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

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Lecture 07

Welcome to this course in manufacturing for turbines. So in this lesson 7 of this course, we will see material selection, precision and metrology in turbines. So the outline of this lesson will be as follows. We will start material selection, precision and metrology in turbines. We will discuss key factors in turbine material selection. We will discuss the mechanical properties of the turbine material - manufacturing and fabrication considerations. We will look at precision and metrology in turbine manufacturing. We will look at key metrology techniques for turbine parts. We will look at calibration and uncertainty management in turbine metrology.

And we will conclude the lesson with looking at the emerging trends and future outlook in this aspect. As we know this course is about manufacturing of turbines in which we will be studying in detail the manufacturing of gas turbine, steam turbine, hydro turbine and wind turbine. So, turbines as we now understand are crucial components not only in power generation sector but also are very important in aircraft propulsion and industrial processes. Selecting the right material for such turbine is very crucial to ensure the efficiency, reliability and safety of the turbines. So, the key factors in turbine material selection, so these key factors include temperature resistance in which the turbines especially the gas turbines and the steam turbines as we know they are operating in the temperature range of gas turbine for example, it is operating In temperature range of 1300 degree centigrade, approximately 1300 degree centigrade, steam turbines, they are operating in say temperature range up to between 600 degree centigrade to 700 degree centigrade.

Because we have understood in gas turbines the hot gases which are produced after combusting say natural gas are produced and in steam turbines the working fluid which is used is the superheated or ultra superheated steam. So, temperature resistance of the materials which are used to make this turbine are very important because at such high temperatures like 1300 degree centigrade or maybe 1600 degree centigrade. So, there are several challenges for the material to overcome. So, these challenges are like creep which is nothing but deformation of material under constant load and elevated temperature.

Then fatigue of materials is very important because turbine blades or turbines are dynamic components means we have rotational components.

And fatigue is basically the failure of such materials and the cyclic loading. Then oxidation because turbines like gas turbine they are operating in ambient conditions and at high temperature we know several materials they have tendency to form oxides and oxidation becomes a big problem in this temperature range. So, the material whatever are selected for making such turbines they should have temperature resistance means their strength, their oxidation resistance, their hardness, their properties to resist creep or fatigue must not degrade with elevating temperatures. Second factor in selecting the turbine material include strength and durability. So, what we mean by this is strength means the turbine materials must be able to withstand the high stresses which are generated because of high speed rotation.

For example, the gas turbine as we have discussed the rotational speed of gas turbine is of the order of 15000 to 25000 rpm means rounds per minute. So, at this level of speed very high stresses are generated. There are dynamic loads because loads are constantly varying and the turbine materials they also should ensure their structural integrity. So, it is not that it should operate only once rather for a turbines are designed to operate over a period of say 10 to 15 years. So, the structural integrity should be intact so that there is durability and reliability while the turbine is operating.

Next important criteria for material selection in turbines is the corrosion resistance. So, this is especially important with hydro turbines. hydro turbines as we now know are basically turbines which utilize flowing water as the working fluid and then this flowing water is basically the kinetic energy of the flowing water is converted into work done and this work done is converted into electricity by the help of generators so hydro turbines as we know are constantly exposed to flowing water the moving parts in the hydro turbine like the runner, the guide vanes, the draft tube, etc., the blades are always immersed underwater. So, such materials which go into making the hydro turbine, they should have corrosion resistance, means they should not be corroded easily or they should in fact resist corrosion to a very large extent.

Second, the most important criteria is cost and availability of materials. So material choice must be economically feasible and must be readily available for manufacturing. We should not have a material which is very scarcely available or is very costly to arrange because then the manufacturing cost will increase drastically as we have understood that in any product it is the cost of the raw material that decides the cost of manufacturing to a very large extent. Several other mechanical properties for turbine materials are also there which determine the performance of such turbines. These include yield strength, tensile strength and ductility.

So, yield strength is basically the stress at which the materials begins to deform permanently. So, generally whatever the mechanical design is done, it is done keeping the yield strength into consideration because the stresses which are induced they should be below the yield stress because in most of the engineering structures it is desired that the loading should be in the elastic zone that is upon removal of load the material should regain the original shape. If the load value increases such that the stresses which are induced it exceeds the yield stress so in that scenario the plastic deformation will be there in the product and which will render it unsuitable for future service. Then tensile strength is also a very important criteria which is the maximum stress a material can withstand before failure in tensile loading scenarios. Ductility is also important because this property helps in converting our material into sheets or maybe drawing into wires and so on ductility and malleability is another property means the material can be easily worked while we are converting into in form of blades or maybe the rotors of the turbines.

So some of the thermal properties are also very important for the materials which are there in turbines. These include heat resistance. Heat resistance is basically the ability of the material to retain its strength and integrity at high temperatures. Second criteria in this is the thermal expansion. Thermal expansion is largely dependent on the thermal expansion coefficients and materials must have low coefficient of thermal expansion to avoid any sort of distortion.

So thermal shock resistance is another important property of the material which is there in the material to withstand rapid temperature changes. So in case there are any rapid changes in temperature, so thermal shock resistance is there because sometimes the material and the drastic change in temperature not only going into elevated temperature or the subzero temperature. So, a material behavior it drastically gets converted to a opposite behavior. For example, a ductile material at room temperature may suddenly act as a brittle material when exposed to ultra low temperatures which is characterized by this ductile to brittle transition and such materials they become difficult to manage if the operating conditions desire a change in temperature while the product is functioning. So sometimes the material itself which goes into making the turbine blades may itself not be sufficient to overcome certain service conditions like in particular to corrosion and oxidation.

Because this corrosion and oxidation, these are surface triggered. So I can say these are surface triggered phenomena. because of which the surface of these components they needs to be engineered in order to provide them corrosion resistance or oxidation resistance. So, this is provided in a pragmatic way by applying coatings of materials which are resistant to corrosion or oxidation. So, coatings can be applied on several of these products like gas turbines or maybe steam turbines or maybe hydro turbines and also the wind turbines.

So, several coatings are also applied as the tertiary process. to overcome the challenges in their respective service environment. For example, the gas turbine blades, so they are exposed to high temperatures as we have just seen the operating temperature is of the order of 1300 degree centigrade. So, there in gas turbines many a times we utilize the application of thermal barrier coatings, or for simply saying it TBCs because such coatings they inhibit the heat flow into the blade thereby enhancing the service life of such blades.

So, coatings are another important criteria in manufacturing of turbines to provide them corrosion or maybe high temperature oxidation resistance. So, manufacturing and fabrication considerations are there. So in this regard the manufacturing and fabrication considerations for any turbine they start with the primary manufacturing processes for that particular turbine and subsequently there will be the secondary manufacturing processes applied. For example the complex parts of turbines they start with for example the gas turbine they start with casting. Now in casting also as we know casting is a very broad manufacturing process.

So, specific casting processes are used to manufacture complex shaped turbine components because in turbine especially the blades they are complex shaped and their shape of the blades in most of the turbine follows the aerofoil shape. So, these blades are aerofoil structures. And specialized casting processes are used to make such plates for example in gas turbine or maybe the steam turbine. Subsequently after casting as we know many a time the casting process itself may not yield the appropriate properties or the microstructure of the product. So, sometimes some of the forming processes are utilized.

Here it is mentioned as forging because forging is also one of the forming process. But, say forging in a different sense may be used in say some components of gas turbine which is can be done by say hot isostatic pressing process. This type of any forming process is essential because it shapes or I can say it strengthens the turbine parts by refining their microstructure, removing any residual porosity or stresses So step number three involves any machining processes in such turbines in order to create precise shape or maybe some type of forms. For example in gas turbine we need to create some film cooling holes. Because this film cooling holes they help to enhance the surface area of the turbine blades and thereby providing maximum surface area for heat transfer.

So, this film cooling holes are produced using advanced machining processes that we will see when we come to machining in gas turbines topic in the next few slides. So next are basically the welding processes. Sometimes in some cases the turbine may need some joining processes. So specific welding processes may also be utilized to join various components together. So now if I discuss about the precision and metrology in turbine manufacturing, it is very important to look at the dimensional accuracy of the turbine components.

Because just now we have discussed that the turbine blades, so these are aerofoil shaped blades, these are complex shaped blades and any sort of distortion with the aerofoil shape will render the turbine blade of no use. So, in this regard, To confirm the dimensional accuracy of turbine components, it is very important to do the performance optimization. This means the precise manufacturing of the component has to be done to ensure efficient operation with minimum losses and maximum output. Second important consideration that the precision and metrology that provide in turbine manufacturing is towards reducing vibration and noise. We know that turbine parts they are rotating at very high speeds and obviously there will be several instances of vibration being induced in the system.

So, because of this the dimensional accuracy if it is not taken care of properly, so then unwanted vibrations and noise level will increase and this will deviate the turbine from a smooth and quiet operation. And many a times these unbalanced vibrations may result in eccentric loading which may also lead to complication with respect to unbalanced loads in high speed rotating machine parts. Third important aspect of precision and metrology in turbine manufacturing is towards increasing the durability and reliability of such turbines. Accurate dimensions contribute towards long-term performance, minimizing wear and tear and extending the component lifespan of the turbines. Dimensional accuracy is also very crucial for the fourth aspect that is safety and efficiency.

So dimensional accuracy is needed for reliable operation, avoiding potential failures and ensuring optimal efficiency. So because of all these reasons, it is very important to look at the precision and metrology, how they help the modern metrology techniques, they help in turbine manufacturing. So in terms of modern metrology techniques which are used in turbine parts, so this include use of coordinate measuring machines or CMMs, laser scanning equipment, optical profilometry. So we will see the details of each of them. So coordinate measuring machines or CMMs are basically used to measure shape, size and position of the turbine components with high precision.

High precision here means with good repeatability. Then we have laser scanning. So laser scanning is important basically to create three-dimensional models of turbine components, ensuring accurate dimensional analysis and defect detection in the turbines. Especially laser scanning is very helpful when we are interested to create digital twins of such turbines to analyze the turbine completely before the actual manufactured turbine goes into service. The third important metrology technique which is widely used in modern turbines is optical profilometry.

So optical profilometry measures surface roughness and other surface characteristics ensuring optimal performance and durability of turbine and its components. So coordinate measuring machines, these have been very popular in metrology and measurement for a very long time. Coordinate measuring machines, they basically function on a presence of a probe which measures specific locations on any object and this probe may be manually or computer controlled. So, coordinate measuring machines generally this probe for probe it functions in three dimensions that is x, y and z and this probe moves on the part to give the information about size shape and position of different profiles on the part. So, dimensional inspection can be carried out using CMMs to verify the accuracy of the turbine components and showing conformance to the design specifications.

Geometric tolerancing can also be done to guarantee proper fit and function of various parts of the turbine. Reverse engineering concepts can also be used to create digital models of existing turbine components for analysis and replication. So laser scanning and three-dimensional imaging is very useful for turbine inspection because laser scanners they help to provide precise three-dimensional data for turbine components generating point clouds. Point cloud processing is used to create complete three-dimensional model of the turbine component. Laser scanning is also useful in dimensional analysis.

The three-dimensional model enables comprehensive dimensional analysis revealing any deviations from specific design specifications. As I mentioned earlier, the laser scanning is very useful to create digital twins, which can be useful to have defect detection. So it can identify surface imperfections, cracks and other defects. in the digital twin or maybe in the actual component which may impact the performance of the turbine. So, by looking at this data of defects, we can minimize these defects ensuring optimal performance of the turbine parts.

Next is use of statistical process control in turbine manufacturing. Now statistical process control is basically application of statistical methods to monitor and control the quality of the production process. So here the objective is to basically efficiently produce the parts and what happens in manufacturing there is lot of variation in manufacturing because of several reasons. So, these several reasons which cause variation in manufacturing are classified in two categories. So, one are the assignable reasons and another category is the non-assignable reasons.

So, assignable reasons of basically deviation are basically unpredictable and they need to be taken care of swiftly because if not taken care of swiftly, so they may result in production of parts which are not confirming to the design specifications. So, these are often. These are also common but they have to be taken care of very swiftly. And then there are reasons which are known as non-assignable causes or we can say then the reasons which are keep the process statistically stable and whatever the variation in the dimensions of the component are produced, they are well within the tolerance limit. So by use of statistical process control using say run charts, control charts, etc.

So we can monitor and control the manufacturing process of the turbines. So using the control chart, statistical analysis and process capability studies, these are various methods in SPC to control the quality in turbine manufacturing. And use of statistical process control helps to reduce variation, improve quality and prevent defects. So, turbine blade manufacturing, component assembly and material testing can be benefited by use of statistical process control. Next, we look at calibration and uncertainty management in turbine metrology.

So, calibration of measuring instrument is very important because regular calibration ensures accuracy of measurement, measuring instrument, maintaining their reliability and traceability. Uncertainty analysis is next important criteria which determines the uncertainty associated with measurements essential to replicate and accurate data interpretation. Measurement traceability, so traceability links measurement to national or international standards, ensure consistency and comparability. And lastly, data validation, that is validation of measurement data ensures accuracy, reliability and absence of errors. So now what are the emerging trends and future outlook in this aspect of precision and metrology in turbines? So as we go forward, we are going to see the era of connected metrology.

What is connected metrology? Connected metrology implies real-time data sharing and remote monitoring to improve process control and decision making. Data analytics, these are advanced data analytic techniques which are employed to extract valuable insights from measurement data. And creation of digital twins which allows for virtual testing, optimization of turbine components, improving design and manufacturing of such components. So, by utilizing these concepts of digital twin with structural health monitoring, artificial intelligence, autonomous control and of course human intelligence with coupled human machine interface, we can say that these modern trends of metrology will be in place in coming times in the industry. So with this we come to the end of this lesson and now we would like to conclude or summarize what topics are covered.

So we have covered the key factors which go in turbine material selection. We have seen the mechanical properties of the materials used in turbines. We have also looked at manufacturing considerations. while making turbine parts. We have seen the concepts of precision and metrology in turbine manufacturing.

And then lastly, we have looked at the emerging trends in turbine manufacturing with focus on metrology and precision. So, these are the summary of the topics covered in this lesson. In the next lesson, we will look at the gas turbine manufacturing starting from the operation of gas turbine on Brayton cycle, specific materials on design of turbine blades in gas turbines. The materials which go into making the gas turbine will in detail discuss the composition and structure of the superalloys, their properties of superalloys and applications. And we will understand - what is the mechanism which makes the super alloy performance suitable for gas turbines and what are the process requirements for manufacturing of the gas turbine.

Thank you.