Manufacturing Processes - II
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Lecture No.10
Dynamometers for Measuring Cutting Forces

Good morning! Come to the subject Manufacturing Processes – II. The Module - 2 is continuing that is Mechanics of Machining and under that we are dealing with cutting forces and power consumption in machining.

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The lecture Number 10, today that covers dynamometers for measurement of cutting forces. It has already been told to you that why it is necessary to measure the cutting forces? So the power pulse measurements of cutting forces have already been described. Now we are going to describe how these forces can be measured? There are different methods; indirect and direct. So direct method is much more reliable and accurate and that is accomplished by some devices call dynamometers which is based on some transducers. So what are the content of this lecture today? Specific Instructional objectives:

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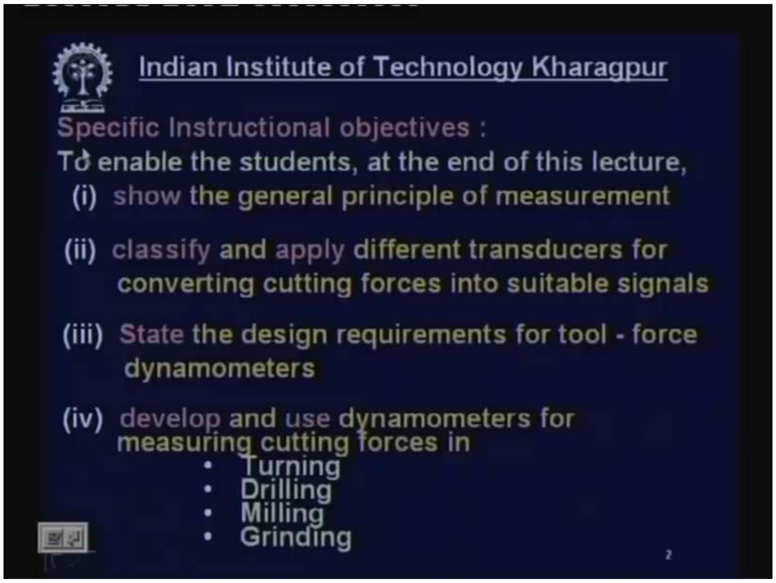

This lecture will enable the students to show the general principle of any measurement then classify and apply different transducers for converting cutting forces into suitable signal. State the design requirements, some factors need to be essentially considered while designing the dynamometer to fulfill the purpose and develop and use dynamometers for measuring cutting forces in some conventional machining process like turning, drilling, milling and grinding. Now come to the basic general principal of measurement. How things are measured?

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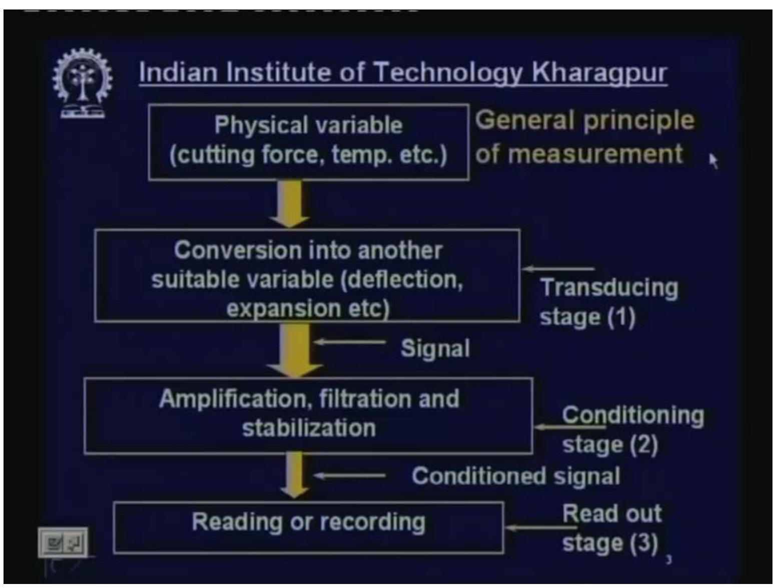

In any measurement process, now the physical variable cutting temperature or cutting force.

Here the cutting force is a physical variable which we like to measure but it is neither visible nor you can grip it by your hands. So we do not handle it directly but we can understand the presence of force of the intensity of force by its effects when some force acts on cantilever beam it undergoes bending or some ball then this will be deformed. So this is how we understand the presence of the intensity of the force. For example, the wind is not visible but from the movement of leaves and branches of tree, we understand the presence and the intensity of the wind.

Similarly temperature is neither visible nor you can catch hold directly. But from the effects, we can understand or detect the temperature from expansion of liquid or gas or something or wending and something like that or EMF generated. So the physical variables like cutting force and temperature which cannot be directly gripped or visible has to be converted into a suitable effect which is visible, which is detectable which is measurable. For example, now this physical variable will be converted into another suitable variable and this another suitable variable may be deflection of elastic beam or expansion of a liquid by temperature like that. This stage of conversion of the physical variable to be measured into another suitable variable which is detectable is called transducing stage. This is stage number 1.

So this conversion is accomplished by some transducer or sensor. They produce some signal, this signal may be voltage or something else or current but the signal that is normally produced by conversion of the transducers is very feeble and noising. Therefore this signal has to be conditioned properly, amplified and rectified and smoothened by some conditioning stages. This stage is called conditioning stage number 2 and purposes are amplification of the signal, to enlarge signal which can be easily measured accurately. Filtration from the noise if any and stabilization if there be any instability in the signal after that we get the condition signal which can be easily measured detected and measured quantified how this can be done. Suppose this condition of signal is a voltage now this voltage can be directly measured by a voltmeter or it can be leave there is pulsation or variation if you want to see the ah time dependence or then we can look into the oscilloscope and if you want to record it, we can record it on pen recorder or strip chart recorder and we can also do it comfortably and make use of it onward by come storing it into personal computers that is called third stage or readout stage.

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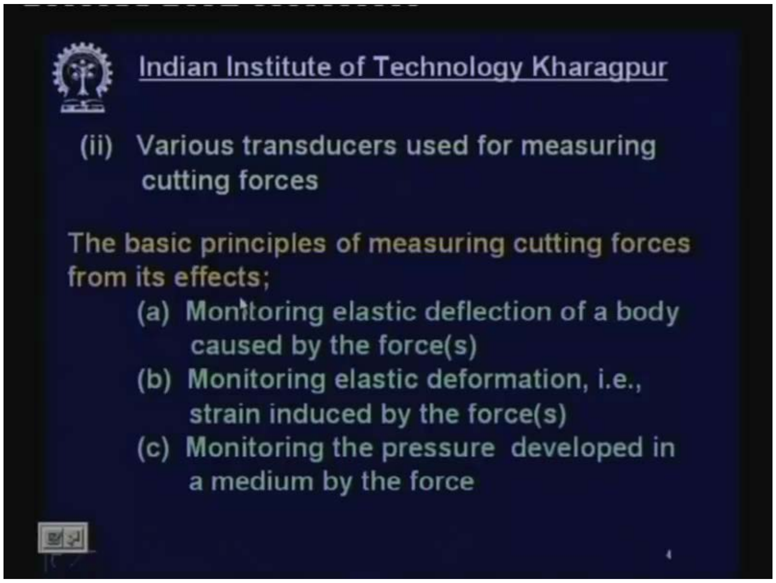

Now in case of cutting force, (ii) various transducer used for measuring cutting forces. What is the transducer or sensor? It is device or element or material which converts a physical variable into another physical variable say pressure into voltage, light into voltage like that. The basic principles of measuring cutting forces; so it is understood that cutting force which is a force has to be measured from its effects and what are the possible effects suitable for measurement of cutting forces. So the basic principles of measuring cutting forces from its effects are (a) Monitoring elastic deflection of a body caused by the force. Here is a beam suppose elastic beam and then this will be subjected to a force due to the force it will undergo bending or elastic deformation or deflection then (b) Monitoring elastic deformation. If it is not a beam or if it is a ball or a solid body then by deformation or strain, we can measure the force and (c) Monitoring the pressure. Because of the force, the force can be converted into some pressure into liquid or solid and this pressure can be measured with certain other methods. So these are the three basic principles used for measuring the cutting force based on its effects. One is the elastic deflection other one is elastic deformation like strain. Other one is pressure which can measure directly measure pressure gauge to a liquid medium or say gas medium or through a sensor which converts pressure into some electro electromotive force or voltage like that.

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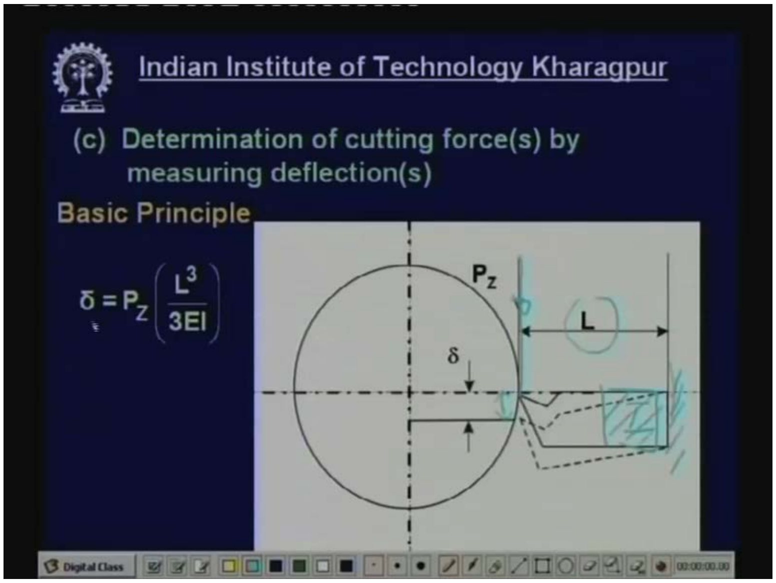

First let us come to those methods which are based on measurement of deflection. (c) Determination of cutting force(s) by measuring elastic deflection(s). The basic principle: Look at this diagram. This diagram shows that here is the job the cross section of a rod which is undergoing machining by a turning tool. This shows the turning tool of the tool holder which is nothing but like a cantilever beam. This is like a cantilever beam subject to a force Pz, suppose one force due to that, this elastic beam will undergo deflection by this amount say delta. Now this delta deflection is visible it can be measured unlike the force Pz.

Now this delta is equal to if it is cantilever beam is equal to Pz the force, L cube is length of the projection or cantilever three EI. E is property of the material of the beam that is Young's modulus of elasticity and I is a section modulus of the plain moment of inertia. This is I plain moment of inertia of the beam. Therefore we can measure Pz in terms of delta provided we know the other parameters L E I this have to be known then Pz can be determined from the deflection delta.

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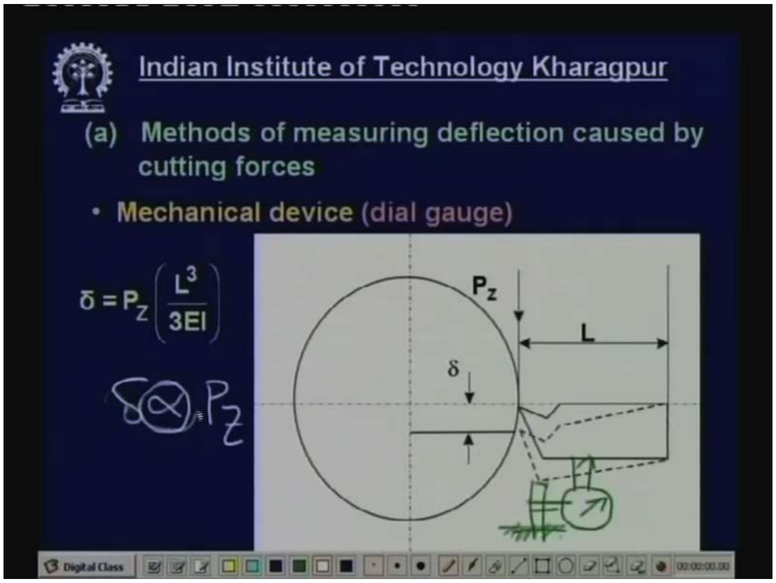

Now come to this one, Mechanical device. Now the question is how shall we measure this deflection delta? This can be measured by various methods mind that this delta is very small. It will be order of say fraction of millimeter, otherwise machining characteristics will be affected like depth of cut will change the diameter will change. So deflection normally is low in the order of say fraction of millimeter. Now the question is how this delta deflection will be measured? Depending upon the method of measurement, the dynamometer varies. So mechanical dynamometer, electrical dynamometer and so on say mechanical dynamometer, mechanical device here we can put say a dial gauge.

Now this dial gauge fixed on a place or structure and then because of the deflection delta under the action of the cutting force the dial gauge will indicate the deflection directly. Now from the deflection is known then L cube three E I are known. Then we can easily determined the forces Pz but instead of knowing all this parameters because in case of deflection or this relation there may be other parameters also like fixing condition other things and this construction may also vary. So there may be other parameters also but once the tool and tool holder are made those remained fixed. So delta remains the delta whatever the situation delta remains proportional to Pz. Now the question is the proportional factor. The value of the proportionality has to be determined and this is done by what is called calibration. Now see the calibration. Let us have a look into the calibration.

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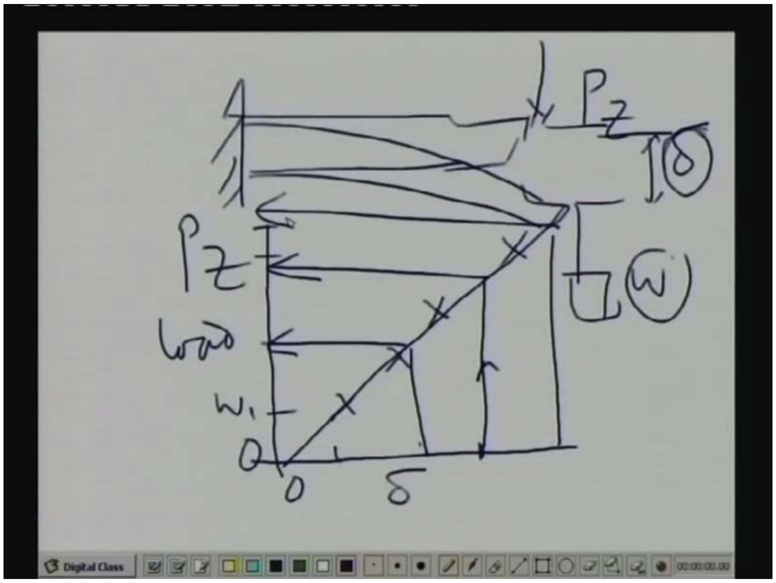

Suppose this is the cantilever beam; it simulates a cutting tool and will fix here subject to a load Pz and because of that this will deflect by an amount say delta. Now how shall we use it as a dynamometer you do an experiment. This is load; you apply some known load say w and measure the deflection by dial gauge. This is deflection delta you measure. Suppose for particular w one you get a point here. Then you change the load get another deflection plot it here, then you keep on plotting and then you get a curve like this. This is call calibration curve which will pass through zero expectedly and should be linear on the elastic condition. Now when you do experiment, then you measure the deflection suppose this is the amount of deflection from the if you know deflection then by extra pollution you can determine Pz is the deflection is less the force will be also proportionally less, if the deflection is large the force will be also proportionally large. So this is called calibration. Now measuring deflection by electrical transducers other methods are electrical method electronic method then optical method there various methods but I shall now discuss some of the common methods like electrical here this is an example.

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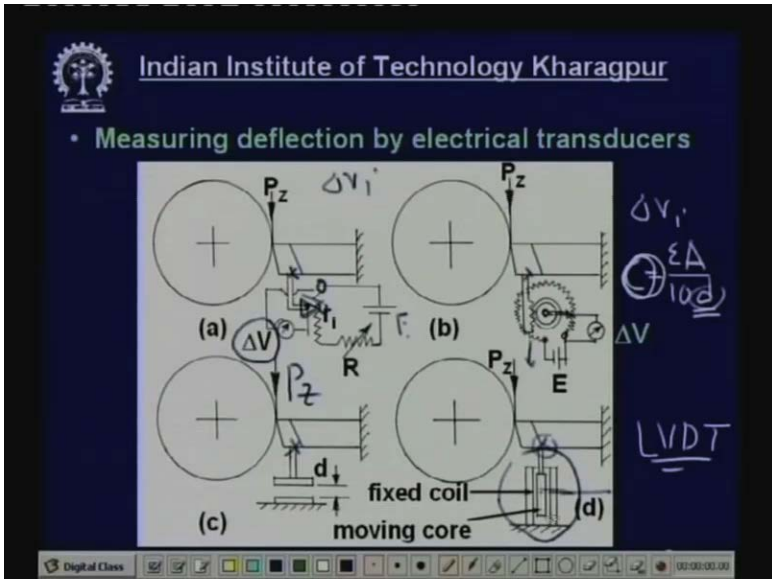

Measuring deflection by electrical transducer is potentiometer. This is the work piece and this is the cutting tool which looks like cantilever beam. Now this really represent the tool, tool holder or any elastic member subject to a force this will undergo deflection. This deflection will transmit there is a L type pointer which is fixed here. Now this pointer will move across the potentiometer here. This potentio is be connected to circuitry, this is the EMF force E and this is the resistance ri R. So this resistance delta r so this delta ri will change because of that some voltage will be created delta V across this point and this point some delta V will be produced that is delta V is proportional to delta ri and delta ri will be proportional to the amount of deflection. So the force Pz will produce proportional deflection. There are proportional change in resistance from the change in resistance you get a proportional voltage. So the delta V becomes proportional to Pz. Now the constant value of the proportionality will be determined from the calibration. So you have to do calibration.

Now this is Linear's linear potentiometer. Now this is not that sensitive, it can be like a circular pot. Here the deflection of the tool is taken by a rake. So the rake will move in this direction and there is a pinion. So pinion will rotate, along with pinion this pointer which will rotate along the circular resistance and from the change in resistance along with the deflection by the force the resistance will change here across the pinion and this point and is delta V the output voltage will also proportionally change. So this delta V because proportional to Pz and by calibration you can develop the relation between delta V and Pz and get it used. It can be inductive pickup type; it can be capacitive pickup type. This one shows the capacitive pickup type.

How does it work? This is the cutting tool on that it fixed a plate and there is another plate fixed at a bottom with a gap d filled here or any dielectric medium, so the deflection due to the cutting force Pz will cause change in the gap d. Now because change in d there will be change in capacitor because capacitance c is equal to epsilon A divided by around 10 d. What is epsilon? epsilon is the dielectric constant. What is E? Is the overlap area between the plates and d is the gap between them. So this capacitance is inversely proportional to this gap. So with the change in gap this capacitance will change and this gap will change because of the deflection of the tool caused by the force Pz. Thus the Pz force and capacitance c are directly connected from calibration we can find out Pz from the capacitance. If we can we have to measure capacitance in terms of voltage again. Now let us take an example of another example say LVDT linearly variable deferential transformer. LVDT linearly variable deferential transformer is this one.

What is it? It is compressed of two coils, so one is core this is the core member is solid say carbon steel which is a cast iron and there is a coil which is tubular. It has got two coils; primary coil and secondary coil. So this coil remains fixed and the core is connected with tool therefore the core will move axially within the coil proportional to the deflection that is force. Now this is the null position. From this position if this core moves upward or downward, say downward because of the force some EM some voltage will be created or generated at the secondary coil and that voltage will be proportional to the length of travel or hub band of this core within the fixed coil and this travel of the core is proportional to the deflection of the tool that is force Pz. Therefore the voltage that will be generated into the secondary coil of this coil due to the movement of the core will be proportional to the force Pz. Now this relation will be established finally by calibration. So by calibration we can determine the value of Pz from the voltage created or obtain in the secondary coil of the linearly variable deferential transformer. Here the moment should not be very large, it should be within the limit. Otherwise the sensitivity will be lost.

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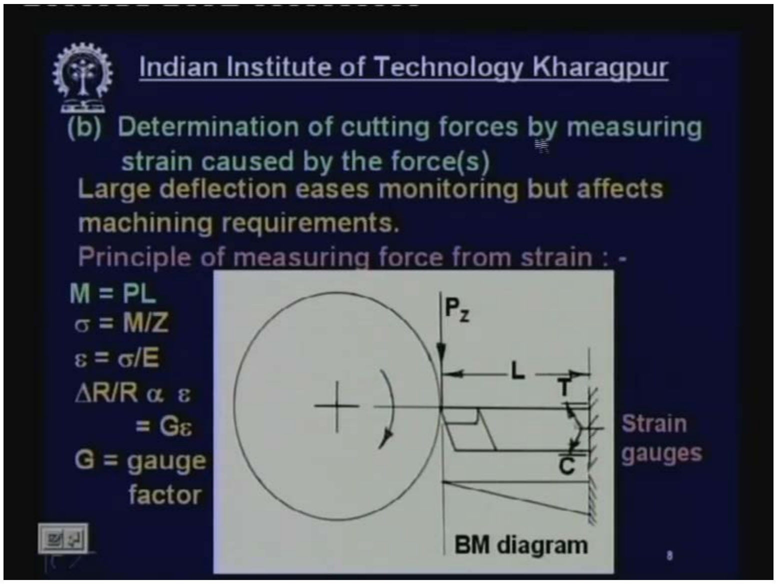

Now the determination of the cutting forces by measuring strain caused by the force; here is the point. Now see here in this case this is deflection. For easy understanding and analysis, we have shown a large deflection. But such large deflection is not very good for the purpose of machining, because if we allow large deflection for the purpose of sensitivity of measurement then the depth of cut with the machining action will change. That is the tool point comes over here. So the diameter of the job will change. So machining will be affected. Accuracy of the machine will be affected and depth of cut will also come down as a feed will come down as force the whole will be changed which is not pursuable. Therefore the deflection should be as small as possible but again if it is very small, then it will be very difficult to measure. Now really were the value of delta is very much restricted for the sake of accuracy of measurement then instead of delta, we should take another feature like strain that will develop at the elastic member. Now this strain that will take place due to stress on the cantilever beam due to the force Pz will be proportional to the force Pz. So this strays from this strain which is proportional to Pz. We can measure Pz instead of delta.

Therefore for delta, large value is restricted then strain measurement is the process. Here you can see the determination of cutting force by measuring strain caused by the force. Now here is a cantilever beam like the cutting tool, subject to the force Pz cutting force and because of this force Pz, some straining and stress will develop at this root. Now this bending moment diagram; So maximum bending moment will take place here, maximum bending moment will take place at the root. Here what is our purpose? Our purpose is to measure the force Pz. Now the bending moment take place at the root of the cantilever beam is equal to PL. What is P? P is the cutting force Pz that is our target, L is length which is fixed because of this bending moment sigma stress will develop in this section. What is value? M by Z, M is bending moment and Z is section modulus. Section modulus means that the plain moment of inertia divided by the height.

Suppose this is the cross section. We take the plain moment of inertia say I divided by the height Y, that is surface under consideration from the neutral plain of beam the distance I by Y. This is called section modulus which represents the cross section of the beam. Switch is fixed. Once made it is fixed. Therefore sigma is equal to M by Z. Therefore the stress that will develop will be proportional to the moment. Bending moment is proportional to force Pz. So the stress will be proportional to Pz. Now strain that will be taking places of surface is equal to sigma by E. So this is proportional to force then due to the strain there is strain gauge. A metallic strain gauge it can be semiconductor also but normal. It is metallic coil like or a wear or a strip which is formally pasted on the surface of the beam were just stress has to be strain has to be measured. So the strain of the surface is transmitted to the strain to the strain gauge which is strip of metallic strip. So the strain here will be proportional to the stress so strain is equal to stress divided by Young's modulus of elasticity of the strain gauge.

Now because of this strain, the resistance will change electric resistance of this conductor or the strip or the strain gauge will change. How? The change in resistance delta r for given R will be proportional to the strain that will occur. So this is equal to the constant of proportionality multiplied by strain. So the delta r, this resistance change in resistance is proportional to strain and what is this constant of proportionality G? This is gauge factor, this is the physical property of the strain gauge delta r by R divided by epsilon that is called strain gauge property. Now what we find from here? delta r the change in electrical resistance in the strain gauge is proportional to strain. Strain is proportional to stress. Stress is proportional to bending moment and bending moment is proportional to the force Pz. So ultimately the change in resistance in the strain gauge is proportional to the force Pz. If we can find out the relation of the constant of proportionality between Pz and delta r, we can easily measure Pz from the change in resistance R. Now the change in resistance R also very small, it has to be measured accurately by another electrical method.

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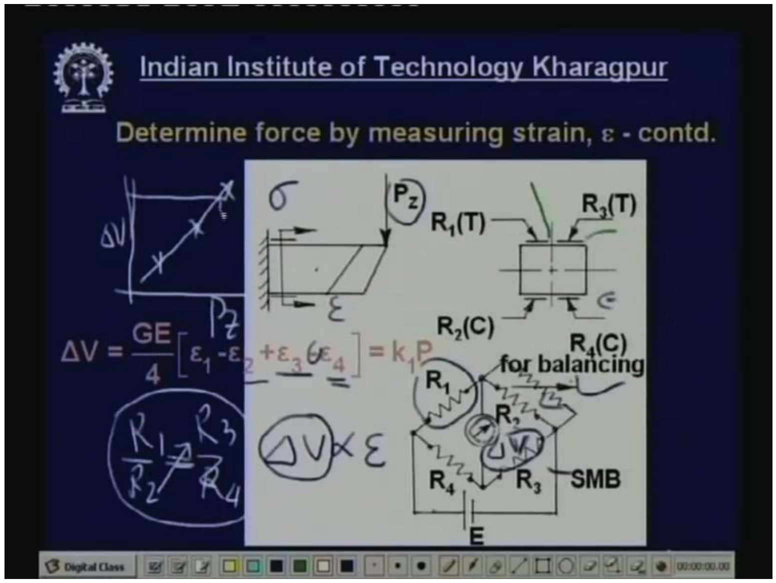

How is that? Now this is the measurement by this strain by strain gauge. Here is a tool, it is a cantilever beam subjective force Pz and because of the bending moment stress will develop here at the root maximum and now. At top it will be strain, stress in bottom it will be compressive stress. If you take the section of this beam, it will look like this. Suppose you have put two gauges, these are strain gauges. This is one strain gauge, this is another strain gauge. So, these two are above the neutral points, so both of them will be intension. So R 1 resistance of this strain gauge number one intension and this is R 3 that is strain gauge number three and that is also put under tension and two at the bottom. So R 4 in compression R 2 in compression. So, four strain gauges are mounted there equally distant from E line up neutral access. Basically this four resistance will be connected into Wheatstone bridge form like this a square bridge form. R 1 R 2 R 3 R 4 tension compression tension compression. This has to be arranged in this fashion. Otherwise it will not work.

Now here the circuit is connected with a potential difference E so long R 1 by R 2 remains equal to R 3 by R 4. There will be no voltage here. This is delta V that is called unbalanced voltage that we created here. So long this ratio will be maintained that R 1 by R 2, R 3 by R 4 will remain same. There will be no voltage. Normally the strain gauges have the same resistance say 120 ohms, 360 ohms, 1000 this standard but it cannot be exactly same. So there can be slight variation. So this may not be perfectly same. In that case, to make it same bring it to the null zero condition. Some additional resistance is used for balancing. By operating this one, we make this ratio same and its voltage will be zero. Now this will be under no load condition then you apply the known force or any force. Immediately this ratio will no longer remain same this will change. Now this is tension, so there will be change in resistance at compression. So here the resistance will change in positively and negatively. Now what will be the value of voltage? Value of voltage delta V will be equal to GE by 4 almost equal to epsilon 1 minus epsilon 2 plus epsilon 3 minus epsilon 4.

What is epsilon 1? That is strain that will occur into the resistance R 1 that is strain gauge. Epsilon 2 is in the compressive stress and three this one and four. Now since epsilon 2 and epsilon 4, the strains will take place into the strain gauges which are in compression. So they will create negative. So this will be minus and this will be minus this will be minus this one and this one. So this minus E4 and minus E2, minus minus this will be plus. So all will be added, so epsilon 1 plus epsilon 2 plus epsilon 3 plus epsilon 4. This will be plus because they are compressive because minus minus plus. So this will be delta V GE by 4 in to 4 epsilon if all this strains are equal. So this is how here you find that this delta V then delta V becomes proportional to epsilon. The strain the strain here is the strains here in any one or all of them will proportional to the stress, stress is proportional to the force Pz. So Pz is now connected with delta V linearly. Now by calibration what we do by calibration say this is delta V and this is Pz or other Pz can be put there delta V. So this will be a curve will be produced by experiment by number of known loads and then you use for machining and suppose you get this by delta voltage and what is corresponding force? This is the amount of force. So this is how it has to be calibrated first and then you use it. So this is how the strain gauge type dynamometer is used. Now measuring another method;

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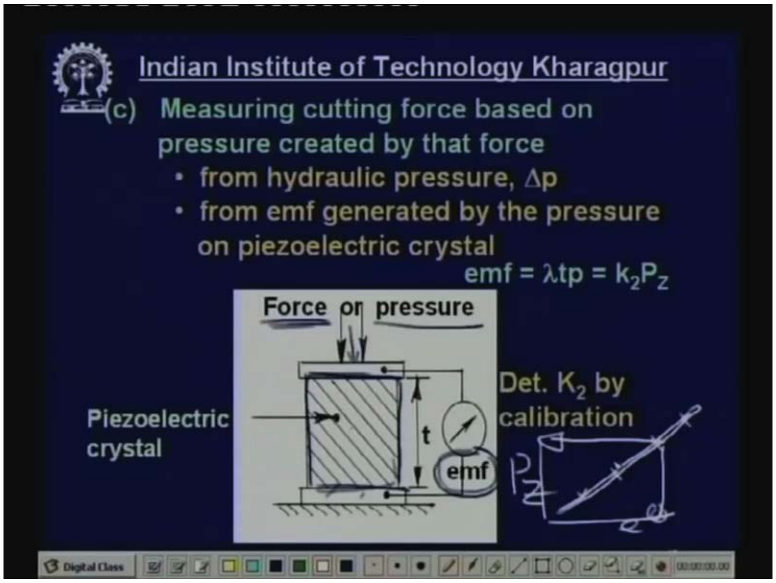

Measuring cutting force based on pressure created by that force; So first we have one we understood that the force causes deflection proportionally and from the proportional value of deflection we measure the force. Second one from the deformation like strain, we can determine the force. Third one from pressure created by the force. Now this pressure can be created through hydraulic medium. In the hydraulic medium suppose this is the cutting tool subjective force this is the hinges point and so because of the force this try to go in this direction, and suppose this is piston and there is hydraulic cylinder and so the pressure here will increase and then you measure the pressure by a pressure gauge.

So this is one method very crude method, but it is feasible say hydraulic method. Now there is another method from emf generated by the pressure on piezoelectric crystal. Now suppose this is piezoelectric crystal this one is piezoelectric crystal what is the property of piezoelectric crystal? If it is subjected to pressure, then some emf will be generated at the end. So this is emf so this is one end of crystal, this is another end of the crystal. They are connected to metallic plates say copper plates and then subject to a pressure, because of the pressure at the end some emf will be generated and this emf is proportional to the pressure of the force that may exerted from the crystal. Now this force can be the cutting force. So this can be connected to the cutting tool or it can be connected that the entire force will be transmitted on to the crystal through this copper plates.

So by calibration here, if you calibrate force P and emf here and you get a curve. You apply known force known force that is known pressure; you get certain value of epsilon. Then we increase it you get another point keep on get it number points, then draw a straight line all line that is called calibration curve. Now you put into action or cutting process. So suppose you get this much emf and this will be corresponding force Pz. This is how the cutting force Pz can be very precisely, accurately measured. This is very precision method, very reliable method, robust method but it is expensive. It has to be now if it is three D dynamometer, then it becomes more complex in manufacture, but it is very good method very accurate, robust, durable and stable and all this things what problem is expensive. Now design requirements for tool force dynamometers; Now dynamometers are available in the market.

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So people can purchase from market and use it, but these are expensive. If what expensive it will be not crude method then it will not be reliable. Those are cheaper but accuracy will be less. If you want high accuracy, precision, reliability and consistency then it has to be a very costly or sophisticated dynamometer which is very expensive. However these dynamometers need not be purchased. This can be designed by users but when these dynamometers used then some factors have to be kept in mind. Some factors have to be essentially taken into account while designing and building the dynamometer. What are those? Sensitivity, the sensitivity should be high, so that the amount of signal that will produce ultimately should be readable, should be substantial amount so that it can be read or it can be recorded but if this signal is very very weak, then it cannot be measured this is called sensitivity. Then on the other hand rigidity, the dinor should be rigid. Such that it can withstand the cutting force. Coming into that it should not be spoiled or broken or plastically deformed.

It has got another reason that if it is not very rigid, then the cutting tool of the compression will undergo very wide deflection which will affect the machining condition and the accuracy of measurement. So this has to be rigid that means there should not be unnecessary large deflection. So sensitivity and rigidity are contradictory to some extent. Sensitivity demands larger signal and rigidity demands that signal should not be too large or deflection or deformation should not be too large. So a good compromise has to be made through design. Cross sensitivity; Now the dynamometer is used for major in not only one force see vertical force Pz them Px and Py and for each force there is a separate Wheatstone bridge channel or a separate piezoelectric crystal. All these things are put together into the device called dynamometer.

Now the cross sensitivity has to be low as possible it means that the accuracy of measurement say a particular force Px or Py should not be affected by Pz. Otherwise the force Pz should not affect the measurement accuracy of Px or Py like that so each one will be independent. One will not effect the measurement of the other. Next stability against temperature and humidity; Now the temperature changes in the environment beside that due to the cutting action lot of heat is produced that heat is transmitted into the tool or the transducer. Therefore the transducer dynamometer should be such that, it should not affect much by the temperature within the range and humidity also should not be affected by humidity. So proper protection has to be taken, time response the response should be very quick that is the effect force the causes is force and effect is deflection and strain, stress and etcetera the voltage this should be simultaneous as almost simultaneous.

If there will be large load gap between these responses the cause and effect then this is chance of error in the measurement. So time response should be very quick. Frequency response; Frequency response means the readings of the measurement values should not be if the dynamometer should be so designed and constructed that the measured values should not be affected or jeopardized or spoiled by the vibration even if the any into the machine. Of course within the range of frequency and amplitude even vibration because to large then the no question nothing will work you know dynamo will fail but within a range of large range of or reasonably large range of frequency of vibration of the machine tool if any this measurement value should not be affected, this is called frequency response. Now consistency and durability; This diameter should keep the reading uniformly of the relation between input and output should remained constant that is called consistency and durability, the dynamometer will survive longer and perform uniformly throughout its longer life.

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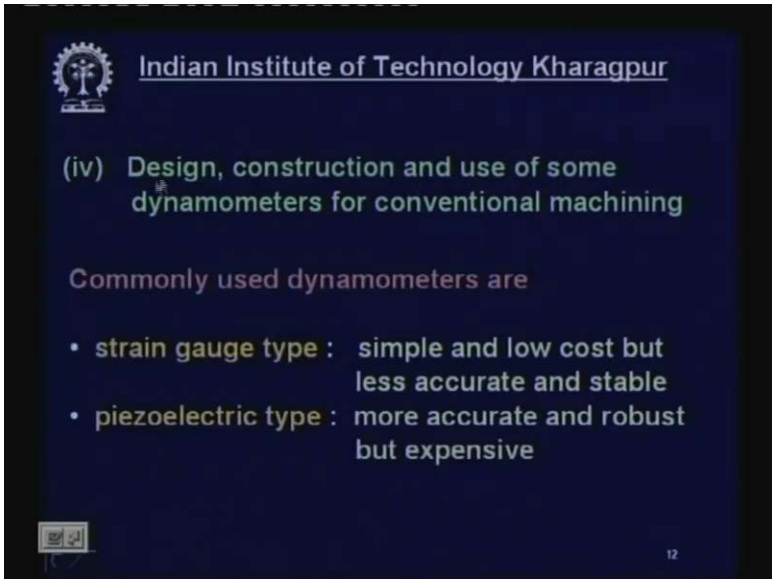

Now we shall discuss about design, construction and use of some dynamometer for conventional machining. As I told that you that you can purchase some sophisticated dynamometer like piezoelectric crystal type 3D dynamometer made manufactured by Chrysler Company of the world Switzerland. This is very very expensive say one 3D turning dynamometer may cost around 12 to 20 lakhs so this is too much. So for that purpose this strain gauge type dynamometer or other kind of dynamometer can be manufactured and used. I shall discuss some of them. Commonly used dynamometers are the dynamometers can be various types as I told you but commonly used are 1. The strain gauge based strain gauge based that is using strain gauges and connecting them now. It will be simple. These strain gauge type dynamometers are simple in construction, design, manufacture, low cost but less accurate and stable.

Time to time it has to be calibrated and it has to be rechecked for consistency or this resistance, this soldering and connection of this strain gauge condition resistance etcetera were as piezoelectric type is very accurate, more accurate much more accurate and robust and consistent reliable but problem is this expensive as I told you if a 3D say strain gauge type turning dynamometer cross around say 60000 rupees or 1 lakh. One piezoelectric type 3D turning dynamometer will cost around 15 lakhs.

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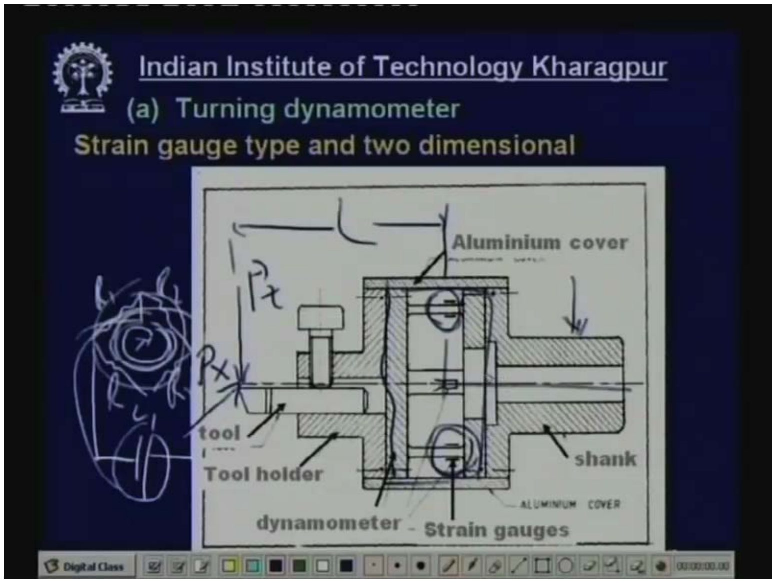

Now turning dynamometer. Strain gauge type two dimensional dynamometer; Here the dynamometers can be one dimensional, two dimensional or three dimensional. It really means if the dynamometer is made can measure only one force say Pz only, then that will be called one dimensional. If it can measure two forces Pz say another force Px or Py, this will be called two dimensional. If it can measure all the three forces, then it will be called three dimensional. So for as cutting forces are concerned particularly say turning etcetera say two dimensional are enough because if we know Pz and Px, from Px we can determine Py also is from a simple relation. But if it is oblique cutting, then possibly and if you want very accurate measurement then three D dynamometer will be required but for orthogonal cutting Px and Py are very simply correlated.

Now here you see the dynamometer it is constructed. It is two dimensional strain gauge type. This is the cutting tool fitted into the tool holder. It is fixed by bolt. The tool holder is clamped with ring. now this is ring. There are two discs connected by four integral ribs. It is single piece made stainless steel. This is single piece does got transducing element main part and this is the shank which is fitted into the tool post which is clamped to the tool post like that. Now this ring now this is the force acting on that say Pz that will be cantilever beam. So this is the length L. So this force Pz will produce a bending moment Pz multiplied by L will create a bending moment. This moment will create stress here.

So bending stress sigma is proportional to strain. The strain will be detected by strain gauges say for Pz, two strain gauges are here, two strain gauges are there four strain gauges. Now we have also noted in earlier slides also we are using four strain gauges. In the Wheatstone bridge, there are four gauges force resistance. If all the four gauges are alive, then the sensitivity will be high. If the two gauges are alive and two gauges are dummy, then the sensitivity will be half then it will be called half bridge. Sometime because of inconvenience of mounting or in in accessibility of space, we use only two gauges and two gauges are dummy taken from the other sources and

that is called half bridge connection and that is sensitivity is half. Sometime we may have to go even one life gauge that is called quarter bridge or sensitivity will be one fourth.
So preferably we should use always four strain gauges and all of them alive. So this is the two gauges. Now this is neutral access. Two at the top in tension and two at the bottom in compression. So this two four gauges will now be connected in a Wheatstone bridge say this is R 1 R 2. This is R 3 tension R 4 and this is connected to a voltage and this is the voltage delta V. Of course this delta V is very small, this has to be amplified, further amplified and rectified and then rate into an unit. So this part, this Wheatstone bridge comprise inside and the rest of thing are put into an instrument called strain measuring bridge were this emf and connection magnification, amplification all this things are carried out. This is called strain measuring bridge.

So this four strain gauges, now this will be another force in this direction say Px horizontal force because of this horizontal force Px, the strain gauge is mounted here this rib and there is another rib on the other side so four gauges will be there. Two in tension two in compression that will produce another Wheatstone bridge or channel that is called Px channel and these four gauges produce a channel for Pz. So this is called two dimensional. How does it look really? You see that this is the dynamometer final dynamometer you know in the constructed is the front part is cutting tool and this is the tool holder. This sensitive transducing element or transducer that is a two disc connected integrally by four ribs. There are four ribs here.

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One, two, three, four and then this is the tool shank and these are the channels. So there are eight wires, four for four makes one channel for Pz, another four for Px they are connected to strain measuring bridge as readout unit were we get finally in the output in the form of voltage or some digital reading.

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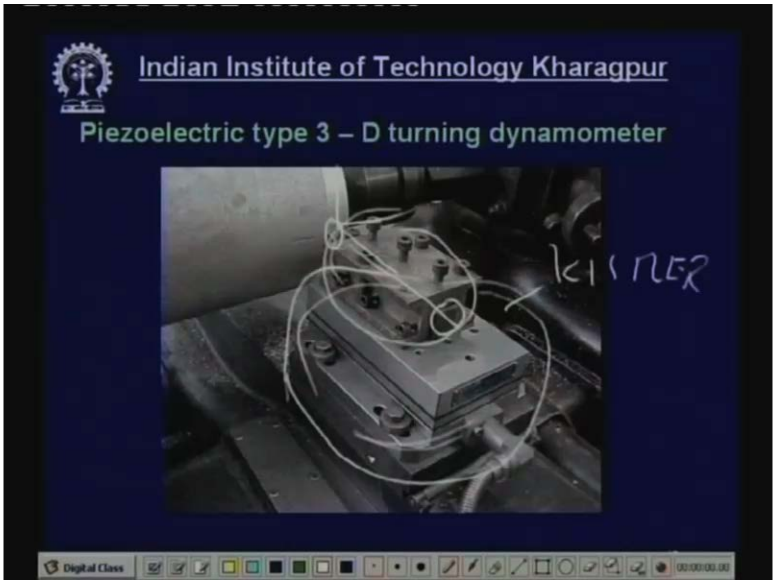

Now this is piezoelectric crystal type three D turning dynamometer, piezoelectric type three dimensional turning dynamometer. Here the crystals are there inside. So once crystal takes care of the force Pz the tangential force another crystal the Px and another crystal Py and all independently and this should be cross sensitivity will be as low that is Pz will not effect the Px and Py and that is called cross sensitivity. So this has to be taken care of very carefully within this, so this is the dynamometer. This is the actual dynamometer and it is manufactured by a company world famous company called Kistler company. Kistler Kistler Kistler company and this expensive may be 12 lakhs to 20 lakhs. Anyhow this works very well. Here is cutting tool mounted on a tool holder. Tool holder is long tool holder fitted into a tool post. Tool post is mounted on the dynamometer. So all the forces Pz Px and Py will come on to the crystals inside and that will produce emf signal and that will taken out through this cable and this will go to the readout unit say charge amplifier or data acquisition system or to the personal computer and so on. So this is a sophisticated method of using three D piezoelectric type turning dynamometers is very precision time, very accurate type and robust.

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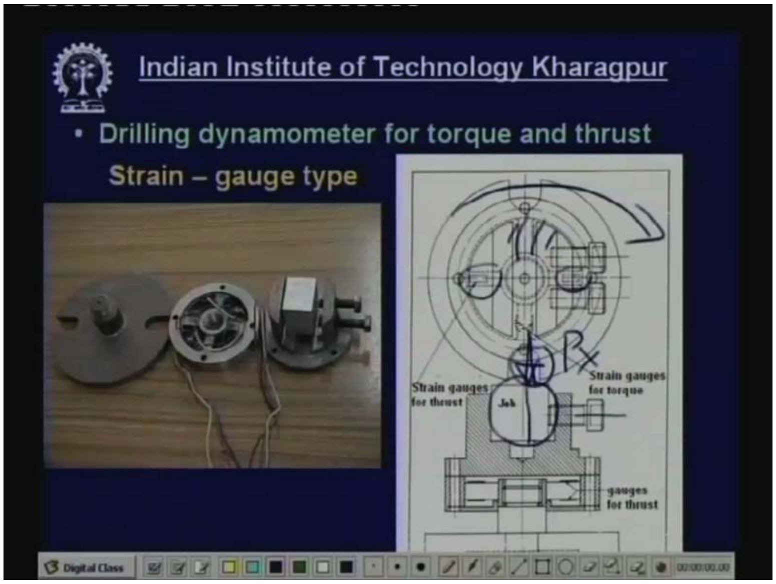

Now this is drilling dynamometer. Now this drilling dynamometer There are three parts; one part is the top this part is shown over here and this is the transducing part a ring like, a ring like made of stainless steel which has got this is the boss a central tubular piece with internal thread connected to the outer ring by four ribs. 1 2 3 4 there are four ribs. So this is the single piece and that is mounted on base. This is fixed on table of drilling machine by clamping. So this is the work piece mounted here this is the work piece mounted here and fitted by this and this now subject to a force say Px due to the force piece axial force. This for two ribs, all the four ribs will subject to bending and this rib and this rib. There are four gauges mounted one here and one there on two at the bottom. So upper two will be inner tension and this upper two will be under tension and the lower tool be under compression because of the force Px thrust force.

Now they will be connected in Wheatstone bridge and then finally into the strain measuring bridge. Now for the torque measurement, due to the torque here this two ribs here will be will be subject to bending like this. So there will be tension here compression there. Tension here and compression there, compression tension so this four strain gauge will be connected to another Wheatstone bridge and we produce another channel. So these two channels will give Pz sorry torque and thrust force. Now this is the milling dynamometer.

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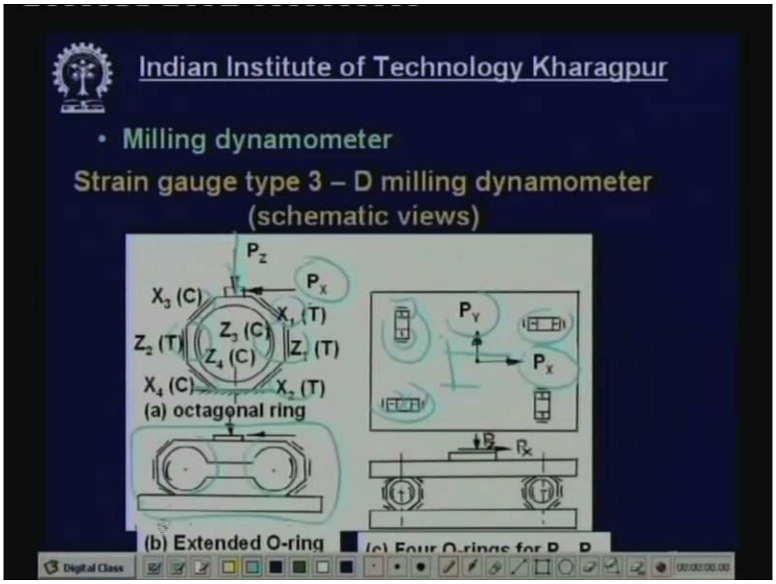

Now in milling dynamometer, the work piece is mounted on a plate the plate is rest resting on four supports they are call octagonal rings and that is fixed in the base plate that is fixed on the based this is the base plate. Now here what is octagonal ring this is called octagonal ring or O ring. If the O ring or octagonal ring fixed over here say fixed over here and apply a force Pz then the stress will develop here and here outside tension tension inside compression compression among four strain gauges here. Say Z 1 that is Pz for Pz Z 1 Z 2 under tension Z 3 and Z 4 under compression, then you complete the Wheatstone bridge and measure it for Px. So there will be tension here tension there and this will be compression this will be compression.

So four gauges X 1 X 2 X 4 when connected Wheatstone bridge will give the Px. Now four such rings will be put here. The number 1 number 2 number 3 number 4. Now this cutting force because of milling that will trouble any direction. So this four supports receive different amount of force so the total force will be summation of the forces acting on this force. So the vertical force will be measured by summation of the force acting here and this one and this one will that is strain gauge is here will measure the forces and Px and this strain gauge is mounted over here and in this direction will measure Py. So this will measure this force Px Py Pz in a strain gauge type many dynamometer. Now this is another called extended O ring. So here this is O ring, suppose here this another O ring type. Now this connected like this. This is useful for another kind of dynamometer called grinding dynamometer. Now this is the milling dynamometer you see that is described.

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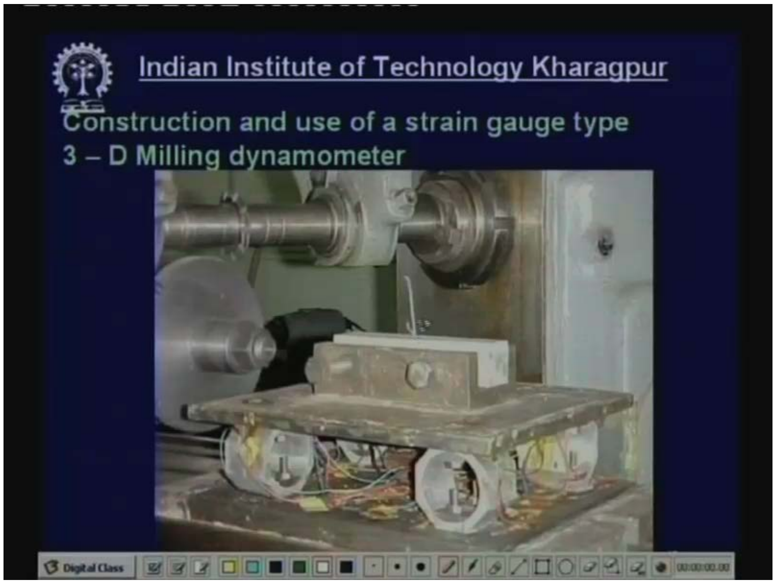

This is the milling dynamometer. It has got four octagonal rings fixed on the bottom plate, which is mounted on the table of the milling machine and there is a top plate which is fixed with this O four rings. You see the orientation. Orientation is different and this is the job, this job which is mounted on the job holder. So, with cutting force will be working here in three directions. So one will be in this direction, other one will be in this direction another in this direction. So this strain gauges mounted on the difference surface of this O ring will be detecting all these forces. Now come to grinding dynamometer. This is one strain gauge type grinding dynamometer. Here you see this extended type dynamometer.

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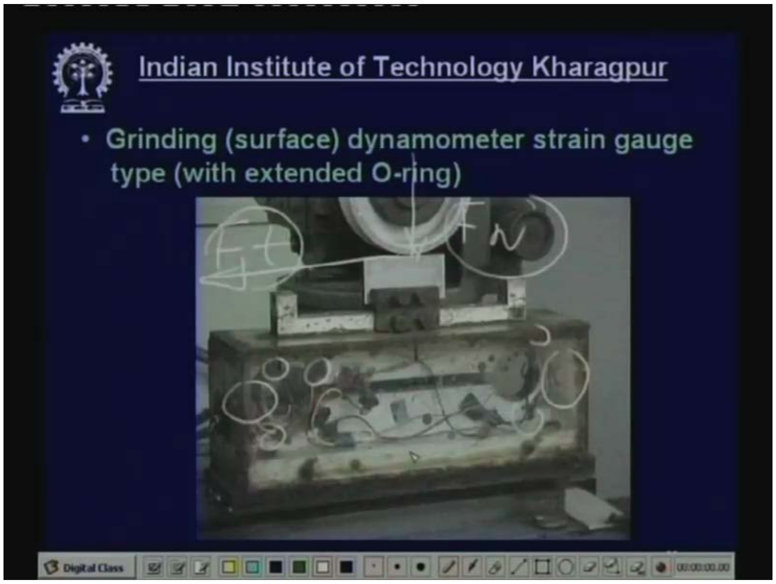

Strain gauge type this will be two forces will be acting here one force in this direction that is called Ft another force in this direction. Say Fn two forces because of the force Fn the strain gauge is mounted at this point will be strain and because of the force Ft the strain gauges is mounted on the slant surfaces the slant surfaces of this ring will detecting this Ft. So this is the strain gauge type dynamometer this is not very well, this is cheap low cost. We can easily design and use but not very reliable not very accurate. If you want very accurate measurement and study and research, then you have to go for piezoelectric crystal type dynamometer. This is the piezoelectric crystal type dynamometer. Again this is the crystal dynamometer three D on which

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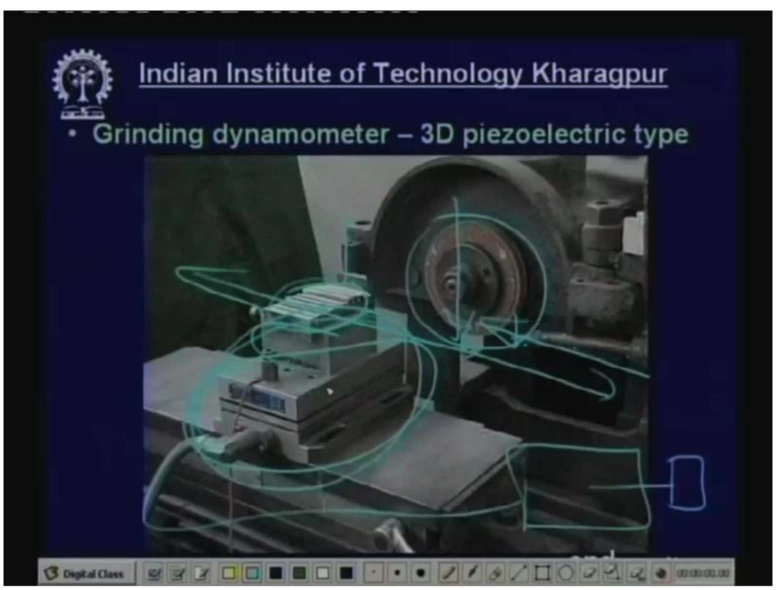

the job holder is mounted, on that a job is mounted and this will subject to the grinding process this is the grinding wheel. So this will be travelling under the grinding wheel. So because of this, there will be two forces acting normal to that and tangent to that on this job and that will be recorded into this monitored by this three dimensional piezoelectric crystal type dynamometer and signal emf will be taken by this cable and put into the data acquisition system into the PC and from the PC you get the enter information. Now this will not only give the average magnitude if any pulsation or vibration that will also be recorded. If there occurs any change variation that will be recorded. So this very very sophisticated method and accurate method which has to be used but this very expensive. So this how some way that force has to be measured that has to be understood and how the force has to be measured preferably by dynamometer and dynamometer can be strain gauge type or say piezoelectric piezoelectric crystal type. If one can afford then piezoelectric crystal type dynamometers are better if not, you know design, develop, calibrate and use strain gauge type dynamometer.

Thank you.