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TUTORIAL ON LARGE STEAM TURBINE SYSTEMS IN OIL & GAS APPLICATIONS

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ABSTRACT

This tutorial provides an overview on large steam turbines systems and their auxiliaries in oil and gas applications from a Contractor perspective. The tutorial is introduced by discussing the basics of steam turbine systems including the thermodynamic background, principles of operation, and the different classifications of steam turbines. The steam turbine arrangements are discussed explaining the differences in casings and internals design and also the various possibilities of shaft line arrangements. Then all the auxiliary systems; and their sub-systems, that are associated with steam turbines are illustrated in details. Auxiliary systems presented in this tutorial comprise the vacuum system, the sealing system, the oil system, the speed control and protection system …etc. among others. Particular issues such as plot plan constraints, precautions for offshore applications, human factors and safety are also addressed with explanations in this tutorial. And finally shop testing, installation, pre-commissioning and commissioning of large steam turbine systems are clarified.

INTRODUCTION

Steam turbines are utilized in many industrial applications; such as in oil & gas and power generation plants. Steam turbines could be coupled to an electric generator to produce electricity or to compressors (or pumps) in mechanical drive applications. Steam turbine drivers are very robust machines compared to other drivers such as gas turbines and electric motor. Speed variations in steam turbine drivers; typically, 70% to 105% of rated speed, allow for operational flexibility.

For the oil and gas applications, steam turbines are specified according to the American Petroleum Institute (API) standards. (API Standard 612, 7th Edition, August 2014) applies for special purpose steam turbines while (API Standard 611, 5th Edition , 2008) standard applies for general purpose steam turbines, depending on the service requirements which include magnitude of power output and criticality of operating conditions, in addition to being spared or not.

Oil & gas steam turbine applications are numerous. In the LNG plants steam turbines are used as main driver of the refrigerant compressors providing close to 60 [MW] in one of the recent LNG projects. In Ethylene plants, steam turbines are also used as mechanical drive for compressors, driving the cracked gas compressor and the refrigerant compressors (Propane or Propylene, Ethylene) on the same shaft line with power output close to 80 [MW] (as shown in ***Figure 1: Steam Turbine in Ethylene service (Courtesy: Elliott Group)***). In the Ammoniac-Urea plant, steam turbines are also used to drive the main compressors. In refinery applications steam turbines are used to drive all compressors and the main pumps because of the abundance of steam.

Figure 1: Steam Turbine in Ethylene service (Courtesy: Elliott Group)

Steam turbines are extensively applied for power generation applications. Steam turbines for power generation applications in the oil and gas industry are designed and sized according to the practices used for oil & gas applications; however steam turbines for the power generation industry are designed and sized according to other different practices. Combined cycle power plants apply a combination of steam turbines and gas turbines to produce electricity with the highest plant efficiency possible as waste heat from the gas turbine is recovered to produce higher power outputs from the steam turbines.

Inlet steam conditions for steam turbines exceed 200 [barg] and 565 [°C]. Nuclear power plants are characterized by long shaft steam turbines (50 [m] through different casings) producing up to 1500 [MW].

Steam turbine are also used in other industrial applications such as in the paper Industry where large controlled extractions are applied.

Steam turbines are also utilized in ship applications to drive propellers and to produce electric power.

This paper focuses on steam turbine applications for oil and gas applications.

Steam turbine systems include various auxiliaries to ensure a workable, safe and reliable operation:

- The lube oil auxiliary system provides lubricating oil to the steam turbine bearings to ensure smooth rotation of the rotor and for dissipating heat from the rotor, and provides control oil for actuation purpose;
- The steam sealing system ensures that steam leakage is minimized and controlled. It prevents the mix of steam with the lubricating oil within the bearings and ensures safe steam containment within the casing. The sealing system also prevents the air from going inside the turbine when the exhaust casing is under vacuum (this is particular for condensing type steam turbines);
- The condensing system and its associated sub-systems creates the necessary vacuum at steam turbine exhaust to maximize power output. (this is particular for condensing type steam turbines);

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BASICS OF STEAM TURBINES

Thermodynamics

To comprehend the principles of steam turbine operation, it is an essential pre-requisite to understand the steam behavior under various thermodynamic conditions, this best described in ***Figure 2: Mollier Diagram***. This diagram allows to determine the steam physical values (notably the isentropic enthalpy) based on a given temperature and pressure conditions. It is used in estimating the power output of steam turbines when inlet and outlet conditions and flow rate are decided, or to determine the steam flow rate requirement for a desired power output at pre-defined inlet and outlet conditions according to the equations listed below.

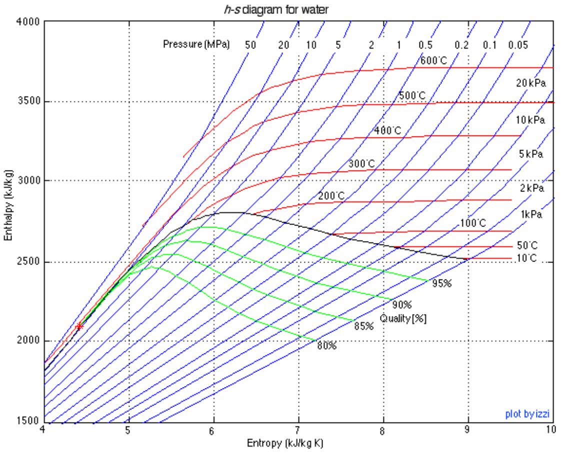

Figure 2: Mollier Diagram

Steam Turbine Power (see ***Figure 3: H-S Diagram for Steam Expansion Process)***:

$$\text{Power} = \text{mass flow} \times \eta \times (H1 - H2is)$$

Steam Turbine Efficiency:

$$\eta = \frac{H1 - H2}{H1 - H2is}$$

Output Power in [kW]
Steam Mass Flow in [kg/s]
Efficiency in %
Enthalpy in [kJ/kg]

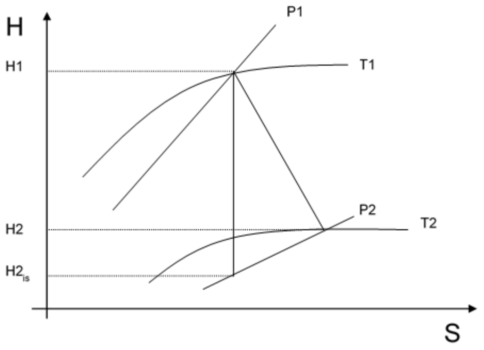

Figure 3: H-S Diagram for Steam Expansion Process

Efficiency of steam turbines can be generally considered as follows:

- From 30% to 60% for small turbines (< 800 [kW]);
- Around 75% for large turbines (> 5000 [kW]).

Principles of Operation

Steam turbines captures power from expanding steam. The steam comes from a boiler then passes through stages of expansion in the steam turbine until finally reaching the pre-defined exhaust pressure. These stages are composed of stationary and moving parts:

- The stationary guide vanes increase the steam speed (through a converging path);
- The rotating blades transform the steam speed into torque;

The casing of the steam turbine ensures full steam containment.

For further details on steam turbine specification and sizing refer to (Aalto, 1992).

Classifications of Steam Turbines

Impulse and Reaction Turbines

There are mainly two families of Steam Turbines: (1) Impulse type and (2) Reaction type.

Figure 4: Impulse & Reaction Turbines illustrates the differences in the steam and pressure profiles throughout the expansion process inside a steam turbine (left: Impulse type; Right: Reaction type).

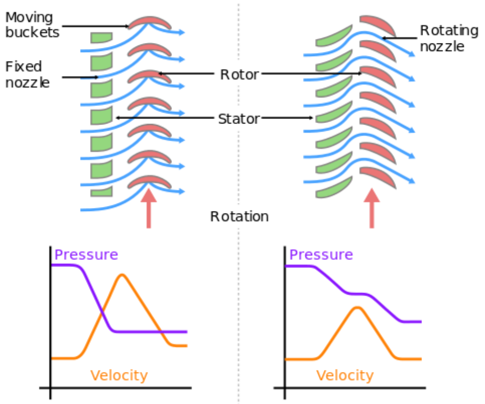

Figure 4: Impulse & Reaction Turbines

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In an impulse turbine, the pressure drop/ recovery is fully made in the guide vanes; whereas for a reaction turbine the pressure recovery is shared between both stationary and rotating parts.

Figure 5: Rotor of a Reaction Turbine

Figure 6: Rotor of an Impulse Turbine

For a reaction turbine the axial thrust on rotor (shown in ***Figure 5: Rotor of a Reaction Turbine***) is higher compared to an impulse rotor (shown in ***Figure 6: Rotor of an Impulse Turbine***) because the pressure drop is fully achieved in the rotating blades.

The increased thrust can be managed in two ways:

1. By increasing the diameter of the balancing piston but this shall be precisely done to avoid increasing the leakage rate on the HP section leading to higher losses.
2. By enlarging the size of the thrust bearing, which would also increase the mechanical losses and the oil consumption.

The efficiency of the reaction turbine is higher than that for an impulse turbine; but subject to deterioration over time. The number of stages of a reaction turbine is higher which lead to much more blades and guide vanes.

Both technologies can be accepted for oil and gas applications; each having its own advantages and disadvantages.

Condensing/ non-condensing Steam Turbines

Steam turbines can also be classified according to the exhaust condition as:
(1) Condensing type: exhaust steam pressure < 1 [Bara]; or
(2) Back pressure type: exhaust steam pressure >1 [Bara];

The exhaust steam in condensing steam turbine is routed through a bellow to a condenser (see ***Figure 7: Rectangular Metallic Expansion Bellow***); while in a back-pressure type the exhaust steam is routed somewhere in the plant for further use. For condensing type turbines, the vacuum is maintained by the condensation process of the steam in the condenser; as the steam at liquid state (condensate) takes less space than the steam at vapor state. However, in the subsequent section an assistive vacuum system is described. The extent of vacuum within the condenser depends on the external temperature of the cooling medium (air or water). Accordingly, the vacuum level may vary seasonally especially for the air cooled condensers. When an air cooled condenser is specified, the design (mechanical and vibration) of the last blades shall be carefully anticipated by the manufacturer to cater for such variations in the exhaust vacuum pressure. It shall be noted that air cooled condensers require more space and foot-print compared to water cooled condensers.

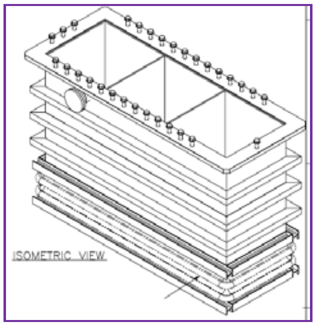

Figure 7: Rectangular Metallic Expansion Bellow

On the other hand, back pressure steam turbines are connected to the steam network of the plant which consumes the steam discharged by the steam turbine. The steam network is normally subject to slight fluctuations in pressure. Accordingly, the steam turbine design shall ensure that the turbine can operate in all these inlet and back pressure conditions and not only at nominal fixed conditions. The fluctuation of the back pressure mandates an impact on the mechanical sizing of the last stage blades of back-pressure steam turbines.

Side extraction/ induction

Some steam turbines are characterized by extracting steam from the steam turbine at an intermediate stage; others are characterized by inducing steam in an intermediate stage of the steam turbine. Extraction and induction are purely governed and decided by the plant requirements and not because of steam turbine requirements. For process purpose in the plant, medium pressure steam might be required, this steam is extracted from the steam turbine at the required level of pressure. Two types of extractions exist: (1) controlled and (2) uncontrolled. Uncontrolled extraction is often applied in power generation to improve the cycle efficiency, in which the extraction conditions are kept flexible according to the online plant requirements. However, in the oil & gas applications the level of pressure is often fixed and shall remain constant even if the steam turbine can tolerate various operating points. Different options are utilized for achieving controlled extraction such as: (1) Control valves and (2) Sliding disk.

For steam extraction applications it is necessary to install in the extraction pipe a non-return valve (preferably with closing assistance) to prevent the steam from going back to the steam turbine in case of trip. The valve shall be located as close as possible to the machine. The supplier shall specify the maximum dead volume between the non-return valve and the steam turbine.
Extraction lines shall be also equipped with PSVs to relief overpressure that might be caused by sudden closure (malfunction) of the controlled extractions.

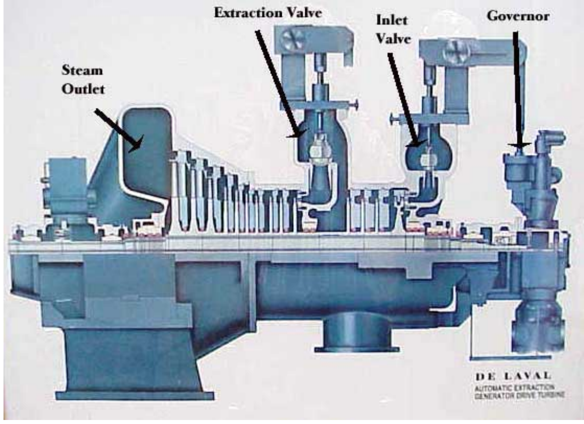

Figure 8: Controlled Extraction Steam Turbine

Specificity of Steam Turbine Design

One of the key design parameters for steam turbines is the management of the thermal expansion (& contraction) of the steam turbine different components during the transient periods of startup (and shutdown). The thermal changes are tremendous, from ambient temperature to above 400°C in a very short time. Thermal expansion phenomenon is unavoidable (see ***Figure 9: Thermal Analysis (FEA) for Steam Turbine Inlet Section***). The difficulty is that each material has its own thermal expansion and stress properties, but the components of the steam turbine, which are made from different materials are physically connected (for typical material of construction of steam turbine components refer to table A-1 of (Cerce & Patel, 2013)). The material will expand in a certain direction from a fixed point. There are 2 fixed points on the steam turbine: (1) on casing; and (2) on the rotor at the thrust bearing. The differential expansion between these reference systems shall be carefully checked to ensure contact-free condition during transient periods such as start-up and shut-down. In subsequent sections of this tutorial the necessity of having a warm-up period managed by dedicated warm-up components is discussed, to minimize the thermal shocks within the steam turbine components.

Rotordynamics of steam turbine are also important to design a robust driving machine that is stable and reliable. For detailed information about the Rotordynamics of steam turbines refer to (Edeney & Lucan , 2000).

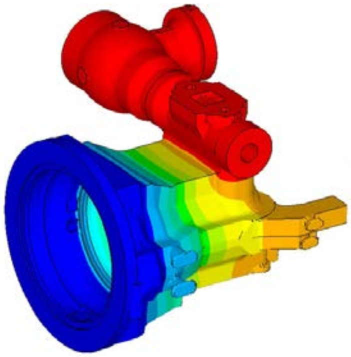

Figure 9: Thermal Analysis (FEA) for Steam Turbine Inlet Section

STEAM TURBINE ARRANGMENTS

Casing Design

The steam turbine casing design depends on the steam volume flow that needs to be handled by the machine, and also depends on the pressure and temperature conditions (especially at the inlet side). In general steam turbine casings are composed of two sections: HP section and the LP section. For the small steam turbines, the casing is made of only one casted piece. However, for larger steam turbines casings might be casted (HP or LP part) or fabricated (LP Part). For steam turbines with very high steam inlet pressure, a double casing design is applied on the HP section in order to limit the stress values on the external bolting. Shown in ***Figure 10: Steam Turbine Exhaust*** is an exhaust casing of a steam turbine.

Figure 10: Steam Turbine Exhaust

Normally in the oil and gas application the upper casing of the steam turbine supports the control & stop valves ***(shown in Figure 11: Steam Turbine Inlet).*** For large volume flow; typically in power generation application (and over 100 [MW] of output power), the control and stop valves are normally installed within separate blocks on the concrete table.

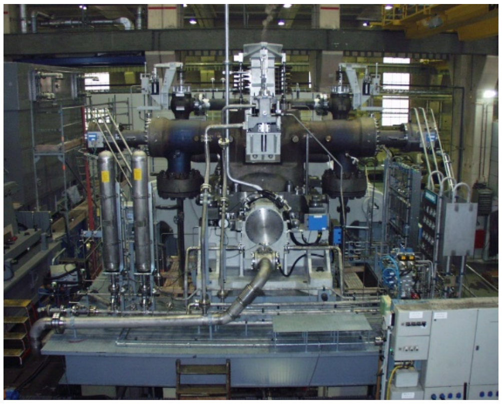

Figure 11: Steam Turbine Inlet System

Internals Arrangements

Steam turbine shafts are composed of various stages, each including two parts: (1) fixed guide vanes supported on the casing, and (2) Rotating blades fastened on the rotor. The first stage is in general designed with higher diameter in order to ensure a large enthalpy drop. ***Figure 12: Steam Turbine Rotor*** shows a typical steam turbine rotor.

The steam needs to be internally sealed between the various stages to minimize losses and maximize efficiency. Sealing components/ elements are located in different locations where steam leakage could be anticipated:

- on the top of blades;
- between the rotor hub and the guide vanes;
- at shaft ends.

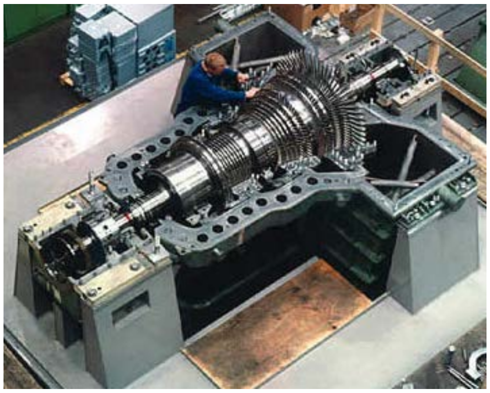

Figure 12: Steam Turbine Rotor

There are various types of sealing elements such as: labyrinth (see ***Figure 13: Labyrinth design (Courtesy: maintenancetechnology.com)*** & ***Figure 14: Labyrinth Seal (Courtesy: Waukesha bearings)***, spring labyrinth, honey comb or abradable seals. The range of clearance for sealing elements ranges in general between 0.1 [mm] to 1 [mm]. Alternatively shaft strips can also be used as sealing elements, however attention shall be paid for strips replacement in case of contact with the shaft.

Figure 13: Labyrinth design (Courtesy: maintenancetechnology.com)

Figure 14: Labyrinth Seal (Courtesy: Waukesha bearings)

The rotor blades might have a straight profile or twisted profile depending on the length of the blade. Twisted profile is applied for longer blades. For the shorter blades elongation when the centrifugal forces are low, shrouds are applied to the tip of the blades to minimize inefficient steam leakage between stages and to improve the aerodynamic performance.

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Figure 15: Twisted Blades – Fir Tree

The root of the blade can be of: bulb type, T-design, finger or fir-tree geometry. Finger type is in general used for the first stage and fir tree geometry for the last two blades. The last blades with high elongation have a special root design. When the turbine is acting as a variable speed machine; while driving compressors or pumps, the last blades are equipped with snubber, lashing wire which improves their tolerance to variable speed (frequency) , as shown in ***Figure 16: Wired Blades***.

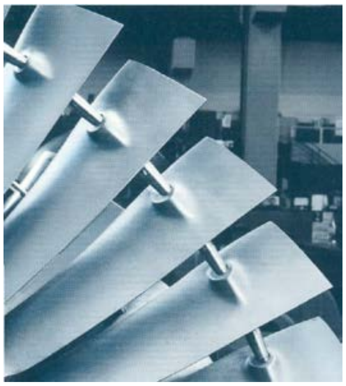

Figure 16: Wired Blades

For power generation application, free standing blades are also applied. Further details on the mechanical design features for the steam turbine rotor can be found in (DiOrio, 2008). Further details on blades design (particularly for LP stage) and their effects on turbine efficiency can be found in (Cosi, 2015).

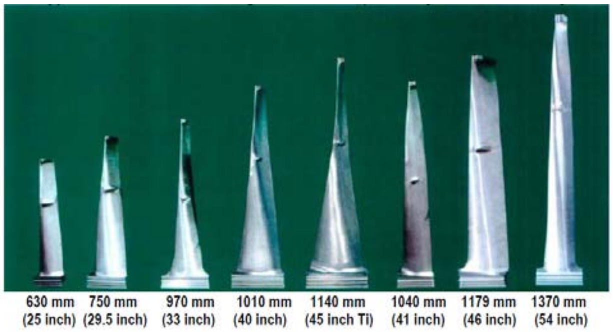

Figure 17: Typical Last Blade Sizes (Courtesy Mitsubishi)

Shaft line Arrangements

Steam turbine shaft arrangements can vary in many different configurations, depending on various requirements such as required speed, plot savings …etc. Shown in ***Figure 18: Shaft Line Arrangements*** are few illustrative examples:

(1) Steam turbine simply coupled to the driven equipment;
(2) Steam turbine coupled to the driven equipment through a gearbox;
(3) Steam turbine split into two casings (HP & LP) which are coupled together through a gearbox and the LP casing is simply coupled to the driven equipment;
(4) One steam turbine simply coupled and driving two driven equipment on the same shaft line.

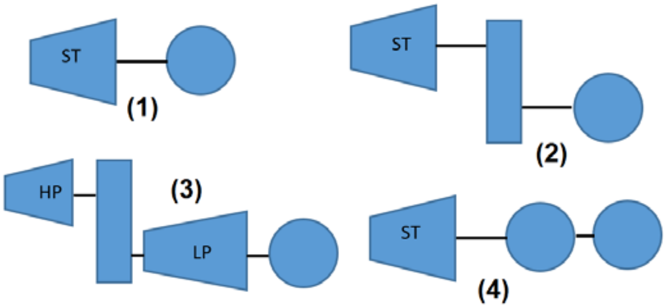

Figure 18: Shaft Line Arrangements

Other arrangements also include tandem and cross compound steam turbine configurations …etc.

Couplings

Couplings for steam turbines shall be designed according to the requirements of (API 671; 4th Ed., 2010). Couplings can be of two types: 1) Diaphragm; or 2) flexible membrane. For some applications, couplings for steam turbines need to remain in place (avoid missile effect) in cases of high over-torque incidents; such as in the case of false synchronization. For installation purpose, couplings are in general installed pre-stretched to adapt with the expansion of the steam turbine after start-up.

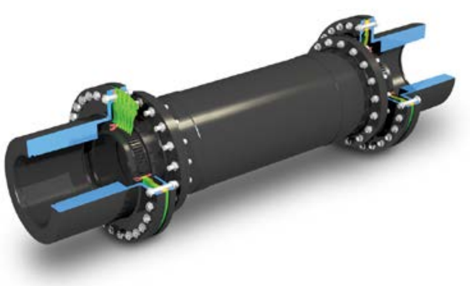

Figure 19: Diaphragm Coupling (Courtesy: Altra - Ameriflex®)

STEAM TURBINE AUXILLIARY SYSTEMS

Vacuum System

The vacuum system is used for condensing type steam turbines only, and is mainly composed of a main condenser and an assistive vacuum generator. The assistive vacuum generator is used for start-up and also during normal operation to mechanically assist in inducing vacuum inside the condenser, while the vacuum is primarily ensured physically by the thermo-fluidic effects of the process of steam condensation and phase change.

Main Condenser

There are two types of main condensers: water cooled condenser and the air cooled condenser. The difference in foot print is quite large and shall be always considered when the selection is made. However, water cooled condenser is often selected when cooling medium (usually cooling water) is available in the plant, to reduce the impacts on footprint and save space in the plot plan. The water cooled condenser should in general be designed as per the HEI (Heat Exchange Institute) code.

For a water cooled condenser, there are two possible arrangements: (1) It can be located below the steam turbine when the turbine is installed on an elevated concrete table; or (2) It can be also in line with the steam turbine exhaust, for this second solution the steam turbine is in general installed on the ground. If the casing fixed point is at the steam suction side, the steam turbine will then push the condenser in operation. Sliding pads shall be provided for the non-fixed condenser supports to cater for thermal expansion.

Figure 20: Steam Condenser (Courtesy: C.A.M.P.I.)

Ejector Vacuum System

Non-condensable fluids (such as ambient air) shall be prevented from entering the steam network. In case of air ingress inside the main condenser, this will adversely affect the efficiency of the main condenser. So, to ensure the proper operation of the main condenser on a continuous basis, ejectors are used to mechanically induce vacuum (by sucking-out the air ingress) inside the main condenser. The ejector vacuum system is also used for inducing the initial vacuum in the condenser that is necessary for start-up; as the vacuum induced by steam condensation could not yet start. In some applications vacuum pumps can be also used instead of the ejectors.

Figure 21: Ejector Vacuum System (Courtesy: Osaka Vacuum Ltd.)

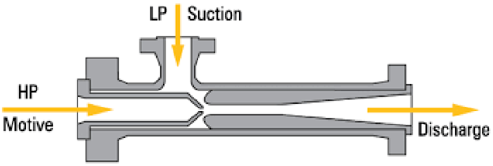

Figure 22: Ejector operation (Courtesy: Transvac)

Vacuum Breakers

Vacuum breakers are used in steam turbine system to assist in reducing the speed of the steam turbine as quickly as possible. Vacuum breakers quickly introduce atmospheric air into the steam turbine through the exhaust which makes it slow down. Vacuum breakers; connected through the condenser, shall be sized for full flow of steam from the steam turbine.

Condensate System

Condensate pumps

Condensate pumps are only required for condensing type steam turbines in which steam exits the steam turbine at vacuum condition and condenses into water in the surface condenser. Condensate pumps are used to circulate the condensed steam (condensate) back to the deaerator tank. For large condensing steam turbine systems, condensate pumps are usually overhung centrifugal type. Although those condensate pumps might not necessarily comply with API 610 requirements, they should be ISO compliant. The condensate pumps are usually designed in 2x 100% configuration in which one pump is operating while the other one is on stand-by mode to ensure the required level of availability of the steam turbine system.
Condensate pumps are designed to operate at a fixed flow rate. It is recommended to have the rated flow condition for the pumps at 120% of the normal operating flow to cater for off case conditions.

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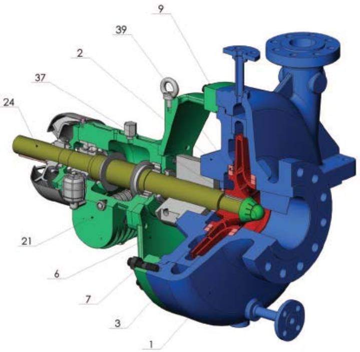

Figure 23: Condensate Pump (OH2) (Courtesy: Finder Pompe)

The major issue that need to be well considered for the condensate pumps is the Net Positive Suction Head (NPSH). The NPSH margin between the available NPSH and the required NPSH shall be maintained to eliminate the risky levels of cavitation (bubbles inception and bubbles collapse in the fluid) in the pump that may adversely affect the impeller's blades deterioration. Because cavitation is more critical for water services and at lower temperature, NPSH margin shall be kept at according to the guidelines mentioned in the Hydraulic Institute 9.6.1.

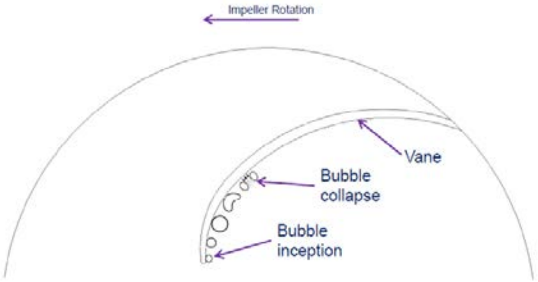

Figure: Cavitation in centrifugal pumps

Condensate pumps are always located below the condenser to ensure the NPSH margin is met. The NPSH available is mediated by the relative location (elevation distance) between the impeller level and the condensate low level in hot well of the condenser (refer ***Figure 24: Minimum Elevation to maintain NPSH Margin***). The relative location of the condensate pump is constrained by the elevation between decks. The condensate level in the hot well of the condenser is affected by the system dynamics, including the steam turbine percentage of full power. While the NPSH required is mandated by the pump design and rotational speed of the impeller (eye).

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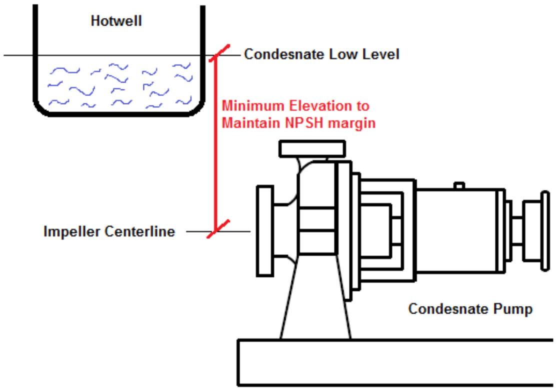


Figure 24: Minimum Elevation to maintain NPSH Margin

The proper selection of impeller material with higher cavitation erosion resistance ensures longer life of the impeller. Hard coating of impellers of condensate pumps might be a technical solution for higher cavitation erosion resistivity. Stainless steel impellers are considered suitable for condensate pumps applications; however, the cavitation erosion resistivity varies with the grade of the stainless steel used.

Parallel operation of condensate pumps shall be avoided because the system curves are designed for one pump operating at a time. Accordingly, the controls shall ensure that if one pump is operating the other shall be stopped and put in stand-by mode. (see ***Figure 25: Pumps Parallel Operation***)

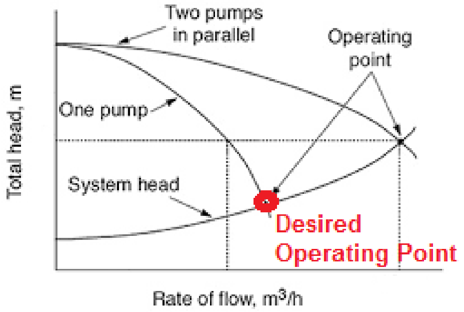


Figure 25: Pumps Parallel Operation

Hotwell level control

As mentioned in the previous section, the NPSH margin for the condensate pumps shall be statically maintained by the relative position of the condensate pump with respect to the condenser, and dynamically maintained by the condensate level in the hot well of the condenser. Once the condensate level in the condenser reaches a critically low level, the condensate pump will start to enter a cavitation level which will damage the impellers, this is why a trip signal is sent to the condensate pump when the low low level condition at the hot well is reached. Also condensate pumps usually have an inhibit-to-start if the condensate level in the hot well is below the low low level. Accordingly, the level in the hot well shall be controlled using flow control valve to maintain the condensate level within two thresholds; low and high. The high level of condensate may also indicate a mal-function in the condensate pump, which triggers the trip of the operating pump and the start of the stand-by pump to reduce the level back to normal (see ***Figure 26: Hotwell Level Control***).

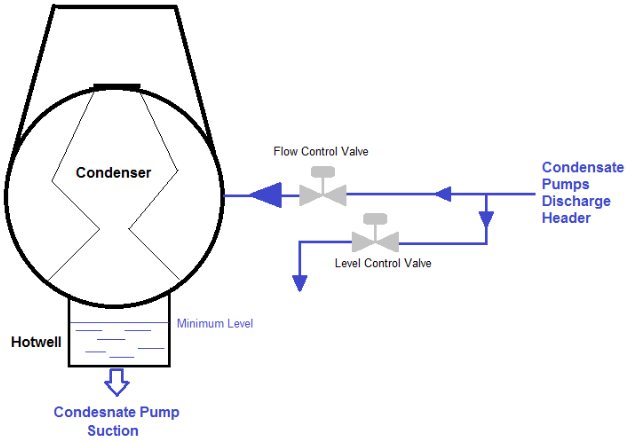


Figure 26: Hotwell Level Control

Oil System

Lubrication & cooling & Control Oil

Large steam turbines are usually equipped with hydrodynamic bearings that need to be lubricated by a pressurized mineral oil system. The lubrication system of the steam turbine can be a common system for both the steam turbine driver and the driven equipment (such as compressors). Lube oil is delivered to the radial bearings at around 1.3-1.5 [barg], and at around 0.5 [barg] to the thrust bearing. The main functions of the pressurized lubricating oil system for steam turbines are to create an oil film between the shaft and the journal bearing so that the shaft can rotate freely with minimum friction drag possible and to dissipate heat from the bearings through circulation of cooled oil. Accordingly, the oil system is composed of an oil tank (with a heater for start-up), oil pumps to provide the necessary level of oil pressure, oil coolers to dissipate the heat from the oil during operation, oil filters to remove erosional debris from the circulating oil, and a pressure control valve to regulate an exact and constant supply oil pressure to the bearings. This is in addition to pressure relief valves to protect the pumps from overpressure (usually rotary type) and an accumulator for ensuring the least pressure disturbance when switching-over between main and stand-by equipment. In addition, a TCV is provided to by-pass the coolers when the oil temperature is low, to ensure correct oil viscosity and efficient lubrication.

Figure 27: Rotor Turning Gear (Courtesy: Voith)

In emergency conditions when the steam turbine (& driven equipment) shaft line is tripped due to loss of AC power which causes the main lube oil pumps to stop (& condensate pumps to stop as well), a rundown tank is made available to provide the necessary lubricating oil for the shaft line to coast down. Run down tank is at a relatively higher position to ensure adequate static oil pressure supply. When DC power is available, a DC operated oil pump is activated to keep oil circulation to the bearings for dissipating the heat away. Barring (slow turning) of the shaft continues; using a turning gear as shown in ***Figure 27: Rotor Turning Gear (Courtesy*: *Voith)***) to ensure that the shaft will not bend under its weight (while the shaft is still very hot) (see ***Figure 28: Shaft Bowing - Courtesy: Istrate Energietechnik GmbH***).

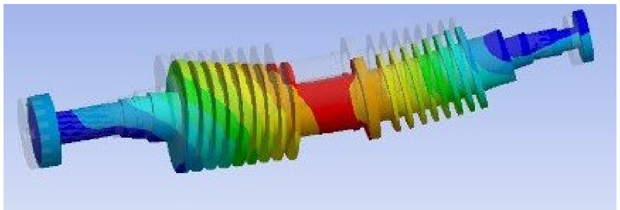


Figure 28: Shaft Bowing - Courtesy: Istrate Energietechnik GmbH

Oil Clarifying

In steam turbine applications, steam can migrate through the shaft to the bearings house which would contaminate the lubricating oil. Steam continuously migrates to the lube oil circuit until the oil reaches a condition with a critical water content. At this condition, oil properties are no longer fit for purpose. Then the oil need to be either clarified or replaced. Depending on the plant location and availability of oil replacement by the operators, an oil clarifier would be decided if necessary or not. For remote and offshore plants an oil clarifier is recommended. Oil Clarifier technology is simple, it is based on the centrifuge separation of oil and water.

Jacking Oil

As mentioned earlier in this tutorial, large steam turbines are usually equipped with hydrodynamic journal bearings in which an oil film separates the shaft surface from the journal bearing surface during normal running conditions. The oil film is created and maintained by the hydrodynamic effect above a certain rotational speed. Below this speed the oil film is not maintained and the shaft can be in friction with the journal bearings which can damage the shaft and the bearings, especially at low speed. Accordingly, at start-up (from zero speed), very high oil pressure (above 100 bar (g)) is supplied between the shaft and the journal bearing to lift the shaft and create a temporary oil separating film. This is done by using high pressure jacking oil pumps, which are usually of rotary type. Once the necessary speed is reached to create the oil film hydro-dynamically, the jacking oil pumps will stop.

Oil Mist Treatment

Oil mist is generated in the bearing house where fine oil droplets get suspended in air due to high speeds and shearing forces acting on the lube oil. If vented to the atmosphere without treatment, oil mist would contaminate the surroundings and also create a safety hazard in case of accumulation of high concentrations of oil mist. Oil mist is sucked from the lube oil tank to the oil mist eliminator where oil is separated from air stream and drained back to the lube oil tank. The technology used for oil mist recovery is usually coalesce cartridge vessel acting as a demister.

Control oil

Control oil is usually provided to the steam turbine system from the same lube oil console. The control oil is used to actuate valves for steam turbine control during start-up and shut-down. The oil pressurized actuation is usually associated with electric solenoids, both acting together as simultaneous opposite actuation forces.

Control Oil is provided to the Stop and Control valves through the same network as the lubricating oil but at a higher pressure (around 8-10 [barg]). Oil accumulators (usually bladder type) are required to provide a constant flow of oil to the stop valves when closing (closure time below 1 [sec]).

Further informative details on lube oil system can be found in (McCloskey, 1995) and (Enz & Hausermann, 1978), although the problems that are referred to in those papers have been eliminated/ improved with time since the papers were written.

Sealing System

The steam turbine rotor is sealed on both sides (drive-end and non-drive-end) by injecting low pressure superheated steam at the steam turbine glands. Figures F.1 and F.2 (in API Standard 612, 7th Edition, 2014) illustrates the line components of the steam turbine gland sealing systems for a condensing and non-condensing steam turbine types respectively. The steam turbine glands include a labyrinth system. (see ***Figure 29: Typical Steam Seal LP Packing Gland - Courtesy: Emerson D352219X012***)

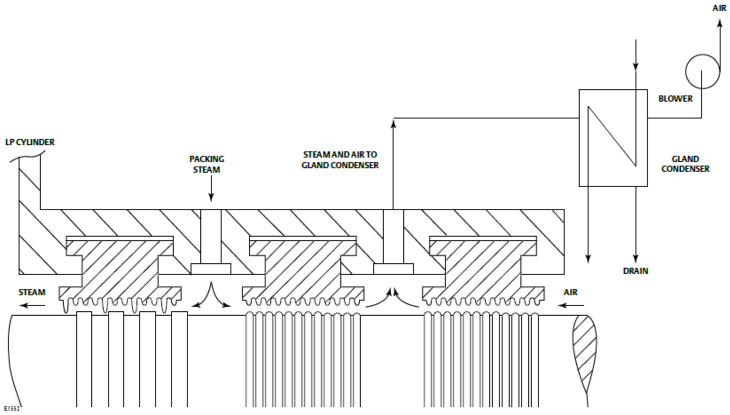
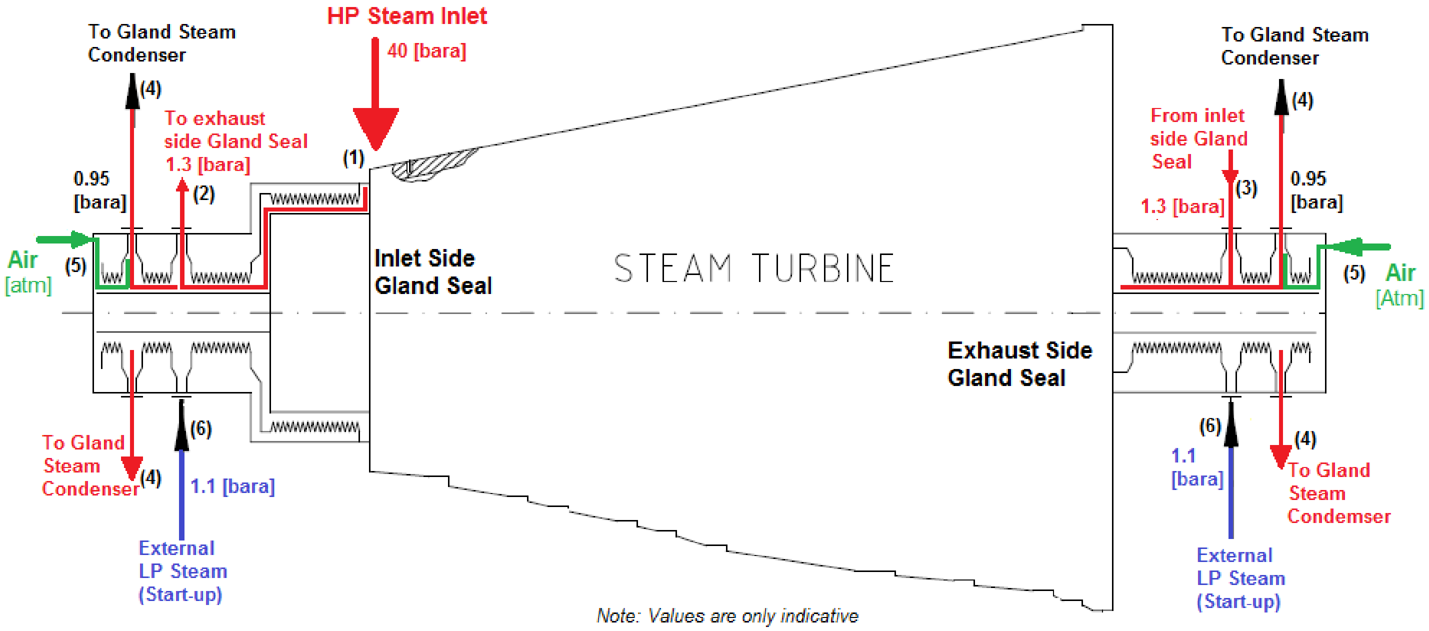


Figure 29: Typical Steam Seal LP Packing Gland - Courtesy: Emerson D352219X012

A typical sealing arrangement for steam turbines is shown in ***Figure 30: Sealing Arrangement for Steam Turbine***. The HP steam at the inlet side (at around 40 [Bara]) migrates (1) outwards through the inward labyrinth and exits the inlet side gland after the 1st intermediate labyrinth (2) at a pressure of around 1.3 [Bara]. Then the sealing steam is routed from the inlet side gland (2) towards the exhaust side gland (3). At the exhaust side labyrinth, the sealing steam (at 1.3 [Bara]) takes two directions, one direction inwards into the steam turbine exhaust through the inward labyrinth, and another direction outwards through the intermediate labyrinth. Then the sealing steam exit the gland steam (4) at around 0.95 [Bara]; to the gland steam condenser, after it gets mixed with atmospheric air which is leaking inside (5) from the outward labyrinth. At the start-up condition when no HP steam is available, external LP steam source (6) at around 1.1 [Bara] is used to seal the steam turbine from the external environment.



Note: Values are only indicative

Figure 30: Sealing Arrangement for Steam Turbine

Cooling System

The steam turbine casing is composed of more than one part/ section; each designed for a specific design pressure and temperature according to the pressure and temperature decrease profile throughout the steam turbine stages. Unlike the inlet casing, the exhaust casing is designed for lower temperatures that shall not be exceeded. Accordingly, the exhaust part of the steam turbine casing is cooled by water sprays when the temperature exceeds a certain threshold, to protect the steam turbine during upset conditions. Excessively high temperature of the steam turbine exhaust casing would mandate a trip of the steam turbine because this would jeopardize the mechanical integrity of the exhaust casing.

Condensate extracted from the steam condenser and pumped using the condensate pumps is also used as cooling medium for the gland steam condenser, inter and after condensers before routing back to the deaerator tank.

Turbine Drainage System

Large steam turbines need to be equipped with casing drain system used mainly for the steam turbine start-up. The casing drain system is composed of multiple drainage valves that are opened during start-up conditions and designed for high temperature. This is to ensure low flow rate of steam circulation inside the steam turbine to warm-up the turbine blades before spinning the steam turbine at a certain pre-defined speed. Those valves are also required to drain out steam condensates that might have accumulated inside the steam turbine when not in operation. The drained condensate is internal to the steam turbine and thus considered to be in a clean condition and thus could be recovered within the condensate/ steam loop; eventually drained to the condenser system via the expansion bottle.

Water Washing System

Deposits of water-soluble salts accumulate with time on the last stage blades of the steam turbine low pressure stage, causing the degradation of the steam turbine performance. In order to recover the rated performance of the steam turbine, the last stage blades are washed to knock-out such deposits. To increase the rate of water within the steam and achieve washing at the last stage blades, the inlet steam is de-superheated by injecting water mist upstream the turbine inlet (***Figure 31: Desuperheater (Courtesy CIRCOR Energy)*** shown mechanical & steam atomizing desuperheater). This is done online and safely at partial load only (reduced speed). The washing period is decided by the operators and the deposits are dissolved within the condensates, which are drained via the last casing drain valves (discussed in previous section). Steam turbine online washing systems are not very well referenced and thus not recommend. But, if an online water washing system selected (for remoteness reasons), the water washing sequence shall be exercised under supplier supervision due to the technical criticality of introducing pure water droplets smashing into the blades which are basically designed for vapor dominant steam only. Further information on steam turbine on-line washing can be found in (Hata, Ikeno, Tasaki, & Walton, 2016))

Figure 31: Desuperheater (Courtesy CIRCOR Energy)

Barring System

The barring system, also known as cranking system, is used to rotate the steam turbine rotor before start-up and after shutdown. This system rotates the shaft at low speed to ensure a homogenous distribution of the temperature during the warm-up period before start-up and to prevent the shaft from bending under its weight in the hot (ductile condition) after shut-down. Shaft bending leads to vibrations at start-up, and to the contact between the stationary and rotating parts.

Speed Control & Protection Systems

Trip Valve and Control Valve

The trip valve; also called Trip & Throttle Valve (shown in ***Figure 32: Trip and Throttle Valve***) in the oil & gas industry, has two main functions:

- Isolate live steam from entering the steam turbine inlet in case of trip to allow a smooth and safe stop of the machine;
- To warm-up the steam turbine; at start-up, by introducing low flow steam (through a hand wheel) entering slowly into the turbine.

During the warm-up period the rotor gets released from the bearing and reaches a low idle speed before the control valve brings the turbine to its nominal speed. Depending on the size of the turbine, one or two stop valves are installed.

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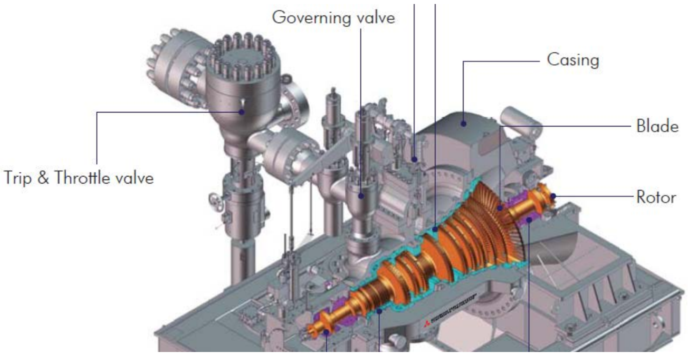

Figure 32: Trip and Throttle Valve (courtesy: Mitsubishi)

The control valves are installed downstream the trip valve and used to control:

- The pressure upstream the turbine;
- The speed of a driven machine (pump or compressor);
- A pressure downstream the driven machine.

In general, three or four control valves are required for each steam turbine which delivers the steam in different arcs upstream the first stage.

Overspeed protection system

When the brake forces are not sufficient to balance the driving forces induced by the inlet steam (and/ or flashing steam), the steam turbine will be in an overspeed condition. In case the steam turbine speed increases out of the allowable operating envelop, the mechanical stresses within the blades (through centrifugal forces) will be subject to catastrophic failures and damages.

There are different overspeed scenarios:

- When driving compressors or pumps, a steam turbine can be considered more protected from overspeed as they act as inertial brakes. However, in case of coupling failure, an overspeed incident may occur;
- When driving a generator, it is a completely different story. As long as the generator is connected to the electrical network, the steam turbine will rotate at a constant speed dictated by the network. When, you lose this connection (breaker open) for any electrical defect, the generator doesn't represent any brake and an overspeed will occur.

An overspeed protection system is always required to close the trip valve and non-return valve in case of unscheduled event. An overspeed is dangerous from a personnel safety perspective and might destroy the complete steam area, as the broken blades might crack the casing causing loss of containment of steam or even fly out of the casing as debris in a bullet style.

Further details on overspeed protection system can be found in (Rutan, 2003) and (Taylor & Smith, 2009).

Machine Monitoring System

Monitoring signals

All mechanical aspects need to be monitored for steam turbines such as radial vibrations at bearing level, axial displacements, pressure at turbine exhaust, steam flow rate, temperature measurements for various parameters (ex: oil temperature, exhaust casing temperature, de-superheating temperature …etc.). Thrust bearing in steam turbines can also be problematic and thus it is necessary to monitor the axial position and thrust bearing temperature. According to (API Standard 612, 7th Edition, 2014), the thrust bearing shall be selected at no more than 50 % of the bearing manufacturer's ultimate load rating. In addition, healthy checks (ex: motor status conditions …etc.) over and above critical safety issues are also monitored such as shaft line speed, gas & fire detection inside enclosure (if provided). All auxiliary systems are also monitored by dedicated instrumentation and transmitters for ensuring proper functioning of the complete package. Some instruments are redundant for which a responsive action is taken based on voting on conformity of reading between the sensors.

Further details on typical monitoring signals can be found in table 2 of (International Association of Engineering Insurers, 2005).

Diagnostics and signs of mal-functions

Steam turbines are considered to be very robust machines compared to gas turbines and electric motors. Excessive vibrations are the main signs of mal-functioning in steam turbine systems. (for further details on steam turbine reliability see (Cary, 1991)).
Reduced condensate level in the hotwell of the condenser is a sign of the condensate pump underperforming.
Other signs of mal-functions exist and are numerous, only the examples above are mentioned for this tutorial.

Further details on steam turbines mechanisms and failures can be found in table 3 of (International Association of Engineering Insurers, 2005).

PRACTICAL ISSUES IN STEAM TURBINE SYSTEMS

Plot Plan Constraints

As discussed in earlier sections steam turbine auxiliaries need to be located relatively to each other to ensure proper overall functioning. For instance, it is recommended that the oil system is located at a lower level relative to the steam turbine to ensure lube oil return to tank by gravity. If the oil system is at the same level with the steam turbine, then the return line shall respect a certain slope (4%). Run down tank shall be located at higher level than the steam turbine to ensure sufficient static oil pressure to the bearings during coast down. Oil mist eliminator need to be located at higher level than the lube oil console to ensure drainage of recovered oil back to the oil tank by gravity. Jacking oil pumps (skid) need to be located as close as possible to the shaft line to avoid safety issues of extended piping network of small bore piping at very high pressure that may have risks of rupture.

On the other hand, the main condenser in oil & gas applications is located below the steam turbine for compactness purpose. And condensate pumps shall be located at a sufficient level below the condenser to maintain the necessary NPSH margin which is critical for the operation of the pumps.

It is recommended to install the gland steam condenser at a lower level relative to the steam turbine; though it is not absolutely mandatory. However, the condensate tank that collects the condensates from the steam gland condenser shall be located under the steam gland condenser to ensure condensate drainage flow by gravity.

Precautions for Offshore Applications

In offshore applications, the modular structures accommodating the steam turbine systems and other balance of plant equipment are very congested and space availability is very scarce. In such consideration, the most complex installation is for a condensing type steam turbine, which requires in addition to all the auxiliaries required for the back-pressure turbine full condensate and vacuum systems. Condensing type steam turbines are very usual for high power applications. However, for low power applications, it is recommended to have a backpressure steam turbine to avoid numerous auxiliaries that are required for the condensing type steam turbine.

In addition to space constraints, site conditions such as wind load and sea motions need to be well adapted in the design. Sea motions are repetitive and returning; every 8 to 15 [seconds], inducing fatigue issues. Sea motions also causes deflections in decks causing relative displacements between fixed points. Accordingly, the design of the steam turbine and all its auxiliaries need to be comprehensive.

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In contrast to onshore applications, sea motions need to be compensated in offshore applications by further increasing the slopes of interconnecting piping. One important example is the return oil line from the steam turbine to the lube oil tank, which needs to be properly sloped so that the oil can return from the steam turbine bearing house to the oil tank under the gravitational force at the maximum roll and pitch conditions. The slope shall be increased to cater for worst sea motion condition for which the package need to be in operation..

Noise Emissions and Mitigations

Large steam turbines are noisy machines with sound pressure levels exceeding long term exposure limits. Accordingly, noise attenuation technologies need to be applied and the area around the steam turbine need to be acoustically restricted without hearing protection. Noise emissions from large steam turbines can be attenuated by adding an acoustic enclosure, however this option adds execution complexity for the package. In addition, a noise enclosure will have an adverse effect on the availability of the steam turbine because of spurious or factual trips generated by high temperature and/or gas detection inside the enclosure. Noise enclosure will also restrict mechanical handling flexibility, so the noise enclosure need to be designed in a way to be partially dismantled (and remain rigidly supported) during heavy mechanical handling such as rotor replacement. It shall be noted that ventilation fans that need to be installed for the enclosure of the steam turbine to dissipate heat by continuous air change-over are also noisy, and the overall noise levels need to be studies before deciding to have the noise enclosure. An alternative to the noise enclosure is to add noise barriers/ walls around the steam turbine (no roof), but this solution is less attractive in offshore projects which use modular design, because the upper deck will be affected by the noise from the steam turbine. Another alternative is to have an acoustically restricted area around the steam turbine; operators/ technicians are not allowed to access this area without hearing/ ear protection. Acoustic blankets on the steam turbine are also another solution, however corrosion issues under the blankets need to be well investigated according to site conditions.

Human factors and Safety Design

Steam turbine systems are characterized by extended area of hot surfaces of various equipment which requires personnel protection. Any surface which is above 60[°C] need to be isolated either by insulation or by a mechanical barrier such as a metallic mesh to avoid operators being in direct contact with the hot surface.

Another important aspect in the design is to avoid threaded connections on high pressure and high temperature steam lines and pressure retaining parts by using flanged connections instead; which would provide better sealing. Threaded connection also need to be avoided for the oil (lube and control) piping which can easily lead to oil fires in case of leakage and contact with the hot turbine surface. In some applications the control oil used is different than the lube oil and can be even more inflammable.

TESTING & INSPECTION

As a general rule in the oil and gas industry, specialists follow the recommendations of (API Standard 611, 5th Edition , 2008) & (API Standard 612, 7th Edition, 2014). The inspection level is Observed or Witness (as per API definition). See also (Bustos & Mossolly, 2015).

On the Steam Turbine Special Purpose - (API Standard 612, 7th Edition, 2014) for example, the main tests are:

a. Hydrostatic test of pressure part;
b. Balancing low or high speed depending on suppliers;
c. 4 hours Mechanical Run Tests;
d. Checks of hydrodynamic bearings after the mechanical run test.

As additional Tests and Inspections, the following can be also requested: Performance Test, Complete Unit Test; Blade static & dynamic vibration tests…

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Figure 33: Steam Turbine Test Control Room - Courtesy: Hitachi

It shall be noted that requesting a performance test or a complete unit test for a steam turbine imply having a boiler (see ***Figure 34: Boiler for Steam Turbine Test, Courtesy: Hitachi***) in Vendor premises, as well as a condensate system which may reduce the number of potential suppliers. Accordingly, the option of performance test is in general not requested.

Figure 34: Boiler for Steam Turbine Test, Courtesy: Hitachi

Further advanced details on testing of novel steam turbines can be found in (Isumi, Mori, & Hata, 2009).

INSTALLATION PRECOMMISSIONING & COMMISSIONING

Installation in offshore & onshore

In offshore applications, steam turbine drivers are mounted on a common skid with the driven equipment. The skid shall be 3-points mount to withstand deflections in decks. The skid support points are either Anti-Vibration Mounting (AVM) or Gimbals. It may happen that the 3-points mounting create heavy punctual load on the structure, mandating that a high structural beam to accommodate such load. Precise shimming preparations need to be done accordingly.

For the 3-points mount installations, the shimming under each point has to be done based on the reference level of the complete skid. This can only be performed onshore before starting to put the complete structural module on sea to ensure that the leveling is not impacted by the sea movement. This level is the reference basis of the skid design. Each manufacturer calculated the skid deformation based on motion and acceleration data to design a structural skid robust enough against the offshore movement and to avoid causing train misalignment. It is important that the skid remain stress free during the installation sequence. ***Figure 35: Example of Skid Deflection Analysis*** shows an FEA.

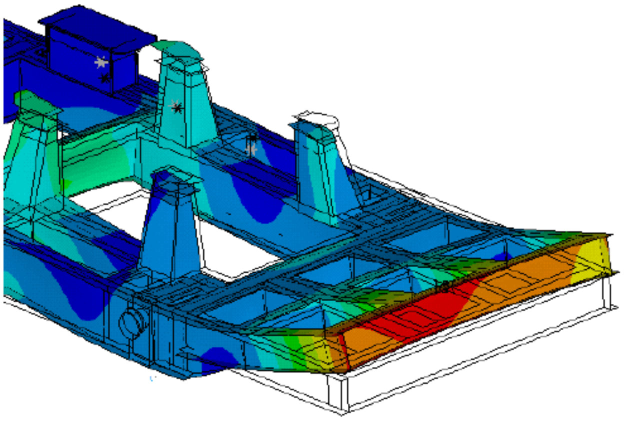

Figure 35: Example of Skid Deflection Analysis

A full welding on each mounting point can be performed (after the skid has been positions and leveled within minimal tolerances) according to supplier's requirements. This weld will be subject to vibration induced by the interference between the structural module and the main skid. It is important that no welding error is applied and that AVMs or gimbals are well in contact with the structural module. Full Non-destructive examination (NDE) will then be applied to control the quality of the weld.

On the other hand, the clearance between the shaft and the turbine labyrinth is approximately within 200 [microns]. After ensuring that the complete skid is stress free, it is important to ensure that the turbine itself is stress free and that the bearings pedestals don't create stress on the casing which might then reduce the clearance between the shaft and the turbine labyrinth. Accordingly, it may be needed to move/shim either the turbine pedestal itself or the thrust bearing depending on the manufacturer design and recommendations. The goal is to ensure that the shaft is well centered into the steam turbine casing. No load shall be addressed to the turbine during this procedure (such as piping loads).

Only after completing the steps mentioned above, auxiliaries can be connected/ tied-in to the turbine.

Onshore, the steam turbine and its driven equipment may be mounted on a common skid (preferred) or on a separate skid equipped with multi-support located at the edges of the baseplate. (API Standard 612, 7th Edition, 2014) & (API 686, 2nd Edition, 2009) provides guidance about installation of such equipment.

Piping Installation Challenges

All piping tie-ins with the steam turbine need to be properly connected in such a way that no stress can be applied on the steam turbine which might affect the complete train alignment and shaft clearance. In addition, all lines have a slope requirement; steam lines shall not convey condensates to the turbine, drain lines cannot have a low point, oil return header shall have a slope to prevent possibility of back flow during the offshore sea motion conditions.

Control System Installation Challenges

The Steam turbine spins and provide power based on the steam flow. If for some reason more steam that the one requested by driven equipment load enter into the turbine, an overspeed can be created. It is very important to ensure that all control and safety system in place react quickly enough to avoid a possibility of overspeed by steam entry. Accordingly, it might be required during the installation and commissioning phases to add additional relays and additional junction boxes, to enhance the responsiveness and effectiveness of the control and safety system. Such late additional changes are very complex in offshore environment where space is scarce.

Pre-commissioning & Commissioning

Pre-commissioning

In the pre-commissioning phase all instrument and electrical auxiliaries are verified for proper operability. A complete loop check on all instrument mounted in the steam turbine package (including auxiliaries) has to be performed. Additional calibration may be needed to confirm the reliability of the instrument. All motors solo runs have to be performed (with pump/fan uncoupled) to verify the cable connection and motor rotation.

As much as possible, all piping networks around the steam turbine and its auxiliaries have to be cleaned. For the oil line, a full oil flushing process has to be performed. Lube oil pump of the oil console can be used to perform such flushing. Filters with fine mesh according to steam turbine manufacturer requirements have to be installed on the return line to capture solid particles oil contaminants in. To perform such oil flushing, steam turbine oil lines are disconnected and bearings are by-passed.

Steam lines also need to be cleaned but with steam blowing. This is to avoid the risk of particles entering into labyrinth seal in operation and also to prevent particle damage to steam turbines.

Figure 36: Steam Blowing

When all lines are clean and ready, it is important to check all the control and functional sequences are operational as designed and simulate that for verification. It is during this phase that we can identify the sequence and control system responsiveness according to the steam turbine requirement. Additional engineering might be required to accelerate the responsiveness of the control system. Additional material can be needed which may delay the pre-commissioning. It is also during this phase that jacking system, barring system, and emergency equipment are run to ensure their operability.

When all this check is performed, a complete reinstatement has to be done, all disconnected line has to be re installed according to piping rule and the steam turbine is ready for commissioning

Commissioning

The commissioning activities of the steam turbine start by the warming-up phase. LP Steam is injected into the steam turbine seal to heat up the steam turbine. Jacking and turning/barring are activated during this phase to ensure a well heat up of the shaft. The time required for this phase is informed by the steam turbine manufacturer. HP steam are kept flowing through the blow-off to heat up the inlet line.
At the same time the condensate system is checked by running the condensate pumps and by running the assistive vacuum ejector system. When vacuum level inside the condenser reaches the rated value and the temperature in the inlet line is confirmed with the right superheating steam, and if the steam turbine has been heated during the required time, then, the control oil system can get pressurized and the TTV can be opened.

Once the steam turbine is in running mode, the first step is to test the emergency system of the steam turbine:

- Test of the emergency push button installed on field: The steam turbine is speed up to the first idle speed, then push button is activated, to witness that the steam turbine is tripped correctly.
- Test of the remote trip button installed in control room: The steam turbine is speed up to the first idle speed, then the operator

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activates the trip to witness that the safety system trips the steam turbine correctly.

- Test of the overspeed system: The steam turbine is speed up to the different idle speed. Waiting time provided by the steam turbine manufacturer shall be followed. If vibrations are still not stabilized at the end of the waiting time, it may be needed to wait additional time or to investigate the root cause before ramping up. If no vibration occurs, then the turbine can ramp up to the minimum operating speed (MOS) using the start-up sequence. Then the operator increases the speed manually up to the trip speed. When trip speed is achieved, it shall be witnessed that the safety system trips the steam turbine correctly with the right response time.

Vibration control shall be performed to ensure a well stabilization after some running time. When vibration is stabilized within an acceptable range, then the steam turbine is considered ready for start-up. During the test runs of the steam turbine, it is possible to test additional auxiliaries such as some redundancy of equipment, or by varying some control parameters.

Further details on steam turbine testing can be found in (Whalen & Leader, 2003).

Permissive to Start and Causes of Trips

Steam turbine shall only be started when the pre-requisite conditions are met. Those conditions are summarized as follows:

a. Oil system is already started with lube oil circulating through the bearings (at the correct oil viscosity temperature) and control oil is pressurizing the control actuators;
b. Steam sealing system (gland steam) is in operation;
c. Stream turbine condensates are drained and turbine blades are warmed up by opening the turbine drain valves;
d. Main start-up ejector for the vacuum system is operating;
e. All electronic controls are reset and enabled (ex: speed governor and overspeed protection);
f. All critical systems check-ups are performed (ex: Trip and Throttle Valves solenoids are operating normally);

Steam turbines are tripped once certain upset conditions are detected, such as:

a. The major trip triggering incident is the overspeed condition;
b. Excessive temperature at the exhaust turbine casing also generates a trip signal;
c. Excessive vibration detected at the bearings level is a cause of trip;
d. Critically low lube and/or control oil pressure triggers steam turbine shut-down;
e. High pressure at steam turbine outlet.

Start-up & Load Sequence

Steam turbine shall be started gradually step-wise and not immediately from zero speed to full speed. There are two different start-up sequences for cold start-up and hot start-up (see Figure 37: Start-up sequence for Steam Turbine).
In general, the following steps are performed during steam turbine start-up:

1. Initial ramp to warm-up speed (the speed value depends on whether it is a cold or warm start-up);
2. When the warm-up duration is completed, another ramp-up is done up to the minimum allowable operating speed of the shaft line; (ramping quickly throughout the 1st critical speed of the shaft line)
3. During the steps 1 & 2 mentioned above, the driven equipment is adapted to the speed conditions through various actions (for example anti-surge valves for compressors are kept fully open overriding the anti-surge controller);
4. After reaching the minimum operating speed, the load is gradually added to the steam turbine (by the driven equipment required torque) and the shaft line ramps-up to the operating set point (controlled by the governor), by gradually increasing the steam flow rate through the Trip and Throttle valve;

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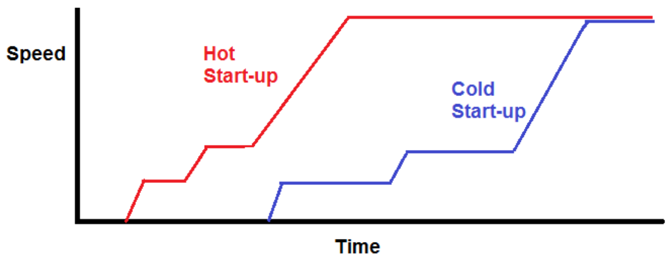

Figure 37: Start-up sequence for Steam Turbine

Shut Down Sequence

Shut down of steam turbine is either a normal shut down or an emergency shut down. Also the shutdown sequence and activation of shut down auxiliaries are affected by the cause of the shut-down (ex: loss of AC power). The control oil system is used to partially control the shut-down of the steam turbine by de-pressurizing the control oil circuit. Also the Trip and Throttle valve is de-energized to close the steam flow to the turbine for achieving the ramp-down. The ramp-down duration should be usually less than 3 minutes depending on the shaft line inertia (mainly the inertia of the driven equipment) and also depending on the various amortization forces such as gas compressibility for compressors, and frictional forces in oil film and sealing elements.

To prepare the steam turbine for a quick restart, the hot steam turbine shaft line is kept rotating at a slow roll speed for a certain duration of time to avoid the shaft line bending under its static weight at the hot condition. Once the cool down period is elapsed the steam turbine speed coasts down to zero. In case the trip was caused by AC power loss, a DC oil pump ensures that oil is circulated to the bearings during the slow roll period.

Periodic Testing

Periodic testing of steam turbine auxiliaries shall be done for critical equipment that need to be available and ready, especially for emergency situations, such as the solenoids of the Trip and Throttle valve. This is to ensure that the Trip and Throttle Valve; which is a safety critical element in cases of turbine overspeed event, is available to immediately stop the steam turbine when needed. The testing is done on the redundant system. Periodic testing shall also be done for other safety critical elements such as the DC cooling oil pump.

CONCLUSIONS

This tutorial provided an overview from a Contractor perspective about large steam turbine systems and their associated auxiliaries. The tutorial is intended to be an introductory presentation of knowledge on steam turbine systems. It is thought that this tutorial would help junior engineers understand steam turbine systems, their range of application, and how they are installed. This tutorial also supports experienced engineers to refresh their memory on the topic. The tutorial presented very useful insights that are important to tackle during the detailed engineering phase of projects and also during the preparation of specifications for steam turbine drivers according to the project context and in line with the project requirements and constraints.

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NOMENCLATURE

H_1 = Enthalpy of inlet steam condition (KJ/kg)
H_2 = Enthalpy of outlet steam condition (KJ/kg)
H_{2is} = Isentropic enthalpy of exhaust steam condition (KJ/kg)

API = American Petroleum Institute
AVM = Anti-Vibration Mounts
CGC = Cracked Gas Compressor
HEI = Heat Exchange Institute
FEA = Finite Element Analysis
HP = High Pressure
HSE = Health, Safety & Environment
ISO = The International Organization for Standardization

LNG = Liquefied Natural Gas
LP = Low Pressure
MOS = Minimum Operating Speed
NDE = Non-destructive Examination
PSV = Pressure Safety Valve
TCV = Thermal Control Valve
TTV = Trip & Throttle Valve

FIGURES

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