STEAM TURBINES

High Efficienct Steam Turbines

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***Abstract*— This paper presents characteristics of steam turbines along with the factor involved in the steam turbine efficiency. The paper will also cover the technologies being introduced in recent years to maximum the efficiency and minimize the losses in a steam turbine. Moreover, this paper will also cover up the application of steam turbine engines.**

Keywords—Steam turbine, HP,LP, efficiency, blades, Active Clearance Control, enthalpy, performance, nozzles; 3 Dimensional.

I. INTRODUCTION

A rotary heat engine that converts thermal energy which is contained in the steam from mechanical energy to electrical energy. A steam turbine is made of a boiler (steam generator), rotating turbine, feed pump, condenser, and a variety of other auxiliary devices. The elementary operation of the steam turbine is very similar to of a gas turbine except for it being operational because of fluid that is water and steam instead of air and gas in the case of a gas turbine.

Steam turbines are one of the most established, most adaptable and the oldest prime mover innovative technological advancement that remaining with everything taken into account use. They drive innumerable machines and deliver control in numerous plants around the world. Steam turbines have been being used for over 120 years, when they supplanted responding steam motors as a result of their higher efficiencies and lower costs. The limit of a steam turbine can extend from 20 kilowatts to a few hundred megawatts (MW) for huge drivers. Steam turbines are found universally and are used to turn generators and produce electricity or create propulsion for ships, airplanes, missiles, etc. Steam turbines convert heat energy in the form of vaporized water into motion using pressure on spinning blades. This is likewise to how hydropower turbines with the exception of that steam moves significantly quicker and the blades are altogether different from the device. Engineers have improved every millimeter of the steam turbines and it is one of the most difficult thing to design and build. There are only a few places in the world which make large steam turbines.

Steam turbines are shared used with many other sources of energy such as:

- Nuclear
- Coal
- Fossil Fuels/Natural Gas
- Geothermal

II. HISTORY OF STEAM TURBINE TECHNOLOGY EARLY PRECURSORS

In a world driven by combustion engines, fanjet engines, nuclear reactors, etc., the steam engine seems like a relic of the past. Without this game changer steam engine invention, the modern world would have been a completely different place to live in. The steam engine eased key developments in the fields of mining, manufacturing, agriculture and transportation.

Figure 1 Double Acting Steam Turbine invented by James Watt.

The first device that can be classified as a reaction steam turbine is the aeolipile proposed by Hero of Alexandria, during the 1st century CE. In this device, steam was supplied through a hollow rotating shaft to a hollow rotating sphere. It then emerged through two opposing curved tubes, just as water issues from a rotating lawn sprinkler. The device was little more than a toy, since no useful work was produced.

Another steam-driven machine, described in 1629 in Italy, was designed in such a way that a jet of steam impinged on blades extending from a wheel and caused it to rotate by the impulse principle. Starting with a 1784 patent by James Watt, the developer of the steam engine, a number of reaction and impulse turbines were proposed, all adaptations of similar devices that operated with water. None were successful except for the units built by William Avery of the United States after 1837. In one such Avery turbine two hollow arms, about 75 centimeters long, were attached at right angles to a hollow shaft through which steam was supplied.

Nozzles at the outer end of the arms allowed the steam to escape in a tangential direction, thus producing the reaction to turn the wheel. About 50 of these turbines were built for sawmills, cotton gins, and woodworking shops, and at least one was tried on a locomotive. While the efficiencies matched those of contemporary steam engines, high noise levels, difficult speed regulation, and frequent need for repairs led to their abandonment.[1]

III. NEW HIGH EFFICIENCY STEAM TURBINES PROPERTIES

New technology, high efficient and reliable steam turbine design has been completed, Figure 2 shows the application point of the recent technologies being introduced in steam turbine. These technologies were examined and its testing were done on actual loads. In order to get a brief understanding of all the above content these expressions and properties of high efficient turbine are used in impulse blades, reaction blades, LP end blades, seal technology, leaf seals and Active Clearance Control (ACC).

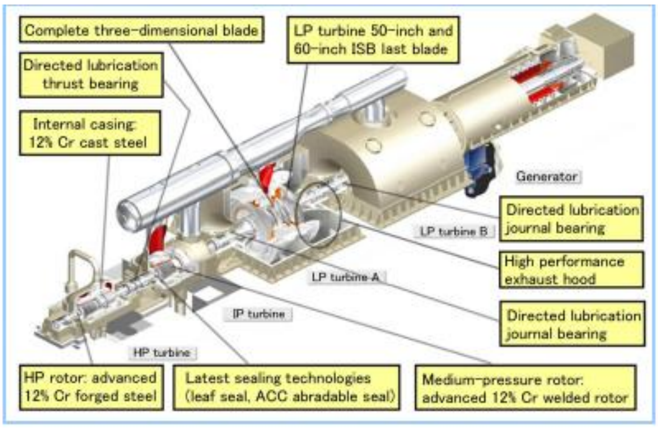

Figure 2 Schematic view of 1000MW tandem compound steam turbine[2]

A. *Complete 3 dimensional blades*

The design of blade and every stage flow pattern of the following tandem compound steam turbine was made in order to maximize its efficiency and output in consideration of all fluid forces which affects the end-wall contour.

B. *New high performance impulse blades*

Based on the knowledge of unsteady flow in stationary blades, a new profile was developed to reduce unsteady losses through optimum design. The new design (called high performance diaphragm structure) is designed with conventional nozzle being separated into profile sections and support columns. The strength of the diaphragm is reinforced by support columns along with the width of stationary blades can be reduced to increase the aspect ratio. A complete 3D blade technique can also be used to support columns and profile of stationary blades.

C. *High Performance Reaction Blades*

A dimensional multi stage flow was used in order to improve the accuracy of the prediction of internal turbine flow. In this regard Mitsubishi Heavy Industry ltd (MHI) have developed an unsteady flow analysis method which is capable of predicting losses produced in the machine. The degree of reaction and 3 dimensional stacking of profile are optimized so that the secondary flow vortexes are controlled and the vortex zone are shifted towards the outside and inside of the end wall of each blade, as a result it reduces the secondary flow in the rotating blades.

Hence new high performance reaction blades have been manufactured through latest analysis techniques along with using new detailed verification of the internal flows.

D. *High Performance LP end Blades*

LP blades largely influences the performance of the turbine. MHI introduced a 36 inch blades which have been developed with multi stage viscous flow analysis to produce high performance LP end blades. This unsteady flow analysis can also be used to evaluate the behavior of the wakes of stationary blades.

With the advancement in technology exciting forces at the blade are predicted with greater accuracy and we can able to improve the vibrational strength of the blades. Now a days it is also possible to predict all the trajectories precisely using the flow analysis, so that positioning of the slit can be optimized in order to reduce the losses caused by drain peculiar to the LP end blades.

[1] https://www.britannica.com/technology/turbine/History-of-steam-turbine-technology
[2] https://www.mhps.com/jp/randd/technical-review/pdf/index_15e.pdf

E. Low Pressure

The shape and position of the water discharge slit are optimized in between the two stages where wet steam unique to steam turbine is generated. This is done by prediction of the discharge of the water droplets which is generated by the wet steam. An unsteady analysis of flow field from the outlet of 50-inch-long blades to the condenser and diffuser in combination of 3D blade rows take place taking into account the properties of non-equilibrium. This was done in order to improve 3 dimensional asymmetrical diffusers which has greater pressure recovery coefficient.

F. Sealing Technlogy

One of the most important performance factor is the loss and leakage loss at the shaft seal. A new sealing technology named Active Clearance Control (ACC) is introduced which allow to minimize rated operation by using low-heat generation sealing material. This is made with superior sliding characteristics sprayed onto internal surface of seal ring as shown in Figure 3. The ACC seal is structures in segments of labyrinth seal rings which are made in order to move in radial direction. During the operation of a turbine these segments are raised by a spring force to keep the clearance between the seal and the rotor. Moreover, when the turbine load is increase, these seal segments are shifted until the proper clearance is maintained. Construction of ACC shown in Figure 3.

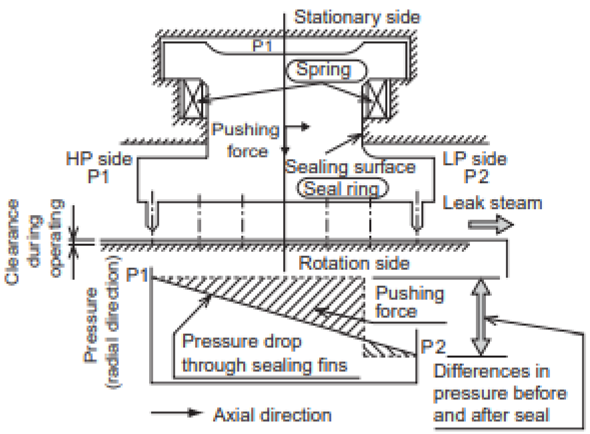

Figure 3 Construction of ACC

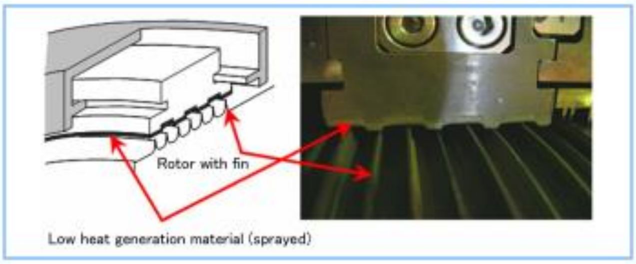

Figure 4 Abradable Active Clearance Control

In new type of steam turbine, T point, four stages of the ACC are installed in line at HP dummy ring. By doing this it reduces the wear of the seal fins which are caused due to the deformation of casing during stopping and starting of the turbine.

On the other hand, a leaf seal arranged in a circumferential direction (Shown in Figure 3), becomes non-contact with the rotor only in operation. It can also be used for sealing points where the pressure difference is larger than the threshold value of brush seal.

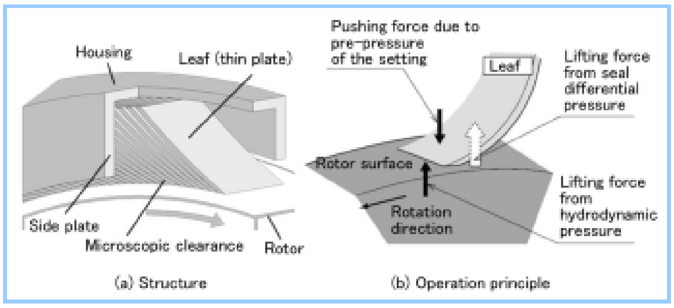

Figure 5 Leaf Seal

G. Directed Lubrication Bearing

A direct lubrication process using PEEK (Polyether-Ether Ketone) which reduce bearing losses. PEEK plastic and carbon fiber is used for bearing sliding parts in order to obtain high surface pressure resistance. The lubrication is supplied using direct injection nozzle (Shown in Figure 4) which results in lower oil temperature, makes a significant impact on bearing losses.

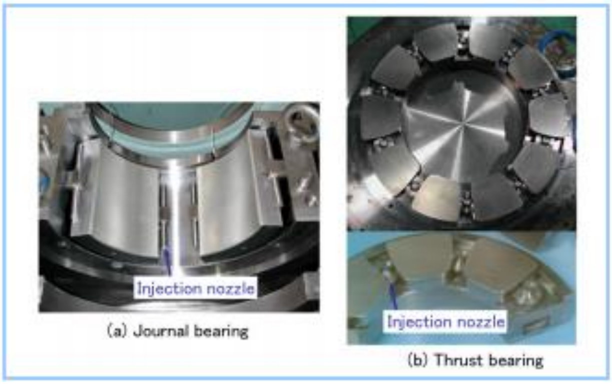

Figure 6 Direct Lubrication

H. Advanced 12% Chromium steel welded rotor

There are many advantages of using Chromium as a rotor, as it has the ability to operate up to 1130ºF (610ºC) because of their higher strength. With such great ability these rotors are a bit expensive and there are fewer suppliers offering higher alloyed forgings to develop it. Though such a welded rotor has been used for more than 20 actual machines and they are verified for its reliability.

IV. EFFICIENCY CALCULATION OF STEAM TURBINES

The calculation of the efficiency of steam turbines is done by using difference in enthalpies of steam crossing the HP body. The efficiency of the HP body is defined as follow:

$$\eta_{HP} = \frac{D_{HRHP}}{D_{HP}} * 100 \qquad (1)$$

Real Enthalpy difference is HP body is given by:

$$D_{HRHP} = H_{vap} - H_{erh}\left(\frac{kcal}{kg}\right) \qquad (2)$$

Where H_{vap} is the enthalpy of steam at admission turbine.
H_{erh} is the enthalpy of steam to overheat HP exit.

The difference in the isotropy enthalpy is given by:

$$D_{HIHP} = H_{vap} - H_{ith} \qquad (3)$$

Where H_{ith} is the final enthalpy calculated after the exit of from the HP turbine.

In additional the external factor which provoke losses mainly by rubbing of mechanical landings, wear and tear between the machine blades. This the efficiency of the turbine is given by:

$$R_t = R_{th} * R_{vol} * R_{mech} \qquad (4)$$

Where R_{vol} is the volumetric efficiency and given by:

$$R_{vol} = 1 - g/G \qquad (5)$$

Where g is the debit of flight and G is the debit of weight.

V. APPLICATION OF NEW EFFICIENT STEAM TURBINES AND ITS APPLICABILITY

Steam turbines are used to run at wide ranges of speed to so that they have better efficiency. The very first commercial use of a steam turbine was in the shape of steam engines and not after long locomotives were introduced. Steam nowadays is used in many stationary applications. A steam turbine consists of a fixed nozzle that is present in the stator of the turbine, all of the high pressured steam is fed into that steam turbine using this stator as a pathway to get to the turbine rotor i.e. that rotating part. This steam than crosses many machine axis along with some moving blades. The task is to expand the steam and for that we make sure that the blades and all the turbine cavities are large enough to allow this expansion. The steam goes in at high pressure, but once it crosses the stator its speed increases while the pressure decreases. This is due to the blades, which acts as nozzles and helps in expanding the steam and as the steam enters the stators, due to its high speed it provides some of its kinetic energy to the moving blades.

Locomotives is a part of a rail transport system. A locomotive provides what is known as a motive power for a train. These self-moving vehicle is very common for passenger trains. At beginning they were supposed to pull a train from the front but advancements in technology has made them versatile and they can know be attached at the back, front or both ends as well.
Electricity Generation is one of the major application of steam turbines. We can generate electricity through these turbines by burning either coal, gas, biomass or heat from nuclear fission. They are nearly 40% efficient in producing electricity all the rest of the heat goes to waste. With time we have come up with better solutions to use this wasted heat by using it for district heating which is called cogeneration. We many steam power plants in parts of countries where there is desalinization. Since the plants efficiency depends on the temperatures of input and output steam, we can increase the efficiency by using higher pressured steam with a certainly high temperature. This might increase the cost but on long term it can serve as a very useful plant.

Ships: Some ships still use steam turbines, mainly military vessels and nuclear submarines. The Cross Compound Double Reduction Turbine is a steam turbine that is a popular choice for marine applications. As ships are supposed to be compact and efficient with an easy mobile system to control, steam turbines provide us with a great possible option. It takes up less space in the engine room. How this works is that we pass steam at high pressure and temperature to the turbine and as this expands through the blades it turns out to be at low pressure. From there we pass it on to another set of turbine blades which then will pass this steam to the condenser for it to condense. These two different high pressure and low pressure turbines are separated; they have their own shafts to operate at the propeller shaft speed. There end speed is about 100 RPM which is due to the double reduction gearbox. This high pressure turbine provides us with great control over the movement of the ship, the several rows of blades that are present can also be used by the ship when arriving or leaving a port. It can also be used in emergencies to act as an emergency stop to avoid collisions.

VI. Conclusion

In the paper, I have completed a survey of the technologies being introduce in order to get maximum efficiency in a steam turbine. Mitsubishi Heavy Industry Ltd. (MHI) for example have developed new high efficient steam turbine with latest advanced technologies. The new technologies discussed in the paper can be applied to a wide range of turbines ranging from small, medium and large scale turbines. Hence these technologies can also be applied to the existing units. This allow companies to reduce their operating cost of their generation.

VII. References

[1] A Research paper on Design and Analysis of Shaftless Steam Turbine Bhavin Bhanushali1, Prince Vishwakarma available at (https://www.irjet.net/archives/V4/i5/IRJET-V4I5355.pdf)

[2] Latest Technologies and Future Prospects for a New Steam Turbine Mitsubishi Heavy Insdustry Technical Review Vol. 52 No. 2 (June 2015)

[3] Development of New High Efficiency Steam Turbine, EIICHIRO WATANABE YOSHINORI TANAKA, available at (https://mhi.co.jp/technology/review/pdf/e404/e404212.pdf)

[4] Efficiency Assessment of Condensing Steam Turbine, available at (http://www.wseas.us/e-library/conferences/2013/Brasov/STAED/STAED-32.pdf)