KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	KLM Technology Group **Engineering Solutions** **www.klmtechgroup.com**	Rev: 01 Rev 01 Feb 2015
KLM Technology Group #03-12 Block Aronia, Jalan Sri Perkasa 2 Taman Tampoi Utama 81200 Johor Bahru Malaysia	**Kolmetz Handbook of Process Equipment Design** **STEAM TURBINE SYSTEMS SELECTION, SIZING AND TROUBLESHOOTING** **(ENGINEERING DESIGN GUIDELINES)**	Co Author Rev 01 Aprilia Jaya Editor / Author Karl Kolmetz

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INTRODUCTION

Scope

Steam is used for large industrial process heating. One of pieces of equipment which uses steam is the steam turbine, as a heat engine. Steam turbines are used in industry for several critical purposes: 1) to generate electricity by driving an electric generator and 2) to drive equipment such as compressors, fans, and pumps. Steam turbines are available in a wide range of steam conditions, horsepower, and speeds.

The design of Steam Turbine is influenced by factors, including process requirements, economics and safety. This engineering design guideline covers the basic elements of Steam Turbines in sufficient detail to allow an engineer to design a Steam Turbine with the suitable inlet and exhaust diameter, Steam rate, enthalpy change and number of stages. The theory section explains properties of steam, types of steam turbine and their characteristics, steam turbine efficiencies and how to calculate the sizing and selection of a steam turbine.

General Design Consideration

A heat engine is one that converts heat energy into mechanical energy. The steam turbine is classified as a heat engine. Other heat engines are the internal combustion engine and the gas turbine. Steam turbines are used in industry for several critical purposes: to generate electricity by driving an electric generator and to drive equipment such as compressors, fans, and pumps. Steam turbines are available for a wide range of steam conditions, horsepower, and speeds.

Typical ranges for each design parameter are:

Inlet Pressure, psig 30 – 2000
Inlet Temperature, °F saturated – 1000
Exhaust Pressure, psig saturated – 700
Horsepower 5 – 100,000
Speed, rpm 1800 – 14,000

The steam turbine has a stationary set of blades (called nozzles) and a moving set of adjacent blades (called buckets or rotor blades) installed within a casing. The two sets of blades work together such that the steam turns the shaft of the turbine and the connected load. The stationary nozzles accelerate the steam to a high velocity by expanding it to lower pressure.

A rotating bladed disc changes the direction of the steam flow, thereby creating a force on the blades that, because of the wheeled geometry, manifests itself as torque on the shaft on which the bladed wheel is mounted. The combination of torque and speed is the output power of the turbine.

Steam turbines used as process drivers are usually required to operate over a range of speeds, in contrast to a turbine used to drive an electric generator which runs at nearly constant speed. The steam turbine permits the steam to expand and attain high velocity. It then converts this velocity energy into mechanical energy.

Mechanical drive steam turbines are categorized as:

- Single-stage or multi-stage
- Condensing or non-condensing exhausts
- Extraction or admission
- Impulse or reaction

Based on Stage

1. Single stage

In a single-stage turbine, steam is accelerated through one cascade of stationary nozzles and guided into the rotating blades or buckets on the turbine wheel to produce power. A Rateau design has one row of buckets per stage. A Curtis design has two rows of buckets per stage and requires a set of turning vanes between the first and second row of buckets to redirect the steam flow.

Single-stage turbines are usually limited to about 2500 horsepower and for larger units need special designs. Below 2500 horsepower the choice between a single and a multi-stage turbine is usually an economic one. A single-stage turbine will have a lower capital cost for a given shaft horsepower but will require more steam than a multi-stage turbine because of the lower efficiency of the single-stage turbine.

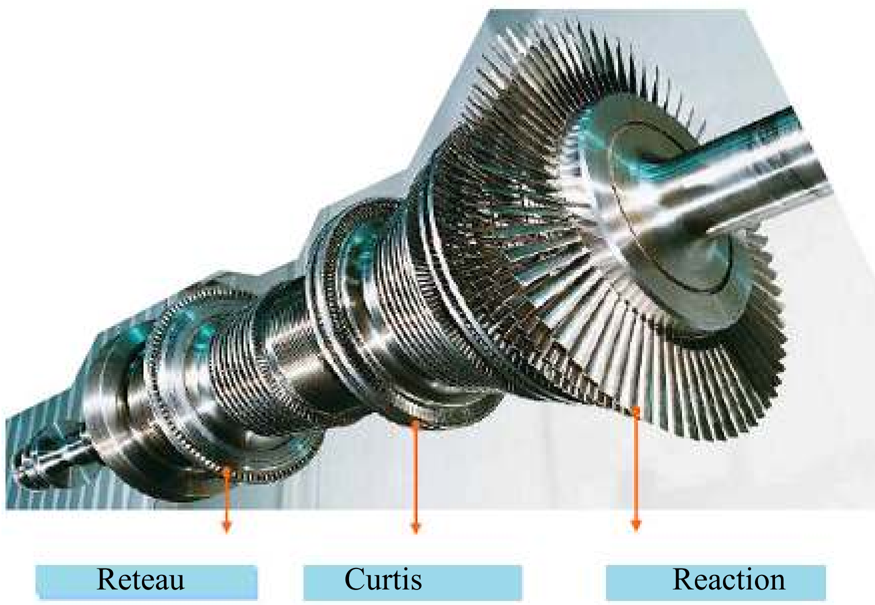
2. Multi Stage

A multi-stage turbine utilizes either a Curtis or Rateau first stage followed by one or more Rateau stages. The following criteria are used for selection steam turbine type

1. Curtis (Stand alone or Single Stage)
    a. Compact
    b. Power is relative small (up to 2000 kW).
    c. Speed is relative low (up to 6000 rpm, except for special design up to 12000 rpm).
    d. Enthalpy drop is high.

2. Rateau (Multi rows)
    a. Efficiency is higher than Curtis
    b. Power is high (up to 30,000 kW)
    c. Generally, speed is higher than Curtis (up to15000 rpm)
    d. Enthalpy drop for each row lower than Curtis but still high, higher than Reaction

3. Reaction (Multi row reaction + 1 row impulse for control stage)
   a. More efficient
   b. Power is high
   c. Speed is high (up to15000 rpm)
   d. Enthalpy drop each row is low
   e. For low steam pressure.



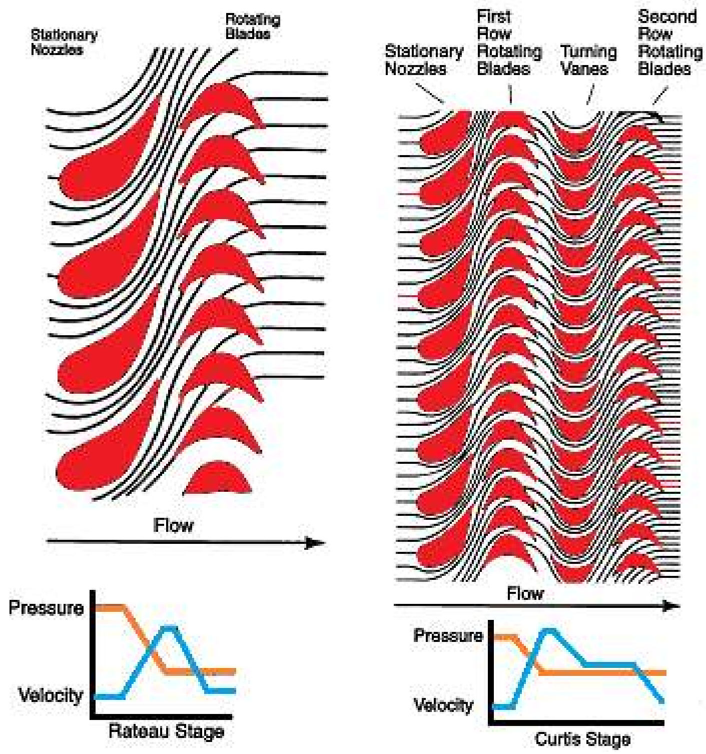


Figure1: Steam turbine blades arrangement

Based on Blade Geometry / Stage Design

In a steam turbine, high-enthalpy (high pressure and temperature) steam is expanded in the nozzles (stationary blades) where the kinetic energy is increased at the expense of pressure energy (increase in velocity due to decrease in pressure). The kinetic energy (high velocity) is converted into mechanical energy (rotation of a shaft increase of torque or speed) by impulse and reaction principles.

In the case of the fire hose, as the stream of water issued from the nozzle, its velocity was increased, and because of this impulse, it struck the window glass with considerable force. A turbine that makes use of the impulsive force of high-velocity steam is known as an impulse turbine. While the water issuing from the nozzle of the fire hose is increased in velocity, a reactionary force is exerted on the nozzle. This reactionary force is opposite in direction to the flow of the water. A turbine that makes use of the reaction force produced by the flow of steam through a nozzle is a reaction turbine.

1. Impulse Turbine

The impulse principle consists of changing the momentum of the flow, which is directed to the moving blades by the stationary blades. The jet's impulse force pushes the moving blades forward. This energy is converted into mechanical energy by rotating the shaft in turbine nozzle. Kinetic energy to be converted to blade become mechanical energy and transferred through rotor, shaft and coupling to the load. Enthalpy drop is high for each moving blades.

It has one velocity-compounded stage (the velocity is absorbed in stages) and four pressure-compounded stages. The velocity is reduced in two steps through the first two rows of moving blades. In the moving blades, velocity decreases while the pressure remains constant. Impulse blades are usually symmetrical and have an entrance and exit angle of approximately 20^o. They are generally installed in the higher pressure sections of the turbines where the specific volume of steam is low and requires much smaller flow areas than that at lower pressures. The impulse blades are short and have a constant cross section

In a pure impulse turbine, when the steam passes through the stationary blades, it incurs a pressure drop. There is no pressure drop in the steam as it passes through the rotating blades. Therefore, in an impulse turbine, all the change of pressure energy into kinetic energy occurs in the stationary blades, while the change of kinetic energy into mechanical energy takes place in the moving blades of the turbine.

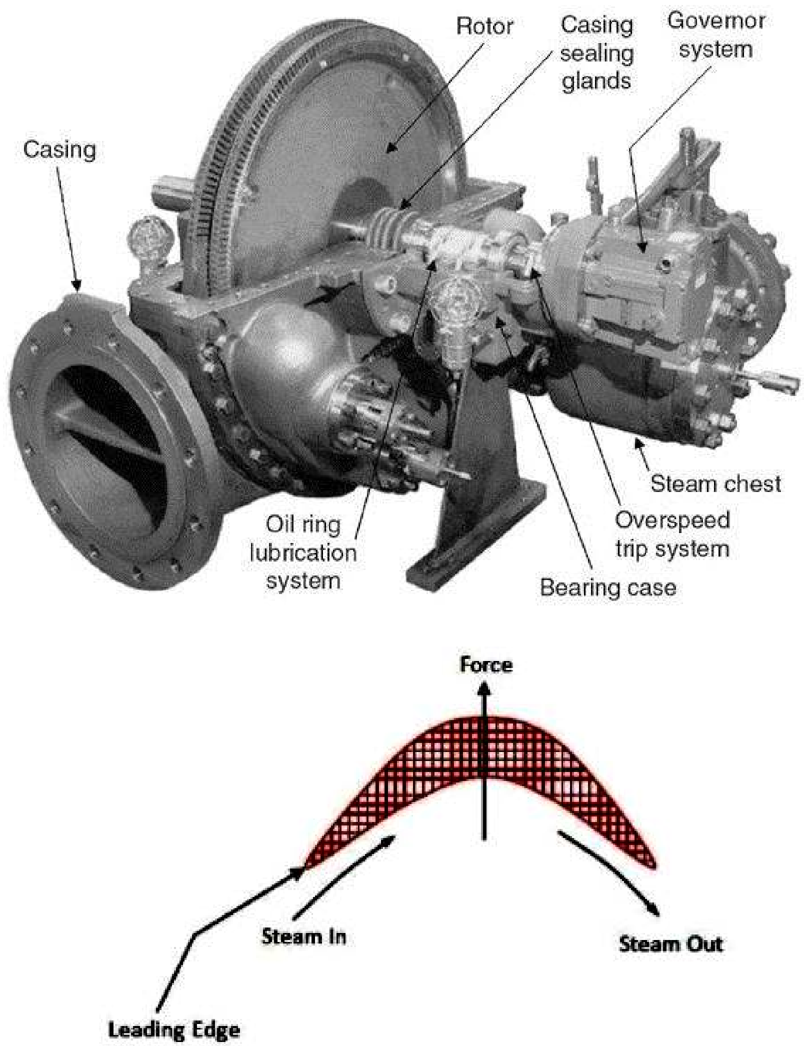


Figure 2: Single Stage Impulse Steam Turbine Cutaway (1)

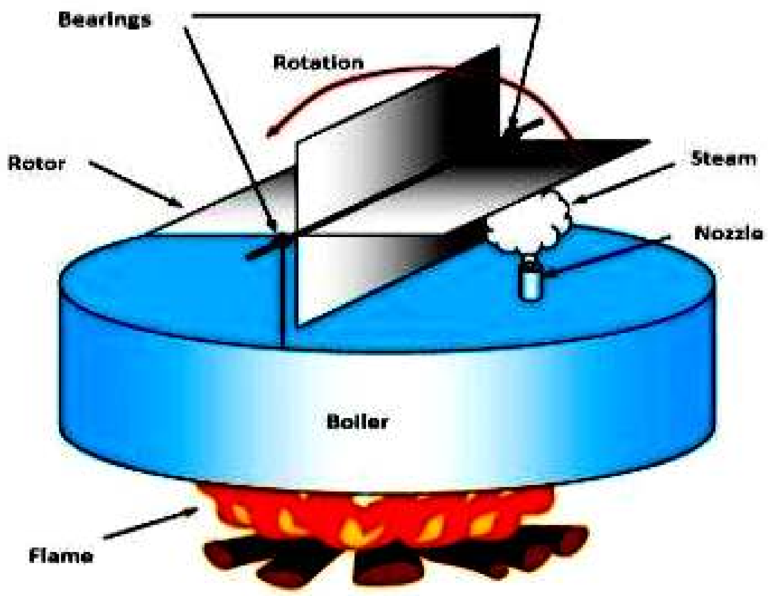


Figure 3: Principle of impulse turbine

2. Reaction Turbine

The reaction principle consists of a reaction force on the moving blades due to the steam accelerating through the nozzles. The nozzles are actually created by the blades. In reaction turbine, there is no nozzle to convert steam energy to mechanical energy. Each stage of the turbine consists of a stationary set of blades and a row of rotating blades on a shaft. Moving blades work due to differential pressure of steam between front and at behind of moving blades.

Since there is a continuous drop of pressure throughout each stage, steam is admitted around the entire circumference of the blades and, therefore, the stationary blades extend around the entire circumference. Steam passes through a set of stationary blades that direct the steam against the rotating blades. As the steam passes through these rotating blades, there is a pressure drop from the entrance side to the exit side that increases the velocity of the steam and produces rotation by the reaction of the steam on the blades.

In general, reaction turbine is not stand alone, but works at behind impulse turbine whether constructed in one rotor or at separated rotor, but still connected by coupling. The purpose of impulse turbine is to control speed and reduce steam enthalpy to specified level. Reaction turbine is just receiving steam condition from impulse blades. The reaction stages are preceded by an initial velocity-compounded impulse stage where a large pressure drop occurs. This results in a shorter, less expensive turbine.

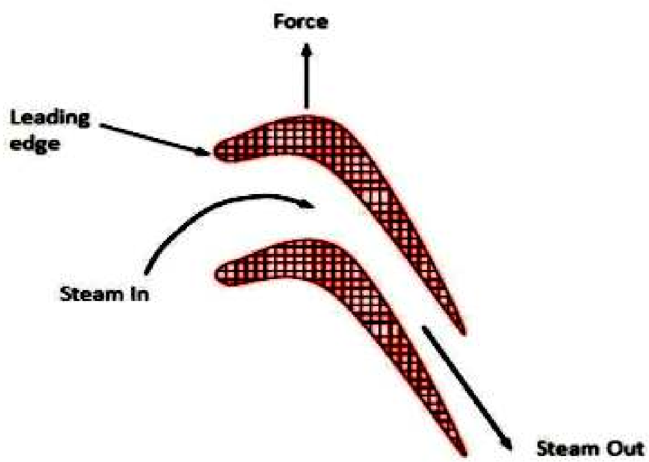


Figure 4: Section of reaction turbine blading

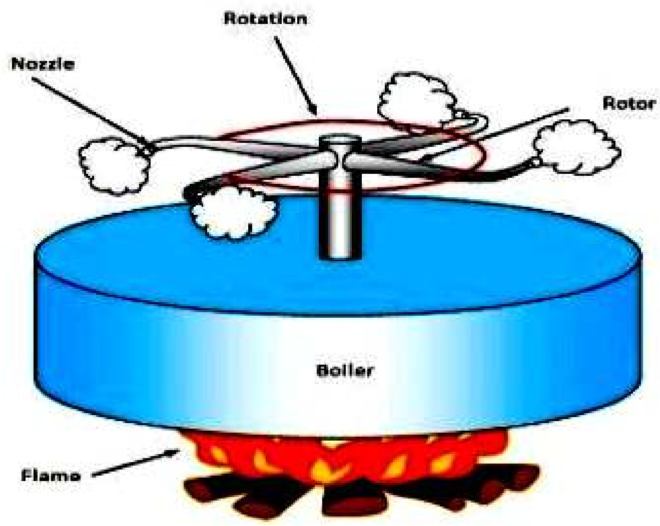


Figure5: Principle of reaction turbine

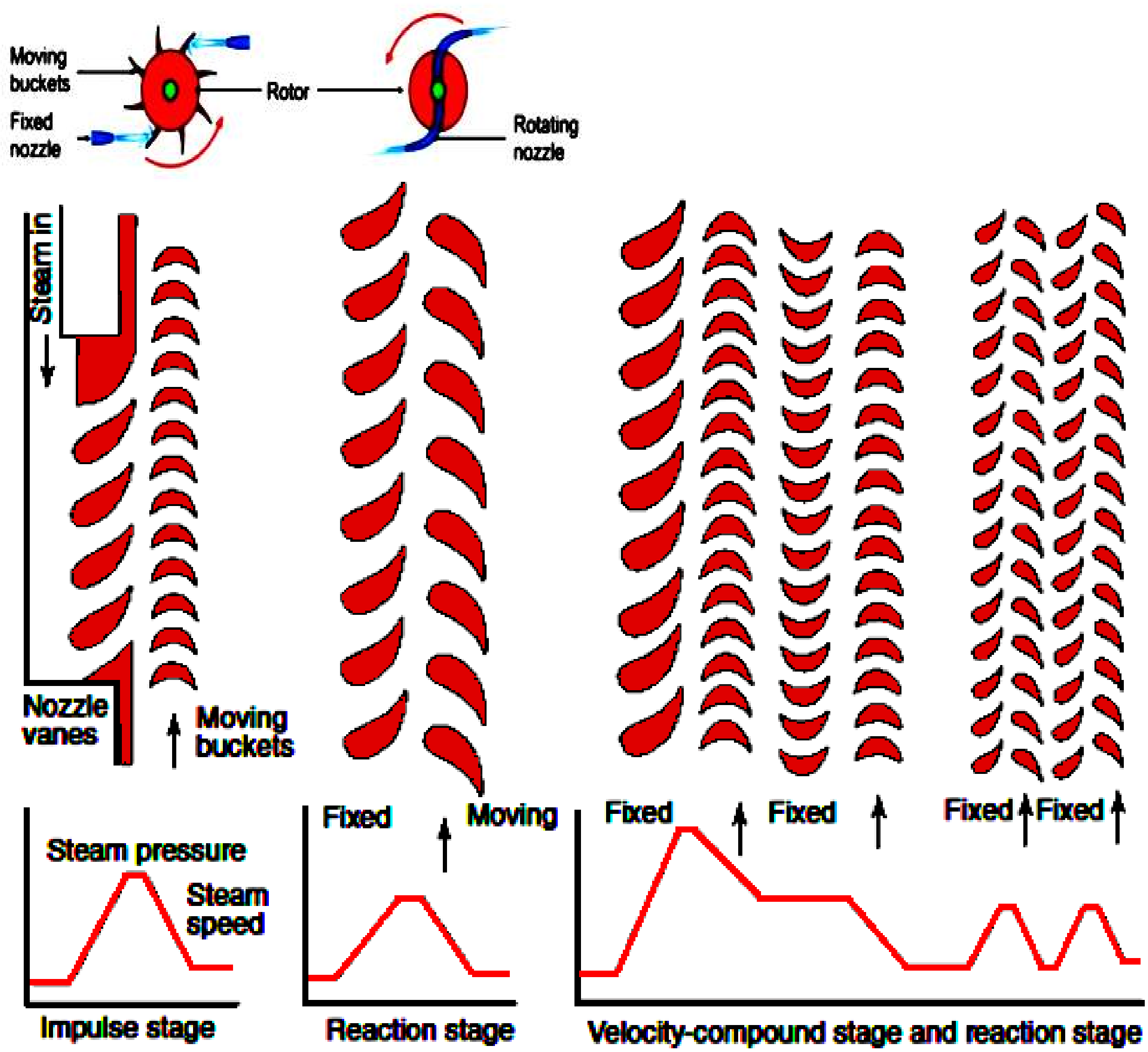


Figure 6: Diagram of simple impulse and reaction turbine stages. (11)

Operating range of steam turbines can be shown in Speed – Power chart such as the following figure.

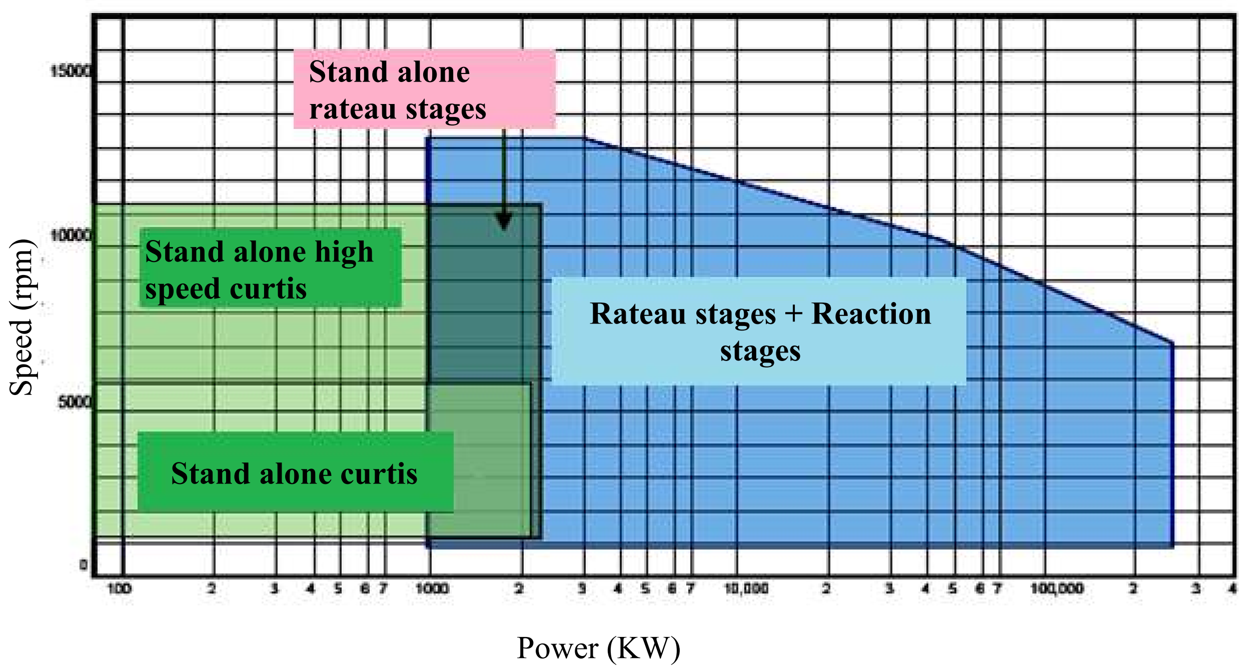


Figure 7: Operating Range of Steam Turbines

Based on Steam Supply

When classifying steam turbines by their steam supply and exhaust conditions, they are categorized as condensing, non-condensing or backpressure, reheat-condensing, and extraction and induction.

1. **Condensing turbine.**

This type of steam turbine is used primarily as a drive for an electric generator in a power plant. These units exhaust steam at less than atmospheric pressure to a condenser

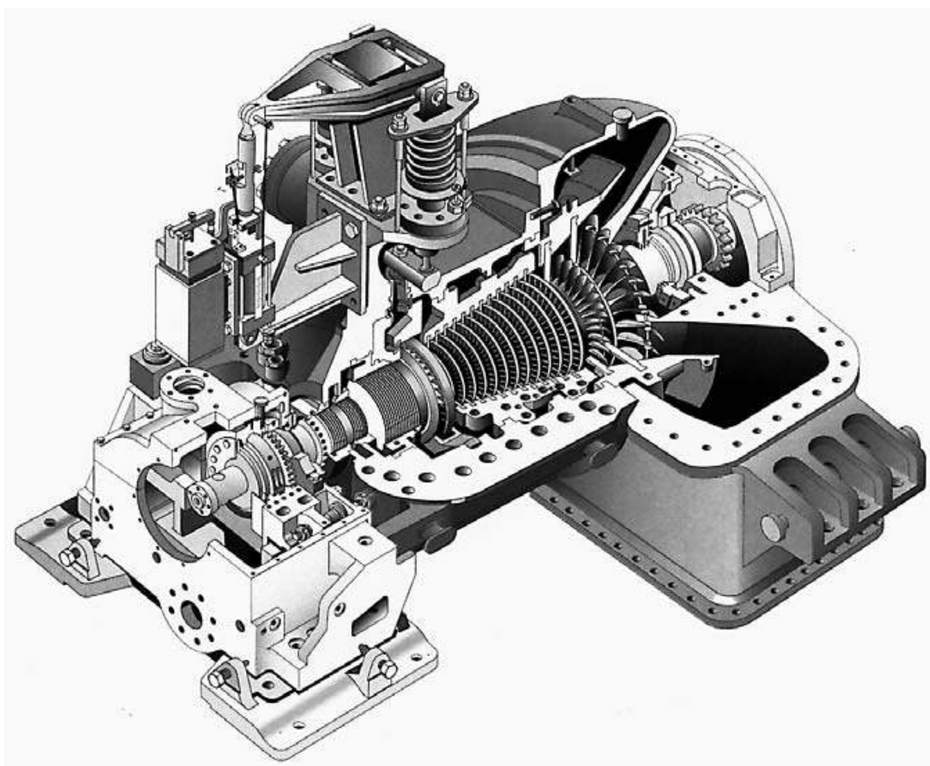


Figure 8: Condensing steam turbine for approximately 65-MW output. (12)

2. Noncondensing or backpressure turbine.

This type of turbine is used primarily in process plants, where the exhaust steam pressure is controlled by a regulating station that maintains the process steam at the required pressure. Figure 9 shows a typical arrangement of a backpressure turbine.

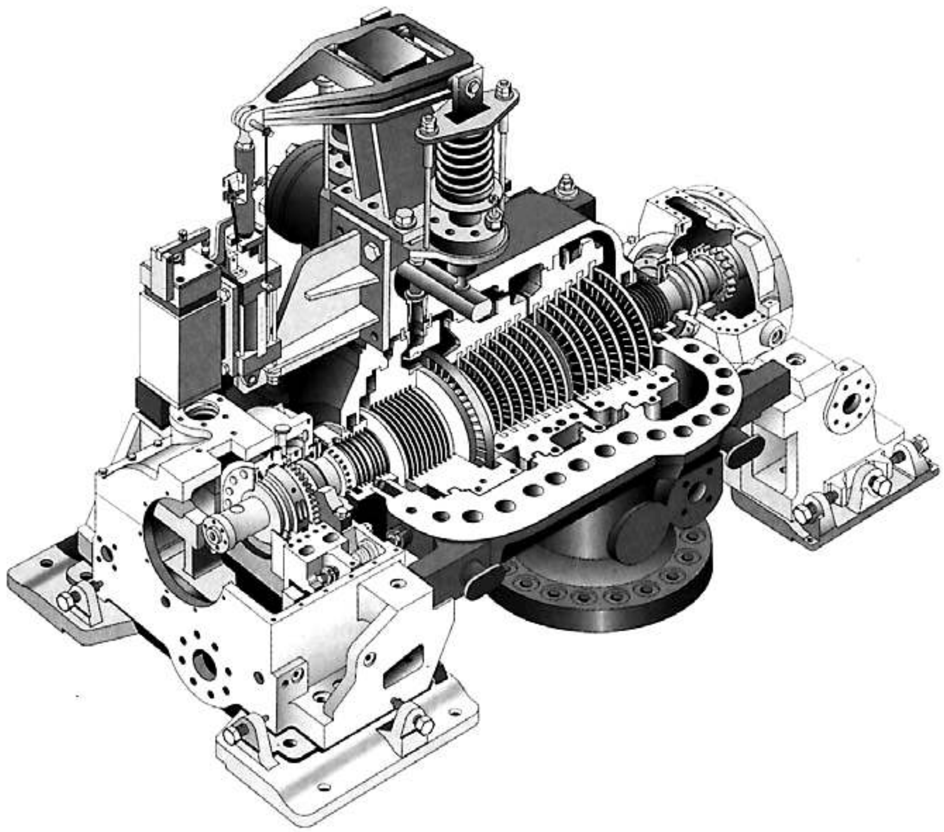


Figure 9: Backpressure steam turbine for approximately 28-MW output. (12)

DEFINITIONS

Blowdown - High pressure water at the steam saturation temperature released from a steam boiler to control sludge and total dissolved solids.

Boiling Point - The temperature at which water boils to form steam. This temperature increases as the pressure is increased.

Boiler - a closed vessel or arrangement of vessels and tubes, together with a furnace or other heat source, in which steam or other vapor is generated from water to drive turbines or engines, supply heat, process certain materials, etc.

Backpressure - Pressure developed in opposition to the flow of liquid or gas in a pipe, duct, conduit, etc.; due to friction, gravity, or some other restriction to flow of the conveyed fluid.

Backpressure turbine - the type of turbine used in turbo chargers it utilizes the back pressure from ones engine to created more horse power. The back pressure turbine discharges the steam into a pressurized piping system to be used for process heating elsewhere or as the supply to other turbines. For instance a turbine may receive steam at 600 psig and discharge into a 100 psig system.

Check Valves - Non-return valves inserted into lines to prevent everse flow.

Condensate - The liquid which is formed as steam condenses. Ideally pure water.

Compounding of steam turbines - the method in which energy from the steam is extracted in a number of stages rather than a single stage in a turbine. A compounded steam turbine has multiple stages i.e. it has more than one set of nozzles and rotors, in series, keyed to the shaft or fixed to the casing, so that either the steam pressure or the jet velocity is absorbed by the turbine in number of stages.

Control Valves - valves used to control conditions such as flow, pressure, temperature, and liquid level by fully or partially opening or closing in response to signals received from controllers that compare a "setpoint" to a "process variable" whose value is provided by sensors that monitor changes in such conditions.[1] Control Valve is also termed as the Final Control Element.

Desuperheater - A device where water is added to return steam to saturated conditions.

Enthalpy drop - the difference in steam enthalpy between turbine inlet conditions and turbine outlet conditions. This is applicable to individual turbine sections such as high pressure section or intermediate pressure section.

Electric generator - a generator is a device that converts mechanical energy to electrical energy for use in an external circuit.

Exhaust steam - to be emitted or to escape from an engine after being expanded

Flash Steam - The steam produced when the pressure of hot condensate is reduced.

Generator - a machine that converts one form of energy into another, especially mechanical energy into electrical energy, as a dynamo, or electrical energy into sound, as an acoustic generator.

Heat rate – Heat consumption per hour per unit output. The turbine is charged with the aggregate enthalpy of the steam supplied plus any chargeable aggregate enthalpy added by the reheaters. It is credited with the aggregated enthalpy of feed water returned from the cycle to the steam generator.

Heat engine - a mechanical device designed to transform part of the heat entering it into work

Impulse Turbine – Type of steam turbine where there is no change in the pressure of the steam as it passes through the moving blades. There is change only in the velocity of the steam flow.

Kinetic energy - the energy of a body or a system with respect to the motion of the body or of the particles in the system.

Latent Heat - Heat that changes the state of a substance with no accompanying temperature rise. When water is changed into steam, the heat is also known as the Enthalpy of Evaporation.

Mechanical energy - the sum of potential energy and kinetic energy. It is the energy associated with the motion and position of an object. The principle of conservation of mechanical energy states that in an isolated system that is only subject to conservative forces the mechanical energy is constant.

Nozzles - A projecting part with an opening, as at the end of a hose, for regulating and directing a flow of fluid. a device designed to control the direction or characteristics of a fluid flow (especially to increase velocity) as it exits (or enters) an enclosed chamber or pipe.

Power – the useful energy per unit of time, delivered by the turbine or turbine-generator unit

Reaction Turbine - Type of steam turbine where there is change in both pressure and velocity as the steam flows through the moving blades

Steam rate – Steam consumption per hour per unit output in which the turbine is charged with the steam quantity supplied

Steam turbine - turbine in which steam strikes blades and makes them turn. Turbine is rotary engine in which the kinetic energy of a moving fluid is converted into mechanical energy by causing a bladed rotor to rotate

Sensible Heat (Specific Enthalpy) - Heat that increases the temperature of the water or steam with no change of state.

Superheated Steam - Steam to which sensible heat has been added to increase its temperature to above its boiling point.

Thermal Fluids - Generally mineral oils with high heat capacities that can be used as alternatives to steam or hot water for process heating in the range 200-400□C.

Throttle Valve - a valve designed to regulate the supply of a fluid (as steam or gas and air) to an engine and operated by a handwheel, a lever, or automatically by a governor; *especially* **:** the valve in an internal-combustion engine incorporated in or just outside the carburetor and controlling the volume of vaporized fuel charge delivered to the cylinders

NOMENCLATURES

An	Nozzle area, in²
ASR	Actual steam rate, lb/hp.hr
Dex	Exhaust diameter, in
Din	Inlet diameter, in
Eff	Efficiency,%
hex	Exhaust enthalpy, btu/lb
hf	Specific enthalpy of saturated water, btu/lb
hg	Specific enthalpy of saturated steam, btu/lb
hin	Specific enthalpy of superheated steam, btu/lb
Pin	inlet pressure, psia
Pout	exhaust pressure, psia
Pwr	Horsepower, HP
RPM	Speed, rpm
S	number of stages
sf	Specific entropy of saturated water, btu/lb.F
sg	Specific entropy of saturated steam, btu/lb.F
sin	Specific entropy of superheated steam, btu/lb. F
Tin	inlet temperature, F
TSR	Theoretical steam rate, lb/hp.hr
vex	velocity of exhaust, ft/s
vin	velocity of inlet steam, ft/s
W	Mass flowrate, lb/hr
x	liquid fraction in the exhaust
y	vapor fraction in the exhaust

Greek Leters

Δh	Enthalpy change, btu/lb
ρ_{gex}	Density steam in exhaust, lb/ft³
ρ_{gin}	Density steam inlet, lb/ft³

Superscript

ASR	Actual steam rate, lb/hp.hr
RPM	Speed, rpm
TSR	Theoretical steam rate, lb/hp.hr