

Manufacturing of turbines (gas, steam, hydro and wind)

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Lecture 21

Welcome to this course on manufacturing of turbines. So, in this lesson 21 of this course, we will see the material selection challenges for hydro turbine. So, the outline of this lesson will be as follows. So, first we will cover the classification of hydro turbines, what are different types of hydro turbines and their operation. We will also go through importance of material selection for hydro turbine efficiency, longevity and reliability. We will cover critical factors such as mechanical properties, corrosion resistance, erosion resistance and economic considerations.

And we shall also focus on the challenges which are there in operation of hydro turbine namely cavitation, erosion and fatigue impacts which ultimately influence the performance of hydro turbine. So, if we see the classification of hydro turbines, so broadly the hydro turbines they are classified based on the action in which they convert the kinetic energy of water into mechanical energy. So, based on this the turbines are broadly classified in two categories such as, impulse turbine and reaction turbine. So, in the impulse turbine, the velocity of the water jet and the kinetic energy in this water jet is converted into the mechanical energy as this water jet impacts on the buckets of the turbine.

Example of impulse turbine include Pelton wheel. Whereas, in a reaction turbine, it is the pressure energy as well as the kinetic energy of the water which is converted into the mechanical energy and these both energies they change as the water flows through the turbine. Examples include Francis and Kaplan turbine which are very popular reaction based turbine. However, there are other turbines also mentioned in the impulse category which also include the cross flow turbine or the Banki turbine. In reaction turbine, other than Francis and Kaplan we have the propeller, tubular, bulb and rim type of turbine.

So, here we can see the impulse action as well as the reaction action as the turbines are functioning. So, as we have discussed in case of the impulse turbine here, it is the kinetic energy of this water jet which is getting converted as this water jet interacts with the bucket. So, these are basically the buckets of the turbine wheel. And the kinetic energy of this incoming water jet basically allows the conversion of energy once the impact takes place with the bucket and rotation of this turbine is then observed. Similar action is also observed

in cross flow turbine which is also one another type of impulse turbine.

In reaction turbine, as we have seen these popular types include Francis, bulb, straflo as well as the tube. So, here both the pressure energy as well as the kinetic energy of the flowing water is converted into the mechanical energy. So, all these turbines are basically utilized in any hydropower plant which is used to generate electricity. So, selection of the turbine is dependent on several parameters such as what is the water head available, what is the flow rate of the water. what is the capacity of the hydropower turbine and so on and so forth.

So, the basic structure of any hydropower plant, it looks similar, wherein we have a dam. So, this dam is created using reinforced concrete structures. Basically, behind the dam, we have a storage reservoir in which the water is stored. So, now it is desired that the storage reservoir should always be filled at an optimum water level. And, for this generally the construction of dams is done in areas where we have a perennial supply of water.

So, the slice gates in the dam they control the flow of water to the turbine through the penstock. So, penstock is basically a tube through which the water flows from the dam or the reservoir to the turbine. So, here is basically the turbine installed and this turbine can be based on what is the water head and what is the flow available of the water. So, this turbine is then connected to a generator and as the turbine rotates it rotates this generator to generate electricity which is then transmitted using power transmission cable. So, generally a transformer may also be utilized in between to basically control the voltage to step up or step down depending on the requirement.

And once the water exits from the turbine, it is allowed to flow in the downstream outlet. So, now here because this water is getting stored over a long period of time so there is often deposition of silt in observed in hydropower turbine and of course during the rainy season the silt concentration may increase to a very high level, which may also cause several challenges while operation of the turbine that we will see as we go forward in these slides. So, now for hydro turbines which are used in hydroelectric plants which convert energy of flowing water or falling water into mechanical energy, there are some other important parts of the hydro turbine. So, these other important parts of the hydro turbine they include the runner. So, this is the rotating part of the turbine where, the water flow causes the blade to spin and they generate mechanical energy.

Second, is the blades so these are attached to the runner and these are often designed to capture the energy from the flowing water and design of the blade it depends what is the type of the turbine. So, for example in various turbines so we have we can have different type of blades example in Pelton turbine we have the buckets while we have an aerodynamic shaped blades in case of Kaplan, which is an axial flow turbine and Francis which is also another type of a reaction turbine. So, then we have the casing which is the outer shell which houses the runner and guides the flow of water over the runner. This helps to direct water to

the blades effectively. Then fourth component is the guide vanes and these vanes they direct the water flow onto the blades at a correct angle optimizing the efficiency of the turbine.

So, often these guide vanes are movable and they can be you know the angle of the guide vanes can be changed depending on the flow condition of the water, rate of flow of water and a requirement of the energy generation. So, then fifth part of the hydro turbine includes spindle or we call it shaft. So, this is basically the central axis which connects the runner to the generator and other machinery. So, it transfers the rotational energy from the runner to the generator. And in some turbines, especially in case of the impulse turbine, we may use a nozzle.

So, this nozzle often directs the water jets by converting the pressure energy of the water into kinetic energy, which hits the blade and because of the impulse action, the rotational of the blades is observed. So, then we have the draft tube which is often located at the exit of the turbine and this helps to convert the kinetic energy of the water leaving the turbine into pressure energy by increasing efficiency. Turbine systems also utilize governing systems. So, these governing systems essentially regulate the speed of turbine and power output by adjusting the flow of water and the position of guide vanes or nozzle. Then, we have the bearings which support the moving parts of the turbine such as spindle, shaft and allow a smooth rotation with minimal friction.

Then, we also have the hub which is the central part of the runner where blades are attached and it is crucial component for distributing the mechanical load evenly in the turbine. So, if we look at the mechanical properties of the materials which are used to make the hydro turbine so there are significant points to note here because the turbines discussed previously such as gas turbine and the steam turbine they operate on a working fluid which is having density of the order of 1 kilogram per meter cube. But, this density in case of hydro turbine is approximately 1000 kilogram per meter cube. So, there is almost a 1000 times increase in the efficiency of the working fluid. Other than this, because of increased density of the working fluid, there are several dynamic forces which are also acting while the turbine is operating.

Because water is 1000 times heavier compared to air or maybe hot gases or maybe steam. So, because of these considerations, the material selection is much different than what it was in the earlier cases. Second, important consideration in hydro turbines is all these critical components that we have discussed. the components such as, blades, guide vanes, runner etc., they are constantly submerged underwater.

So, there is a very high probability of aqueous corrosion taking place on these components. So, material selection for these components has to also take into consideration how to minimize the aqueous corrosion because corrosion is one of the significant operating challenge in hydro turbine parts. So, we start with the mechanical properties where, first we discuss the strength and toughness. So, because the density of the working fluid here is almost 1000 times more than the density which is used of the working fluid in gas turbine. So, components in the hydro turbine must withstand high mechanical loads without failure.

So, challenges include balancing high strength and sufficient toughness to prevent brittle fractures and also it should ensure resistance to dynamic stresses and operational wear and tear. So, in this regard materials such as 13% chromium, 4% nickel martensitic grade stainless steels are used which have a yield strength of approximately 800 MPa and these are very suitable for high stress components like runner blades. Other than that sometimes nickel based alloys having yield strength of the order of 1030 MPa with excellent fatigue creep may also be used. But more popularly we have the martensitic grade stainless steels which are used in case of the hydro turbines. The fatigue resistance is another important criteria in which the components must endure prolonged operational cycles at varying loads.

So challenges include mitigation of crack initiation and propagation under cyclic loading, addressing stress concentration and operational vibrations. In this regard also, austenitic stainless steels like 316L with fatigue resistance and combined corrosion resistance are popular materials. So, here we can see how corrosion affects a hydro turbine where we can see the corroded parts on the runner and the blades of the hydro turbine. So, corrosion is another important challenge in case of hydro turbine. There are different types of corrosion which can take place and corrosion as we know is a surface induced phenomenon.

So, there can be uniform corrosion which is even and predictable and corrosion of this type occurs on the surface of the turbine components. Second type of corrosion is the localized corrosion which includes pitting, crevice corrosion, stress corrosion cracking and often results in concentrated damage. Third type of corrosion is basically a synergic action between erosion and corrosion and it occurs on combined action of corrosive media and mechanical wear which accelerates material loss. The components which are widely impacted because of corrosion in hydro turbine they include turbine blades, so here corrosion can lead to weakening and reduced efficiency. Blades exposed to aggressive water chemistry are particularly vulnerable.

Casing and draft tubes are another components where corrosion can damage the components leading to structural failures and leakage. Bearing and shaft assemblies, so here corrosion can impair the mechanical function and lead to increased friction and wear in the hydro turbine components. So, the mechanism of corrosion, it involves certain chemical reactions such as oxidation and electrochemical corrosion. So, oxidation basically involves reaction of turbine materials with oxygen in water leading to formation of rust. While the electrochemical corrosion involves interaction of materials with electrolyte that is water resulting in metal dissolution and degradation.

Corrosion factors are dependent on water quality. So, generally it is observed with high salt levels or minerals. So, acidic and alkaline conditions may accelerate corrosion. Temperature, especially in case of elevated temperature, they also can increase the rate of chemical reaction thereby increasing the rate of corrosion. and flow conditions of the flowing water also influence the corrosion rate.

So, in this regard turbulent flow and cavitation may exaggerate the corrosion by increasing the mechanical wear and introducing corrosive particles. So, on the right hand side we can see how corrosion erosion are affecting the various surfaces of the hydro turbine component which compromise with the efficiency of such systems. So, now to mitigate corrosion, there may be certain strategies. So, in this regard, examples of corrosion damage on the turbine blades which can cause surface pitting and erosion can lead to reduced efficiency and potential blade failure. And another potential region of corrosion in hydro turbine systems is the draft tubes and casing.

Corrosion damage can cause leaks and structural weakness. So, mitigation strategies include material selection. So in this regard, corrosion resistant materials are widely utilized to manufacture the turbine components. These include stainless steels, nickel based alloys, which can reduce the susceptibility to corrosion. Protective coatings, so these are applied to resist corrosion and erosion and can protect turbine component from aggressive environments.

Water treatment may be another strategy implemented to control the chemistry of water and minimizing corrosive effects. Fourth strategy, can be design improvements where designing the components may reduce areas where corrosive agents may accumulate ensuring adequate drainage. So material selection where we have just discussed the utilization of stainless steels, in this steels with minimum chromium concentration of 12 percent are desired in hydro turbine components. Because presence of chromium leads to formation of a passive oxide layer on the surface which prevents any form of corrosion while the hydro turbine is under operation. So, if we can summarize the corrosion challenge in the hydro turbine.

So, the process includes the mechanism of electrochemical degradation of metals when in contact with water and oxygen leading to rust and material loss. Effects include structural weakening, surface pitting and component failure. And it is very much required and desired that components must resist corrosion in fresh water, salt water or brackish water conditions. Challenges involve preventing pitting and crevice corrosion in aggressive environments, ensuring long-term stability of protective oxides. Materials such as austenitic stainless steels 316L is having superior corrosion resistance because of high chromium and nickel content.

Similarly, duplex stainless steels having combination of austenitic and ferritic structures, they also are excellent in resisting to stress corrosion cracking. Next very important challenge in hydro turbines includes the cavitation damage. So, cavitation damage is a localized damage in hydro turbine caused on the turbine blades when exposed to high velocity flow. In turbine blades this cavitation damage often manifests as pitting and erosion on blades and can be seen on different types of turbines such as Francis and Kaplan. Casing and draft tubes of the turbines are also exposed to cavitation damage and this can lead to material loss and structural issues.

So, examples include Francis turbine blades where cavitation damage can penetrate the blades reducing their efficiency and structural integrity. Concrete spillways also are subjected to cavitation damage and large scale cavitation damage like that on Hoover Stamps spillway shown here in the figure highlights extensive impact damage that can be have on the infrastructure because of cavitation. Mechanism of cavitation involves bubble collapse mechanism in which collapsing of cavitation bubbles generates intense shock waves and high speed jets leading to localized stress and material erosion. So, micro jets may also be there which involve a bubble collapsing near the solid surface and it can produce a high speed jet of fluid that impacts the surface creating a localized damage. Second mechanism involves shock waves which are generated subsequent to collapse of remnant bubbles cloud generating additional shock waves that further contribute to damage.

Flow effects in hydro turbines where bubbles may be distorted or broken by shear forces and turbulence before collapse influencing extent of pattern of damage. So, cavitation and mitigation strategies involve the blade damage where the turbine blades are particularly vulnerable to cavitation. and repeated collapsing cavitation bubbles can take place because of fatigue failure and erosion. In Kaplan turbines, the turbine blades are adjusted which are susceptible to cavitation erosion when operating under varying flow conditions. Component damage, so cavitation can also affect other turbine components such as draft tube casing leading to decline in performance and potential operational issues.

So, mitigation strategies here also involve proper material selection. So, use of advanced materials with higher cavitation erosion resistance such as hardened alloys composites may improve durability. Certain types of surface coatings may also be applied to deflect the effects of cavitation and can help to reduce damage. Design optimization enhancing the turbine design to minimize cavitation prone zones. Optimizing flow conditions may also reduce the likelihood of cavitation.

Flow management of water, properly managing the flow of water through the turbine can also avoid conditions which promote cavitation. So in summary, the cavitation has the mechanism of forming and collapsing of vapor bubbles in low pressure regions caused by localized high impact forces and surface pitting. So insufficient hydraulic pressure heads are one of the reason for this. Effects of cavitation are visible in form of surface pitting, material degradation, noise and vibration. The components are required to withstand cavitation erosion due to bubble implosion in high velocity water flow.

Challenges involve protecting against surface pitting and material degradation, ensuring smooth hydrodynamic profiles. So in this regard, duplex stainless steels with yield strength of the order of 550 MPa will have excellent corrosion resistance and coatings based out of cobalt such as stellite may also be applied on the hydro turbine components. And these coatings are applied using various means like laser cladding or weld overlay deposition have exhibited superior resistance to cavitation and wear. here we can see how the next challenge in hydro turbines affects the performance which is erosion. So, erosion we can see is

basically a direct contact with the abrasive particles which are entrained in the water and upon impact of these hard abrasive particles on this turbine blade surfaces material is gradually removed and we can see how the erosion is removing the material from the blade thereby disturbing the blade profile and reducing the efficiency of the turbine.

So, erosion is basically caused by several reasons in which the primary and most popular reason is the abrasive erosion. This is caused by impact of solid particles. These are abrasive particles of grain, gravel or other debris suspended in water. So, this type of erosion is prevalent in turbines operating in environments with high sediment loads. Impactive erosion results because of high velocity impact of water on turbine surfaces leading to material removal and surface wear.

Sediment erosion specifically removes erosion caused by sediment particles carried by water. These particles can cause significant wear in turbine components especially in areas with high sediment content. Turbine components such as turbine blades, casing and draft tubes, bearing and shaft assemblies are significantly affected by erosion. Mechanisms of erosion involve particle impact where sediment particles suspended in the water may strike on the surface of the turbine blade at high velocity causing material removal and surface degradation. So, this impact is particularly severe when sediment is hard or abrasive.

High velocity water flow can also cause erosion because water at high speeds may erode surfaces and cavitation effect of course because of collapsing bubbles can contribute to additional material loss compounding the effects of erosion because of sediment and high velocity flow. So, in turbine blades, all these regions such as turbine blades, draft tubes, casing and bearings and shaft can be significantly affected by erosion. And mitigation strategies for erosion involve proper material selection which are utilization of erosion resistant materials such as hard alloys composites, protective coatings, Which can withstand abrasive and sediment induced erosion, flow management such as to reduce the turbulence which can reduce the erosion effects. Implementing sediment control measures can also reduce the sediment entering into the turbine and thereby reducing erosion. Regular maintenance and routine to routine inspection and repair can further prevent damage and ensure optimal performance.

In this regard, the mechanisms involve mechanical wear by abrasive particles in the water impacting and removing material from the surface. This causes surface roughening, material loss, reduced efficiency and we need to have erosion resistance from abrasive silt particles in water particularly in silt laden rivers. Mitigating material removal from the mechanical components and ensuring long-term durability are the challenges for the hydro turbine with respect to erosion and certain materials Utilizing high velocity oxy fuel flame coatings of cermets like tungsten carbide cobalt with high hardness and erosion resistance can be utilized and sometimes utilization of nickel Aluminium oxide coatings are known for high hardness and toughness and are also suitable for high erosion environments. So, economic considerations of the turbine, they involve trade-off between cost and performance to achieve optimal performance while adhering to the budget constraints. So, the challenges in

this regard involve balancing initial material cost with long-term maintenance and operational expenses, ensuring cost effectiveness without compromising quality, Example approach involves utilizing cost-effective base materials with advanced protective coatings.

So, in many cases it is seen the carbon steels may be subjected to certain surface treatments, may be an economical choice with appropriate coatings to enhance performance and lifespan of hydro turbine components. Another important economic consideration is availability and fabrication of the material. So, whatever material is selected to manufacture the hydro turbine, it should be easily available and the ease of fabrication should be there for large scale production. So we can select materials which are readily available and can be easily manufactured which involve machining, welding or other processes. Material quality and consistency may also be desired across batches.

Examples again involve carbon steels which are widely available and cost effective for non-critical components whereas utilization of stainless steels can be done for more expensive components with superior properties such as enhanced corrosion resistance for critical parts. So, with this we come to the end of this lesson. We will now summarize what all topics have been covered. So, we have covered the hydro turbine operation. We have also covered classification of hydro turbine then we have covered various challenges in hydro turbine and we have looked at the mechanism of these challenges.

How they can be mitigated so primarily we have looked at the challenges such as cavitation erosion and corrosion. So, in the next lecture we will see the manufacturing processes for hydro turbine starting with the casting process utilizing sand casting and investment casting to start manufacturing the hydro turbines. Thank you.