

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

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Lecture 22

Welcome to this course on manufacturing of turbines. In this lesson 22 of this course, we will see the casting processes used to manufacture the hydro turbines. So, the outline of this lesson will be as follows. First, we will go through with the importance of casting in hydro turbine manufacturing. We will look at comparative analysis of casting techniques used for manufacturing of hydro turbines. We will look at details of sand casting.

What are the materials used? What are the components of the hydro turbine produced using sand casting? What are the advancements in sand casting process for hydro turbines? We will also look at a case study by Zollerin. Subsequently, we will look at investment casting process where we look again at materials which are used and processed for investment casting with focus on hydro turbines. So, hydro turbines as we have seen earlier are the energy production turbines in which the flowing water is used to generate electricity. So, the density of the working fluid that is water here is approximately 1000 kilogram per meter cube and with this high density the turbine has to be robust.

It has to withstand the dynamic forces and loads of flowing water. And as we have seen classification of hydro turbines, so these turbines are classified based on impulse action or reaction action based turbines. So, we have to see that according to the head of the water available. and the flow rate of the water, the appropriate turbine is selected. Certain components in these turbines are common like the generator shaft, the guide vanes, etc.

So, turbine manufacturing techniques may be applicable to all of these turbine components. So the various techniques which are used in manufacturing of hydro turbine they include the primary manufacturing processes or the shaping processes which are sand casting, investment casting, So, sand casting it is ideal for large components where sand casting is a versatile and cost effective technique. Although, this technique may not provide the ideal surface finish, but certain secondary processing may be needed to reach up to the level of the desired surface finish. Second process is the investment casting process. We have seen this process in much detail in the previous sections of this course

and we know that this process is known to produce components with near net shape, as well as high precision with complex shapes and investment casting is particularly useful to manufacture the blades of the turbine.

Then comes the CNC machining. So, here again the conventional machining is utilized with the control of computer numerical control machine tools. So, this is commonly used for its precision, high quality finish and in CNC machining also various machining processes such as milling, grinding, polishing and balancing may be done and this may be used for both the complete runners or the individual blades of the turbine. The fourth process that comes into picture in manufacturing of hydro turbines is forging. So, forging as we know is a metal deformation or a material deformation process.

Where, the forces are applied so as to induce stresses which are beyond the yield strength, but of course below the fracture strength. So, all these processes they function in the plastic deformation regime of the materials. So, components which require high strength, so forging provides excellent mechanical properties, but it is limited with design flexibility. So, the shape of the component is limited with the die shape but nevertheless because of application of these forces there is refinement in the microstructure which improves the mechanical properties of the component. Next, we look at the importance of casting process in hydro turbine manufacturing.

Casting is integral to hydro turbine manufacturing due to several key advantages. So, because casting as we know it involves melting of the molten material, then allowing the molten material to solidify in a mold cavity. The shape of the mold cavity is basically created using a pattern which is replica of the product to be produced. And subsequently the solidification of the molten material takes place in the mold cavity and upon completion of solidification, the solidified part is removed from the mold. So casting as we know is having special abilities with controlled parameters to generate complex geometries.

So, casting allows for creation of complex shapes that would have been otherwise quite difficult with other methods. As we know that, in turbines the blade have to be have aerodynamic shape so as to they can extract maximum energy from the flowing water. The size flexibility is also there in casting processes as in case of hydro turbines, the size of the components is very large. So, therefore, such components are economically manufactured using casting process rather than any other process and especially this is more applicable towards turbine casings as well as draft tubes. Then comes the material properties which are yielded from the casting process.

So, casting can produce components with desired properties such as strength and durability because by controlling the microstructure during the cooling of the casting, we can tailor these properties as per need of the application. So, next we look at the

comparative analysis of various casting techniques which are used in manufacturing of hydro turbine components. So, in case of hydro turbine components, the sand casting process and the investment casting process are widely used. So, sand casting process although is known to produce very large components with not so good surface finish, it is used to manufacture other sub components of the turbine hydro turbine like the shaft casing etc. While, the investment casting process is specifically used to cast the turbine blades.

So, if we look at the design freedom parameter, so in case of sand casting the freedom is an average freedom while we get most freedom with investment casting because of the presence of the wax pattern which can be shaped into complex shape products. Then we have the tolerance control. So, as we know sand casting has poor tolerance control whereas the investment casting because of it utilizing the wax pattern it has the best tolerance control. The surface finish is poor in case of sand casting whereas we get a very good surface finish in case of investment casting. Material selection, so sand casting is more popular with ferrous based materials whereas, in investment casting it has a wide flexibility over materials ferrous or non-ferrous.

The large components are possible with sand casting whereas average sized components are possible with investment casting. Cost that is unit cost and tooling cost is low for sand casting whereas it is high or average for investment casting process. So, in the sand casting process for hydro turbines, we will see the overview of this process. So, sand casting, it is a fundamental process of manufacturing for several components in the hydro turbine. So, here what is there that we have a mold of sand into which molten material is poured.

So, this molten material is then allowed to solidify into the mold and using the sand mold we can produce patterns replicating the final product and by employing core print we can directly do it without a model. Materials which are used in sand casting for hydro turbine primarily involve high performance materials such as aluminum, bronze, various grades of stainless and acid resistant steels. These materials are selected for their mechanical properties which include strength, wear and corrosion resistance and are critical for harsh environments of hydroelectric turbines. So, we see the outline of the sand casting process. So, in the sand casting process we can see that generally for conducting the sand casting we have the mold created out of sand.

So, this is the mold. So, in this mold basically we create cavities using pattern which is nothing but it is the replica of the product which needs to be cast. So, subsequently once the mold cavity is produced the pattern is removed and in this case we have a non-expandable pattern which is used which can be used multiple times. And once the cavity is created, we pour the molten material from the pouring basin, then allow it to

flow into the cavity via the ingate. And upon solidification, we remove the solidified part from the mold.

So, different types of components which are produced using this sand casting for different types of hydro turbines. For example, this includes runners in case of Francis turbine. So, these are the primary rotating elements in Francis turbine engineered to manage substantial water volumes, converting the hydraulic energy into mechanical energy efficiently. Then, we have the turbo runners which are utilized in impulse turbines and turbo runners are designed for medium to high head applications capable of handling high flow rates than Pelton wheels. Kaplan blades, so these blades form a part of Kaplan turbine adjustable for optimal performance in low head and high flow conditions.

Then, we have the guide vanes and hub bodies which are essential for directing water flow accurately onto the turbine blades ensuring optimal energy conversion in an efficient way. So, next we look at the advancements in the sand casting process for hydro turbines. With the rise in additive manufacturing processes, there is significant advancement in casting processes for hydro turbines. Binder jetting of foundry sands has particularly revolutionary change in sand casting allowing the whole body casting of variety of complex structures. These molds are produced by layer by layer fashion bounding the sand molds which is binder jetted at the required positions controlled by a movable head.

So, here the binder jetting has brought huge scope in manufacturing of complex structures leaving behind complications, limitations to only imagination of a designer and this technology may be used to manufacture the turbine runners. So, here we can see an image of sand mould of Francis turbine developed using binder jetting process which is one of the additive manufacturing process. So, another advancement in case of casting processes for hydro turbine it includes the ice casting is which is one of the latest form of casting, in which ice molds are used for casting so that all the materials during the molding process are kept below 0 degree Celsius which requires large freezer that is capable of keeping all the supplies refrigerated. So, next we come to the advantages of the sand casting process manufacturing of hydro turbines. So, advantages of sand casting process involve design flexibility.

So, sand casting offers extensive design freedom, allowing the manufacture of complex geometries and intricate shapes required for turbine components, accommodating custom and specific designs. Cost effectiveness is the next advantage. This is particularly suitable for producing large parts and low to medium volume productions. Sand casting also provides cost effective solution compared to other manufacturing processes. The sand casting process as we know is quite versatile in handling different types of materials.

The process supports wide range of metals, alloys, be it ferrous or non-ferrous, enabling

optimal selection of materials during mechanical and environmental requirements. Rapid adaptation, so here in this case sand casting facilities, quick modifications and adaptations are possible to meet new design requirements crucial for custom and evolving designs. So, now we look at a case study by Zollerin which is one of the manufacturer of hydroelectric turbine parts. So, this manufacturer utilizes sand casting to produce high quality turbine components which offer custom designs and can rapidly adapt to new specifications provided via 3D data. Their capabilities include producing parts up to 8000 kg in aluminium bronze and 2000 kg in cast steel, ensuring a broad range of applications from small to large hydroelectric systems.

Zollerin steel and aluminium bronze alloy for turbine components. So, this is widely used for Francis running wheels, turbo running wheels, Kaplan turbine blades, guide blades, hub bodies. Then, we look at the overview of the investment casting process. So, investment casting also known as the lost wax casting process is a precision process which is used to create complex detailed metal components. This process is highly suitable for manufacturing of intricate parts of hydro turbine.

So, because the process produces a very good surface finish so components like runner blade which require high dimensional accuracy and smooth surface finish are manufactured using investment casting. So, materials which are commonly used here include nickel bronze alloy. This is C99350 alloy composed of around 65% copper, 16% nickel, 7% aluminium and 7% zinc along with other minor elements. This alloy offers excellent toughness, resistance to cavitation and erosion and is cost effective for local manufacturing. So, here we can see the typical microstructure of nickel bronze alloy using casting for a runner where we can see the aluminum rich zones in the microstructure.

So, here we can see the different photographs of the Francis turbine runner which is manufactured using investment casting. So, we can see the relatively smooth surfaces on the turbine runner formed by investment casting and we can see how the complex shape blades are also effectively cast using the investment casting route. So, now if we look at the process for investment casting for hydro turbines in, what are the modern updates in this process. So, the process steps in this regard have changed and now we have utilization of computer aided design and simulation. So, the process begins with a detailed CAD model of turbine components.

Tools like computational fluid dynamics, finite element analysis, are used to optimize the design for specific water potential of operational sites, ensuring that there is maximum efficiency. Modern softwares like, solid cast or flow cast may be used to simulate the casting process, analyzing metal flow and solidification to predict and mitigate potential defects. The second step involves the wax model of the turbine part to be produced. So,

this is done using modern 3D printing technologies like stereolithography that can create precise wax pattern directly from the CAD model and this prototype can also be used to create silicone based molds. So, the wax model is then carefully inspected, refined to ensure it matches the desired specification including considerations for shrinkage during casting.

So, we can see here silicone mould components of the casting being produced as well as on the right hand side we can see the ceramic shell which is coated along the wax pattern of the investment casting. So, after this the mold creation is done. The wax pattern as we know is repeatedly dipped into ceramic slurry, adding each layer to add strength and detail of the mold. Initially, a fine ceramic powder is applied followed by coarser materials. This process continues until a robust ceramic shell is formed.

The mold is then dried in a controlled environment to achieve optimal hardness and durability. Wax removal is then done. This process is known as the burnout. So, ceramic mold containing the wax pattern or mold is heated in a furnace or a kiln causing the wax to melt and drain leaving a hollow ceramic mold. So, this step is crucial to ensure the final metal casting is free of wax residues.

Subsequently, in step number five we have the metal pouring where preheated ceramic mold is filled with nickel bronze alloy. The alloy has high fluidity which ensures it completely fills the mold capturing all intricate details of the original wax model. Solidification simulations they help to optimize the gating system and pouring parameters to prevent defects such as porosity and incomplete filling. Then we come to step number 6 which involves cooling and shell removal. The filled mould is allowed to cool and solidify.

Once the metal is cooled, the ceramic shell is broken away, revealing the cast component. Any ceramic material is removed using mechanical or chemical methods, ensuring a clean and smooth surface. Then, last step is the finishing step in which the casting component undergoes various finishing processes. These finishing processes include grinding, machining, polishing. This step also ensures that the final dimensions and surface finish meet the required specifications.

Various non-destructive testing methods such as, X-ray inspection may also be used to detect any internal defects in the cast components. So, here we can see photograph of a runner which is cast out of nickel bronze alloy and after doing all the secondary processing of finishing, machining etc., we can see the final runner shape which is on the right hand side. So, with this we come to the end of this lesson where we have now, where we will now summarize the content. So, in this lesson we have looked at the casting processes.

Which are specifically used in manufacturing of hydro turbines. So, we have seen specific details with respect to sand casting and investment casting. which are used to make various components of the hydro turbines. So, blades etcetera they are cast using investment casting and other components such as casing and runners etc.

Are cast using sand casting. And then, we have also looked at the case study of nickel, aluminium and bronze alloy. where, we have seen how these casting processes have been specifically used to cast the components of hydro turbine. So, in the next lecture, we will see the manufacturing process for the hydro turbine in terms of the forging which is used to form the various components. Thank you.