Metal Cutting and Machine Tools

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Lecture - 09
Measurement of cutting forces

Welcome viewers to the ninth lecture of the course Metal Cutting and Machine Tools. So, in this lecture we are going to cover you know some discussion on measurement of cutting forces, but previous to that whatever leftover portion was there for calculation of cutting forces, we will quickly have a look at that and then continue with the with today's discussion.

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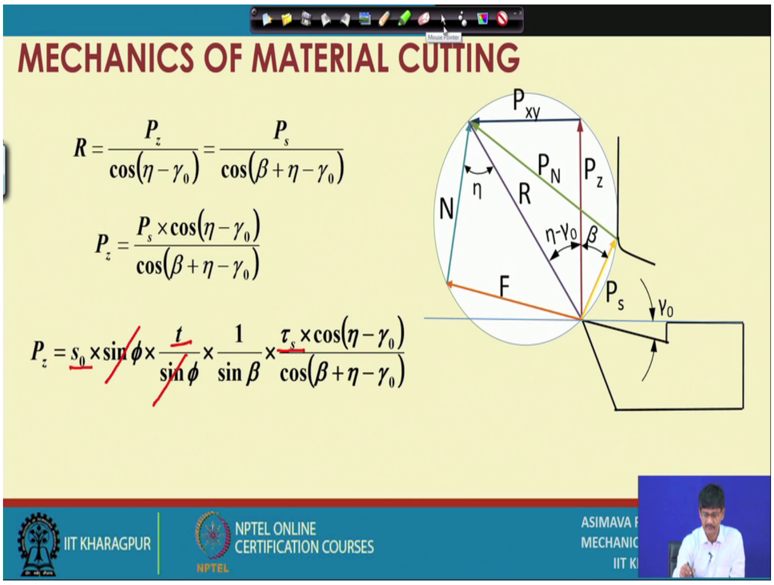

So, to start with, in the last discussion that we were having we derived the relation between the main cutting force P z and the shear component of the resultant force P s. P s along the shear plane which is equal to P s and therefore, P z was found to be P s into cos eta minus gamma 0 divided by cos beta plus eta minus gamma o. We had proceeded up till this and then we replace the value of P s by the shear strength of the material, dynamic shear strength of the material and the area on which it is acting.

The projected area we had found was equal to t by sin phi into s 0 sin phi. So, that sin phi cancels out, let me just do it on the on a here itself that is this we can cancel out. So, that we have s 0, s 0 into t into tau s into all these trigonometric functions sin beta, cos beta plus eta minus gamma o, and cos eta minus gamma o.

The trouble is we cannot handle all these angles because while we are knowing the value of gamma o; gamma o is known from the tool angles orthogonal rake. We do not have a concrete idea about what is the shear angle and what is eta. So, let us quickly go through the possible ways in which we can find it out.

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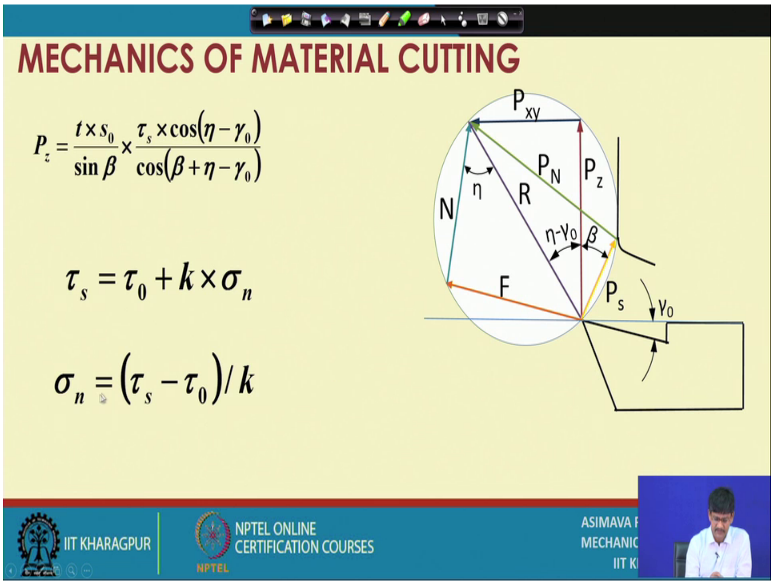

So, here this tau s which is not known to us up till now this tau s is actually you know taken to be assumed to have a relation with; a constant value tau o tau 0 plus it is a proportional part with the normal stress how do you find out normal stress? We know the normal force on the shear plane that divided by the area of the shear plane that will give us the normal stress. So, that way if we divide sorry just let me go on to the next slide. So, just you know just shifting the terms and getting an expression of sigma n in terms of tau sorry yeah.

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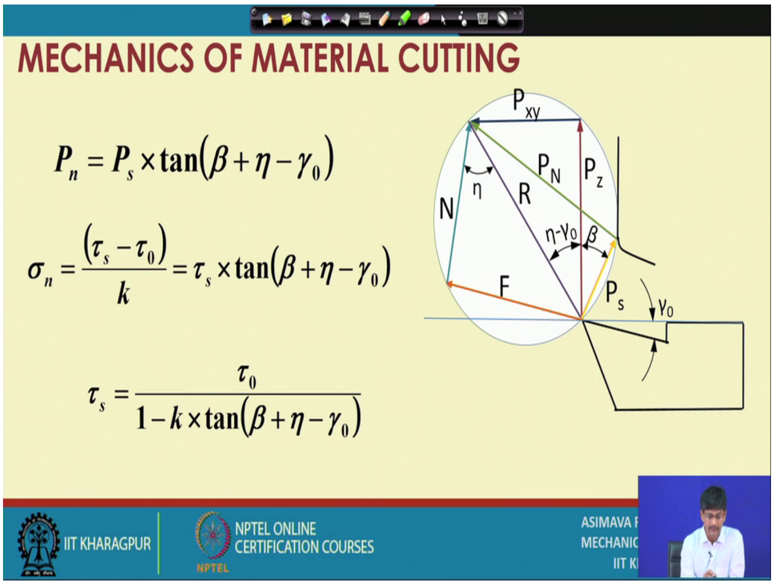

So we also have a relation between the normal force, normal to the shear plane and the plane and the force you know tangential to the shear plane, we have a tangential relationship y you know P n is here P s is here, and this is the angle beta plus eta minus gamma o.

So, we have a tangential relation between these two. So, if we divide it by the shear plane area, in that case we have sigma n replacing P n, P n by area of a s is equal to sigma n and that is equal to P s gets replaced by tau s in the process and tan remains as it is if we you know if we rearrange the coefficients and find out the value of tau s because tau s is having one component from here and another component from here. So, if we collect coefficients and express tau s as a function of tau o, we get a relation of this type alright. So, this is the constant of proportionality between the normal stress and the shear stress on the shear plane yes.

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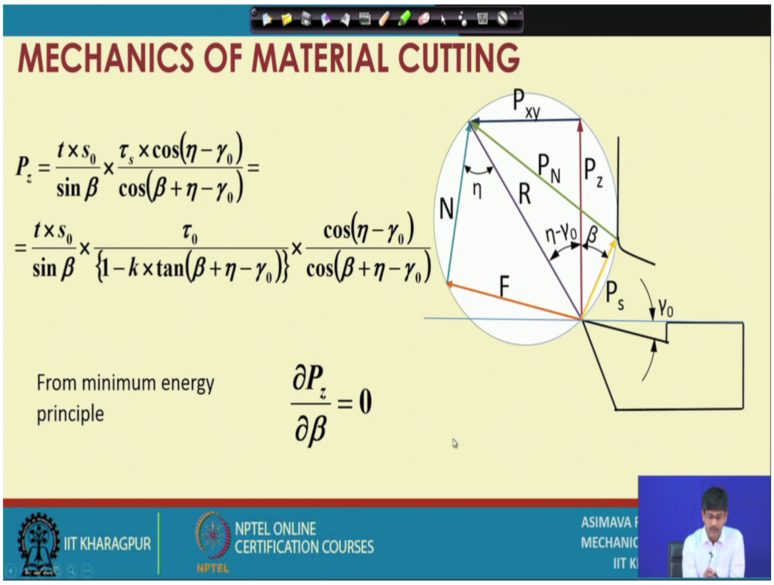

So, if we do that we can replace tau s in terms of tau o, tau 0 the constant you know portion of the shear stress, and this term appears at the bottom this added the term in the denominator appears.

So, that the expression of P z is t s 0 into these things were previously there cos eta minus gamma o sin beta cos beta plus eta minus gamma o, additionally this term comes in. Now what is exactly the value of P z? For this we use the minimum energy principle that is in order for any process to be carried out, it will always follow the natural you know natural process of expending minimum energy to achieve that.

So, if shear plane is creating the you know shear between lamina of the uncut chip, its getting sheared off it will happen in such a way that minimum energy is expended otherwise why should it go for any plane in which more energy is spent; it will go for that plane in which minimum energy there that will happen first. So, from the minimum energy principle, the least amount of P z will define this particular plane. The least value of P z occurs when this minimum energy is expended, because energy is equal to P z into v c. So, if we differentiate with P s it with respect to beta, we will be able to solve for that beta for which P z is minimum.

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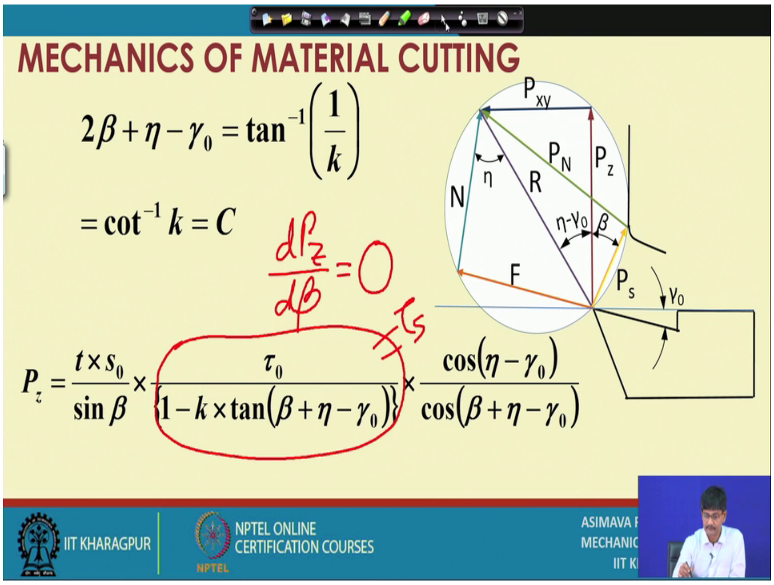

So, following that principle if we differentiate I have not included the whole mathematical derivation here, if you are interested I will upload it in the form of a separate file, but believe me if you try yourselves, I am sure you will be able to do it; that means, this particular sorry this particular expression I am sure you will be able to derive it yourselves very easily.

That is if you try deriving this particular; so, here as you can well understand all terms which are not containing beta, they will be treated as constants. So, you might be having only two terms one is sin beta and another is cos beta plus theta minus gamma o and of course, another term that is 1 minus k into tan beta plus eta minus gamma o in the denominator to be derived.

So, I am sure you will be able to do it yourselves. So, I am not including the formal discussion here. So, that finally, gives us a relation twice beta plus eta minus gamma o is equal to tan inverse 1 by k. Now what does this exactly mean? It means that the angles are going to have a relation in such a case, which case for minimum energy to be expended to achieve chip formation; the angles are going to have this sort of a relationship is this the final thing in metal cutting? No. In fact, 10 to 11 different what you call it different types of theories are there, what can be the relation between these basic angles and we are discussing just one of them, this is called merchants second solution following the minimum energy principle.

So, that is equal to tan inverse 1 by k where that is equal to cot inverse k, which is equated to a constant C which is called the machining constant by in some literature. So, that ultimately we can replace the relation between these angles in this expression. Now if you notice this term in the middle, it is equal to tau s and if it if we keep it that way we do not have to bother about the changes that will be happening due to incorporation of this relation here. So, we can remove it from consideration by just keeping the original value of tau s here. So, let us replace these values and see what happens yes.

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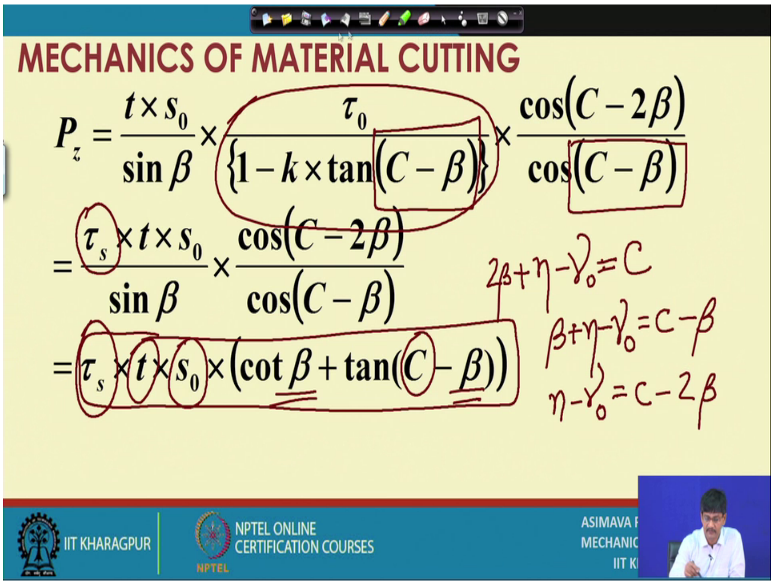

In that case, we find that the expression comes out to be all these things are untouched, this one expression since twice beta plus sorry plus eta minus gamma o is equal to, what is it called C. Therefore, we can write beta plus eta minus gamma o equal to C minus beta and therefore, we have replaced those values here. We have replaced that one here beta plus eta minus gamma o has been replaced here and it has been replaced here alright. And therefore, after replacement still we are knowing that this thing is equal to tau s and we have straight replaced that formatively large expression here.

So, that we have leftover sin beta here cos C minus beta from the other side of the denominator coming here. And of course, previously we had cos eta minus gamma o here which gets replaced by cot eta minus gamma o is naturally equal to C minus twice beta, that we have replaced here and therefore, we get this particular expression. If you expand this expression, we will find that it will become equal to cot beta plus tan C minus beta cot beta plus tan C minus beta and therefore, we can say that this expression will give us an estimation of the main cutting force P z, if we are knowing t, t we are knowing of course, it is the depth of cut if we are knowing feed, feed we are knowing definitely in millimeters per revolution it will be set by us only. If we know the shear strength dynamic shear strength of the material, yes that will be known and of course, if this machining constant is found (Refer Time: 12:41) and of course, as I said beta now if you remember beta eta and zeta they were related together.

So, that we can directly replace the value of beta here; so I leave this to you find out the value of tan beta which we had found out to be equal to cos gamma o minus divided by zeta minus sin gamma o. If you put it here we can replace beta as well. So, all the terms being known, we can find out the value of P z. If P z is known we can find the value of p x y and also we can find out the other values of like friction normal force f n and f and n etcetera everything can be known.

So, we will have in the next lecture some numerical discs and a new discussion of some numerical problems, in which we can find out the force components of you know turning I mean force components during orthogonal turning. Now let us move on to the next subject or discussion.

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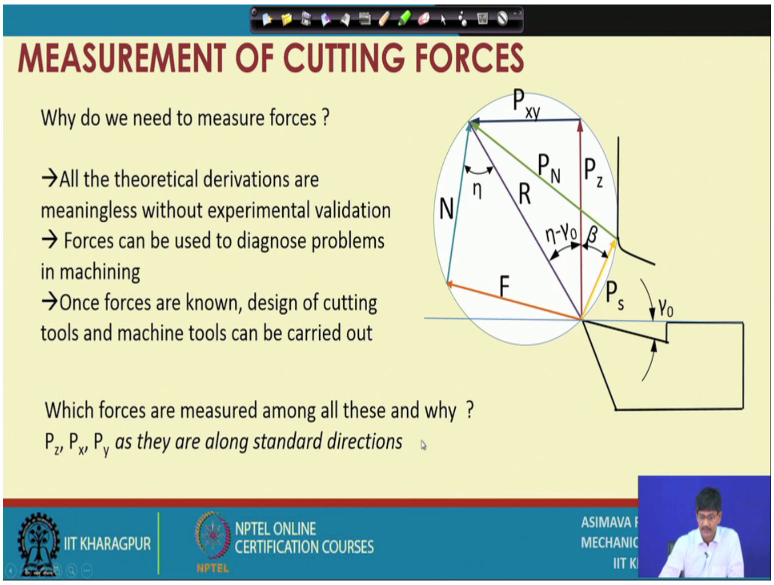

The thing that we had proceeded to discuss today that is the measurement of cutting forces; why do cutting forces have to be at all measured, is there any need? First of all from common sense approach we can say that if we are measuring the cutting forces and rather unless we are measuring cutting forces, how do we know all these discussions that we are having about calculation of cutting forces to be correct?

So, in order to validate our calculations on cutting forces we need to carry out experiments to find out whether we are really getting those forces as per calculations or not. But you might ask me, what is the whole point of cutting and calculating and measuring cutting forces? Suppose we know nothing about them what is wrong? First of all if we do not know cutting forces, we cannot estimate what should be the dimensions of the machine tool on which this cutting is going to take place. For example, suppose I am you know feeding a tool in the longitudinal direction with the help of a lead screw.

So, the cutting tool is moving and its experiencing feed forces you know actually to the feed screw which is making the carriage move. So, unless I know what sort of forces I am going to experience, how can I design the dimensions of this feed screw? So, for design, calculations and other you know other activities cutting forces will have to be known, you might still argue that the machine; machine tool was already there on which you are using the cutting tool.

But its you know the everlasting question about which came before and did the egg come first or the chicken come first? So, that way if you want to design machine tools you have to know the cutting forces you have to carry out the experiments; the experiments have to be carried out on them on a machine tool only.

So, machine tool must be present, but in order to make the machine to present, design has to be done I mean a measurement of the cutting forces have to be done in order to design it etcetera etcetera that is absolutely essential that is knowing the forces through experiments, in order to use their use that data for machine design. So, many other reasons are there, I am not touching all of them because you know these things I can give you references from which you can pick up this information [FL].

So, what do we exactly measure, do we measure for example, P s? Somebody is interested to measure p s. So, that you cannot directly put it into the calculation of you know that merchant second solution etcetera etcetera or P n generally we are interested to measure or other v are capable of measuring forces in standard unchanging directions and that immediately makes it clear that we measure it along P x P y and P z. Why do not you measure it along I say the shear plane that is because the shear plane does not have the same orientation in every case.

So, that is out of question. So, standard directions are chosen for the measurement of cutting forces like P z P x and P y. So, next how can we measure cutting forces?

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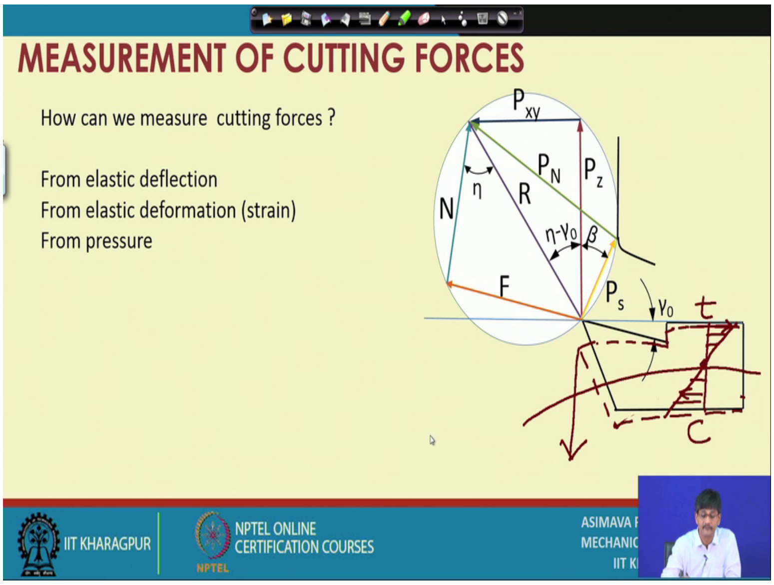

Cutting forces can be measured you know from elastic deflection now what do we mean by that? We mean that you know if under the action of cutting forces just a moment; if under the action of cutting forces this tool deflects. Why should it deflect? Because the force is in the other direction, this force mind you is on the chip. The cutting tool experiences this force because of which this is the force on the cutting. Cutting tool it deflects like a cantilever beam my drawing is not very perfect because it should have you know beam here let me mean that correction this line is not supposed to be here that is right.

So, it deflects as a cantilever beam and from the deflections, we can find out the forces if they are (Refer Time: 19:21) in proportional limit. So, elastic deform deflection can be measured and from that force can be estimated. We can have elastic deformation that is strain what do we mean why this? I mean that you know if there is a cantilever beam and if this be if this be the neutral axis, then we can estimate the strain here to be of tensile nature bending of beams and the strain on the bottom side is going to be compressive, and at the middle in the neutral axis there is no stress at all. So, that we can expect something of this type to happen you know stresses are sorry stresses are like this and I am just giving some arrows here to make you understand.

So, its reversed on the top its tensile on the bottom its compressive. So, from these strains we can estimate what is the force within elastic limit. So, we can also find out from the pressure. So, next let us see what do we have after this.

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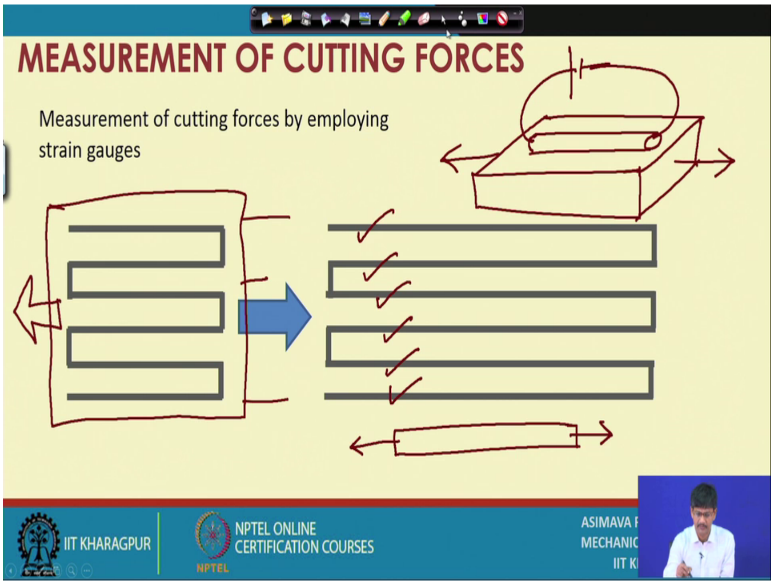

So, first of all if you want to measure strains we can make take the help of something called the strain gauge, how does the strain gauge work? The strain gauge you know it is like I will try to give you the idea in simple words suppose I have here a simple shaft or say a rod of whatever cross section.

So, this one I start pulling if I pull it will undergo a strain. Now in the same manner suppose I have a body, on top of which I have put a sort of conductor, its absolutely cemented onto the body. If I pull the body the body is going to undergo longitudinal strain and this body will also undergo the same amount of I mean whatever it lay its length qualifies to, it will undergo strain there will be no relative motion between the top surface and the this particular element.

So, it undergoes longitudinal strain together with that it will undergo some change in the lateral direction also, but what do we achieve from that? We want to say if it is undergoing a change in length if its say increasing in length due to tensile forces and if its diameter is decreasing. If I measure its resistance or say I measure the current flowing through it I will be definitely able to register a change.

So, from this change I can estimate what is going to be the you know what is the strain that is what I will be estimating what is the strain from the resistance change, if they are proportional my work will be easier. I mean it is it would be possible to extrapolate also. But the problem is how much should be this length you will say one meter that is impossible on the cutting tool when the cutting tool is mounted on the lathe there is hardly any elbow space you have to do things within a very small space. But small spaces will mean that this length will be limited and within this limited length, you can hardly register you know hardly expect some appreciable change in resistance to take place due to strain.

So, what we do is within a very small space say this particular space is restricted within a few square millimetres, maybe this side is two milli say 4 millimetres that size is 6 millimetres like that. Within that we enclose a large number of zigzag conductors some sort of you know structure is pattern is chosen. So, that the lengths are of a large quantity what about this side? This side hardly you know there is any length almost negligible. So, all these lengths add up when the thing is stretched this is the thing when the thing is stretched on two sides all these lengths get stretched.

So, that within a confined zone of area, I will be having considerable change in the resistance. Due to considerable amount of strain getting registered. So, let us now see what happens after this yes.

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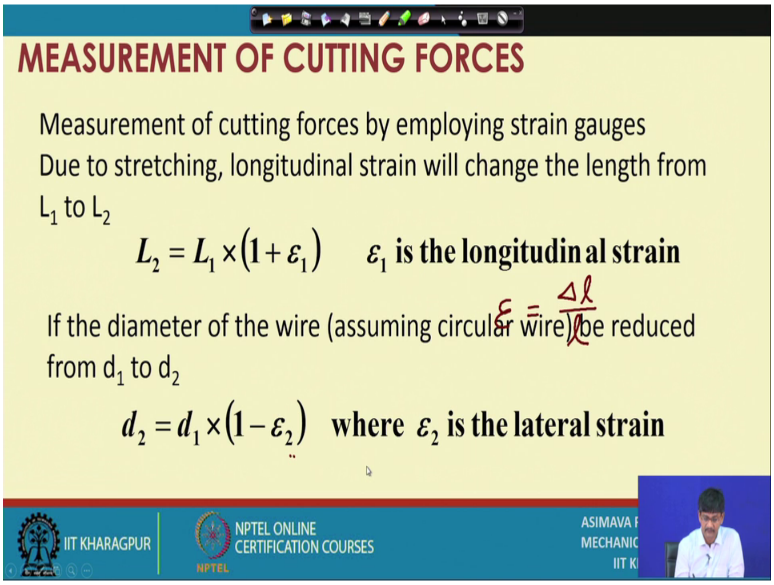

So, if we employ such strain gauges, due to stretching longitudinal change longitudinal strain will change the length from L 1 to L 2. So, how do we estimate L 2? L 2 will be equal to L 1 multiplied by you know taking into consideration that epsilon one is the longitudinal strain. So, strain is defined as delta l by l where l is the original length and delta l is the in small increment in length.

So, if we multiply it by the original length L 1 we will get the corresponding change in length therefore, L 2 is equal to L 1 into 1 plus epsilon 1, where epsilon 1 is the longitudinal strain; that means, in the direction of the stretch we are considering for the moment that it is tensile stresses which have arisen in the work piece or the part under of our interest due to the forces which are applied.

Tensile forces giving rise to tensile stresses. So, this tensile strain; however, if we consider if we assume we can generalize it also, if we assume that say the cross section is defined as a circular cross section of those strain gauge wires in that case that will undergo generally a compression. But it is this compression is definitely not going to be you know following constancy of volume rather from Poisson's ratio, we will get a relation between this lateral strain and longitudinal strain. Lateral strain by longitudinal strain is equal to Poisson's ratio, but anyway the new diameter will be decreased by you know original diameter multiplied by one minus epsilon two.

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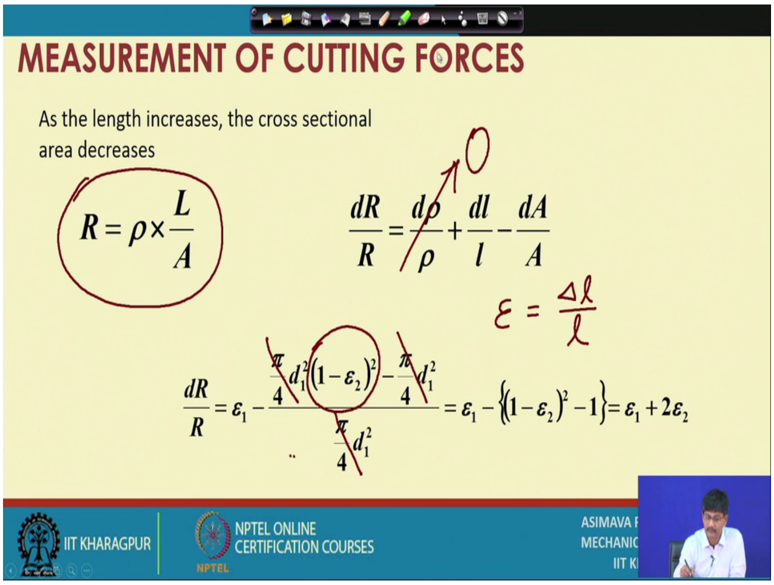

So, that is the lateral strain therefore if we have the resistance to be defined as you know rho into L by A, we can differentiate this and get this particular relation between the differentials where do we what is the; you know origin of this one? This is simply resistance is equal to resistivity multiplied by length divided by cross sectional area resistivity for the time being we will consider to be constant; it is not affected by any of these physical phenomena which are occurring like stretching etcetera.

So, in that case if we differentiate this we will get d R by R is equal to d rho by rho plus d l by l plus d A by A minus d by A because it is in the denominator. This thing we will assign a value of 0 now itself, there is no change in resistivity. Hence in the leftover terms what we notice is that d l by l is nothing, but the strain and d A by A v you know painstakingly put in all the terms.

So, that we get pi by 4 into changed value of diameter square minus pi by 4 into d 1 square original diameter. So, change in area divided by original area equal to epsilon 1 and naturally as d 1 square is there I mean d 1 square d 2 square is equal to this thing; we get 1 minus epsilon 2 whole square and from here we get 1. This thing cancels out this thing will cancel; so, this is simply this term minus d 1 square sorry what do you call it this term; simply this term minus 1. So, that is what has come. So, if we increase it by binomially and not even binomially one if we say that this is a minus b whole square the square of that strain term we neglect.

So, that when we consider all these signs out comes epsilon 1 plus twice epsilon 2, and hence if we divided by epsilon through the expression, we will get just a moment.

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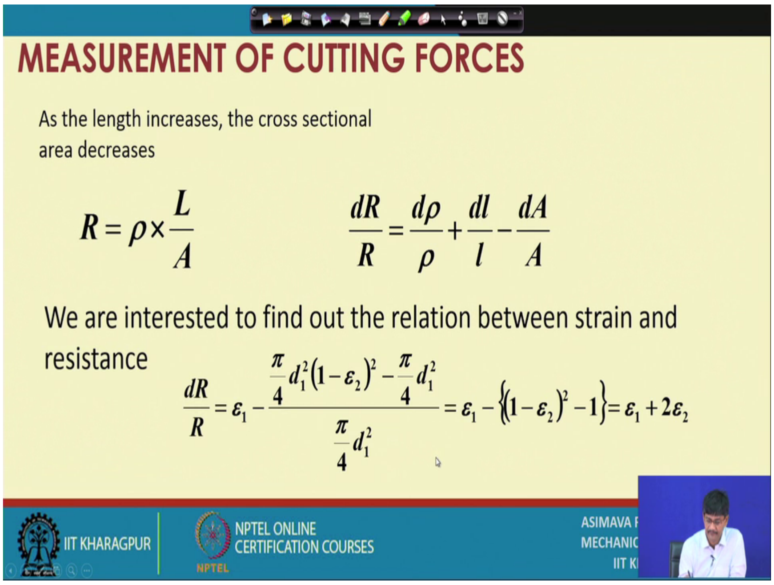

Dividing the equation throughout by epsilon 1, we get d R by R by strain.

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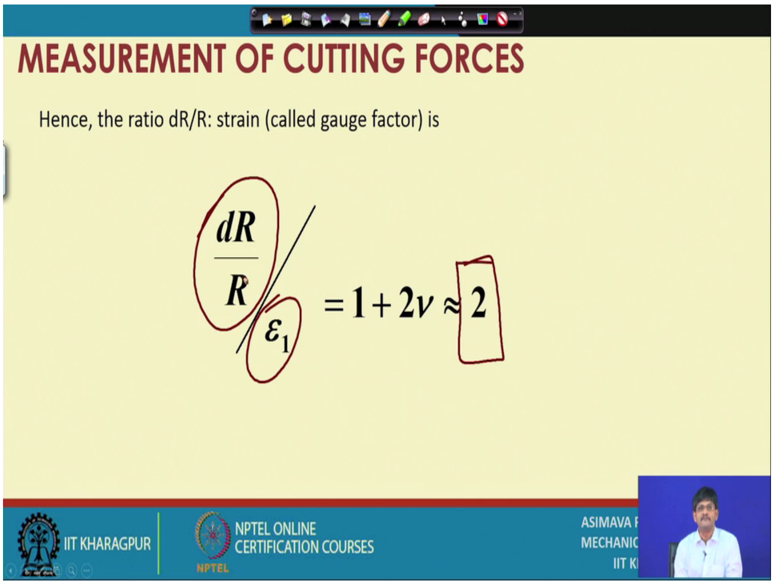

That means, change in resistance per unit strain is equal to 1 plus twice Poisson's ratio, because we will get epsilon 2 by epsilon 1 here and that can be assumed to be equal to 2; which means that change in resistance per unit resistance divided by strain is actually a constant these two things are proportional.

So, this brings us to the end of the ninth lecture, in the tenth lecture I want to exclusively discuss problems I mean numerical problems; and in the eleventh lecture I will be completing some part of the calculation on measurements; measurement of cutting forces, which I could not cover in this half hour lecture, but that part will not be included in the second weeks syllabus. So, whatever I discuss on measurement of cutting forces in the eleventh lecture, will be treated as syllabus under the third week. So.

Thank you.