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

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Week -04

Lecture 19

Welcome to this course on manufacturing turbines. In Lesson 19 of the course, we will see the deformation and machining processes that are used to manufacture steam turbines. So the steam turbine assembly consists of several parts, such as the turbine housing, turbine blades, turbine shaft, turbine diaphragm, and other components. Machining processes are used to manufacture these components of the steam turbine. Before we go into discussing the details of deformation and machining processes for steam turbines, we will take a quick recap of steam turbines. Steam turbines are used in both nuclear and fossil fuel-based power plants to generate electricity.

Here, the steam first passes at high pressure through the high-pressure turbine, then it enters the intermediate pressure stage, and finally to one to three low-pressure turbines. So these turbine parts form an essential assembly of the steam turbines, which includes housing, blades, shafts, and diaphragms. Starting with this manufacturing process of deformation, as we have seen in the previous lesson, the role of investment casting is to give the basic shape to the steam turbine blades. So after the investment casting, there may often be some inclusions, micro porosity, or some sort of micro voids present in the structure of the turbine or the steam turbine that is cast.

So, in order to remove such defects, it is essential to undergo deformation because, in deformation-based processes, the refining of the microstructure takes place. So, if you look at the casing and housing of the steam turbine, deformation processes such as rolling and bending are very useful. Rolling forms the initial or basic shape of the casing from flat sheets. Follow by bending to achieve the cylindrical form. So the benefits are that it is very efficient in producing large, consistent parts with smooth surfaces.

And some of the important process parameters include consistent pressure application, controlled rolling speeds, and bending angles. So, if we tightly control the process parameters as mentioned, we can achieve a very good shape for this casing, which is very suitable for the steam turbine. The next process in the deformation-based processes for the turbine includes precise forging. So precision forging involves shaping the blade by applying compressive forces and allowing the blade material, which is the nickel-chromium alloy, to flow within the die, because as the compressive force is applied, stresses are generated. Under the influence of compressive stresses, the material will flow in the die and take the shape of the die; thus, the benefits of precision forging include near-net shape manufacturing.

Whatever the shape of the die, exactly the same shape will be formed in the product once it solidifies, or it is basically deformed into the die; this also helps enhance the grain structure. So what happens in all these deformation processes? By applying force, the forces lead to the generation of stress. So now the stress that is generated is often beyond the yield point, and this stress often functions in the plastic deformation zone. And the stress value is always less than the ultimate tensile strength. To prevent the final fracture of the component from taking place.

However, under the influence of plastic deformation stresses, the material just flows, and the shape of the material is changed. While changing the shape, especially in forging or precision forging, the die has a limited volume in which the material has to flow. Upon compressing it and forcing it to flow within the same volume, the microstructure generally refines because the material flows. The micropores, porosity, or microvoids present will be filled with the flow of the material. This basically leads to an overall enhancement of the mechanical properties of the component and the process parameters, which include the right temperature.

Often, precision forging is conducted at high temperatures and proper pressure, which will ensure the Proper material flow within the die is essential. So, if we look at the image showing the precision forging process, we can better understand it. So here we can see that there is a table, and on the top part, we have a ram that can move up and down to apply the compressive force. Then this ram also has some springs attached, and below the springs, we have the dies in which the blade is loaded. Upon application of the compressive force, the dies are closed, and the material is then allowed to flow within the die, as shown here, allowing it to take the shape of the die cavity.

Another important point to note here is that during this material flow, almost negligible material is wasted in the form of chips or scrap. So, the processes only change the shape of the material by applying stresses that are beyond the yield stress and within the plastic deformation zone of the material. So next, if we see how the microstructure refinement is done, especially on the shaft of the wind turbine, we will understand the process better. So here, the processes of hot rolling and extrusion are utilized. So he hot-rolls the metal into a long cylindrical form, and the extrusion of this material ensures refinement of shape and dimensions.

So, the various benefits include the production of shafts with excellent mechanical properties and surface finishes. Parameters such as high temperatures for rolling and precise die dimensions, especially in the case of extrusion, are essential to obtain the right properties in the shaft. So here we can see a typical hot rolling process once the material has passed through the two rollers. So these are the two roles. Roll 1 and roll 2 through which the material is passing, and we can see that as the rolls compress the material, the grain structure is refined as the old grain structure breaks into the formation of new and elongated grains, especially along the direction of rolling.

Next are the manufacturing processes, specifically deformation-based processes, which are used to manufacture the diaphragm of the steam turbine. So, in diaphragm manufacturing, the sheet metal forming process is utilized. In sheet metal forming processes, techniques such as shearing, bending, stretch forming, and deep drawing are utilized to change the shape of the sheet. Before doing that, it also involves cutting these high-strength alloy steels or sheets into the required form of a diaphragm. The sheet metal forming processes ensure dimensional accuracy and uniform thickness.

The various parameters in the case of sheet metal forming, which are very suitable for mass production, involve controlled force application to achieve the desired shape. Without compromising material integrity. So in the manufacturing of the steam turbine, the role of machining processes is to generate a very smooth surface on the blades to ensure that the proper aerodynamic shape is maintained for good efficiency of the steam turbine. So, in this regard, the material used in steam turbine housing includes high-strength alloys. High-strength alloys are typically made up of superalloys like INCONEL, as well as stainless steels or nickel-chromium-based high-alloy steels, which ensure durability and resistance to high temperatures and pressure.

The technical overview here basically utilizes machining; it is based on conventional machining processes. So, as we know, conventional machining processes are subtractive processes in which a tool, generally harder than the workpiece, removes material from the workpiece in the form of chips. So, in the case of conventional machining, we have seen several processes in earlier classes, such as turning, facing, drilling, and milling. With respect to the steam turbines, it is the milling process that is very popular for developing the final shape with a proper surface finish on the blades. So, workpiece preparation is basically the first step for milling, where material selection with respect to high-alloy steel is chosen because of its durability and resistance to high temperatures and pressure.

The fixturing of these workpieces is another important aspect to consider because, in conventional machining, it is the forces applied when the tool interacts with the workpiece that generate the shear stress along the shear plane, which basically removes the material through the formation of chips. So, in fixturing, the workpiece is securely clamped onto the milling machine, which uses precision fixturing to ensure accuracy and repeatability. The next important criterion while machining steam turbine blades is basically the types of cutters or cutting tools. So, different types of modern milling cutters can be selected based on the geometry and features of the turbine housing. The cutters may also be chosen based on their compatibility with the workpiece.

Commonly, carbide, ceramic, or cubic boron nitride-based cutters are utilized as insert materials. Now, in this case, the cutting tool basically has several inserts that can be indexed, and the utilization of inserts reduces tool changing time and cost because by indexing the inserts, we can quickly bring the new edge of the insert to machine the workpiece. The materials of the insert, as mentioned, are very hard and effective in machining high-alloy stainless steels that contain a significant proportion of nickel and chromium. So the third important step is to set the milling parameters. So milling, as we know, is a conventional machining operation in which a multipoint cutting tool interacts with the surface of the workpiece to remove material in the form of chips.

So cutting speed is the most important milling parameter that is optimized for efficient material removal. With minimal tool wear because some amount of material is also removed from the tool, which is known as tool wear, the material removal should typically take place at a rate of 100 to 300 meters per minute. Feed rate is another important criterion that balances the speed of machining with surface finish quality, which is typically on the order of 0.05 to 0.3 mm per tooth, because there may be several teeth on the milling tool.

Depth of cut is the third most important milling parameter that maximizes efficiency while avoiding tool overload. Typically, a depth of cut of the order of 0.5 millimeters to 3 millimeters is chosen depending on the operation. Next is the sequence of milling operations. The sequence of milling operations involves the use of rough milling, which removes bulk material quickly using larger cutters and aggressive feed rates.

Then comes the semi-finishing milling operation, in which it is used to refine the shape and dimensions with smaller cutters and precise feed rates. Third is the finished machining, which basically achieves the precise dimensions and surface finish using fine cutters and precise milling parameters. It is often seen that rough milling takes the minimum time, while finished machining takes the maximum time as the machining operation progresses. The third important criterion shown on the slide and the fifth in the sequence is the coolant application. Coolants, as we know, are essential in conventional machining because they help to remove heat from the machining zone.

They also prevent the formation of built-up edge on the cutting tool. Different types of coolants are used, especially in the case of machining steam turbine blades. High-pressure coolant systems are used, in which case several oil-based coolants may also be utilized to reduce friction and heat in the machining zone. Coolant delivery is conducted directly into the cutting zone through nozzles or internal channels of the cutter for effective cooling and lubrication. So if we look at the overall processes that are utilized to manufacture the housing of the steam turbine, we can gain a better understanding.

So this basically starts with mold making, which is typically done using a sand mold. Then we have the molding operation. Sand cleaning is done after the cleaning is finished. The casting of the housing is heat-treated, risers are removed by grinding, and then some shot blasting is done to remove any sand particles from the surface of the housing. Subsequently, some types of destructive or non-destructive testing can be done to estimate the quality assurance of the housing that is cast, and sometimes grinding or repair welding may be needed after casting is finished and machined.

Subsequently, the finishing operations are utilized to create a good surface finish on the housing, and once the appropriate surface finish is achieved, the housing is then assembled with the steam turbine blade and other parts, such as the shaft and diaphragm. The next important criterion or component of the steam turbine is the blade. So there are several challenges in blade manufacturing and blade machining for steam turbines. Because a turbine blade operates at full load, it may reach very high speeds on the order of 500 meters per second. This results in a centripetal acceleration of the order of 160,000 meters per second squared and centrifugal forces of the order of 550 tons; moreover, the blades have a complex aerofoil shape in which the blade profile is difficult to cut from materials such as Inconel.

They present significant challenges, so the goal of any machining process is to produce. Faultless components that meet the stringent market requirements are shown here; this is basically the low-pressure last stage turbine blade that failed because of some manufacturing defects. So even for machining the steam turbine blades, conventional machining or conventional milling operations with very hard or modern cutting tools utilizing ceramic or CBN are employed. The multi-axis CNC machines are utilized to machine the blades to ensure the accuracy and repeatability of the process. Excessive use of coolants is implemented so that minimum heat generation takes place in the machining zone and the blades are effectively machined.

So here we can see a typical steam turbine blade held in the headstock. Excessive use of coolants is implemented so that minimum heat generation takes place in the machining zone and blades are effectively machined. So here we can see a typical steam turbine blade being held in the headstock. And the other part is held in the tail stock and a CNC milling cutter with the cutting tool here is then utilized to machine the surface of the steam turbine blade and this steam turbine blade the surface finishing is done by removing material in the form of chips. So then what can be the machining solutions to machine the steam turbine blades? To overcome the challenges as mentioned previously, a precisely matched range of tools for both rough and finishing processes should be employed, to handle the complex blade profiles and difficult to cut materials, such as high-strength alloy steels or Inconel.

Tool selection should be done to ensure advanced tools which are optimized for high strength alloys and complex geometries are used which will ensure efficient material removal and precise finish. Roughening tools are also utilized to remove bulk material quickly. while maintaining the stability and minimizing tool wear. So this process shapes the basic blade shape. Then are the finishing operations which are basically utilization of finishing tools to provide high precision and surface quality of the turbine blades to ensure that they meet the tight dimensional tolerance.

Then another important component in steam turbine is the shaft because the rotor and the blades are mounted on the shaft and subsequently this shaft is also used to take the rotational power to the generator for generation of electricity. So turbine shafts are mainly machined through turning and groove cutting operations with some amounts of drilling. Large amounts of material are removed and demanding grooves to be cut. So materials for shaft they include high strength steel and super alloys for durability and performance under extreme conditions. So machining operations involve turning, groove cutting and drilling to achieve the required shape and dimensions of the turbine shaft.

So we can see here a typical cut section of the turbine shaft where we can see various types of grooves being cut on this shaft and other stringent machining requirements because the shaft has to further be assembled with other components of the steam turbine. So then we have the step-by-step machining operations where we start with a rough turning with the objective to remove the bulk material to form the basic shape of the turbine shaft. The tooling utilized here is a heavy duty double-sided insert with the latest insert geometry. Parameters such as large depth of cut and high feed rates are utilized for efficient material removal. Challenges involve managing strong cutting forces and also ensuring the tool durability and edge security of the insert.

Then is the groove cutting operation which ensures precise grooves of specific features are manufactured on the turbine shaft. Here the angled inserts are used to access difficult grooves with techniques to employ 90 degree angled insert for standard groove profiles. The benefits of using group cutting is that we don't need any special tool. Standard blanks may be available for dedicated profiles. Then high pressure coolant application is also used to improve the chip control and tool life, especially in the finishing operations.

And utilization of high pressure coolant systems enhance the cutting performance of the machining process. The advantages of utilizing high pressure coolant involve increased cutting speed and reduced thermal deformation. So a steam turbine is also consisting of moving and fixed plates and stationary plates or the stator are often fixed on the diaphragm which was previously given a basic shape using sheet metal forming processes. So this also helps to direct the steam flow onto the rotor plates and is made up of high strength alloy steels. And machining processes for diaphragm involve turning the outer and inner rings with precise dimensioning.

High precision inserts, turning inserts are utilized, which may help to reduce the cycle time from 2 to 20 hours. Cutting parameters such as speed, depth of cut, and feed rates have to be optimized. Several grooves may also be needed here to hold the blades into their position and again angled inserts are utilized here. Here also excessive use of high pressure coolant is done to increase the speed life and tool life and improve the chip control. So with this we have seen the processes which are used to basically manufacture the steam turbine in terms of deformation and machining processes.

We will see the summary. So, in summary we have mainly seen the deformation based processes which essentially utilized the processes such as rolling which was specifically hot rolling, extrusion. Then precision forging and sheet metal operations and in case of machining processes we have seen processes like the conventional milling processes being used in machining different parts of the steam turbine which include housing, shaft, blades as well as the stator blades etcetera. So, in the next lesson we will see laser metal direct fabrication processes used in the steam turbines.