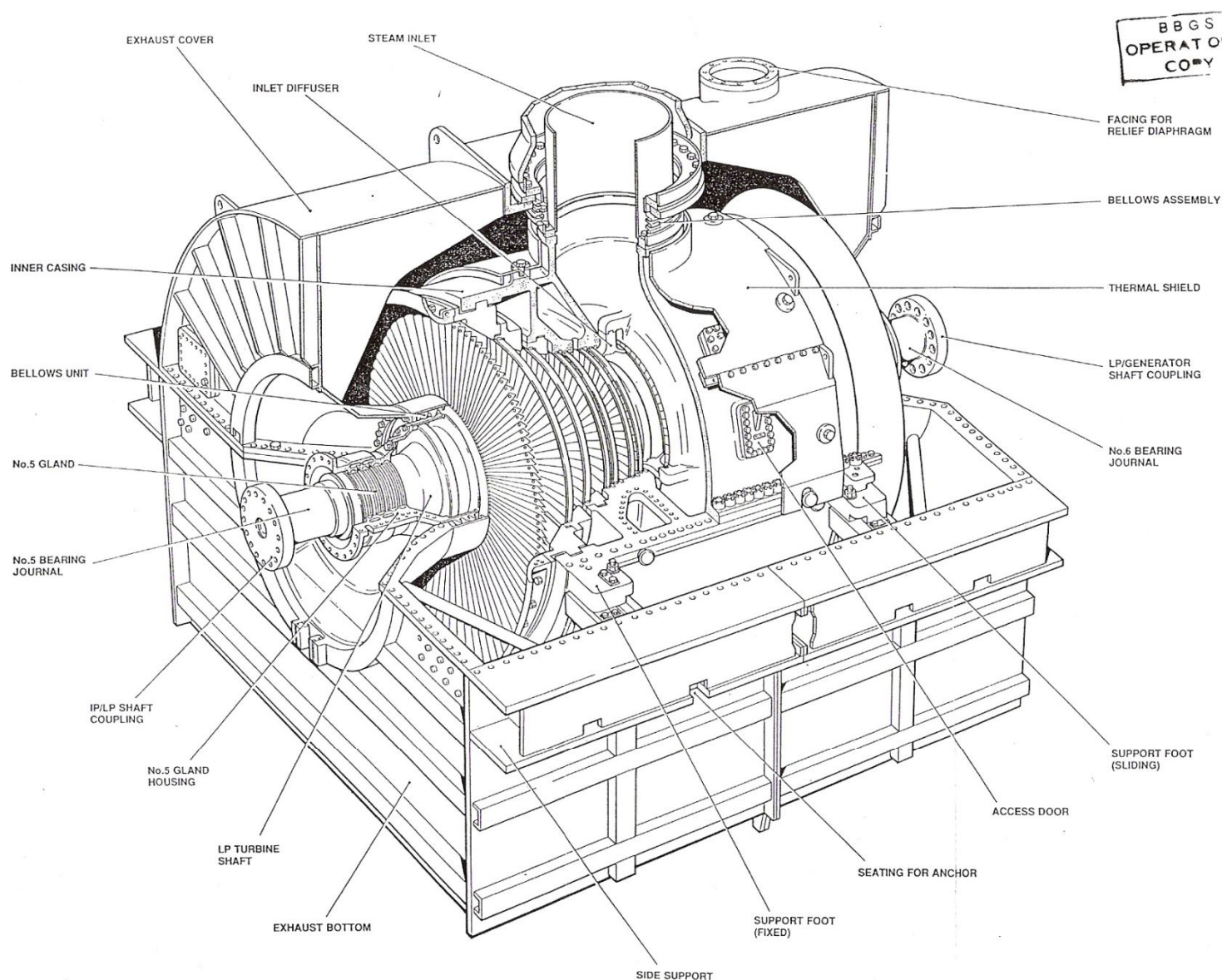


FIG 7 LP TURBINE  
SM0429

# LP SPINDLE NCGS 2



# LP Turbine Glands- BBGS

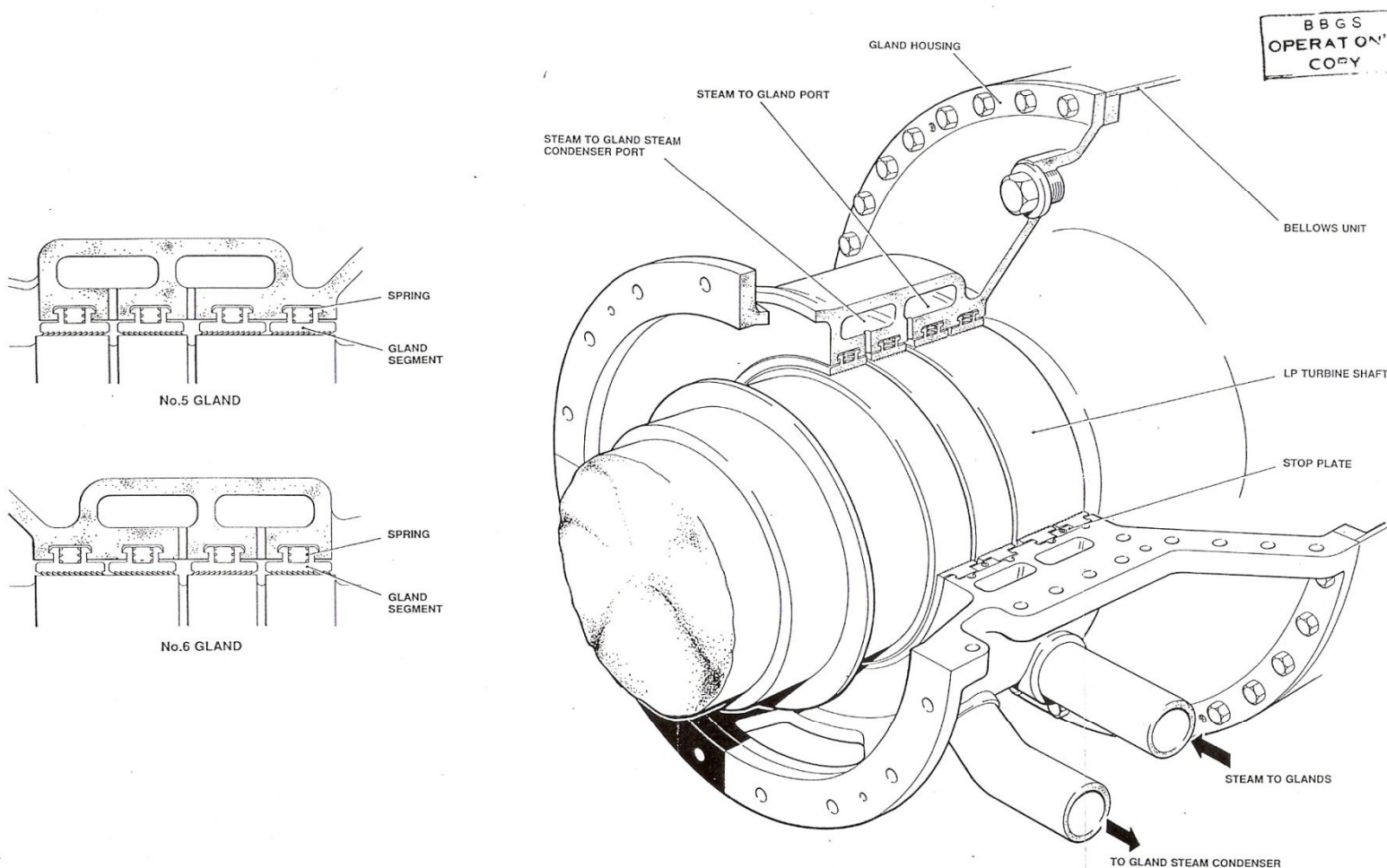


FIG.8 LP TURBINE GLAND  
SM0536

# BBGS LP CASING



# BBGS LP CASING



# TURBINE BEARINGS

# Turbine Bearings- BBGS

## (Nos1,2 & 3)

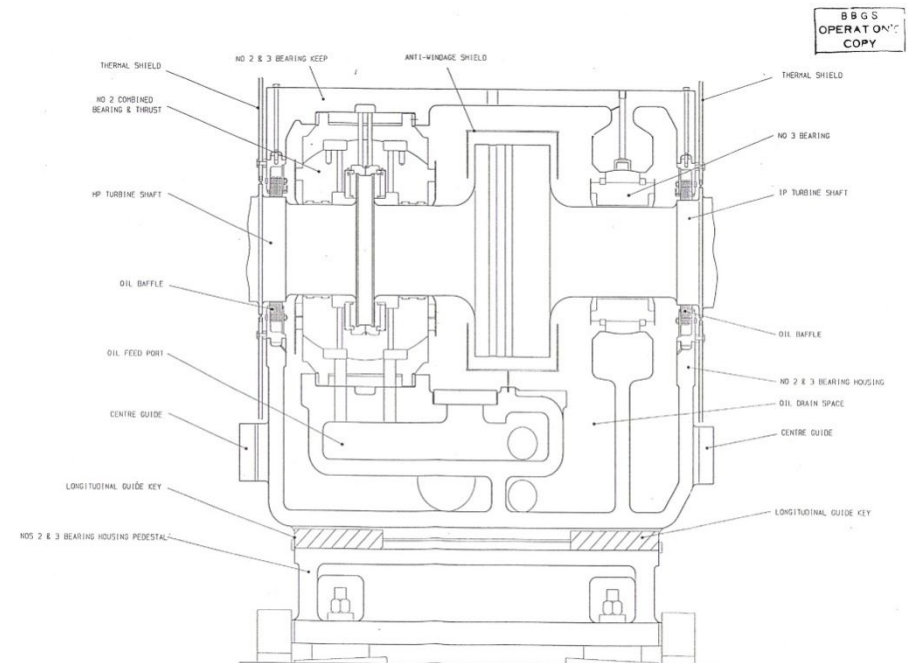
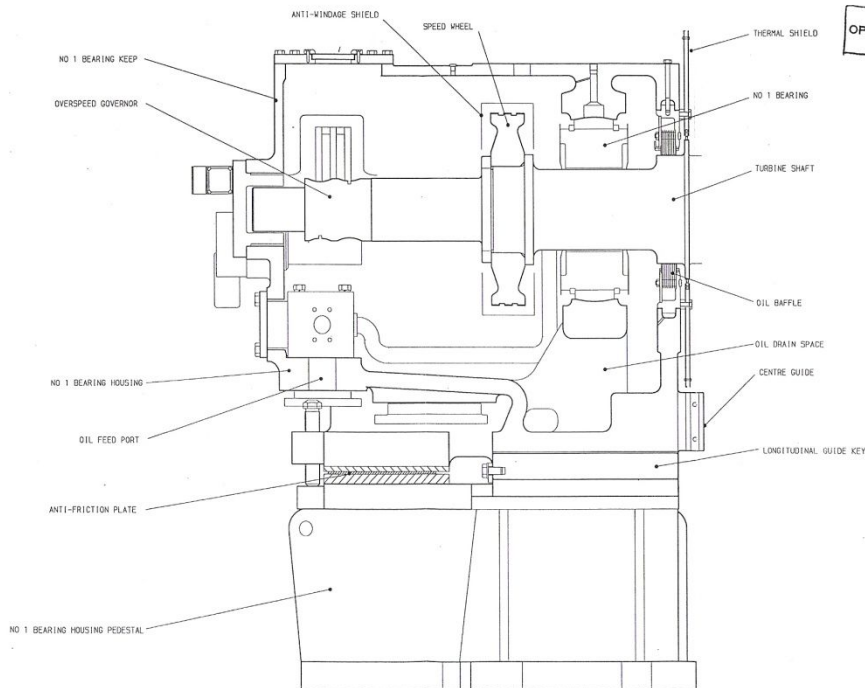
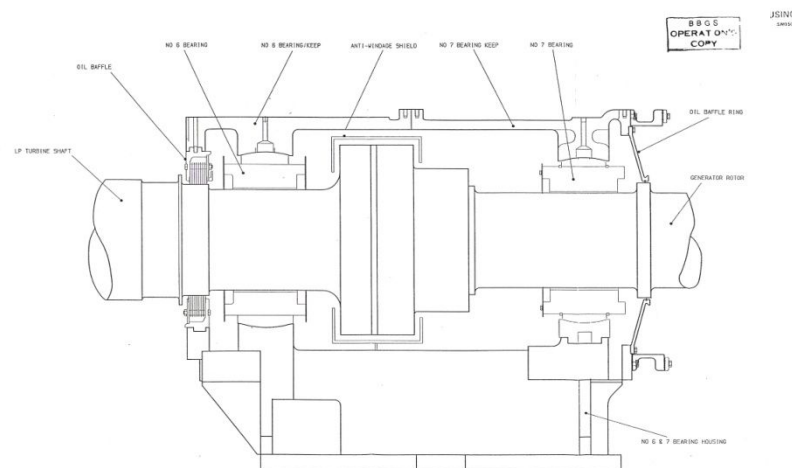
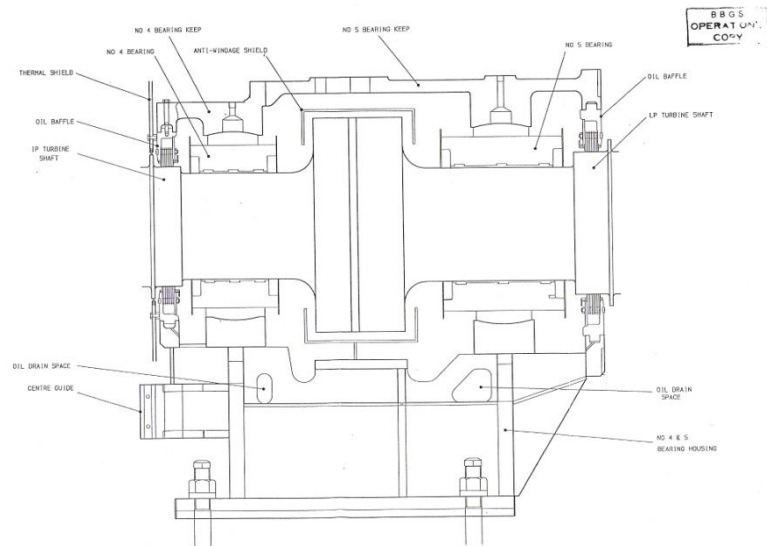


FIG 2 No 2 & 3 BEARING HOUSING

- Bearing Nos 1 & 2 supports HP Turbine Rotor
- Bearing No 2 is combination of Thrust & Journal Bearing
- No 3 supports one end of IP Turbine Rotor

# Turbine Bearings- BBGS

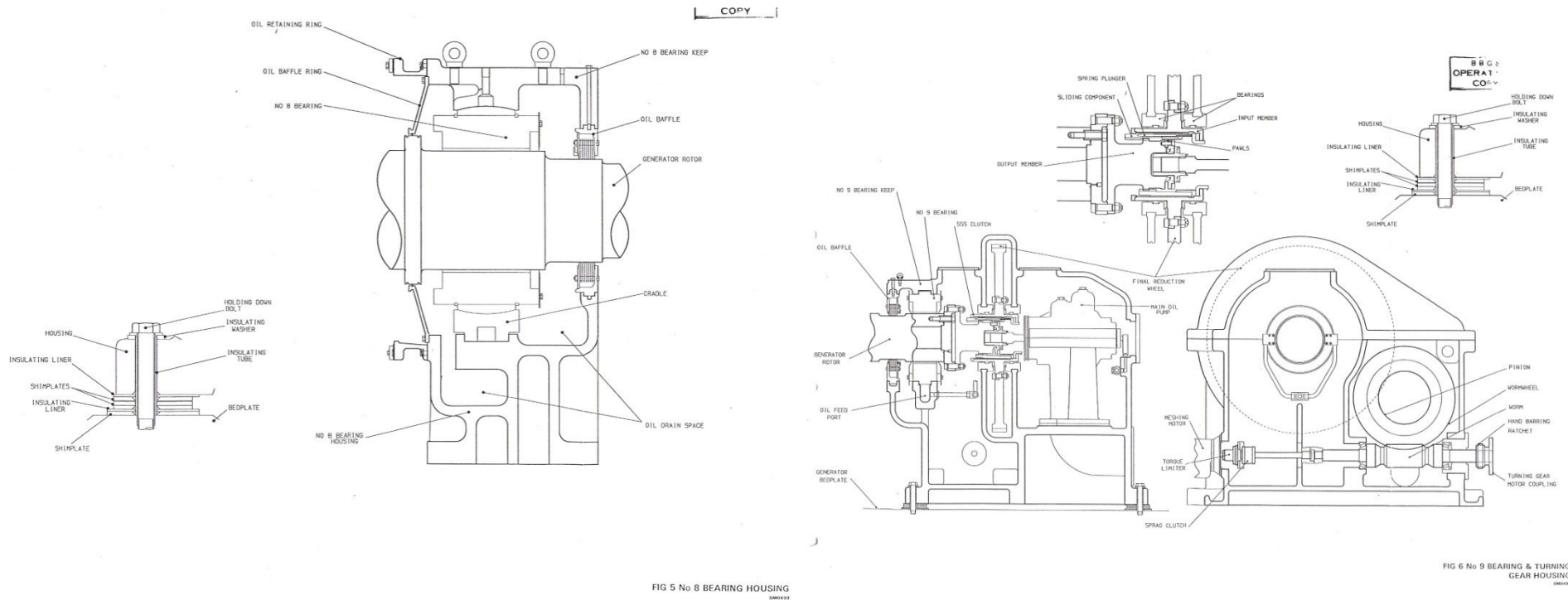
## (Nos 4,5,6&7)



- No 4 bearing supports the other end of IP rotor
- Similarly No 5 bearing supports one end of LP rotor
- And no 6 bearing supports the other end of LP rotor
- Generator rotor is supported by Nos 7 & 8

FIG 4 Nos 6 & 7 BEARING HOUSING

# Turbine Bearings- BBGS



- Beyond No 8 is the No 9 bearing, which is housed in common chamber for Main Oil Pump, Barring Gear & its clutch Arrangement

# Turbine Bearings- BBGS

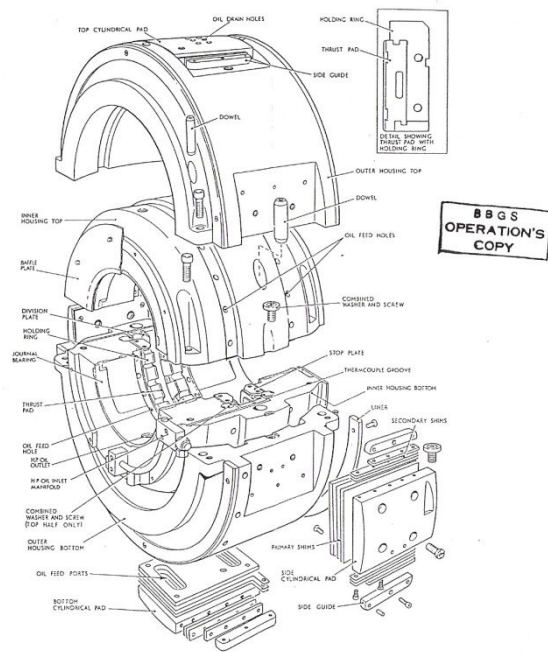


FIG 7 COMBINED BEARING & THRUST  
SM0113

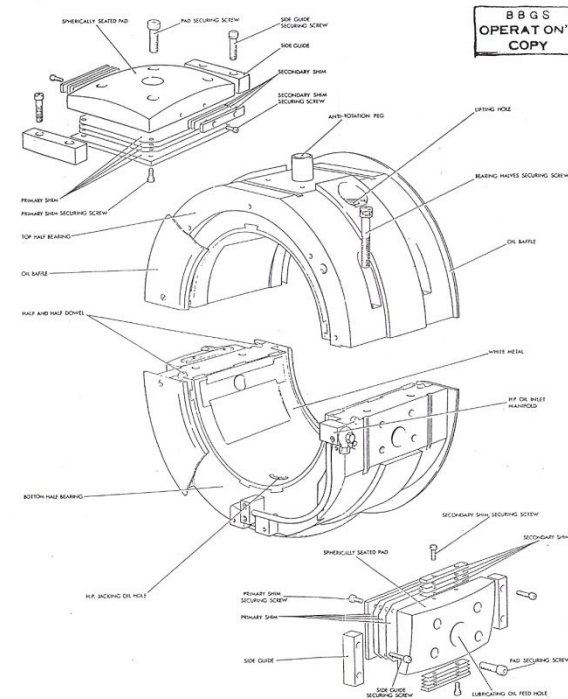


FIG 8 SPHERICALLY SEATED BEARING  
SM0114

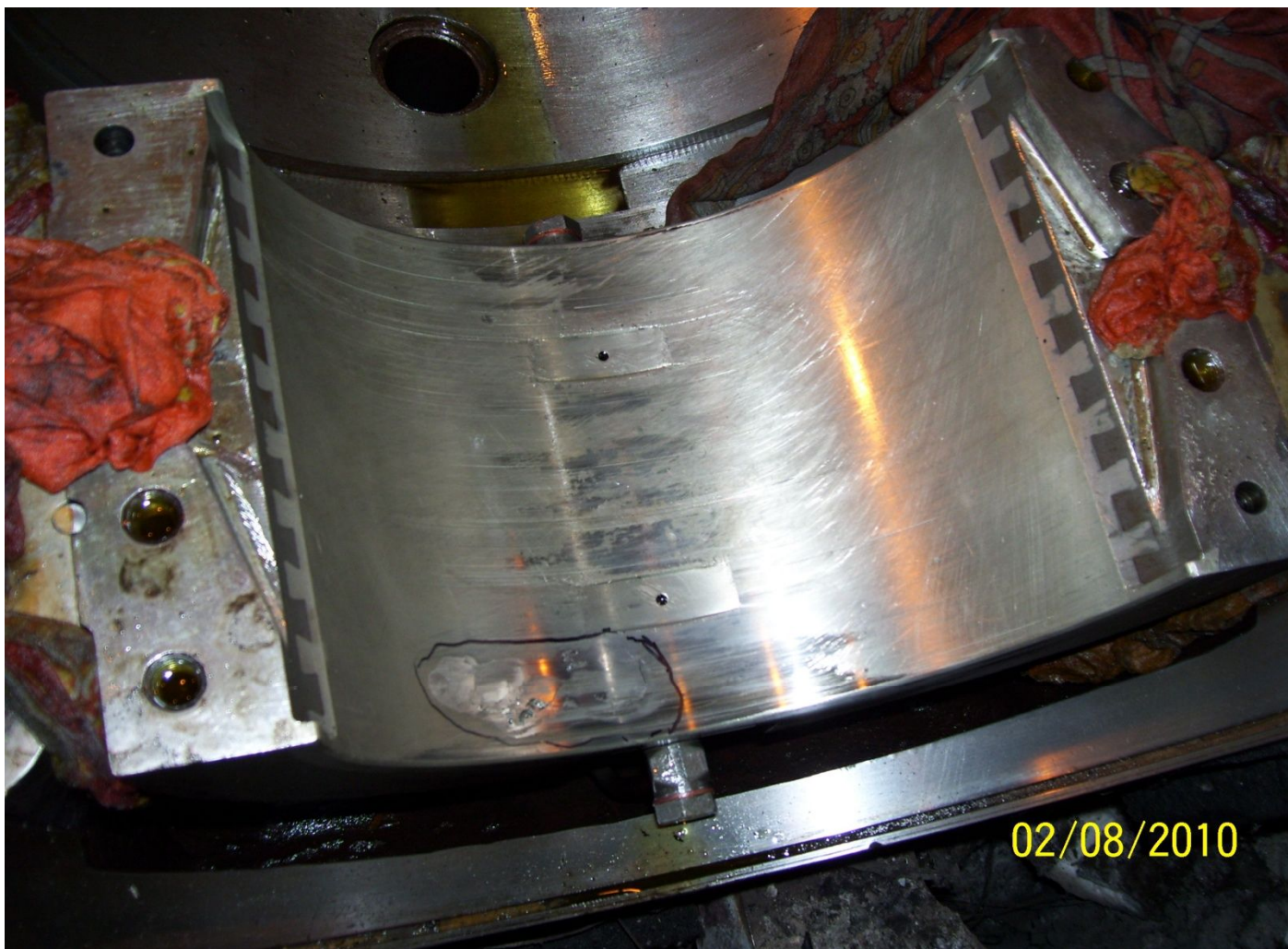
On the left is the figure of bearing No 2 which is a combination of Thrust and Journal

On the right is the figure of remaining Journal bearings which are spherically seated

# BBGS UNIT 1 BEARINGS



## SGS BEARING NO. 2 BOTTOM



# Turbine casing

- Turbine casings are of cylindrical shape having a horizontal parting joint
- The two halves are flanged at the parting plane and are jointed by bolts
- The resting paws are integral to bottom casing
- There can be one or more steam admission pipe connected to the casing



# Turbine casing

- According to main steam pressure the thickness of casing used to be designed
- The shell thickness at HP end gradually reduces towards LP end
- Most of the early casing were built of cast steel machined to mount rows of blades
- With the increase of operating pressure the thickness of turbine casings went higher and higher



# Turbine casing

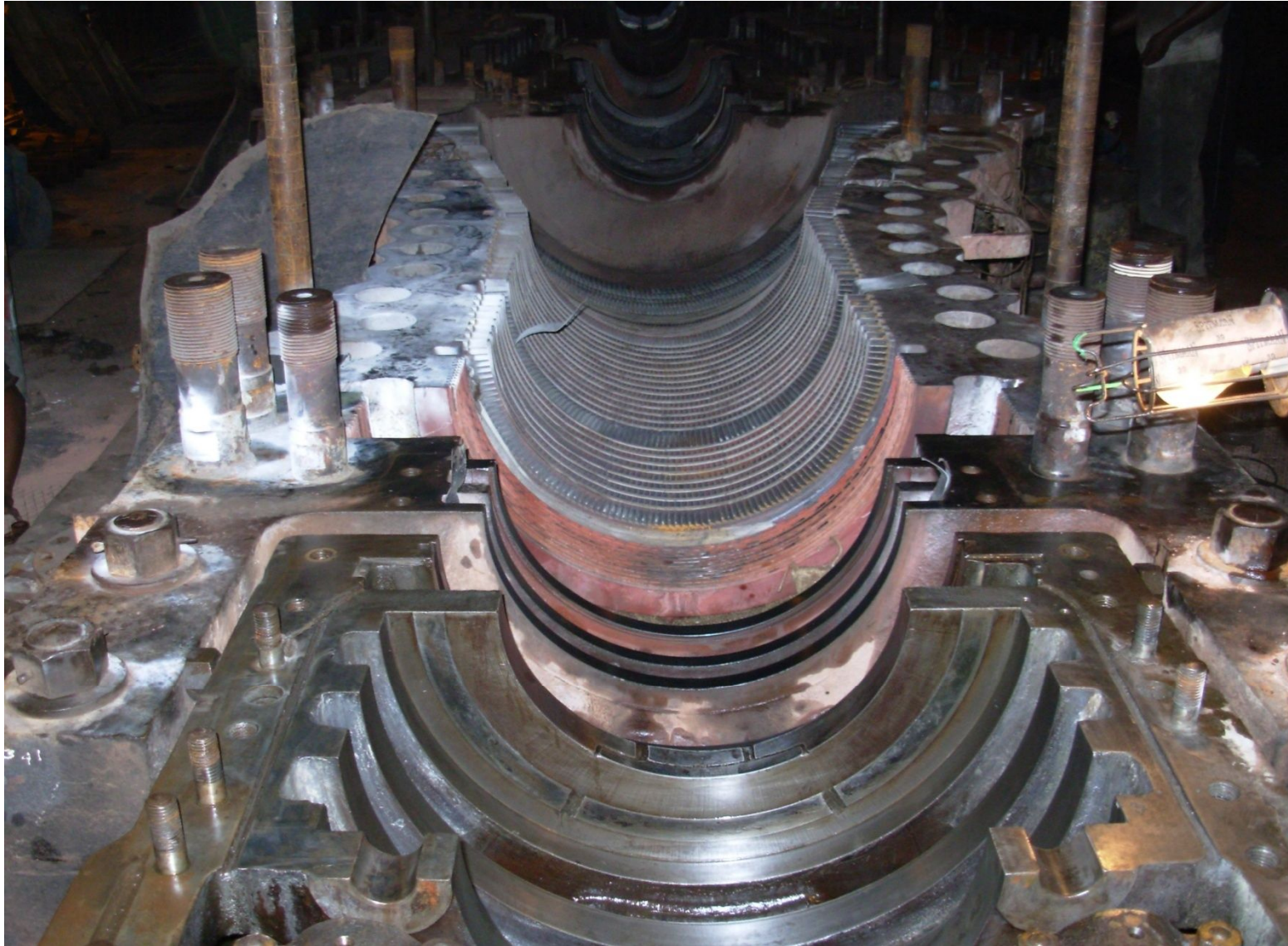
- The increased thickness gave rise to number of problems these are
  - Too heavy to machine/handle
  - Difficulty to warm up avoiding undue thermal stress (Leading to start-up problem)
  - Very long time to cool down
- To overcome this problem double casing turbine was evolved
- Then evolved barrel type design double casing
  - Which gave faster start-up & load cycling feature and
  - Lesser problem related to stress

# Turbine casing

- The 250 MW Turbine set of Budge Budge power plant has 3 casings HP, IP & LP
- While the HP cylinder is completely double barreled, the IP & LP is also double casing but of different type
- The stator inner casings along with blade assembly are in annular segments housed on the outer casings
- LP outer casing has a sealing diaphragm to prevent any over pressurization



## HP SINGLE CASING OF NCGS 2

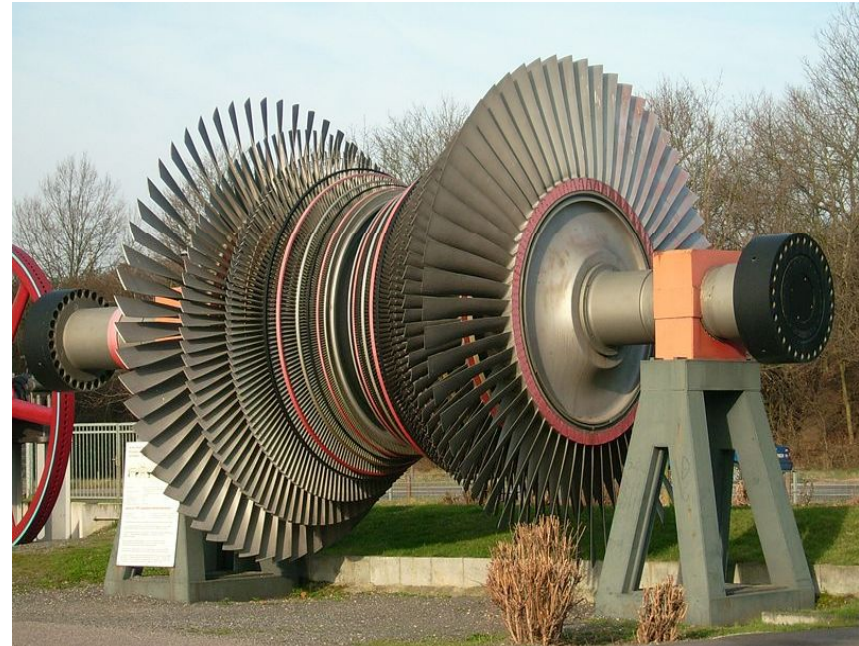


# BBGS HP INNER CASING



# Turbine Rotor

# Turbine rotor



# Turbine rotor

- Turbine rotors are machined out of a single steel forging
- Grooves are similarly machined to mount rotor blades
- Rotors are additionally featured with dummy piston, gland, bearing journal and coupling flange
- The metallurgy in turbine construction has evolved gradually over the years based on growing needs



# BBGS IP AND LP TURBINE ROTOR



# Blades and mounting arrangements



# Turbine blades



# STEAM TURBINE BLADES



# Blade mountings

- Blades are fixed singly or in groups into their grooves with the help of roots commonly configured like ‘fur-tree’
- Mounting arrangements of blades has to take care of the followings:
  - Rigidity so that they do not give away to momentum of steam or vibrations
  - Withstand high centrifugal force that rotor blades experience at 3000 rpm



# Blade mounting arrangements

- The entire array has to be inserted through a open slot in the groove
- The requisite number of blades are thus inserted to form a circular array and are packed tightly by means of wedges
- Special locking arrangements to secure the lot is again an art of construction
- The rotor blades have to be specially assembled to avoid mass unbalance

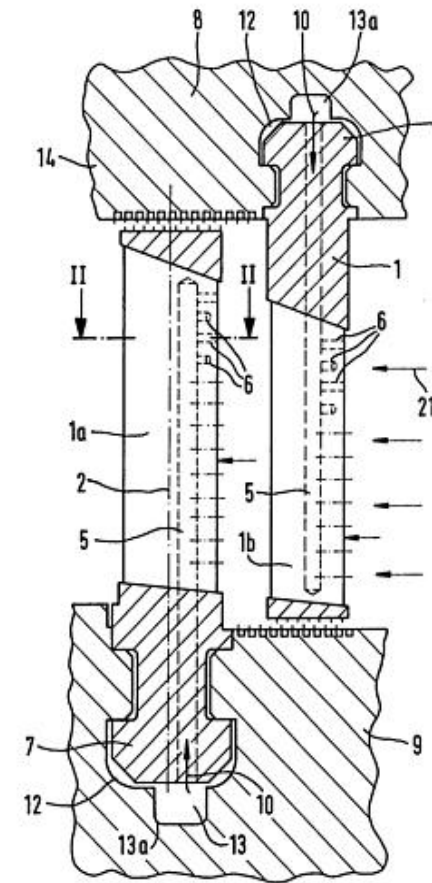
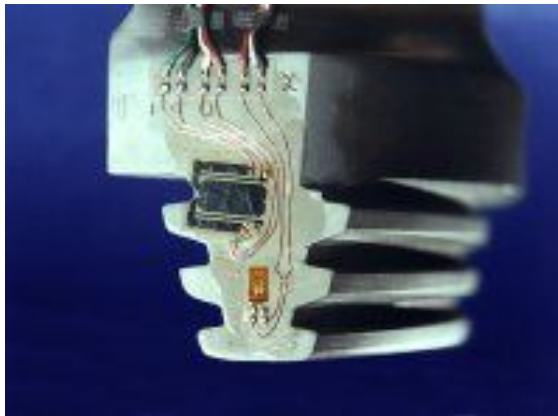


# Blade mounting arrangements

- Subsequent to blade assembly rotors are subjected to dynamic balancing and over-speed testing at shop and site before being put into service
- To correct any mass unbalance rotors are provided with adjusting screw which can be accessed from outside
- Blades at HP stages are usually provided with shrouds



# Blade mounting arrangements



# Blade mounting arrangements

- LP blades are most critical to construct as they can be very long (900 MW sets can have blades 1.2 m long)
- LP blades made of steel cannot be used for making even longer blades
- Titanium alloys having high strength-to-density ratio is making progress
- LP blades are usually provided one or more laces to minimize vibration (other arrangements are also there)



# Interconnected tips of LP blade at BBGS Turbine



# LP blade of BBGS Turbine



# Blade mounting arrangements

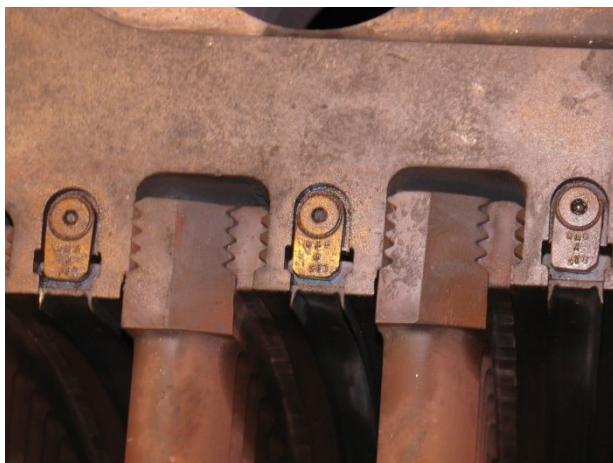
- LP blades are also subjected to torturous operating conditions of handling very wet steam
- The water droplets impinge at very high velocity and cause erosion
- In order to prevent or minimize damage due to erosion, practices followed are:
  - Putting of erosion shields on last few stages
  - Blades are hardened to withstand impact
  - Wet steam is partly by passed to condenser

# Turbine of BBGS

- HP turbine of Budge Budge has 17 stages of reaction blading over an above one impulse wheel
- The IP turbine has 8+5+3 stages in 3 segments of reaction blading
- The LP turbine is double flow type having 7 rows of Left hand blades towards IP end and 7 rows of Right hand blades towards Generator



# BLADE FITTING ARRANGEMENT AT BBGS

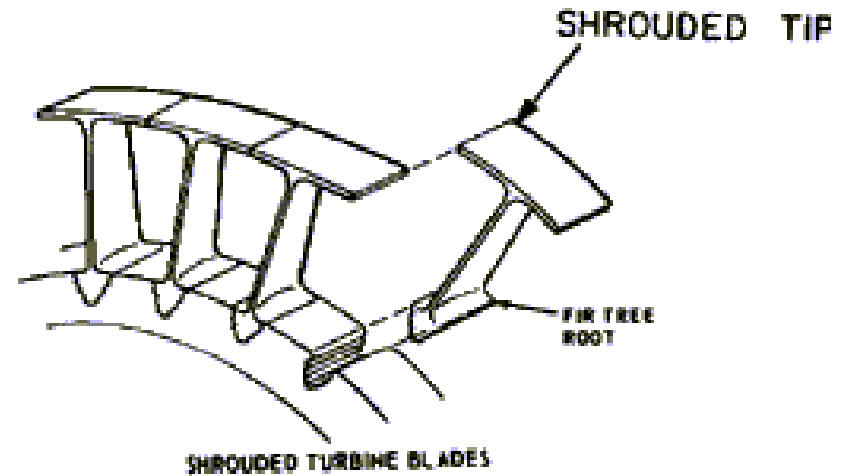


- Most parts and components of steam turbines, are made of steels containing various amounts of the principal alloying elements chromium, molybdenum, vanadium and nickel, etc. Most high temperature rotors, valves and blades, etc. are made of high strength materials such as CrMoV steels and 12% Cr steels

# Shrouds, Axial and Radial seals



# Shrouds, axial and radial seals

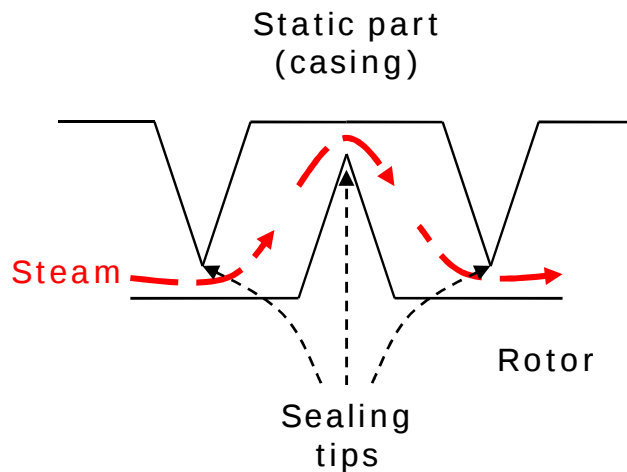


- Figure on top shows the shrouds on blade tips
- Figure on left shows the photographs of turbine blades of various size and shape

# Shrouds, axial and radial seals

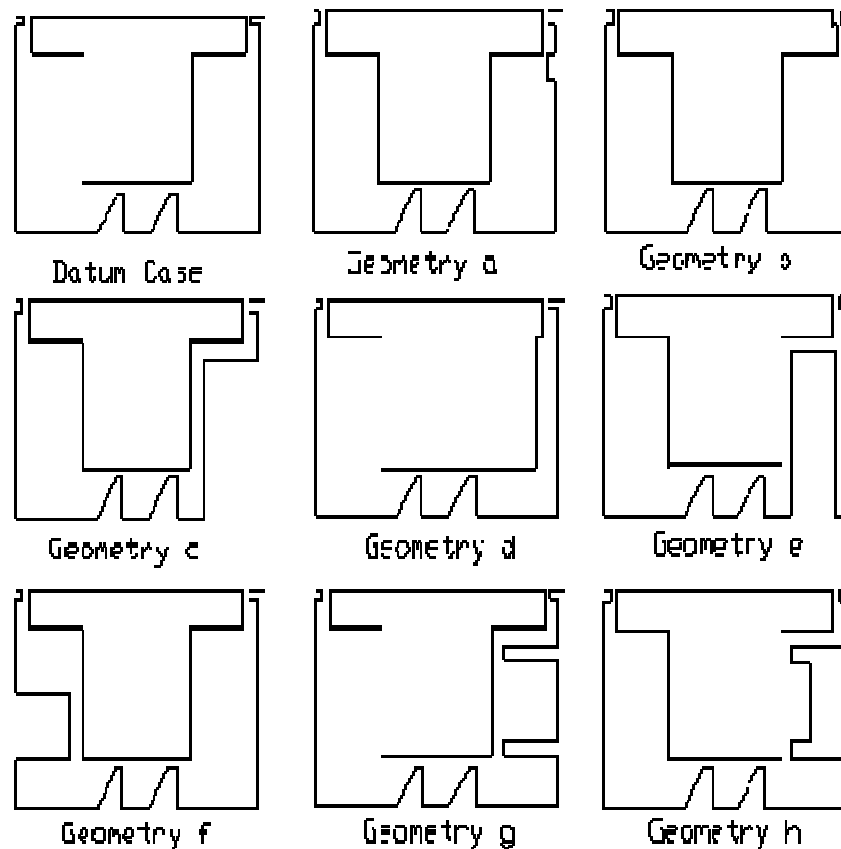
- To prevent steam from by passing the blade passage, the sealing arrangements are provided
- Both static and rotating blades are provided with seals
- Depending on their orientation with respect to the turbine axis these are termed as radial or axial
- Seal offers a more resistive path to steam in between stages

# Shrouds, axial and radial seals



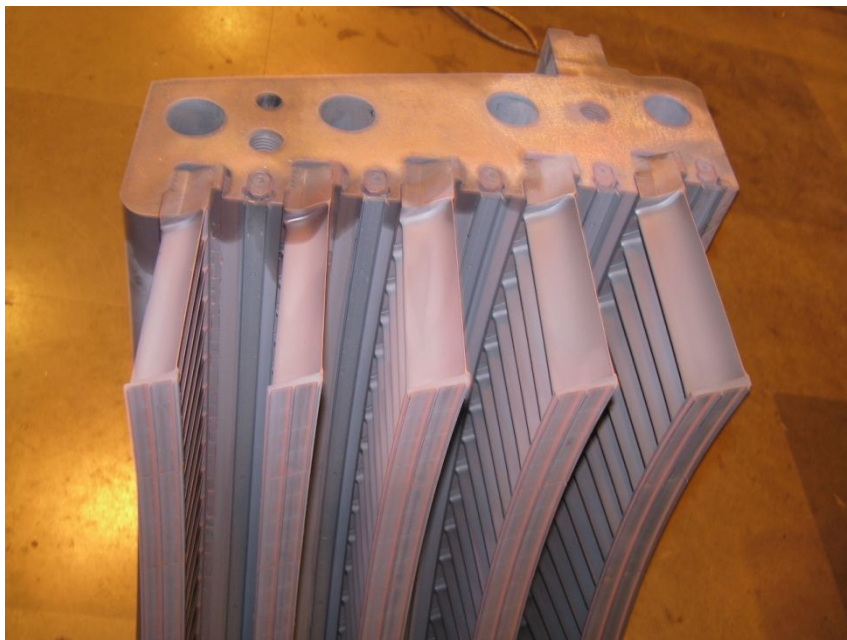
- There are very small clearances between the tips of static and rotating parts
- Multiple constrictions throttle the steam and creates a resistive path
- Shrouds over the blades are fitted with such seals

# Shrouds, axial and radial seals



- Figures on the left show geometries of typical blade seals
- Designers adopt a configuration that suit best to specific requirement
- The seals play vital role in deciding internal efficiency of Turbine

# SHROUDS AND SEALS



# Material

- **15Cr11MoV** is used as blade material for operation at 540 deg C
- **15Cr12WNiMoV** is used as blades, fasteners, turbine disks & rotors for operation at 550-580 deg C

*Both of these are Martensitic & Martensitic-Ferritic Steels*

|              | C         | Cr      | Mo      | V        | W       | Ni      |
|--------------|-----------|---------|---------|----------|---------|---------|
| 15Cr11MoV    | 0.12-0.19 | 10-11.5 | 0.6-0.8 | 0.25-0.5 |         |         |
| 15Cr12WNiMoV | 0.12-0.18 | 11-13   | 0.5-0.7 | 0.15-0.3 | 0.7-1.1 | 0.4-0.8 |



# Advancements

- The progress have been made in
    - material technology
    - in casting and forging techniques
  - These have lead to development of steels for rotors, casings and turbine blading to suit steam conditions above 600°C
  - Adoption of advanced design techniques like
    - finite element method in mechanical calculations
    - use of computers in flow mechanics
- Has lead to development of 3-D blade profile that is 96% efficient and is gradually getting standardized

# Advancements

- Improvement through the followings will contribute marginally
  - in sealing techniques such as brush type glands
  - use of abrasive coatings (like gas Turbine)
- Other major avenues are
  - development of material science and further increase of steam temperature
  - optimizing the ‘cold end’ i.e. LP blading

# Advancements

- To cover all sorts of demands from the market manufactures have gone for Standardizing modular product range as the present trend.
- The customer can choose from various standard models according to unit size, cost and specific needs
- Some such modules from Siemens/ Westinghouse USA are as follows  
( These modules are the basic building blocks for higher ones)

# Thrusts in a steam turbine

# Thrust arrangements

- Thrust along the rotor axis in a turbine is generated due to
  1. reaction force (axial component) due to change in axial momentum of steam between blade entry and exit
  2. pressure difference between either sides of blades in a row (this is mainly applicable in reaction turbine)
  3. friction in blade (in an impulse turbine thrust produced is only due to this)(direction of the force in 1 is opposite to those of 2 & 3)

# Thrust arrangements

- The effect of all such forces produced by a single blade when summed up for the entire turbine produce huge amount of force
- There are various means by which the resultant thrust in the rotor is counter acted, these are:
  - Counter flow arrangement
  - Dummy pistons, applied with appropriate pressure on either sides

# Thrust arrangements

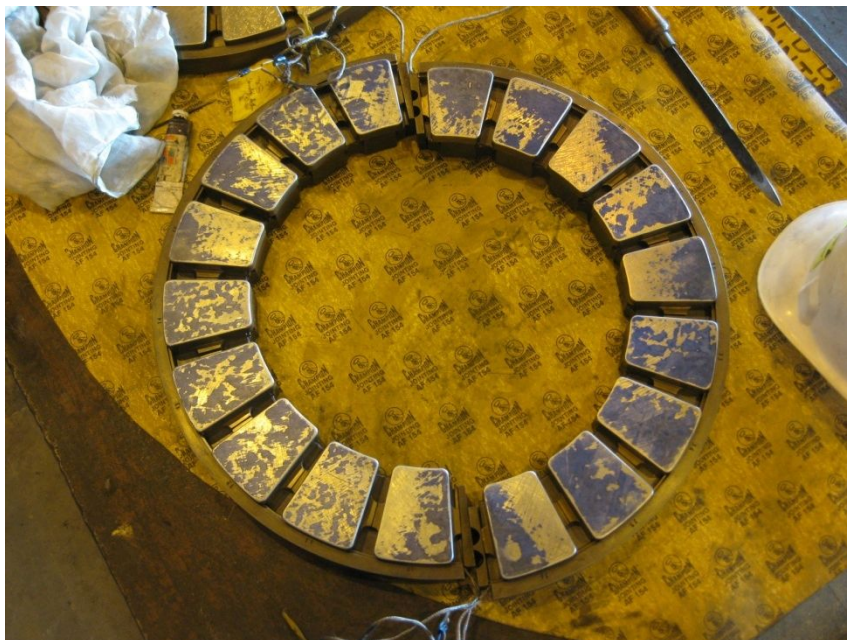
- Dummy piston



# Thrust arrangements

- Complete balance cannot be achieved for the entire range of turbine load with the above arrangement
- Collar (s) on rotor with oil lubricated thrust pads take the residual thrust
- Turbines having multiple cylinder & rotor can have one single thrust collar when rigidly coupled, otherwise rotors have individual thrust collars

# TURBINE THRUST BEARING



# Support anchor & expansion provision of Turbine

Following slides are in reference  
to Budge Budge Turbine

# Provision for Expansion

- Heating and cooling takes place in a turbine during start-up, shutdown and load changes
- Relative expansion and contraction also take place between various part
- Guides and keys are designed to accommodate the movement of cylinder, shaft due to thermal changes
- While doing so the relative alignment has to be maintained

# Provision for Expansion

- HP & IP cylinders of Budge Budge unit 1,2 turbine have cumulative axial expansion from its anchor point at LP end of IPT towards HP end
- The LPT expands axially from its own anchor point in either direction
- Transverse expansion of cylinder take place from machine centre to maintain axial alignment
- Cylinders are supported on centerline permitting expansion in vertical plane & ensuring running clearances between shaft and cylinder

# BBGS Turbine

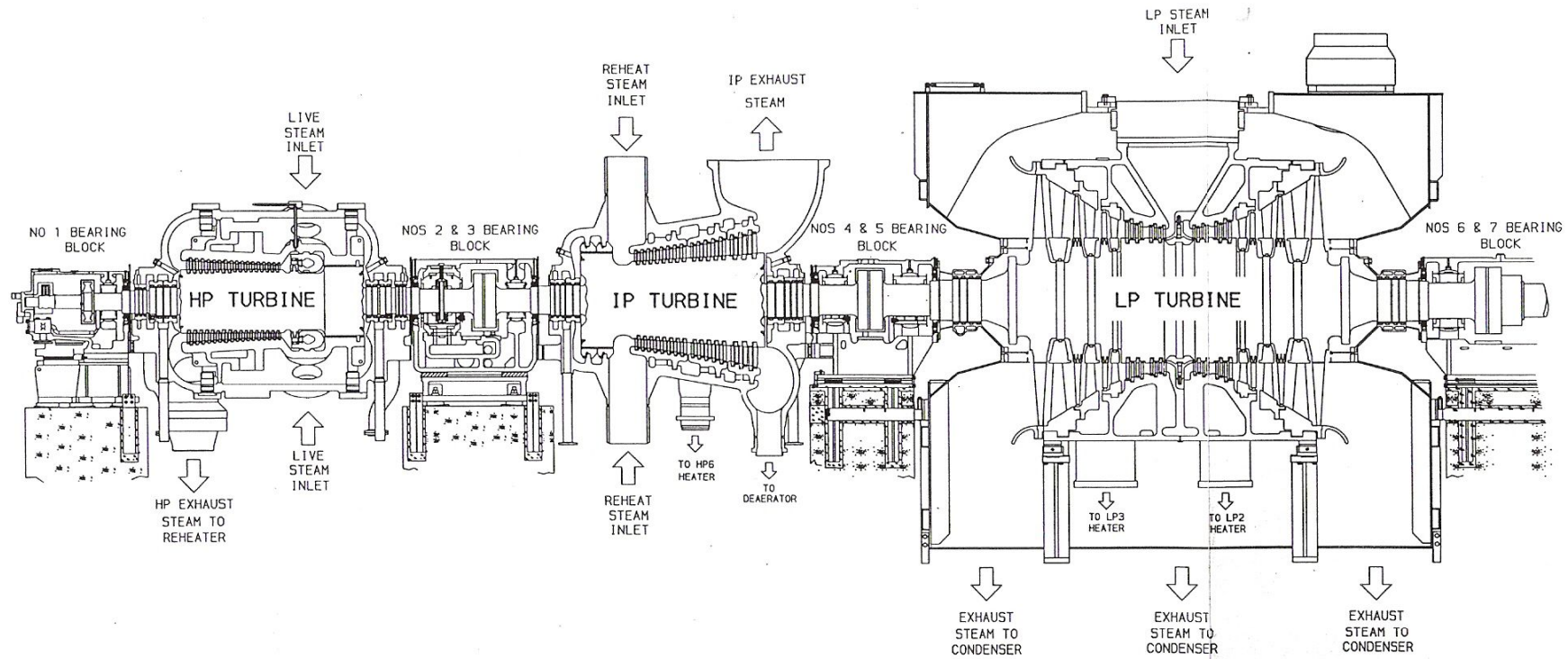
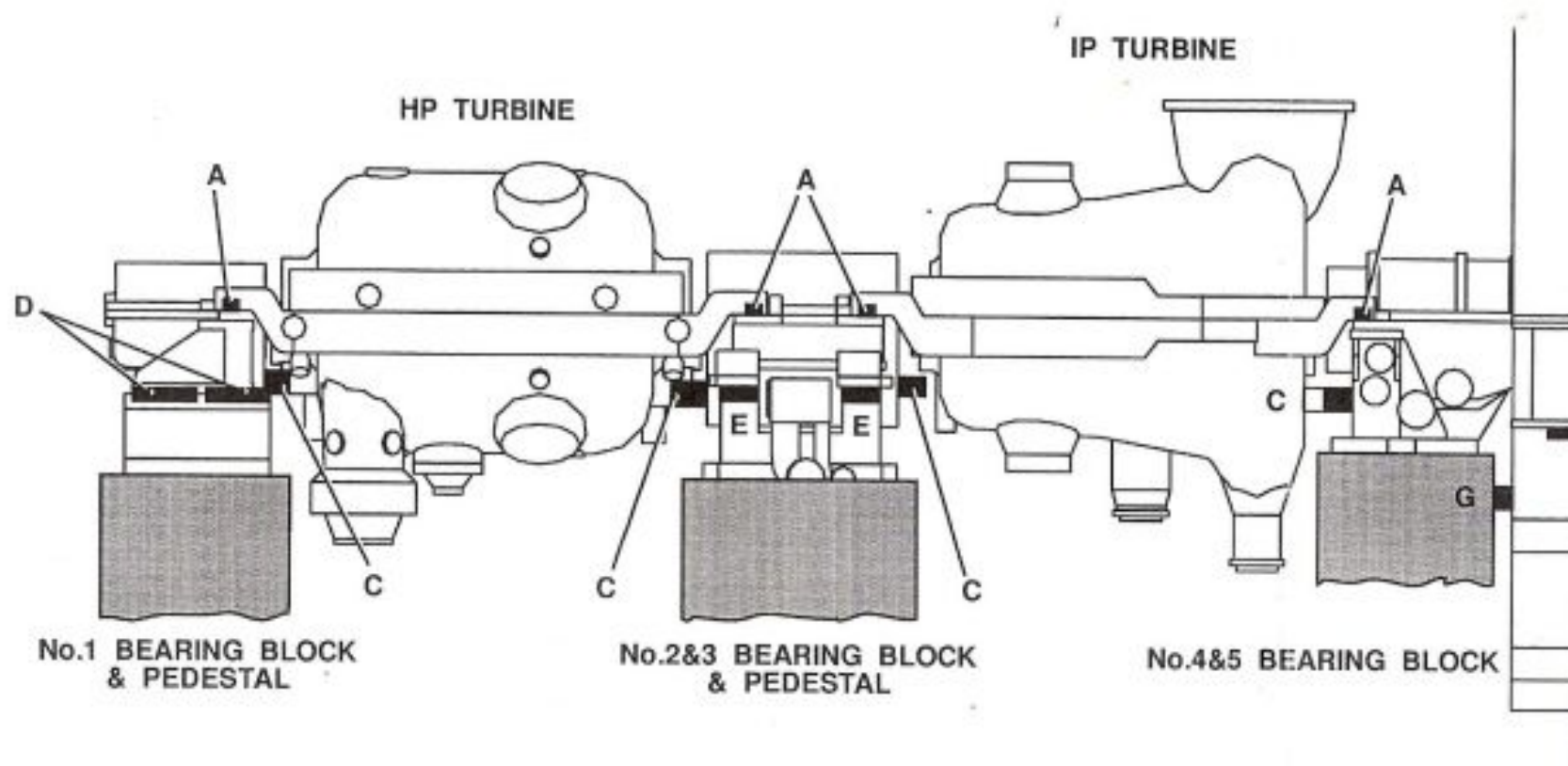


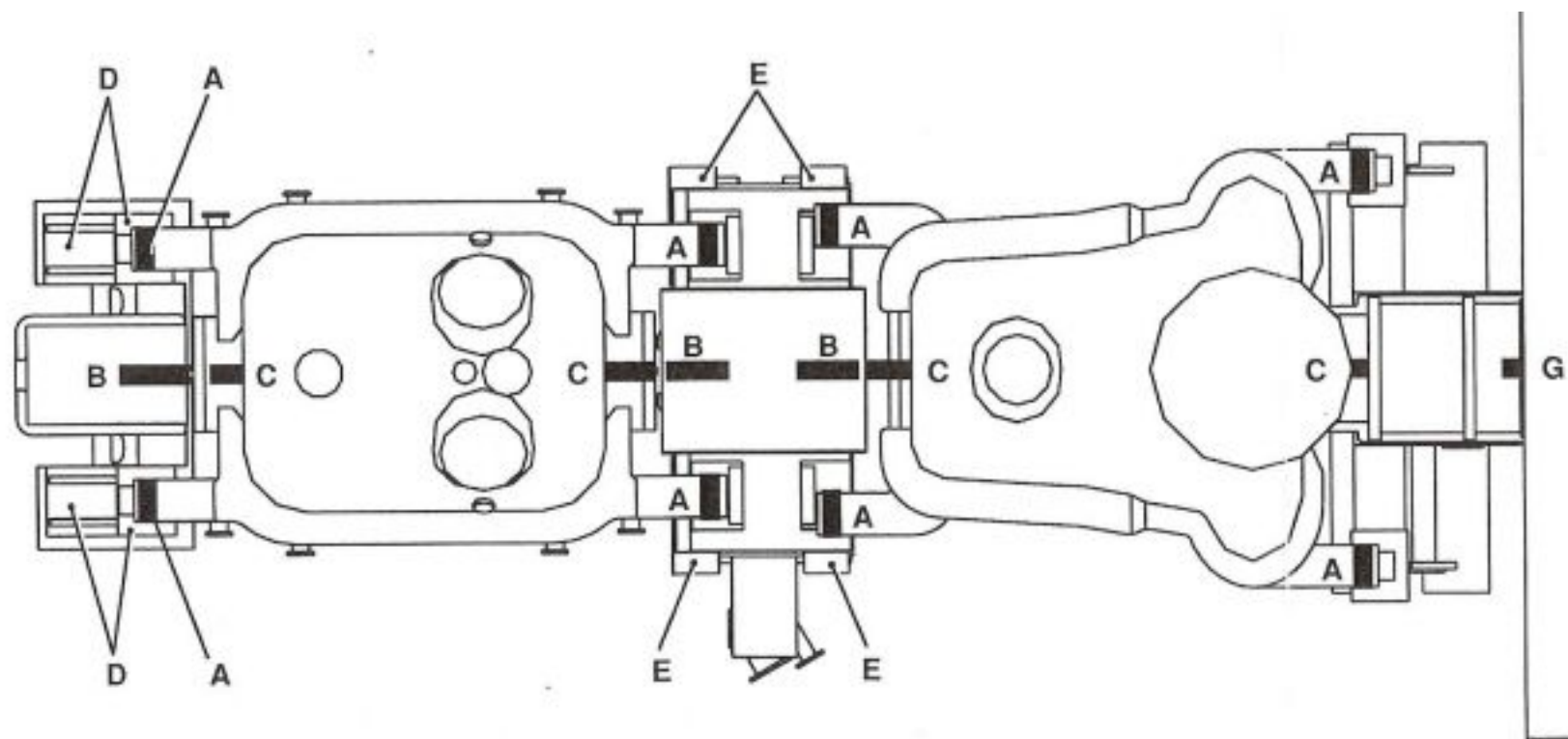
FIG 1 THE TURBINE  
SMO747

# Supports and anchor of HP & IP Turbine at BBGS (elevation view)



A   B   C   D   E   F   G   H

# Supports and anchor of HP & IP Turbine at BBGS (plan view)



A   B   C   D   E   F   G   H

# Provision for Expansion

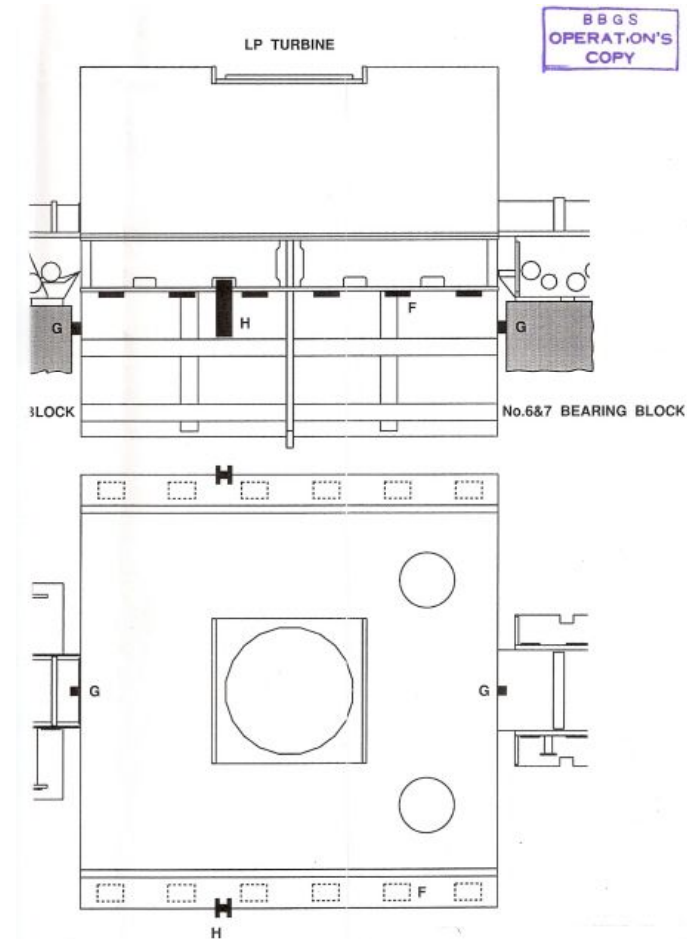
- No 1 Bearing Block supports the free end of HP Turbine
- Nos 2 & 3 combined bearing blocks support coupled ends of HP & IP turbines
- Both blocks can slide freely on their pedestals
- The No 4 & 5 combined bearing blocks support coupled ends of IP & LP turbines has fix pedestal that acts as the anchor point for cylinder expansion

# Provision for Expansion

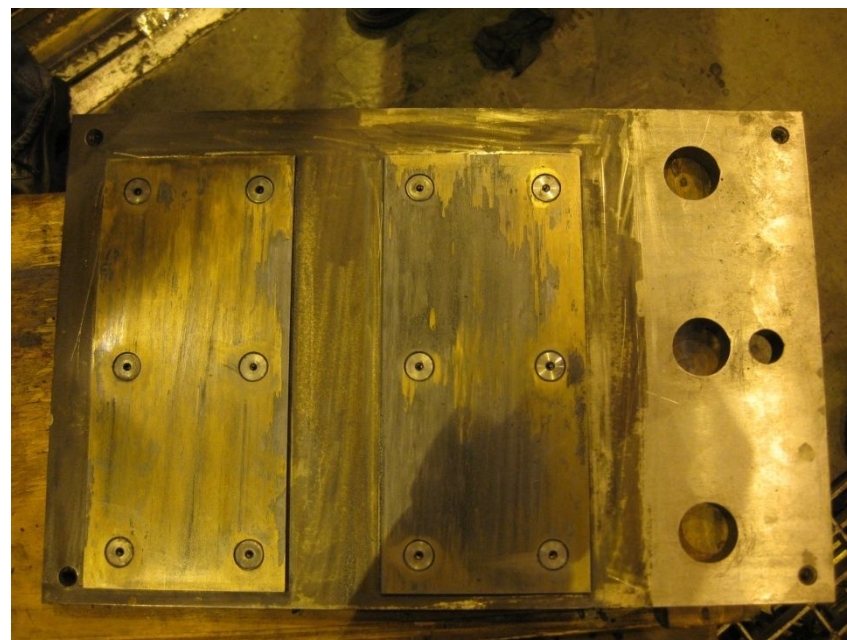
- Wherever sliding movement has been envisaged between two relatively expanding surfaces anti-friction plates are placed
- Pointer and scale fitted on moving and stationary bodies give reading of expansion directly
- In order to monitor the expansion from control room position transducers (LVDT) are used in most modern turbines

# Provision for Expansion

- The figure on right are views of plan and elevation of LP turbine casing showing locking arrangement and provision for expansion



# LUBRIDE PLATES FOR EXPANSION



# Differential Expansion

# Differential Expansion

- With increase of temperature, both rotor and the cylinder expands
- Ideally both of them are supposed to expand uniformly as both are heated by same steam
- Practically because of difference in thermal mass and conductive heat flow they expand unequally
- Differential expansion is the relative difference between the expansions of rotating shaft and stationary cylinder

# Differential Expansion

- If expansion of stator be  $e_s$  and expansion of rotor be  $e_r$ , then conventionally differential expansion is  $e_s - e_r$
- In the above convention +ve increment of value will signify a relatively hot stator and vice-e-verse
- It is important to monitor differential expansion to ensure blade clearances are maintained
- Physical restraints on rotor is the thrust collar (located in no 2 bearing)

# Differential Expansion

- As the IP cylinder expands with temperature the thrust collar on no 2 bearing housing moves towards HP end along with the rotor
- The IP rotor expands towards LP end from the thrust collar
- The HP rotor expands towards HP end from the thrust collar
- However relative movement of HP & IP shaft and cylinder can be assessed from No 1 & No 4 bearing housings respectively

# Differential Expansion

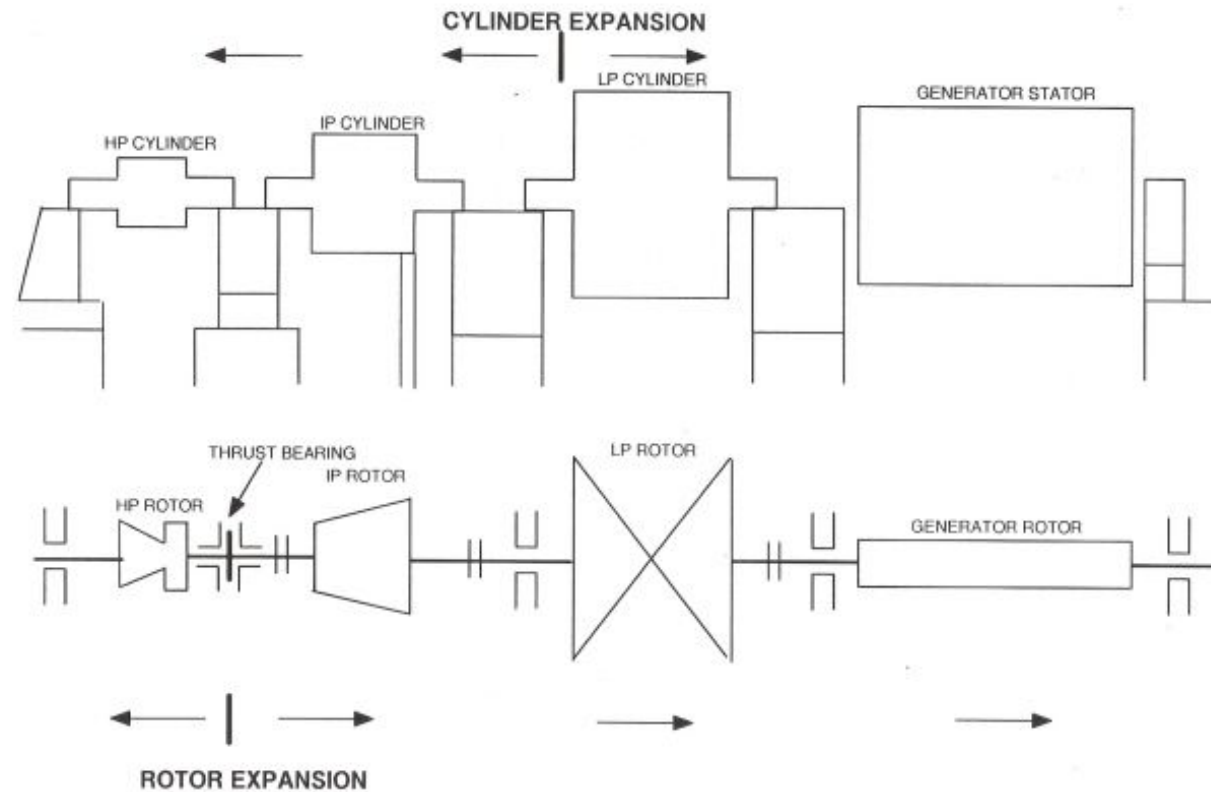
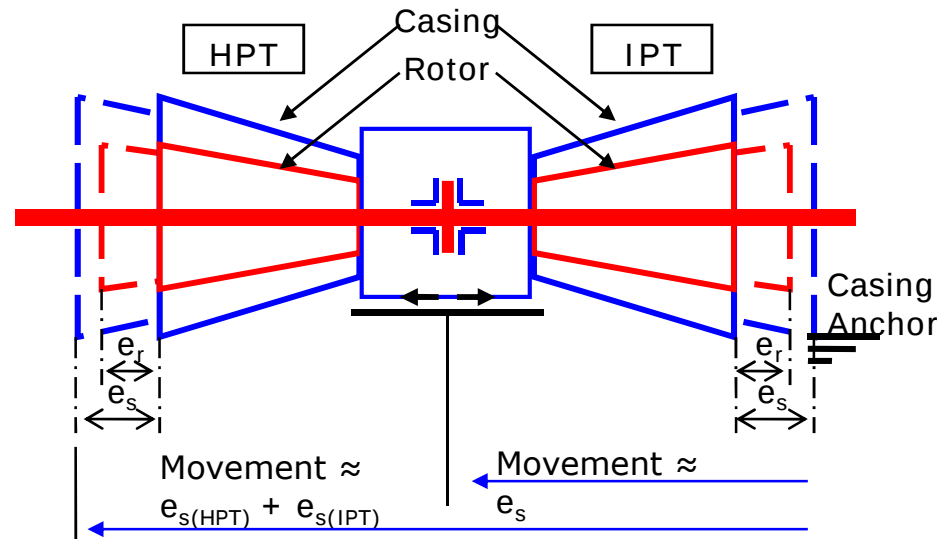


FIGURE 5.1 EXPANSION DIAGRAM

# Differential Expansion



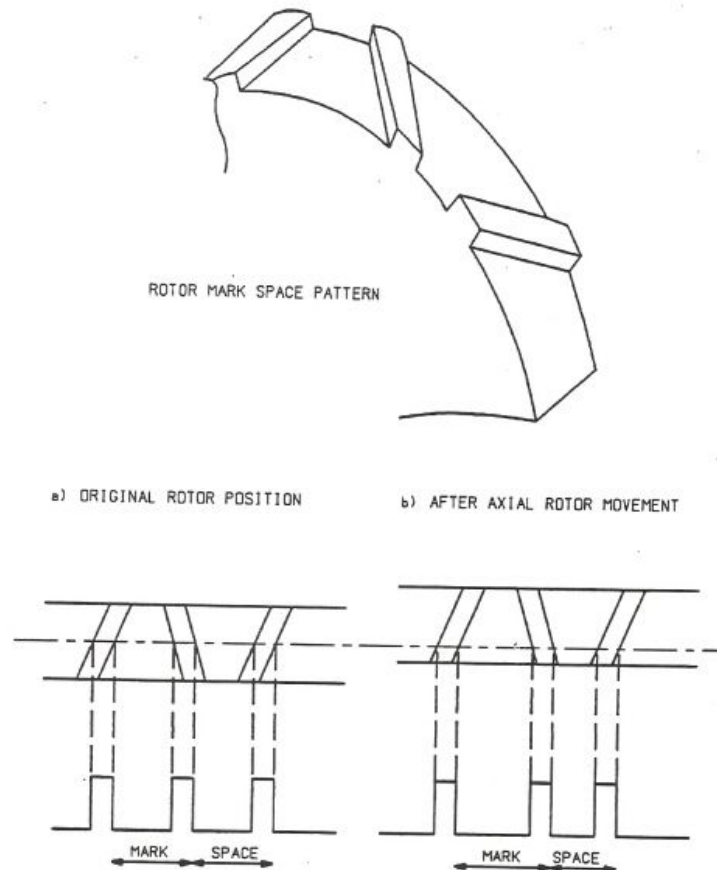
- HP differential Expansion is  $e_{s(HPT)} - e_{r(HPT)}$
- IP differential Expansion is  $e_{s(IPT)} - e_{r(IPT)}$

# Differential Expansion

Method of measurement of IP and HP differential expansion (refer to previous diagrams)

- The axial movement of shaft relative to the housings of No 2 & No 4 bearings give the respective differential expansions of HP and IP Turbine
- These movements are registered by sensors mounted on housings which senses markings on the shaft from very close proximity

# Differential Expansion



- Patterns known as 'Mark' and 'Space' is inscribed in a collar of the rotor
- A probe is positioned centrally above the collar
- The movement of shaft off sets the probe from the centre
- While the collar make a complete rotation it senses different intervals

# Differential Expansion

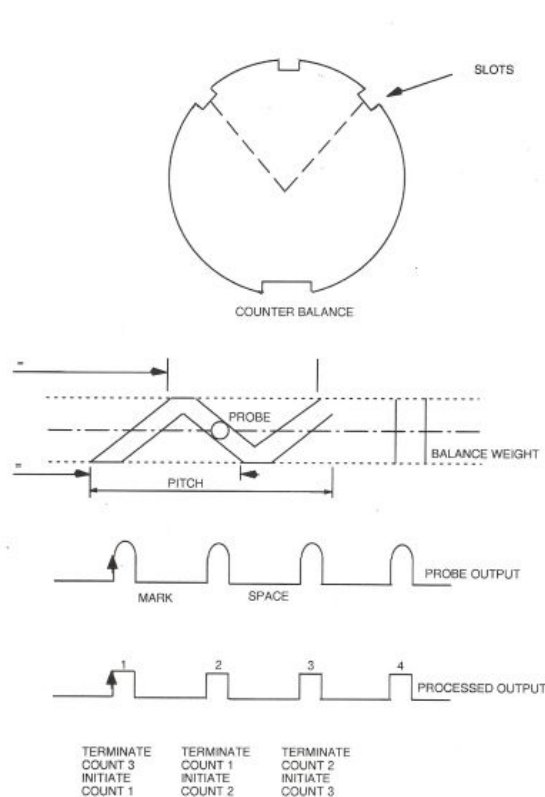


FIGURE 5.3 SINGLE MARK / SPACE PAIR WITH COUNTER BALANCE

- The figure on the left is the real version of differential expansion measurement markings in Budge Budge
- The bottom slot is cut to equalize any unbalance of mass due to the markings groves made on the top
- Differential expansion =  $\text{Ratio} (\%) / \text{Gain} - \text{const.}$

(where  $\text{Ratio} = \text{Mark Count} \% (\text{Mark Count} + \text{Space Count})$ )

# Differential Expansion

- Differential expansion of LP is assessed by deducting LP shaft movement from LP casing movement
- The measurement does not really indicate the sole differential expansion of LP because LP shaft movement is influenced by the effect of IP differential
- The turbine manufacturers specify the maximum & minimum limit values for each of these

# Axial Position of Rotor

- The turbine rotor remains located by means of thrust collar and pad arrangement at a definite location (which is No 2 bearing for Budge Budge Turbine)
- The rotor can float axially only to the extent of gap that exist between the two pad assembly at front and rear of the collar and the collar itself
- In the event of excessive rotor-thrust the pads can wear off and the shaft location can get disturbed

# Axial Position of Rotor

- It is important to monitor the position of a rotor of a turbine during normal running
- Some old machines had mechanical pointers to indicate shaft position, which at present have been replaced by electronic transducers
- Modern turbines incorporate 'trip' from axial shift as a basic Turbine protection scheme

# Turbine Barring Arrangement

# Turbine Barring

- Once a running turbine is shut down, the shaft speed starts to "coast down" and it comes to a complete stop
- Heat inside a turbine at stationary condition concentrate in the top half of the casing
- Hence the top half portion of the shaft becomes hotter than the bottom half.
- If the turbine shaft is allowed to remain in one position for a long time it tends to deflect or bend
- The shaft warps or bends only by millionths of inches, detectable by eccentricity meters.

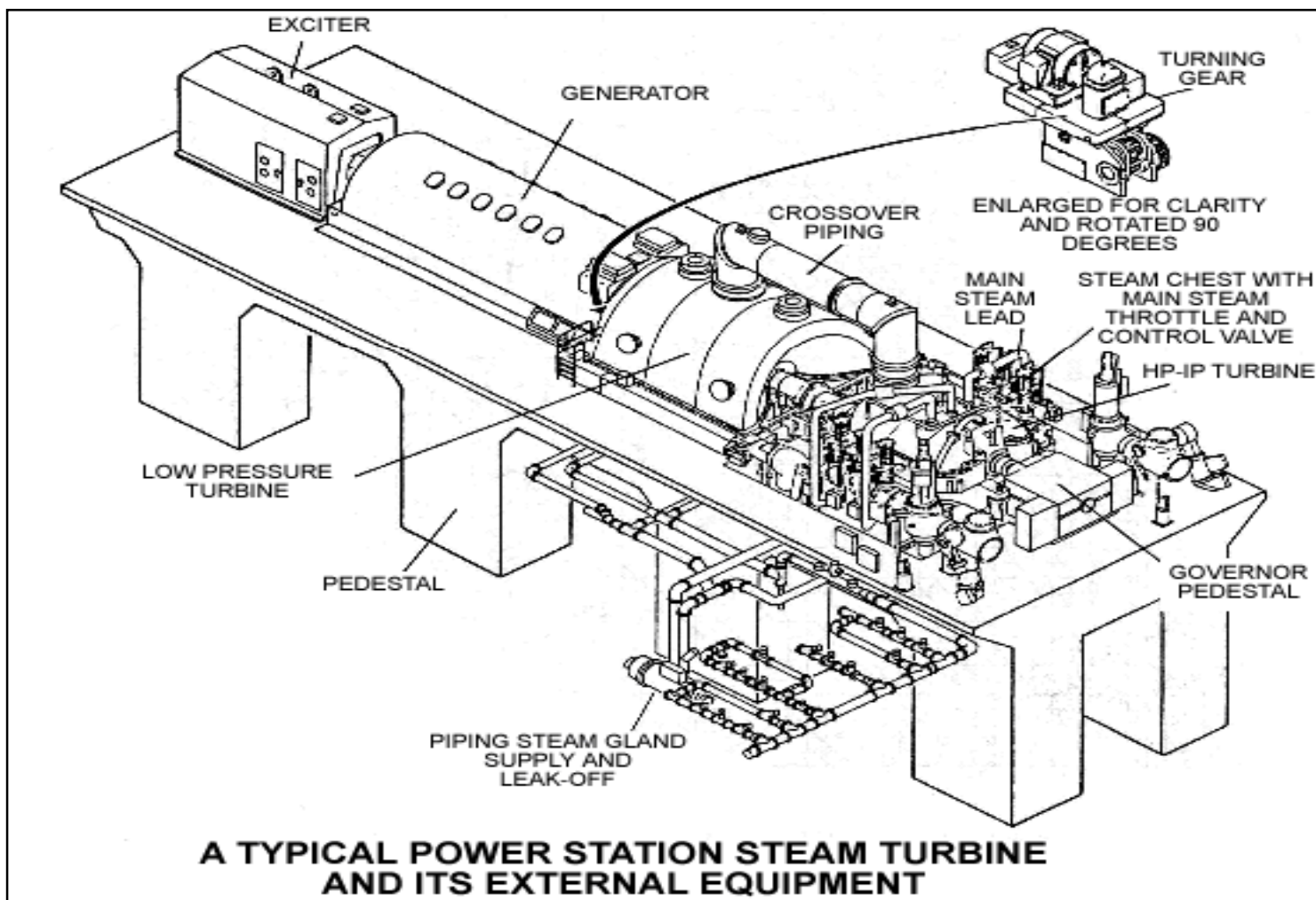
# Turbine Barring

- But this small amount of shaft deflection would be enough to cause vibrations and damage the entire steam turbine unit when it is restarted.
- Therefore, the shaft is not permitted to come to a complete stop by a mechanism known as "turning gear" or "barring gear" that takes over to rotate the shaft at a preset low speed.
- The barring gear must be kept in service until the temperatures of the casings and bearings are sufficiently low

# Turbine Barring

- There are various drive systems to achieve this slow rotation, powered by electric or hydraulic motors
- They are mounted on the main shaft directly or through gears
- Barring speed usually range from 1 to 50 rpm
- When the turbine is speeded up the drive automatically disengage itself
- The engagement can either be manual or automatic
- At Budge Budge turbine the electrically driven turning gear can automatically disengage or engage itself during startup or shutdown

# Turbine Barring



# Turbine Barring (BBGS)

- Barring gear

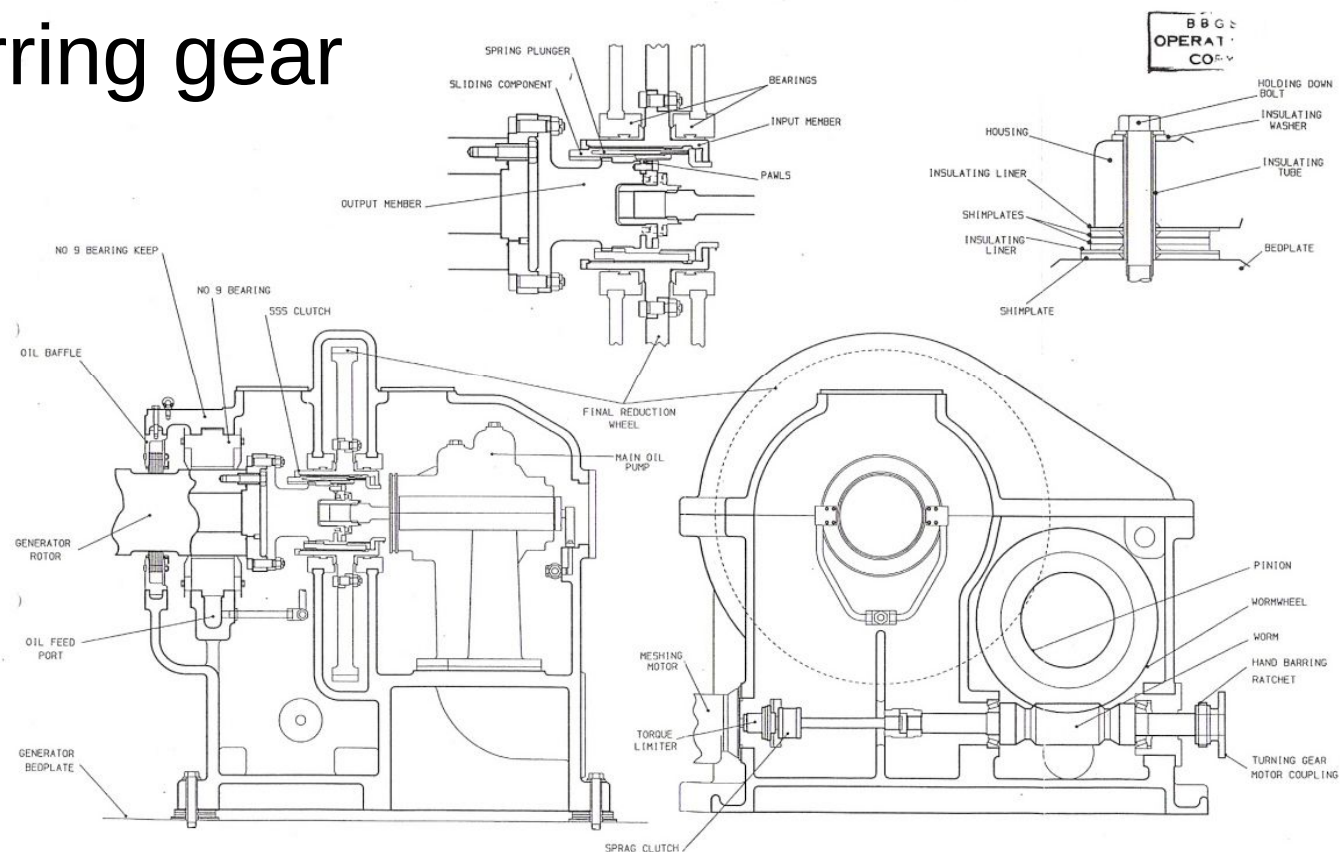


FIG 6 No 9 BEARING & TURNING  
GEAR HOUSING  
SM0494

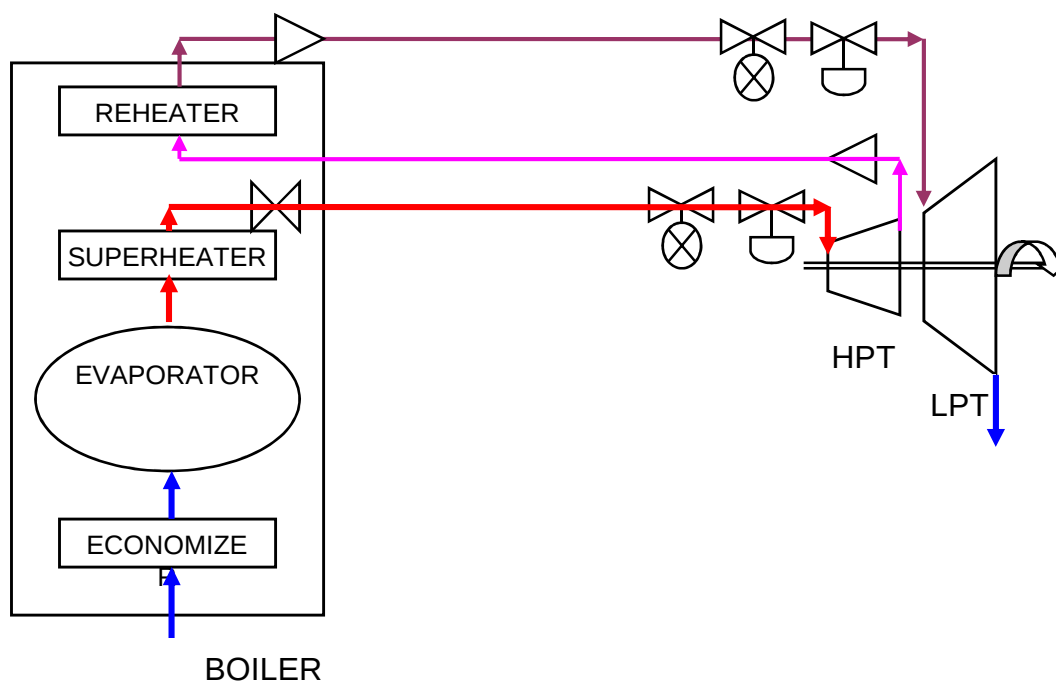
# Steam admission system

## Valve layouts

# Steam admission & control valves

- In order to enable the final steam from boiler to enter the turbine, piping and valves are suitably arranged
- Boilers are usually provided with stop valves to isolate steam, for large units these are motorized
- Turbines are essentially equipped with steam valves for two purposes, these are known as:
  - a) Emergency Stop Valve (ESV) that can shut off steam very quickly in case of turbine trip
  - b) Governor Valves that regulate steam admission into the turbine according to its output loading

# Steam admission & control valves



**Boiler stop valve**  
**HRH NRV**  
**Turbine ESVs**  
**Governor Valves**  
**CRH NRV**

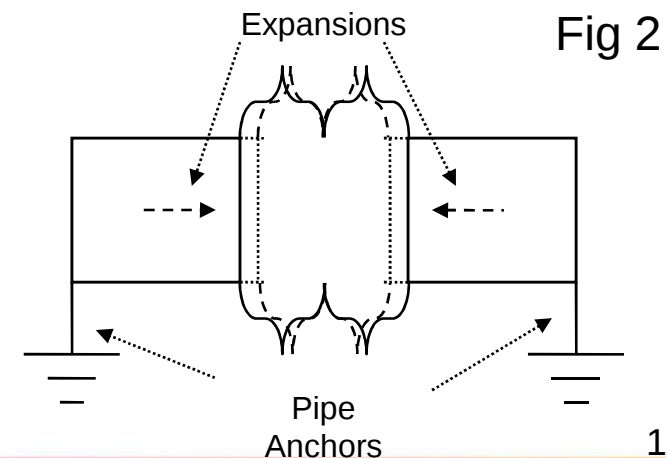
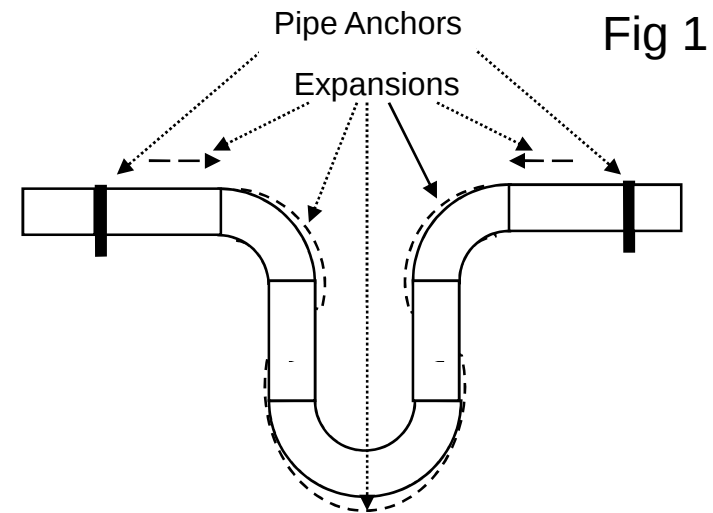
**The above is the  
schematic layout  
configuration of  
steam valve for  
normal turbines**

# Steam admission & control valves

- Piping layout for all the steam lines from boiler to turbine has to take care of the followings:
  - Adequate support arrangement to sustain normal as well as shock load and also proper freedom of movement
  - Provision for thermal expansion in accordance to the predetermined restrain and freedom of movement allowed in the support arrangements, thereby avoiding of undue stress
  - Facility to drain out condensation that can accumulate during start up as well as normal running
  - The draining arrangements should also allow steam flow to warm up the pipe line at a desired rate
  - The pipelines has to be heat insulated according to their temperature levels to prevent stress and heat loss

# Steam admission & control valves

- Sometimes due to space constraints linear expansion cannot be accommodated in a single run
- In such cases two popular method of expansions are shown
  - Fig 1 is for high pressure applications
  - Fig 2 in low pressure



# Steam admission & control valves

- Pipes carrying steam from the boiler arrives at the “Steam Chest” close to the turbine
- Steam Chest is a thick walled casing divided into compartments that house the Emergency Stop Valve and Governor Valves
- Steam chests and are also fitted with strainers to trap objects that may be swiped by steam into the turbine
- Outlet pipes from Governor Valves enter into the turbine

## Steam admission & control valves

- Emergency Stop Valve and Governor Valves are powered to open hydraulically against spring force
- The hydraulic systems can be of low pressure or high pressure types
- Hydraulic pressure derived from pumping arrangement of lubricating oil are usually Low pressure type of system
- High pressure systems have separate pumping units independent of lubricating system and can use special fire resistant fluid instead of hydraulic oil
- High pressure systems are lesser in size and faster in action compared to Low pressure version
- Outlet pipes from Governor Valves enter into the turbine

# Steam admission & control valves

- Entry of steam into the turbine can be controlled by two basic means
  - Throttle Control
  - Nozzle Control
- By-pass governing is another method which is not very popular
- Schematic arrangements of throttle and nozzle governing are shown in Figure 1 & 2

Fig 1

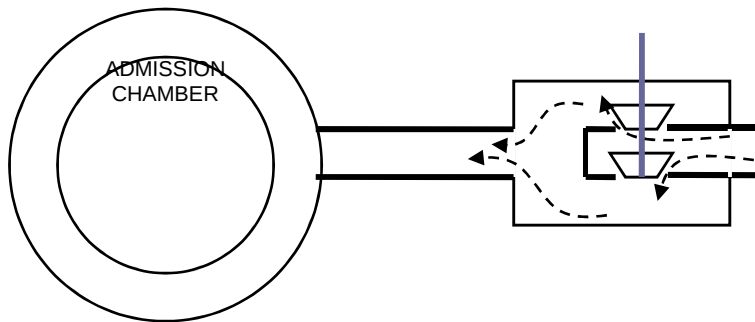
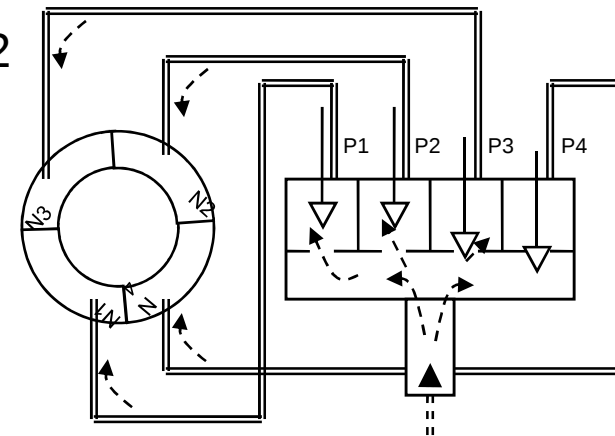
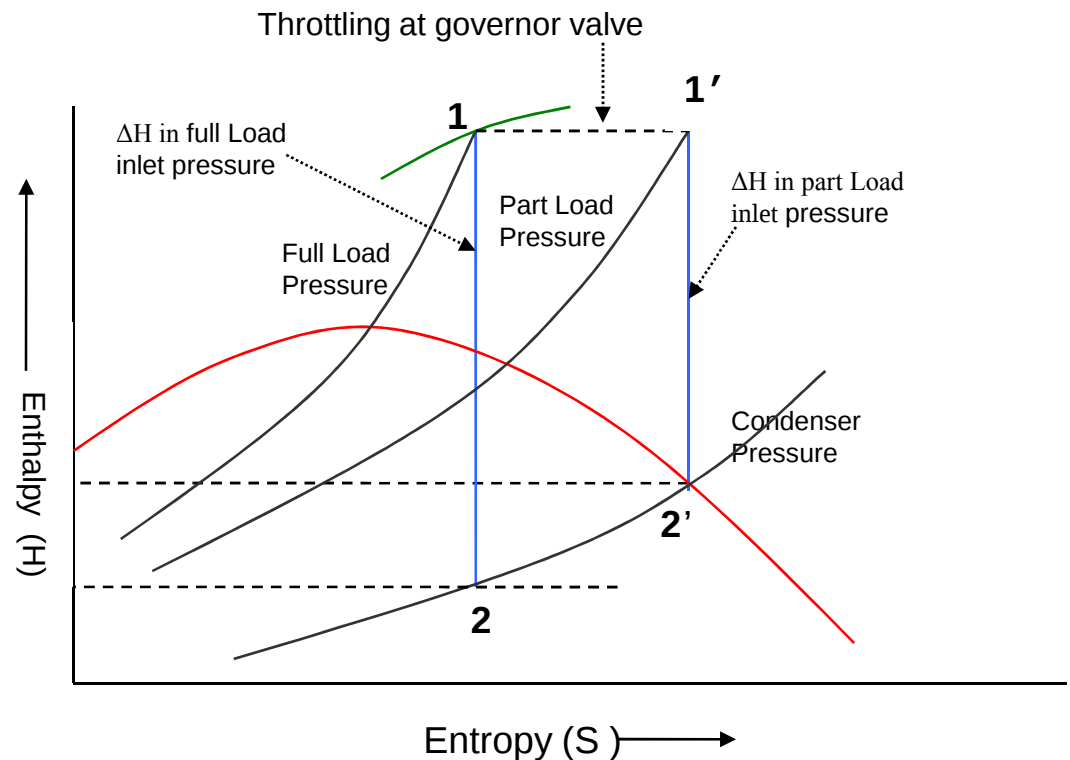


Fig 2



# Steam admission & control valves

- The H-S diagram shows the principle difference between the two modes
- In case of nozzle governing there is a throttle loss in intermediate positions of nozzle control valves, [ i.e. between two “valve points” (vide previous figure);  
During turbine loading, when (say) P1, P2 is full open while P3 is part open (and P4 shut)]



Enthalpy drop from 1- 2 is more compared to that from 1' – 2'

# BBGS STEAM VALVES



# Turbine Governing

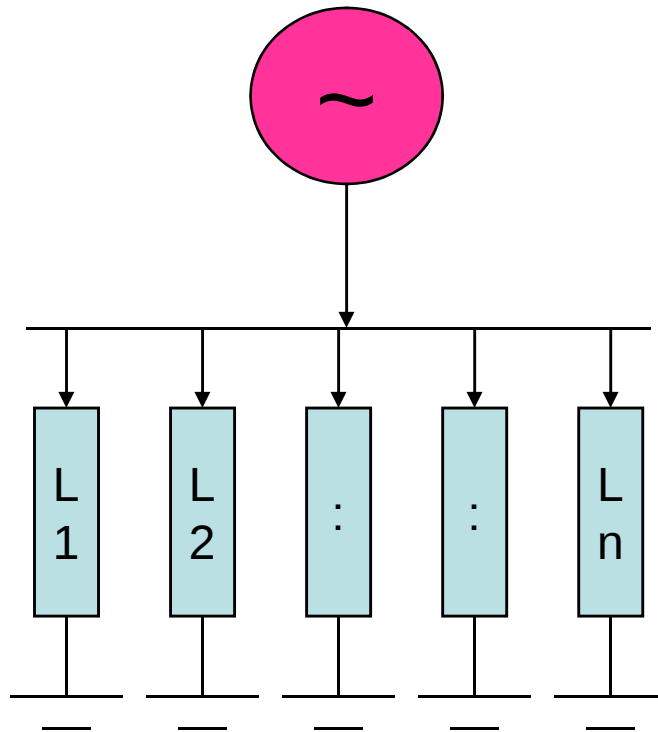
# Need for Governing

- Governors are associated with all Turbo-Generators to control the working fluid entering the prime-mover
- The fluid can vary from **water** (for hydel plants) to **steam** (for thermal) or **fuel** (for Gas Turbine)
- The basic control elements are valves capable of controlling the required quantum accurately
- Functioning of governor is basically to interpret signals and power of the valves accordingly
- The mechanism has developed from very simple arrangement to a complicated system to meet ever growing needs

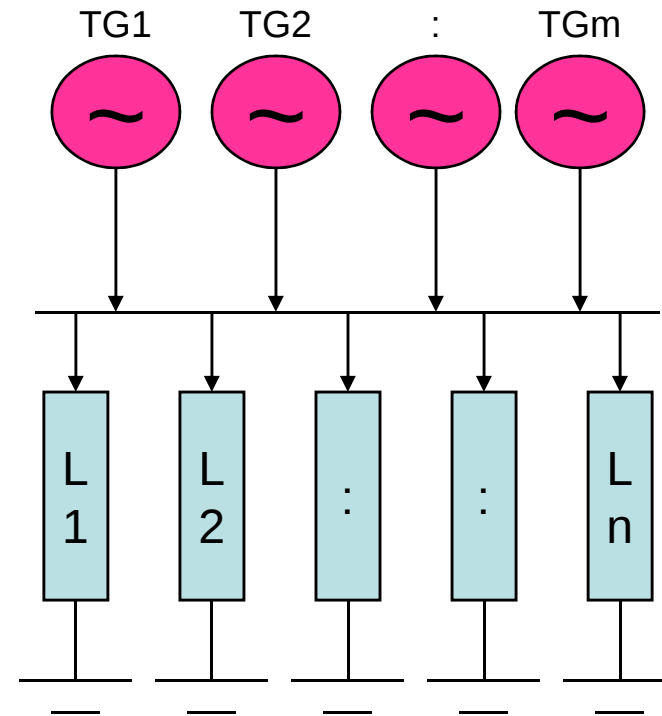
# Need for Governing

- There can be two situations envisaged in understanding the basics of Governors
  - a) Single Machine Operation: Under this condition One Turbo-generator supplies to a group of Load connected to it
  - b) Parallel operation of Turbo-generators: In this case Two or more parallel connected Turbo-generator supplies a common Load  
(The following slide shows the single line configurations of the above two systems)

# Single & Parallel operation of TG



SINGLE TG OPERATION



PARALLEL TG OPERATION

# SINGLE TG OPERATION

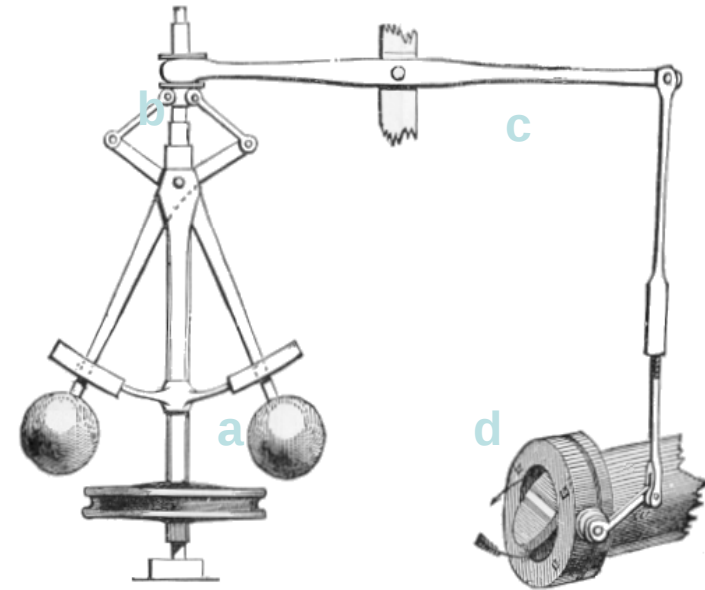
- A Turbo Generator operating under a steady load condition is assumed to possess:
  - Fixed speed (say synchronous speed of Alternator)
  - Fixed governor valve opening, that admits exact amount of fluid to produce the connected power
  - The state remains in equilibrium if not disturbed
- If the equilibrium is disturbed by increment of load from the previous state then:
  - The TG will try to meet the excess load demand from its storage of rotational kinetic energy
  - The speed of turbine will therefore decelerate

# SINGLE TG OPERATION

- Similarly if there is a decrease of connected load then
  - The TG will have additional prime moving power to add up to its storage of rotational kinetic energy
  - The net effect will be acceleration of TG speed
- Either of these situations are unstable and not desirable for the machine and its connected load
- Governors are intended to keep the speed of TG at a steady level by regulating the flow into the prime-mover under the aforesaid conditions

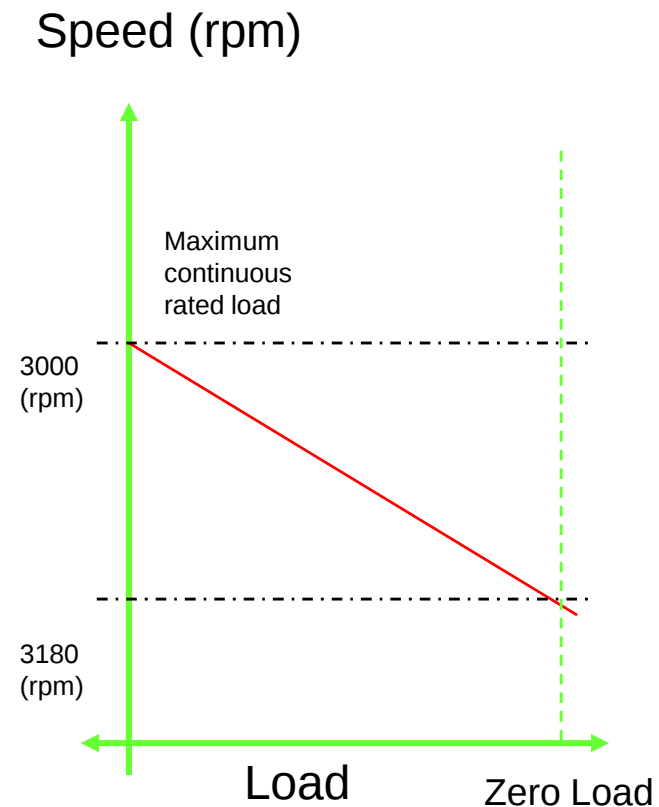
# SINGLE TG OPERATION

- A simple arrangement of valve control is shown in the figure
- In response to falling speed (i.e. higher load) the fly-balls drop down that opens valve via lever arm to admit more fluid
- The additional fluid flow copes with increased demand and retain speed (Vice-verse happens under rising speed)
- The basic components that accomplish the process are:
  - a. Speed variation sensor (Fly ball)
  - b. Control function (Linear movement in proportion to change in 'rpm')
  - c. Actuator drive (Lever arm that powers the movement of valve)
  - d. Final control element (The valve that regulate flow)



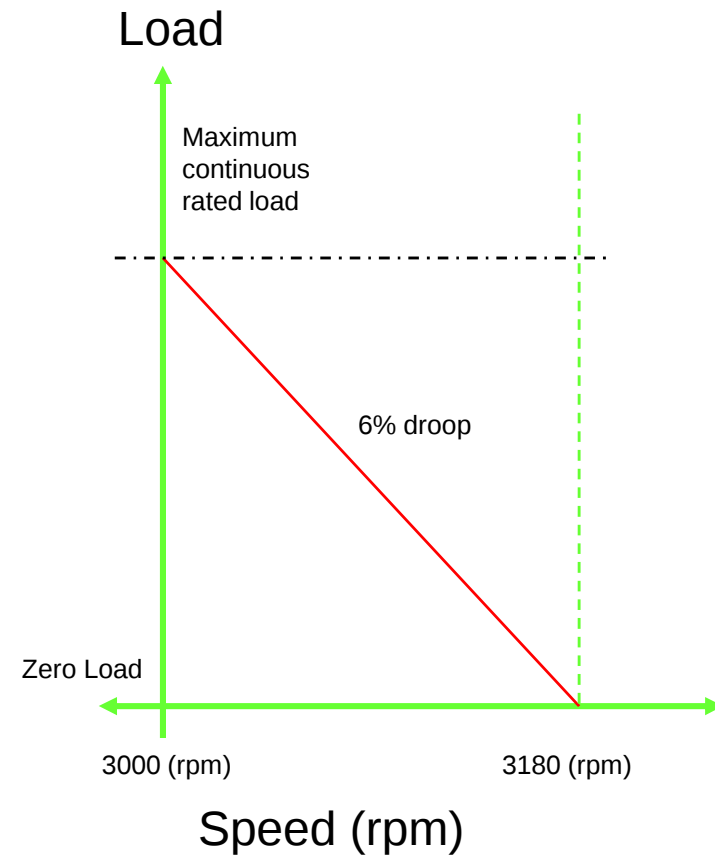
# SINGLE TG OPERATION

- From this simple device it is evident that corresponding to every position of fly-ball the control valve has a definite opening
- The two aspects in the process can be interpreted as
  - The position of fly-ball to represent **speed of TG**
  - The opening of control valve to represent steam flow & **TG loading**
- Relationship that exists between these two parameters, known as “Governor Characteristic” is shown in the plot (vide figure)



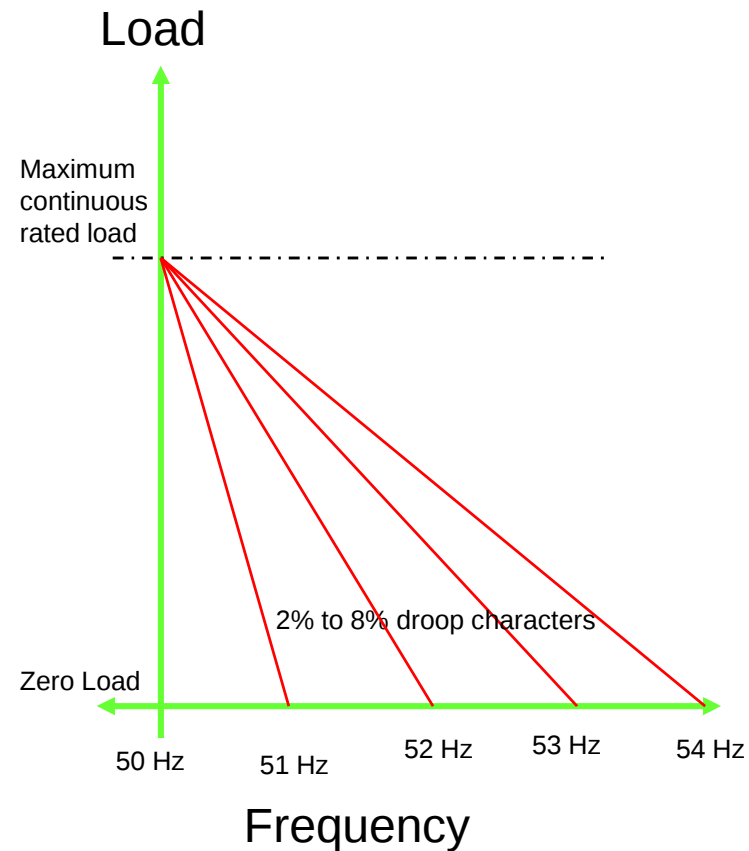
# SINGLE TG OPERATION

- The regulation characteristic is drooping in nature (i.e. the valve close with rise in speed) that ensures a stable operating point
- Every governor has its intrinsic droop character that decides the extent of speed change that can bring about a 100% load change
- This is usually expressed as change of frequency as the percentage of rated frequency  
[The co-ordinates characteristic can also be otherwise, viz, speed (x) vs load (y)]



# SINGLE TG OPERATION

- The droop characteristics of conventional governors were fixed by their design and construction to somewhere between 5 - 8% droop
- In the modern design (hydraulic/ electro-hydraulic type, specially with  $\mu$ -processors) the droop can be changed suitably



# SINGLE TG OPERATION

- Governing of modern high capacity steam turbines are scaled up version of the simple governing system, but principles are same:
  - a. Speed sensors pick up signals from: Fly balls, Oil Pressures, Voltage, Digital Pulses (etc)
  - b. Control function can be obtained from: mechanical/hydraulic arrangements, analog or digital computers
  - c. Actuator drive are mostly: hydraulic drives with mechanical or electronic coordination
  - d. Final control element constitute of steam admission valves

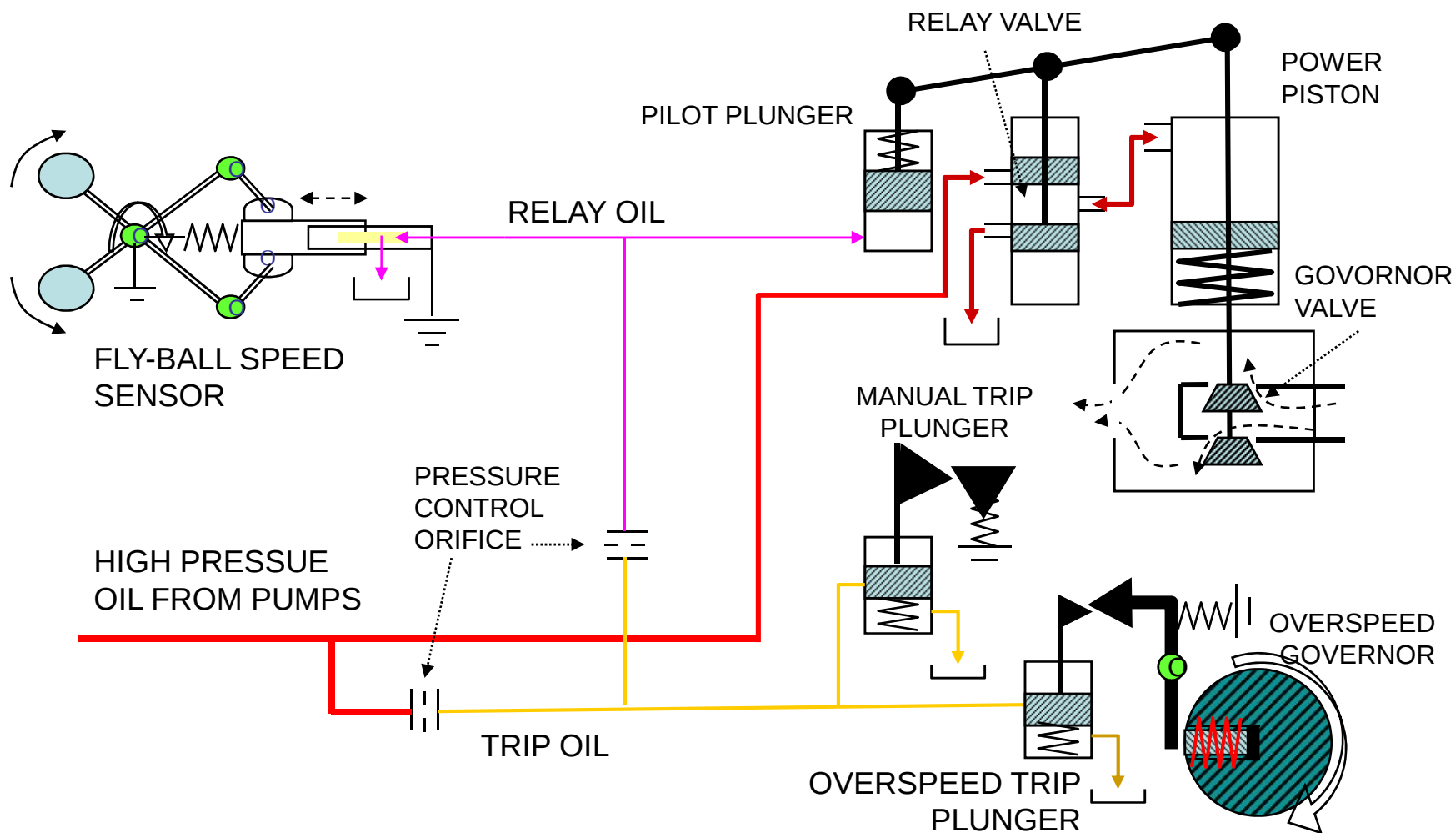
# SINGLE TG OPERATION

- Mechanical arrangements has been reliably used to detect speed
- ‘Speed’ can be translated into hydraulic signal (relay oil pressure) to control governor valve opening and load thereby
- Change of relay oil pressure is small and is incapable of overcoming large forces of spring / ‘steam pressure’ and move the valves
- The pilot plunger and main valve piston acts as a hydraulic amplifier that operate the steam admission valves

# SINGLE TG OPERATION

- The basic governing is also provided with some additional features such as:
  - Over-speed protecting system known as ‘over-speed governor’ (in the scheme shown centrifugal action on slight ‘off-centric bolt’ operate a plunger at set speed)
  - The hydraulic oil is used in various steps as control oil each assigned to a definite purpose
  - ‘Trip oil’ is one such that enable governing only when the system oil pressure is available
  - Trip plunger both for ‘over-speed’ and ‘manual trip’ need to be reset for development of pressure
- The figure in the next slide is a schematic of such simple governing system

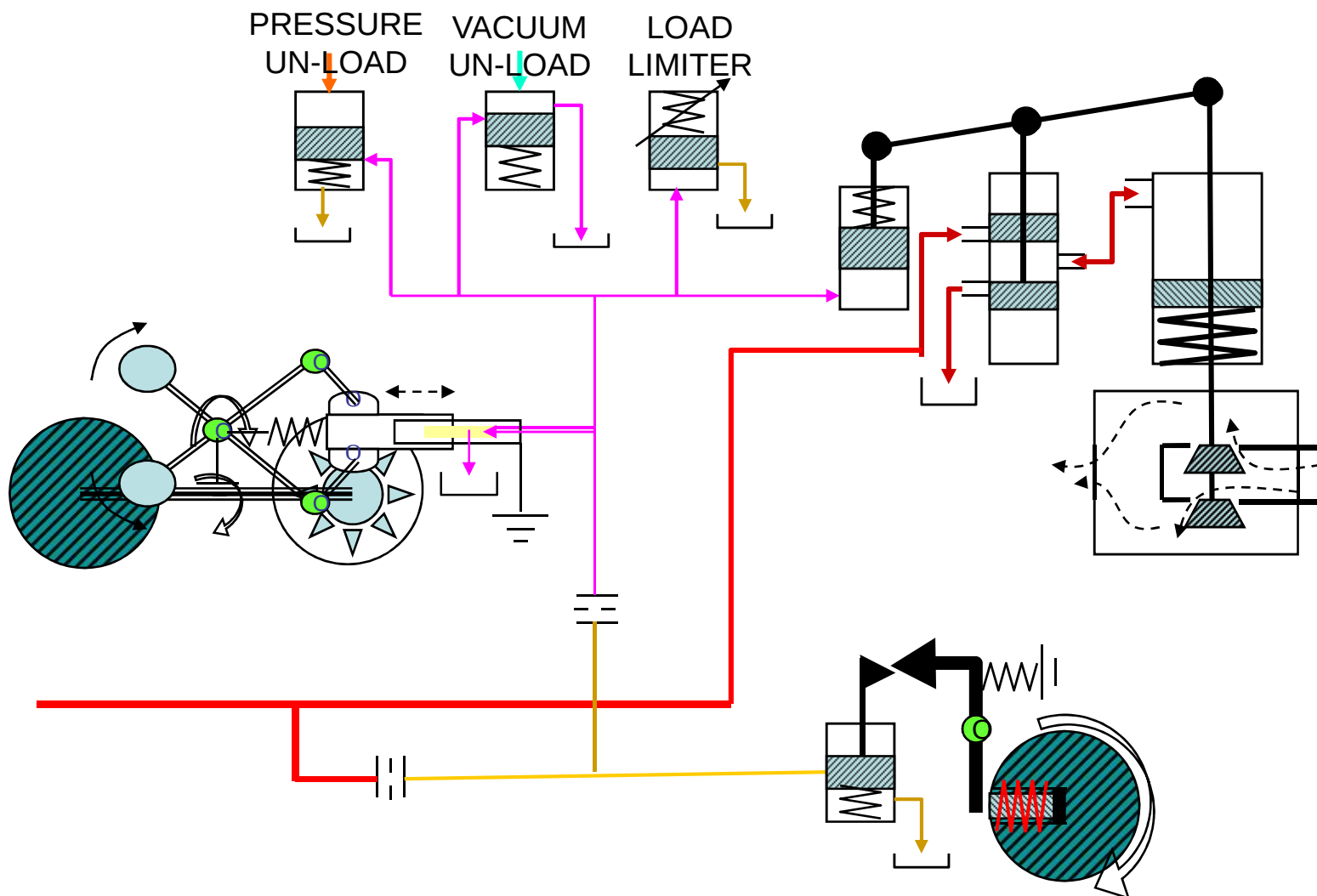
# SINGLE TG OPERATION



# SINGLE TG OPERATION

- Speed can also be sensed as oil pressure ( $H \propto N^2$ ) developed by an impeller rotating at shaft speed
- Governors of modern power plants also incorporate various load limiting functions that arises out of process parameters, such as
  - Load restriction due to any shortcoming/ de-rating
  - Load restriction due to pressure fall
  - Load restriction due to vacuum fall
- The following slide give brief introduction to those

# SINGLE TG OPERATION



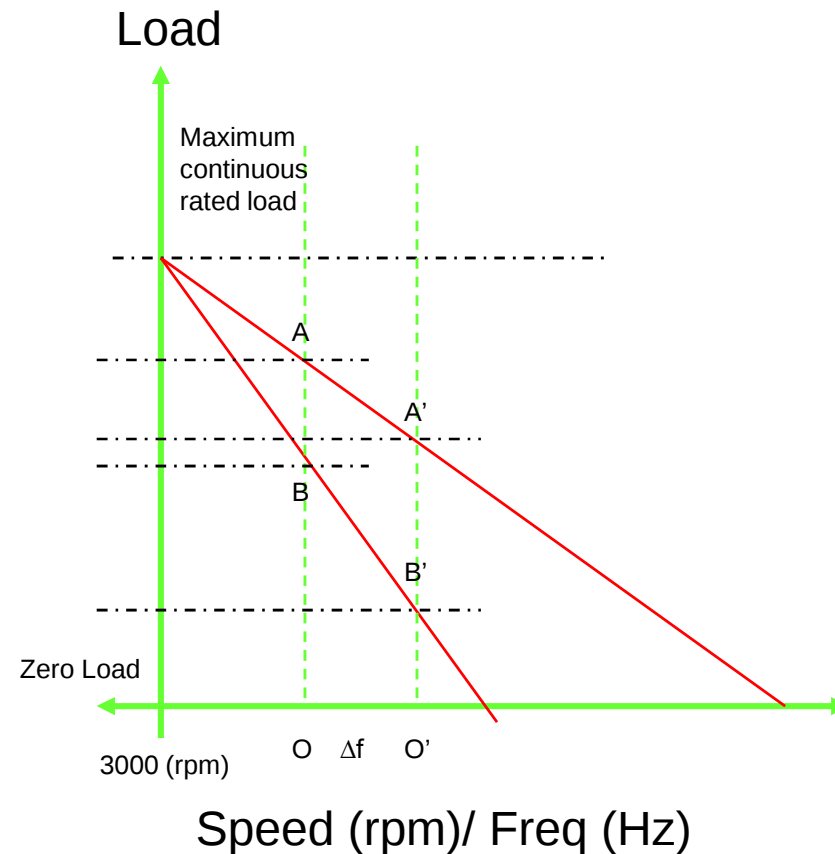
# PARALLEL TG OPERATION

- When a number of Turbo Generators run in parallel the notion of speed governing has no relevance individually
  - All the sets collectively respond to rise or fall of frequency by shutting or opening their governor valves respectively
  - The extent of load change take that place in ideal case is in according to the governor characteristic of individual TG sets
  - Turbo-generators connected to an infinite grid\* have lot more control inputs other than speed
- \*(total connected load is very large compared to TG rating)

# PARALLEL TG OPERATION

The following example show Load sharing of 2 sets

- The frequency is at O (say)
- The loading of two sets are OA & OB (Total load = OA+OB)
- The frequency rises by  $\Delta f$  to O'
- The operating points shifts from A to A' & B to B'
- The loading of two sets changes to O'A' & O'B'
- New  $\sum \text{load } O'A' + O'B' < OA + OB$



# PARALLEL TG OPERATION

- It can be shown that similar event of load sharing would happen under falling frequency
- Also the similar of load redistribution will take place if there are more than 2 TGs in the system
- In an infinite bus the change of frequency can be originated from load changes beyond the scope of the TGs concerned
- Then, if the sharing of load has to depend on droop character only (as shown) the TG would not be able to deliver its stipulated load

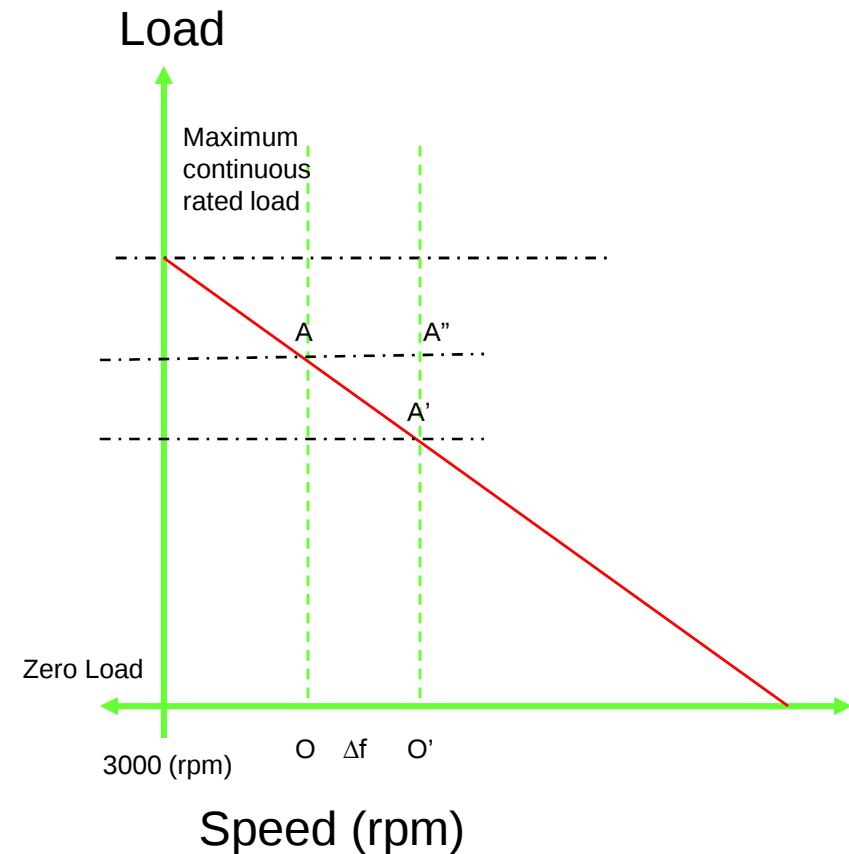
# PARALLEL TG OPERATION

- In order to cope up with such situation small change was done in governing system
- The basic intentions are
  - To support the system under frequency changes so as to ensure its stability (*i.e. add MW generation if frequency falls or shed MW generation if frequency rise*)
  - To redistribute the load according to their capabilities of individual machines, as the droop characteristics of all are not same
  - To regain the original load status gradually once the frequency has stabilized to a new value

# PARALLEL TG OPERATION

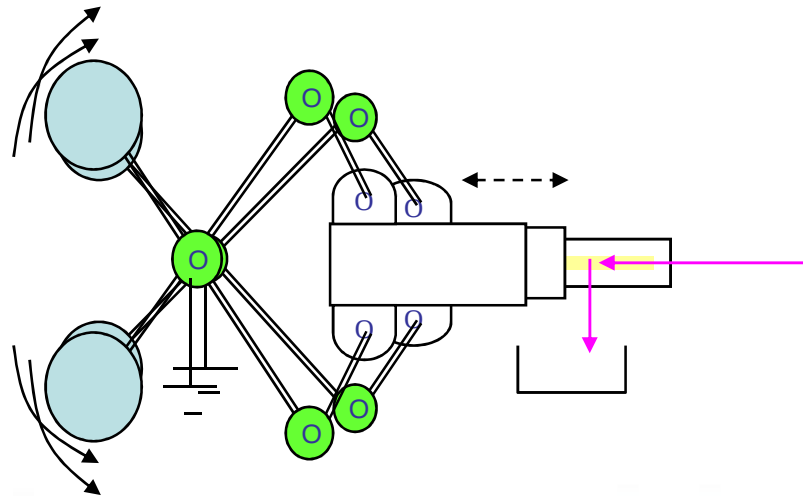
This figure show how the TG can recover its load after giving initial support to the system

- The frequency is at O (say)
- The loading the TG is OA (which is part of System Load)
- The frequency rises by  $\Delta f$  to O'
- The operating points shifts from A to A' (OA' < OA, to support the cause of frequency change)
- The machine can go back to its previous load condition if the Governor line be shifted to A'', (OA = OA'')



# PARALLEL TG OPERATION

- The simple arrangement depicts how a governor picks up after a load-drop due to frequency rise
  - With the rise in frequency the fly-balls move out pulling the sleeve back and uncovering the oil port
  - As more oil gets drained the relay oil pressure falls, so does the load
  - The port can be arranged to move back into the sleeve that will restore the previous opening as well as load

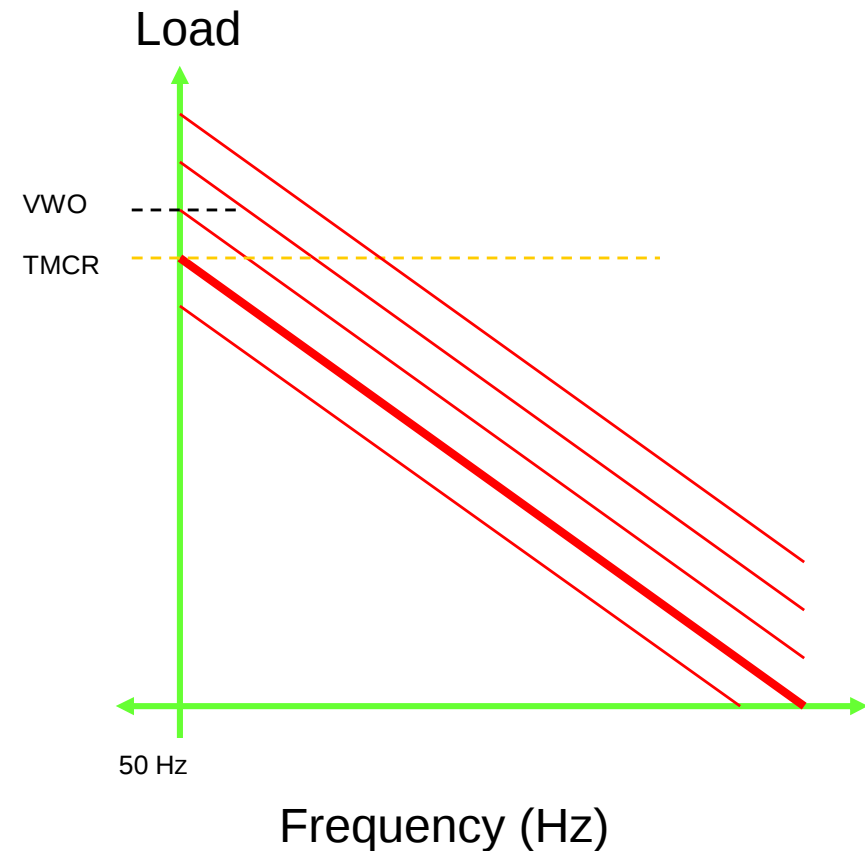


# PARALLEL TG OPERATION

- The provision to move the plunger having graduated port allows manipulation of relay oil pressure and load in either direction
- This feature (or other equivalent mechanisms in a different model) enables raising and lowering of load independent of frequency
- The effect of above manipulation on governor is actually observed as the characteristic line to move up or down in parallel
- In other words, corresponding to every position of the 'plunger port' there is a characteristic line

# PARALLEL TG OPERATION

- There can be unlimited number of characteristic curves as shown
- Above TMCR/ VWO load value, the lines are virtual as no operating point can be envisaged (physical limit in valve opening and steam flow will restrict the TG load)
- The machine can be made to operate at any point below it



# MODERN TRENDS IN GOVERNING ELECTRO HYDRAULIC

# ELECTRO HYDRAULIC GOVERNOR

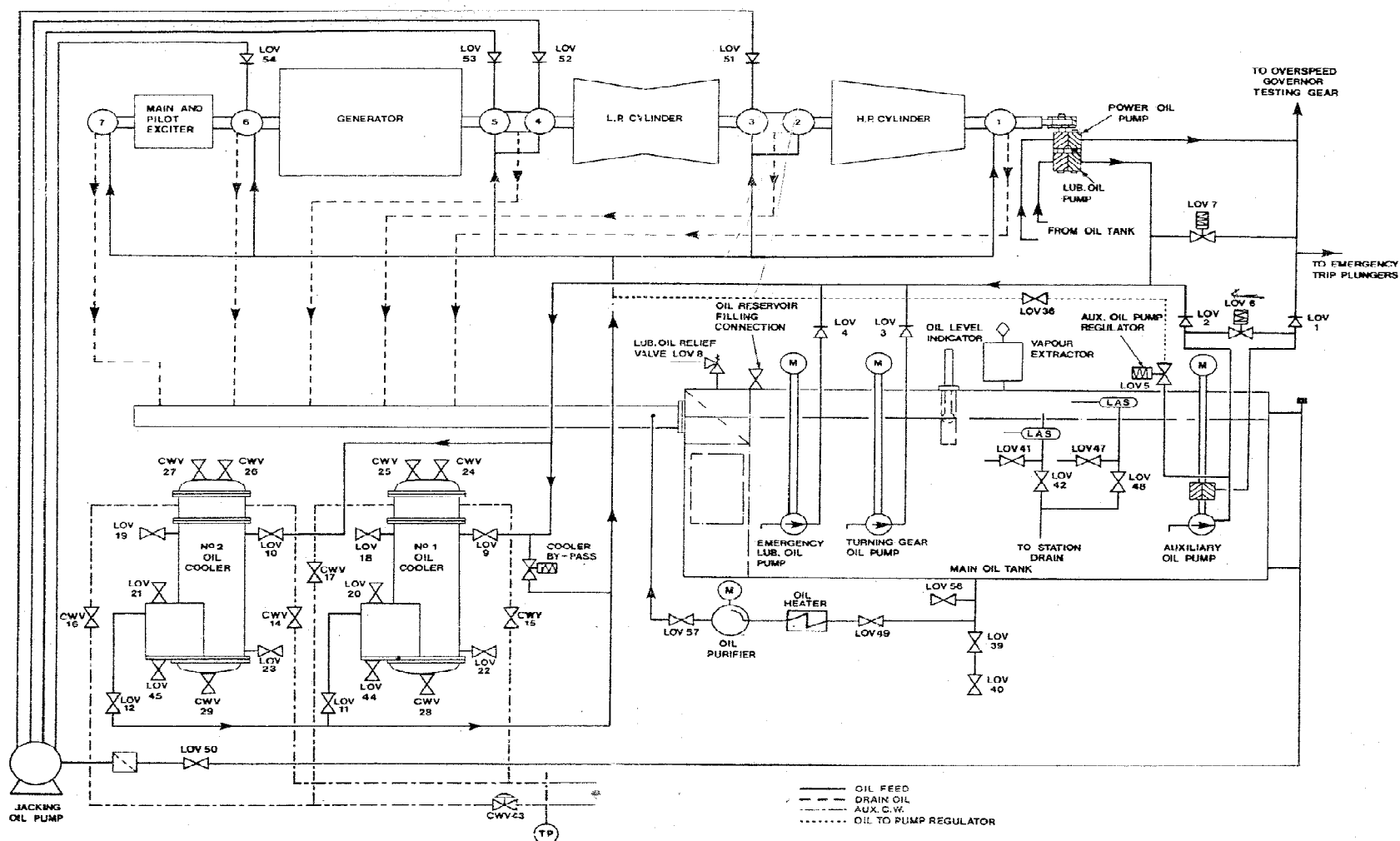
- Turbine Governing should essentially be:
  1. Rugged
  2. Reliable &
  3. Responsive (and preferably adaptive)
- The hydraulic and mechanical models definitely satisfied the first two conditions
- The advanced microprocessor technology could translate the entire governor control algorithm into software

# ELECTRO HYDRAULIC GOVERNOR

- Selection of appropriate hardware architecture could make the system to satisfy all three conditions
- Many more than the basic features relevant in present power system have been possible to be incorporated in “real-time”  $\mu$ p control
- These comprises the Electro Hydraulic Governor (EHG), the hydraulic system only powers the movement of valve

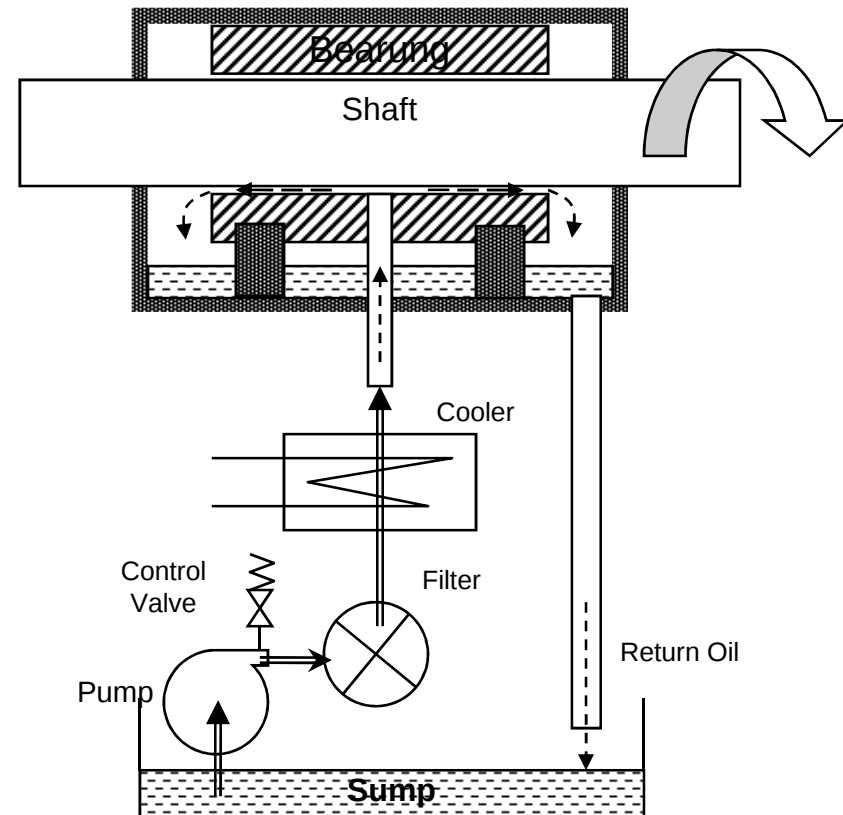
# TURBINE LUB OIL SYSTEM

# TGS TURBINE LUB OIL PID



# Bearings and Lubrication

- **Forced Lubrication:**
  - Comprises of pumps that pressurize oil & supply to bearing
  - Return oil from the bearings is collected back to the sump
  - Usually the pumping system includes, pressure control feature, filters and coolers



# Bearings and Lubrication

- Each of the turbine shaft is supported on either ends by journal bearings and are forced lubricated by low viscous oil
- The oil is filtered to remove solid particles and centrifuged to remove any water
- In turbines where two shafts are rigidly coupled the common coupled end can be supported by single bearing
- A journal bearing consists of two half-cylinders that enclose the shaft
- They are internally lined with Babbitt, a metal alloy usually consisting of tin, copper and antimony

# Bearings and Lubrication

- Alignment and clearances in a bearing decide a lot of the turbine performance
- To allow minor misalignment/ distortion of shafts, the bearings are mounted inside the housing fitted with spherical pads
- These bearings can self-adjust themselves while running and can take up minor distortions
- Since the shafts are quite heavy, it is difficult to establish a proper lubricating layer between the shaft and bearing
- In Budge Budge turbine bearings lubricating oil enters through twin ports at horizontal joints

# Bearings and Lubrication

- Figure to the right is of a typical “spherically seated bearing”
- All the bearings of BBGS turbine are of this type
- The housings have provision to mount temperature monitoring device (to reach to the depth of white metal)

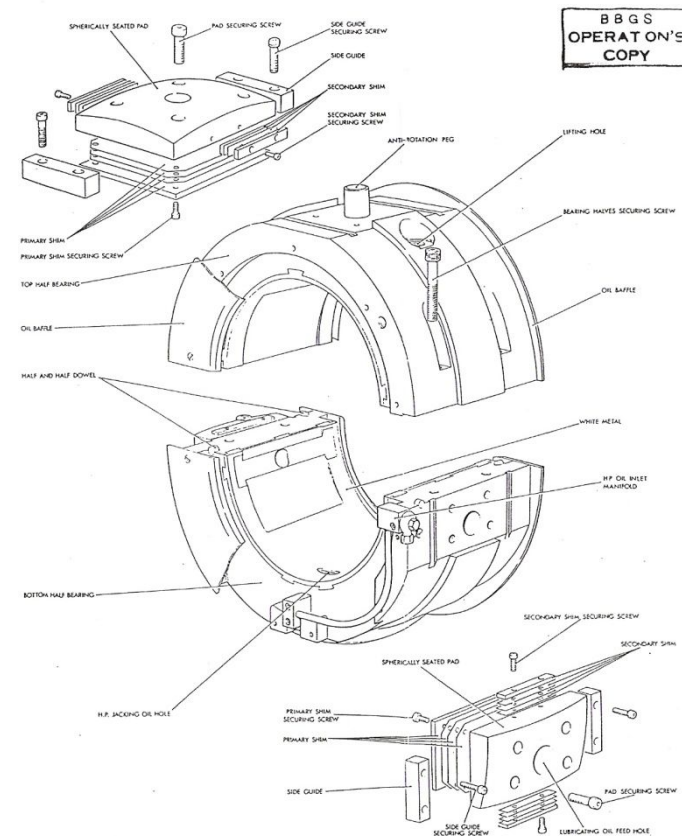


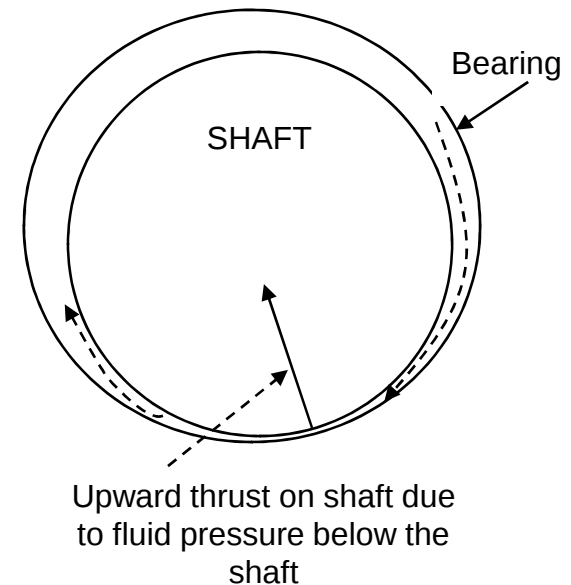
FIG 8 SPHERICALLY SEATED BEARING  
SM0114

# Bearings and Lubrication

- The lubricating layer also saves the white metal (having low melting point) from receiving heat from the hot turbine shaft
- The turbine requires to be adequately speeded up before a wedge pressure is established below the shaft to sustain the shaft load
- Before a turbine has sufficiently speeded up, oil at high pressure is applied below each shaft to jack up and make them free to rotate
- In Budge Budge turbine jacking oil enters through twin ports from the bottom of the bearing

# Bearings and Lubrication

- The clockwise movement of shaft drags the lubricating oil as shown
- The drag force generates a pressure below the shaft
- Higher the speed of shaft more oil is dragged and the magnitude of force also increase
- As this resembles a wedge acting between shaft and bearing, the pressure is called “wedge pressure”
- Turbine Shafts are lifted up slightly after a certain speed which help to minimize rotational resistance



# OIL WEDGE THICKNESS

During normal operation, the shaft rotates at sufficient speed to force oil between the conforming curved surfaces of the shaft and shell, thus creating an oil wedge and a hydrodynamic oil film. This full hydrodynamic fluid film allows these bearings to support extremely heavy loads and operate at high rotational speeds. Surface speeds of 175 to 250 meters/second (30,000 to 50,000 feet/minute) are common. Temperatures are often limited by the lubricant used, as the lead and tin babbitt is capable of temperatures reaching 150°C (300°F).

It is important to understand that the rotating shaft is not centered in the bearing shell during normal operation. This offset distance is referred to as the eccentricity of the bearing and creates a unique location for the minimum oil film thickness. Normally, the minimum oil film thickness is also the dynamic operating clearance of the bearing. Knowledge of the oil film thickness or dynamic clearances is also useful in determining filtration and metal surface finish requirements. Typically, minimum oil film thicknesses in the load zone during operation ranges from 1.0 to 300 microns, but values of 5 to 75 microns are more common in midsized industrial equipment.



# Bearings and Lubrication

- Single line diagram showing Lub-oil distribution layout and instrumentation for BBGS turbine

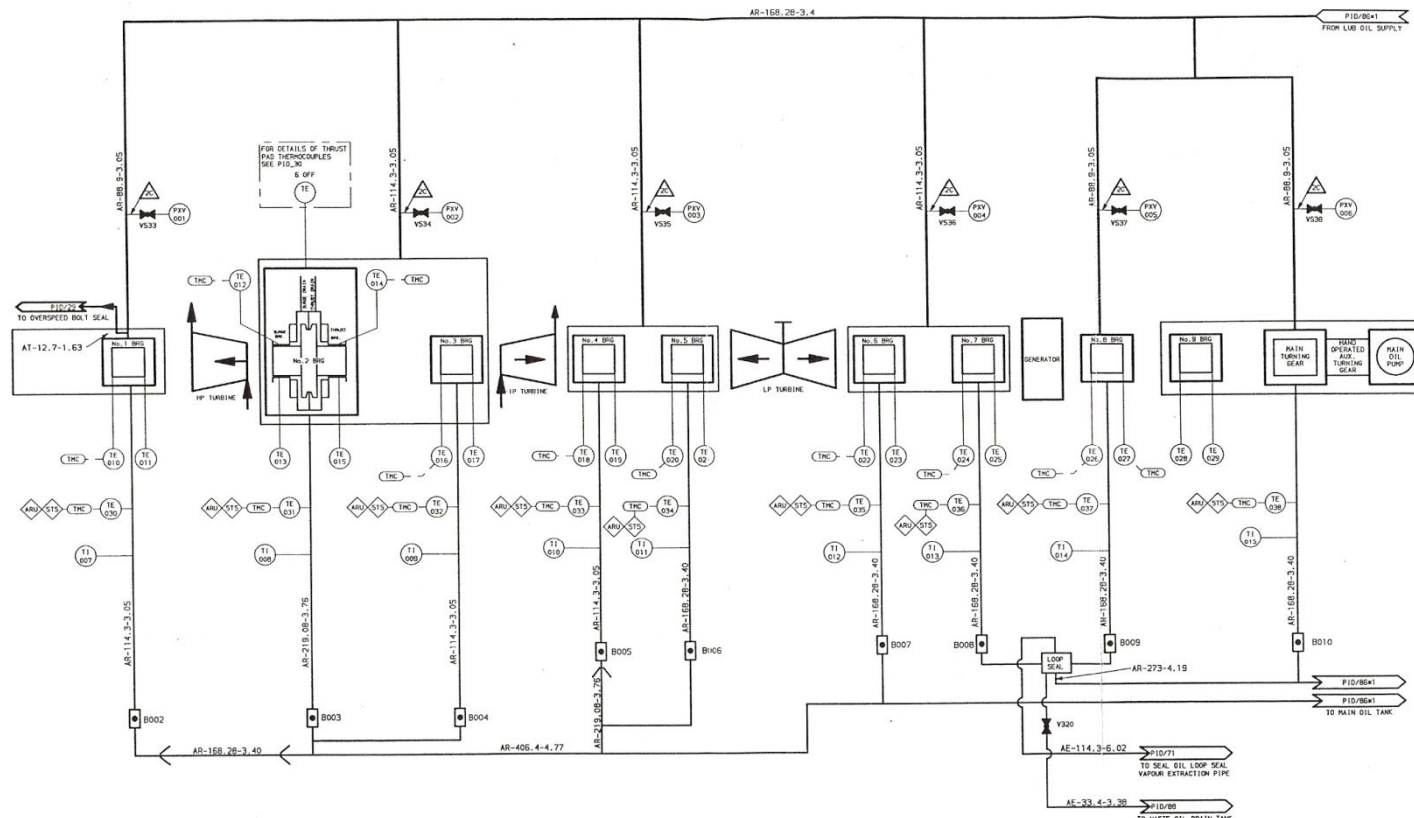
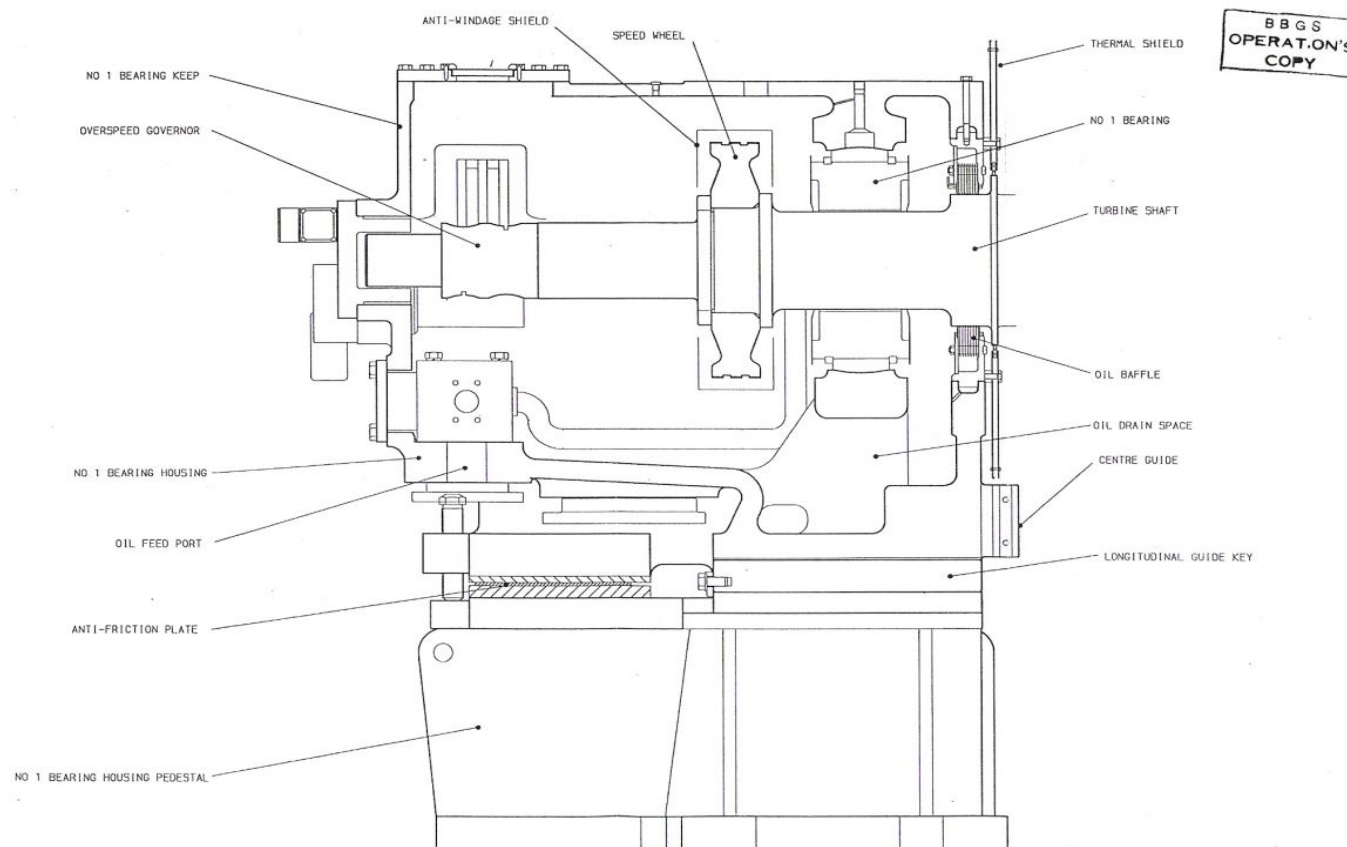


FIG 2 LUBRICATING OIL SYSTEM  
[AT BEARINGS]

# Bearings of BBGS units

- Bearing No1



# Bearings of BBGS units

- Bearing Nos 2 & 3

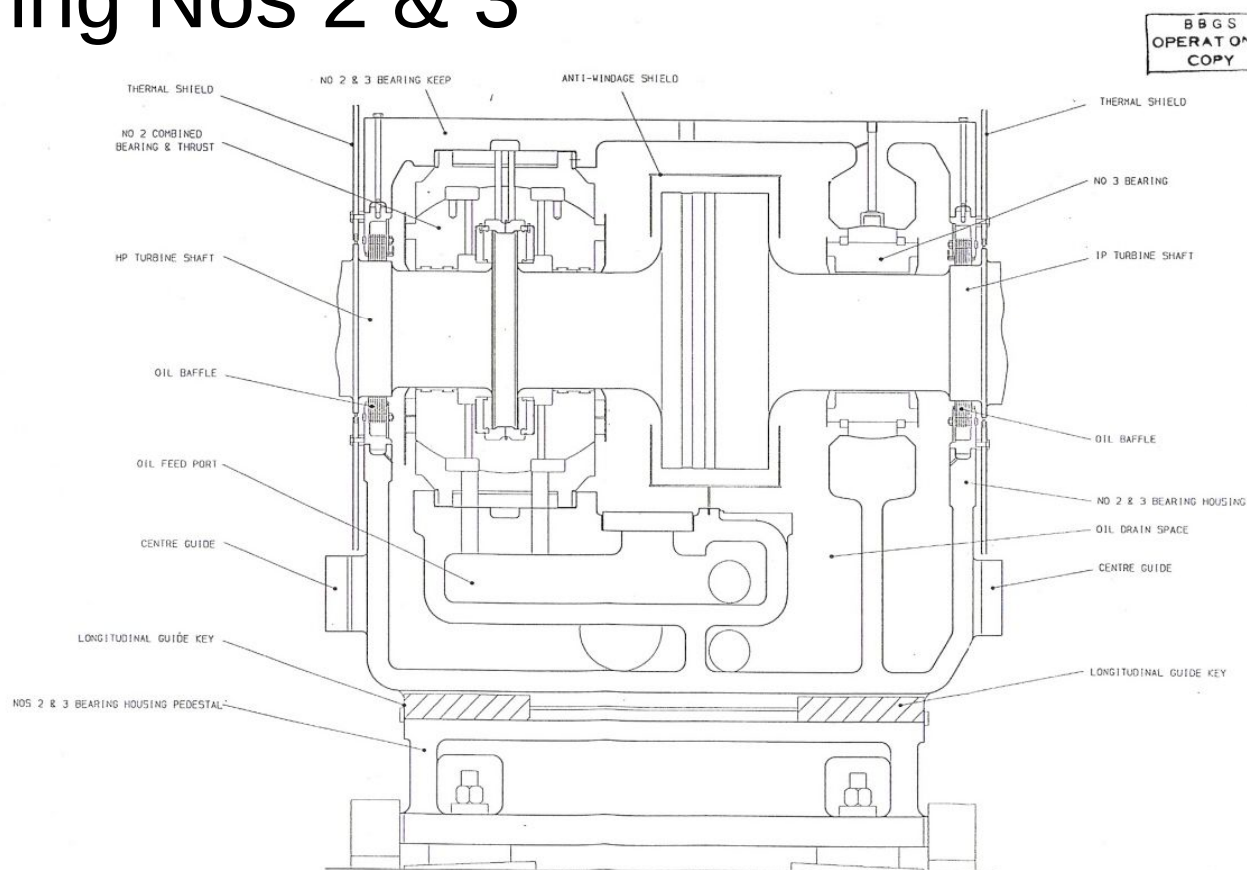
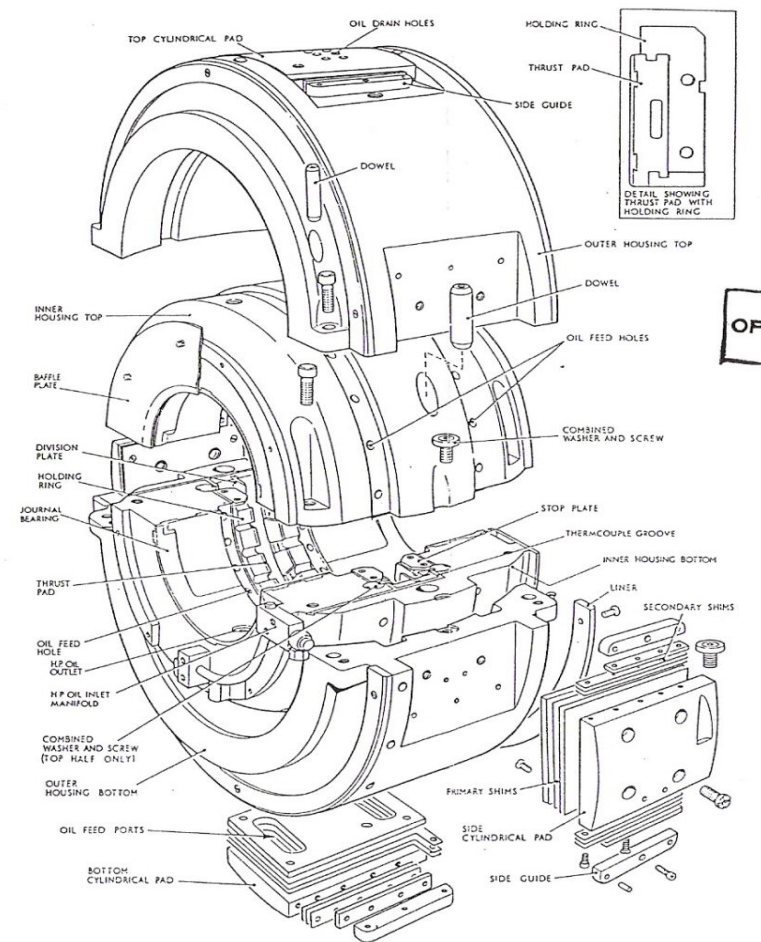


FIG 2 No 2 & 3 BEARING HOUSING

# Bearings of BBGS units

- Bearing No 2 of BBGS is a combination of thrust and journal bearing
- Figure on right is the split up view of the same



# Bearings of BBGS units

- Bearing Nos 4 & 5

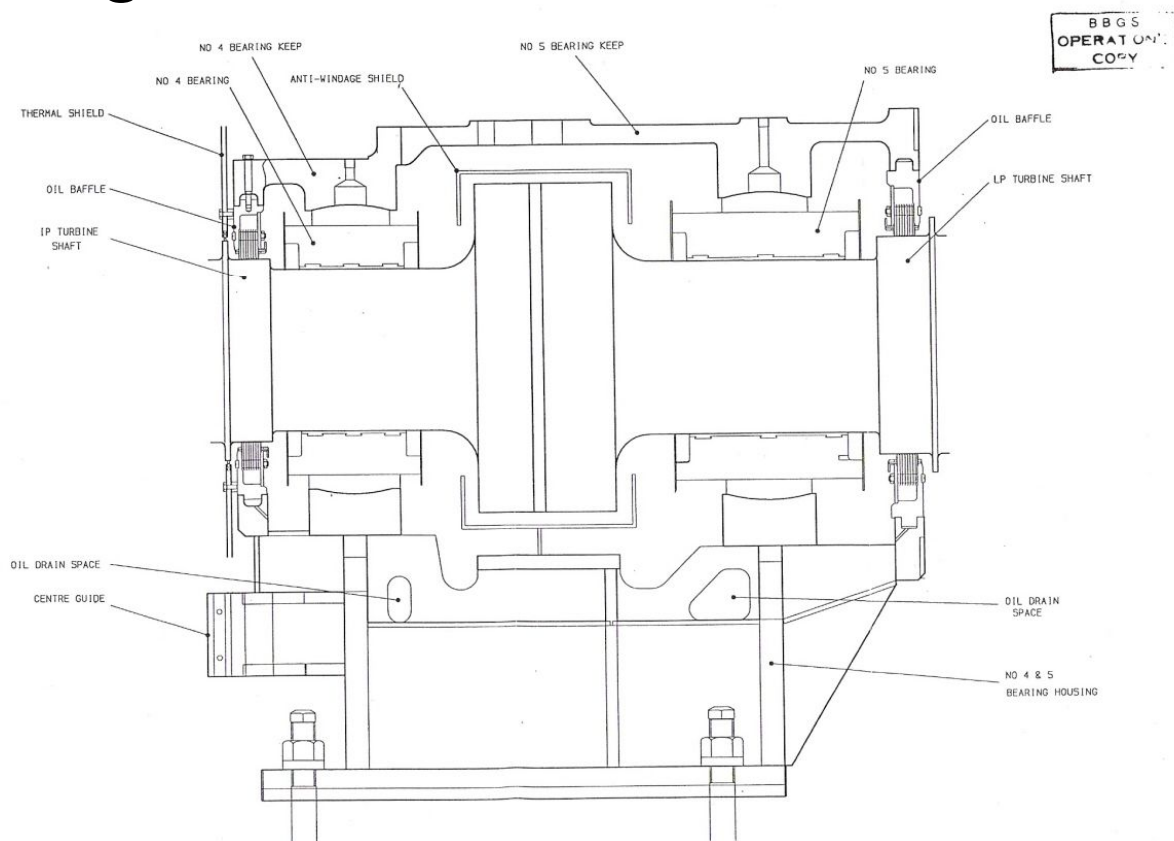


FIG 3 Nos 4 & 5 BEARING HOUSING

# Bearings of BBGS units

- Bearing No 6 & 7

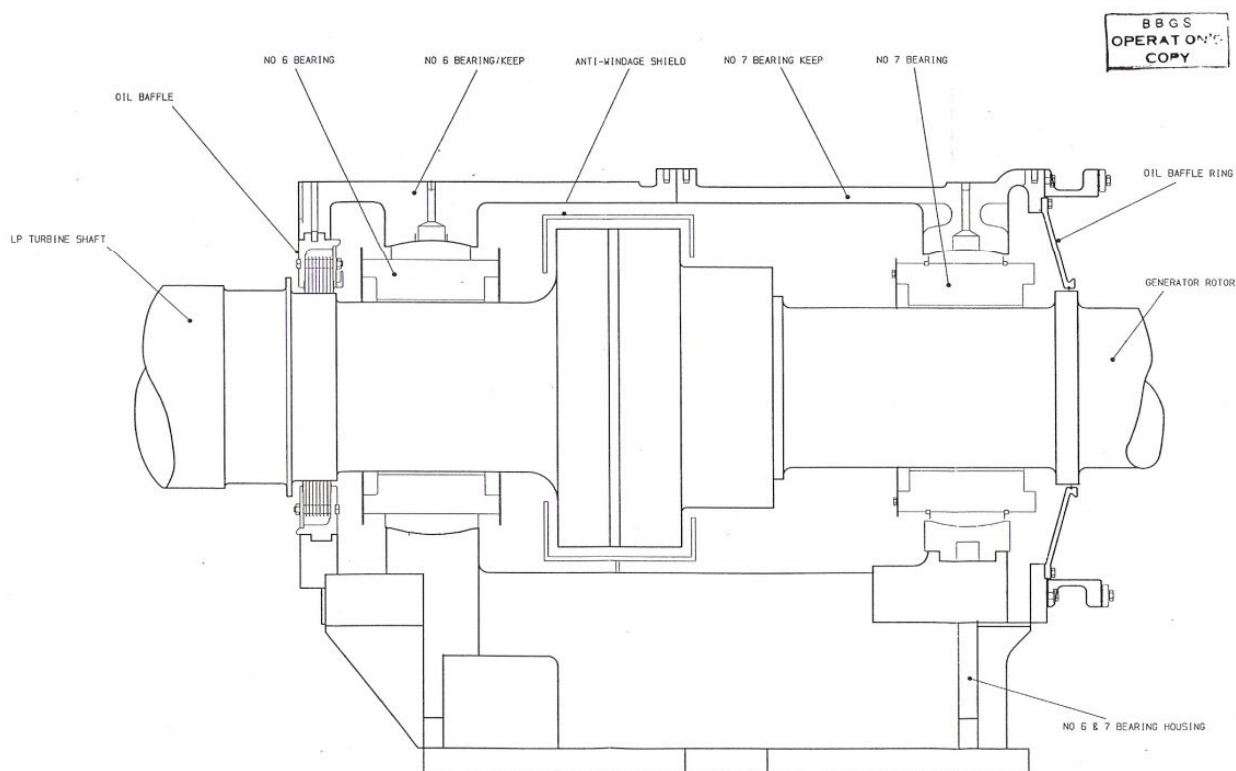


FIG 4 Nos 6 & 7 BEARING HOUSING  
SM0543

# Bearings of BBGS units

- Bearing No 8

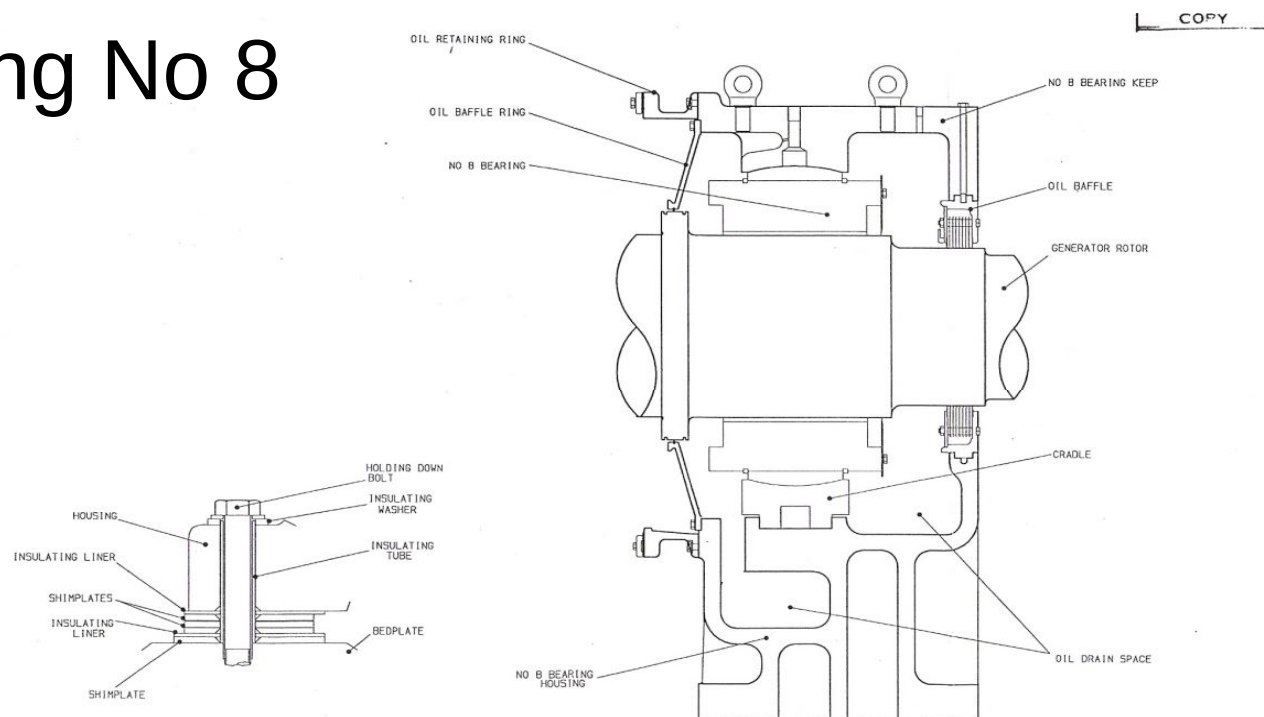
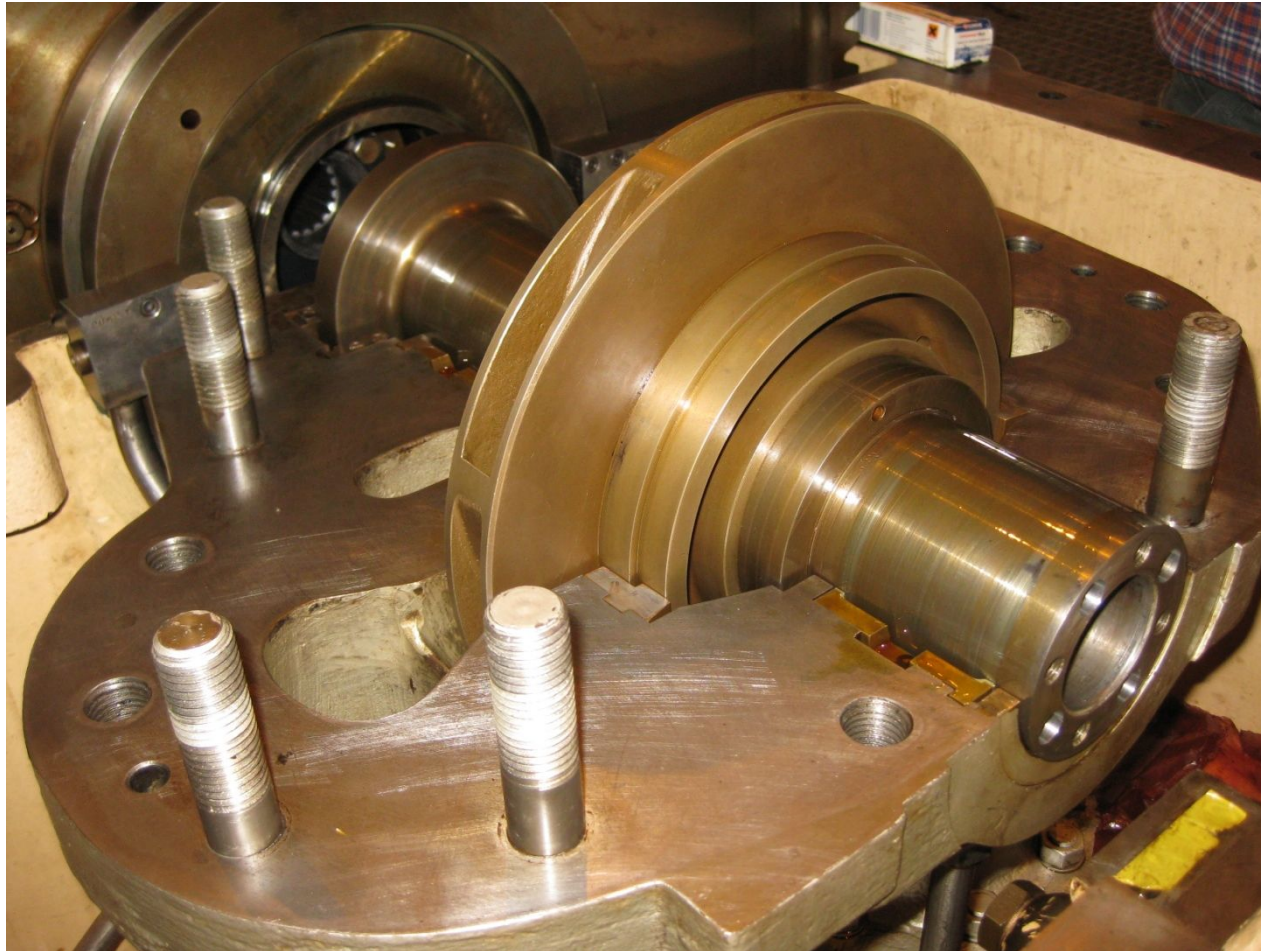


FIG 5 No 8 BEARING HOUSING

# Bearings and Lubrication

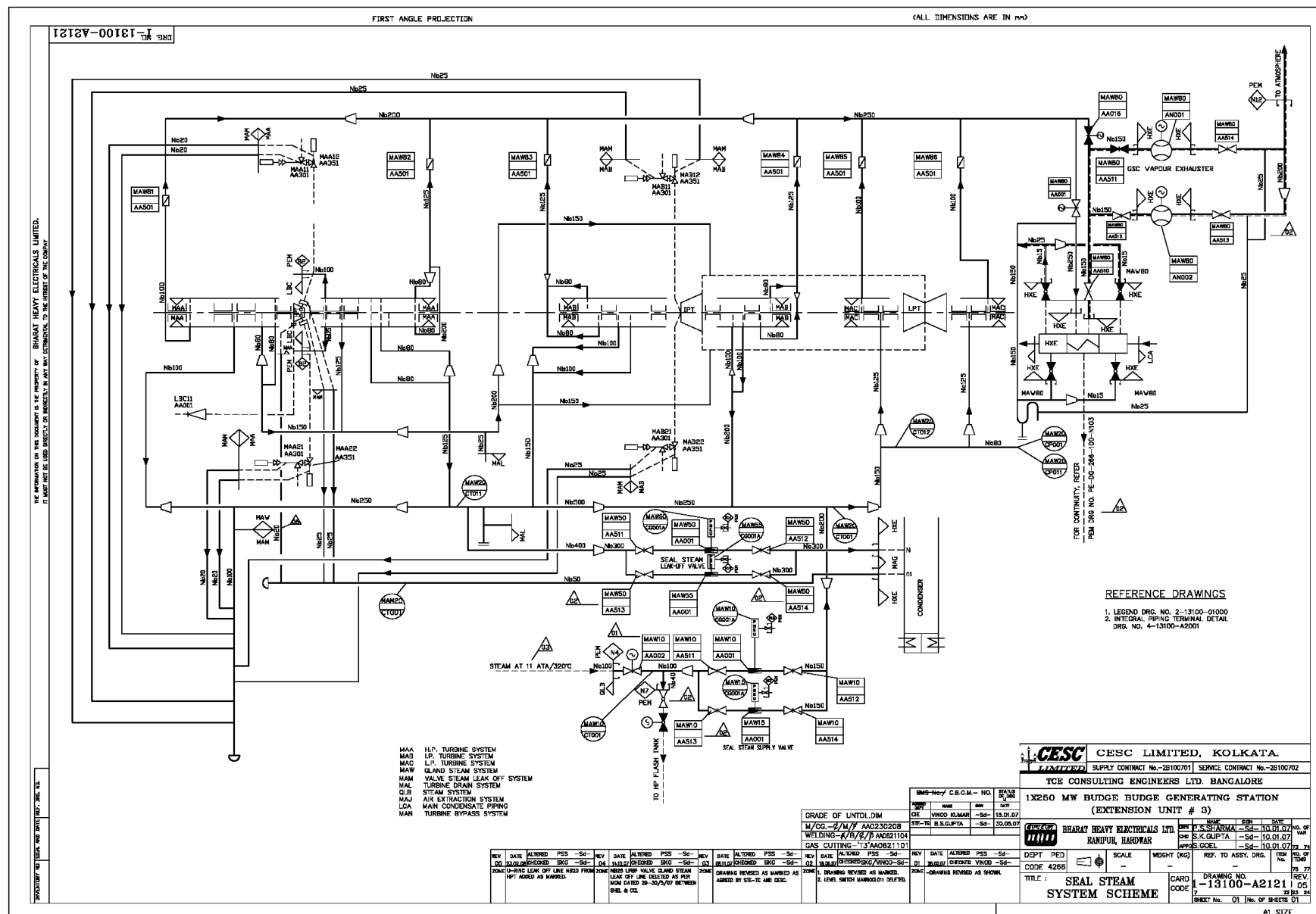
- There are certain important monitoring parameter pertaining to shaft and bearings, these are:
  - Bearing metal temperatures
  - Drain oil temperatures
  - Pedestal vibration
  - Shaft vibrations (usually measured in two positions 90° apart)
- The parameters can be utilized to analyze shaft behaviour and diagnose problems

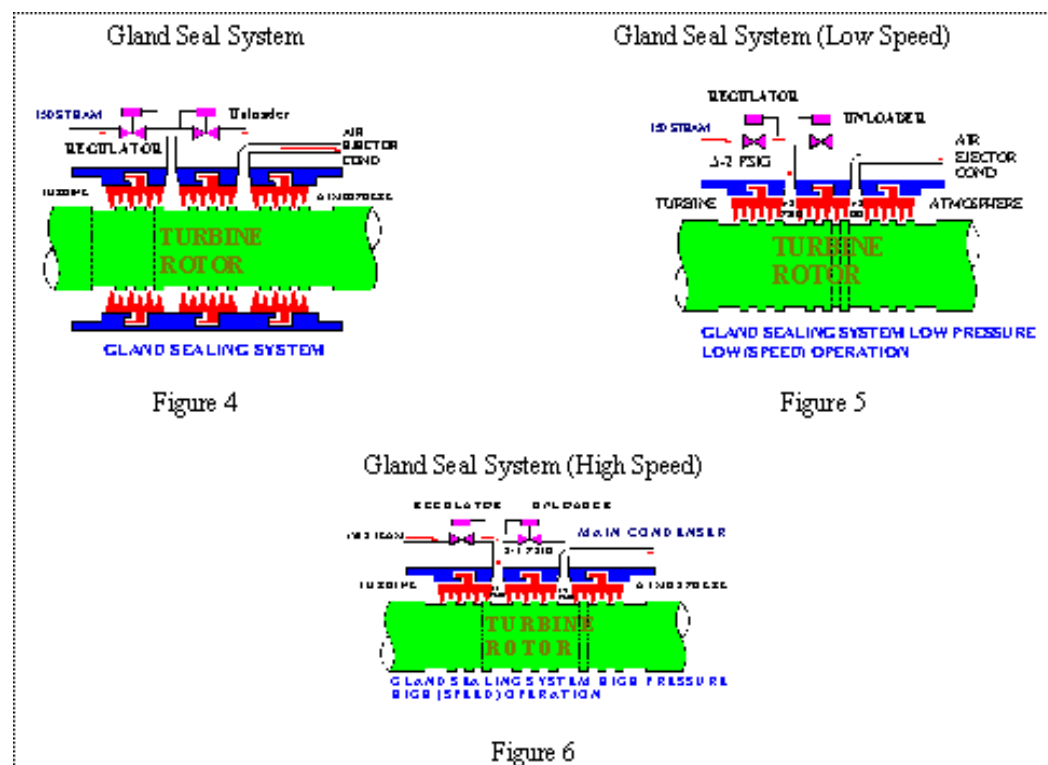
# MOP OF BBGS



# GLAND SEALING SYSTEM OF A STEAM TURBINE

# BBGS 3 SEAL STEAM SYSTEM PID





# Shaft seals

- It is important to seal the turbine internal from the outer atmosphere as
  - The inner part contains steam at high pressure during normal running and
  - Vacuum during start up

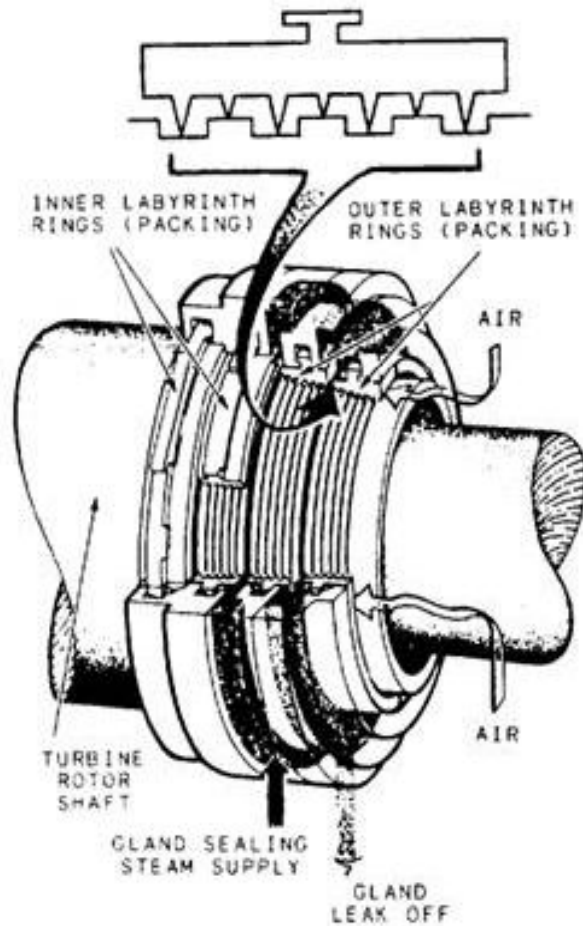
The former results in steam (heat) loss while the later may lead to ingress of foreign elements getting sucked inside

LP turbine however have pressure less than atmosphere continuously

# Shaft seals

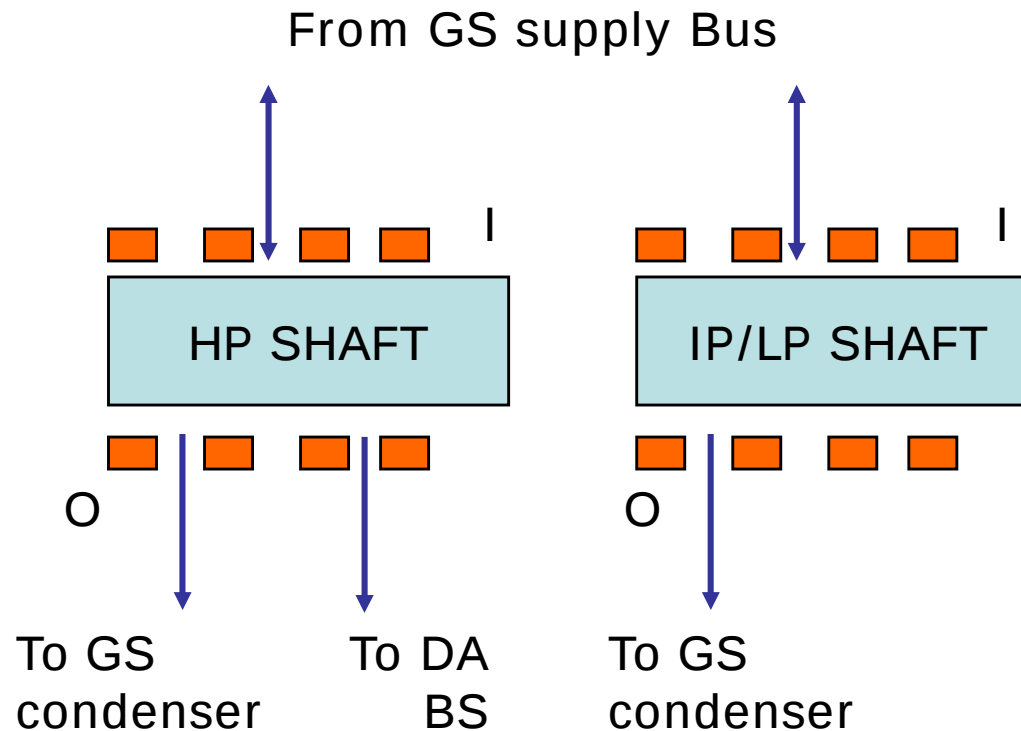
- Either ends of rotor shaft that come out from stator need such seals
- Both the stator and rotor have typical arrangements known as 'glands'
- Conditioned Steam provides excellent sealing medium in modern turbines, while some old turbines use this in combination to Carbon glands
- The glands of HP IP & LP differ from one another constructionally

# Shaft seals



- The glands are spring backed labyrinth type arranged in segments termed as inner gland and outer gland
- Port opening between each segments allow steam to enter or leak off
- The grooves on the rotor accommodates to the stator segments

# Shaft seals

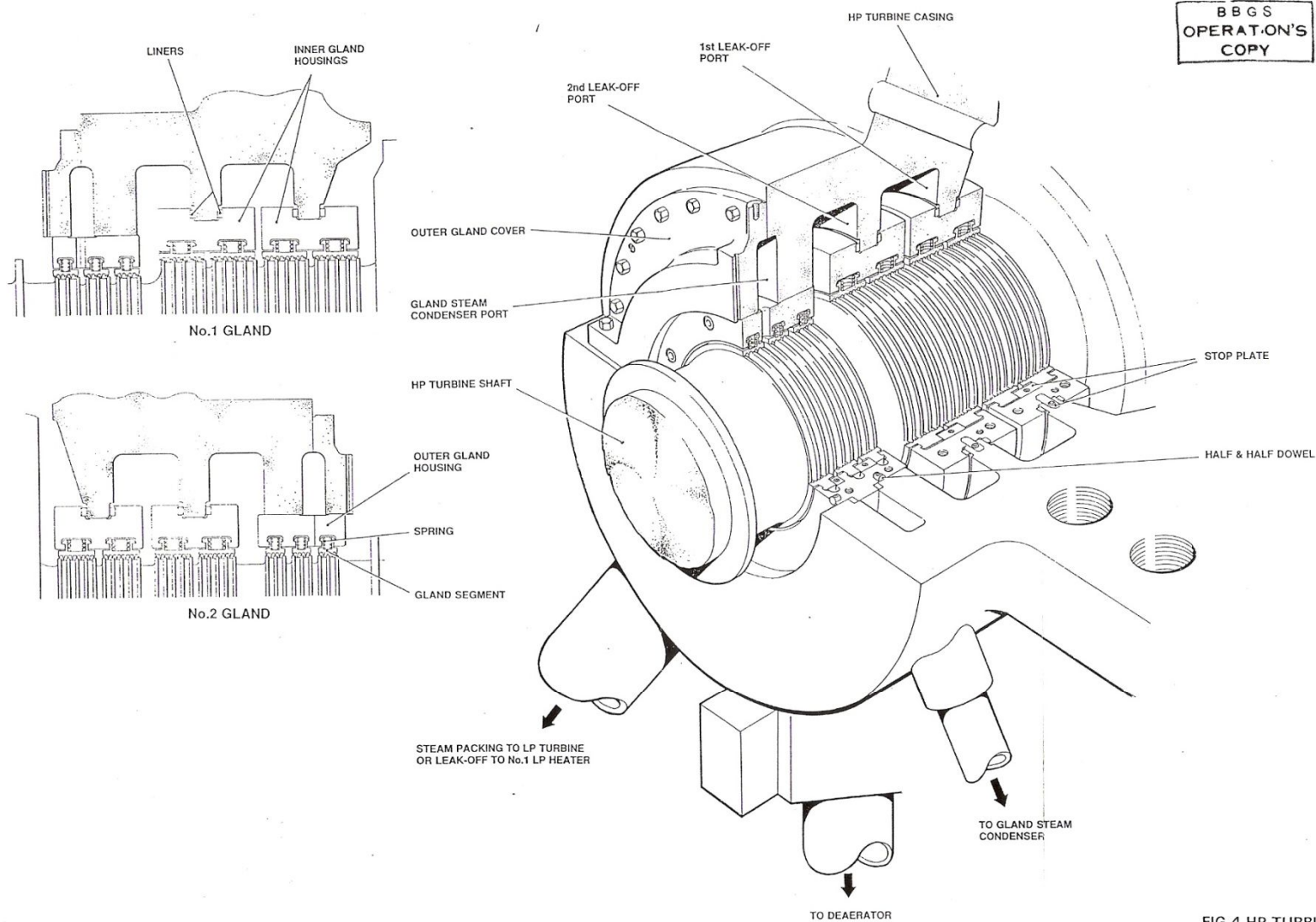


Figures on left show steam distribution arrangement in glands of Budge Budge Turbine

There are cavities between segments connected to the points as labeled

HP Gland at BBGS IP/LP Gland at BBGS

# HP Turbine Glands - BBGS



BBGS  
OPERATION'S  
COPY

FIG.4 HP TURBINE GLAND

SM01

# IP Turbine Glands- BBGS

BBGS  
OPERATION'S  
COPY

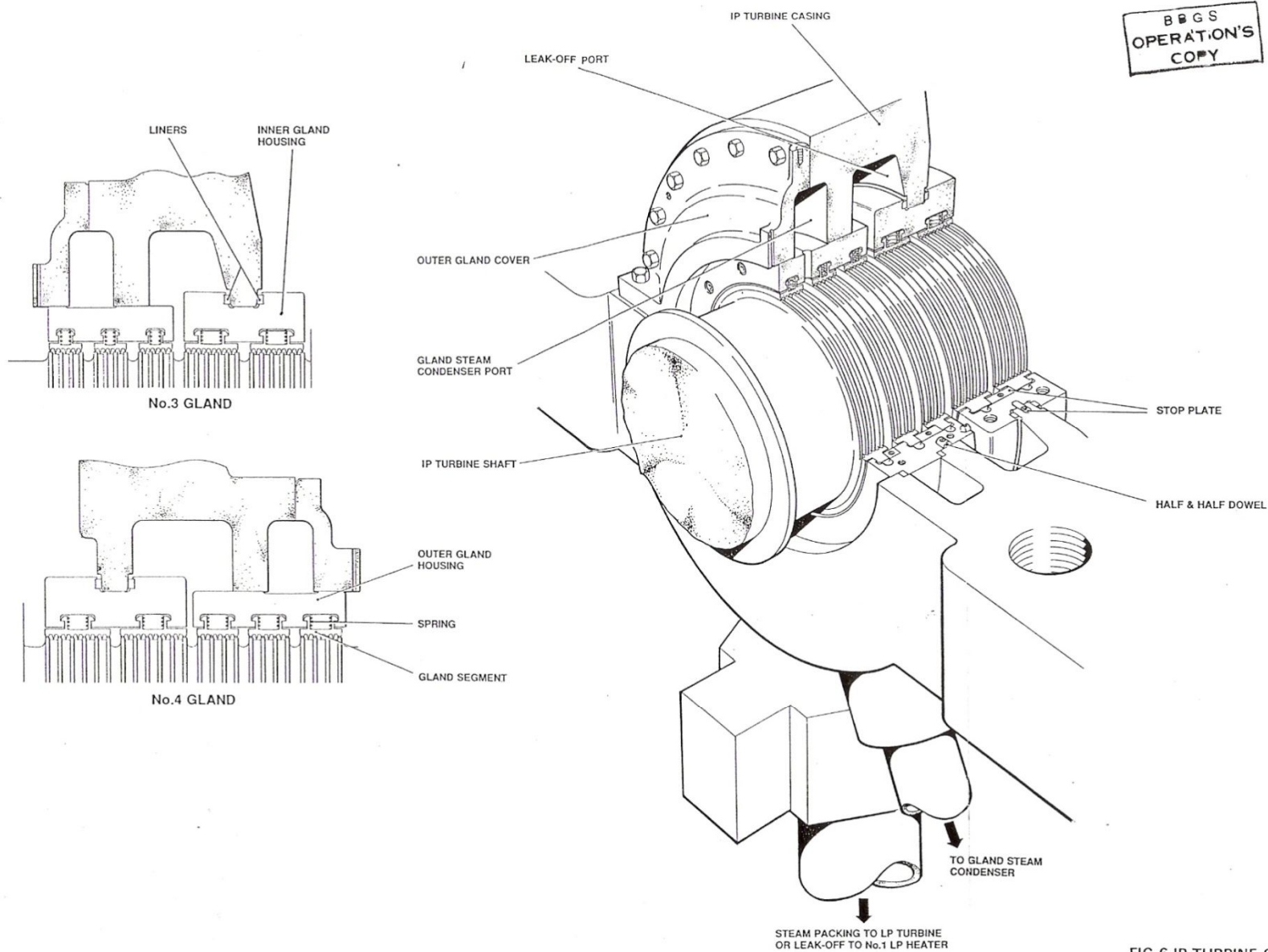


FIG.6 IP TURBINE GLAND

SMDS

# LP Turbine Glands- BBGS

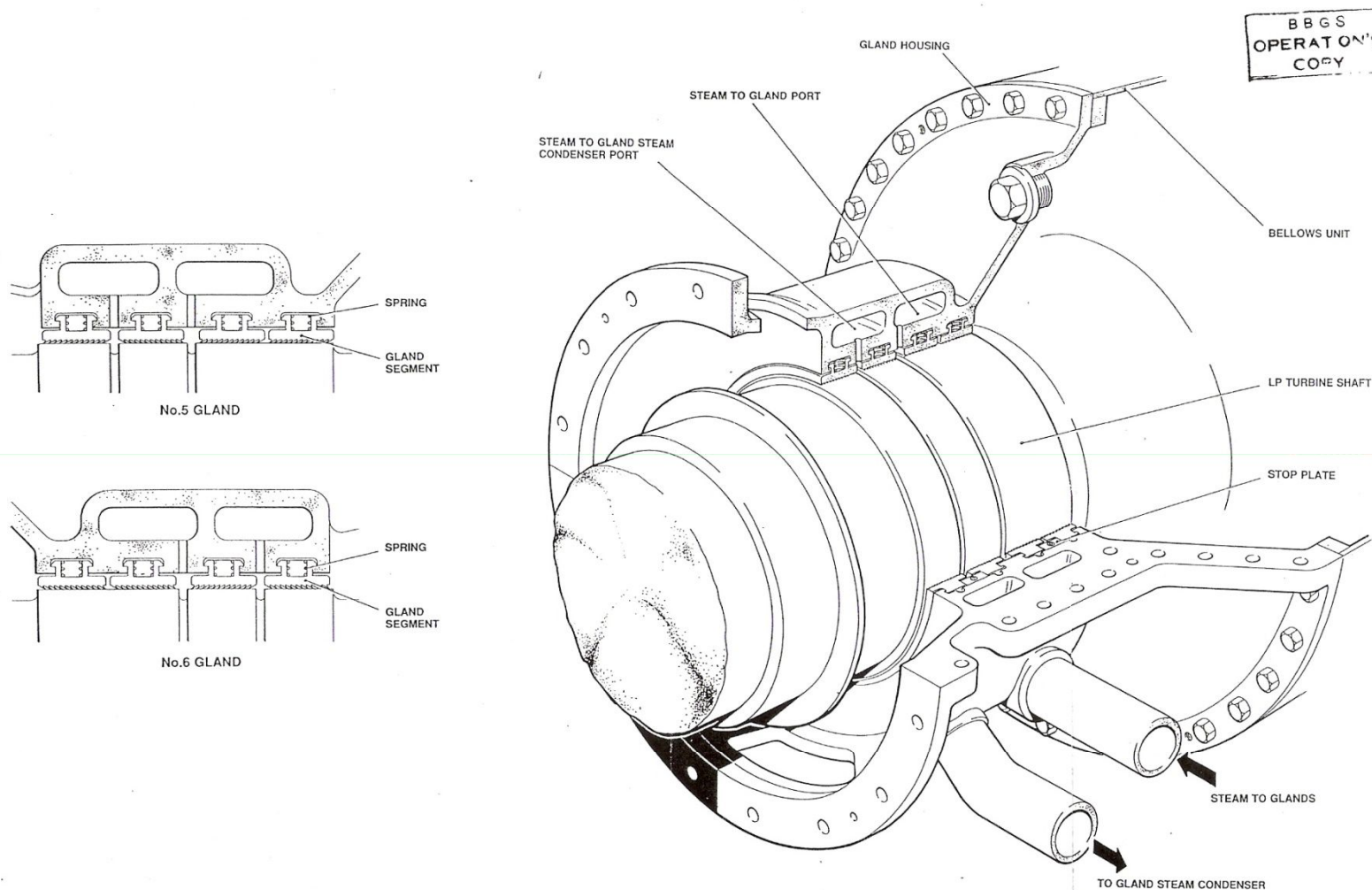


FIG.8 LP TURBINE GLAND  
SM0530

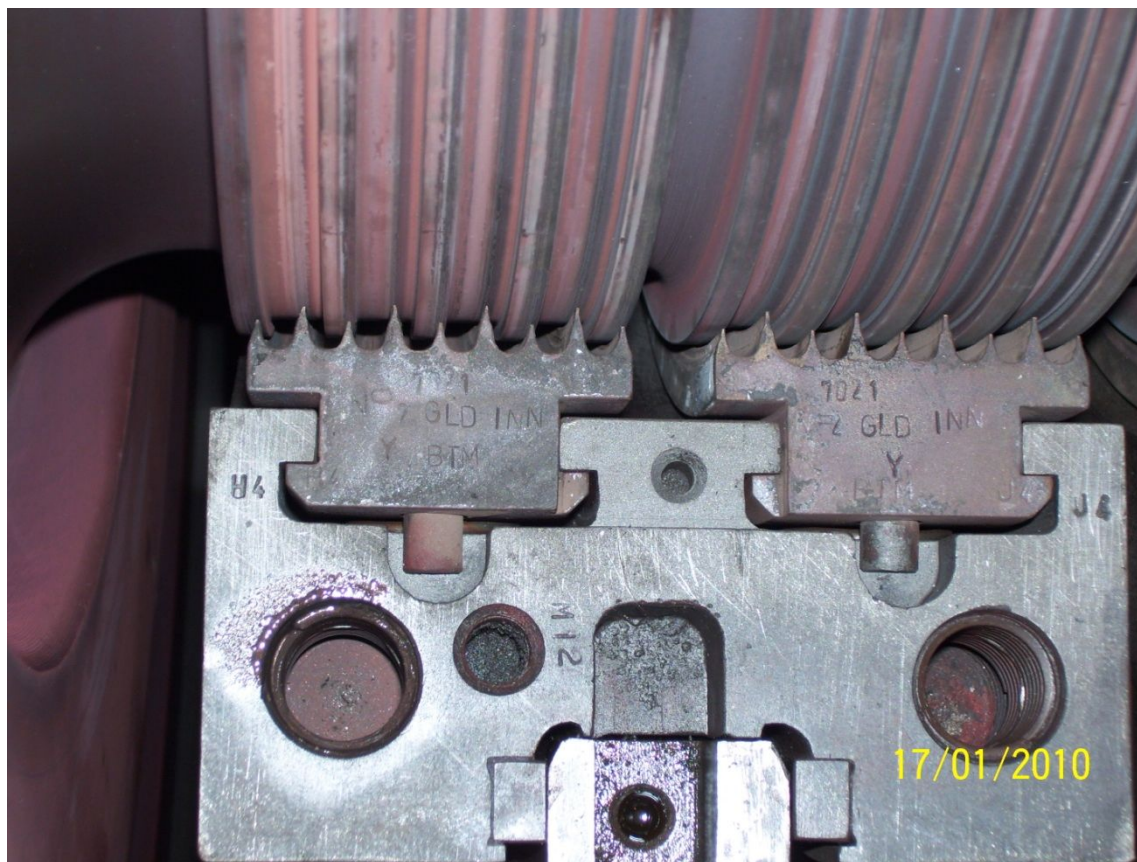
# Shaft seals

- During normal operation the gland ring segments are held by spring pressures against the shoulders of T shaped grooves in gland housing
- Movement towards shaft is thereby limited, so that the fins maintain predetermined distance from the shaft
- This arrangement can take up disturbances in shaft that tend to bring contact between static and rotating parts

# Shaft seals

- In such an event the segments can move radially outward against spring pressure and limit the contact pressure
- Low pressure Steam with sufficient degree of superheat is used for gland sealing
- This is normally obtained from a PRDS station
- As the LP gland steam requires a lower temperature additional de-superheating has to be done

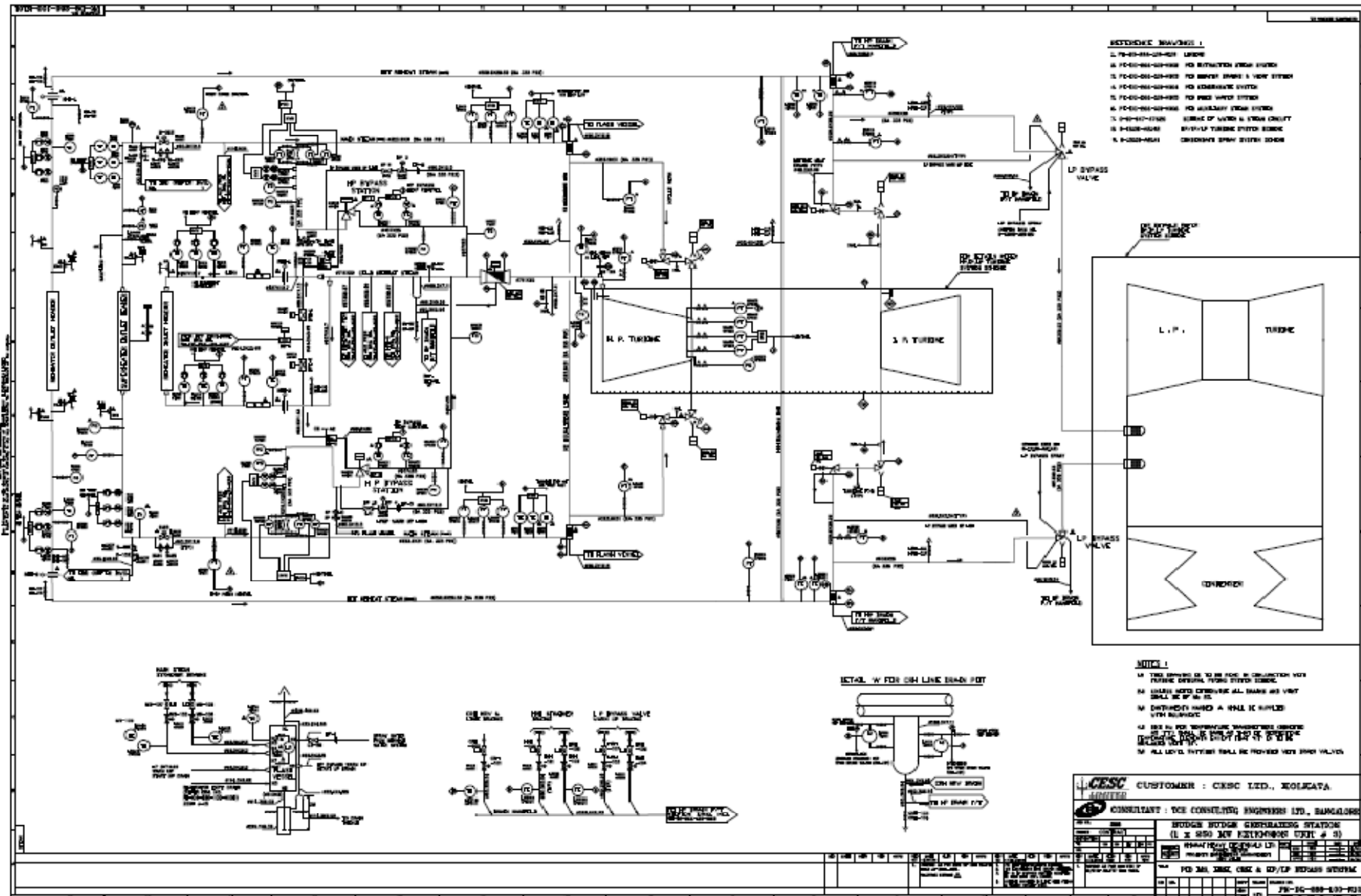
# LABYRINTH SEALS



# HP LP Bypass System

Concepts  
&  
Component Description

# MS PID FOR BBGS UNIT 3

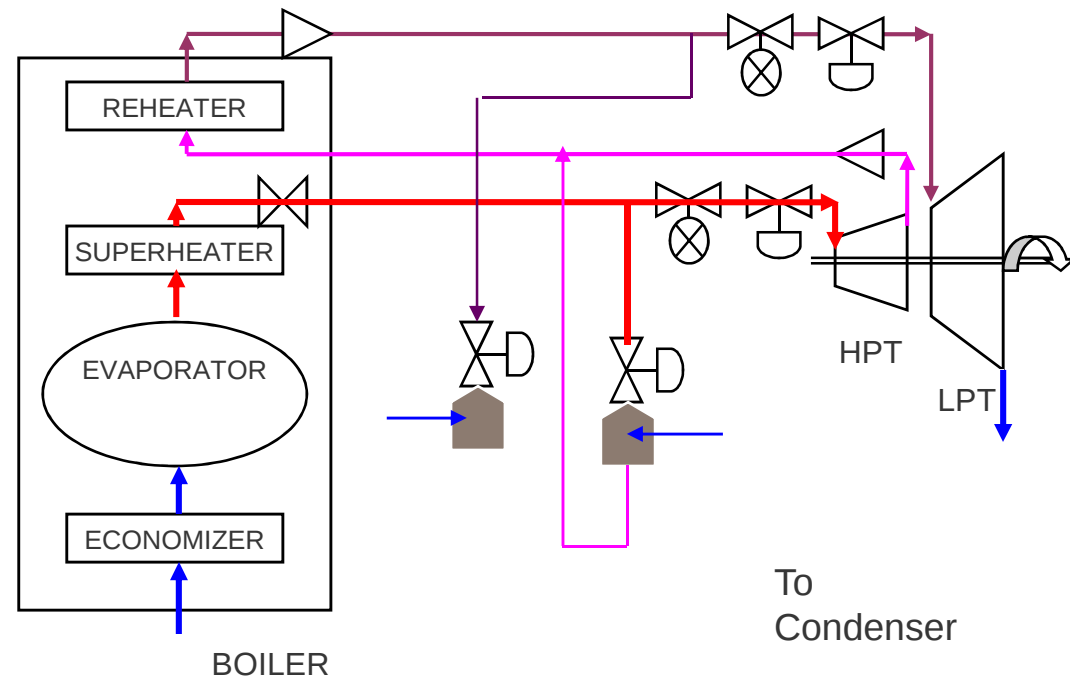


## Basic concepts of HP LP Bypass

- Need to have HP LP Bypass
  - To prevent Steam loss during start-up / shut down
  - To control boiler temperature during cold starts
  - Matching of boiler outlet steam parameter with that of turbine metal during hot starts
  - Allow transient excess steam flow under load throw off saving boiler safety valve operation
  - Protect re-heater during such transient
  - Avoid boiler trip in the event of turbine trip

# Basic concepts of HP LP Bypass

- HP Bypass arrangement
- LP Bypass arrangement
- Atempuration spray to match the downstream conditions



## Basic concepts of HP LP Bypass

- Main Steam from boiler is bypassed into Cold Reheat line i.e. HP turbine exhaust
- Steam, after flowing through Reheat stage in boiler is again dumped to the condenser before entering the intermediate turbine
- The condenser cooling water condense the steam and carry away the heat
- Although there is a considerable heat loss in the process but the gains surpasses losses

## Basic concepts of HP LP Bypass

- The total flow handling capacity can vary from 30 to 100% of turbine MCR steam flow depending on the size of the valves
- For large units this can be achieved by using more than one valve in parallel
- HPLP bypass system having lower capacity can mainly cater to start up and shutdown requirements but cannot provide boiler protection

## Basic concepts of HP LP Bypass

- High Capacity system are designed to prevent boiler trip and over pressurizations due to disturbances external to boiler
- The system has become so reliable that some units consider HPLP bypass as a substitute to boiler safety valve (for 100% HPLP Bypass)
- In the above case the valves should have a very fast response\* and very good pressure regulation characteristic

## Basic concepts of HP LP Bypass

- The bypass system usually remains dormant during normal running of unit
- When required it has to act immediately, therefore the following features are essential:
  - A supply unit that provide hydraulic oil at required pressure all the time
  - Warm up arrangement to avoid thermal shock during any sudden operation after long time
  - A continuous watch dog monitoring system

# Components in HP LP Bypass

HP Bypass system

# HP Bypass system

- The HP Bypass system consists of
  - a) A pressure reducing valve
  - b) Associated spray water control valve
  - c) An atemperator to cool the steam downstream of pressure control valve
  - d) All control valves have actuators powered hydraulically
  - e) Field Control devices (servo, solenoid valves etc) and instrumentation (sensors for pressure, temperature, position, etc.)

# HP Bypass system

- The HP pressure reducing valve can reduce the pressure from rated turbine inlet pressure to the cold reheat pressure
- There is an atemperator unit, either separate or integral to the main valve
- The atemperator brings the temperature down to suit the CRH steam parameters
- Discharge from boiler feed pump is used for tempering the steam

# HP Bypass system

- The HP pressure reducing valve can be designed to open either aided by the main steam pressure or against it [The former type is then a pressure safety device\*]
- The valve capacity determines its aperture design
- The valves are provided with sophisticated hydraulic actuators that can open or close the valve at normal as well as fast rate

## HP Bypass system at Budge Budge

- The HP pressure reducing valve at Budge Budge is of Sulzer make and is 'steam to open' type
- It is designed to for 60% TMCR steam flow at rated pressure
- The pressure reduction and atemperation is within the same valve chamber
- This valve is therefore designed with an unique profile that can withstand stress due to sharp temperature gradient between inlet and outlet
- Discharge from boiler feed pump supplies the spray water through control valves

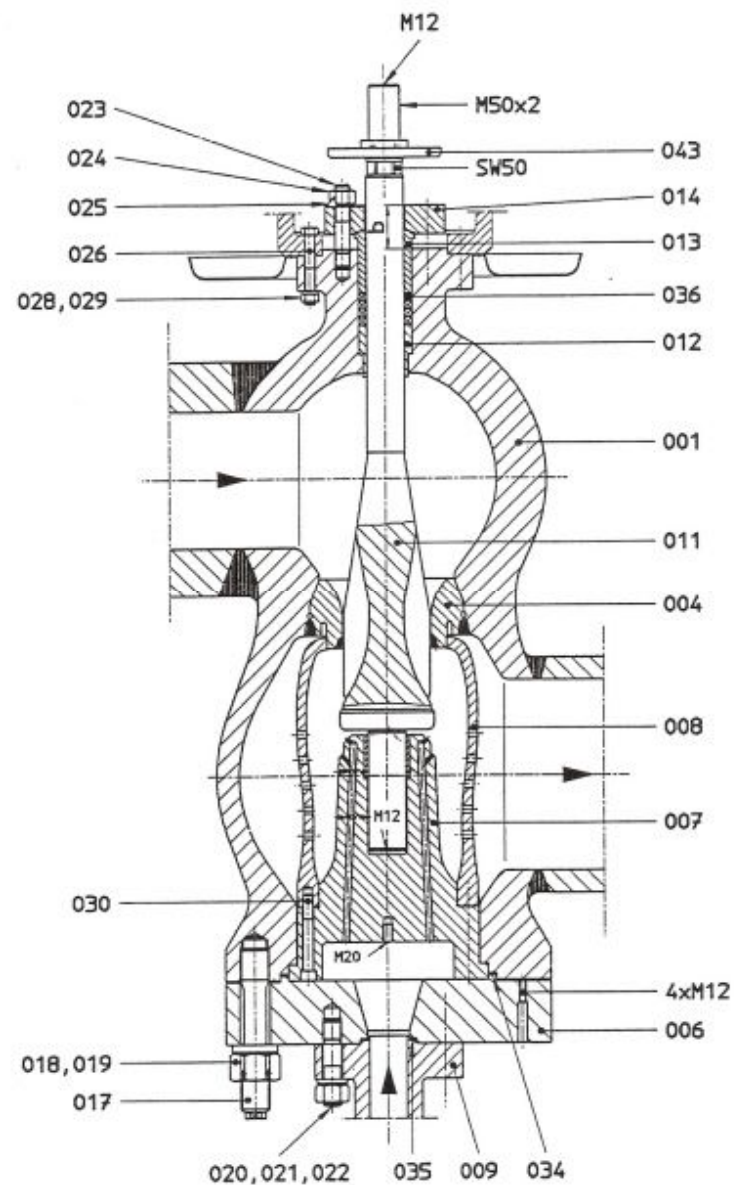
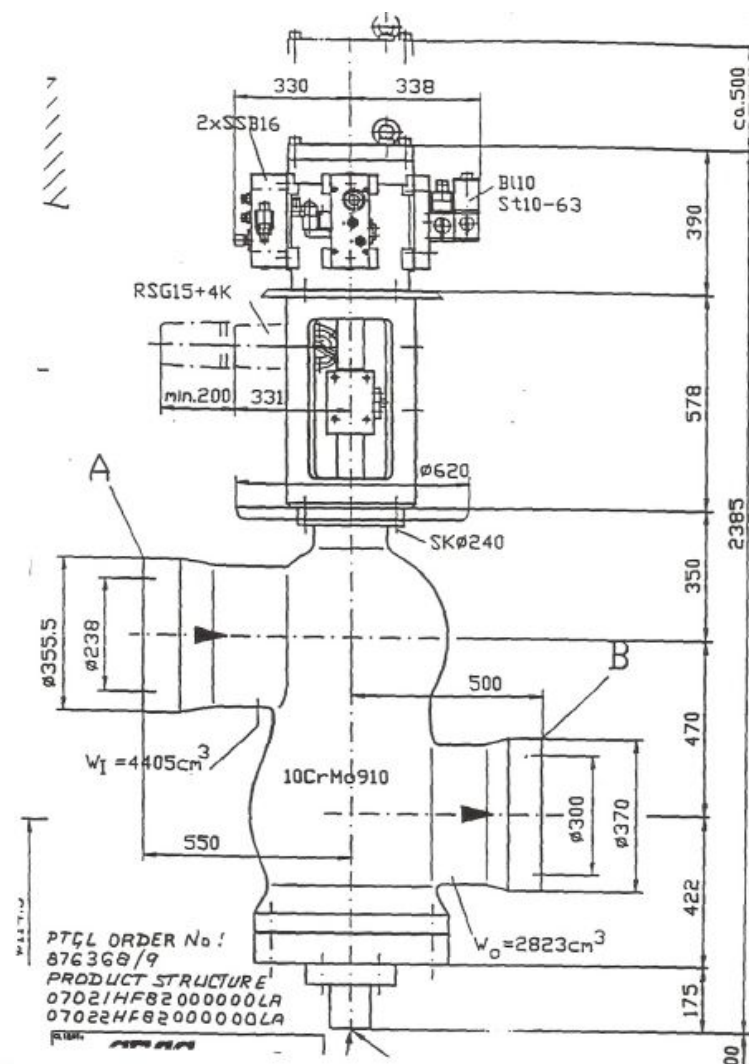
## HP Bypass system at Budge Budge

- During normal running when the steam valve will remain shut spray water should not find its way to the valve
- Since the spray water through control valve cannot ensure tight shut off, an additional isolating valve is provided
- The feed water lines also have a warm up line to avoid sudden change in pipe line temperature
- The pressure control valve opens on sensing its upstream pressure and as long as it remains open it tries to maintain a set pressure

## HP Bypass system at Budge Budge

- While the pressure control valve is open the water isolating valve opens fully
- The temperature controller senses downstream temperatures and modulate the valve to maintain a set temperature
- A steel cage in a temperator chamber ensures proper mixing of steam and water
- Both the water valves shut close as soon as the pressure control valve closes
- HP bypass valve actuator is specially designed to open very fast under sharp load throw off, so that the boiler operation is not affected

# HPBP Valve



The drawings show construction of the HP Bypass valve of BBGS



# Components in HP LP Bypass

LP Bypass system

# LP Bypass system

- LP Bypass pressure control valves are designed to handle the exact amount of steam that the HP valve bypasses into reheater
- The LP pressure control valve regulate the reheat pressure to a set value
- As the specific volume of HRH steam is more the valve has to have a higher size or more numbers of them are to be used

# LP Bypass system

- Downstream of LP Bypass pressure control valves are atomizers that mix the steam with water from Condensate Extraction Pump discharge
- The required amount of atomizer spray water is regulated by a control valve
- The steam mixes with water and flows into the condenser finally

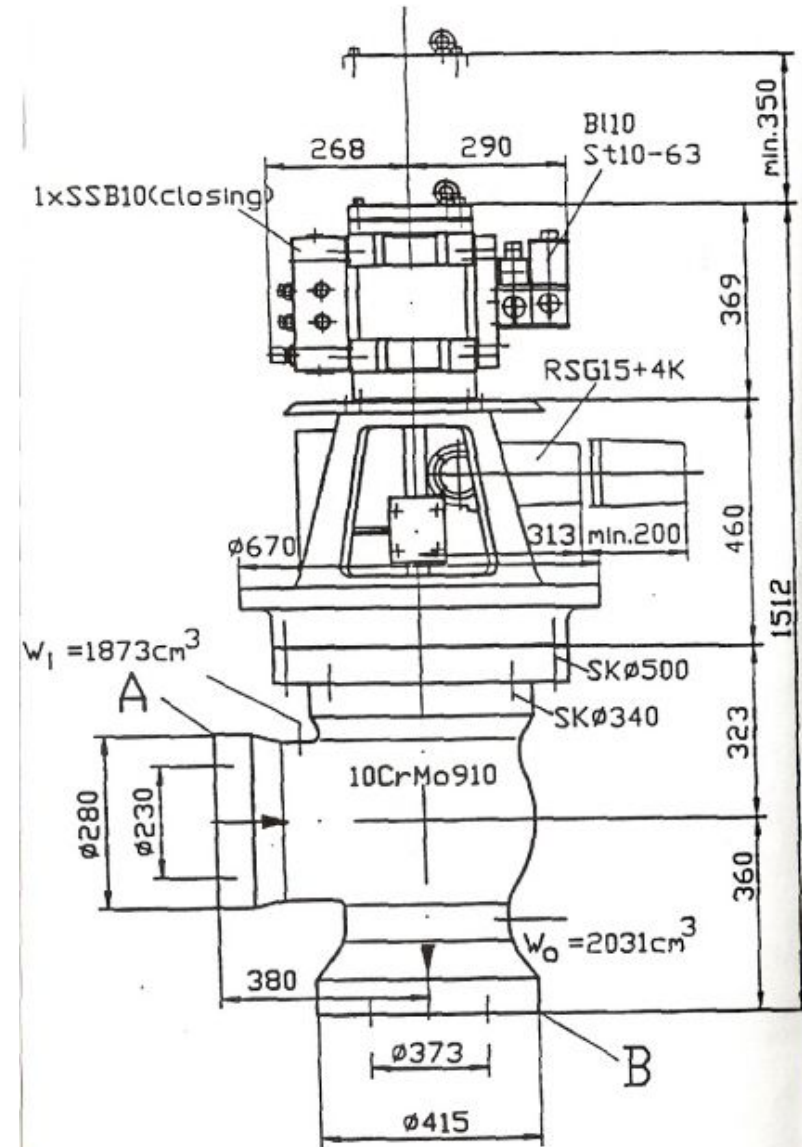
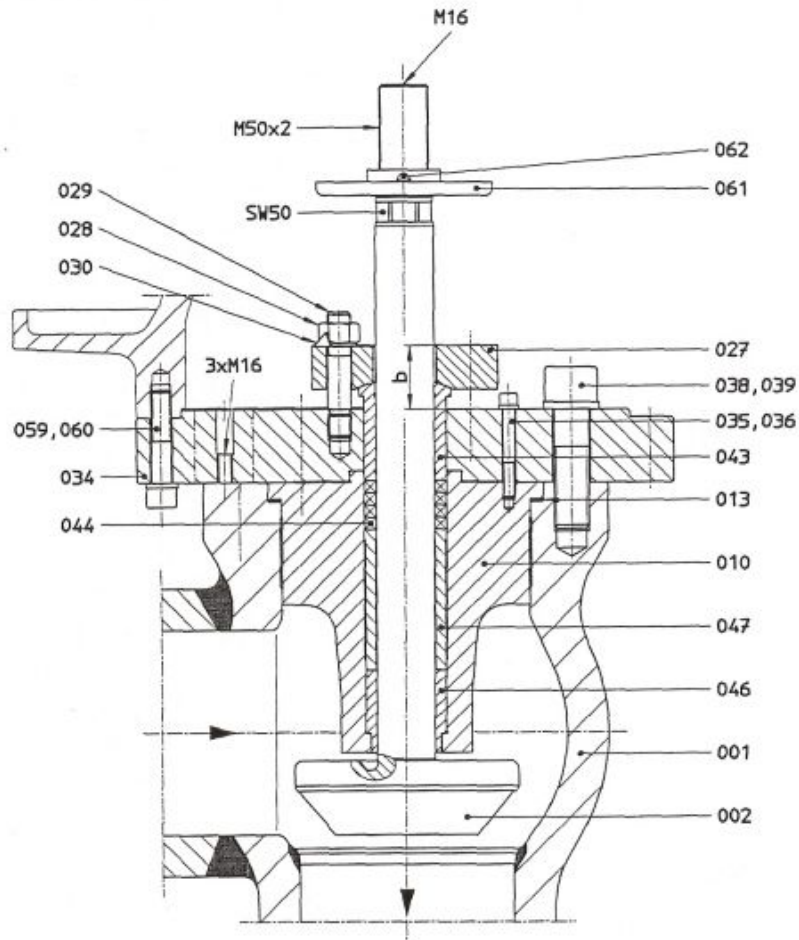
# LP Bypass system

- LP bypass (HP bypass as well) valve can therefore be put into operation only after condenser is under vacuum
- Condensers are built to handle the additional heat load from bypass system
- In Budge Budge two numbers of LP bypass valves have atemperators downstream of them, mounted on condenser neck

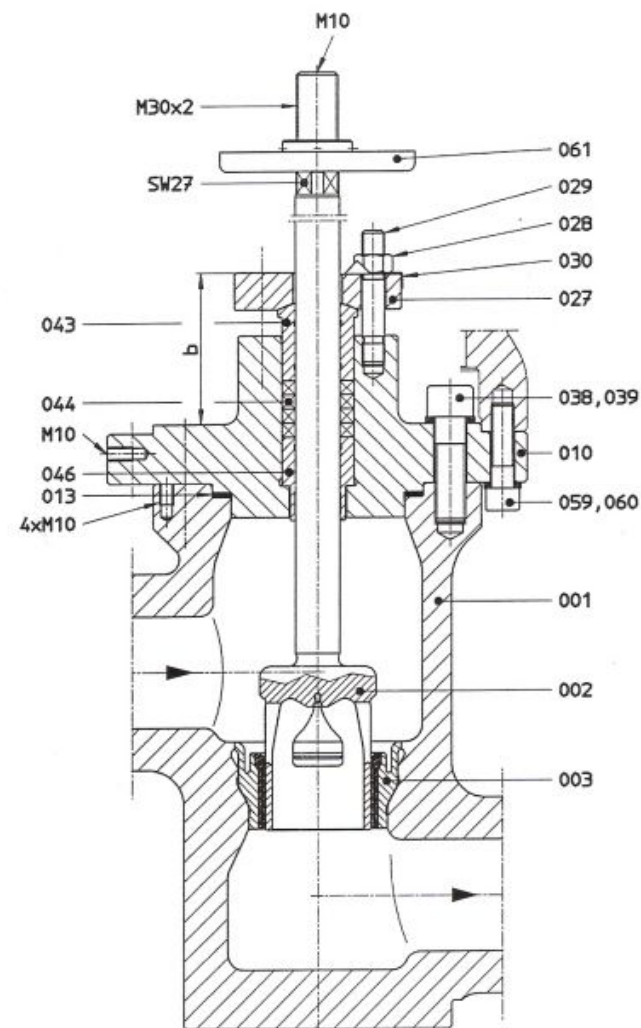
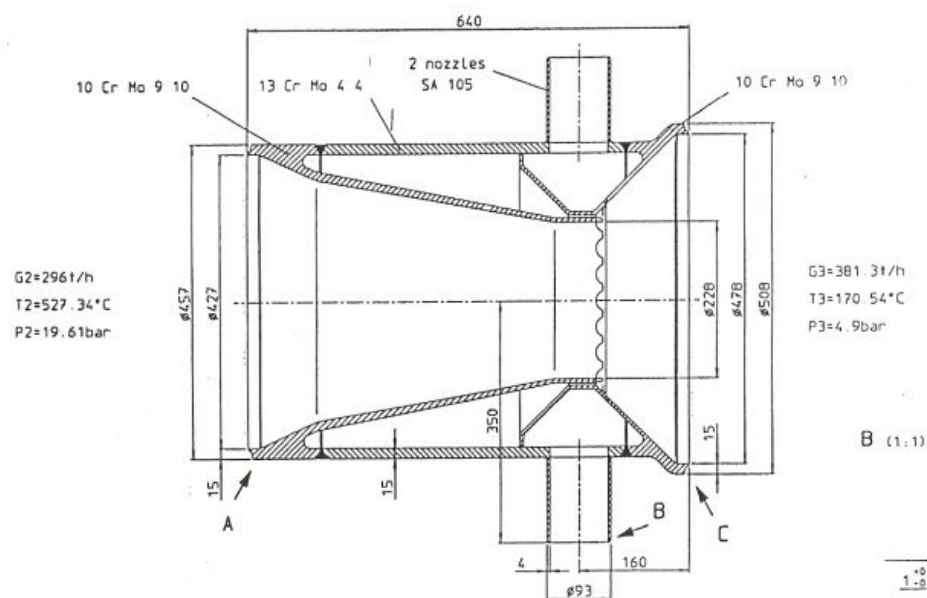
# LP Bypass system

- Atemperrated steam is dumped into condenser through dump pipes inserted inside the condenser shell
- Additional spraywater arrangement is also provided over these “dump pipes” to achieve further quenching of steam

# LP Bypass Valve



# LP Bypass Spray-Water Valve & Atempperator



# Thank you!