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

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Lecture 14

Welcome to this course on manufacturing for turbines. So in this lesson 14 we will learn about the finishing processes which are used in the gas turbine blades so this lesson will cover the finishing processes in which we will see in detail the process of creep feed grinding. We will see the classification of the finishing processes the classification of grinding processes need of creep feed grinding in gas turbine blades. We will look at the cutting action of the aggressive grain, the continuous dressing, creep feed grinding process, the advantages and applications. So, first we will understand what are finishing processes, why they are needed. So finishing processes are basically processes which are very essential to any manufactured components because it is managing the surface of the component by providing a smooth surface finish which is not only necessary for the dimensional accuracy but is also important for the service of that particular component.

Such processes they provide a smooth surface with tighter tolerances and smooth surfaces are also desirable not only from the aesthetic perspective but also from the perspective of performance such as fatigue and improved surface resist, fatigue failure or maybe other types of cracks which are generated on the surface in service. So finishing processes, they are categorized in four types. These include the grinding process, honing process, lapping process and some other processes which of course they include the like polishing or they also include buffing etc. Now here what happens that in all these finishing processes these are sort of abrasive action based processes.

So here we will understand what is an abrasive? Irregularly shaped particle with sharp edges and often the abrasive is also known to have high hardness. so we look at a typical shape of an abrasive so an abrasive may look like this where we have these sharp edges and corners and because of this presence of the sharp edges or corner the abrasive when it comes in contact with any surface especially the metallic surface so the abrasives they cause material removal because of which the finishing action takes place and material removal is carried out using micro chipping or micro ploughing. So, because of this micro chipping and micro ploughing action this results in cutting or we can say micro cutting through which material is removed in form of very fine chips and the finishing processes they vary based on the form of abrasive. For example in the grinding we have the abrasives which are available in form of a wheel which are bonded so here in case of grinding we have bonded abrasives. In honing also we have bonded abrasives, so this means in honing we have sticks, honing sticks.

In case of grinding we have wheels. In lapping of course we don't have bonded abrasives, rather we have free abrasives which are suspended in a slurry and similarly in polishing and buffing. So, because of this material removal from the surface, the finishing processes, they remove burrs or maybe they provide a very smooth surface by removing excess material. So, they also come in category of machining, but they are always looked at as a tertiary process. So, in the gas turbine blade, we will see where the requirement of the finishing processes is there.

So, if we compare the current process that we are discussing that is the creep feed with the existing grinding processes. So, creep feed grinding or it is known as the CFG. It is a sort of a process where the speed is there, but what is there the rate at which the grinding wheel is moving, the feed is extremely slow. So, what this results in? So, this results in a typically higher material removal compared to the conventional grinding or maybe the high speed grinding. So, in this case, we can see that in case of the conventional grindings, for example, the workpiece speed or the feed at which the workpiece is fed is around 1500 millimeter per second.

In high speed grinding, so this goes to around 2500 millimeters per second. But if you talk of creep feed, so this is around 50 meter per second. So, here the word creep it is different than the creep failure that we have studied earlier so creep means slow moving this is the meaning of creep here feed of course we know this is the speed at which work piece is fed against the grinding wheel and then grinding of course is the action of finishing here. So, the speed at which the wheel is rotating is similar to the speed which is there in the conventional grinding. So, because of this slow moving feed, so the depth of cut in CFG is very high.

Because we can compensate the productivity of the process, if we are reducing the feed rate or feed speed, so we have to increase the depth of cut. Another important characteristic of creep feed grinding is the shape of the grinding wheel it confirms to the shape of the workpiece which is in our case is the gas turbine blade here so we will see now more details where the creep feed grinding is needed in the gas turbine blade so in the gas turbine engine the blades as we know are fixed on the rotor disc If you look here, this is basically the rotor disc on which the blades are fixed. So, now this fixing of the blades on the rotor disc is done using a dovetail connection because when we draw the gas turbine blade. So this lower part of the blade forms the dovetail joint in the rotor disc. So this basically locks in here because we have slots in the disc.

So this locking of this dovetail part of the gas turbine blade into the disc, it happens only when we have an extremely smooth surface finish on this dovetail part. Because up to now we have seen that the top part of the blade, which is of course aerodynamically shaped because of the aerofoil structure, it is single crystal cast because of the single crystal casting process. Subsequently, the blade is subjected to hot isostatic pressing to consolidate the microstructure, remove the porosity, micropores and so on. Other than this, in general it is observed the most of the manufacturing processes are they do not give the required dimensional accuracy, beat any process. For example, even if we are using the investment casting route, still the dimensional accuracy or surface finish is not up to the level what is needed for the blades or the gas turbines.

So in generally the grinding processes or the surface finishing processes, so the phenomena of abrasion is utilized to remove the small amount of material from the surface by cutting or micro cutting which produces tiny chips. And abrasives as we have already discussed these are small, hard, irregularly shaped particles generally made up of non-metallic materials. Non-metallic materials here specifically for engineering purpose or finishing operations. So, the different type of abrasives which are used this include alumina. This also includes silicon carbide.

Then we have cubic boron nitride and diamond is also a very popular abrasive which is used. So in this the first two they come in the category of conventional, abrasives and the last two they come in the category of super-abrasives. So this terminology differs based on their characteristics, hardness. and their ability to retain shape under the grinding forces and so on. So, here in this photograph which we can see how the creep feed grinding process is utilized to grind the dove tail part of the gas turbine blade.

So we can appreciate the need of concrete grinding from this image so through grinding we are able to remove material with the help of a rotating abrasive wheel in this wheel as we have discussed earlier in grinding the abrasives are bonded abrasives and the bonding takes place with the help of bonding agent In grinding, it is same as any other machining process in which material removal takes place because of plastic flow deformation, which results in formation of chips. So, here we can see the cutting action of the grinding wheel, wherein we can see the irregularly shaped abrasives, they are sometimes also termed as grits. these abrasives are held together using a bonding material and this bonding material this can be different type of bonding materials like rubber/shellac/vitrified material etc. And here we can see the workpiece, the interaction of these abrasive or grits with the workpiece. So, depending on the position of the grids, so at different point of times different grits they interact with the surface of the workpiece and they remove material because of plastic deformation and chips are formed.

And continuously the grits they also undergo change in shape. and the ability of the grit to maintain the sharp edges is known as free ability. So free ability is the ability of these chips because as you can see that as the grinding process continues the chips the sharp edges of the ship chips. They also keep on losing but at the same time as the chip is irregularly shaped new edges also keep on forming so the materials which are used to make these chips they should have the ability to create new edges and corners so that the performance of the grinding process does not decrease and this ability of the chips to keep on creating new edges and corners during the grinding process itself is known as the creability. So, the creep feed grinding process, we can now see the details.

So, this process was invented in Germany in 1950 by Edmund and Gerhard Lang. So, creep feed grinding process is characterized by deep cut or the depth of cut is much deeper or much higher which is focused towards higher material removal rate. And to achieve this higher depth of cut, we have a lower feed rate in place of a fast reciprocating motion, as it is there in a conventional grinding process. So, depth of cut of the order of 6 millimeter is used on the low workpiece feed and surfaces with softer grade of resin bond. So, this resin bond is nothing but the bonding material which is used to hold the abrasive grits in place so that we have a wheel with us.

It is used to keep the workpiece at low temperature and also results in improved surface finish of the order of 1.6 micron of the max value. And because of this high depth of cut, the material for the same amount of material to remove the same amount of material. The creep feed grinding process for example takes 117 seconds to remove for example 1 cube inch of material and for the same material precision grinding process may take up to 2000 seconds. So because of high depth of cut, we can see that creep feed grinding process is much faster and even compared to the precision grinding, it is very much faster to remove the same amount of material.

Other aspects in the creep feed grinding, they also include monitoring of the temperature. Because of high depth of cut, the arc of contact in the creep feed grinding process is much higher. So, the temperature of the wheel and workpiece interface needs to be continuously monitored. The high depth of cut, because of this high, we can say depth of cut, there are several challenges. First challenge includes the high temperature in the arc of contact.

Second is the extensive loading of the grinding wheel. Loading here is basically the process by which the removed material it gets stuck in between the gaps between the two adjacent grits or abrasive grits. And presence of this loaded material in between the grits, it not only reduces the grinding performance, but also compromises with the free ability of the grits subsequently. So, in order to remove this loaded material from the space between the grids, continuously dressing using a diamond tipped tool is done on the creep wheel grinding wheels. And after the dressing, the wheels are continuously cleaned using compressed air.

And to manage the temperature or to minimize the temperature in the arc of contact, there is application of coolants in the cutting or the grinding zone. So, because of all these measures, the 3 feet grinding not only takes care of the shape to maintain - the shape of the workpiece, but also the dimensional accuracy of the workpiece. So, here we can see the comparison between the reciprocating grinding or a conventional grinding with creep feed grinding. So, here we can see in terms of depth of cut, so in millimeters in case of the reciprocating grinding, so there is 0.001 to 0.1 meter, for creep feed it is 1 to 12 millimeter, so high material removal rate.

And in case of this reciprocating grinding, there is low material removal rate. So, workpiece speed here is 10 to 40 meter per minute, here it is 0.07 to 1 meter per minute. Wheel speed it is comparable, it is 20 to 50 meter per second. In this case, it is 15 to 45 meter per second. Here we can see the arc of contact that is the contact length between the circumference of the wheel and the workpiece. It is of the order of 0.5 to 6.7 millimeters.

And in case of creep feed grinding, it is almost double or maybe 10 times to what it is in case of the reciprocating grinding. So, it is around 17 to 70 millimeters of arc of contact. And because of this high arc of contact, we can understand that there is probability of thermal damage to the workpiece. But this also results in high material removal rate of the order of 8 to 80 millimeter cube per meter per second, which is only values only 0.5 to 4 in case of reciprocating grinding.

And what this results in, in case of reciprocating grinding to achieve the same level of material removal, we may need to do several passes. And in case of creep feed grinding, only one pass is sufficient to remove the material completely. So we can now see the summary of creep feed grinding. Creep feed is longitudinal slow movement which is resulting in slow feed or creeping feed like the creeps it moves slowly towards the grinding wheel. Creep feed wheels are also characterized by their shape, which is often dressed according to the shape of the workpiece.

So, these are not flat cylindrical wheels, rather the shape of the wheel is confirming to the shape of the workpiece wherever the grinding needs to be done. So, multiple profiles on the wheel they allow a shorter cycle with high throughput or high grinding ratios. So, this results in high stock removal even for hardened materials. Example, the nickel based super alloys which are used in the gas turbine blades. But to execute the creep feed grinding, it is understood that the extent or the magnitude of the grinding forces will be much higher.

So the robust and stiff design of the machine tool which is doing the creep feed grinding is desired. And it is also very economical to machine several grooves, serrations and deep slots. And one of the major problem which is encountered in creek feed grinding is basically the high thermal damage and heat affected zone on the workpiece which is of course managed by or minimized by application of cutting fluids. So, creep feed grinding has this also another disadvantage of the wheel which can constantly degrade under the influence of high depth of cut which requires also requires high spindle power. So, in this regard to address the problem of reducing wheel sharpness continuous dressing creep feed grinding process was developed in 1970s.

And in this case, the wheel is constantly dressed while it is grinding, keeping in the state of specified sharpness. And of course, here it takes only 17 seconds to remove 1 cubic inch of material, which is a huge gain in productivity compared to 117 seconds that we saw earlier. And the spindle speed is also reduced from 38 kilowatt to 28 kilowatt, which is comparable to say low or grinding speeds of conventional spindle speeds. So CFG machines or 3 feet grinding machines can have powers of the order of 225 kilowatt with high stiffness, high damping capacity, variable spindle and work table speeds with ample capacity of grinding fluids. And grinders are equipped with features for continuously dressing the wheel using a diamond roll.

So here we can see the positive and negative speed ratios. This is depending on the relative direction of rotation between the grinding wheel and the dressing wheel. So we can see here how the continuously addressing this dressing wheel is continuously dressing the grinding wheel, while the grinding takes place which reduces the flow to flow time here shown in the photograph is a air aircraft engine blade route within which because of the continuous dressing creeping grinding the process time reduces from 6 to 8 minutes to 20 to 30 seconds. So as there is high arc of contact, so there is important role of coolant in creep feed grinding. So long arc of the wheel, it translates into higher heat generation during the process.

Coolant is therefore crucial in creep feed grinding to perform the grinding process effectively. Other machining processes which apply flood coolant using nozzle to point of coolant system stream roughly in the direction of cut. So, here the coolant application is to be taken more seriously and coolant delivery speed is often matched to the speed of the grinding so that the effectiveness of the coolant is not compromised. So here we can see how the creep feed grinding wheel which is confirming to the shape. So this shape of the grinding wheel confirms to this blade root or the dove tail part of the gas turbine blade.

It is utilized to grind these areas of the gas turbine blade for effectively assembling the gas turbine blades on the rotor disc. So we can now summarize the advantages of creep feed grinding, which include shorter cycle time. So the low feed rate is compensated by higher depth of cut. So fewer passes mean there is less time to lose against acceleration and deacceleration. So, there is reduced machine wear because of less frequency of machine reversals, longer wheel life, so lower force per grit is there in higher MRR which reduces the demand on the wheel, thereby extending its lifespan.

So, creep feed grinding process can also result in finer tolerance with complex geometric control because the shape of the wheel conforms to the shape of the workpiece where grinding is needed. So not only gas turbine blade, the creep feed grinding process is also utilized in several other applications which include as listed here. Some of them are notable applications include aerospace flap, lubrication grooves for bearing industry, teeth grinding for shaver blades, steering pistons, sliding caliper, rocker arm, so on and so forth as shown here in this non-exhaustive list. with this we come to the end where we now we will summarize the lecture so in this lecture we have looked at the concepts of creep feed grinding cfg for gas turbine blades we have looked how the cfg process compares with the conventional grinding process. And lastly, we have looked at some of the applications of creep wheel grinding process.

So, in the next lesson, we will look at the other and the last manufacturing process for the gas turbine blades which include the application of thermal barrier coatings on the gas turbine blade.

Thank you.