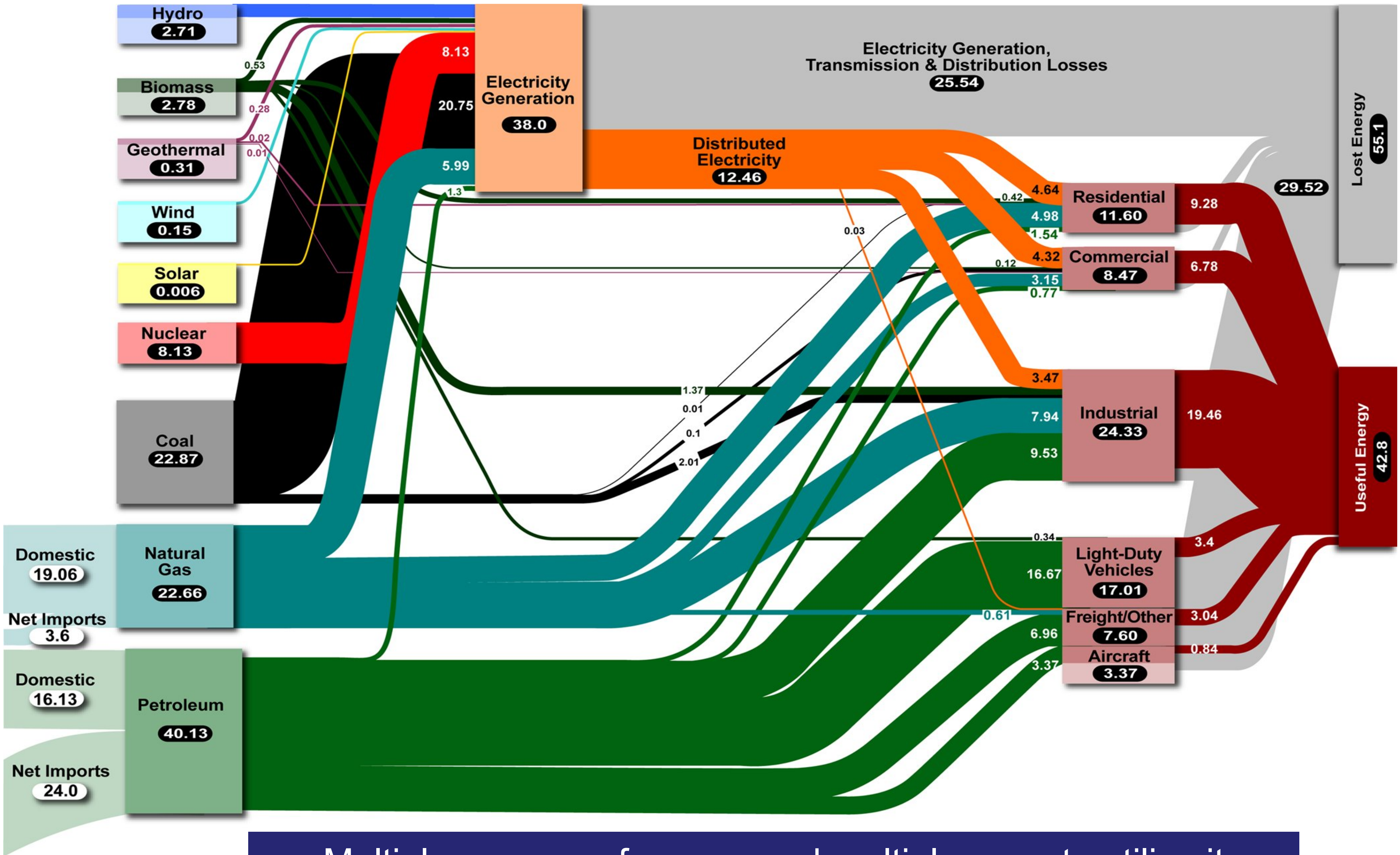
BORN TO ENGINEER

ENERGY AND POWER DOMAIN

November 2010

ENERGY IN U.S.A. - % production and consumption



Multiple sources of energy and multiple ways to utilize it

ENERGY: POWER GENERATION

- What is the power generation industry?

  - To supply energy to consumers ***in form of electricity*** is the core business of power generation industry

Power generation industries focus on electric power in the following ways

- ***Producing*** it from other available energy resources.
- ***Distributing*** to consumers

QuEST's Energy and Power Domain expertise as of 2010 is largely in the area of ***producing*** of electric power

What is Electric Power?

- Charged particles in motion carry with them a kind of energy called Electric Energy

- Thus source of charged particles in motion = Source of Electric Power

- Pros of Electric Power
  - Easily transportable as Alternating Current (AC) over long distances through metallic wires.
  - Easily transformed into Mechanical Power or Heat or Light

- Cons of Electric Power
  - Cannot be easily stored in large quantities, must be generated “on demand”

Sources of Electrical Energy

- Energy in Nature in many ***non-electrical*** forms:

  - CHEMICAL ENERGY contained in the chemical bonds between atoms in the molecules.
    - Carbon and Hydrogen chemical bonds in **FUELS**
  - POTENTIAL ENERGY available in masses located at high position.
    - **WATER** stored at high level
  - KINETIC ENERGY available moving masses.
    - WIND or SEA WAVES
  - RADIATING ENERGY contained in photons
    - SOLAR radiation
  - NUCLEAR ENERGY contained in the bonds of nuclei of atoms
    - Proton neutron bonds in URANIUM or PLUTONIUM

Power Generation Industry is about transforming above forms of Energy into Electrical Energy.

SOME HISTORICAL DATES

Giovanni Branca	Impulse steam turbine proposal.	1629
Thomas Newcomen	Atmospheric engine using steam.	1700
James Watt	Condensing steam engine idea.	1765
John Barber	Gas turbine ideas and patent.	1791
N. L. Sadi Carnot	Principles for an ideal heat engine.	1824
Michael Faraday	First electric current generator.	1831
Robert Mayer	Equivalence of heat and work.	1842
James Joule	First Law of Thermodynamics.	1847
Rudolph Clausius	Second Law of Thermodynamics.	1850
James C. Maxwell	Principles of electromagnetism.	1865
Niklaus Otto	Four-stroke internal combustion engine.	1876
Charles Parsons	Multistage, axial flow reaction steam turbine.	1884
Thomas Edison	Pearl Street steam-engine-driven electrical power plant.	1884
C.G.P. de Laval	Impulse steam turbine with convergent-divergent nozzle.	1889

SOME HISTORICAL DATES

Rudolph Diesel	Compression ignition engine.	1892
	First hydroelectric power at Niagara Falls.	1895
Albert Einstein	Mass-energy equivalence.	1905
Ernst Schrodinger	Quantum wave mechanics.	1926
Frank Whittle	Turbojet engine patent application.	1930
Otto Hahn	Discovery of nuclear fission.	1938
J. Ackeret, C. Keller	Closed-cycle gas turbine for electric power generation.	1939
Enrico Fermi	Nuclear fission demonstration at the University of Chicago.	1942
	Production of nuclear fission electricity by a utility at Shippingport, Pennsylvania.	1957
Electricité de France	Superphénix 1200-MW Liquid Metal Fast Breeder Reactor first grid power.	1986

A CLASSIFICATION OF POWER GENERATION

- Fossil Fuels (Coal, Oil, Gas)
  - Thermal Power Plants
    - Boiler + Steam Turbine
  - Gas Turbine Open (Simple) Cycle Power Plants
    - Gas Turbine
  - Combined Cycle
    - Gas Turbine + Heat Recovery Steam Generator + Steam Turbine
  - Endothermic Engines
    - Gas or Diesel Reciprocating Engines
- Renewable (Gravitational, Thermal, Kinetic, Radiation)
  - Geothermic
  - Hydro
  - Solar
  - Wind
- Nuclear (Fission of Uranium or Plutonium)
  - Thermal Neutron Reactors
  - Fast Breeding Reactors

FOSSIL FUEL POWER

(Generated by Gas Turbines And Coal-Fired Steam Turbines)

FOSSIL FUELS

Fuels Such as

- Natural gas
- Oil
- Coal

- Called fossil fuels because they are the result of decomposition and aging (= fossilization) of large deposits of biological masses.

- In fossil fuel power generation the heating phase of a Carnot cycle is based on the combustion of
  - fossil fuels (or)
  - fuels refined from fossil fuels.

2 Performance Parameters define Fossil Fuel Power - η and H

- THERMODYNAMIC EFFICIENCY

$$\eta = \frac{\textbf{Work at Shaft}}{\textbf{Compression Work + Heat Transferred}}$$

- HEAT RATE

$$H = \frac{\textbf{Heat Transferred by Fuel}}{\textbf{Work at Shaft}}$$

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Thank you. For more information:

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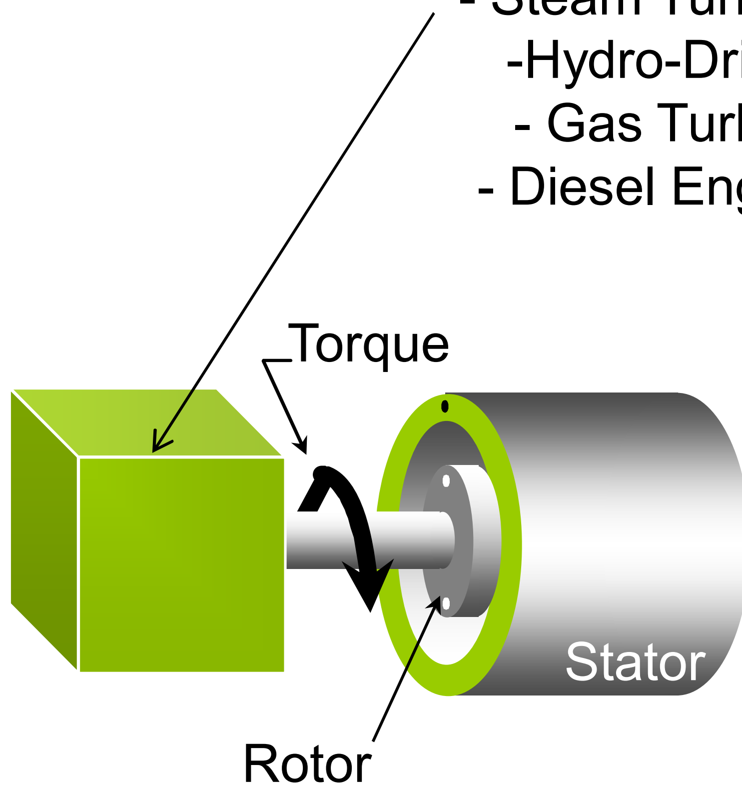
How is AC Power generated?:

Commercial utility power is generated by rotating electrical generators

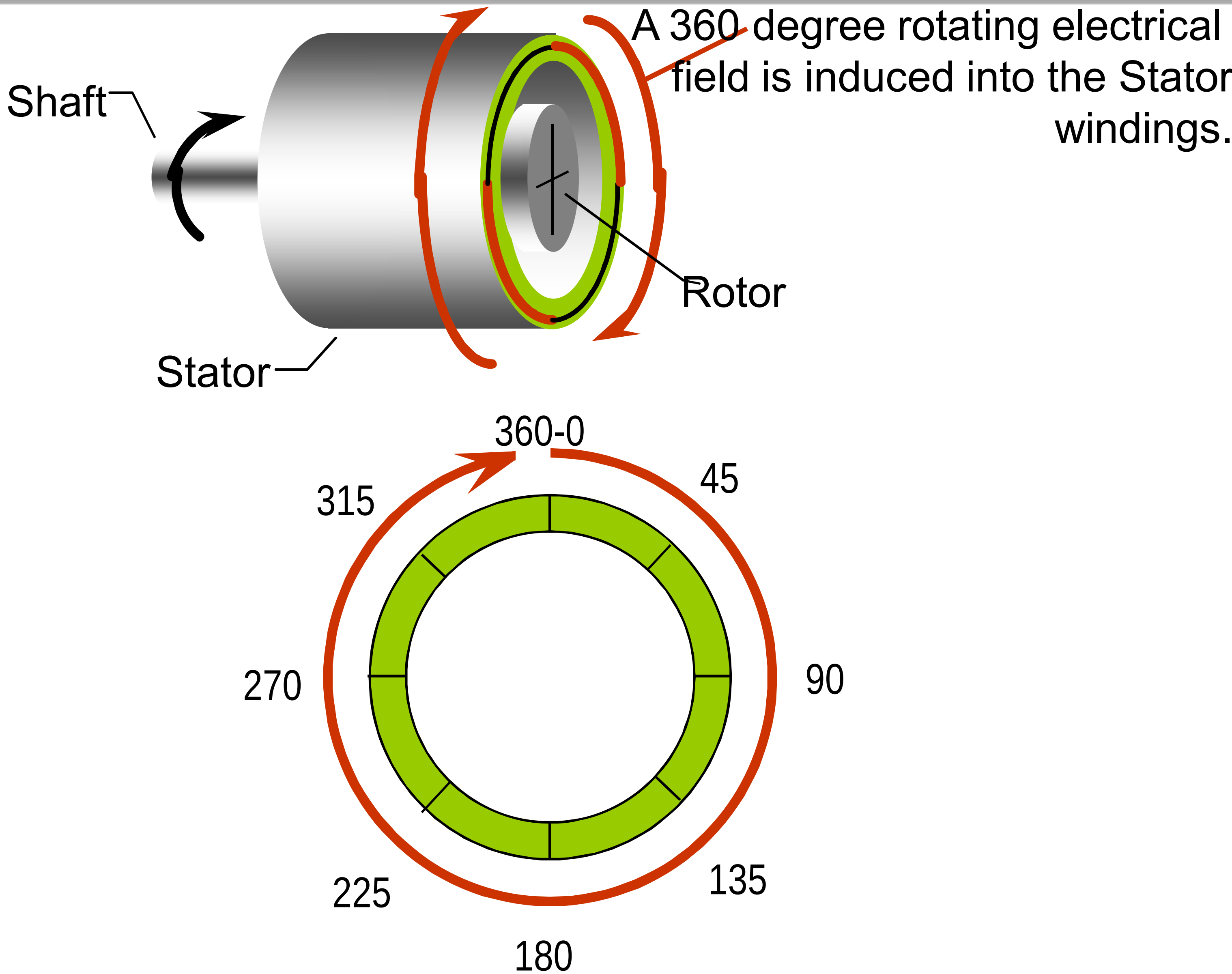
Mechanical Prime Movers
- Steam Turbine
-Hydro-Driven
- Gas Turbine
- Diesel Engine



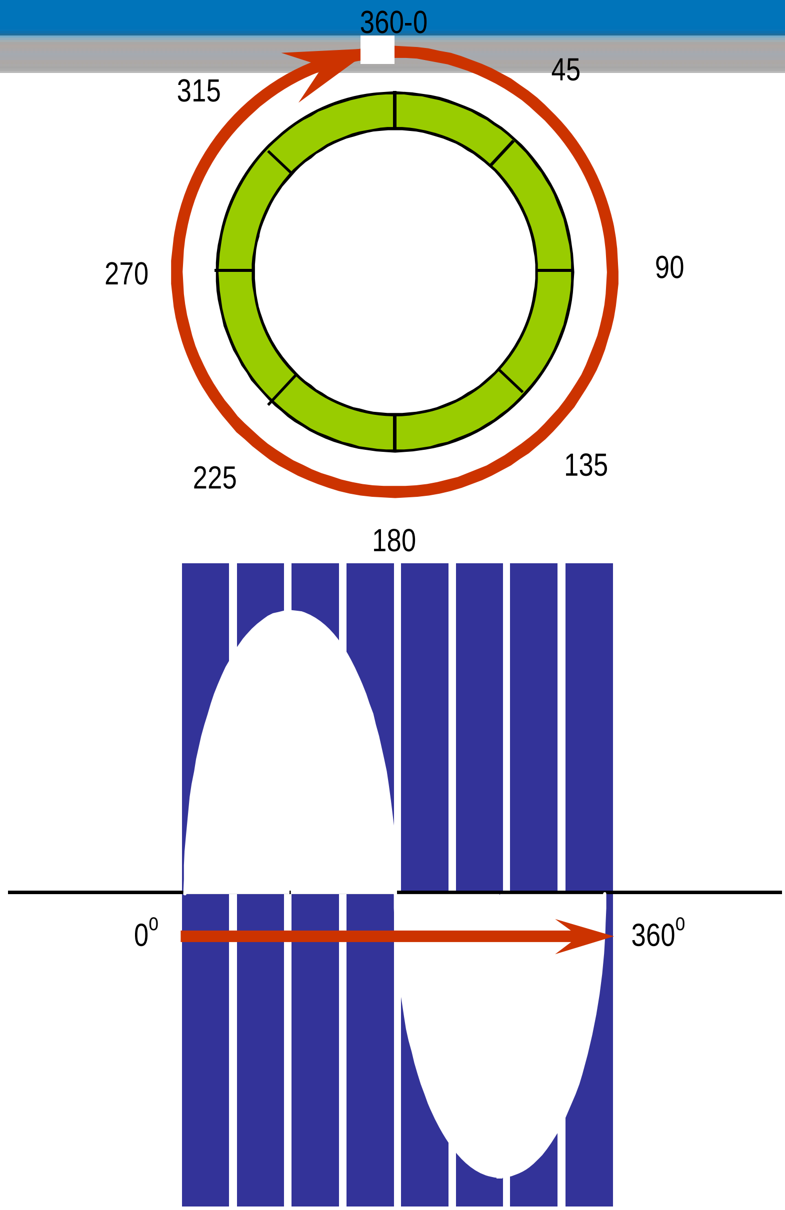
- Shaft torque Turns Rotor Electrical Generator
- Rotor Induces Rotating Magnetic Field Into Stator
- Stator Is Mechanically Fixed In Place (does not rotate)

- This generates electric power through electromagnetic induction

Rotating magnetic field:



This field induces electric current

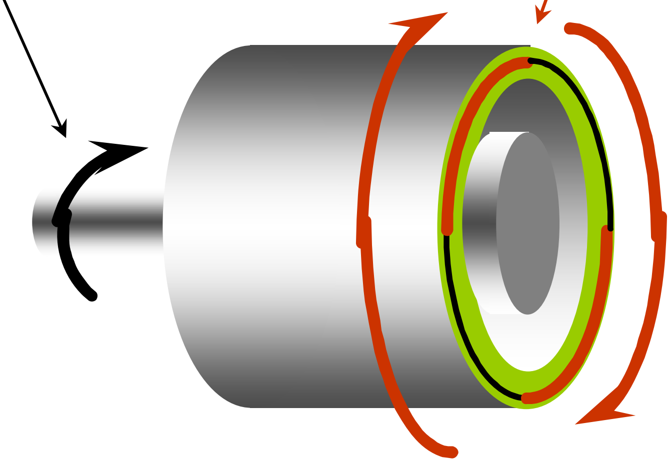


The Rotating Magnetic Field In The Generator Produces Alternating Electrical Current In A Sinusoidal Fashion (Sine Wave)

Shaft rpm linked to Magnetic field rpm

There is a fixed relationship between the speed of the rotating shaft (and rotor) and the speed of the rotating magnetic field:

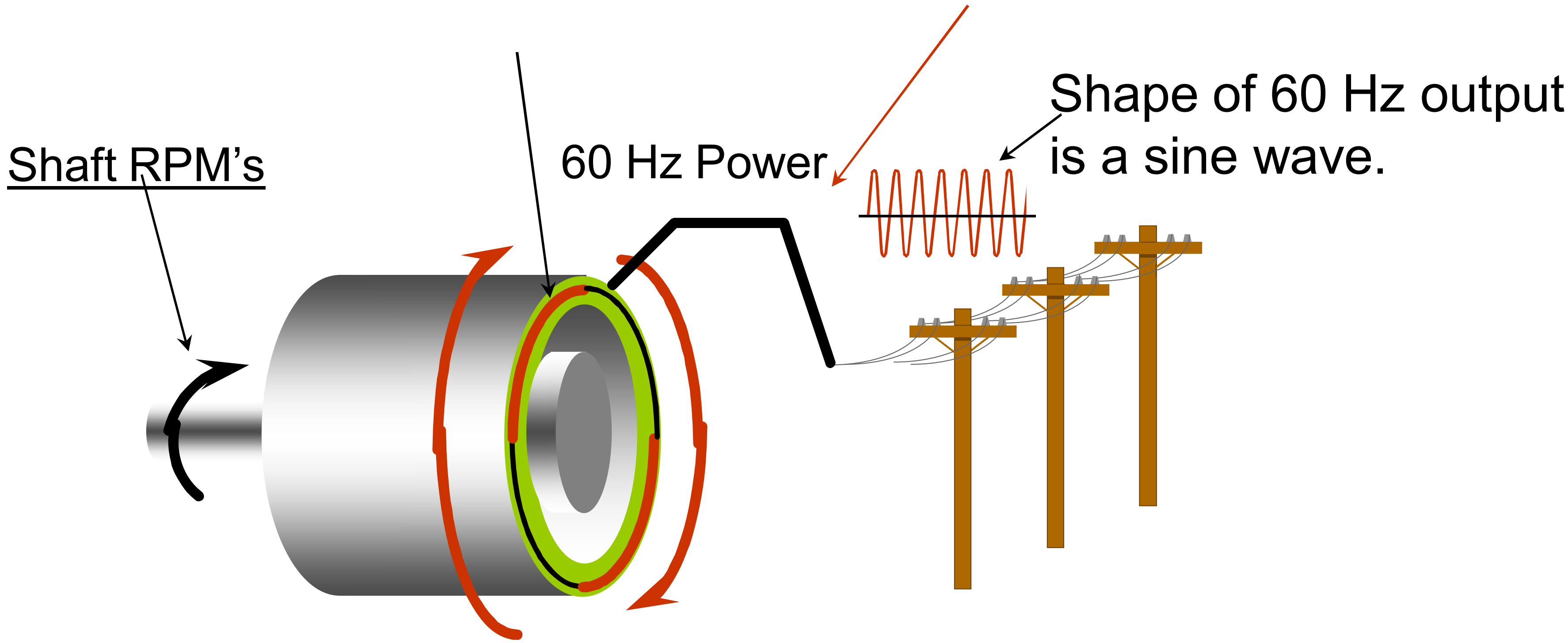
<u>Shaft RPM's</u> = <u>Rotational Speed of Magnetic Field</u>



Shaft rpm also linked to power frequency

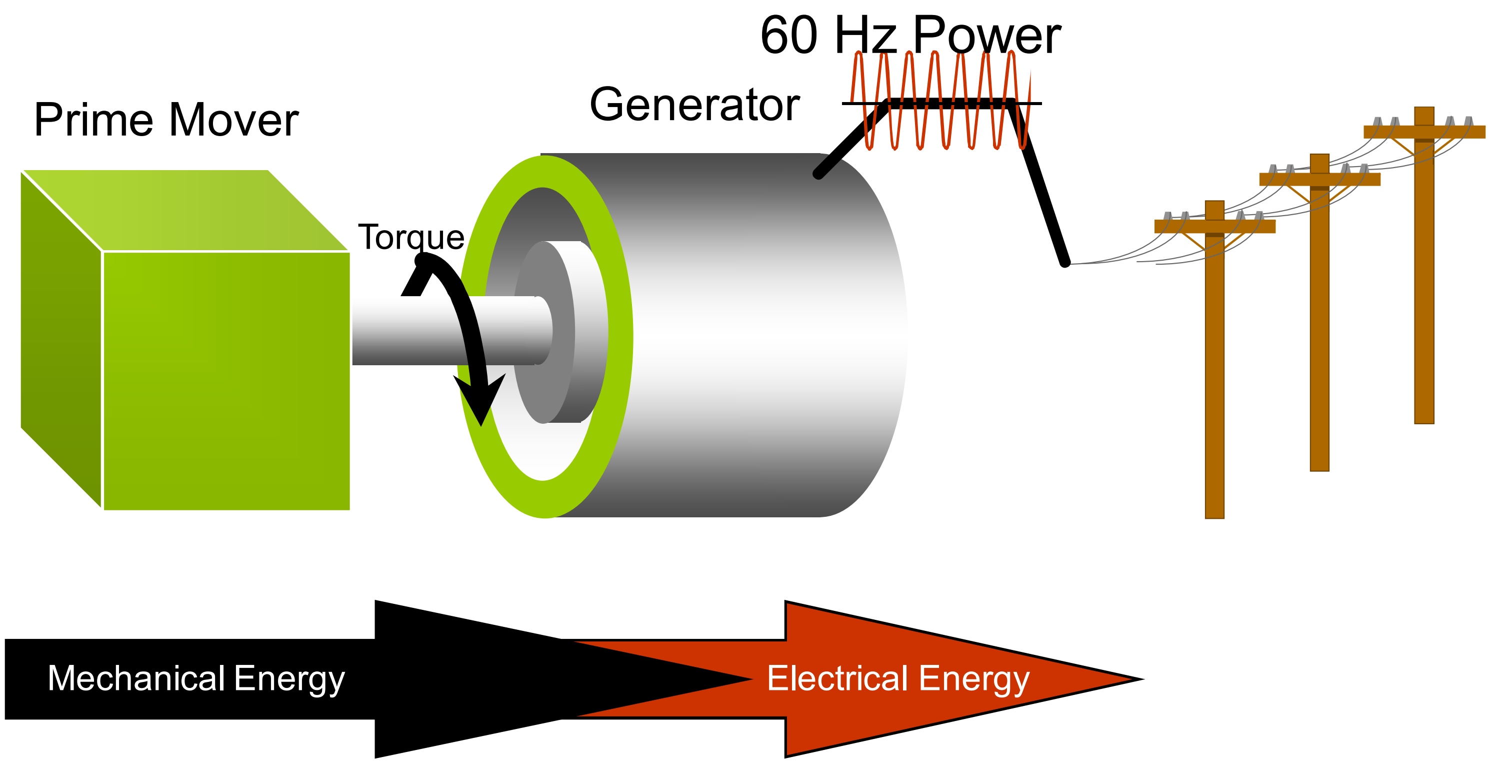
There is also a fixed relationship between the speed of the rotating magnetic field and the output frequency of the generator:

Rotational Speed of Magnetic Field = Generator Output Frequency



Line frequency varies from country to country
In USA power is distributed at 60 Hz
In India Power is distributed at 50 Hz

Mechanical - Electrical linkage



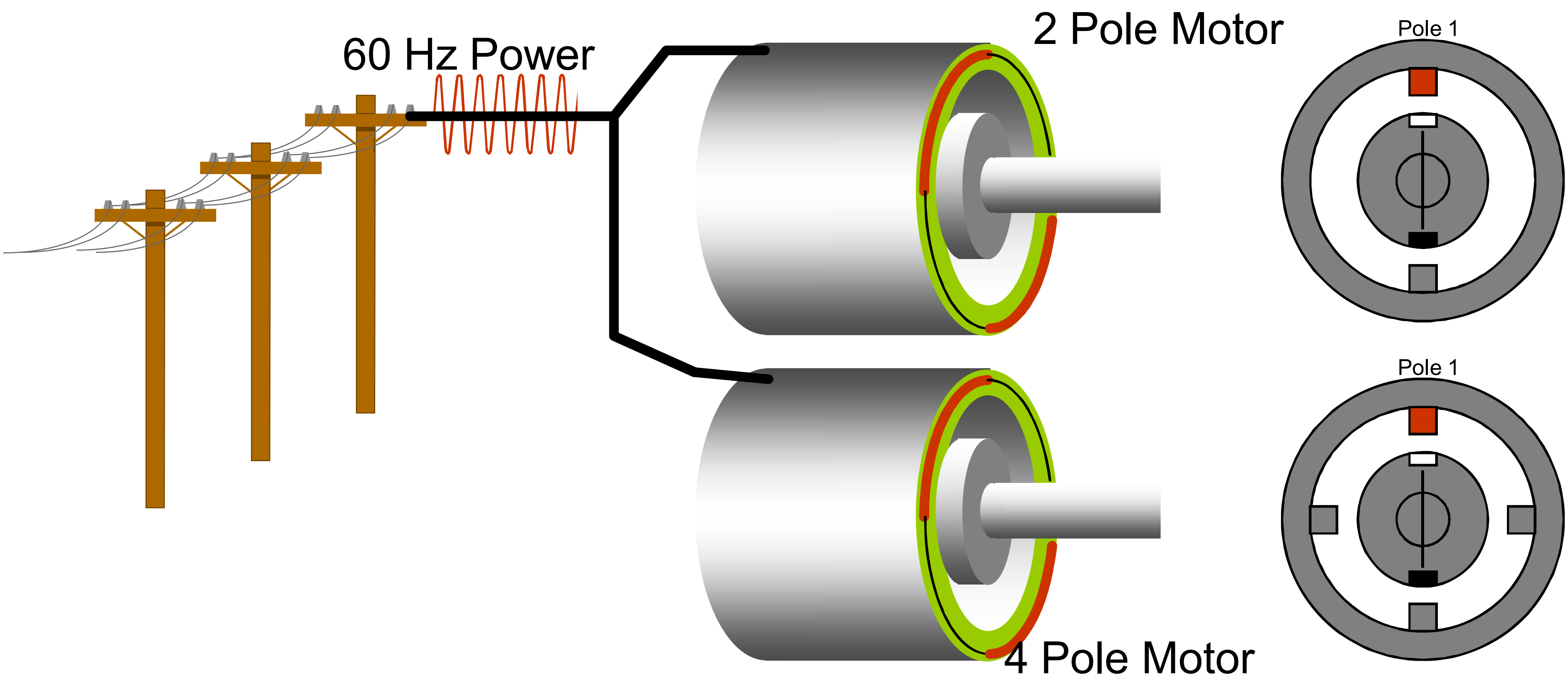
A Generator Converts Rotating Mechanical Energy Into AC (Alternating Current) Electrical Power

Shaft rpm link to power frequency

This relationship is defined by the formula:

$$\text{Shaft Speed (RPM's)} = \frac{120 \times f}{p}$$

{f = freq. of input power}
{p = no. of poles in stator}



RPM of machine linked to frequency and no. of poles

No. Poles	Sync. Speed (RPM's) @ 60 Hz	Sync. Speed (RPM's) @ 50 Hz
2	3600	3000
4	1800	1500
6	1200	1000
8	900	750
10	720	600
12	600	500

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Energy


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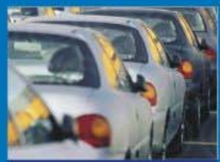

Transportation

INTRODUCTION TO HYDRO GENERATORS

TYPES OF HYDRO TURBINES & GENERATORS

T.R.KHAJURIA

HYDRO POWER

Hydro Power is not only environmentally friendly, but also cost effective. Hydro Power Plants have the highest operating efficiency of all known generation systems. They are largely automated and their operating costs are relatively low. Hydro Electric Power Plants also play an important role in water resource management, flood control, irrigation and creating recreational area.

P(Power) = K X Q(Quantity of Water flowing) X H(Head of Water)

At any Power House.

P has following Variables.

No. of Units.

KW Capacity of Each Unit.

Peak load or Base Load Duty.

Horizontal or Vertical Placement.

IMPORTANT TURBINE DATA WHICH GREATLY INFLUENCES GENERATOR DESIGN

Runaway Speed:

This is the maximum speed, that the Generator and Turbine set, with a given moment of inertia, attains, when full load is suddenly thrown off the unit, with simultaneous failure of Turbine Governor.

All Rotating parts are to withstand this speed with a factor of safety of 1.5 on yield point strength of material used.

IMPORTANT TURBINE DATA WHICH GREATLY INFLUENCE GENERATOR DESIGN

Hydraulic Thrust:

Hydraulic Thrust is the Downward and Upward (sometimes) flowing water thrust which acts as an additional load on the generator Thrust Bearing.

It's magnitude can be one to three times the weight of Rotating parts.

TYPES OF TURBINES

KAPLAN TURBINE

FRANCIS TURBINE

PELTON TURBINE

DERIAZ TURBINE

BULB TURBINE

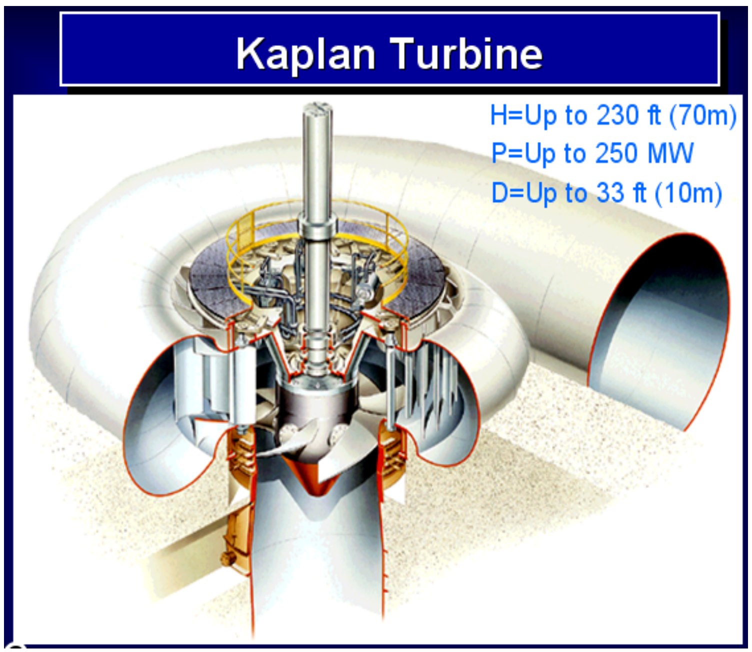
KAPLAN TURBINE

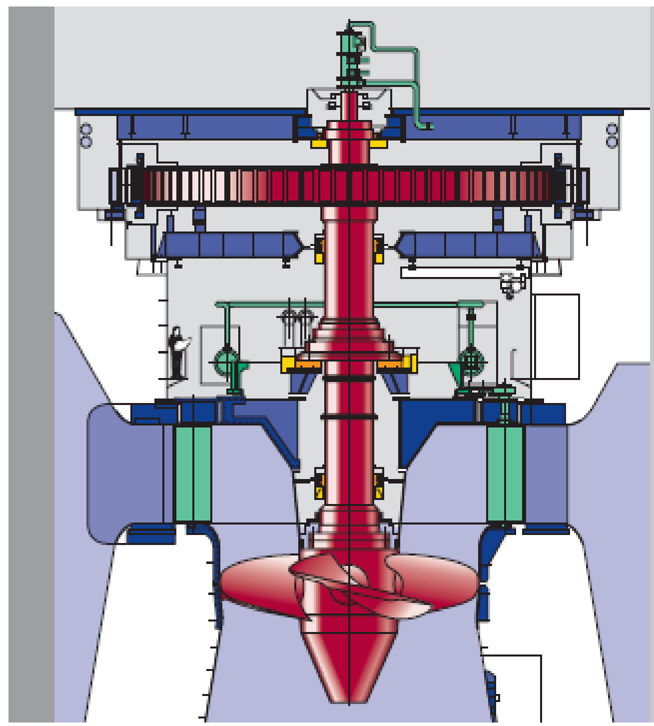
Axial flow reaction turbine, double regulated

Head Range 5 - 85 m.

Capacity Range 0.5 – 200 MW

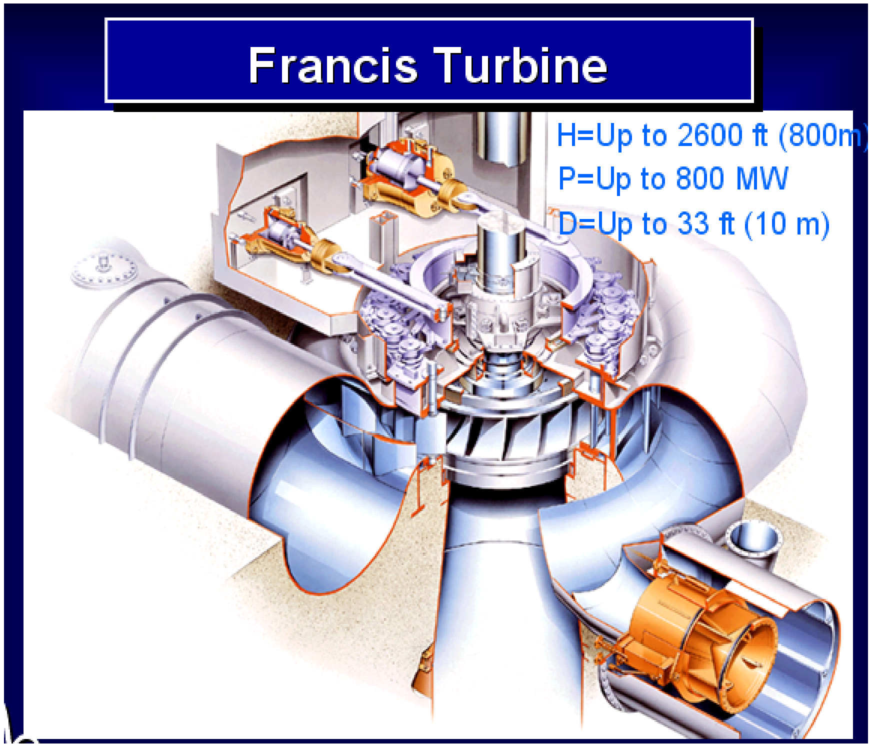
Runner Dia 2.5 - 10 m

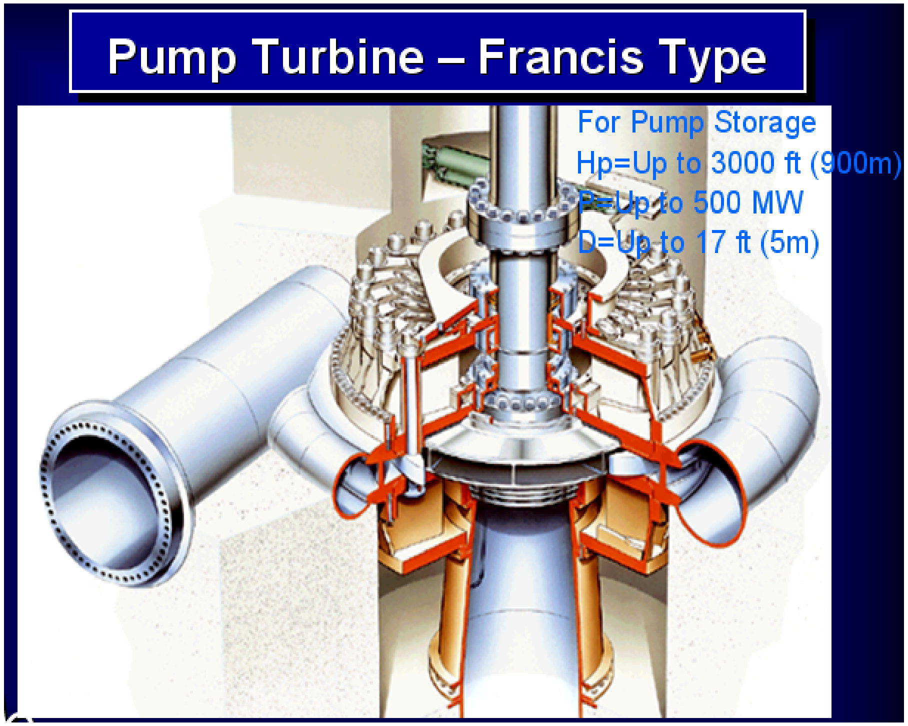




FRANCIS TURBINE

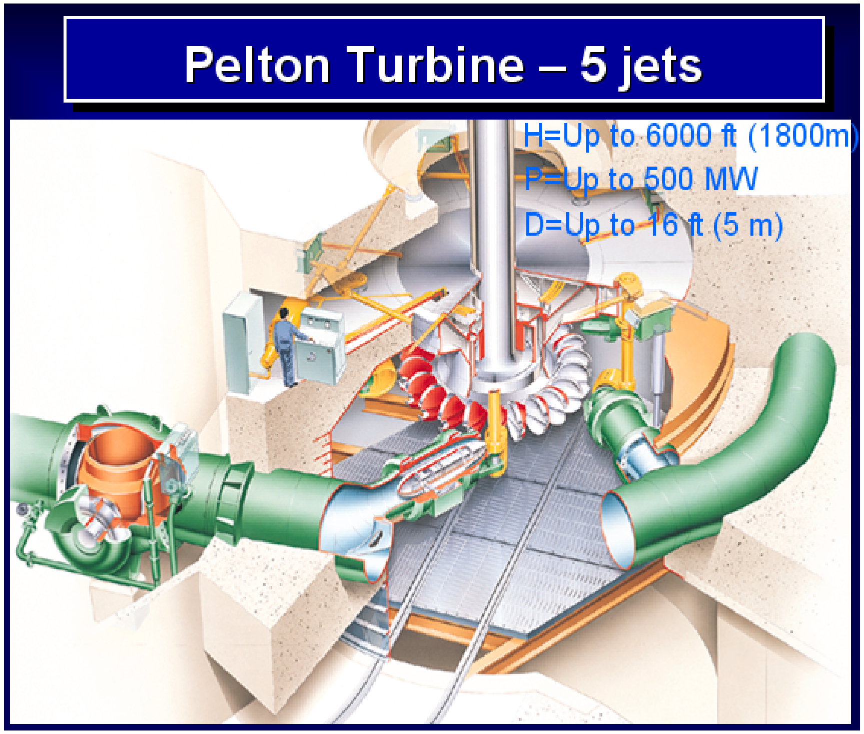
Inward flow reaction turbine that combines radial and axial flow concepts

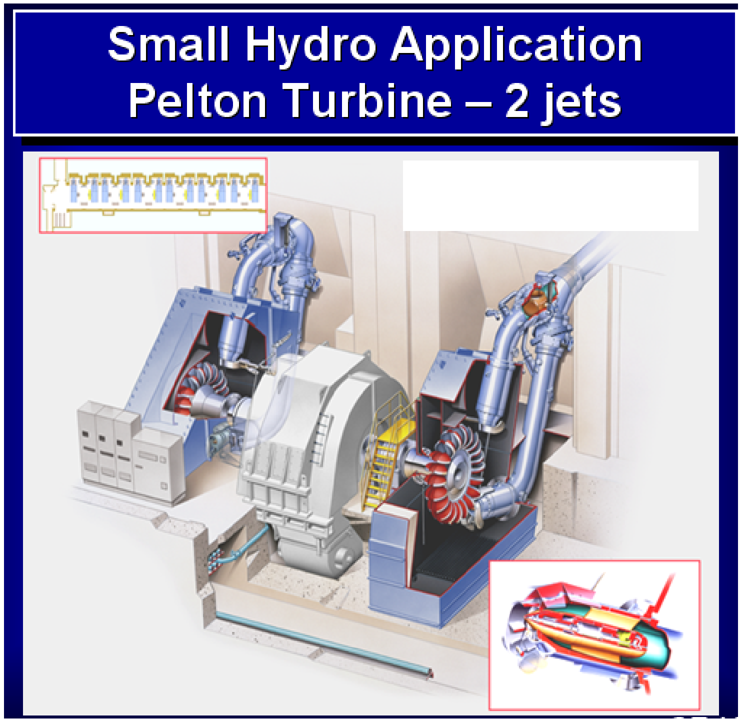




PELTON TURBINE

Impulse Turbine / Turbine that use kinetic energy of water





DERIAZ TURBINE

Double regulated reaction mixed flow Turbine

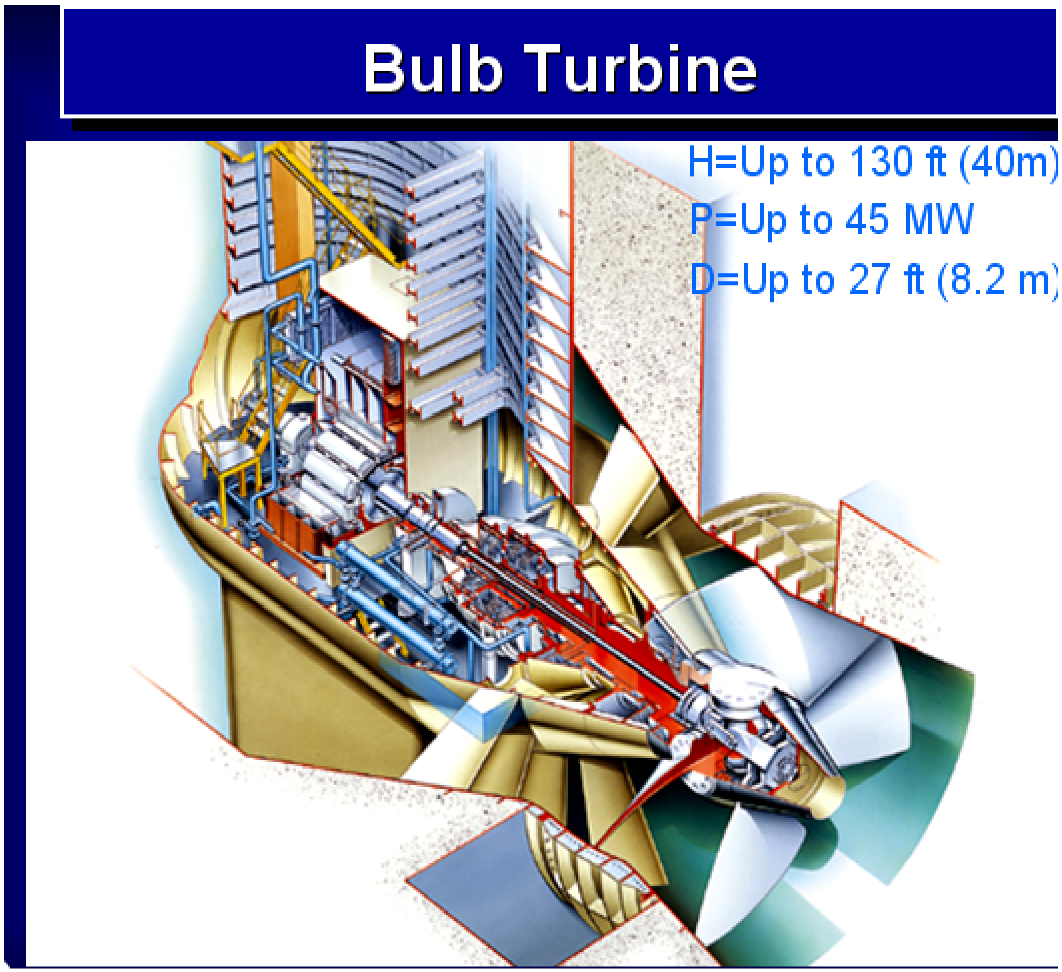
Head Range 25 - 45 m.

Capacity Range 2 – 150 MW

Runner Dia 1 – 5 m

BULB TURBINE

Very low and low head turbine having generator in capsulated within turbine water path



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HYDRO GENERATOR

STATOR WINDING

Prepared by : Srikrishna M S

QuEST, 06 JULY 2010

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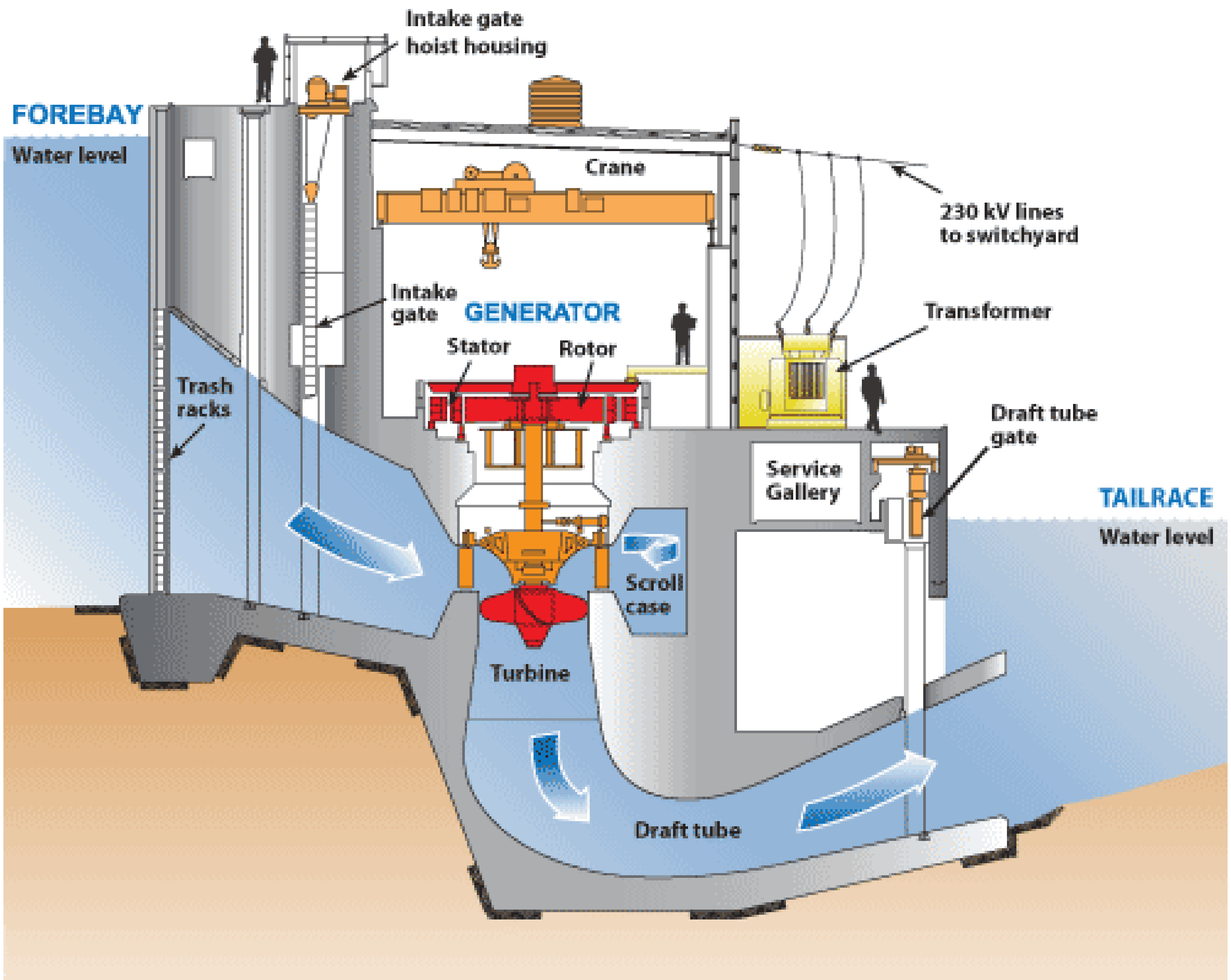
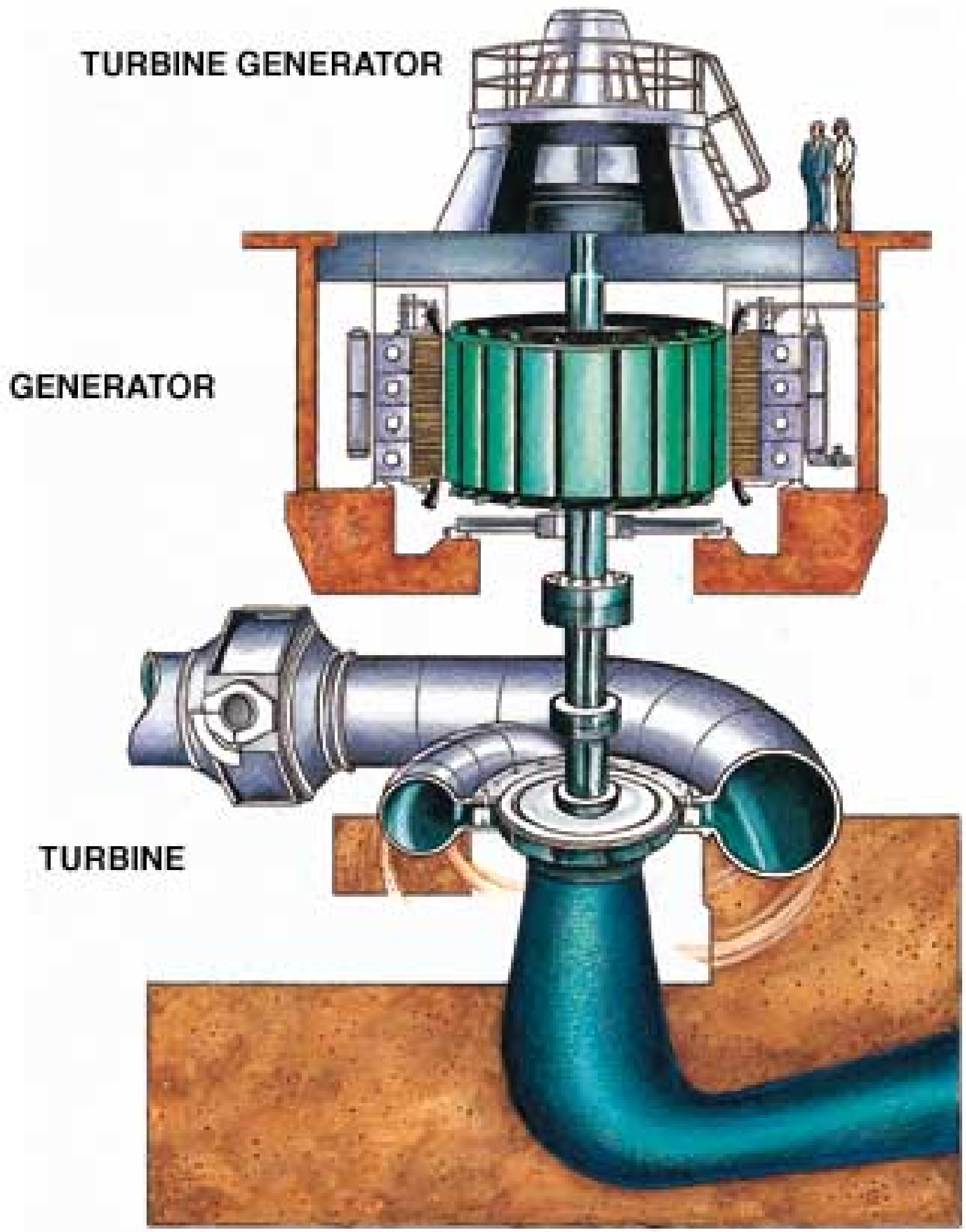
HYDRO POWER PLANT OVERVIEW

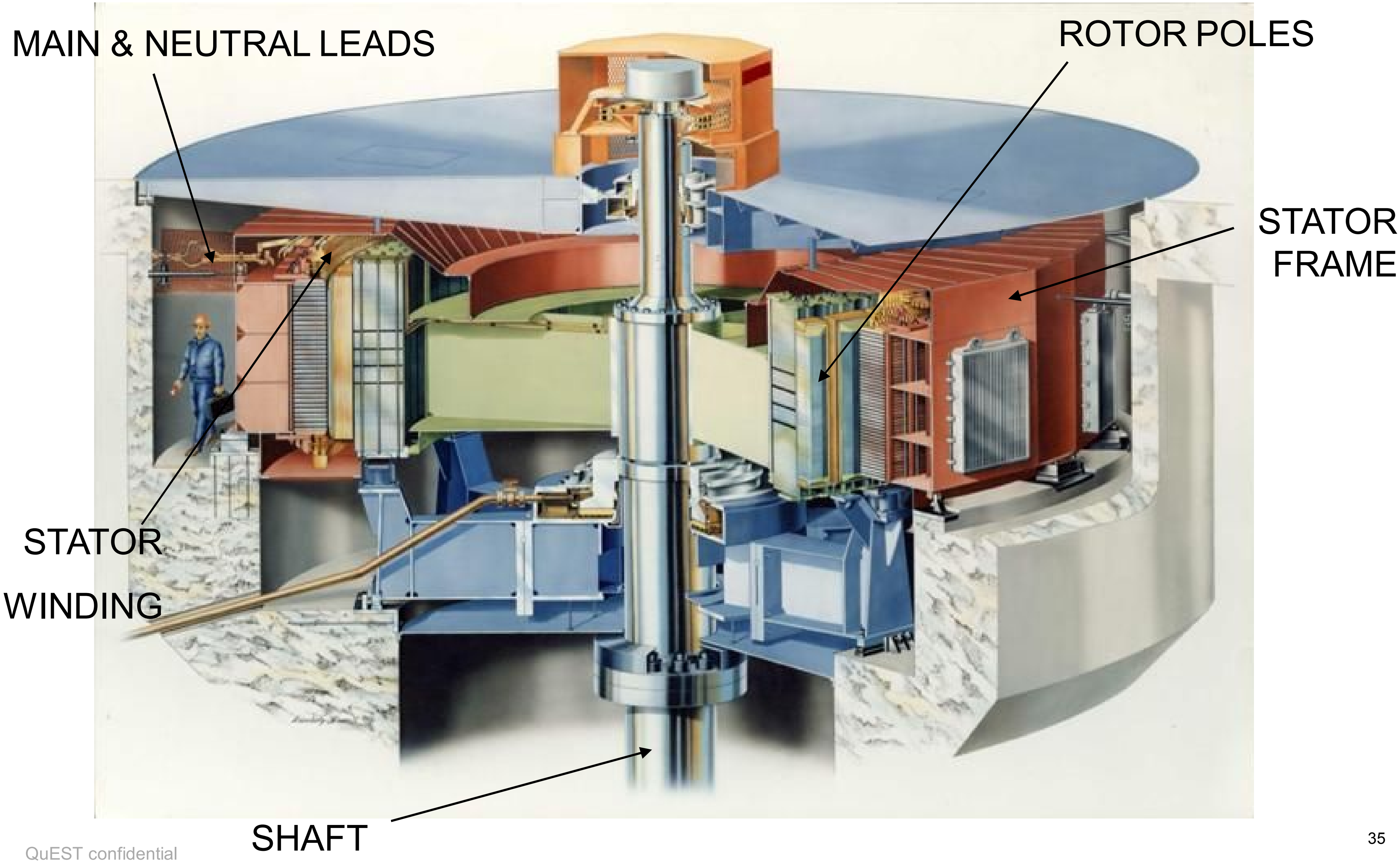
Water – Wire



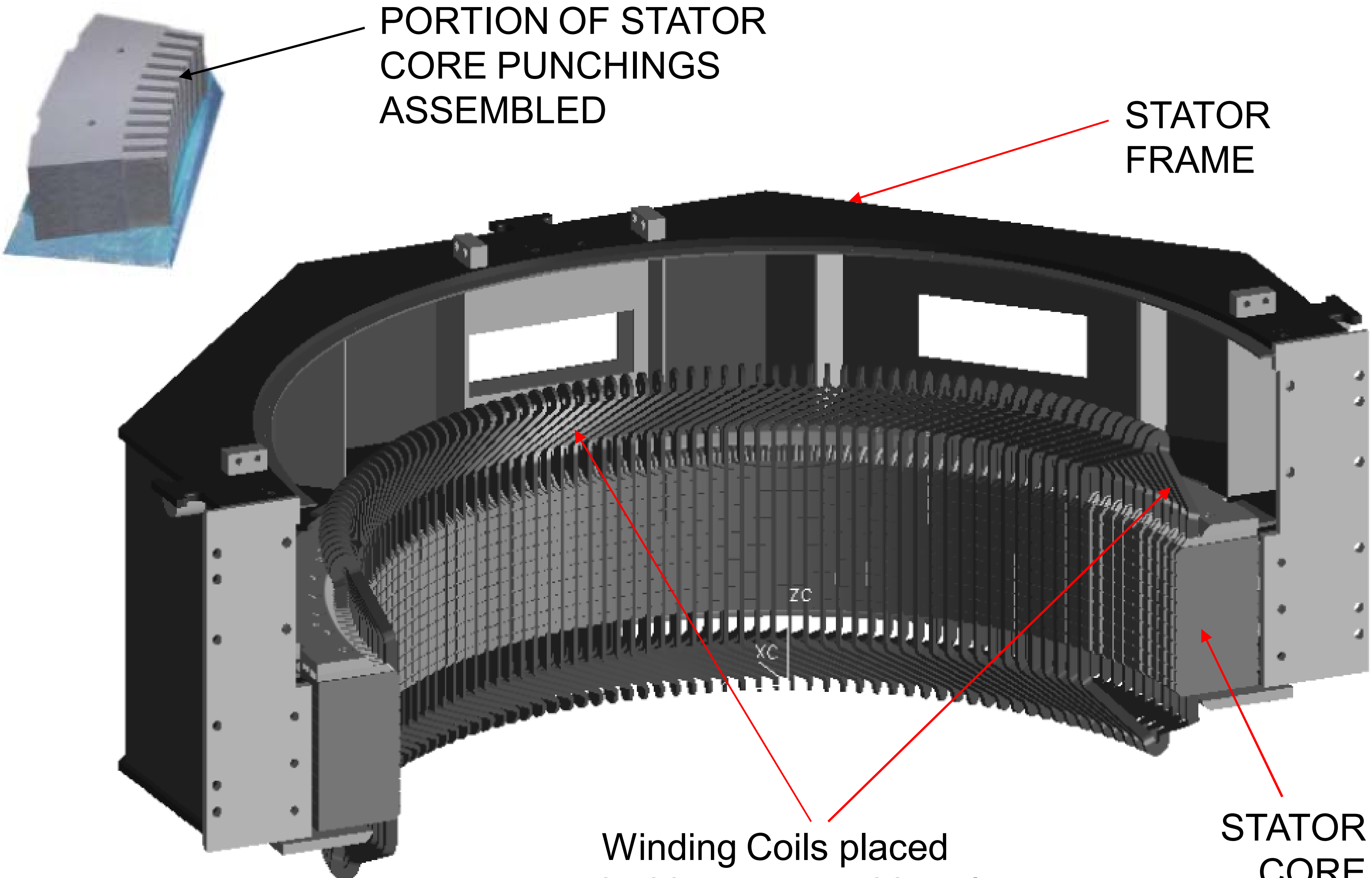
SECTION SHOWING TURBINE & GENERATOR OVERVIEW



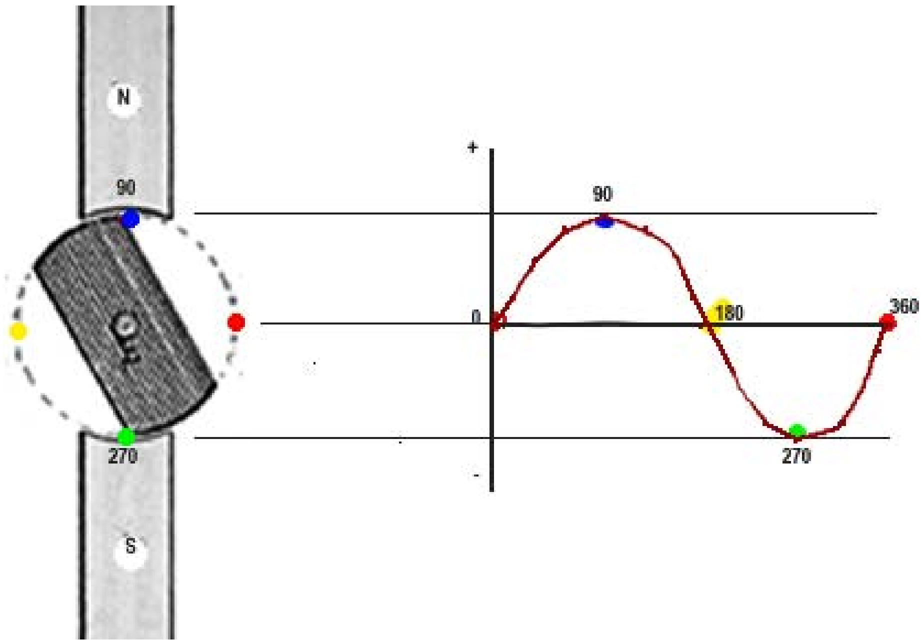
SECTIONAL ARRANGEMENT OF HYDRO GENERATOR

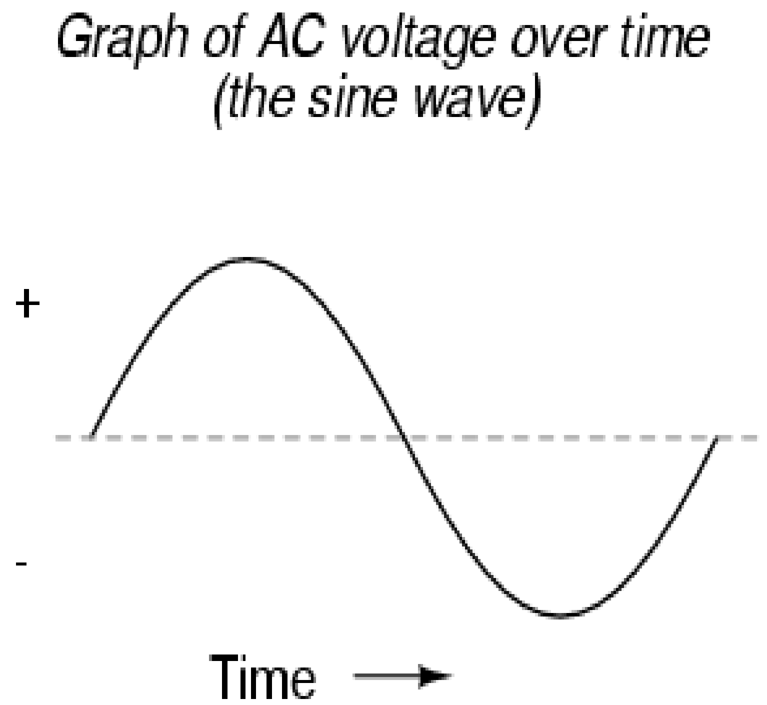


SECTIONAL VIEW SHOWING STATOR WINDINGS IN SLOTS



STATOR WINDING FUNCTION





As per Faraday's Law, by rotating the rotor poles and hence varying magnetic flux, a voltage will be induced in the stator winding. When the same is connected to an external electrical system network so as to form closed circuits, then a current will be passed through the stator winding and external system by the induced stator winding voltage.

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THERMAL GENERATOR OVERVIEW

Prepared by : Madhukara B

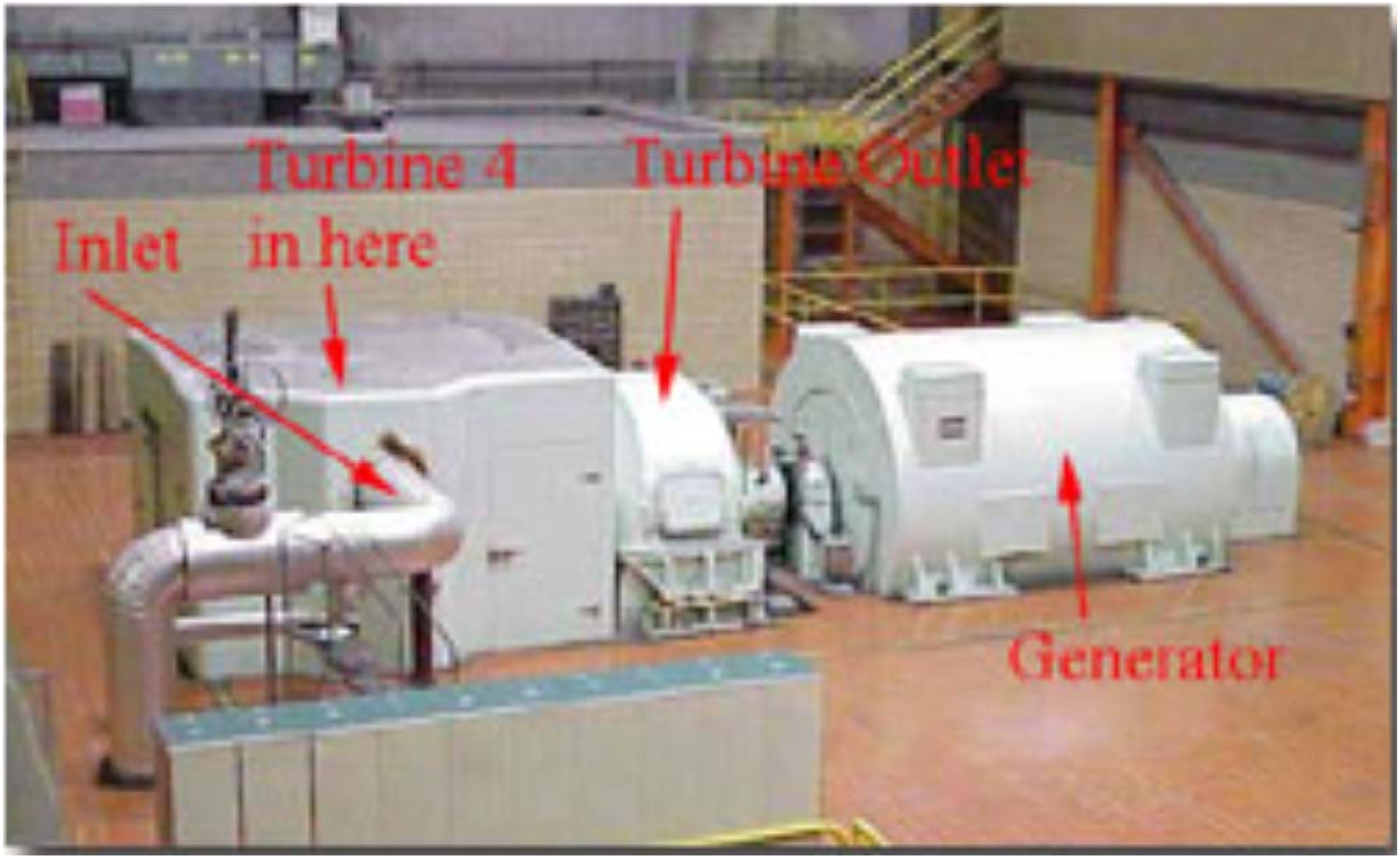
QuEST, 19 July 2010

11th October 2010

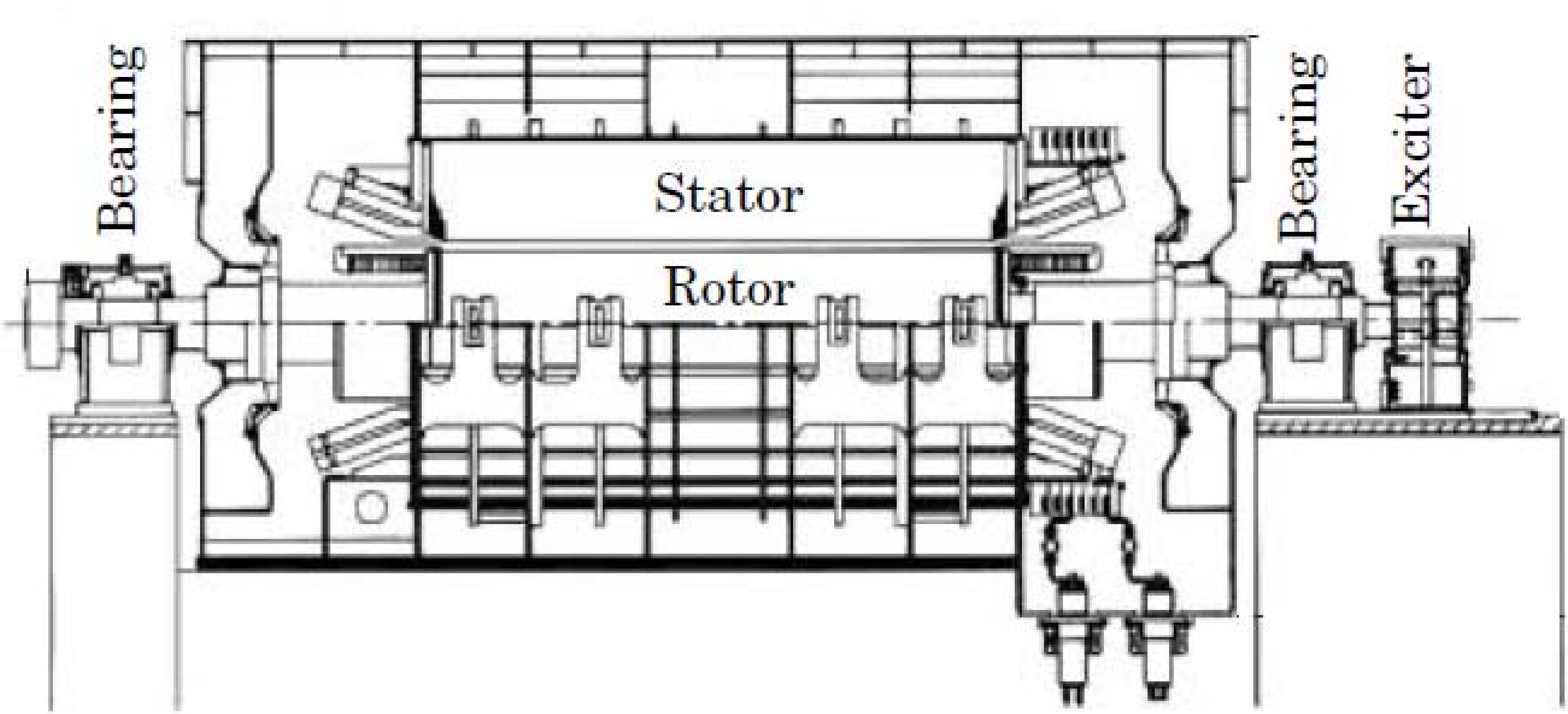
Types of Generator

- Air Cooled Generators 5 to 200 MVA
- Hydrogen Cooled Generators 175 to 500 MVA
- Water Cooled Generators 400 MVA & Above

Steam Turbine Generator



Generator Cross Section



Generator Parts - Stator

- **Stator**

  - Stator Frame

  - Magnetic Core

  - Armature Winding

  - Coolers

  - Foundation Interface

Generator Parts - Rotor

- **Rotor**

  - Shaft- Steel Forging

  - Copper Field Winding

  - Journals

  - Coupling(s)

Generator Parts – Excitation System

- **Excitation System**
  - AC Power Source
  - DC Rectifier
  - Control System (Voltage Regulator)

Generator Parts – Auxiliary System

- **Auxiliary System**

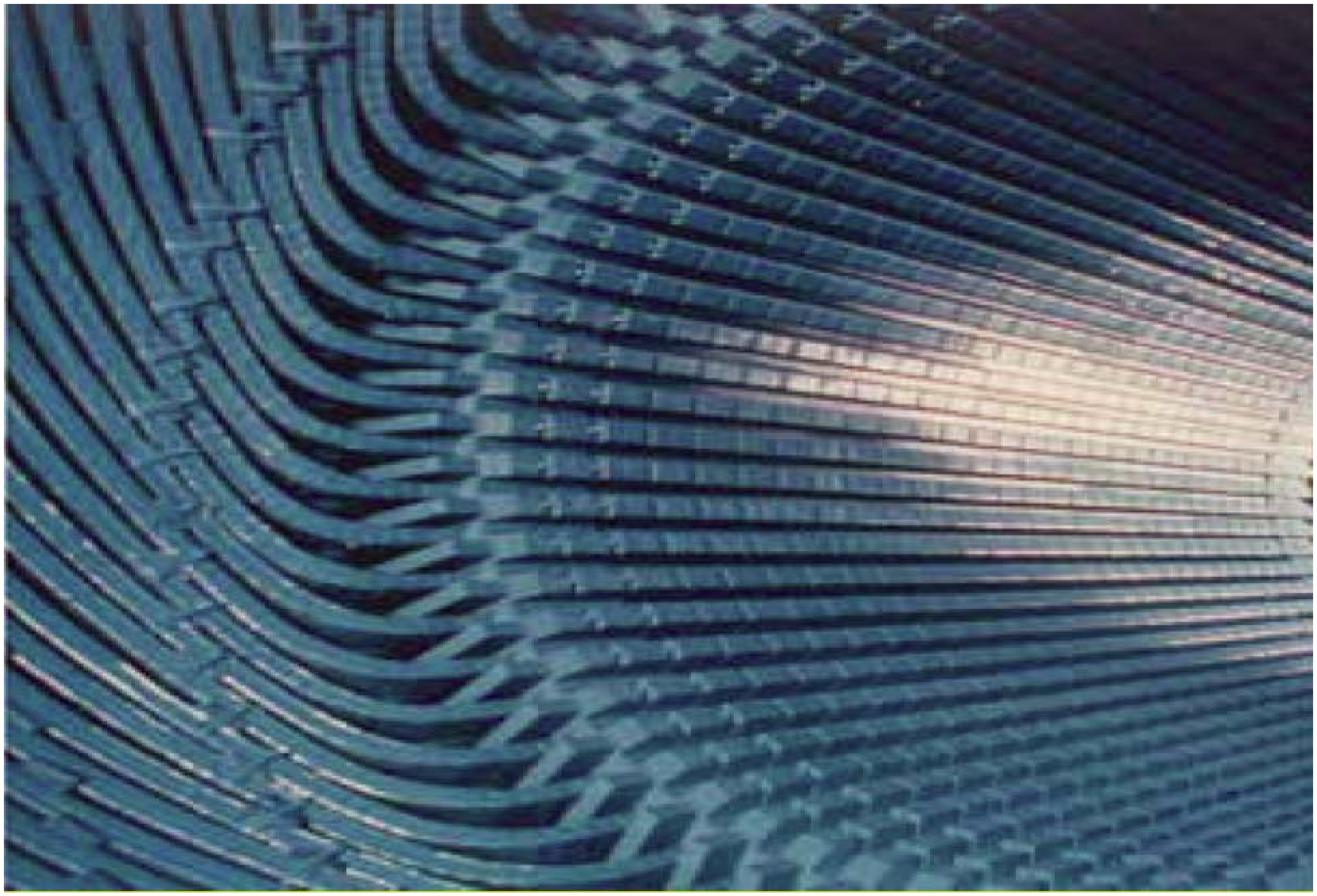
  - Lube Oil
  - Cooling Water
  - Hydrogen Supply
  - Deionized Water Supply

Stator Frame

Stator Frame

- Supports stator core
- Transmits torque to foundation
- Defines ventilation circuit
- Contains hydrogen (if used)

Wound Stator Core



TO ENGINEER

INTRODUCTION TO HYDRO GENERATOR'S ELECTRICAL DESIGN ASPECTS

GOMATHI .K

11th October 2010

INDICATIVE TECHNICAL DATA REQUIRED FOR GENERATOR DESIGN

<u>FROM TURBINE SUPPLIER ,THE FOLLOWING DETAILS ARE OBTAINED</u>

- RUNAWAY SPEED
- HYDRAULIC THRUST
- UNBALANCED JET FORCE FOR PELTON TURBINES

<u>FROM CUSTOMER, DETAILS SUCH AS THE FOLLOWING ARE OBTAINED</u>

1. PERCENTAGE VOLTAGE AND FREQUENCY VARIATION AND COMBINED VARIATION.
2. ELEVATION OF POWER HOUSE FROM M.S.L. (mean sea level)
3. CLASS OF TEMPERATURE RISES AT RATED LOAD AND MAXIMUM LOAD.
4. LINE CHARGING CAPACITY.
5. SYNCHRONOUS CONDENSER CAPACITY.
6. MAXIMUM TRANSIENT REACTANCE X'd.
8. REQUIRED MAXIMUM NEGATIVE SEQUENCE LOADING.

HYDROGENERATOR LOSSES

THE FOLLOWING ARE THE MAIN LOSSES IN THE GENERATOR.

1. Friction and Winding Loss.
2. Core Loss.

Fixed Loss.

3. Stator Copper Loss.
4. Load Loss.
5. Field Copper Loss.
6. Exciter Loss.

Variable Loss
Depending on Load

LIMITING TEMPERATURE RISE IMPROVES GENERATOR LIFE

GENERATOR WINDINGS ARE INSULATED WITH CLASS ‘F’ INSULATION

CLASS “F” - MATERIALS WHOSE MAXIMUM CONTINUOUS WORKING TEMPERATURE IS 155ºC.

THE PERMISSIBLE TEMPERATURE RISES OVER AN AMBIENT TEMPERATURE OF 40ºC. ARE AS FOLLOWS. TEMPERATURE RISES ARE LIMITED TO CLASS ‘B’ THOUGH THE INSULATION IS CLASS ‘F’. THIS INCREASES THE LIFE OF THE MACHINE BY HAVING LESS THERMAL STRESS ON THE WINDING.

FOR STATOR WINDING 90ºC.
FOR FIELD WINDING 100ºC.

CLASS	MAX. CONTINOUS WORKING TEMPERATURE ,° C
A	105
B	130
F	155
H	180

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ORIENTATION PROGRAMME IN HYDRO GENERATOR

INTRODUCTION TO HYDRO GENERATORS

MAJOR ASSEMBLIES AND THEIR FUNCTIONS

T.R.KHAJURIA

BORN TO ENGINEER

NAME OF MAJOR ASSEMBLIES

STATOR

ROTOR

UPPER BRACKET

LOWER BRACKET

GUIDE BEARING

THRUST BEARING

COMPLETING ITEMS

STATOR

Stator

Comprises of stator core, stator frame and stator winding.

Electric output is tapped from stator winding terminals

Stator winding is assembled in the slots on inner periphery of stator core.

Stator Core

Stator Core is assembled from thin stator core punching of silicon steel.

The punching are varnished to reduced eddy currents in stator core.

Ducts are provided in stator core for flow of ventilating air.

STATOR – frame and windings

Stator frame

Frame provides the rigid structure to

- **apply force for compression of stator core**
- **transfer stator winding short circuit force to foundations**
- **provide flow path for ventilation and transfer of actual load from upper bracket to foundations.**

Stator winding

Windings may have either lap or wave wound bars or multi turn coils.

ROTOR

- Provide rotating sinusoidal flux necessary for generating voltage in the stator winding.

Main parts of rotor

Lower Shaft

Bolted to turbine shaft at one end and rotor spider at the other.

Rotor Spider

•Fabricated structure having

- **Thick disc at the lower end for coupling to lower shaft.**
- **Disc at the top end that connects with upper shaft.**
- **Arms which support rotor rim and transfers torque from shaft to rotor.**

Main parts of rotor

Rotor Rim

- The function of the rotor rim is to
  - support the poles and
  - take centrifugal force of poles at all speeds beside its own centrifugal force CF.
  - Act as major contributor for flywheel moment of unit.

Main parts of rotor

Rotor Poles:

- Consists of pole body and pole winding
- Pole windings is provided on the outer periphery of pole body.
- Pole winding insulated from pole body by class F insulation sheets and insulation flanges.
- DC current flows through the pole winding during operation of the unit to make poles as electro-magnets.
- Flow of current through pole winding provides necessary mmf for flux circulation through pole body , air gap, Stator core & Rotor rim.

Lower bracket

- Fabricated structure made from steel plates.
- Houses thrust bearing & guide bearing for Umbrella / Semi Umbrella units.
- Houses only guide bearing for suspension units.
- Lower bracket supports brake assembly at the outer end of the arms.
- Also supports turbine pit covers and generator lower shroud.

Upper bracket

- Fabricated structure made from steel plates.
- It houses T.B & G.B for suspensions type of generators and only G.B for Semi Umbrella units.
- Supports generators flooring for all types of generators.
- Upper shroud is assembled at the bottom side of upper bracket.
- U.B also supports oil header for supply of oil to Kaplan rotor blade servo motor

Completing items

Comprises of braking and jacking system, air coolers, oil coolers, water pipe lines, oil pipe lines, generators pit lighting system, brake dust extraction system, brush rigging etc……

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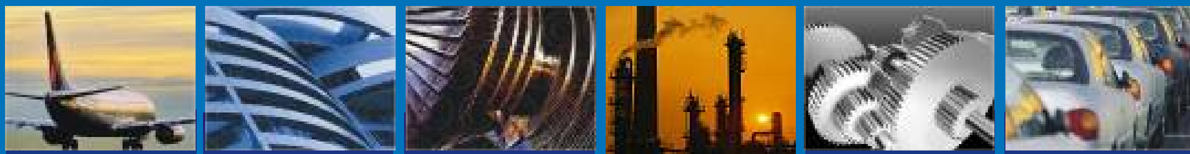


Aerospace | Civil Structures | Power Generation | Oil & Gas | Industrial Products | Transportation

Introduction to Rotating Equipments

Date : 31st Aug 2010

What is a Turbo Machine ?

A Turbo machine is defined as an equipment that extracts energy or imparts energy to a continuously flowing stream of fluid by the dynamic action of one or more rotating elements.

They are Two types

- Prime movers: Machines that consume thermal / potential / electrical energy and convert it to mechanical energy from fluid. A decrease in pressure takes place in turbines

  e.g : Steam & Gas Turbines, Hydro turbines and Electric Motors

- Driven equipments: Machines that use the mechanical energy and produce an increase in pressure energy or electrical as in case of generators

  e.g. : Pumps, Fans, Compressors and Alternators

Prime movers & driven equipments

- Power Generating Equipments
  - Steam turbine Uses Thermal energy of Steam
  - Gas Turbine Uses Calorific Value of Gas burnt
  - Hydro Turbine Uses Static Head from Water
  - Wind Turbine Uses Wind energy
  - Solar Uses Heat from Sun
  - Geo thermal Uses Heat from depth of earth
- Power Consuming Equipments
  - Pumps
  - Compressors
  - Motors
- Prime movers
  - Steam turbine
  - Gas Turbine
  - Electric Motor
  - Reciprocating Engine

Prime Movers (Drivers)

Prime mover is a machine that transforms energy from one form into Mechanical torque and makes it available at a shaft:

- Gas Turbine:
  - It transforms thermo-dynamic energy contained in hot pressurised air through rotating blades.
  - Heat is obtained in the machine through combustion.
- Steam Turbine:
  - Transforms thermodynamic energy contained in high pressure steam through moving blades. Steam is supplied from external source called boiler.
- Electric motor:
  - Transforms electric energy supplied from an A/c power grid.
- Reciprocating Engine:
  - Works in a similar way as Gas turbines but through Pistons

Energy

Power Generation Domains

Power Generation equipments

Captive power	Utility Power	Industrial Drives
For Industry needs	Community & public distribution	Drives for Mech.Equipments
Thermal, Gas based	Thermal, Gas, Hydro & Nuclear	Thermal, gas Based

Power Generation equipments

Sector	Equipment	Fuels / Medium
Thermal	Steam Turbine Generators	Superheated Steam
Oil &Gas	Gas Turbine Generators	Natural Gas, Naphtha, HSD
Hydro	Hydro Turbine Generators	Water
Nuclear	Steam Turbine Generators	(Close to) Sat. Steam
Industrial	Steam Turbine Generators	Superheated Steam
Industrial	Gas Turbine Generators	HSD, Fuel oil
Un- Conventional	Generators	Wind, Solar, Tidal

Major Players - Power sector

Gas Turbine		
Key Players	Market Share	Position
GE	41%	1
Siemens	13%	2
Alstom	10%	3
MHI	10%	4
Solar	10%	5
Ansaldo	3%	
Hitachi	4%	
DR	2%	
MAN	2%	
RR	3%	
KHI	2%	

Steam Turbine		
Key Players	Market Share	Position
GE	15%	3
Siemens	25%	1
Alstom	18%	2
MHI	10%	5
Toshiba	10%	4
Ansaldo	3%	
Hitachi	6%	6
DR	4%	
MAN	3%	
Skoda	2%	
Elliott	4%	

- This information is indicative only

What is a Gas Turbine ?

Gas turbines

A gas turbine is a rotating machine transforming the thermodynamic energy stored in a pressurized hot gas into mechanical energy made available at the shaft end.

Gas Turbines

- From Duty

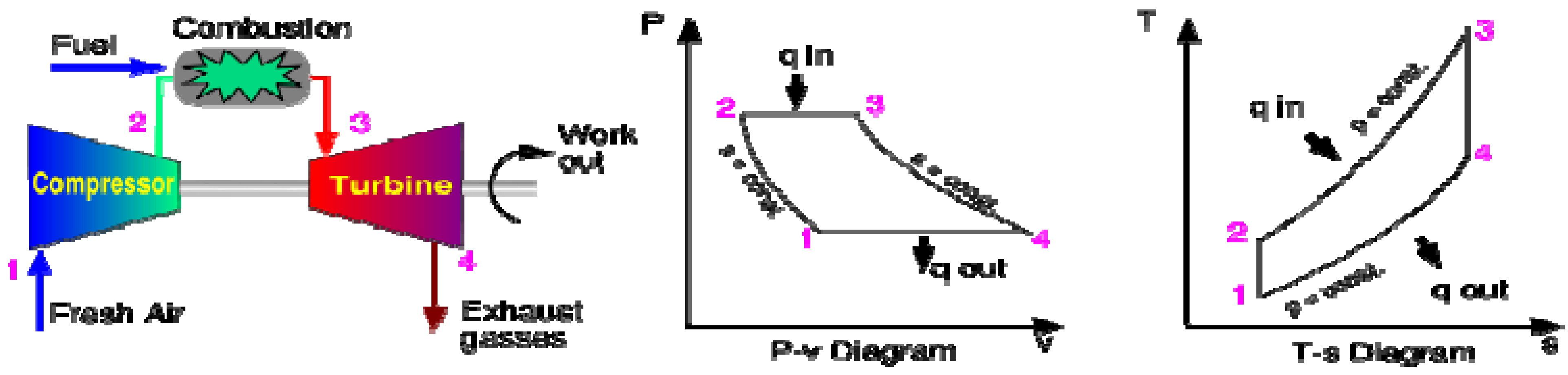
  1. Generator drive 2. Mechanical drive
- From their construction

  1. Advanced class Heavy duty 2.Heavy Duty 3. Medium Heavy Duty

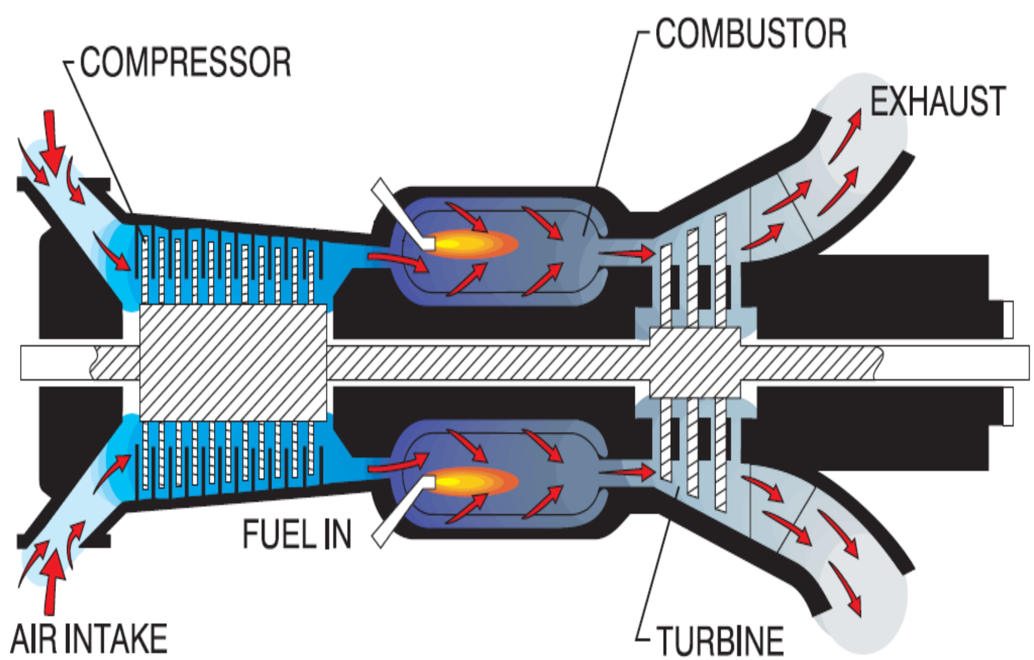
  4. Small Duty 5. Aero-derivatives 6. IGCC
- From Applications

  1.Propulsion 2.Power Plants (50Hz,60Hz)
- In the propulsion engines, the main target of the turbine is to run the compressor. The Flue gas while getting out of the turbine gives a reaction force which gives the propulsion. (Jet engine)
- In power plants, the turbine generates power to drive the axial compressor and the connected load like a generator.

Gas Turbine operating cycle



Idealized Brayton Cycle



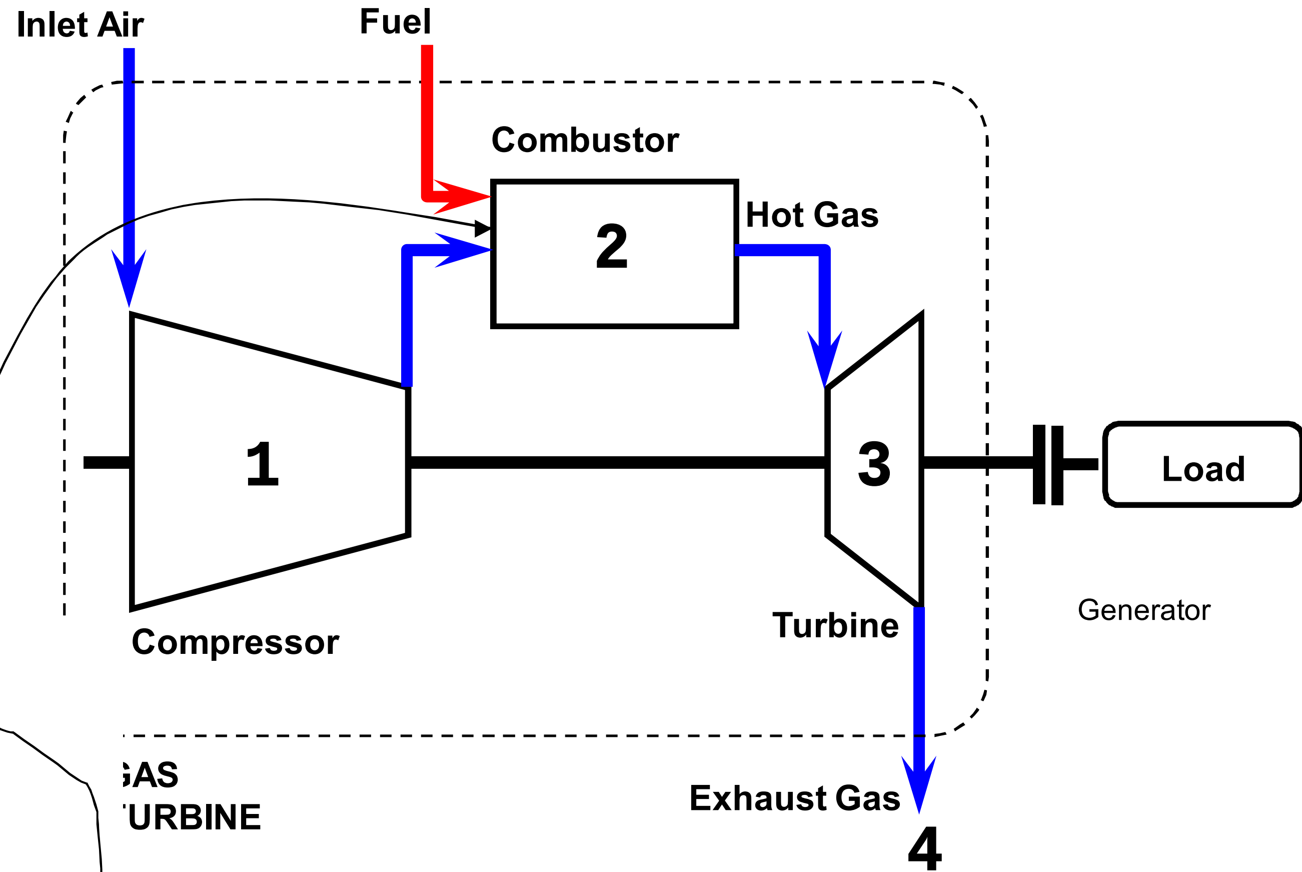
Isentropic Process - **Ambient air is drawn into the compressor, where it is compressed.**
Isobaric Process - **The compressed air then runs through a combustion chamber, where fuel is burned, heating that air, a constant-pressure process,**
Isentropic process - **The heated, pressurized air then gives up its energy, expanding through a turbine (or series of turbines). Some of the work extracted by the turbine is used to drive the compressor.**
Isobaric process - **Heat rejection (To the atmosphere).**

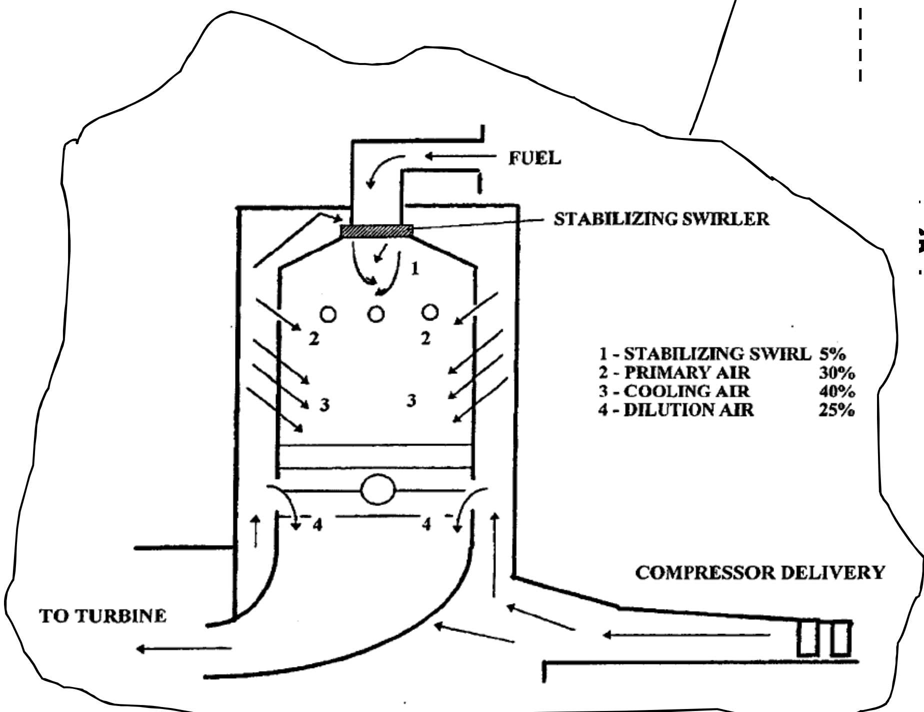
MODERN GAS TURBINE WORKING PRINCIPLE

1. Air is taken in by the axial compressor from atmosphere, pressure & temperatures are increased in an adiabatic compression process.
   - Around 3 kg/s of air are taken in for every MW of generated Power.
   - Discharge Pressure of Compressor for Gas Turbines is between 20 - 50 bar.
   - Discharge Temperature after Compression is between 200 - 500 °C
2. Heat is added to the compressed air, by burning fuel in one or more combustors depending on the design. Part of the air **(PRIMARY AIR)** is used for combustion of the fuel, and part of the air **(SECONDARY AIR)** is used to dilute the heat generated by the combustion keeping the hot gas within material resistance safe limits.
   - Almost up to a quarter of Air is used for COMBUSTION.
   - In a modern Gas Turbine Hot Gas Temperature is of the order of 1000 °C.
3. The hot gas is expanded in one or more turbine wheels that provide mechanical power to drive the compressor as well as to drive the external Load.
   - The work required for the COMPRESSION is as much as around 60% of the total produced.
4. Hot gas is then exhausted back into atmosphere.
   - Exhaust Gas Temperature are as high as around 500 °C.

Process Flow Diagram for a simple cycle GT – single shaft

Legend:
1. Axial compressor
2. Combustion Chamber
3. Turbine wheel
4. Exhaust



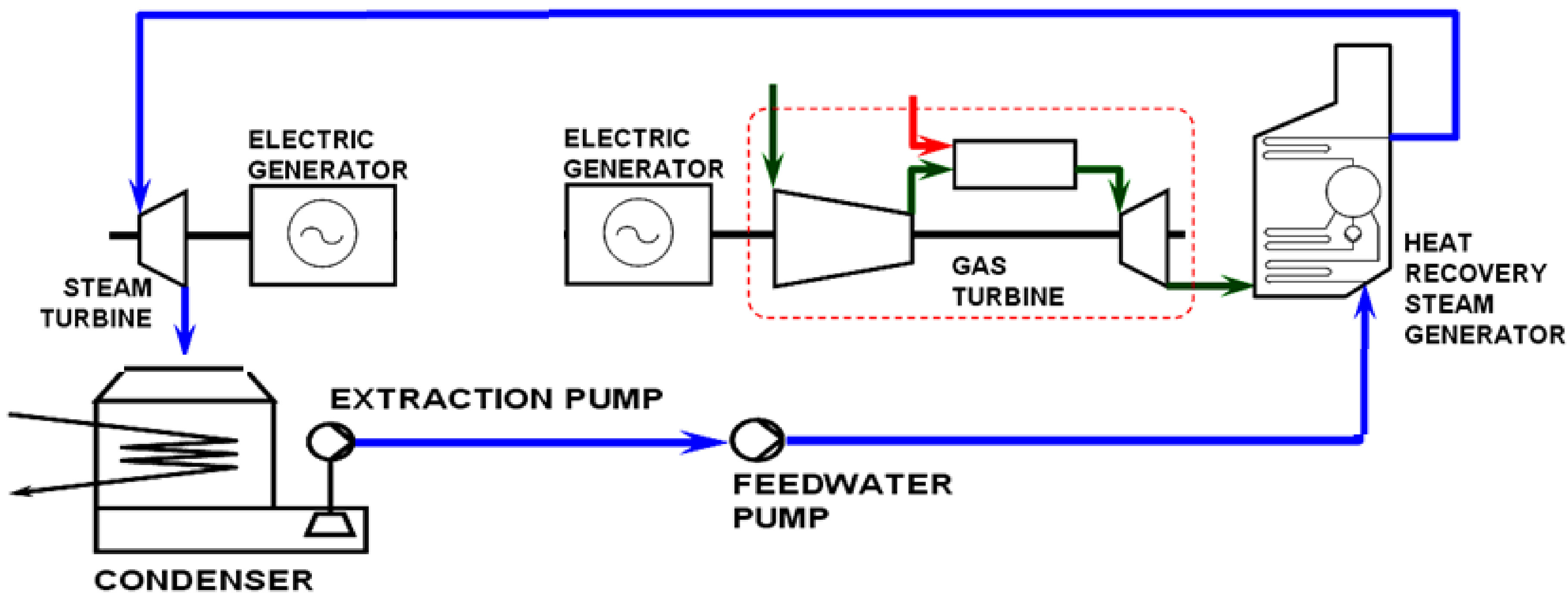


Simple cycle GT

(Single shaft)

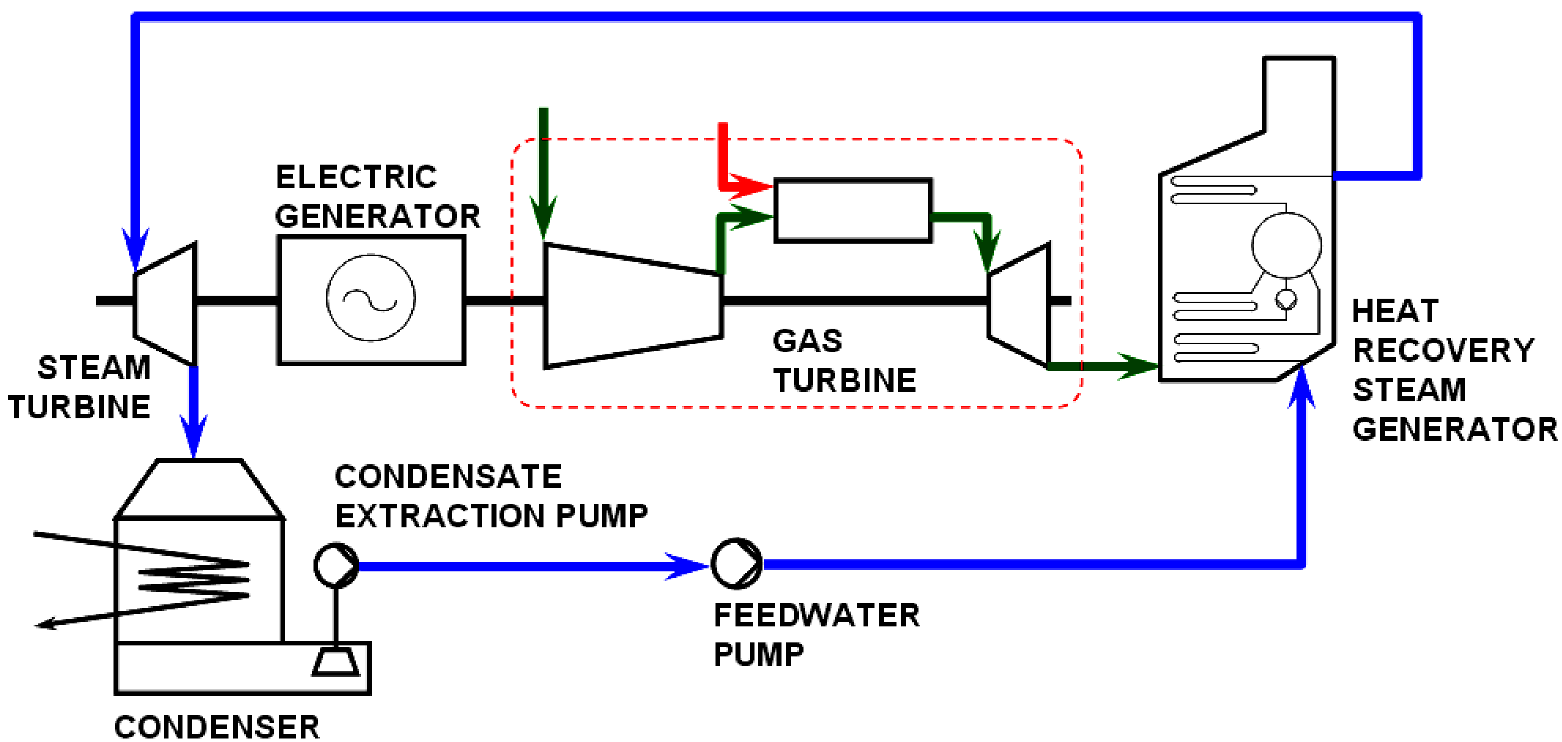
Combined Cycle 1

In a combined cycle, the waste heat from Exhaust gases is utilized to increase the cycle efficiency. The waste heat is used to raise steam which will be used to expand in a separate steam turbine generator to get additional power



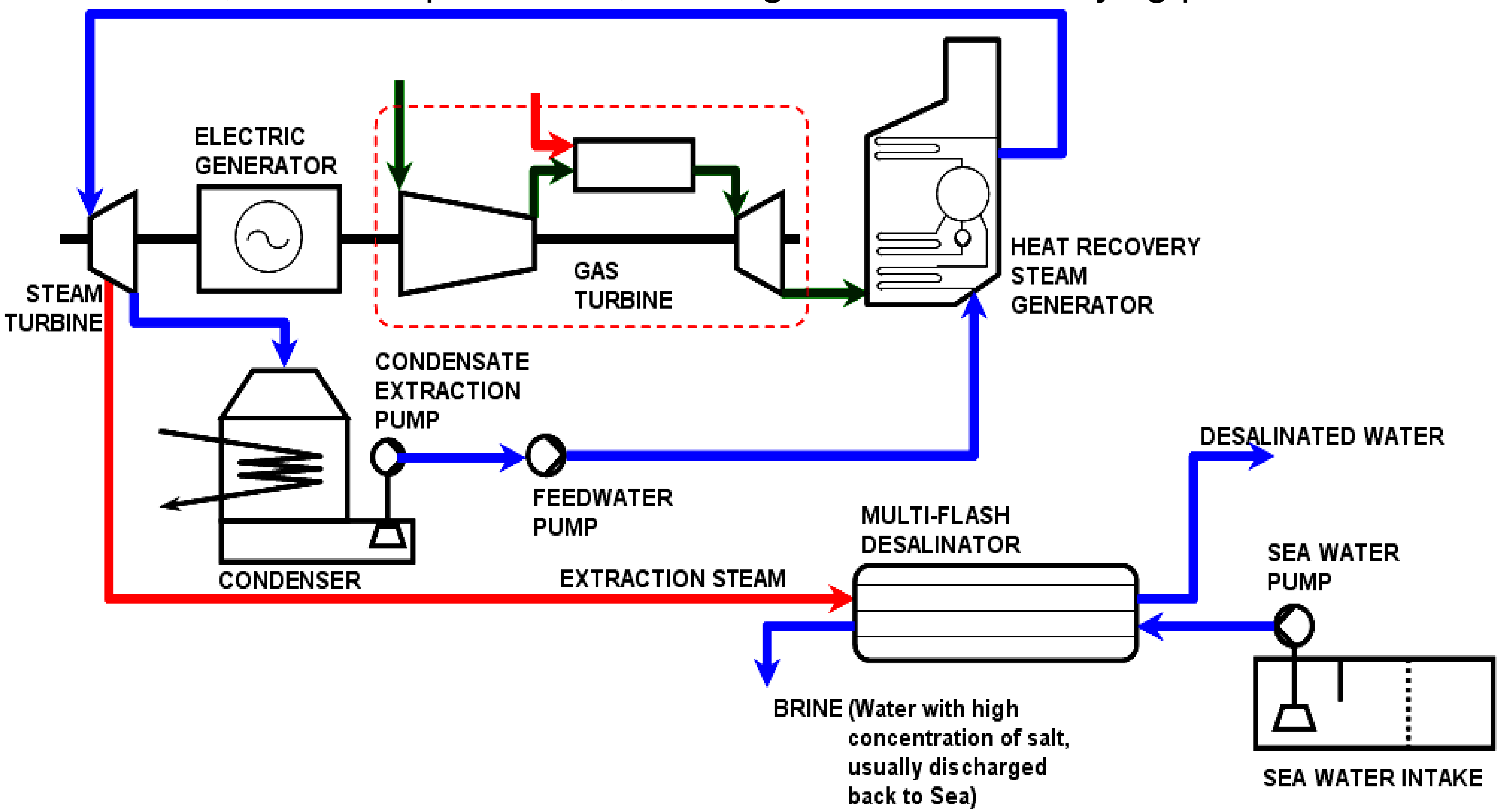
Combined Cycle 2

In combined cycle, the waste heat from Exhaust gases is utilized to increase the cycle efficiency. The waste heat is used to raise steam which will be used to expand in a separate steam turbine to get additional power



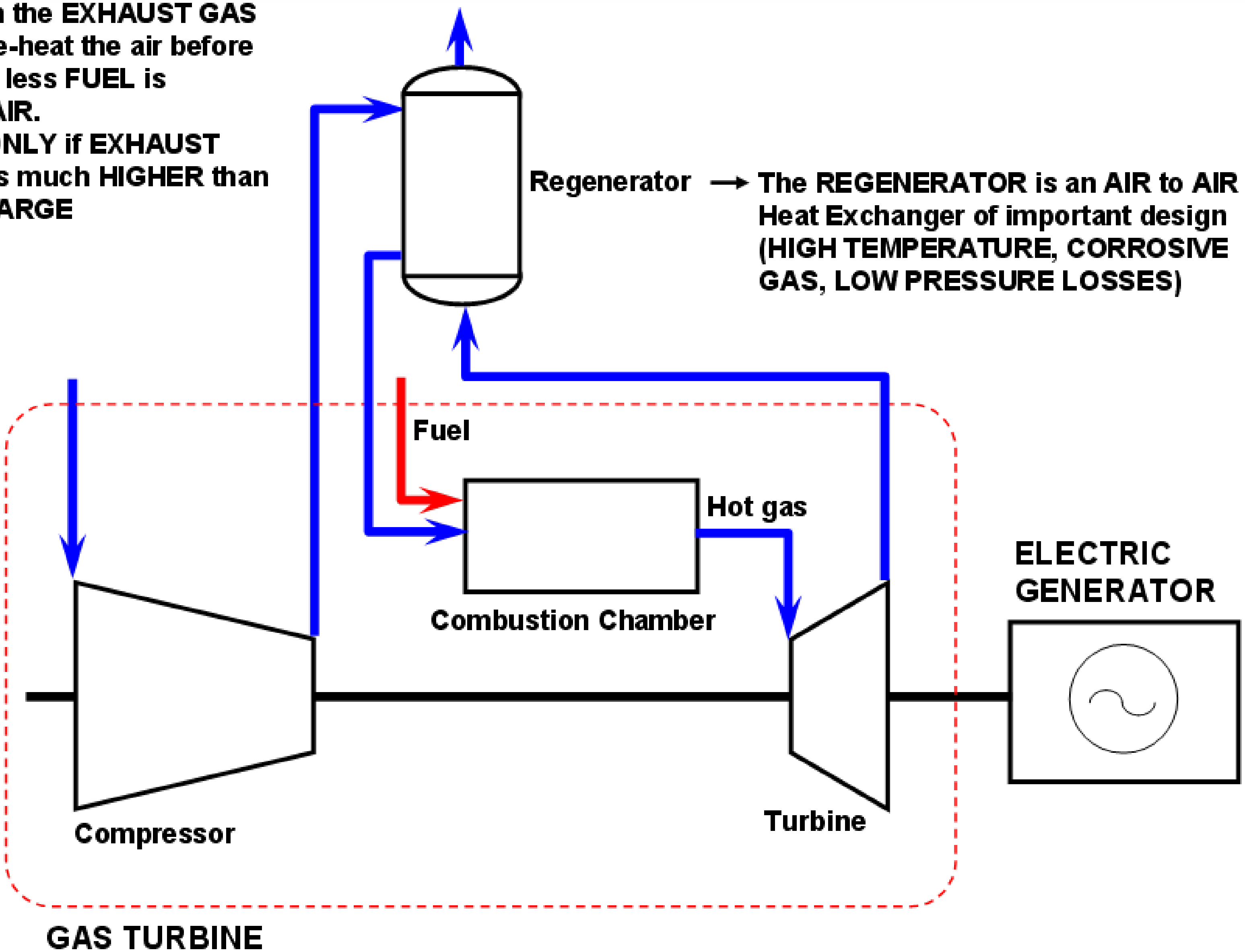
Cogeneration Cycle GT

In cogeneration cycle, the waste heat from Exhaust gases is utilized to raise steam which in turn will be used for special industrial applications like Desalination, hot water production, steam generation and drying processes



Regeneration cycle GT

The HEAT contained in the EXHAUST GAS (~500 °C) is used to pre-heat the air before the Combustor so that less FUEL is required to HEAT the AIR.
This is very effective ONLY if EXHAUST GAS TEMPERATURE is much HIGHER than COMPRESSOR DISCHARGE TEMPERATURE.



→ The REGENERATOR is an AIR to AIR Heat Exchanger of important design (HIGH TEMPERATURE, CORROSIVE GAS, LOW PRESSURE LOSSES)

Important Gas Turbine Parts

- Inlet Plenum
- Axial compressor- Fuel system
- Combustion Chamber- Nozzles - Buckets
- Cooling & Sealing System
- Exhaust Plenum
- Starting system- Bearings-Load gear

Some important points about gas Turbines

- Axial Compressors generally used in large Power Gas Turbines.
  - In a Gas Turbines the Pressure Ratio required is relatively small and Flow Rates are relatively very large …see next slide
  - A centrifugal compressor of large size is required to handle this which is not practicable.

- ISO RATING :ISO 3977-2: Gas Turbines Std. reference conditions and ratings.
  - Ambient Temperature 59 °F (15 °C)
  - Barometric Pressure 14.696 psi(a) [101.4 kPa(a)]
  - Relative Humidity 60%
  - Altitude Sea Level

$$\text{Heat Rate} = \frac{\textbf{Heat Supplied (Btu/hr)}}{\textbf{Power Output (kW)}} \qquad \frac{\text{Kcal/hr}}{\text{kw}}$$

The higher is the heat rate the less efficient is the turbine and vice versa

GT Fuels

Liquid Fuel Type
Liquid Petroleum Gas
Gasoline
Naphtha , Kerosene
Diesel, Fuel Oil

Gaseous Fuel Type
Pipeline Natural Gas
Medium BTU Natural Gas
LPG: Liquefied Petroleum Gas
Refinery Gases

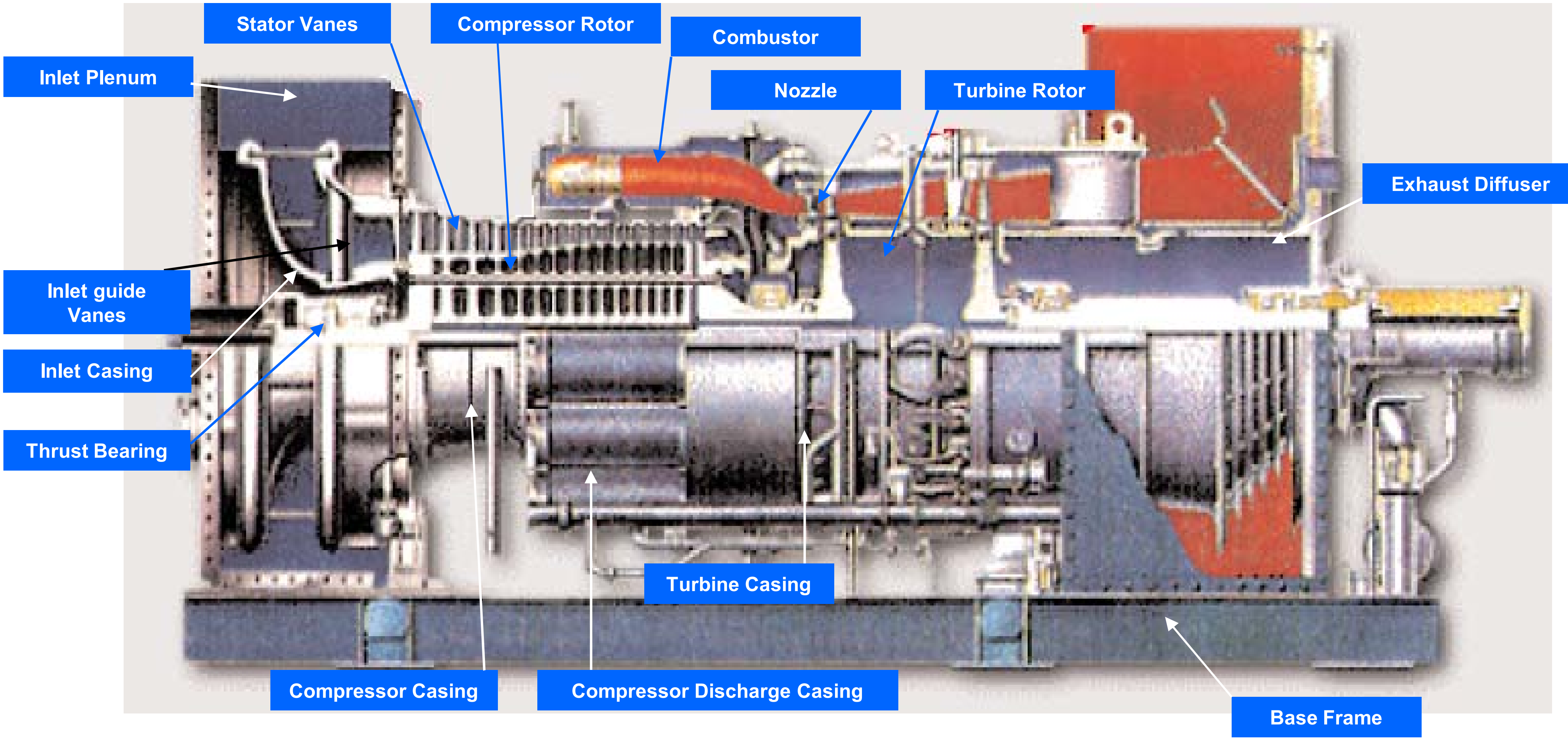
Range Of Application axial Vs Centrifugal

Positive displacement machines are generally below 3000 M^3 / Hr.
Flow regions between 3000 -12,000 M^3 / Hr. can be considered over-lapping between positive displacement and centrifugal compressors
Centrifugal compressors are generally below 100,000 M^3 / Hr.
Flow regions between 1000 - 12,000 M^3 / Hr. can be considered over-lapping between positive displacement and centrifugal compressors
Axial compressors generally above 1,20,000 M^3 / Hr.
Flow regions between 80,000 - 1,20,000 M^3 / Hr. can be considered over-lapping between centrifugal and axial compressors.

AXIAL COMPRESSORS

Axial compressors are designed for high volume and relatively low pressure applications.

Cross section of a Gas turbine



This information is taken Courtesy J R Johnston Paper on 'Performance and reliability analysis'

Steam Turbines

Introduction

WHAT IS A STEAM TURBINE !!

- Steam Turbines are rotating equipments used to produce Mechanical Power from Thermal Energy of steam
- Steam turbines are mostly 'axial flow' types. (Steam flows over the blades in a direction parallel to the axis of the wheel.)

HOW DOES IT WORK !!

- The steam is expanded in nozzles, resulting in the formation of a high velocity jet. This impinges on the moving blades, mounted on a shaft.
- Here it undergoes a change of direction of motion which gives rise to a change in momentum
- The shaft power in a turbine is obtained by the rate of change in momentum of a high velocity jet of steam impinging on a curved blade which is free to rotate.
- Power plants involving Steam Turbines employ Rankine cycle. The Rankine cycle is modified many a time to improve the cycle efficiency by incorporating Reheat and Regenerative loops.

CLASSIFICATION

Turbine Type	Feature
Application	Utility , Captive & Mechanical drives
Size	Small < 15 MW Medium > 15 MW Large > 300 MW
Principle	Impulse & Reaction

Turbine Type	Feature
Condensing	The exhaust steam is expanded down to condenser Pressure (Vacuum)
Back Pressure	The exhaust steam is sent for a process needing low pressure steam
Extraction Condensing	Part of steam is extracted at intermediate pressure and rest expands to condenser pressure) (Vacuum)
Extraction Back Pressure	Part of steam is extracted at an intermediate pressure and rest is sent for a down stream process

Industrial application of Steam Turbines

ST Nomenclature

<u>ST Industrial Product Line</u>

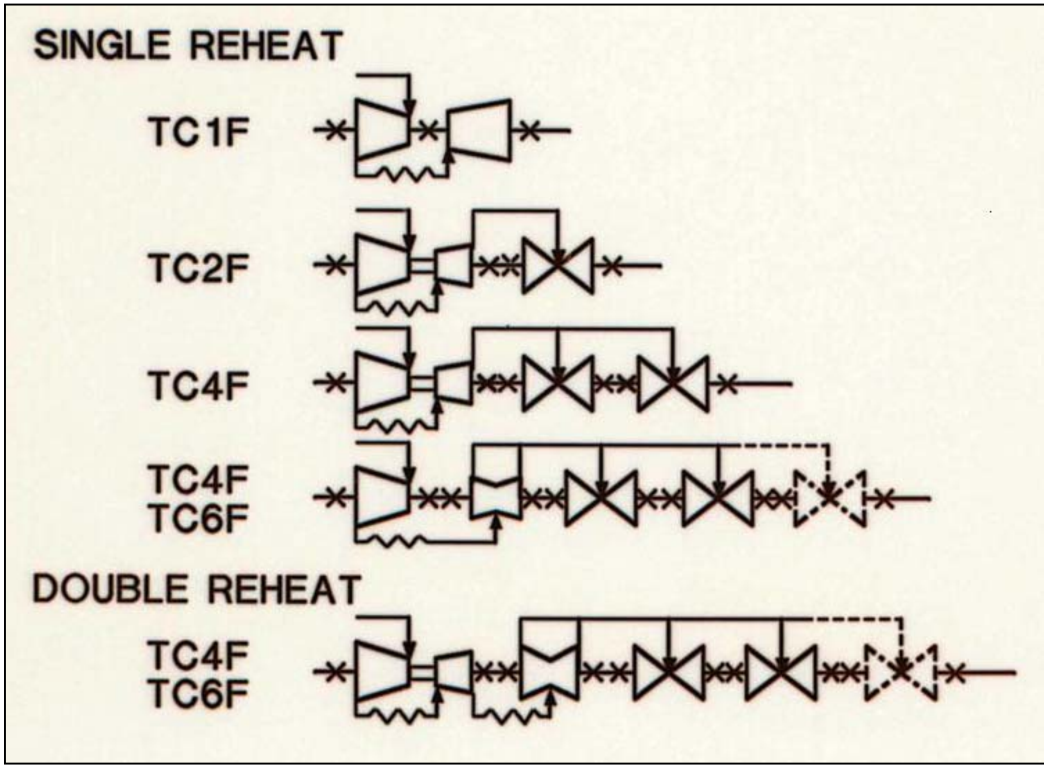
- Single Casing
- Megawatt Ratings from 20 MW to 100 MW
- TG Sets, Boiler Feed pumps, Mech Drives

<u>ST Combined Cycle & Fossil Product Line</u>

- Megawatt Ratings from 100 MW to 1100 MW
- Non-Reheat, Single Reheat,& Double Reheat
- Single Casing to Five Casing Machines

<u>ST Nuclear Product Line</u>

- MW Ratings from 500 to 1500



Ex: TC1F : Tandem compound 1 LP flow

**This nomenclature is taken from Toshiba and GE product catalogues*

About the fluid

Fluid	- Superheated Steam
Inlet pressure	- 2400 – 4500 PSIG
Inlet Temp	- 1000 – 1100 Deg F

Suggestive parameters

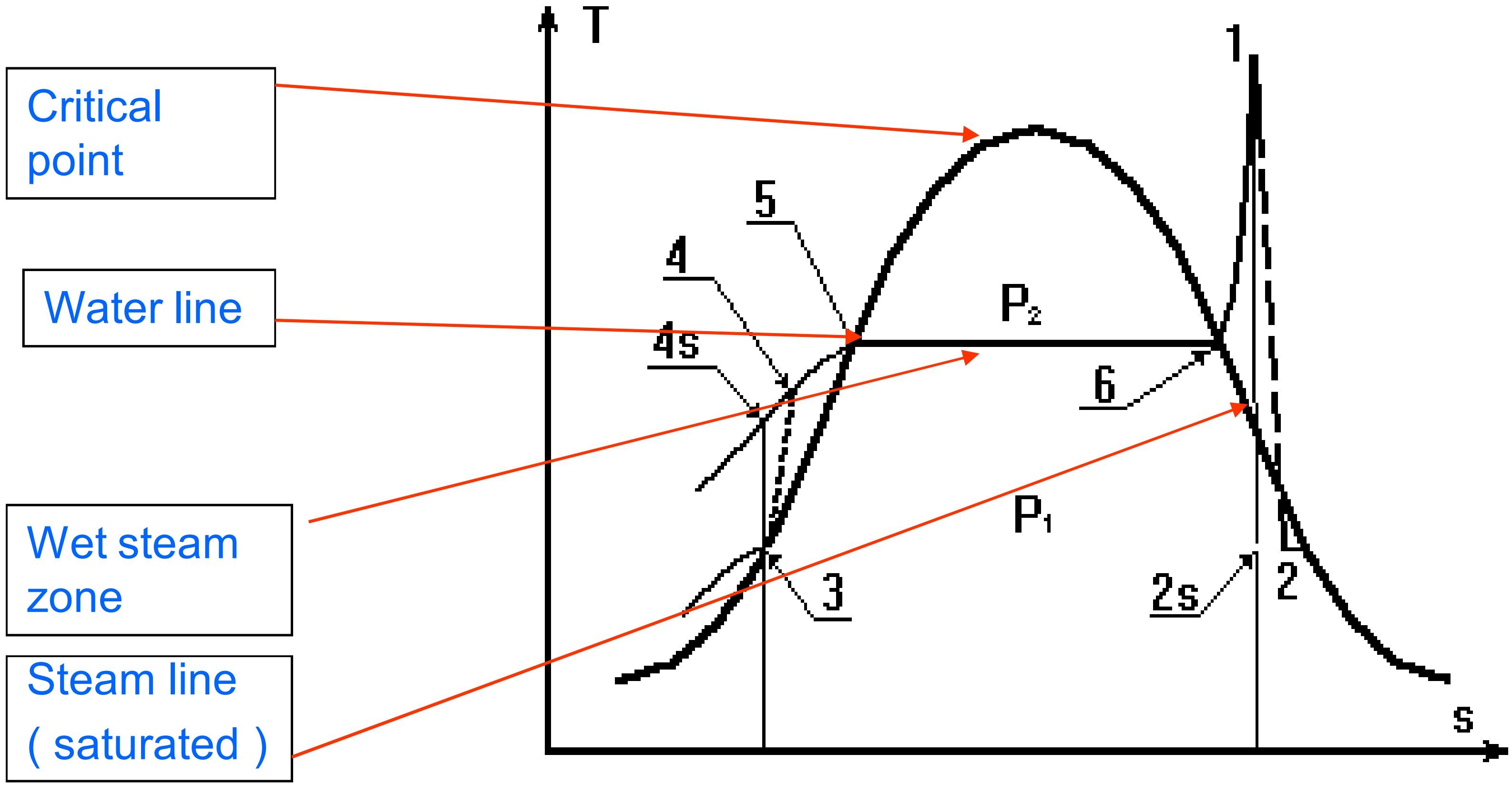
Sub Critical	>= 2400 Psig -1000 F (165 bar / 538 C)
Super Critical	>= 3500 Psig -1050 F (240 bar / 565 C)
Ultra Supercritical	>= 4500 Psig -1112 F (310 bar / 600 C)
* Nuclear applications	~ 1100 Psig - 570 F (78 bar / 300 C)

Improvements in power plant performance are achieved by raising inlet steam conditions to Supercritical and Ultra supercritical levels.

* Illustrative and typical parameters

STEAM TURBINE OPERATING CYCLE

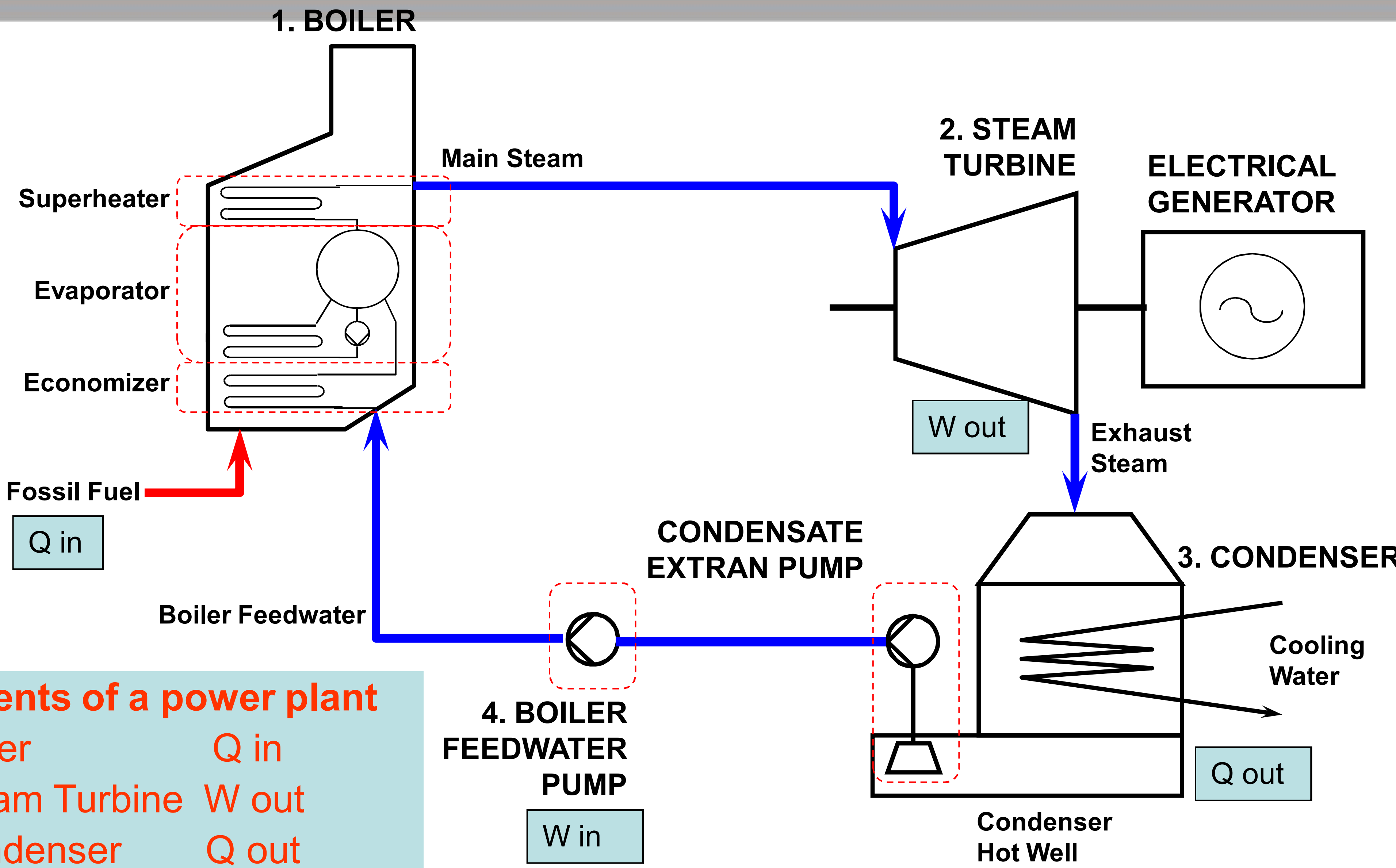
Simple Rankine Cycle



T-s diagram for a Rankine cycle.

4 to 1: Isobaric heat supply (Boiler)
1 to 2: Isentropic expansion (Steam turbine),
2 to 3: Isobaric heat rejection (Condenser),
3 to 4: Isentropic compression (Pump),

Steam Cycle With Boiler -- Rankine Cycle

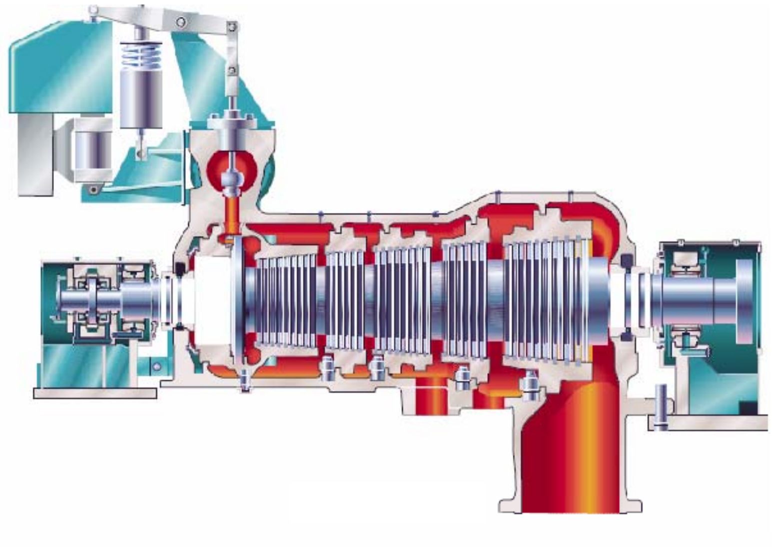


Elements of a power plant

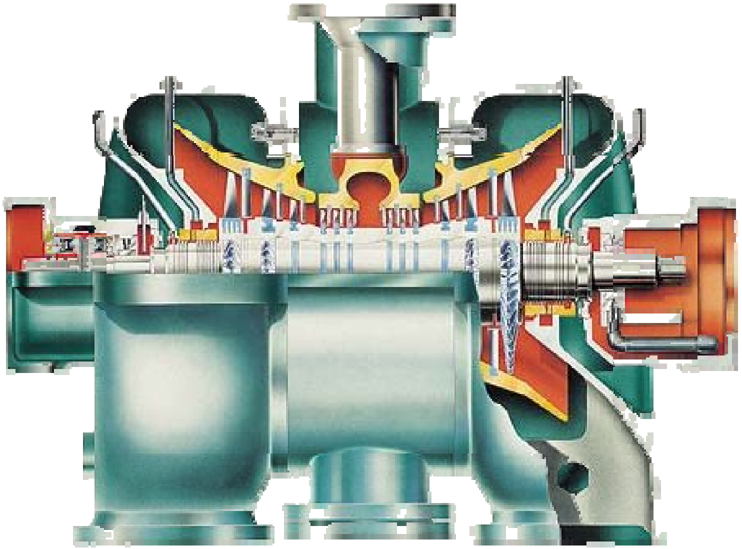
1.Boiler	Q in
2.Steam Turbine	W out
3.Condenser	Q out
4.Feed Pump	W in

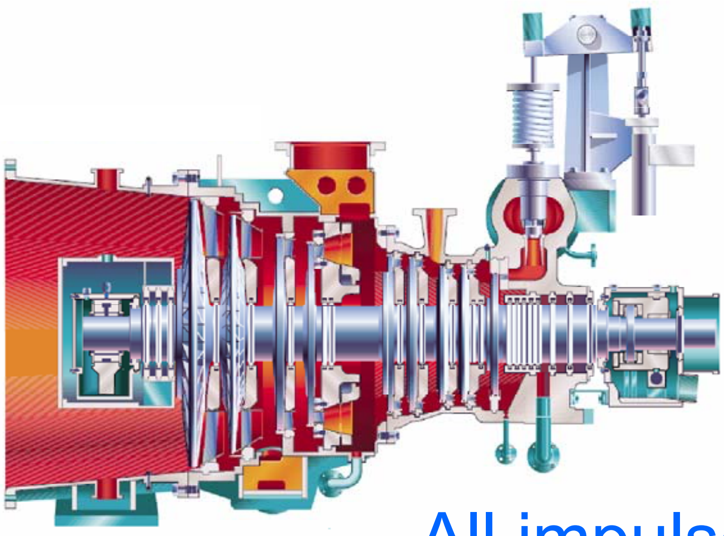
Typical arrangement of Steam Turbines

1 impulse + reactions



All reaction stages





All impulse stages

Working principle

Basically Steam Turbines are 2 types

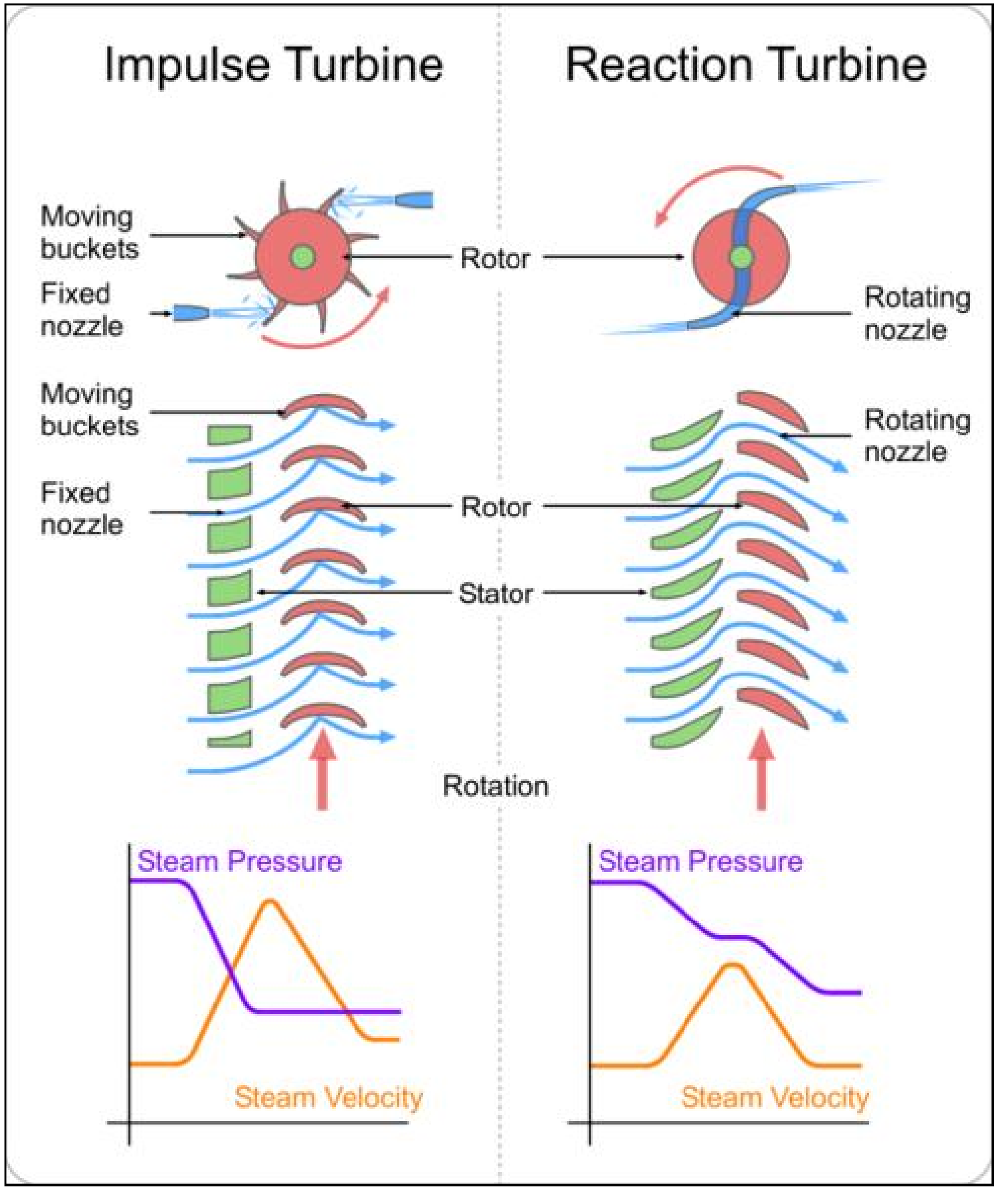
Impulse : Most of the pressure drop for the stage takes place in nozzle

Reaction : Pressure drop in a stage takes place aprox. 50% in Nozzle and 50% in Buckets

Reaction = δH bucket / δH Stage

δH bucket : Isentropic heat drop in bucket

δH Stage : Total stage Isentropic heat drop

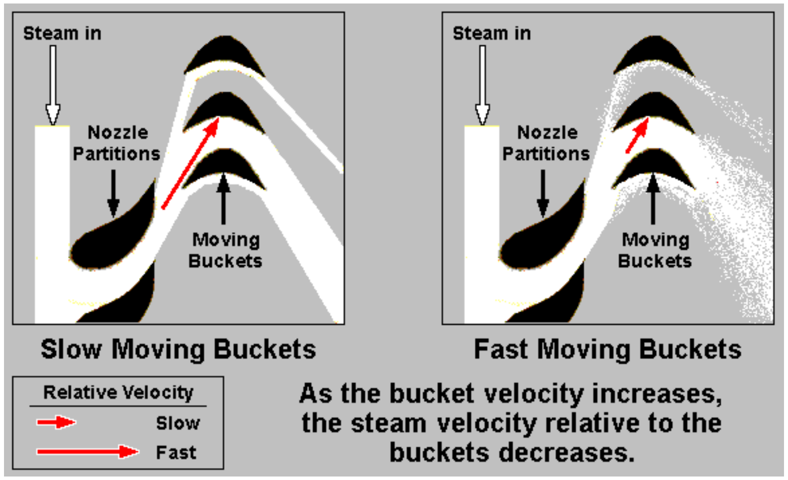


Working principle contd.

Impulse

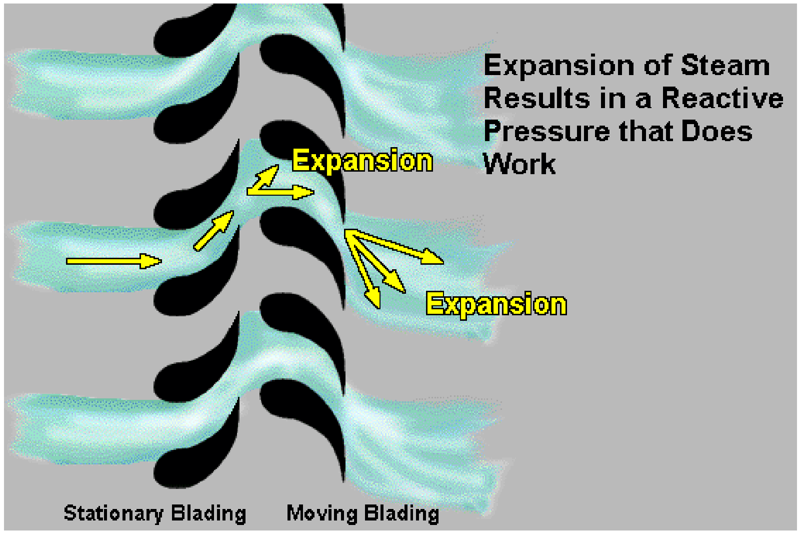
Impulse stages can take a higher enthalpy drop across the stage

This makes the ST compact

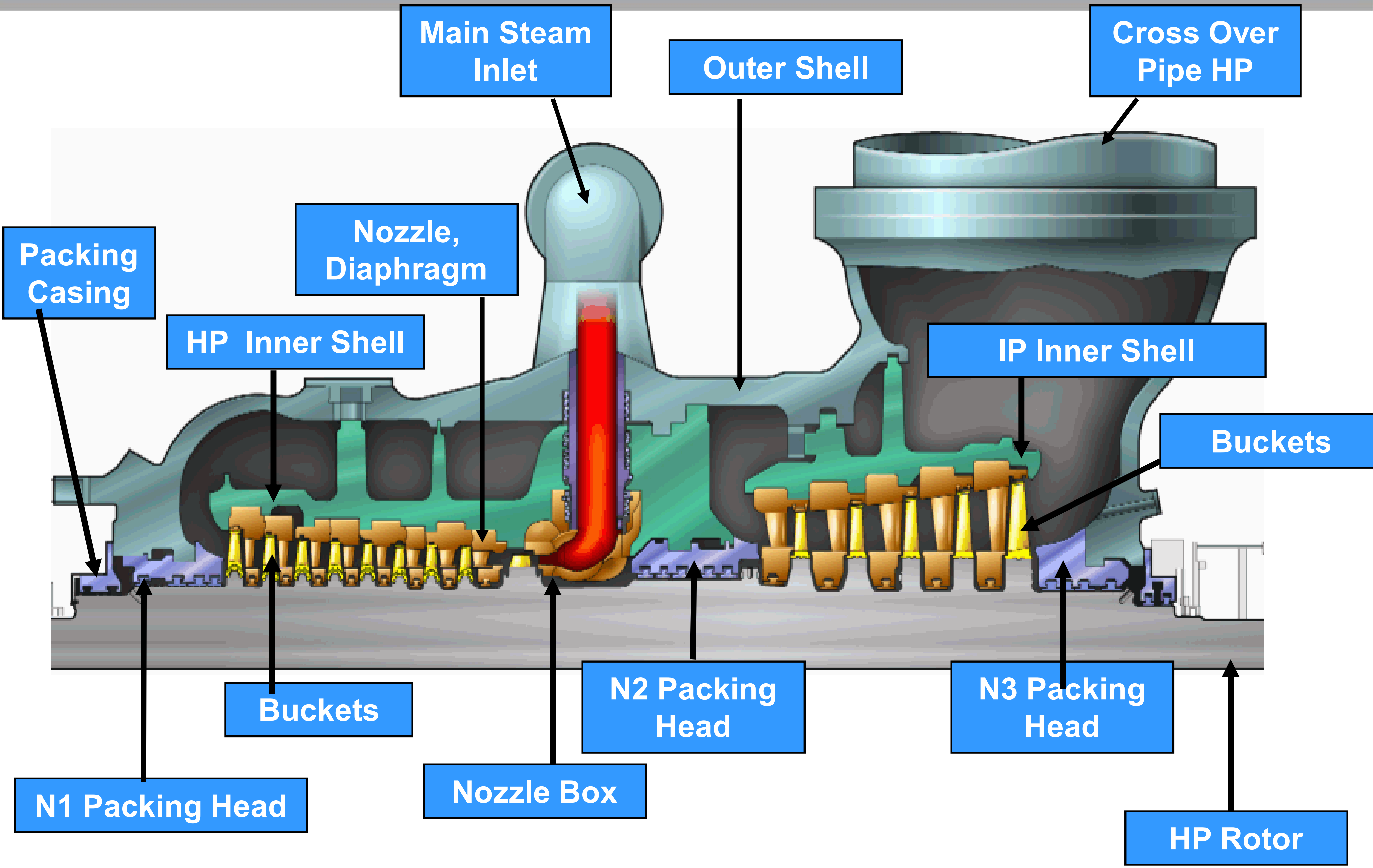


Reaction

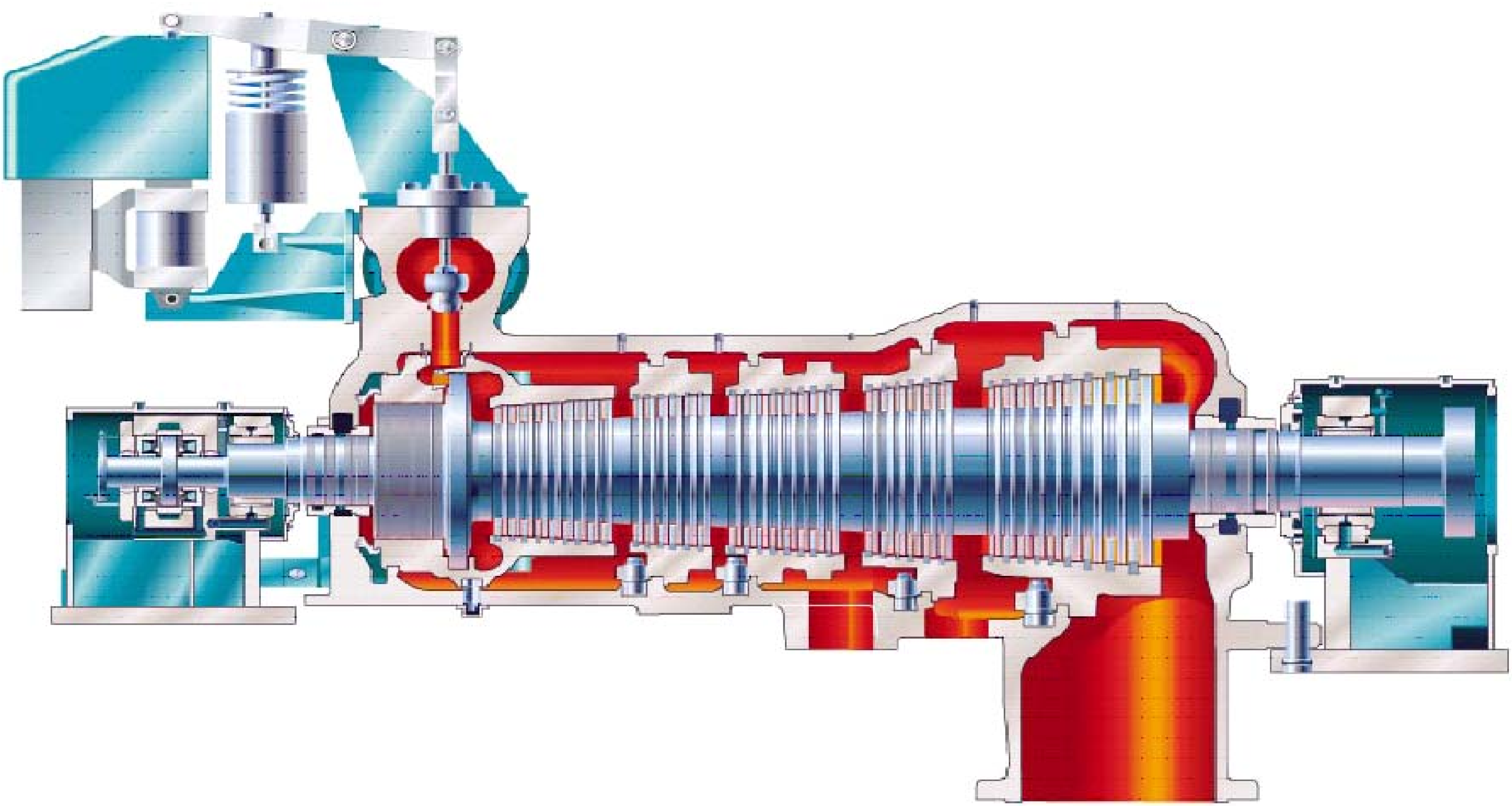
Reaction stages are more efficient and takes relatively less enthalpy drop across stage



Steam Turbine Critical Parts



Double extraction and Condensing Steam Turbine



MATERIALS USED IN ROTATING MACHINES

Materials Used in rotating equipments

Materials employed in a Turbo Machinery depends on

- Higher Stresses demand Alloy steels and Precipitation hardening steels
- Gas medium being highly Corrosive, high Humidity etc , needs High Chromium and Stainless St.
- Temperature of Gas like
  - Low temperature applications in Refrigeration services employ high Nickel alloys
  - High temperature applications like steam turbines Creep resistant steels are used
    (Chromium , Vanadium steels)
  - Very high temperatures applications like GT hot gas path employ High Ni alloys like Inconels
- Pressure Rating of the machine
  - Low pressure applications employ castings
  - High pressure applications employ Forgings
- Manufacturing Processes
  - Steels with low carbon are recommended for good Weldability
  - Machinability and weldability

Piping & Auxiliaries

PIPING AND INSTRUMENTATION DIAGRAM

A Piping and Instrumentation Diagram(P&ID) is :

A Drawing showing the Piping parts, Process parts of a system and the Instrumentation parts required to operate and control the system itself. This is the starting document for building any Process plant

- Piping : The set of PARTS specifically engineered to convey FLUIDS from one point to another point according to some specific process requirements. Piping parts :*Pipes, pipe fittings, tubes, tube fittings, valves*
- Instrumentation: The set of instruments used to operate and control a system
- Process Parts : *Pumps, Filters, Heat Exchangers…*

Standards Relevant to Piping

The American National Standards Institute's standards used in the design of the Piping System are as listed. ASME B 31. Code for Pressure piping is at present a non-mandatory code in USA, though they are adopted as legal requirement.

ASME B 31.1 - Power Piping
ASME B 31.2 - Fuel Gas Piping
ASME B 31.3 - Process Piping
ASME B 31.4 - Pipeline Transportation System for liquid hydrocarbon & other Liquids
ASME B 31.5 - Refrigeration Piping

ANSI - American National Standard Institute
API - American Petroleum Institute
ASCE - American Society of Civil Engineers
ASME - American Society of Mechanical Engineers
ASNT - American Society for Non destructive Testing
ASTM - American Society for Testing Materials
AWS - American Welding Society
CGA - Compressed Gas Association
EJMA - Expansion Joint Manufactures Association
MSS - Manufacturers Standardization Society of Valve & fitting Industry
NACE - National Association of Corrosion Engineers

PIPE FITTINGS

PIPE FITTINGS

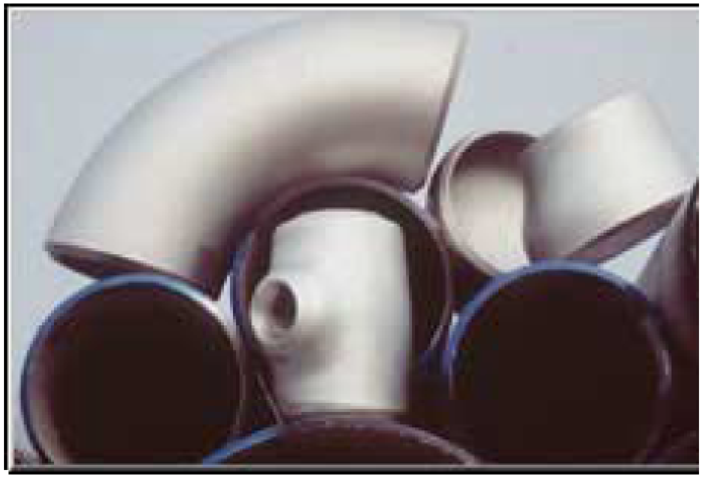
DIMENSIONAL STANDARDS

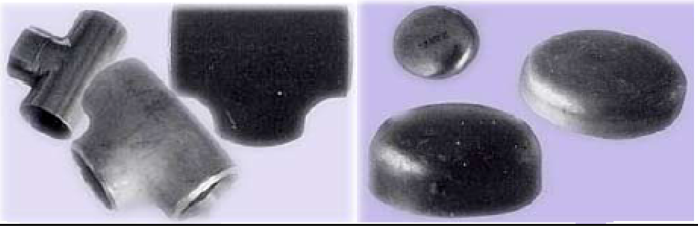
1. ASME B 16.1 - Cast Iron Pipe Flanges and Flanged Fittings
2. ASME B 16.3 - Malleable-Iron Threaded Fittings
3. ASME B 16.4 - Grey Iron Threaded fittings
4. ASME B 16.5 - Pipe Flanges and Flanged Fittings
5. ASME B 16.9 - Factory-Made Wrought Steel Butt welding Fittings
6. ASME B 16.11 - Forged Fittings, Socket welding and Threaded
7. ASME B 16.28 - Wrought Steel Butt welding Short Radius & Elbows
8. ASME B 16.42 - Ductile Iron Pipe Flanges and Flanged Fittings
9. MSS- SP- 43 - Stainless Steel Fittings

- For PIPES and WROUGHT BW FITTINGS, wall thickness is given in INCHES or mm.
  Some series of thicknesses are standardized.
  There are two series of systems of standardized thicknesses.

Schedule	Carbon Steel ANSI B16.10	5, 10, 20, 30, 40, 60, 80, 100, 120, 160.
	Stainless Steel ANSI B16.19	5S, 10S, 20S, 30S, 40S, 60S, 80S.
Weight Series	Std	Standard
	XS	Extra Strong
	XXS	Extra Extra Strong

Pipe fitttings & Flanges





Bends

30° - 45 ° - 60° - 90°

Long Radius R=1.5 D

Short Radius R=D

Tees

Straight Full Tees

Reducing Tees

Reducers

Concentric Reducers

Eccentric Reducers

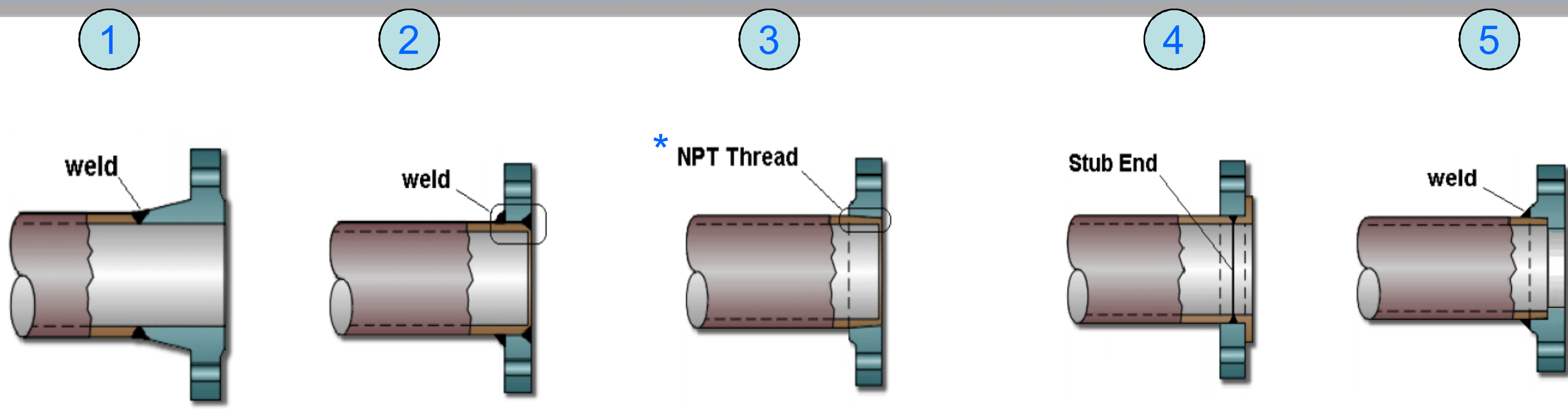
Caps

Butt welded fittings to ANSI B16.9

Flanges to ANSI B16.5

1. **Pipe Connection**
   - Welding Neck
   - Slip On
   - Lap Joint
   - Socket Welding
   - Threaded
2. **Mating**
   - Flat Face
   - Raised Face
   - Ring Joint

Types of Flange joints



1. WN: Used for all sizes They allow full penetration weld between Pipe &Flange. For this reason they are used for severe applications such as high pressure and high temperature ratings, where failure of weld can not be accepted.

2 Slip On: Used for all sizes They are very much economical because their shape. They do not allow full penetration welds so they are used for lower ratings and less severe applications

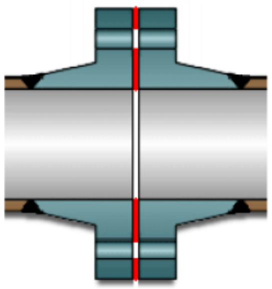
3 Threaded: : Used for smaller sizes They are very used limited for threaded lines and hence for less severe applications

4. Lap joint : A stub end is welded on the pipe after the flange inserted on . This solution is generally used for SS lines for low pressures

5. Socket Weld : Used for small sizes < 2 inch also for less severe joints on SW lines

* NPT : National Pipe taper threads

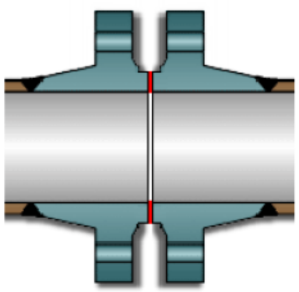
Types of Flange Joints



Flat Face

Gasket: Full Face Flat

It covers the entire surface of the flange



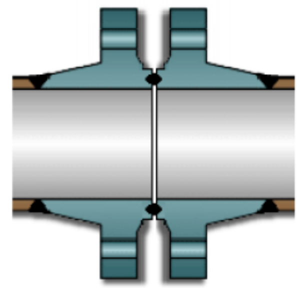
Raised Face

Gasket: Flat

It covers the raised surface of the flange

Spiral Wound

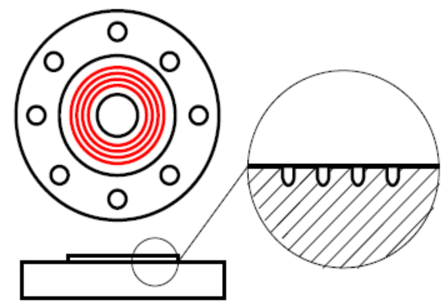
Also known as Spirometallic, or Spirotallic, its a wounded spiral of Stainless Steel and Graphite to withstand high temperatures or severely aggressive fluids



Ring Joint

Gasket: Metallic Ring

It is normally made up of Steel. It deforms inside the ring joint grooves assuring sealing at very high pressures.



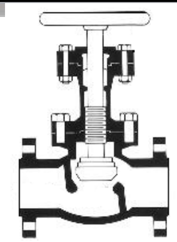
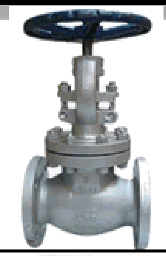
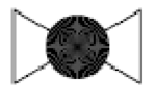
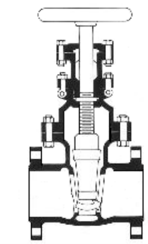
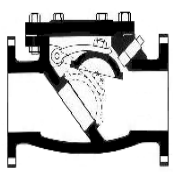
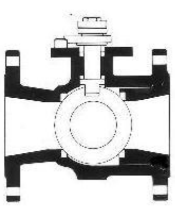
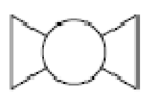
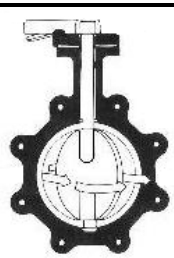
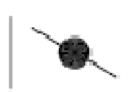
Surface Finishing of Flanges

To improve the sealing effect of plane gaskets, the surface of a flange can be machined. A set of circular scares is machined in the surface. When the gasket is tightenly squeezed between the flanges, it penetrates into the scares improving sealing.

Gaskets

- Selection of gasket depends upon following factors.
  - Compatibility of the gasket material with the fluid.
  - Ability to withstand the pressure-temperature of the system.
- Based on the type of construction, gaskets are classified as:
  - Full Face Flat asbestos Fibre
  - Inside bolt circle
  - Spiral wound metallic
  - Ring Joint type
  - Metal jacketed

Most Commonly used Valves

			**GLOBE**	**Good behavior when partial opening for regulation of flow is required.**
			**GATE**	**Used as On/ Off valves for isolation of pipe lines**
			**CHECK or NON RETURN**	**These valves are designed to allow flow only in one direction.**
			**BALL**	**A ball valve is a valve with a spherical disc They are therefore an excellent choice for shutoff applications for high pressures**
			**BUTTERFLY**	**A butterfly valve is a valve which can be used for isolating or regulating flow. A butterfly valve is from a family of valves called quarter-turn valves. "Quarter Turn" only required to fully open or close the valve.**

Most Commonly used Valves

OTHER VALVES (LIKE INSTRUMENTS)

- PRESSURE SAFETY VALVE
  - A valve that discharge fluid to the atmosphere when the pressure in the system is too high. The valve must be closed manually by the Maintenance Staff after verification of what caused the event.

- RELIEF VALVE
  - Often used as a synonym of Safety Valve.
    Indeed the difference is that a RELIEF VALVE will close automatically when the pressure in the system lowers to normal.

- CONTROL VALVE
  - A Valve that in conjunction with some SENSOR will open or close to maintain a set VALUE of a specific PHYSICAL PARAMETER in a part of the SYSTEM.
  - Main Fluids Parameters are Pressure, Temperature and Flow Rate, so main kind of Control Valves will be:
    - PCV: Pressure Control Valves
    - TCV: Temperature Control Valves
    - FCV: Flow Control Valves

Auxiliaries - Steam Turbine

Steam Turbine	Purpose
Governing system	Steam turbine control system is designed to contol certain critical parameters like turbine speed, Live steam pressure, / quantity, exhaust pressure and driven equipment parameters like compressor suction pressure.
Condensing system	By creating a vacuum, it helps the exhaust steam to condense at sub atmospheric pressure
Sealing system	To provide gland steam leakage and inter-stage steam leakage
Barring gear	To help the steam turbine to coast down after trip and keep it running at very low speeds to prevent thermal distortions
Lube oil system	The Lube oil console takes care of the lubrication requirements of compressor and its driven equipment in case of a generator.
Base plates	The fabricated supporting structure for the equipment which gives rigidity and fixing of the rotating equipments.
Instruments & control System	The measurement control and monitoring of rotating equipments such as vibrations , bearings temperatures, flow control etc.

Auxiliaries - Gas Turbines

Gas Turbines	Purpose
Inlet system	The inlet system is meant for drawl of air for combustion and ventilation air, filtration, minimize pressure drop, noise reduction, inlet cooling, anti-icing.
Exhaust systems	Ducts discharging exhaust air from the enclosure, expansion joint and exhaust silencer
Starting system	To accelerate the gas turbine to self sustaining speed
Fuel system	The Main Fuel System provided on the GAS TURBINE has the task of delivering the correct flow rate of fuel demanded by GT
Accessory Gearbox	To connect starting means with the GT shaft, and also to drive a number of user elements like MOP, Hydraulic pump, liquid fuel pump and atomizing air compressor.
Lube oil system	To supply oil to the GT bearings, integrated auxiliaries, and control oil to the hydraulic oil systems.
Base plates	In addition to supporting the GT , the base plate holds number of auxiliary equipments like Lo tank, accessory gear, starting systems, fuel control systems, pumps and filters
Instruments & control System	Ensure correct operation of the GT and protects the machine

GT Air Inlet system

- Air is taken in by the GT Air Inlet system for two main systems:

  Combustion air : It is the air taken in by the Axial Compressor and it is mainly used as medium fluid for the Thermodynamic Cycle.

  (Only about 25% of this air is used for the Combustion of the Fuel.)

  Ventilation air : It is air flowing through the Gas Turbine Enclosure with the help of a Fan. It cools the Enclosure area and dilutes possible gas leakages.
- Basic design criteria:
  - Correct degree of filtration.
  - Compliance with noise regulations.
  - Low friction losses to meet guaranteed power.
  - Structural design in compliance with building codes
- Inlet cooling: To cool the Air at Intake to increase the Gas Turbine Power.
- Anti-icing : To avoid formation of Ice in the Ducts or at Compressor bell-mouth

Air Inlet system - components

- **FILTER HOUSE**
  - Steel box housing the filtering elements and accessories like Pulse Jet Cleaning System, Heating / Cooling Coils and Evaporative Cooler
- **FILTER HOUSE STRUCTURE**
  - Steel Structure to support the Filter House.
- **INLET DUCT**
  - Ducting work connecting the Filter House to the Inlet Plenum. Includes Transition Pieces, Elbows, Straight Empty Ducts, Silencer and Expansion Joints
- **INLET DUCT STRUCTURE**
  - Steel Structure to support the Inlet Ducting. It usually supports also the Ventilation Inlet Ducts
- **INLET PLENUM**
  - It distributes the Air Flow on the Circular Section of the Axial Compressor inlet.
- **VENTILATION INLET DUCTS.**
  - Connects the Filter House to the GT Enclosure. Dampers are provided to seal the Enclosure in case of Fire.
- **FANS**
  - Driven by Electric Motors. They provide the required Head for the Ventilation air Provided with Silencers.
- **VENTILATION EXHAUST DUCTS**
  - Ducts discharging hot ventilation air from the enclosure. Dampers are provided to seal the Enclosure in case of fire.

Filter House

- **Weather protection** :protection from rain fall or snow fall. Hoods.
- **Inlet screen** :a wire mesh to avoid ingestion of large flying objects, birds, insects.
- **Pre-filter** :(Optional) Media filter used to remove larger solid particles before the high efficiency filter.
- **Inertial filter**: Optional pre-filter separating high inertia solids from low inertia air by impressing a sudden change in direction of the air stream.
- **Demister**: Always supplied with cooling systems to eliminate moisture designed to drain out liquid drops larger than 20 µm.
- **Coalescer**: A media filter designed to gather liquid droplets smaller than 20 µm until the liquid drop is big enough to be drained out by gravity.
- **High efficiency filter**: Also called barrier filter the main and only filter always present. It is a media filter specially designed to remove 99.9 % of solid particles larger than 5 µm.
- **Pulsed jet filter**: A pressure differential transmitters monitor inlet pressure and activates the pulse filters at 3 inch WG (76 mm) increasing signal. About 10% of total Cartridges are cleaned through reverse air pulse at a time. The pulse filters remain active until a 2.5 inch WG (51 mm) decreasing signal is reached.

Filter House

Is the First component of the Inlet System, Where the filtered air will be sucked by Gas Turbine.

Based on application, Static and Pulse Jet Filter house will be selected.

Inlet Duct Assy

Inlet System Consists of

Expansion joint, - connected to Filter house on one end and takes care of axial variations.

Empty Duct - straight duct which will be fitted with other accessories like Internal Bleed heater, Cooler Flange based on site conditions.

Silencer Duct, - fitted in the row of the empty duct, which is internally insulated and fitted with panels - reduces the noise of Inlet air.

Elbow Duct, Internally insulated duct, Which guides the air to plenum of the Gas turbine.

Inlet Ventilation System connecting the filter house and Enclosure of the gas turbine, which will supply the cleaned air to the Gas turbine enclosure, by means of fans.

The ventilation system consists of the Expansion joints and the ventilation ducts, which are supported on Inlet empty duct or on support structure of the Inlet/Exhaust accessories.

Exhaust stack Assy

Exhaust System Consists of

Expansion joint, which will be connected to Exhaust Plenum to Exhaust Duct, The Expansion joints are internally insulated to with stand the exhaust temperature of 500Deg C.

Exhaust Duct, are Uninsulated / internally / Externally insulated ducts and supported on the support structure

Exhaust Silencer Duct, will be fitted in the row of the Exhaust duct, which is internally insulated and fitted with panels which reduced the noise of the Exhaust air.

Exhaust Ventilation System connecting to the Enclosure and other end opened to atmosphere, so that air from enclosure go

The ventilation system consists of the Expansion joints and the ventilation ducts, the end of the duct covered with bird screen, so that foreign component shall not enter the duct. All the ducts are supported on support structure of the Inlet/Exhaust accessories.

Support Structure, which supports the filter house and Inlet exhaust ducts, and provided with the platforms/ladders to access the doors of the filter house and different elevation of Inlet/Exhaust system during installation and maintenance

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QuEST Recognition

Ranked 2nd among ESOs in 2006 Black Book of Outsourcing

Ranked among Top Emerging Service Providers in 2007 Global Services 100

Listed in IAOP's 2007 Global Outsourcing 100

Listed in Deloitte's Technology Fast 500 companies in Asia Pacific

UT500 Preferred Supplier

Supplier Excellence Award from GE

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