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

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Lecture 03

Welcome to this lesson 3. In this course of manufacturing for turbines. In today's lecture, we will look at general specifications and design philosophy of turbines. So, the outline of today's lesson will be specification of turbines that is gas turbines, steam, hydro and wind turbines. In these specifications, we will be specifically looking at general specification, key components, applications, design consideration and materials which are used to make such turbines. Next we will look at key design principles, what is the turbine blade market, how this turbine blade market is going to grow in coming years and what are the challenges and future directions in this aspect. So, we start with the gas turbines.

So, we have already discussed the gas turbines are one of the popular sources of energy generation which utilize natural gas or some other source of fuel to produce hot gases and then these hot gases are used as the working fluid and when these gases they interact with the blades of the turbine, they cause rotation of the blade of the turbine and then this rotation that is the rotational work is used to generate electrical power when connected to a generator. So, if you talk of general specification of these turbines, so here we look at the fuel type. So, in gas turbines, natural gas is one of the popular fuel which is used as it is relatively cleaner compared to liquid fuels like kerosene and diesel. Nevertheless, in some cases, land based gas turbines, kerosene and diesel may also be used.

The power output of gas turbines, it typically ranges from 1 megawatt to over 400 megawatt. Gas turbines which produce a power of the order of 1 megawatt, they are used directly in several industries to generate power locally. And of course, the gas turbines which can produce power of the order of 400 megawatts can be used for supplying electrical power to residential, commercial or industrial areas on a larger scale. The gas turbines as we know they work on Brayton cycle so they have a typical efficiency about 35 to 40 percent for simple cycle and when they are used in combined cycle arrangement their efficiency can increase up to 60 percent. The key components in any gas turbine are three key components which include the compressor, the combustor and the turbine itself.

So, this turbine is subsequently connected to a generator as we have discussed in the previous lesson and the gas turbine is not only used in power generation, but they are also popular in aviation and several other industrial processes which utilize energy. Next we look at the design considerations for gas turbine. So, now in gas turbine as we know hot gases are the working fluid here. So, hot gases they are available at temperatures of the order of say 1100 degree centigrade to 1300 degree centigrade and they may also reach up to 1500 degree centigrade. So, this very high temperature in the gas turbine, it poses several challenges for the materials which are used to manufacture blade of the gas turbines.

Primarily, these challenges come in form of creep, then high temperature oxidation, fatigue etcetera. So, we have to look at materials, the selection of materials has to be done so that whatever material is chosen, it can function in the high temperature while overcoming these set of challenges and several others. And also the pressure ratios which are available in gas turbines, they are also quite high of the order of 30 is to 1. So if you look at the popular materials which are used to make gas turbine blades, they are the nickel based superalloys which have high temperature strength and they are also able to retain their strength and hardness at elevated temperatures. The gas turbines they also use combustor liners in form of ceramic materials for thermal resistance because the combustor is the region in the gas turbine system which experiences the maximum temperature because there is where the combustion of the fuel that is say the natural gas is taking place.

So, it is often lined with ceramic materials and sometimes even on the blades of the gas turbine blades we may also use in combination of the superalloys we may also be using thermal barrier coatings which we will look into more detail as we move forward into this course. Thermal barrier coatings are also ceramic based coatings which are primarily also used on the blades for thermal resistance. So, next we look at general specifications of steam turbine. So, steam turbines are also very popular in modern energy systems as they are used in thermal power plants, they are also used in nuclear based power plants, they are also used in power plants where heat is generated by combusting natural gas and subsequently the heat of combustion is used to generate superheated or ultra superheated steam. So, steam turbines they are available in power output ranges of 50 megawatt to up to 1500 megawatt.

The efficiency of the steam turbine it can reach up to 45 percent in optimized conditions. We also know that steam turbines are based on Rankine cycle and the key components in any steam turbine are basically the high pressure turbine, intermediate pressure turbine and low pressure turbine. So, this means the turbine has several stages in which the expansion of the steam is taking place in order to maximize efficiency. So, this was not the case in the previous turbine that was the gas turbine, but here in say three stages, high pressure, intermediate pressure and low pressure, the expansion of the steam is taking place, which will maximize the efficiency.

And of course, we can also use the heat regenerator systems to further enhance the efficiency of the steam turbine. So, steam turbines are also not only used in power plants, they are also used in industrial power to run industrial machinery like compressors, pumps, etc. They are also used in marine propulsion for propelling many marine vessels. So, next we look at the design considerations of the steam turbine. So, Pelton turbine is the only turbine which is based on the impulse action of the flowing water whereas the Kaplan and Francis turbine they are based on the reactive action of the flowing water.

So, the power output in these cases is generally from few kilowatts to several gigawatts. But generally in any hydropower plant, it is not one turbine, but maybe there may be four, six or more number of turbines operating. So, the total power output may be in order of gigawatts for any hydropower plant. So, the hydro turbines they typically operate in efficiencies range of 85 to 95 percent and depending on the design and flow conditions this efficiency may be varying to a certain extent.

The key components in any hydro turbine they include the runner, the guide vanes, the spiral casing and the draft tube. So, it is important to design these key components in a proper way so that the efficiency of the hydro turbine is not compromised. So, hydro turbine is only primarily used in hydroelectric power plants where perennial supply of water is used to generate electricity throughout the year. So, if we look at the design considerations, so here the water head and the flow rate they determine what type of turbine will be used in the hydropower plant. For example, the Kaplan turbine is an axial flow turbine which is known to function at low head and high flow rates whereas the Pelton turbine is known to function when we have high head of water and low flow rates.

Similarly the hydro turbines they are also subjected to cavitation erosion. So cavitation erosion resistance is also essential for the longevity of these turbines because when the water is flowing in the spiral casing in the turbine, So, many a times there will be a pressure drop below the atmospheric pressure which will result in generation of water vapours and this collapsing water vapour bubbles when they impact the surface of the essential components like the guide vanes, runners of the turbine. So, there they create shock waves and there is material loss because of the bursting bubbles of the water vapour which is known as the cavitation erosion. So, hydro turbines they have to be importantly designed to manage the cavitation erosion for longevity. And what materials go into making the runners and blade are essentially the stainless steel for enhanced corrosion resistance.

And not only these stainless steels are used, on top of it we may also use some coatings which are basically there to enhance. So, these coatings are the applied to enhance the sediment erosion resistance and using various thermal spraying methods we will discuss in the next part of the course. We will see how the sediment erosion resistance is imparted by these coatings and then the casings of these hydro turbines, they are made up of high strength structural steel. Next, we look at the general specification of the wind turbine. So, wind turbine is again based on renewable energy source that is constant blowing wind.

So, wind turbines they are available in two types. One is the horizontal axis wind turbine abbreviated as HAWT and the other is the vertical axis wind turbine. So, what I mean by this axis is the axis of the wind turbine suppose this is the axis of the wind turbine. When this axis is parallel to the ground, so this becomes the horizontal axis. So, this is the ground here and this is the blade axis of the turbine blade.

So, this is parallel. So, this becomes the horizontal axis wind turbine and in many cases the wind turbine axis may be perpendicular to the ground. So, this will become the vertical axis wind turbine. So, for commercial scale power generation, the horizontal axis wind turbine are very popular, but on a small scale, so nowadays vertical axis wind turbines are also becoming popular, but the capability of generating power is much, the vertical axis wind turbine they generate power at a much smaller scale compared to the horizontal axis wind turbine. So, the power output for the wind turbine in general it ranges from 1 kilowatt for smaller units for example the ve rtical axis wind turbine to it can go to as high as 10 megawatt for offshore wind turbines which are primarily horizontal axis wind turbines.

The efficiency of the wind turbines theoretically they are limited to 59.3 percent, but in general we know that the wind conditions and weather conditions they keep on changing and because of that the practical efficiencies which are realized are in the range of 35 to 45 percent. The key components in any wind turbine they include rotor blades, the nacelle, the tower and the gearbox. We have seen the details of this arrangement in the previous lesson where rotor blades they are primarily are responsible to extract energy from the blowing wind and they are made up of lightweight high strength materials. Nowadays, the wind turbine blade is also modified so as to eliminate the gearbox because Gearbox is one such component in wind turbines which experiences maximum failure and needs maximum maintenance and there is high cost involved. So, in future we will be finding that the wind turbines are gearless, wind turbines are also being introduced to manage the maintenance issues with the gearbox.

So, wind turbines they are primarily used for power generation. and they can be installed in onshore locations that is on land or they may be installed in offshore locations that is in the sea. And wind turbine blades they do not are installed in a single number rather they are installed in several numbers and that combination of several numbers of the wind turbine blades this is termed as the wind farms. So, wind farms are installed so that the collective power output is much significant and it can be supplied to the grid. So, if you look at the design considerations of wind turbine, so in wind turbine there are design consideration with respect to the blade aerodynamics.

Because it is very critical the aerodynamic shape of the blade is important to capture the wind energy efficiently. Second and foremost is basically structural integrity because we know that wind conditions are not always pleasant. At times, the wind conditions may become much aggressive in conditions of storm or any hurricane. So, the wind turbine blades, they must also withstand high wind speeds and fatigue which is induced by varying wind conditions which include wind speed and direction. The materials which go into manufacturing of the wind turbines as discussed earlier, they are lightweight and high strength materials.

So, composite materials in particular polymer matrix composite materials with reinforcement in form of fiberglass and carbon fibers are very popular because once we are combining the fiberglass or also known as glass fibers and carbon fibers, we can expect high strength and stiffness from the composite materials. Secondly, the towers on which the blade and the nacelle of the wind turbine is installed, it is generally made up of steel or concrete. And of course, there may be some challenge in installing such towers in offshore location where the depth of the seabed is much higher. So, in some cases, floating wind turbines are also used where the depth of the sea floor is too deep to do the permanent fixing of the towers. So, if you look at the comparative study between all these four turbines that we have discussed, so we can see that in terms of power output.

The gas turbine they are from 1 megawatt to 400 megawatt, steam turbine it ranges from 50 to 1500 megawatt, hydro turbine from few kilowatts to several gigawatts when used in several numbers and in wind turbine 1 kilowatt for say vertical axis wind turbine to up to say 10 megawatt for horizontal axis wind turbine. In case of efficiency, the gas turbine can operate in efficiency range of 35 percent in standalone condition, 60 percent when used in combined cycle. The steam turbine can reach up to the efficiency of 45 percent. Hydro turbine can go up to 85 to 95 percent of efficiency. The wind turbine can go from 35 to 45 percent of efficiency.

The main materials which are used in making of the gas turbine particularly the blades are nickel based super alloys and in case of steam turbine these are chromium molybdenum steels in hydro turbines these are austenitic or martensitic grade stainless steels and in case of wind turbines these are polymer matrix composites with reinforcement in form of glass fibers and carbon fibers Then if we look at the key component in terms of the gas turbine, the key component was compressor and the turbine and combustor. In case of steam turbine, it is the high pressure turbine, intermediate pressure turbine, low pressure turbine. In terms of the hydro turbine, it is the runner and the guide vane. In terms of wind turbine, it is the rotor blade. And these are generally the applications, most of them are used in the power generation sector and the gas turbine is the only exception which is also used in the aviation sector.

So, now we would also like to discuss the turbine design philosophy, on what philosophy the turbines are designed. So the main philosophy that drives the turbine design is focused towards achieving high efficiency, reliability and optimal performance so that the efficiency is not compromised because in several cases like the gas turbine or the steam turbine where fossil fuels are burnt. So, we want the maximum efficiency so that we can minimize the greenhouse gas emission. We also want to look at the reliability component in the design so that in varying conditions of operating parameters, the turbine should reliably keep on functioning and supplying power to the grid. And we also need to optimize the performance based on the varying conditions.

So, design process it is basically a balance of different considerations which include aerodynamic considerations, thermodynamic considerations and mechanical considerations. We will look into the detail of these three considerations in next few slides. And to achieve the balance during the design process of all these considerations, extensive simulation, testing at lab scale or a prototype scale, iterative improvements are basically essential to meet out these goals. So the key design principles while managing the design of turbines they include aerodynamics which is primarily focused on optimizing the blade shape for maximum lift and minimal drag because it is the lift which generates the rotational force and torque. Then the thermodynamics aspect, it mainly focuses on efficient energy conversion process to maximize the power output.

So, we want to have maximum output at a minimal input so that we can minimize the emission of greenhouse gases. Thirdly, we also look at the structural integrity so that we can ensure all the essential and non-essential components of these turbines, they can withstand the operational stresses and fatigue. For example, I discussed the wind turbine. So, in wind turbine, the design of the wind turbine blades, the tower on which the wind turbine is installed, it has to be efficiently designed. So, that not only it can withstand pleasant breeze, but it can also withstand strong wind forces which are generated because of storms.

And the material selection as we have just highlighted the material selection in all four types of turbines these utilize use of advanced materials ranging from nickel based super alloys to high performance advanced structural polymer composites which can endure the different conditions in which the particular turbine is operating be it high temperature conditions for gas turbine or maybe the varying wind conditions in the case of wind turbine. So, we will now look at in little detail the different considerations which are going to design designing philosophy of these turbines. We start with the aerodynamic consideration. So, in the aerodynamic consideration we primarily are looking at the blade shape and the angle of attack, which are critical for capturing and converting the incoming energy of the wind.

So, if you look at this schematic here, so in this schematic we can see that one blade is shown of the wind turbine and the cross section of the blade is shown as the aerofoil shape. So, here the shape of the blade is designed such that the resultant wind velocity is maximized and the drag force here is minimized. And this resultant wind velocity, it creates the torque force which rotates the rotor. So, computational fluid dynamics is basically used to simulate the airflow to further optimize the blade design. So, blade design is also done to minimize losses with precise design to reduce aerodynamic drag and turbulence for enhanced performance of the wind turbine blades.

So similar aerodynamic considerations can also be brought into gas turbine blades or steam turbine blades, but the essence will be on the blade shape and the angle of attack. Next is the thermodynamic efficiency. So thermodynamic efficiency is more important in gas turbine and steam turbine as they utilize heat in some form. So here the efficiency cycle which can be further optimized is to be looked at very carefully. For example, the schematic here highlights the Brayton cycle on which the gas turbines are operating.

So, Brayton cycle essentially consists of these three main components which include the compressor, the combustion chamber and the turbine itself. So, the turbine and compressor are coupled together with a shaft so that to make the system self-sustaining and we can look at this schematic of an open cycle gas turbine based on the Brayton cycle where we have this T-S diagram and the P-V diagram. So, the heat recovery in case of the thermodynamic based turbines is also important. So, heat recovery is basically the waste heat can be recovered and utilized again. So, we can incorporate several heat exchangers to improve the overall efficiency.

The temperature management is also important in such turbines because design of optimal temperature distribution is also important to enhance the performance and lifespan of such turbines. The next aspect in the design philosophy comes from the structural and mechanical design where we are interested to look at the stress analysis, whatever are the stress values which are generated, we need to ensure the key components of any turbine, the blades and the rotors are able to withstand these stresses without failure. Next important aspect in mechanical design is the fatigue and failure testing. We would also like to simulate long-term use to prevent fatigue failures in these turbines. Vibration reduction is another important criteria where we want to design so as to minimize the harmful vibration which can overall reduce the efficiency and may cause damage to such turbines.

Next we come to the material selection criteria. So, material selection criteria is essential to look at because in some cases we are dealing with high temperature. So, in that scenario we go with high temperature alloys which are essential for components when functioning in high temperature conditions. The corrosion resistance may become very important especially in case of hydro turbines. So, this is also important to look at. And in some conditions like wind turbine blades we are interested to have materials which are light in weight and they have high strength.

So, composite polymer matrix composite materials they come into picture when we are dealing with such situations. So, to manage all these material selection criteria we have several charts which we will discuss in more detail in the next module of this course. And these charts are known as material selection charts which highlight the different properties of the materials and map them to different material types. What I mean by different material types is whether the material is polymer, whether it is metal, whether it is ceramic or it is any type of composite. So, based on certain properties as one of the examples shown here is specific modulus.

So, in case of specific modulus, we can see that the specific modulus here is mapped with the specific strength and then how different materials like foams or maybe non-technical ceramics, technical ceramics, composites, metals, polymers, how they are placed relative to each other. So, by looking at such charts, it becomes very easy to select the appropriate material. So next comes the design optimization techniques. So computational modeling here comes very important where we use advanced software to simulate and optimize design of such turbine blades. Prototyping and testing is maybe very important for rigorously developing the prototypes to validate the designs which are developed using computational modeling.

And when we do the actual experiment against the computational modeling, there may be need of iterative improvement to continuously refine the designs based on the test results and feedback. So, now we would also like to look at the turbine blade market, how the turbine blade market is going to get increased. So, as we know our needs for energy is going to get increased in coming times. So, it is expected the turbine blade market is going to keep on increasing. Especially the turbine blade market will be increasing with respect to the renewable energy sources, for example, the wind turbine.

So, if you look at the wind turbine example shown in the slide, so the advanced blade design will significantly improve the efficiency. In case of gas turbines, there may be more innovations needed for cooling techniques and of course, the new materials may need to be developed for enhanced performance and reliability. The hydroelectric turbines may also need new designs to accommodate varying water flow conditions as with climate change sometimes we are experiencing more rainfall in seasons when it is expected the rainfall will be less for further optimizing the energy generation. So, here we can see for the wind turbine blades. Market over the next decade is going to get increased at the compounded annual growth rate of 7%, which is very significant.

So, this basically highlights the importance of studying the subject on manufacturing of such turbines when we see the market of such turbine is going to get increased in coming times. So, now I would like to mention what are the challenges and future directions. So the challenges and future directions they include from the terms of sustainability where we are interested to develop eco-friendly and sustainable turbine technologies to reduce environmental impact. We would also like to integrate the turbines with renewable energy by adapting the designs to integrate renewable sources of energy like say solar or wind power. The technological advancements, the turbine design and manufacturing and operation may also need to embrace new technologies like artificial intelligence, internet of things to develop smarter and more efficient turbines.

So, with this we come to the end of this lesson and I would like to summarize the points that we have studied. We have studied the specifications of the turbines. which in which we have looked at all the four turbines in detail the gas turbine, we have looked at steam turbine, we have looked at hydro turbine and we have looked at the wind turbine. Then we have looked at the key design principles, we have also looked at turbine blade market. And lastly, we have seen what are the challenges and future directions with respect to design and say manufacturing of turbines.

So, in the next lecture, we will be looking at manufacturing concepts, classification of different materials which are used in engineering products. We will look in detail the concepts of manufacturing, then product design and development and engineering materials.

Thank you.