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

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Lecture 25

Welcome to this course on manufacturing of turbines. So, in this lesson 25 of this course, we will see coatings for hydro turbines. So, the outline of this lesson will cover corrosion resistant coatings, erosion resistant coatings. Then we will see the introduction to thermal spray methods for depositing such coating, principle of thermal spray coating. then, plasma spraying, high velocity oxy fuel flame, oxy fuel spraying, high velocity air fuel spraying, comparing various thermal spray methods, cavitation resistance coating, quality control, inspection of hydro turbine coatings. and we will conclude the lesson with futuristic direction with novel coatings which can be used on hydro turbines.

So, before we go into details of the coating we will also understand why the coatings are needed on hydro turbines. So, as we know the hydro turbines are basically the turbines which generate electricity from flowing water. But this water is always flowing from the mountains and in this case there is always some silt deposited or is also being flowing in the water. So, presence of the silt particles in the water, basically these particles are very hard particles, generally made up of silicon oxide or other hard abrasive particles.

So, when this hard particle they come in contact with the surfaces of the hydro turbine, they cause material removal by removing small amounts of material and this process is known as erosion. So, to prevent the erosion in the hydro turbine components, hard material coatings are applied on the surfaces of the various components like runner and blades of the hydro turbine so as to extend their service life and thereby minimizing any damage from the erosion. So, in this regard, particularly in some seasons like whenever there is rainy season etc., the amount of silt in the rivers it increases because of which sometimes the hydropower plant may need to also shut down. This causes lot of economic loss.

Therefore, presence of this coating is very vital for efficient functioning of the hydroturbine. Coatings are not only applied for erosion but may also be applied for giving the corrosion resistance but largely as we know because of the material selection the corrosion is already there. The corrosion resistance is already there in the material

which is selected to manufacture the hydro turbine which is the stainless steel or duplex stainless steel. So, with this background, we will see the details of coatings used in hydro turbine. Coating in hydro turbine, they are very essential to mitigate the effects of degradation from corrosion, erosion and cavitation.

So, proper selection of the coating is much needed to enhance the lifespan and efficiency of the turbine components. So, corrosion resistant coating, the purpose is to mainly protect the turbine components from corrosive element in water bodies. So, water is never available in pure form, so as we have discussed there may be certain abrasive particles entrained with the water and water may itself contain several salts, minerals as well as other contaminants. So, presence of these components in the water they enhance the corrosion rate because of which the functioning elements or the functioning components in the hydro turbine may corrode. So, to mitigate the effect of corrosion we may apply certain coatings for example use of epoxy coatings which are known to have excellent adhesion as well as chemical resistance and mechanical properties.

Sometimes the epoxy coatings may be modified with certain additives to improve the flexibility and impact resistance. Second type of coatings which are used to mitigate effects of corrosion include polyurethane coatings which are highly flexible as well as are ultraviolet resistant and as well as abrasion resistant. These may be suitable for exterior surfaces which are generally exposed to atmospheric conditions. So, the application process of such corrosion resistance coating it follows these steps in which the first step involves surface preparation. Surface preparation is very important because in coatings generally there is mechanical interlocking between the coating material and the surface of the component.

So, in this regard surface preparation involves grit blasting to achieve a clean surface with a specified surface roughness value. In the second step, the removal of the dust or debris is conducted using compressed air or vacuum systems. Then the next step is primer application. So, epoxy primers may be applied which provide a robust bonding layer. So, these are applied using airless spray systems to achieve a uniform thickness.

The third step involves application of top coat. So, application techniques such as airless, spring or roller application to achieve the desired dry film thickness of 200 to 400 micron is done. So, after this spraying of the material epoxy material, so then curing of the epoxy material is conducted which is generally done in ambient condition or sometimes we may use external heat sources or ultraviolet light to accelerate the curing of this epoxy because it is a thermoset and creation of the thermoset leads to development of cross link bonds which are done by applying heat. So, the next and the most important type of coatings which are applied in hydro turbine involve erosion resistant coatings. So, erosion resistant coatings they protect the hydro turbine components against abrasive wear which is caused by suspended abrasive particles in the water.

These are very essential to extend the life of critical components of turbine such as runners and guide vanes. So, typical properties and different types of coatings which are used to impart erosion resistance they involve ceramic coatings. So, ceramics as we know are very hard materials. So, ceramic coatings composed of alumina and zirconia which offer extreme hardness of the order of 2000 HV. Other type of coatings involve Cermet coatings where tungsten carbide waste coatings are used which are also known to provide high hardness as well as adequate toughness, Which are usually applied using high velocity oxy fuel spraying and they may also render hardness of the surface of the order of 1500 HV with excellent bond strength more than 70 MPa.

So, application of erosion resistant coatings largely uses thermal spray methods before which the surface preparation is important on the substrate or the hydro turbine component. So, in the surface preparation, the pretreatment step involves utilization of ultrasonic cleaning to remove the contaminants, which is followed by grit blasting. Preheating may also be done on certain components to 100 to 200 degree centigrade to avoid a situation of thermal shock because the methods which are used to deposit these coatings are thermal spray based methods. And if there is the thermal shock, presence of thermal shock which may lead to generation of residual stresses which may be manifested in the form of residual cracks or micro cracks on the deposited layer. The second step is itself the thermal spraying or the step in which through which the coatings are manufactured or deposited on the components of the hydro turbine.

So, in this regard high velocity oxy fuel flame spraying or HVOF utilizes high velocity gas streams which are generated by combustion of a fuel gas or a fuel with oxygen. So, this combustion basically generates a gas stream, a high velocity gas stream into which the powder particles are propelled onto the substrate to form a dense tightly bonded coating. So, in this regard the thermal spray methods are basically a surface engineering process used to apply materials onto a substrate in molten or semi-molten state utilizing a stream of accelerated particles which upon impact on the base material develop the coating. So, the relevance of such coatings is there not only to provide erosion resistance but they may also be used to provide corrosion resistance, thermal resistance to components for critical durability and efficiency of hydro turbines. So, here we can see a photograph where the thermal spraying is being carried out on the turbine components and we can see the deposited layer is getting built up on the components of the hydro turbine here.

So, the principle of thermal spray coating involve material feeding. So, coating material in form of powder, wire or rod is fed into the heat source where it is melted or it is semi molten. The particle acceleration is the second step where the molten or semi molten particles are then accelerated towards the substrate using gas stream. The deposition upon impact with the substrate leads to particle flattening, cooling and solidifying to form laminar structure that builds up to form the coating in a layer by layer fashion. So, we can

see the schematic, the spray material which will be of course the combination of ceramic or maybe some metal to develop the cermet coatings.

So, generally with say example tungsten carbide, cobalt is a popular metal because of its high toughness. So, then this spray material is melted when or it reaches the semi molten state once it comes in contact with the high velocity hot gases which are generated in the thermal spray process. The high velocity of the gases imparts momentum to the powder particles as well as adds heat, thereby leading to rise in temperature and generation of molten or semi-molten particles. So, the acceleration is because of the momentum transfer from the high speed gases, hot gases. And because of this momentum, the powder particles, they impact the substrate.

Each powder particle upon coming in contact with the substrate immediately flattens and cools down to develop the splat like structure on the substrate and, the deposition of the splats on the surface of the components is observed to have a brick wall like a structure which was also previously discussed in detail in the development of thermal barrier coatings for gas turbine components. so, the working principle of the various techniques which are used in the context of developing the erosion resistant coatings in hydro turbine. So, in this regard we will see the plasma spraying process which is one of the popular thermal spraying process. So, the plasma spraying process the plasma jet is generated, a working gas such as argon or hydrogen mixture it is passed through a powerful electric arc discharge formed between the gap between the cathode and anode. So, the energy is which is generated in this arc is rapidly used to heat up the gas mixture converting it to a high temperature plasma with temperatures of the order of 14,000 Kelvin.

Rapid expansion of the hot gases occurs lifting the speed of the jet giving it to a very high speed of the order of 800 meter per second. Coating material in form of fine powder with the range of say 20 to 90 mm is then injected in the plasma jet. The molten droplets are formed which are propelled at high speed towards the coated object. So, we can see here the powder image, SEM image here. So, powder particles may be available in different size range few micron to nanometers.

And this distance between the plasma jet and the substrate also known as the standoff distance, it also plays a crucial role in deciding the properties of the deposited layer. Sometimes in the plasma spraying the plasma spraying equipment may also be cooled using water. So, this water going in and water coming out is basically used for cooling the gun, because of the high temperature generated because of the plasma jet. So, various materials which are used in plasma spraying they involve ceramics which include alumina zirconia. Thermal barrier coatings may also be utilized utilizing such materials for high temperature components.

Metal alloys such as Inconel or the MRC-ALY coatings may also be used for corrosion and oxidation resistance and sometimes we may also utilize composite coatings like cermets which give combined benefits of metal and ceramic. So, these are best suited to Francis and Kaplan turbines which benefit from the thermal barrier and corrosion resistant coatings. The next process in the thermal spray is the high-velocity oxy-fuel spraying. So, in this regard, during the HBF process, a fuel gas, typically hydrogen or kerosene, is burnt with oxygen in a combustion chamber. This causes a flame to start burning, ejecting hot and quickly moving molten material onto the surface of the component being coated.

Enhanced mechanical coating with thick layers of firmly adhering particles is produced combining because of the high particle velocity and extreme heat. So, here the difference between the HVF and plasma is that, in case of plasma the heat was generated because of the plasma and between the cathode and anode. But, in case of HBOF the heat generation is because of combustion of the fuel which is a gas like kerosene etc. or like a liquid fuel like kerosene or propane and it is burnt with oxygen in a combustion chamber. The deposition characteristics will vary that we will see in the comparison of various thermal spray coating methods.

So with respect to high velocity oxy fuel springs method the coating materials of tungsten carbide and cobalt are popular which generate wear resistant coatings for turbine blades and other high wear areas other type of materials which involve, chromium carbide nickel chromium coatings they are also popular which are known to have corrosion and wear resistant properties. Sometimes nickel based alloys may also be deposited as they are well known for corrosion resistant coatings. By varying the deposition material or the coating material, the parameters of the HVF process or be it any thermal spray process need to be optimized for effectively depositing the coating with appropriate properties. And HVF spraying is very suitable for the Pelton turbine, Francis or Kaplan turbine given their complex geometries and high wear ranges. So, here we can see a photograph where HVF spraying spray coating is being utilized on a Pelton wheel turbine to impart wear resistance.

So, the third type of thermal spray method which is used to deposit the coatings or the erosion resistant coatings involve high velocity air fuel spraying. So, the working principle of HVAF is similar to HVOF. The only difference in this case is the process utilizes air instead of oxygen. This results in relatively lower flame temperatures and HVF technology is also known to utilize propane as the fuel gas which is mixed with compressed air. So, like HVF, the HVAF or the high velocity air fuel spraying, it basically mixes, it differs by including a heat baffle to further stabilize the thermal spray mechanisms.

The material is injected into the air fuel stream and coating the particles which are

propelled towards the component HVAF it offers faster coating at lower spray temperature while increasing the corrosion and wear resistance. So, in case of HVAF the various materials which are used in coating involve nickel based alloys which are known for their corrosion resistance for turbine component, cobalt based alloys for high temperature corrosion resistant coatings, tungsten carbide which is superior to wear resistance for high wear components. Advantage areas involved effectively being used on Pelton and Francis turbine which require high quality coating with minimal thermal impact. So, on the right hand side we can see the utilization of high velocity air fuel spraying method being done on a turbine shaft. Then, next is the comparison of the properties of the coating.

Here, we can see the micro hardness comparison of the various coating done on certain substrates and we can see by adding the coating we have increased the micro hardness of the coating layer. For example, by adding the tungsten carbide the micro hardness is increased to in the range of 1100 to 1200 HV and this was conducted on plasma nitrided 13% chromium 4% nickel steel which had an average micro hardness between 700 to 900 HV. And while comparing it with the plasma nitrided 12% chromium steel, which had a micro hardness value of 1000 to 1200 HV. And we can see this is significantly less in case of uncoated steel, 12% chromium steel, which has micro hardness around 300 HV. So, now we can see the comparison between the various thermal coating method comparison. So, we are comparing here the plasma spraying with high velocity air fuel and high velocity oxy fuel spraying method.

So, all these are basically the coating method. So, this means the bonding between the coating material and the substrate is mechanical based bonding, which is dependent on the interlocking between the splats and the surface of the substrate. In case of plasma spraying which has the maximum temperature of the order of 6600 to 19000 degree Celsius given the presence of plasma and in case of HVAF the temperature is around 3000 degree Celsius and minimum temperature of around 2000 degree Celsius was observed in HVAF process. Particle velocity was highest in case of HVAF which is around 1000 meter per second and at the second level we can see the high velocity oxy fuel has velocity up to 600 to 900 meter per second. And the lowest velocity among all was with the plasma spraying maxing out at 800 meter per second the spray rate or the deposition rate so high deposition rate was observed in HVAF process which is 160 kg per hour.

And coating thickness range so with the HVAF we can get the maximum coating thickness in one go that is from 50 to 1300 microns and coating in all cases they result in excellent wear and corrosion resistance. The next type of coatings which are used in the hydro turbines they involve cavitation resistance coating. So, as we know certain components in hydro turbine may be subjected to cavitation which is basically the damage caused by the imploding or exploding bubbles which are of the water which are

generated once the pressure drops below the atmospheric pressure. So, water converts into vapor and these bubbles upon coming in contact with the surface of the hydro turbine component they burst causing pitting and material loss, particularly in high velocity region like trail of the blades. So, coatings with elastomeric coatings, which are polyurethane coatings, they offer high elasticity, more than 300% elongation at break, are quite resilient to absorb the cavitation energy.

And metallic coatings utilizing nickel and cobalt-based alloys deposited via plasma spraying may be suitable to provide a hard surface with good cavitation erosion resistance. So, application process also involves here precision machining for tight tolerance and proper fit of the component. Surface activation may be done with chemical treatment to enhance the coating adhesion. So, coating again can be developed using the conventional thermal spraying like plasma spraying which involves ionizing gas or a plasma jet which melts and accelerates the coating particles. Or sometimes layering techniques may be developed with multiple passes to achieve the final thickness between 300 to 800 micron which ensures optimal protection of the hydro turbine parts.

Next aspect in terms of coatings comes in quality control and inspection. So, the coatings once deposited they also need to be checked for quality control and what are the properties of the coating certain defects like visual defects can be detected with visual inspection on the coating thickness and certain tests may be conducted like adhesion test some non-destructive testing techniques such as utilization of ultrasonic testing x-ray eddy current may be utilized to get more details about defects in the thickness or the section of the coatings. And parameters, process parameters like spray distance, angle, particle velocity, substrate temperature etc. may need to be documented properly for proper inspection and corrective actions. So, next topic is basically the futuristic coatings which may be utilized in hydro turbines.

So, these involve hydrophobic coatings in which the material, nanostructured materials and fluoropolymers may be used. So, these coatings are developed to have contact angles greater than 150 degree Celsius, thereby significantly reducing drag and cavitation. So, this will lead to increased efficiency with reduced hydrodynamic drag and improved resistance to water ingress. Second type of coatings which are utilized are anti-fouling coatings because sometimes the biological species present in the water may develop a layer on the components of the hydro turbine. So, biocide releasing polymers, silicone based materials and foul releasing coatings may be utilized.

These result in lower surface energy. They prevent biological growth and cell cleaning abilities. They also help in reducing maintenance and biofouling, thereby prolonging operation between the cleaning cycles. So, with this we come to the end of this lesson on hydro turbine coatings. So, we will summarize what all topics are covered. So, we have understood the importance of coating in hydro turbines.

Then, we have looked at various thermal spray methods which are utilized to coat in this particularly we have looked at plasma spraying then we have looked at high velocity oxy fuel spraying we have looked at high velocity air fuel spraying. Then, we have looked at comparison of the thermal spray methods what are the properties of the coatings, the resulting coatings. And lastly, we have looked at some futuristic directions in coating for hydro turbines. So, with this we have completed the manufacturing of the hydro turbine. And in the next, we will start with the manufacturing process for wind turbine where we will discuss the material selection for wind turbine. Thank you.