Manufacturing Processes II
Prof. A. B. Chattopadhyay
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture No. 8
Machining Forces

Our topic is subject is Manufacturing Processes II that is continued,

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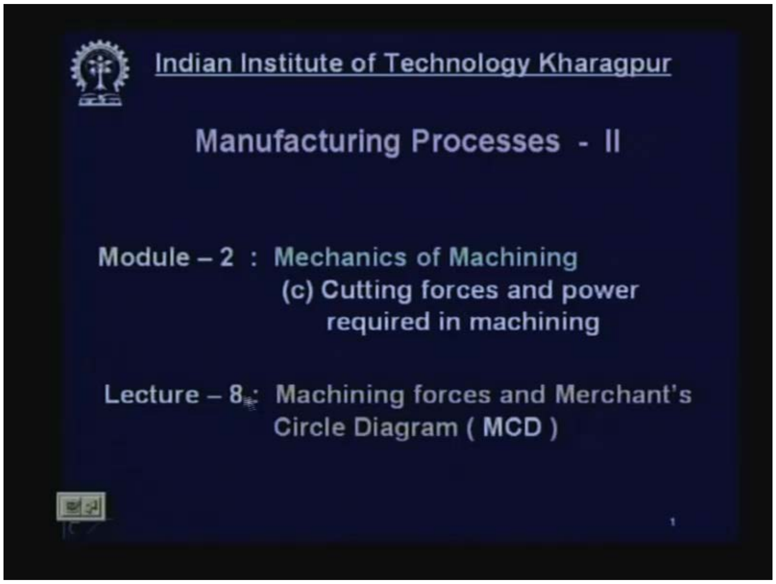

Module Number 2 - Mechanics of Machining; We are continuing and under mechanics of machining today our topic will be cutting forces and power required in machining. Now today is eighth lecture on this. Today we shall cover Machining forces and Merchant's circle diagram which deals with cutting forces. Now what are the contents subjected today? Specific Instructional Objectives: To enable the students, at the end of this lecture,

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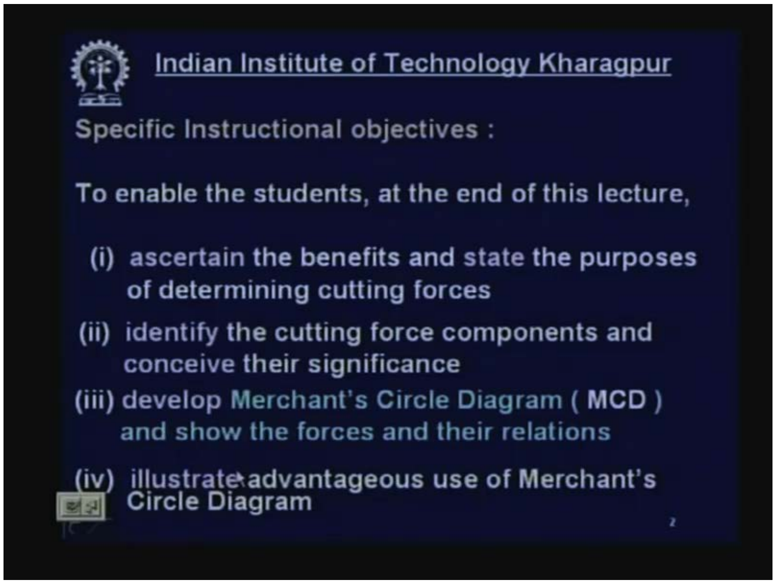

(i) ascertain the benefits and state the purposes of determining cutting forces. Why we should learn cutting force, why we should like to know the cutting forces, what is the utility? (ii) identify the cutting force components and conceive their significance in machining. (iii) develop Merchant's Circle Diagram (MCD) and show the forces content into that and (iv) illustrate advantageous use of Merchant's Circle Diagram.

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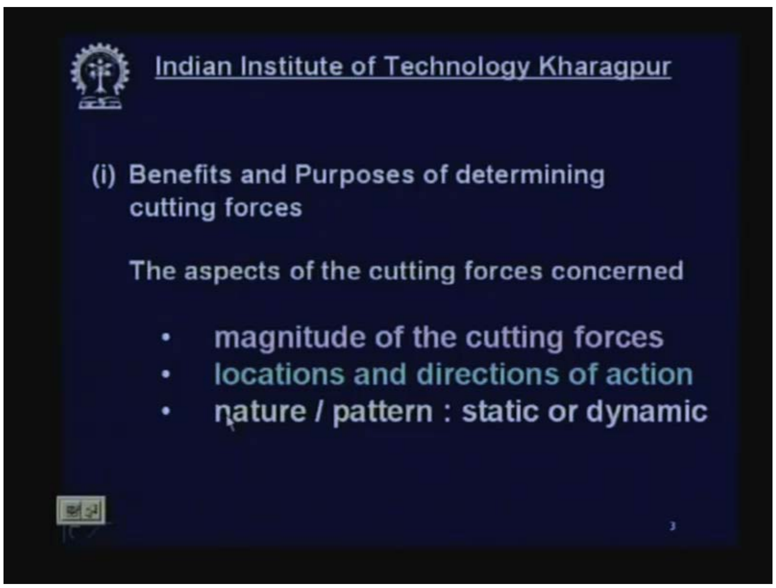

First let us see the benefits and purposes of determining cutting forces. Why one should learn this subject, why should we try to determine either theoretically or experimentally the cutting forces. Before we do that we should know that what major aspects we are interested about the cutting force. The aspects of the cutting forces concerned; The magnitude of the cutting force that is most important then locations and directions of actions of those cutting forces in the machines. Nature or pattern of the cutting force whether static or dynamic. If dynamic, then what is the frequency and amplitude? Now the determination of the cutting forces facilitates or is needed for:

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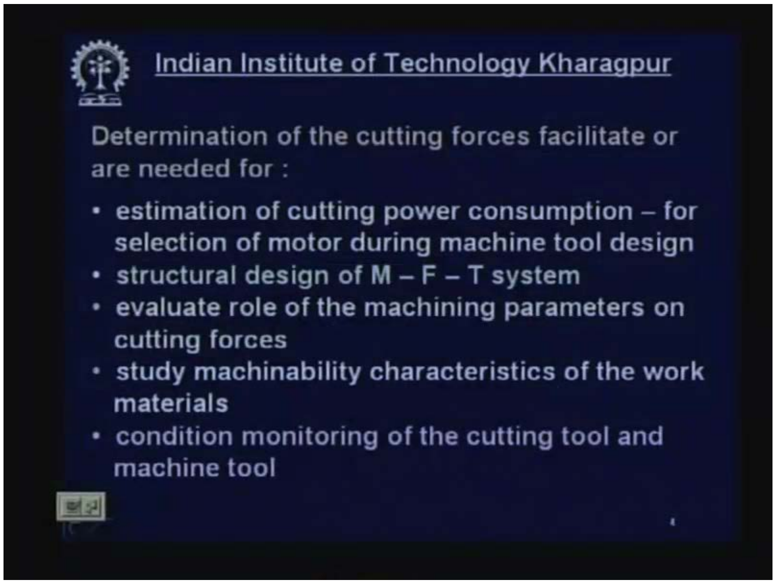

This is actually advantages or the purposes of determining the cutting force. How does it help us? This information knowing the cutting forces enable engineers or anybody estimation of cutting power consumption. Cutting power consumption is a major issue for everybody. It has to be minimum as far as possible. Now in cutting some power is consumed that has to be known and then we should act accordingly. Estimation of cutting power consumption - for selection of motor, machine tools is driven by some motors and what should be the specification of that motor? When we design a machine tool, we design the power drive and in the power drive, we have to select one say motor what should be the power of the motor and what should be the rpm or speed of the motor and that requires knowing the cutting force.

Structural design of machine tool fixture and the tool system; what is meant by design of a machine element? By design of machinery element, we understand if you remember that this is the machine element we have to design and first of all we have to select the materials and then determine the dimension of this component such that this component does not fail due to stresses caused by the forces acting on the component during its functioning. So the forces have to been known which will cause stress, and then we shall see that stress does not exceed the strength. So magnitude of the stress forces the direction and locations of the forces have to be known to determine the stresses.

Evaluate role of the machining parameters on cutting forces; as I already said, you also understand that attempt should be made to reduce the cutting force which is detrimental because cutting forces cause more power consumption and dimensional inaccuracy and vibration. So we have to control cutting force but not at the cost of productivity but how can we reduce the force until unless we know what factors govern or affect the cutting force. Therefore we have to evaluate the role of the machining parameters on cutting forces. What do you mean by machining parameters? Say process parameters, cutting velocity, feed and depth of cut if we change or increase the velocity feed and depth of cut what will be the effect of the force and this effect of on the force have to be evaluated by measurement on knowing the cutting force.

Then tool parameters, the cutting tool material and the tool geometry which play role on the cutting forces, then environmental parameters like cutting fluid application or any special technique. So we have to know about the cutting forces. Study machinability characteristics of the work material. Now the work material has got certain strength or shear strength. More the strength the material possess more amount of force will be developed and more amount of energy will be required, but the classical property of the material that we observe may not be maintained in the cutting condition. Suppose the shear strength of the work material may be widely changed during the cutting process or cutting condition. So we have to know the actual cutting force in the cutting condition and if we know from this cutting force we can study or understand the behavior of the material with respect to machinability.

Condition monitoring of the cutting tool and machine tool; Now during machining the cutting tool undergoes gradual wear and tear. Sometime it may under go very rapid plastic deformation because of high temperature and pressure. Whatever be the case the tool becomes dull and this is very undesirable if it becomes too dull then we have to replace it we have to withdraw the cutting tool and replace it immediately. But how do you know that the tool has worn out. We cannot take it out time to time stopping the production so we have to continuously monitor or measure the cutting force from the change in the magnitude and pattern of the cutting force, one can understand the condition of the cutting tool or even the machine tool. If the machine tool is defective or has some problem then cutting force pattern will change. So we should continuously measure or look in to the variation in the cutting force magnitude and pattern whether static or dynamic like that. So for these reasons and for the purposes the cutting forces have to be known offline and online always.

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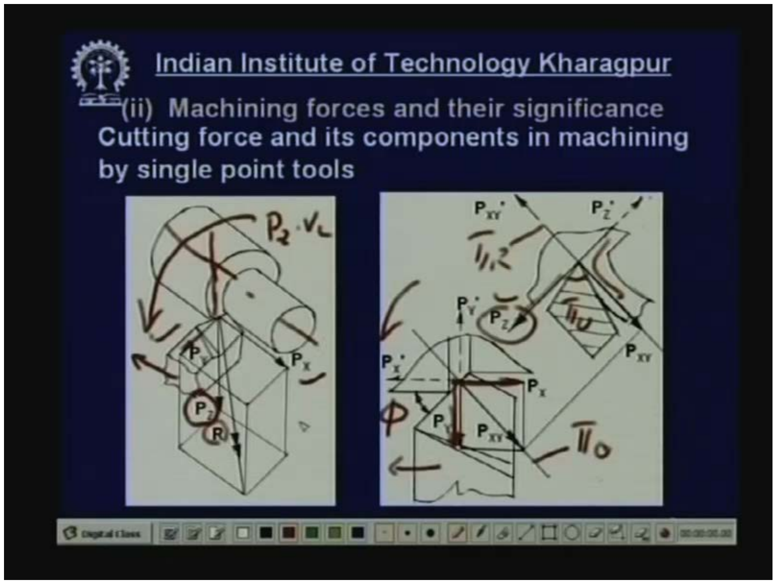

Now machining forces and their significance; Let us say cutting force and its components in machining by single point tools. Now there are different types of cutting tools. They are grouped like single point cutting tool and multipoint cutting tool. Single point cutting tool are characterized by only one main cutting edge and on that cutting edge there is only one force. For example, say single point turning tool. Shaping, planning, boring these are the slotting. These are the single point cutting tools and multipoint cutting tools drill has got two cutting edges and milling cutters have got multiple teeth they are different.

First we shall discuss about single point cutting tool. The force analysis of single point cutting tools say turning. This is the turning process. This is the work piece which is subjected to rotation that is cutting velocity and the tool moves in this direction that is feed motion, so this is the contact area. Now at this point there will be only one force developed. As I said in the single point cutting tool is characterized by having only one cutting force this is the cutting force denoted it by R and this is resulting to three components. One tangential say P z, other one in the axial direction around the axis of the job. This is called P x and another transverse or in y direction called P y. So vector summation of P x, P y and P z will be the resultant force R.

Now you can see on the right hand side diagram, this is the top view or the reference plane view of the cutting process, turning process and this is the cutting motion of the job and this is the feed motion and this is the cutting point. At this point if you take a section along the orthogonal plane this is orthogonal plane and this is orthogonal view of the cutting process this is the uncut chip that flows into the form of a chip and here one on the cutting tool, there will be one force acting P z that is along the direction of cutting velocity vector. Another one P xy, that will act over the reference plane because this is the reference plane and this will be shifted along this this is also along the orthogonal plane. So P xy will be perpendicular to P z and will act along orthogonal plane and over the reference plane.

Now this P xy is again resolved in to two components, P x in the direction of feed direction and another P y called transverse force P y in the opposite direction and this angle is phi. So there is only one force which is resolved in to two components P z and P xy. P xy is again resolved in to P x and P y. So the resultant force R is equal to P x plus P y plus P z the vector summation. So this force R is resolved in to three components and these three directions are right angle to each other, and at the end this axis x y z are the axis of the machine tool. So these are all in machine reference system. So that, we can easily measure and analyze this forces and identify the forces.

Now what are the significance of these forces? What are the contribution or role of the forces. As you see the force component P z that is the largest in magnitude amongst P x P y P z. So that contributes maximum and its acts along the direction of the cutting velocity. So this force multiplied by this P z multiplied by the velocity will give the cutting power consumption. So this is also called power component main component or power component of the cutting force this P z. Then comes P y, now P y may be usually smaller then P z as such P xy is around half or less then P z generally so it is the small and P xy is further resulting to P y which may be quite small but since it acts in a transverse direction of the cylinder rod this will create lot of elastic deformation of the work piece, tool headstock, tailstock and all the parts of the machine and will result in dimensional inaccuracy and cause lot of vibration so it is very detrimental P y.

P x is least important least significant because in this direction the machine is rigid as such P x is small in magnitude and secondly P x acts in the direction where the machine fixture tool work system is quite rigid. So you understand the significance of all this force components in turning process. Next comes to drilling. Cutting forces in drilling operation.

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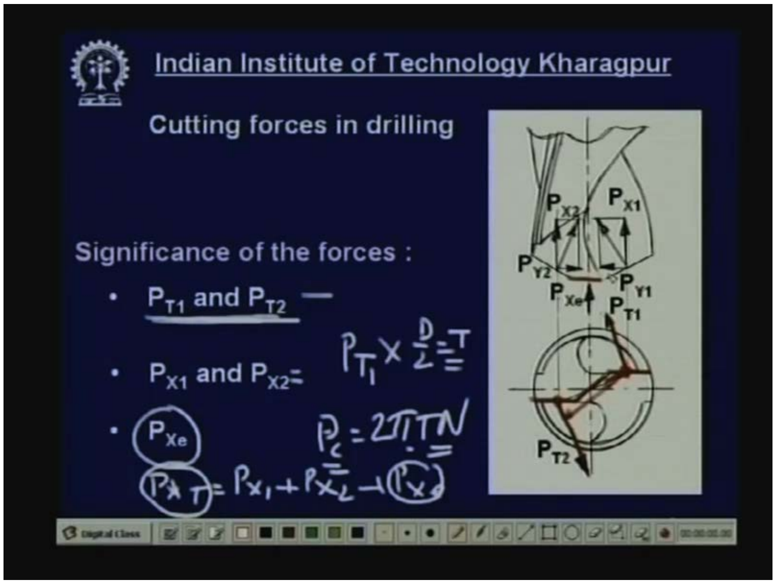

As I told you the drilling drill is a cutting tool which has got two main cutting edges. This is one main cutting edge. This is another main cutting edge connected by one small chisel edge intermediate chisel edge. Now it will have two cutting forces and its origin suppose this was the point taken arbitrarily on the main cutting edge. So there will be a tangential force P_{T1} and similarly there with another tangential force P_{T2} so they are tangent to the circle here and this P_{T1} and P_{T2} will be same in magnitude if the tool geometry are symmetrical and perfect.

Now this tangential force multiplied by this distance will give you the torque. So if you want to determine the torque then this PT one has to be multiplied by this distance, so the average diameter or D by 2 if D is the diameter of the drill. So this PT multiply anyone say P_{T1} into say D by 2 this much is approximately D by 2 will give you the torque. This is equal to the torque which is essentially for design of the cutting tool spindle bearings and so on and then what is power consumption Pc? Pc is two pi TN. What is N? N is the rpm of the drill, the rotating speed of the drill so and T is the torque.

So this P_{T1} and P_{T2} are very important. They are quite large in magnitude as well as these are the power component and this is basically the P_{T1} P_{T2} are equivalent to P z in case of turning. Pc equivalent to P z in case of turning, tangential force of the main component and this helps you get the torque as well as the power consumption. Now come to the other force. There will be two more forces acting perpendicular to P_{T1} and P_{T2} and along the rake surface or flute. So this is one force P xy1 and this is another force almost perpendicular to the cutting edge and working in the phase plane. This force will be resolved in to two components P x1 alone the axis of the drill and P y1 in a radial direction.

Similarly this force component P xy2 will be resolved in two components P x2 and P y2. Here you see that P x1 and P x2 are in the same direction. They are parallel, so the total force in the axial direction will be sum of P x1 and P x2. P y1 and P y2 will be same in magnitude if the drill geometry is perfect or symmetrical but you see that they are working in opposite direction. So ideally P y1 and P y2 will nullify as such they have got no significance but if they are not equal because of imperfect in the tool geometry, then there will be one lateral force acting on the drill and that is very harmful it may break the drill. In addition to that, what is the significance on the forces PT1 and PT2? They are very large in magnitude and they help in determining the torque as well as the power component. P x1 and P x2 work simultaneous the same direction so they give us the total axial force.

Now what about P xe? This is P xe here. This is the axial force caused by the chisel edge. Now the chisel edge is quite small but the axial force produced by the small chisel edge P xe is very large may be 60 percent of the total thrust force and as such this P xe will be added with P x1 and P x2 to get the total axial force. So total axial force will be summation of P x1 plus P x2 plus P xe. Now P xe alone can be 50 to 70 percent of the total force, because the small chisel edge removes the material by some stringent condition like unfavorable condition like indentation or extortion because of very large negative break at that point and very low velocity may be zero at the center. So this is about the drilling force. Now come to milling force.

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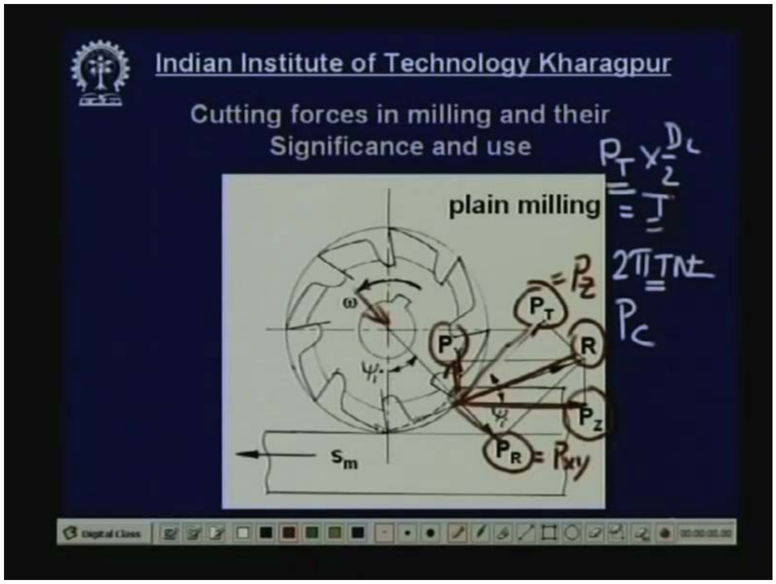

Cutting forces in milling and their significance and use; Milling cutter can be different type form milling cutter and profile sharpen cutter like this but most of the milling cutters are profile sharpen cutter and of different type slab milling cutting or plain milling cutter which looks like a roller with a flutes and end milling cutter and phase milling cutter. Now let us start with plain milling cutter with straight flute. Here the flutes are assumed to be straight parallel to the axis of the cutter and this is the plain milling cutter having eight teeth and we also consider for the beginning that only one tooth is engaged at a time. This is called single tooth engagement condition. Only one tooth will be engaged at a time but it can be made multi-tooth engagement and these cutting edges can be helical fluted we shall discuss later on. But first let us consider the cutting forces due to the single tooth engagement of a plain milling cutter without helix.

Now at this point cutting point here this cutting edge, one force will be tangential force PT tangent to the work piece and this is equivalent to P z of turning. So this is the most important force. There is another force that will be acting PR. PR is equivalent to P xy of turning. Now resultant of these two is R. R is a vector summation of this tangential force and the radial force PR. Now this force R can be resolved again for analysis further into a force P z along the axis of the machine tool and another P y transverse direction. So the main forces coming from the cutting process are the tangential force PT and the radial force PR resultant of which is R. This can be resolved like P z and P x P y in the transverse direction and z and y are the axis of the machine tool. What are the importance or significance of the forces? Here you see PT. PT is equivalent to P z. This PT when multiplied by the diameter half of the diameter of the cutter radius this will give you the torque and the torque is necessary to be determine for design of the cutter cutting tool, design of the milling arbor, drilling and design of the spindle design of the gear box and so on.

This PT 2 pi TN. This gives us the power consumption so what will be the power consumption that will depend upon the torque and torque will depend upon the tangential force PT. So PT is one end is very large in larger component so its important PT and it is power component. It helps in determining the torque for design of the machine tool components and the power consumption. PR is also important because the PR acts radially so this will cause bending on the milling arbor; therefore this will also is utilized for design of the machine tool. Now result of this tool is PT into P z and P y. So P y and P z will be utilized and important for design of the machine tool and cutting tool holders and any fixtures and all these things. So these are the significance of this cutting tool. Now as I told that there can be multi-tooth engagement. So number more than one cutting edge can be involved in that case what shall we do?

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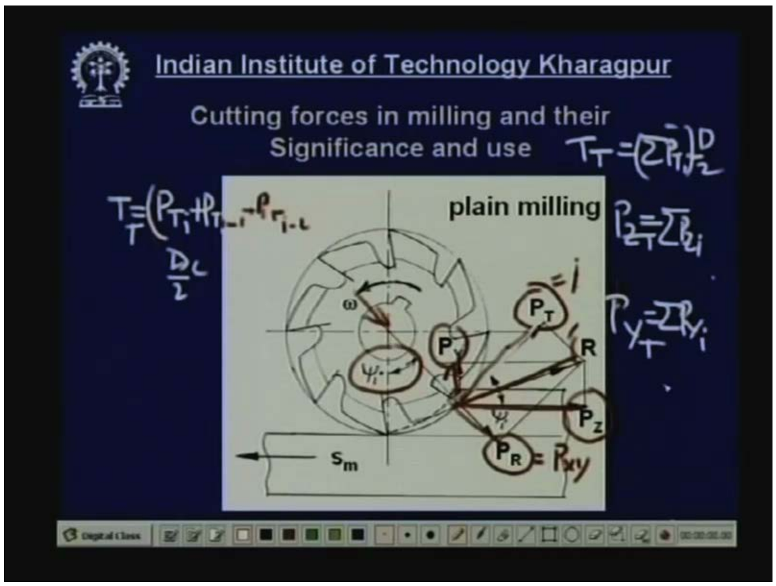

In case of multi-tooth engagement the torque will be equal to PT1 or plus PT i minus one plus PT. If there are three PT I minus two and so on say one cutting edge will be here and for every cutting tooth engaged there will be a force PT and that is a vector quantity but when this will be multiplied by the diameter half the diameter then this will give us the total torque. So total torque will be equal to summation of the P Ti that is a tangential force this multiplied by diameter by two. This becomes a scalar quantity and now you multiply this with the angular speed you will get the total power consumption then P z, what is total P z? Total P z will be equal to summation of P zi i means any particular cutting edge which will have different angle of engagement this is called angle of engagement. Then P similarly P y total will be summation of P yi i means 1, 2, 3 depending upon the number of the cutting edges involved.

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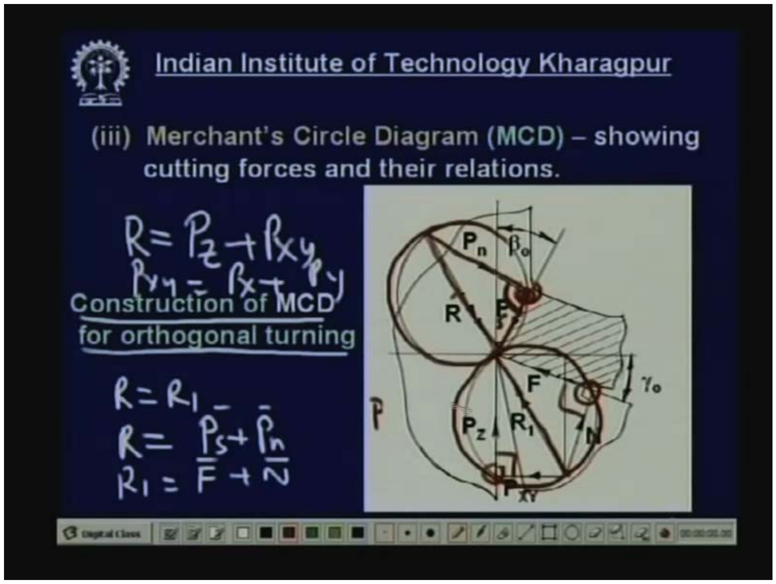

Now next is Merchant's circle diagram simply MCD. Merchant is a scientist who carried out lot of metal cutting research and he is the professor and he did lot of work in research R and D and industry and he developed a beautiful method of dealing with the cutting forces involved in machining and this is very helpful. You will gradually see that how is it constructed and how does it help the people to analyze and understand to conceive or conceptualize the cutting forces. So now we shall deal with Merchant's Circle Diagram (MCD) showing the cutting forces and their relations.

First see the construction the construction of the MCD for orthogonal turning. Here a point has to be noted that this Merchant's circle diagram is very unique method is applicable for orthogonal cutting only. It is not applicable for oblique cutting. What are the forces acting let us see before going to Merchant's diagram, let us have a look into the forces acting on an outgoing chip. Let us consider that it is a machining orthogonal turning of a ductile metal producing continuous chip and here we see a segment of a chip coming out from the parent body and being separated along the shear plane. This is a shear plane just after which it is getting separated.

So there is a slip between the parent body and the chip so a shear force will act in this direction a shear force and which will exceed the shear strength of the material and it will be slipped out in the direction compared to the work material. Now the shear force P s this one is P s P s shear force is accompanied by another force P n it is called force normal to the shear force. These are the two forces to be induced into the work piece in order to accomplish machining. However so the chip is subjected to two forces from the work side one shear force P s other one force P n normal to the shear plane so from the job side the chip is subjected to two forces. Now the chip is coming out at a constant velocity we can consider this chip part of the chip or segment is in a state of equilibrium because the velocity is constant. From the tools side what forces are acting on the chip? One force is the friction force when the chip comes out it slides over the tool so there will be force acting in the opposite direction friction force and another force N normal to the chip cutting coming from the tool. So from the work side the chip is subject to one shear force Ps and one normal force PN and from this tool side it is subject to force F and friction force and N. Anyway now what is significance of the forces and how do they help in constructing the Merchant's circle diagram. This P s and P n are the forces to be is provided into the work piece for cutting action this is the resultant force R.

Now this resultant force has to be induced into the work piece through the cutting tool so there is another force R1 acting in the same direction but in the opposite sense and they are action and reaction R and R1 so we can write that R is equal to R1. What is R that is a resultant of R is resultant of P s and P n vector summation of all this. Now this R1 again is resolved into two components. It is obtained in it is provided through two forces. One along the friction F and N therefore this R1 is equal to force F vector and force N vector now mind that the force is only one. So there will be only one force either R or R1 anyone we can consider this only force in single point cutting like turning can be resolved into P s and P n or F and N through that F and N is the forces that resolved in coming from the cutting tool P s and P n induced into the work piece. Now this R1 we do not know the direction and magnitude so we have to measure it sometime so we have to resolve in to two known directions. This is P z, P z direction that is cutting velocity vector and another component perpendicular to that P xy which is in reference plane this is in reference plane so this is one P xy and this is P z.

So here we can see that this R is also equal to P z plus P xy where you remember P xy is equal to P x axial force plus P y transverse force. Now if we clean it what is the Merchant's circle diagram. Is it a Merchant's circle Merchant scientist Merchant drew a circle and produced a diagram for analysis of mechanics of machining? Now here you take this R as the diameter and draw a circle taking R as the diameter of the circle. Now this point will pass through the point of intersection of P s this P s and P n because it is 90 degree since it is 90 degrees so this point will be situated on the periphery.

Similarly if you draw another circle as it is shown over here taking R1 as the diameter this is the circle this will also contain this point because this angle is 90 degree. This will also contain this point so this is 90 degree. Now here you see in this circle this P s and P n are contained as intercepts end points of the forces are situated on the periphery. Similarly the end points of F and N are situated on the periphery similarly P xy and P z. This anyone of the circle is called Merchant's circle and the total diagram is called Merchant's circle diagram. Now all the forces can be shown in one circle.

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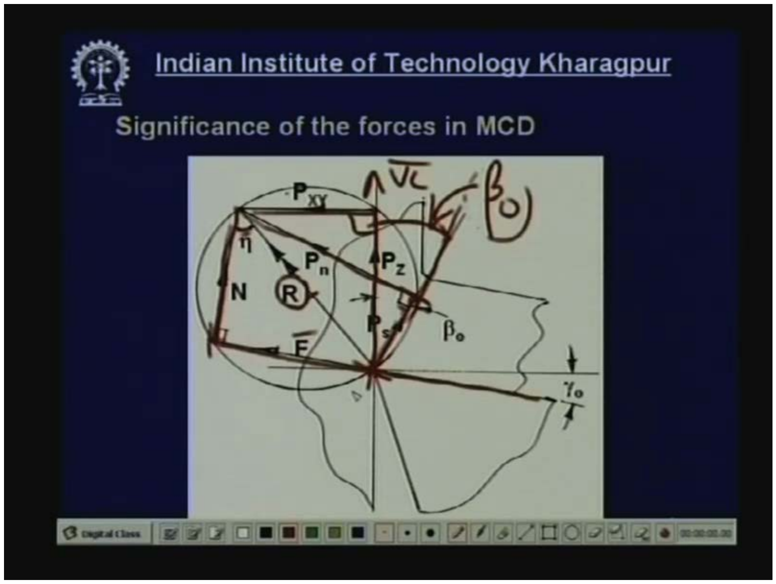

Here you see the actual Merchant's circle diagram where there is only one circle drawn as the resultant force R is a single force as the diameter and in this circle all the force components concerned are contained as intercepts which are end points on the periphery. This force Ps is very important because this is the amount of force essential to cause chip separation or chip production that is machining P s cannot stay alone. So there will be inherently force acting normal to this so P s and P n resultant is R.

Now this R is again resolved into two components F now this force friction force F has been obtained into this by extending the rack surface because the friction force acts in the rack surface so it is extend in this direction and contained as an intercept into the circle. So this is the magnitude of the friction force and normal force is this one because F plus N vectorially is equal to R and this is the friction angle eta. Now if you resolve into the direction of velocity vector say this is P z all right and the other one is P xy. So this P z and P xy are normally obtained by measurement and P s P n F and N these are all function of the machining condition and they can also be resolved from P xy and P z.

Suppose if we know P z and P xy by measurement or by galvanometer then we can draw this P z with a proper scale. We have to choose a scale 200 Newton is equal to 1 centimeter then 1000 Newton will be 5 centimeter like that you draw P z first in the direction of the velocity vector then P xy normal to that according to the scale join the tips and you get R. Taking R as the diameter draw the circle then you extend the surface rake surface you get F, join this line you get N. Now regarding Ps what is this angle? This is called shear angle the shear angle has to be determined from other data. If we know shear angle, then we can draw this line and this intercept will be Ps inter semicircle and the other intercept will be will represent P n this is how the forces can be determined this we discussed in more detail. Now use of Merchant's circle diagram. How can we utilize it or exploit it?

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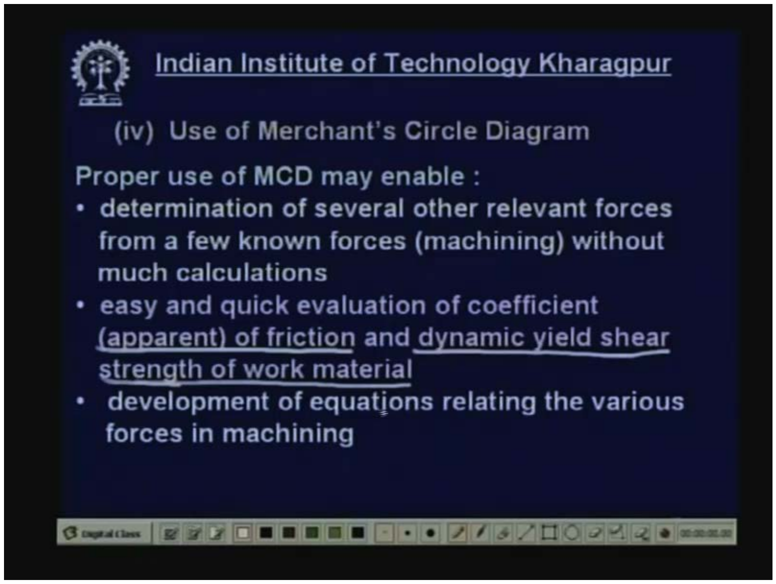

It not only enables only force analysis it can help us further you can see proper use of Merchant's circle diagram may enable if you can use properly determination of several other relevant forces say P s P n friction force F normal force N etcetera from a few known forces say P z P x or P y or P xy without much calculations. So calculations are not necessary simply by drawing the diagram you can get the forces just by an intercept multiplied by the scale or divided by the scale easy and quick evaluation of the coefficient of friction.

Now the machinability whether machine is good or bad is just by the chip tool interaction that is the interaction at the chip and tool interface like friction built up edge formation etcetera. Now this friction force can be measured on fixed normal force N can be measured from the Merchant's circle diagram and ratio between F and N will give you the coefficient of friction but this is apparent coefficient of friction its not a real but apparent coefficient of friction just a ratio between F and N. So this important information can be derived because the friction is a measure of good machining or poor machining can be obtained by measuring F and N knowing. If you know the values of F and N from Merchant's circle diagram then you can determine the friction as well as you can also determine the dynamic yield shear strength of the work material.

The work material has got certain shear strength but under the cutting condition the shear strength may change because of the strain rate work hardening or say strain hardening like that and we should be able to measure how does the material behavior under the cutting condition and that can be best assist by the value of the force that will develop during actual machining. So the behavior of the material under cutting condition and its dynamic yield shear strength can be determined from the cutting forces and using the Merchant's Circle Diagram. Further the development of equations relating the various forces and machining. Now you know that some people are very strong in mathematics they like to use equations and solve problems. Some people are very strong in graphics some method of drawings sketching and slightly reluctant about using equations for them Merchant's circle diagram is very good but some people may not like to draw the Merchant's circle they like to use equations if available for calculations or analysis or determination of other forces from the known forces like P z P xy. Now even then if you want somebody to use the equations only to avoid Merchant's diagram that equations will also be developed from the Merchant's circle diagram. So Merchant's circle diagram also helps in developing the equations which will be used to avoid Merchant's circle diagram and this equations will be shown later on. But limiting conditions for MCD Merchant's circle diagram;

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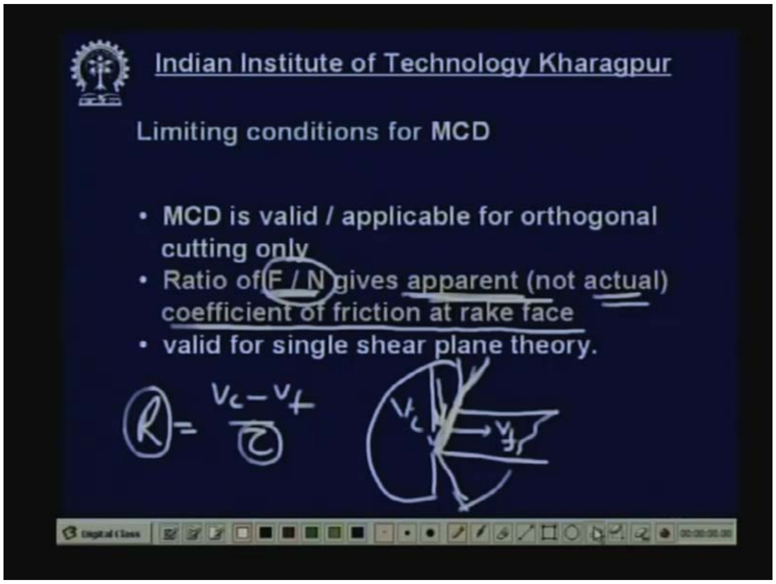

As you see the Merchant's circle diagram is a very good technique or a very beautiful diagram which enables very quick and easy determination of the forces involved in machining but it has got certain limitations also we should be careful about using it. It cannot be used universally under all machining conditions like oblique cutting. What are the constraints? Merchant's circle diagram is valid or you can apply it only for orthogonal cutting when all the forces will be contained in the orthogonal plane both P z and P xy both P z and P xy will be contained in the orthogonal plane. There will be no force in the cutting edge direction or other direction ratio of friction force and the normal force gives apparent this is apparent friction this is apparent friction this is not the real coefficient of friction this is only simply the ratio.

If you want to get the actual friction then you have to do some more work but however this is very close to coefficient of work which is an index of machinability or the characteristics of machining so this Merchant's circle diagram will give you only this ratio that is apparent coefficient of friction but not actual for that some more work has to be more analysis has to be done. Now this Merchant's circle diagram is valid for single shear plane theory now what is single shear plane theory the diagram that we draw that the cutting process this is the cutting tool and this is the uncut layer and this goes out in the form of chip. We assume that there is a shear plane in single plane along which the deformation the chip comes in this direction then goes out in this direction. This velocity is very low it is a chip velocity and this is cutting velocity V c. Now here the cutting velocity at high magnitude immediately becomes V f low magnitude within zero time almost zero time if the plane is a single shear plane almost in zero time, that is the deceleration R is equal to V c minus V f by tau.

Now if we take single shear plane then this tau is almost zero then R will be infinity the deceleration similarly strain rate everything will be infinity which is not really true which cannot be. So the single shear plane theory so this cannot be single shear plane theories. What is true is shear zone theory what is shear zone theory?

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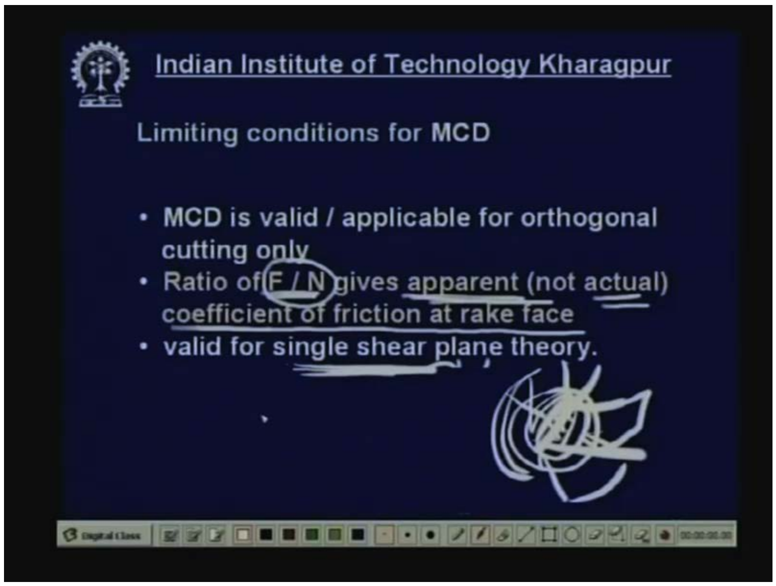

If the tool is here and then the chip will deform over a region so this is the chip flow region and this is the true picture but of course the thickness of the shear zone is very thin and with increase in velocity this becomes thinner and thinner in the order of micron say 50 micron and we consider for convenience as a single shear plane but this is a limitation this is not true. So but so this Merchant's circle diagram which assumes that the entire process is based on single shear so this is slightly approximate process. Now let us see the utilization of this. A typical example of application of Merchant's circle diagram;

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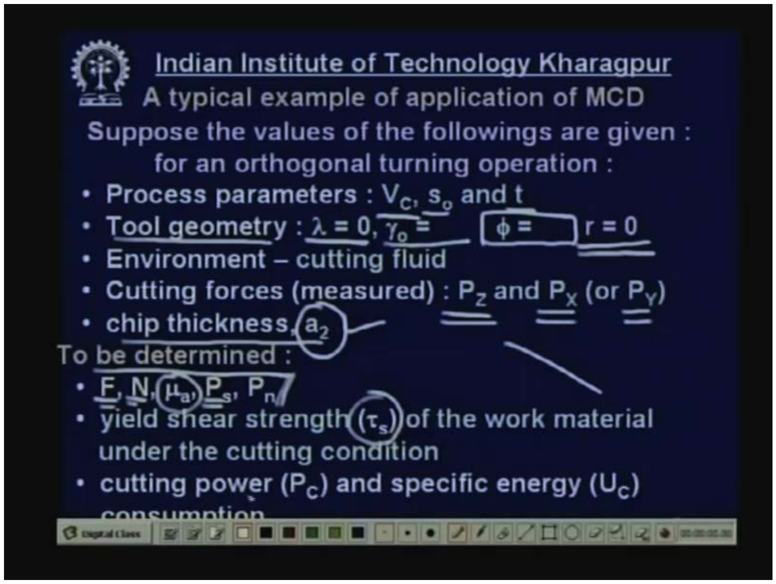

Now you learn how to utilize this Merchant's circle diagram for solving problems for analyzing and for determining other components and so on. Suppose the values of the followings are given some data are given for an orthogonal turning operation. Orthogonal turning means the chip flows along orthogonal plane now what are the informations given. Suppose the process parameter like cutting velocity is known the cutting velocity is known feed is known, depth of cut is known, tool geometry here the lambda has to be zero the inclination angle otherwise it will not be orthogonal cutting this nose radius should also be zero for orthogonal cutting and almost zero not exactly zero gamma o rake angle should be known and this principle cutting edge angle should also be known these are suppose these are given say gamma 10 degree or 65 degree like that environment cutting fluid the environment means cutting fluid suppose we are not using cutting fluid or any say soluble oil cutting forces measured so by galvanometer we measure the forces P z and P x or P y or P z P x P y all this three forces we know the values from measurement. These are available and the thickness of the chip that comes out after deformation. So the thickness of the chip is also known if not known it has to be measured.

With this information suppose we have to determine some more information, what are these? The friction force F normal force N the apparent coefficient of friction and the chip interface, the shear force Ps and the force Pn normal to that so this forces have to be determined from this known values yield shear strength tau s of the work material under the cutting condition and cutting power Pc and specific energy Uc consumption. This has to be determined from this limited information provided. Now let us see how this can be done? Solution of this kind of problem:

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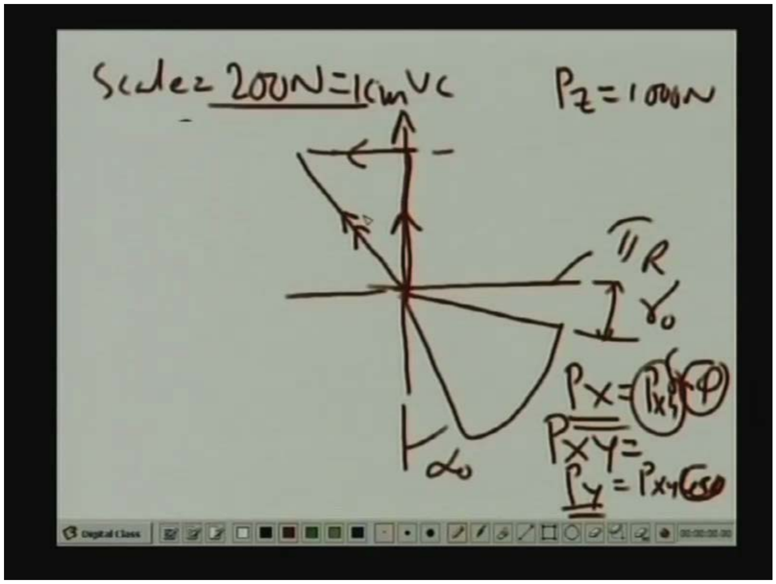

What we shall do? First of all we shall do, we are solving the previous problem. First you draw the cutting tool and the chip. So this is a reference plane pi R and this is the velocity vector Vc. This is the cutting tool with rake angle orthogonal rake and this is orthogonal clearance alpha o now this is the first part. Next part is we have to choose a scale you choose a scale say 200 Newton is equal to 1 centimeter. If we know the P z suppose P z is 1000 millimeter 1000 Newton then it will be 5 centimeter so you take P z here. Suppose this is the amount of P z which is given in length suppose it is P z is 1000 sorry P z is equal to say 1000 Newton and scale is 200 Newton per centimeter. So this intercept will be 5 centimeter.

Similarly you draw here P xy how do you get P xy? P xy P xy you know that or P x is equal to P xy sin phi or P y is equal to P xy cosine phi. So if you know P x or P y from the dynamometer or from the measurement and phi is already known then we can determine P xy. So you put P xy. Now you join it, you get the force R like this. Now let us go back to the previous so

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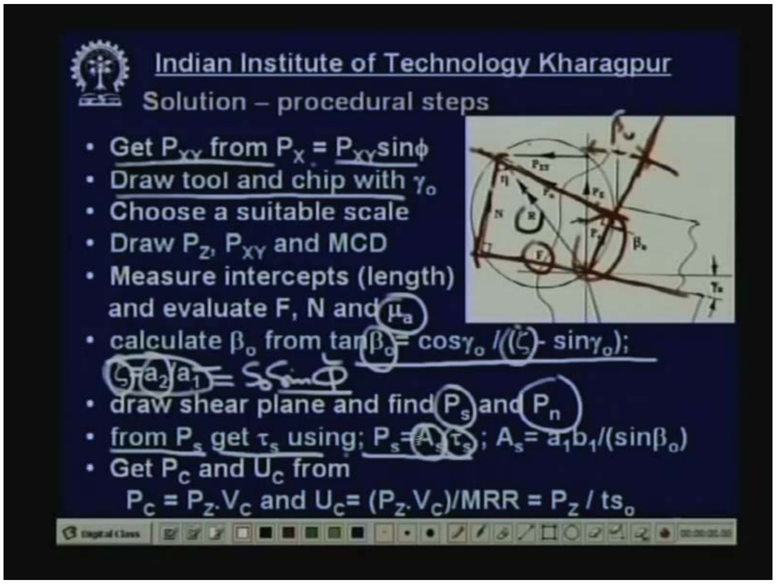

You get this P this resultant this R now take this R as diameter you draw the circle, the Merchant's circle. Here what you have done get P xy from P x from P x or P y as P xy sin phi
draw tool and chip like this the chip and the tool with gamma o. Draw P z and P xy that I have already described now you draw the circle taking R as the diameter. Now it is ready the circle is ready now you determine the forces one by one measure intercepts. Now this is the rake surface this is the rake surface which has to be extended until it meets over here so this is the length of the force F friction force. Now divide this length by the scale, the scale that you have chosen that scale we have chosen and then we have we get this force F. Here you see measure the intercepts length and evaluate F N what is N?

This length is measured and divided by the scale suppose it is 4 centimeter so 400 Newton or 800 Newton and what is mu a? This coefficient apparent coefficient of friction either you take the friction angle eta as such or the ratio of F and N will give you the value of friction. Now how to determine the values of P s and P n for P s which has to be drawn along the shear plane along the shear plane and we must know the shear angle beta. Calculate beta that is the orthogonal shear angle from this equation from this equation which is known tan beta is equal to cosine gamma orthogonal rake zeta minus sin gamma divided by what is zeta chip reduction coefficient.

Again we note chip reduction coefficient is equal to the ratio of the chip thickness of the chip after cut thickness of the chip before cut a2 is measured or known. What about a1? a1 is equal to S o sin phi. S o is the feed given value and phi is also known. So from known value you get a1 from known value of a2 and a1 determine zeta put zeta here gamma known determine value of beta. From known value of beta you draw this shear angle shear plane this one and this intercept is Ps. Now join this one, you get P n so you get P s and p n from the circle directly. So you get all the forces F N mu and P s P n directly without any calculation no calculation is done.

Now you have to determine the shear strength of the work material. What is the shear strength of the work material from Ps get tau s shear strength of the work material. How this shear force Ps is equal to shear strength of the material multiplied by the shear area this is the shear area what is meant by shear area. The shear area of the chip, cross section area of the chip along which shear takes place. Now let us have a look into this.

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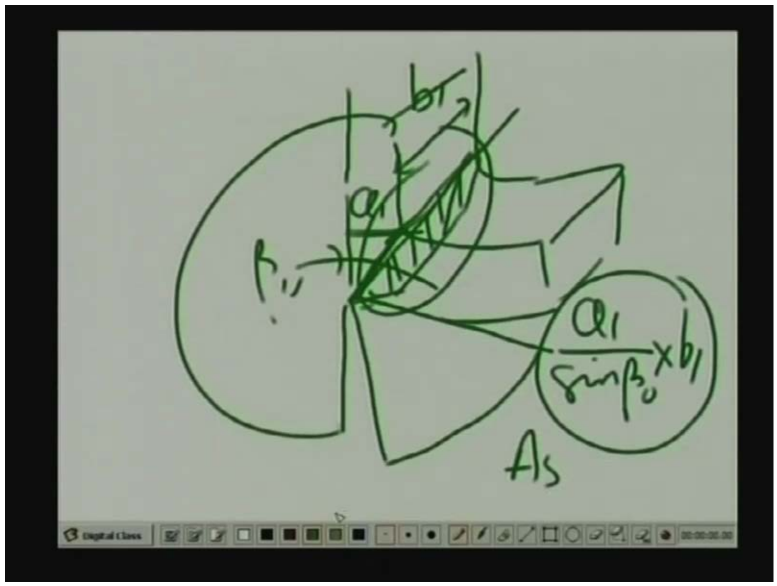

Suppose this is the orthogonal cutting. This is the cutting tool, this is the velocity vector. Chip is flowing like this. This is shear plane. This is the work piece and this has got certain width. So what is this? This is width of cut b1 and this is the thickness of uncut layer and then this is the area. This is the area along which the shear takes place. Now this area is equal to this multiplied by this, so this is b, this is a, what is this is beta o? So this length this length is a1 divided by sin beta o is this length and this length is b1 that multiplied by b1 that is the shear area. Shear area along which slip takes place so this is as now here you find that from Ps the shear As we have determined, As is equal to a1 b1 by sin beta but a1 and b1 is equal to this a1 b1 is equal to t into S o. What is t? depth of cut and S o is the feed. So from where we get As, As and put As value here. Ps is already known from the Merchant's circle diagram and then you get tau snow get the power and power consumption and the specific energy requirement why power requirement is required as I told that that decides that how much power has to be provided into the machine tool through the motor or it is also an index of machinability if the power consumption is high, then machining is poor. So our attempt should be to reduce the power consumption as far as possible but not at the cost of productivity. But how shall we know that how much cutting power is consumed.

This cutting power this depends upon the force. This cutting power Pc is equal to the product P z into Vc. Actually there is another component that Pc the cutting power is equal to P z into Vc plus feed force into feed velocity. The velocity, the feed velocity is very very low P x is also small so this part can be neglected so Pc the cutting power can be considered as almost equal to P z into Vc. So if we know the velocity is known already, if we know the cutting force P z then we can determine this Pc. So P z is known already is given velocity is also known so we get it directly but what about this cutting power specific energy consumption. What is specific energy consumption that means amount of energy required by the work material to be removed or amount of energy required for unit volume of metal removal that is P z into Vs. The amount of energy per unit time and metal removal per unit time so this means amount of energy required per unit volume of metal removal so P z cancels so P z tSo. So this Uc can also be determined by this process but here we need knowing the cutting force. Now let us see some example exercise.

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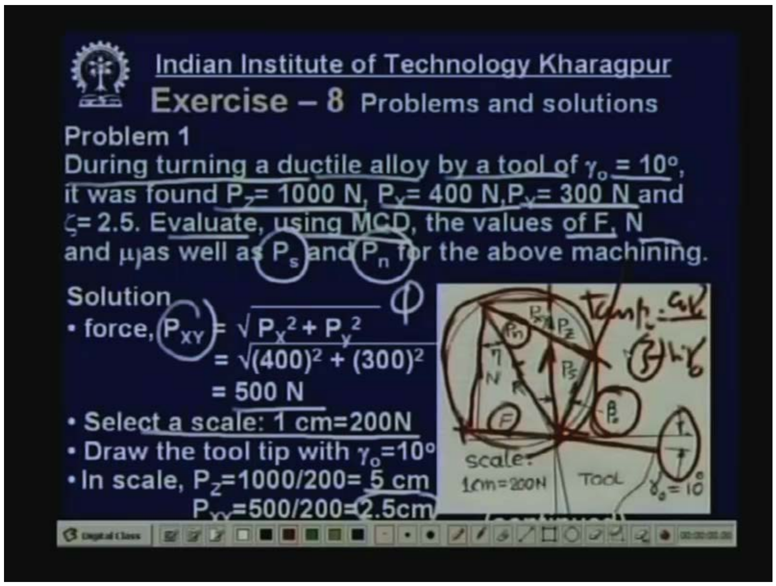

You will find here there are two exercises. I shall very quickly tell you the kind of exercise the problems given or faced in machining to utilize the Merchant’s circle diagram and how to exploit the Merchant’s circle diagram to solve it very quickly and easily. Suppose the problem number 1. During machining during turning ductile metal continuous chip by tool of gamma rake angle of 10 degree that is orthogonal cut it was found that the cutting force P z is 1000 Newton and P x is 400 Newton, P y 300 Newton. Why P x and P and zeta chip reduction coefficient is 2.5?

Now what has to be determine evaluate using Merchant’s circle diagram the values of the force F N the coefficient of friction then P s P n etcetera have to be determined so the problem is like this. So what are given the forces P x P y P z that is obtained possibly by dynamometer and the chip reduction coefficient from the chip and we have to determine the other forces. Now solution we have to first draw the Merchant’s circle diagram, first you draw the cutting tool with 10 degree with a 10 degree rake angle. So this is the rake surface and then you draw this direction of velocity vector and P z in this direction. How will you draw P z? The P z is known 1000 Newton that divided by scale; you have to select a scale first so select a scale 1 centimeter 2200 Newton, then what will be the value of P z length that is 1000 divided by 205 centimeter. So this is 5 centimeter then what about P xy? This P xy P xy has to determine the P x and P y unknown. So you can draw take the root of the P x square plus P y square because phi is not known. So you have determine P xy from this equation because phi is not known.

Now what is this 500 Newton approximately, if the 500 Newton divided by scale 200 it makes say 212.5 centimeter, So this two forces have been determined, get the resultant force now take in this diameter draw this circle called the Merchant's circle. Now fasten very quickly, things are being ready extend the rake surface. This is the intercept, so this is friction force F measure the length put into the scale that is divided by scale or sorry multiply by the scale that is suppose it is 3 centimeter multiplied by 200 is equal to 600 and this length you measure and multiply by the scale and you get the force.

Similarly Ps but before that you must know what is B tau? How will you get B tau, B tau o tan beta o is equal to cos gamma divided by zeta minus sin gamma, so gamma o are known what is zeta. The value of zeta is given 2.5 already so very quickly and easily determine B tau draw the shear plane. This is the intercept measure the length multiplied by multiply this length by this scale. So you get the force and similarly this one intercept P n P n measure the length and multiplied by the scale and get the value of force. So you can see in the next part next part so what is the process solution? I have already told you the summary.

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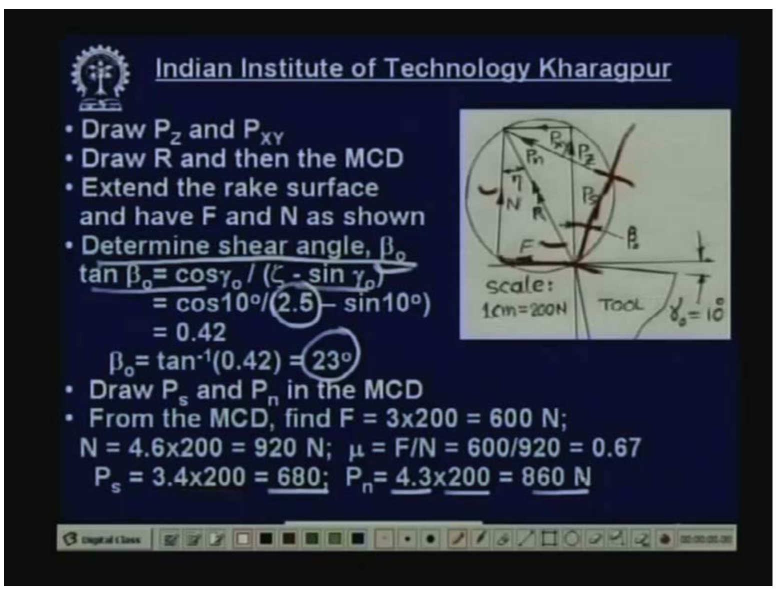

Draw P z and P xy. In this diagram you draw P z and P xy. Draw R as a resultant exchange the rake surface like this and get this intercept F, the F and N together and so F and N. F has determined N measure the length and multiply by the scale you get it determine the shear angle b tau from this equation tan beta cos gamma zeta minus sin gamma. Gamma is known zeta is known 2.5 given already so this is 23 determined draw this so this shear angle shear angle this is shear angle the shear plane so this is the intercept as I told you and then from the Merchant's circle diagram determine F suppose this F is equal to 3 centimeter multiplied but scale so 600 Newton.

Similarly N will be see it is suppose is 4.6 centimeter multiply with 200 900 and 20 Newton mu is the friction apparent coefficient of friction is the ratio of F and N. So this is 0.67 so Ps the shear force this much measure the length 3.4 multiplied by the scale and you get 680 then Pn you know this length say 4.3 multiplied by the scale you get 860 Newton. So this is how such kind of problem can be solved. Next time we will see that how this Merchant's circle diagram can be used for develop the equations for solving the problems without using Merchant's circle diagram in the next lecture.

Thank you.