**Metal Cutting and Machine Tools**
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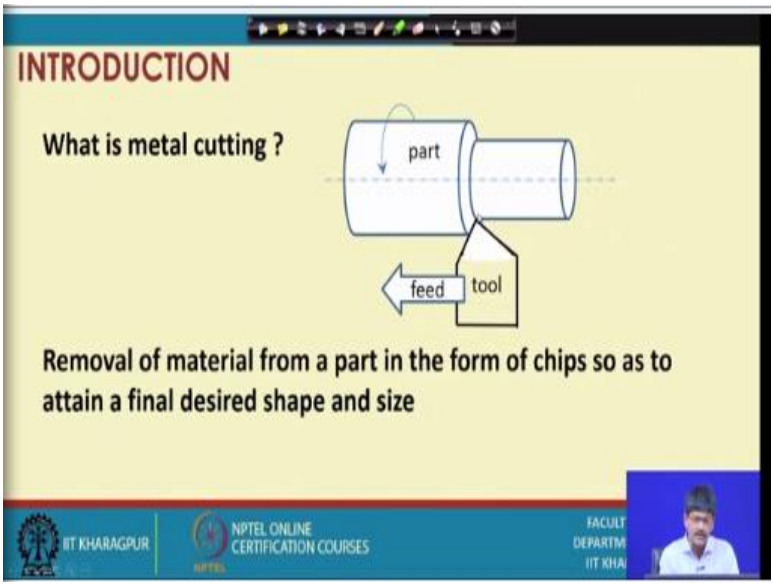
**Lecture-01**
**Introduction**

Welcome viewers to the starting lecture of the course metal cutting and machine tools**.** So, this will be a 10-hour course in which we will be discussing different aspects of metal cutting and different types of machine tools, their applications etc. So, by way of introduction I will go through a rough overview of the 2 ideas, metal cutting and machine tools, their relation etc. And then from the next lecture onwards we will be taking up all the aspects in more detail.

So, first of all metal cutting, what do we exactly mean by that? Metal cutting is concerned with removal of material. Metal cutting at this age does not necessarily involve only the removal of metals or only the cutting of metals but it is referred to all materials in general. So that, if you consider it is correct to say material cutting or material removal, why are we removing material?

Because we want to achieve a particular shape and size in a part by removal of material, so let us have a look. Metal cutting in machine tools, my name is Asimava Roy Choudhury and I am professor in mechanical engineering department of IIT Kharagpur. So, let us have a look at this particular figure, what do we have? **(Refer Slide Time: 02:09)**



If you look at this particular figure what do we have? We have here a work piece or part or job shown here rotating. And there is something called a tool or a cutting tool here and how is it characterized? It is characterized by a sharp point and some sharp edges here and it is moving past the rotating member that is removing material.

We will look at several other figures in which the removal of material is shown in more detail. What happens is when this part is coming here it gets into the path of the moving tool and this material comes out in the form of a chip, a ribbon of material is removed here**.** So, removal of material takes place from a part in the form of chips, so as to attain a desired shape and size.

I want to attain a desired shape in size and for that I am removing material from the main body which is called the part or workpiece or job etc. I am removing part of it, so that a particular shape is attained. So, naturally this particular exercise is carried out always on a part where there is excess material is there, but why would we do that? We are doing that because there might be intricate geometries present on the surface of the part which cannot be attained by other means.

So, immediately there is the identification of other methods of attaining a particular predetermined shape and size. And all these things together they are referred to as manufacturing**.** So, let us have a quick look what is manufacturing all about?

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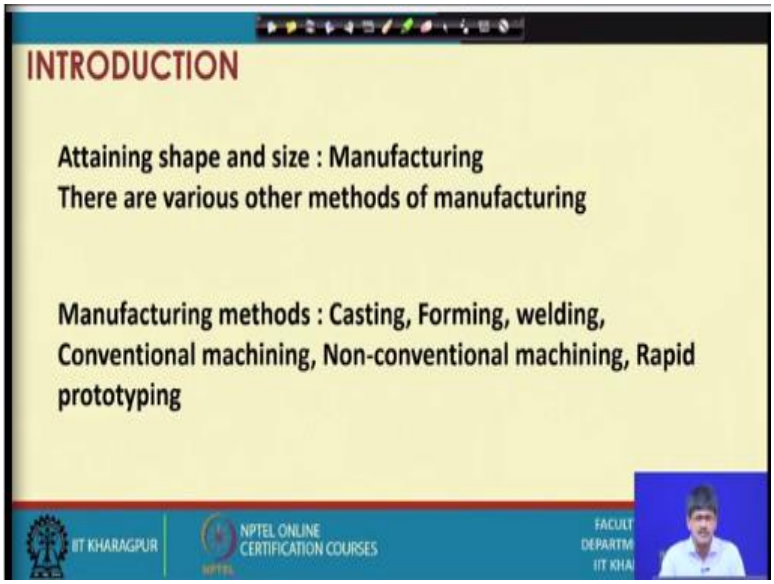

Attaining shape and size predetermined, this is what manufacturing is all about. We can have different ways of manufacturing these shapes and sizes and metal cutting happens to be just one of them. So, let us have a look what are these methods by which we can manufacture parts of different shapes and sizes. We can have casting, we can have forming, we can have welding, we can have conventional machining, we can have non-conventional machining and we can have rapid prototyping.

These are some of the main methods of attaining shapes and sizes. There can be other methods also, there can be hybrid methods that means a mixture of two of the processes etc. Now in that case first of all where is metal cutting? I cannot see metal cutting or material removal etc. Metal cutting belongs to this particular group, conventional machining**.** Material removal, conventional machining, metal cutting, metal machining etc., all these things are belonging to this particular group.

They are being called conventional because we are going to apply certain practices. There will be particular types of material removal which can be categorized under a single principle of material removal and that we are calling as conventional but what are these principles? It is something like this, if I remove material from a body by mechanical means by applying force and remove material that is generally referred to as conventional machining.

We will see this in more detail of course. Non-conventional machining is when we remove material from a body where some other principle of material removal is taking place, we refer to it as non-conventional, what is that. What are the principles by which material removal can be carried out without mechanical means? For example, in electrochemical machining, we can apply electrolysis and electrolytically dissolve a particular body, so that material is removed.

There we are not applying mechanical forces in order to remove material. So, non-conventional machining can be electrical discharges across a gap so that these electrical discharges cause thermal damage to the material, that means simply it heats it up to such an extent, so that is called electrical discharge machining. So, electrical discharge machining can be there,

electrochemical machining can be there, laser machining can be there. So many such non-conventional machining methods are there.

Generally, we will only be having a brief overview of these non-conventional methods. In our lectures we will be mainly concentrating on the conventional machining principles. Rapid prototyping, just like you are say removing material and attaining a particular shape that means you are moving by subtractive principles, we are subtracting certain volumes from a main part, main volume and attaining a definite shape and size.

In the same way we might be adding on, that means we might be going for additive manufacturing, we might be adding different volumes together, so that they stick to each other. And form our definite shape and size, in that case call it the method of rapid prototyping or additive manufacturing. I will just in one or two lines I will just try to give you the idea of casting, forming, welding etc. So, that we have a brief overview of the main methods of manufacturing.

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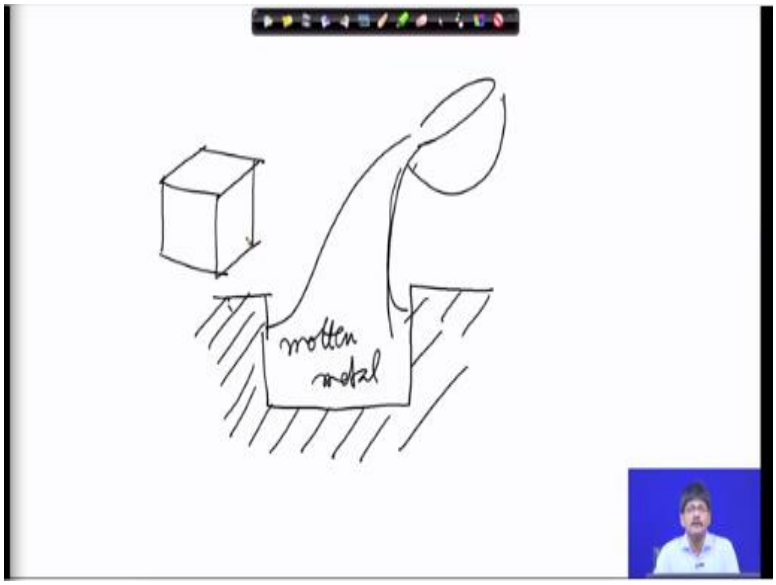


Suppose I have a cavity, I am showing very simple principles, so some material is here, so that a cavity is formed. Inside this cavity I pour molten metal, so ultimately the molten metal will solidify. So, if it solidifies it will attain the inside or internal shape and be of a definite size, so this is casting. Melt the material; pour it into a cavity of predetermined shape and size.

And when it solidifies we can take it out this particular sand mould which is shown here, that can be destroyed and we can take it out. And we will get a solidified body say it might be something like this. And if this is exactly the shape that you wanted and you are satisfied with the surface roughness and whatever imperfections might be there, that is it, in a single process you will be achieving what you wanted.

If, however there are some surface imperfections which you have to do away with or the surface is too rough for sand particles are sticking to it, so many other sorts of defects can be there. In that case what we do is we go for secondary processes in order to make the job or the part or the workpiece or the casting acceptable.

So, this is what casting is all about, we basically go for melting and re solidification in a cavity of predetermined shape and size. There are so many other details about casting which I am not touching here. Because we just want to have the basic idea by which this particular process works. Second, so if we once again look at this.

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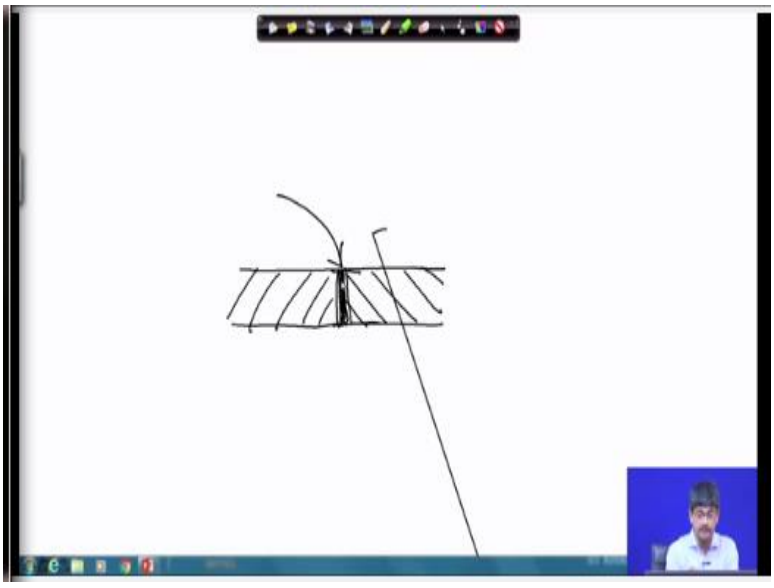

So, let me quickly go for another page, yeah. So, here welding, what are we doing? We are fabricating we are say connecting up, these two pieces that need to be joined. So, welding is a

joining process and we can build up shapes with that. So, some material in between or make them very close together and heat them.

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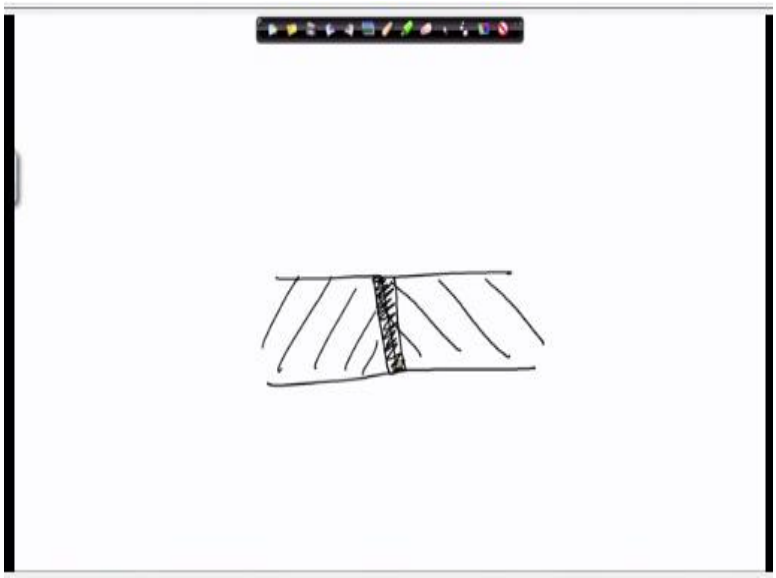

So, if I have two such materials, this is one, this is the other and I heat them at this point, so that this part melts, that is it. This part melts when it solidifies this will be a single piece, so that we can join parts and make up shapes. Our main concern is to make shapes of predetermined shape and size. So, many times you might have seen even in civil activities, gates, grills, window grills etc., these are made very elegantly by welding.

So, just imagine if welding had not been there how would you have done these things? So, it is a very important manufacturing process. So, we come to know of casting, we come to know of welding. Now, different welding methods can be there but that is not our concern today in today's lecture. Our concern is to get to know to have an overview of the different manufacturing processes.

So that we understand where exactly machining or metal cutting or material removal process stands. Next we come to forming, so let us have a quick look at forming. Forming method essentially involves deformation, I deform a particular body into a definite shape, let us have an example.

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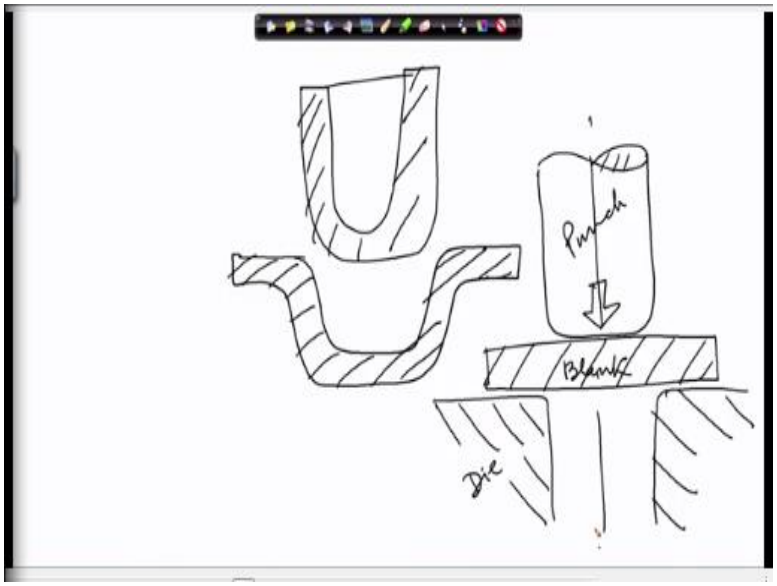


This is a very simple and explanatory example, someone shows you this part which is a sheet metal and we are seeing it only from the side sort of sectional view but how was this done? And that particular person says that it was done by say deep drawing, what is deep drawing? So, initially there must have been a body of this type, a sheet metal piece may be circular, circular this way and there was a punch and there was die.

Now what are these punches and dies? They must be materials which are made of hard and tough materials. So, that they do not deform but this deforms, this is our blank. Blank refers to the shape of a part before machining or before metal forming or before any such formative or manufacturing process, the blank. So, this we call the punch, this we call the blank and this we are calling the die.

So, if this goes down we will have gradual deformation and this is one intermediate step, when it is fully through this will be drawn in the form of a cup. So, at that time the internal shape will correspond to that of the punch outside shape and it will be a conjugate of that surface. And the outside diameter will be corresponding to the inside diameter of the die. So, this is one example of metal forming, you can deform a body into shape, you are not having removal of material in the form of chips, you are not having melting and you are not having joining.

But you are basically deforming by plastic deformation, please note that had it been elastic deformation it would have sprung back into shape. So, it is definitely plastic deformation which means that once it is deformed it cannot come back to the original shape. So, what is this called? This is called deep drawing and there can be other methods also, for example there can be rolling, there can be forging, there can be extrusion, there can be back extrusion and similarly many methods are there.

But as we just need to have an overview I am sure that you will get the basic idea of metal forming from this example. So, this part we have already discussed, overview of casting, forming, welding. Conventional machining, we are going to discuss that is actually our topic. And non-conventional machining, let me give you a quick idea about some of the processes.

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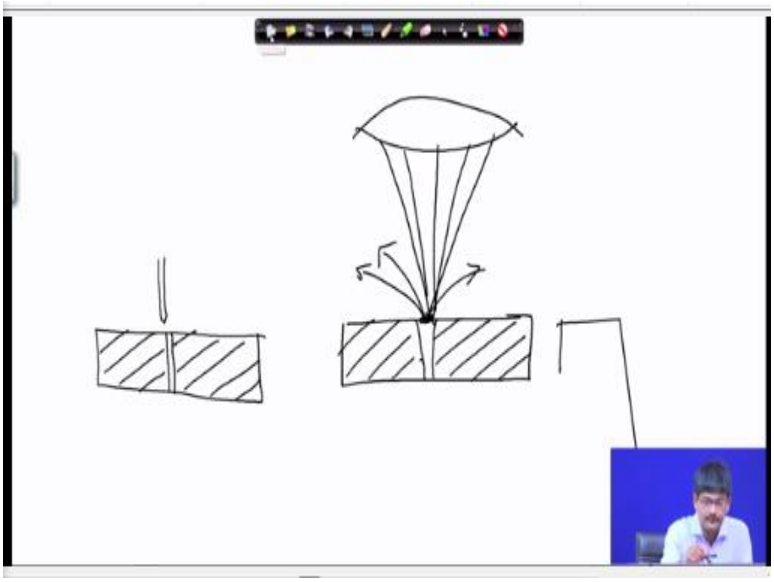

Non-conventional machining, say I will start with laser I need to make a very narrow hole here, what kind of dimensions am I talking about? I am talking about say dimension of say 250 microns; if it is 250 microns it means it is 0.25 millimeters. Now is it possible to drill a hole of 0.25 millimeters by conventional means, that means by mechanical means, having a tool which can push away material and cut it off and produce this hole, maybe it is possible.

But the thing is that as the size goes on getting reduced it becomes increasingly difficult to do it, why? Because a thin a very small diameter drill will have to sustain or withstand the stresses

which will be induced during cutting and it might not be able to sustain that. So, as the drill is becoming narrower and narrower or smaller and smaller diameters are being cut, we have the possibility of drill snapping or it might even buckle if the L by D ratio is very high, what defines the L by D ratio?

If you are having the drill coming here, if you have a look at this, if you have the drill coming here, conventional drill sorry this has to get inside and therefore its length has to be at least larger than this length. So, if this length is very high compared to the diameter you have a high L by D ratio drill that is a problem, why? Because it might be buckling even if it does not snap under the stresses it might buckle.

So, indeed there is a degree high degree of difficulty in drilling such a hole by conventional means. Let us now think of the laser, how can the laser solve the problem? You can have this job under the laser beam and a lens is focusing it here. The laser beam is basically a light beam electromagnetic radiation, if it is focused here since the laser has coherence there will be phase coherence here.

So that there will be buildup of intensity and this energy will be converted to heat energy, most of it will be converted to heat energy if it is not reflected or by some other means lost. There will be tremendous temperature rise at this particular position. This temperature rise will give rise to melting evaporation and ultimate removal of the material in the form of vapour and in the form of liquid ejection and we will find that the hole is initiated which hopefully will be propagated right through, so that we have a hole.

So, instead of using conventional means of applying mechanical forces and having a sharp edge etc., we can remove material this way also. This is one non-conventional method; other methods can be there as I mentioned.

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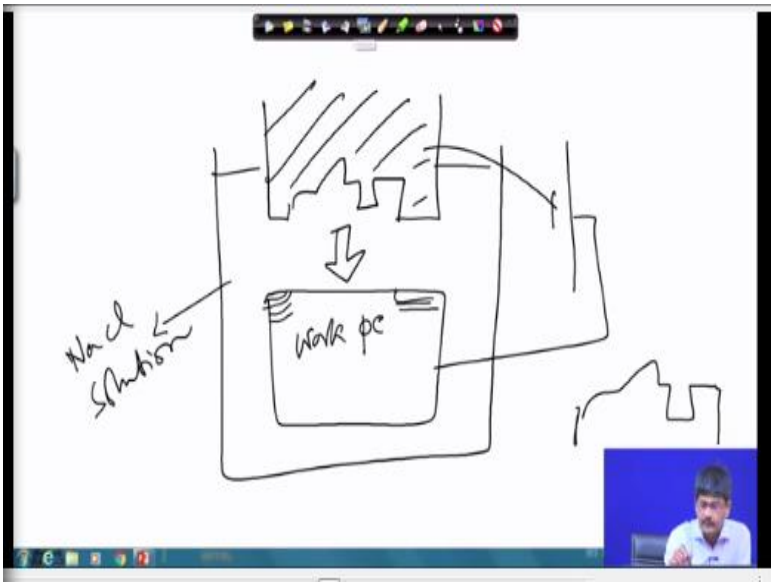


You have the part here and you are having a job of this type. And you bring it towards the job; you give it electrical connection; you submerge the whole thing in electrolyte solution say NaCl solution. This is your workpiece at this moment, it is the blank. So, the conjugate of this surface will be produced because other parts like this protruding part it will be dissolving electrolytically, this will be dissolving, this will be dissolving etc.

What will remain is the conjugate of this, so that you will find that this part has been produced. Of course there are some mistakes in this drawing, these surfaces will be creating some issue for us, so please consider that actually straight or tapering surfaces only will be produced. So, this will produce a reentrant side here at this moment, so that is a mistake it is very difficult to produce this surfaces.

So, we can dissolve material instead of mechanically stressing them, so these are some non conventional methods. Let us come back to our original discussion, so in our original discussion. So, now we come to the discussion of metal cutting.

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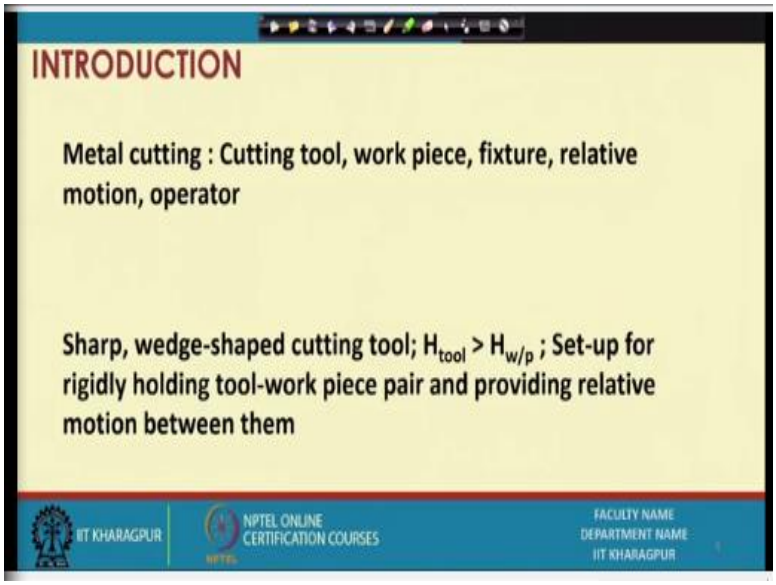


So, if you have a look here, metal cutting involves cutting tool, workpiece, fixture, relative motion and in many cases operator, what will be exactly mean by this? We mean that just like we were having some active member which was removing material from the workpiece or the blank. In case of metal cutting we have something called the cutting element or cutting tool which actually removes material by dint of its higher hardness by a presence of a sharp edge, at least 1 or 2 sharp edges on it.

And of course by its shape; by its wedge-like shape. So, a cutting tool is required for removing material. The workpiece has to be there, that means naturally if you are giving shape to a particular body, that has to be present. And it is important that the blank has higher dimensions than that of the final job and that is called machining allowance. We allow or we put some extra material which can be removed, so that the final shape can be attained.

If you do not give machining allowance, then you cannot machine because there is no material left. There is no material on the basic shape which can be removed and the final job can be produced, what is the problem with that? If you produce the exact shape by some other means, like if you produce it by casting or welding or by metal forming etc., there is a chance that the surface characteristics which are present, it might not be suitable for the final application that we are planning it for.

Like suppose you say that I am going to produce the exact dimensions by casting, what is the guarantee that the surface will be acceptable? If the surface is not acceptable, you have to do some machining on the surface and there you have no machining allowance left if you plan it that way. So, some machining allowance has to be there, just before you start machining.

So, by the workpiece we understand a blank, next fixture, what is the meaning of the fixture? Fixture here has specific meaning in case of metal cutting but for the time being we are referring to fixture as some sort of fixing or holding steadfast the workpiece and the cutting tool rigidly. You want to hold the cutting tool and the workpiece rigidly, so that when they are in contact with each other and they are having relative motion.

They do not get displaced or deflected or they do not slip out of their holding positions. That means hundreds of Newtons might be acting between them, they should not lose their rigid position at that time, if they lose it then machining will not be possible. Unless you hold the work piece and the tool very rigidly you cannot have machining possible in those cases. But you might say but the cutter is moving, cutter may be rotating or the workpiece might be rotating.

In that case how come you are still claiming that you are holding them rigidly? They might rotate, they might move but they cannot get displaced from their positions by the application of the cutting forces which arise during machining. We will have an explanation of this thing when we discuss those aspects. Now comes the question of relative motion, unless we have relative motion between the tool and the workpiece we cannot have the production of surfaces, we cannot generate surfaces unless we have relative motion.

Now these relative motions can be categorized, at this moment we will not go to it. But basically if you are having a primary generating motion it is generally called cutting speed which basically means that the cutting tool moves very fast past the workpiece and on its way it removes material from the workpiece. And if it is successful and this strip of material if it is removed, then we will be shifting the cutting tool from time to time.

So that this cutting action is extended to different parts of the job surface or the blank surface that is called feed motion and sometimes it is called directrix motion. Operator, operator is a very important part of this whole system in manually operated machines. You know manually operated machines are still there, we cannot deny their presence just because we are having automated machines, automation.

Just because we are having CNC, special purpose machines, cam control machines. All sorts of automation we cannot deny that a sizable part of the production is also done by operators. So, if the operator does something wrong machining will not be possible, so that is why more on the negative side the operator is very important. If he does his work correctly, we have no issues.

So, now we come to this particular aspect that is sharp wedge-shaped cutting tool. Now we are giving more details about the cutting tool, the cutting tool has to be sharp, the cutting tool has to be wedge-shaped, its hardness has to be more than that of the workpiece. Generally, it should be at least 1.3 times the hardness of the tool. And there has to be a setup for rigidly holding the work piece and the tool pair and relative motion has to be provided between them.

Why does the cutting tool have to be wedge-shaped and why does it have to be sharp? What is the necessity of such a particular shape? Let us have a quick look.

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See if we are having a body of this type, these are two bodies say they are extremely hard and they are totally rigid, there is no question of deformation. And just beneath them I am having a blank piece of material, this is our blank and I am having tool 1, I am having tool 2. Among these 2 tools I am asked to operate them and remove material. So, what are we supposed to do?

We are going to first do one indentation, that is we will be penetrating this inside, this one also inside and then we will be producing relative motion. Obviously in this case if this particular definite shape is not a basic requirement. That is suppose someone says that this is the shape that I want to be reproduced here if that is not an issue. Then what is generally done is suppose you want to remove material up to this point.

I want to remove this material, in that case this comes down I apply forces, so that this comes down right up to this point. And then for example suppose you move it this way, so this whole thing peels off, when it comes here the whole thing you will find it peels off in the form of a ribbon-like material called chip, move this, remove this. Here also if you move it up to this point and remove this, so it is basically case of indentation or pressing.
And creating a sort of indentation and then moving this way here also the same thing will happen, so what is the difference between them? The difference that, here there will be a tremendous force that you have to apply unnecessarily. Because you had this one, how is it this characterized? It has a wedge-shape, by wedge shape I mean something like this, it has a wedge shape with a sharp point, with this it can easily penetrate while this cannot.

So, that is why generally the tools have to have this particular shape because it is easier for indentation. So, when it indents and it starts moving towards one side and if these two bodies are rigidly held, we can have removal of material. So, sharp point, wedge shape and we will also learn that if we have sharp edges it will always help us to remove material. So, this is understood, we have identified what should be the desired shape of the tool, so that it can remove material.

You might say why not this shape, say a knife introduce it this way and then scrape off, cut it here, so that this comes out. Problem is now we are talking of removal of metal, not removal of

soft materials for example say bread or butter or what you call it? chocolate, no I mean slightly soft chocolate, no, or ice cream, no, no knife will be able to sustain the heavy forces which will be coming when you are trying to cut metal.

If you are trying to cut metal, these have to be sizably robust. That is why whenever you are seeing cutting tools, you must have seen cutting tools used on the lathe on the milling machine, they are the size is quite robust. You might be having a cutting tool which is of this shape and it might have always may do weigh curious, why do we use a shape of this type, why not a knife?

If you have a knife it would not be able to withstand the huge forces which are coming. So, we have understood these things, metal cutting what it is all about. Now comes the next aspect the setup for rigidly holding tool workpiece pair and providing relative motion between them, this is what the machine tool is all about. So, cutting tool is that particular small piece which removes material by dint of its hardness and what you call it and sharp point and wedge shape.

And the machine tool is the one which is the body which holds the workpiece and tool rigidly, so that they cannot deflect and also it provides the relative motion between them, that is the machine tool. So, cutting tool and machine tool they are absolute necessities in the metal cutting system. Now let us go to the next slide our last one possibly in this particular first lecture, just a moment, yeah.

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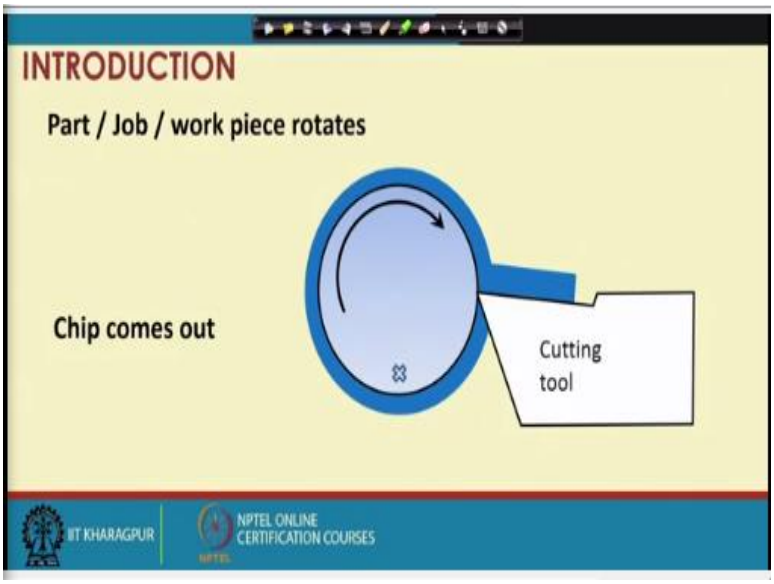


So, let us have a look at how this whole thing can be done on the lathe, the lathe is the most common machine tool. On that surfaces of revolutions are produced, surfaces of revolution mean that about an axis the body will have a symmetric shape, axis symmetric bodies are produced, what is this body? For example, just one moment, this body is a cylindrical body seen from the end, so this is the axis of rotation, it is rotating this way.

And this is the cutting tools that wedge shape which has indented or gone inside or pressed inside by a certain amount, this is the depth up to which it has moved in. And after that relative motion will be produced by rotation of the cylinder. Cylinder is rotating while cutting tool is not therefore relative motion is produced. If this relative motion is produced if they are held rigidly then material will be removed in the form of the chip that is the material which is coming out.

So, on the tool, material comes out it might be slightly curling up all also depending upon the cutting conditions. So, we understand that part or the job of the workpiece rotates and the chip comes out, this is the basic model of material removal specifically we have taken up this example on the lathe. And now that we have identified all those things we can find them all here wedge shape, sharp point, chip coming out, relative motion being provided to the blank.

So, that this material is getting removed in the form of the chip and you are going to get a smaller cylinder. So, now that we have identified the basic requirements say in the process of

metal cutting. Now that we have identified it s exact position in the family of manufacturing processes. In the next lecture we can take up more detail about first what is a cutting tool and what is a machine tool?

Cutting tool as such can be characterized by different geometry elements and we will take that up in more detail in the next lecture. After description of the cutting tool is completed we will take up description of different types of machine tools. So, that is the end of the first lecture, thank you very much.