Experimental Physics i
Prof. Amal Kumar Das
Department of Physics
Indian Institute of Technology, Kharagpur

Lecture - 56
Mutual inductance

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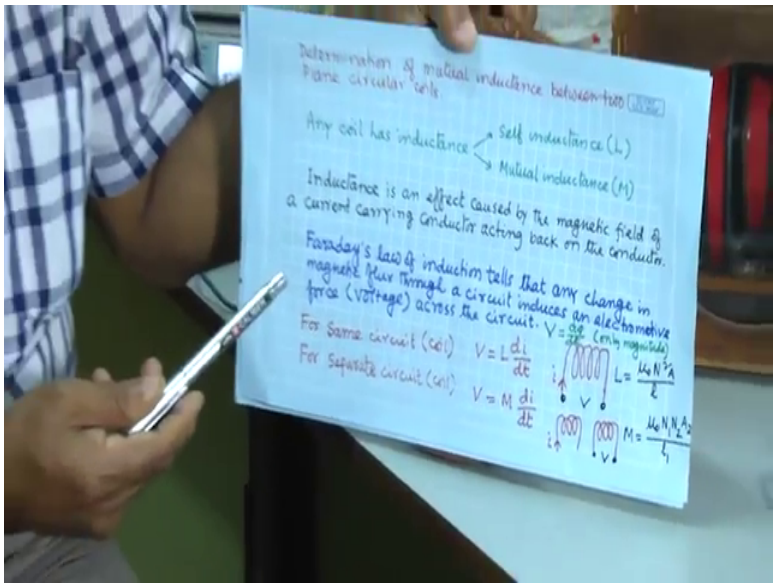

So, today we will demonstrates the Mutual Inductance of a coil. So, how to measure mutual inductance in a laboratory so that we will demonstrate? So, let us discuss about the about the about the theory of this experiment. So, you know that mutual so this any coil has inductance; so, either the two types of inductance, self inductance L and mutual inductance M right.

So, inductance is an effect caused by the magnetic field of a current carrying conductor acting back on the conductor, acting back on the conductors. So, what does it mean? Basically from Faraday's law of induction, it tells that any change in magnetic flux through a circuit induces an electromagnetic electromotive force that is voltage across the circuit right. So, basically V equal to d phi by dt, change of flux with time, rate of change of flux ok. So, here only we have taken magnitude that there is a negative sign basically so just we note these sign ok.

So, so if you have only one coil ok, and you have passing current through this coil. Then this flux produced by this coil that is linked with this with the same coil itself. So, in that

case, we will we will get basically self inductance. And this due to this change of flux, linked with this coil itself ok. So, it will generate voltage electromotive force on this coil itself right.

So, basically this by definition, there is voltage induced in the same coil that is proportional to the change of current in the same coil ok, rate of change of the current with same coil. So, these proportionality constant is L. So, V equal to L di by dt, so for single coil ok. So, there is the self inductance L. And if you have two coils; in one coil you are producing magnetic field or and that magnetic field linked with the nearest coil another coil.

So, if change of this magnetic field if any change of the magnetic field in this coil, so that is that is that flux linked with the second coil, there also it will change the flux with time right. So, due to that this induced emf on the second coil that is if we get this V, so that V is proportional to the rate of change of current in the in the first coil ok.

So, then this basically this induced voltage in second coil is proportional to the change rate of change of current in the first coil. So, this proportionality constant is M, and it is called mutual inductance. So, basically we are going to today, we are going to study this mutual inductance M ok, so that means it is it is related with the two coils, so that is why here we have written between two plane circular coils.

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So, this is basically this I see, this is a coil. You see this coil is very important inductor, you will tell is the inductor for producing magnetic field, we use this coil right. So, you see here. So, this we tell this is a coil, so there are some arrangement for connection these two ends are connected here basically here just you see wires are turned over this, wires are turns over this copper wire ok. So, it has 2 tau turns here written this total turns is 500 ok, and its resistance is approximately 10-ohm ok.

So, here this connection one connection will be here, and this another connection, if you put take from here, so this it is connected with 100 turns, if you this one is a 250, and this one is 500 means, this all turns are considered, when we will connect between these two half of it between these two only 100 is connected in this. So, basically here there is a option, you do not need it, but it is the good option that from same coil you can vary the number of turns ok. Number of turns whatever this you want to use that you can select from yeah anyway. So, this is the coil this simple coil you take copper wire, and just make it round, so that then it is coil is a inductor ok.

Now, here where what the coil I was talking here, so that is basically this type of coil. So, far this experiment now, we want to find out the mutual inductance of the the two coils right. So, this so for this experiment or for the experimental geometry, we have to find out the theory working formula right.

So, so yes, so here I also I have written here, you see this L equal to basically mu 0 N square A by l. Mu 0 is basically the air medium, we have used no code it is a code is here. So, these are medium air medium, so mu 0. And N is total number of turns in this coil ok, and A is area cross sectional area of the of the coil area of the coil A. And l is the length of the length of the coil length of these coil.

So, basically N by l if you write small l small n; so that is the number of turns per unit length. So, then small n this is the number of turns per unit length into capital n again, so this why this 2 l 2 l is coming, so that we will that probably we will know I will I will tell you. So, now for mutual inductance, so these are mu 0 N 1 N 2 A 2. So, number of total turns here, and l 1 is length of this one, and these N 2 is the number of turns here and A 2 is area of this coil ok. So, this is the mutual inductance expression for mutual inductance.

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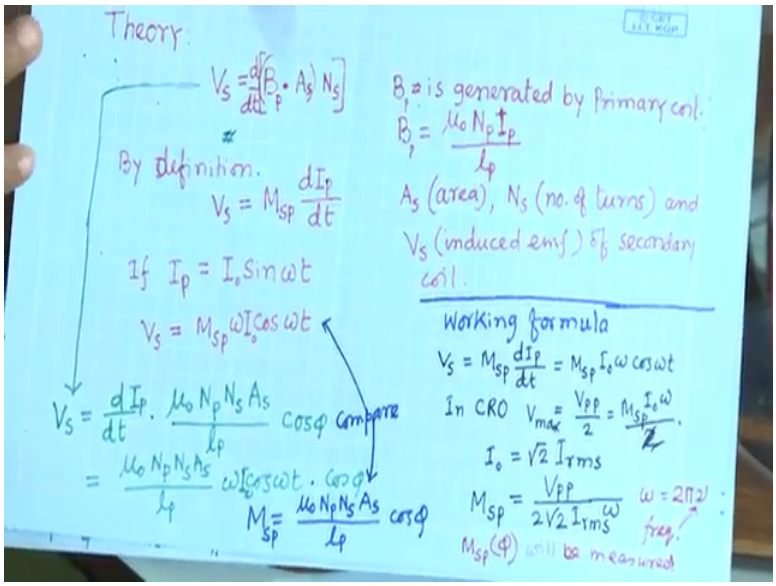

So, if I just so working formula for our for our experiment, let me just let me just first showing the set up, then it will be easy to understand the purpose of this theory the yeah the final expression of the of the of the working formula. So, why we are taking this working formula in final form, whatever I will show you, so that depends on basically your experimental setup.

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So, let me just show you the experimental setup first experimental setup first. So, this is the experimental setup for studying the mutual inductance ok.

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So, here you see this whatever coil I show, this here two coils are kept bigger coils two coil circuit. This we are telling the primary coil ok. We could do the experiment with one coil ok, but here just two coils we kept that two just to increase the magnetic field. So, it will be just double, and then your signal will be higher.

So, you just consider that is it is just one coil ok. Another coil just we put for getting the uniform field that basically we do not need, but it is better to have this type of uniform field. So, then your signal will be strong, but just consider you have one coil either this or that on one coil and another's coil in middle ok, so that is so that middle one that the secondary coil ok.

So, I told this two coil mutual inductance between two coil. So, you can take this bigger one is primary coil, and the smaller one is secondary's coil. So, they are they are parallel their planes are parallel ok. So, primary coil and that the secondary coil, now primary coil we will produce when I will pass current through the primary coil, so then it will produce magnetic field. So, I have to pass current through the primary coil. So, I need arrangement for that.

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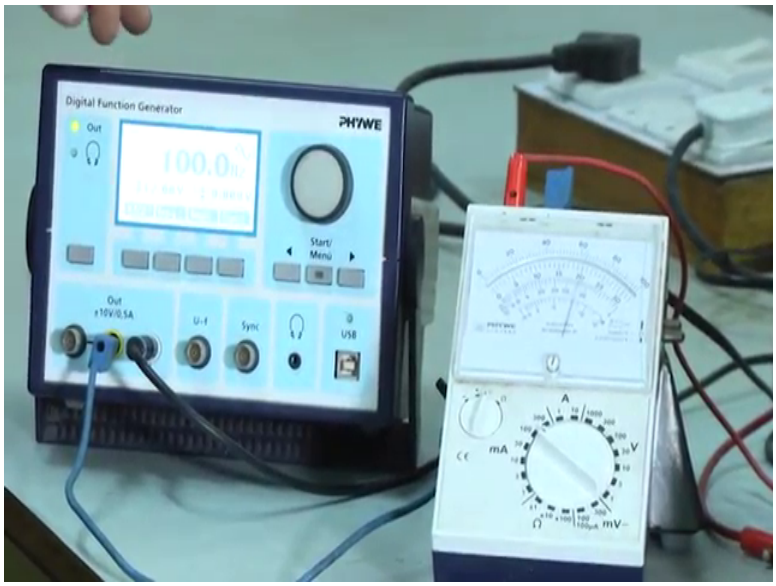

So, so this is the meters ok, this is the meter power supply, this is the function generator. So, here we will use ac current we will use ac current, because this as we have seen the di by dt change of the current we require, so that is why we will take ac current ok. So, this is the function it tells function generator, you can you cam take the either sign form of the current or some square shape of the current, square form of the current, short route kind of variation of the current ok. So, here we will use sign wave sign form of current.

So, and here what is the you can select the frequency of the current, here is a already we have selected this 100 hertz. So, current ac current of 100 hertz is coming, and we have put here we have put here these two connection, because one is one is for primary coil, and another is for secondary. So, this current ac current and the is going to these coil primary coil ok, and how much so it has resistance. So, how much what is the magnitude of the current, so that we will take reading from this ammeter ok. So, we had ammeter that will tell us what is the magnitude of the current ok, and this meter we will tell us the frequency of the of the of the current, since it is ac current ok.

Now, current is going passing through these primary coil, so while current passes through a coil, so it will generate magnetic field. So, the magnetic field will be in this is a perpendicular direction to the coil ok. Now, that magnetic field secondary coil is placed nearby, so that magnetic lines of course we will pass through this secondary coil, it will pass through this secondary coil. Now, this that means, these secondary coil is linked

with parts. Now, in primary coil these current is changing means, magnetic field is changing means facts linked with the second coil secondary coil that also changing right.

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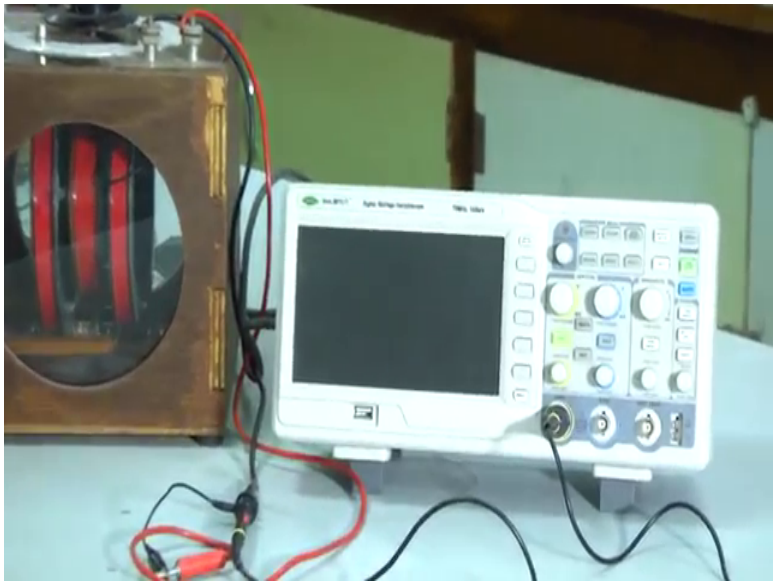

So, there will be induced emf on the secondary coil, so that induced emf ok, so we will we will we will so this is the these two are from this secondary coil. So, this induced emf ok, this voltage we have put in this oscilloscope this is oscilloscope. So, from this oscilloscope, I will know this voltage induced voltage whatever generated in secondary coil, so that voltages reading I will get from this oscilloscope ok.

So, I think it is a oscilloscope skin is dead I think it has clipped, so yeah it is there ok. So, this so this is the experimental set up now for this we need the working formula for this experimental set up we need the working formula, so that is why we have to find out.

So, now theory so induced emf, you know this induced emf is basically in the secondary coil s for secondary coil is d phi by dt that phi is basically linked with the with the secondary coil ok. And now so what is the flux what is the flux, what is the magnetic field from the coil one, so that is B p from primary coil, magnetic field from the primary coil.

Now, this field link this magnetic field is passing through the secondary coil. So, now flux is basically B dot a you know this A is the area of this coil, area of the secondary coil. So, B dot A ok. And this is for fluxes for each turn of the secondary coil. So, if

number of turn is N s, so I have to multiply with N s. And now this total flux linked with the secondary coil, now rate of change of this flux will give you voltage, so d by dt right.

So, by definition now V s we have seen this equal to M sp means, secondary or primary coil between secondary primary coil, this mutual conduct inductance M di by dt. So, M sp and here d I p by dt. So, I p as a if I p takes sign form of the current, so it will be so I 0 sign omega t. So, then if you if you just differentiate it, so omega I 0 cos omega t ok. And so V s will be M sp, and then d I p by d t will give you this ok and this V s from here, so from definition I got this one. And from here so V s equal to V s equal to what is this B p what is this B p, what I no. So, V s equal to, so here you know this in B p I p is there in B p I p is there. So, this and only in this case this current is changing right with time all other are constant, so I will get d I p by dt, so that is why that is I have written here. And rest of the part mu 0 N p, then here N s A s divided by l p ok, this is the length of the primary coil ok.

So, then this dot product is there, so this cos phi. What is this phi, phi this angle is basically between the angle if this primary and secondary coil are parallel, this angle phi is 0 ok. Now, this angle between these between these between the plane between the plane of the two coils; primary coil, and secondary coil ok. So, if parallel, then it is 0; if it is perpendicular, then it is 90 degree. So, this two coil, now when parallel this phi is 0. Now, if you change the angle, so this basically that is the phi is change ok, then it will perpendicular position of these two planes that will be phi will be 90 degree ok.

So, then basically it depends on the it depends on the angle of this angle between these two coils. So, mutual inductance is a function of the mutual inductance is a function of the phi basically you know. So, working formula for our experiment is basically if you compare these two, so your V s equal to V s equal to M. So, if you compare these two, so V s equal to M sp d I p by dt d I p by dt, so which one V s equal to yes so V s equal to M sp. This is basically d I p by dt, so these things these things I have written here so ok.

So, these I can take as a formula for my working formula for my experiment, because this part here just I have shown there what is the M sp M sp is basically this one. M sp if I compare these two, then I am getting that M sp is this one. So, M sp is basically mutual inductance as a function mutual inductance of this secondary and primary coil, it

depends on the phi ok, it depends on the cos phi. So, M sp is basically is the function of phi.

So, so here if I take this one my working formula working formula, so in CRO I can measure in CRO, I can when I will measure this V s, so that V maximum value that because it is the ac signal ac voltage. So, V max will be basically peak to peak V peak to peak divided by 2 V peak to peak V peak to peak divided by 2 that will be V max that will be V max. So, V max equal to b V pp by 2 equal to this part this part, this V yes; I 0 omega I 0 omega M sp I 0 omega. And cos omega to peak to peak, I have taken right. So, peak to peak, they are these are basically is a one peak to peak this value is one 1 and minus 1 basically. So, depends is basically 2, so that is why we have to divided by 2, then you can get V max ok.

So, so I 0 ac current I 0 ok, I 0 we are we are using this ammeter ok. So, they are basically whatever value we will see that is the rms value, so that we will see the rms value. So this relation between the I 0 and I rms. So, I 0 equal to square root of 2 I rms right. So, this I 0 I will replace by this ok, then I will get M sp from here M sp we can find out. So, these V pp divided by 2 square root of 2 I rms omega.

Now, here basically we are we are ge[t]- we will get reading of the this frequency this is nu, so 2 pi nu equal to omega 2 pi nu equal to omega. So, basically here since in our experiment instrument, we will get nu ok. So, here we will replace this omega by 2 pi nu ok.

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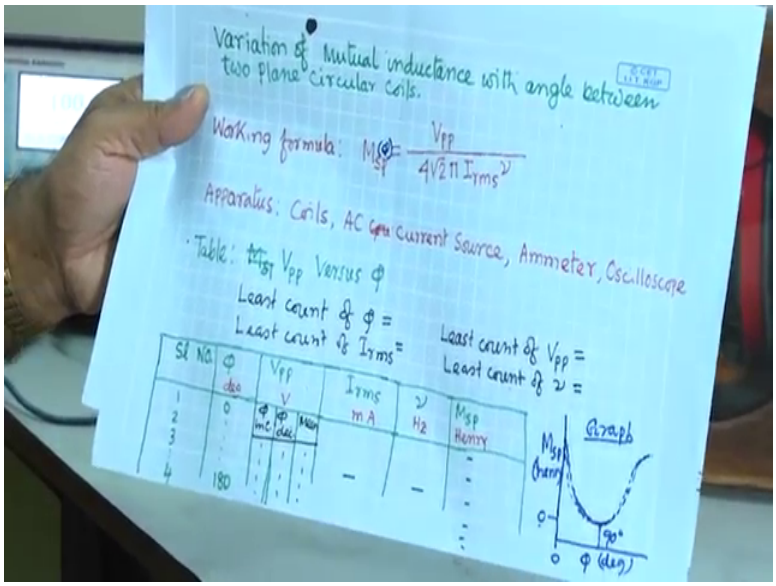

So, now basically reading this setup, we are going to study we are going to study the variation of mutual inductance with angle between two plane circular coils between two plane circular coils. So, there is the experiment, we are going to demonstrate now. And working formula for that is basically M as a function of phi, sp because is just to represent primary or secondary coil, people write 1 2 M 1 2 etcetera, so that equal to this V pp by whole square root of 2 by I rms nu ok.

So, V pp peak to peak value we will get from CRO. I rms that value we will get from this we will get from this ammeter ok, and nu frequency we will get from this function generator right. So this is the working formula, and for this whatever the instrument you needs already I have shown it.

Now, let us do the experiment. So, I think so again do not confused with this three coils. Effectively, primary coil one primary coil, and one secondary coil is enough to study. But, the signal will be this weaker, because flux passing through the secondary coil, it we will be will be will be small arithmetic field is stronger. So, then obviously this flux will be higher, and induced emf will be higher, so that is why also if you take two coils, so magnetic field between two coils, you will get uniform ok.

So, this whole secondary coils will be linked with this its whole area will be linked with the with the magnetic fields of equal strength ok, so that is why we have taken this two bigger the coil primary coil, but that is the purpose. But, one coil is enough, and

whatever theory we discussing just one coil. So, here this two coils is equivalent to one coil only, it is just giving us the two times of magnetic field ok.

So, so this coil take primary coil one and secondary coil one, now it is set at 0 degree that means, these two coils are parallel these two coils are parallel primary and secondary coils are parallel ok. For this so what we will do we will vary the phi, angle between these two coils. And for each angle, we will take the reading, we will we have to find out the mutual inductance for each angle.

So, then we will plot the mutual inductance physically our aim is to plot mutual inductance versus phi mutual inductance versus phi, so that is what we are interested to study to demonstrate here. So, to calculate this one. So, I have I will so this current is we will fixed current, we will fixed this frequency, now only we will vary this angle phi, then this V pp will vary. So, now that V pp reading we will get from their oscilloscope, and then we will put here. Then for each angle V pp will be different, so I have to note down basically angle versus V pp or V pp versus angle that is what I have to note down for a particular value of nu n current I rms ok.

So, here you can see, we have put this rms this is the I thing scale we have taken 100, so that means, top scale. So, current is around 65 around sixty si[x]- yeah I have to take this 66 Milli ampere, this current is Milli ampere this scale we have taken its a milliampere ok. So, this current we have fixed. Now, here we have taken this this ac current its frequency also we have fixed here that is 100 hertz, so that you have to note down first. For this nu M I rms, now we are going to study we are going to find out the mutual inductance or we are going to find out the voltage V pp for different angle of for deferent angle phi ok.

And here we have column serial number, so phi will vary 0 to 180 with 10 degree change step or 5 degree step, whatever it go for V pp. So, basically here, I forgot to so later on just I put this column, so two twice we will take reading. So, when we are increasing the angle 0, 10, 20, 30, 40 up to 180 ok. So, we will take reading V pp, then again, so that is phi increasing. So, reading increasing of phi, I will take V pp reading, and then again during the decreasing of phi from 180 to again I will come back to 2 0 in with same step ok, so giving that again I will take reading ok.

Now, we can take average of these two reading, and then we will give mean reading, so that will be the V pp for each angle for each angle. And I rms I should note down this is I rms, it is the 60 say 66 Milli ampere 66 Milli ampere as my reading is here. And there is frequency is the 100 is the 100 is the 100, I have to write this 100 ok.

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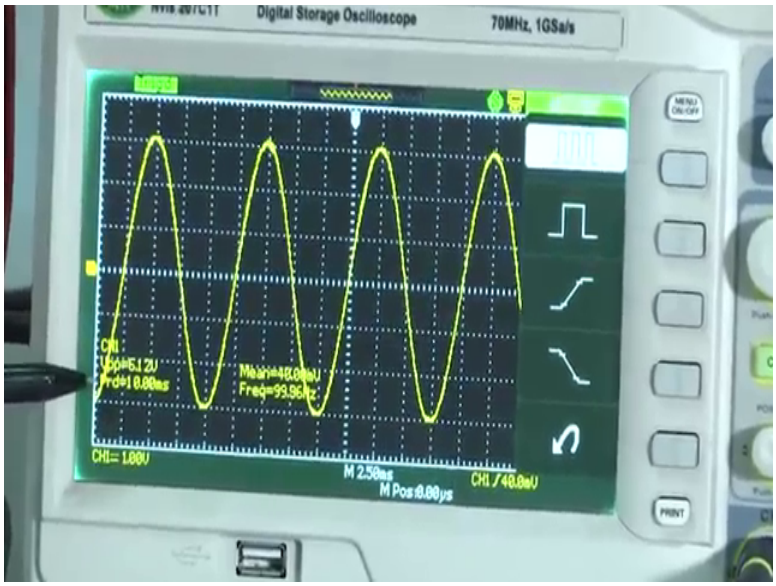

So, now here it is the take reading for 0 position take reading this for 0 position this is the here is it is giving reading ok, it is the V pp 6.15 volt. It is giving 6 point I can see properly, yes I think 6.20, it is changing. So, let me write 6.20. So, for 0 angle. Now, this for this 6.20 ok.

And also you have to note down the least count of this instrument least count of this one, what is the that we have to note down, it is the I think 0.01 volt 0.01 volt that is the least count of that one that means, 10 milli volt least count of that is one. And least count of this one is two Milli ampere least count, because is division is two Milli ampere.

So, least count of high it is I think here, it is in 1 degree yes. You cannot see probably, but I can see this 1 degree. So, here I will write least count, so not same thing you get it is the 1 degree, least count of phi 1 degree, least count of I rms this is as I told this is the 2 Milli ampere 2 Milli ampere that I have to write 2 Milli ampere, least count of V pp is the 0.01 1 volt means, 10 milli volt. And least count of nu, so it is by 0.1 hertz is a 100.1. So, it is a 0.1 hertz 0.1 hertz ok. So, least count of your instrument that you have to note down ok.

So, now everything you have noted down, now just vary and take the reading of this one. So, I will go in 10 degree step, so I will go to the next step. So, it is yeah, so I changes with 10 degree, you see what is the value just I have to select auto, then automatically it will to give value. I think it is yeah it is giving 6, it is giving 6.08. So, for 10 degree you write for 10 degree 6.08 ok.

So, similarly I will go I will change to 30 degree, then 40, 50, 60, let me go to the 90 degree. So, for each 10 degree, I will take point, but I will not take reading for all. So, I think I have to go it is you see it is a 90 degree with this primary coil this secondary coil. Primary coil is this now, secondary coil is this secondary coil is this. So, it should be 0. So, it is more or less 0, it is more or less 0 I think perfectly we have to make it the yes or I have to take it auto then we have to perfectly no oh it is just change the scale ok, it has come to the milli volt, so that is why anyway ok.

So, it is you see here reading it is showing 1.9 in it is 2 millivolt it is a showing 2 to millivolt. So, error bar is 10 millivolt ok. So, these 2 millivolt is a error noise ok. So, this we can take reading 0 ok. So, this so this after 90 degree, then again you just change 100, 110 up to 180, take the reading, write the reading, during increasing of phi.

Now, again you come back to come back to form 180 to 170, 160, then again 90, and then up to 0 ok. So, you are changing the angle your angle is decreasing. So, during that time you take reading, and then find out the mean. And this V pp you know now, so working formula in working formula just for each value of work this V pp, you calculate this mutual inductance. It is in Henry or Milli Henry, it should be in Milli Henry I guess, it should be in Milli Henry better to write in milli Henry or Henry bar e to 10 to the power minus 3 kind of things you have to write ok.

So, this way now this phi versus this mutual inductance these data is available just plot it. And this is a very familiar curve for this mutual inductance. So, whether you see this, whether you are getting this type curve formula, so that is the experiment thus you are starting the variation of mutual inductance with angle between two plane circular coils. So, this is the experiment I demonstrate it I demonstrate it right.

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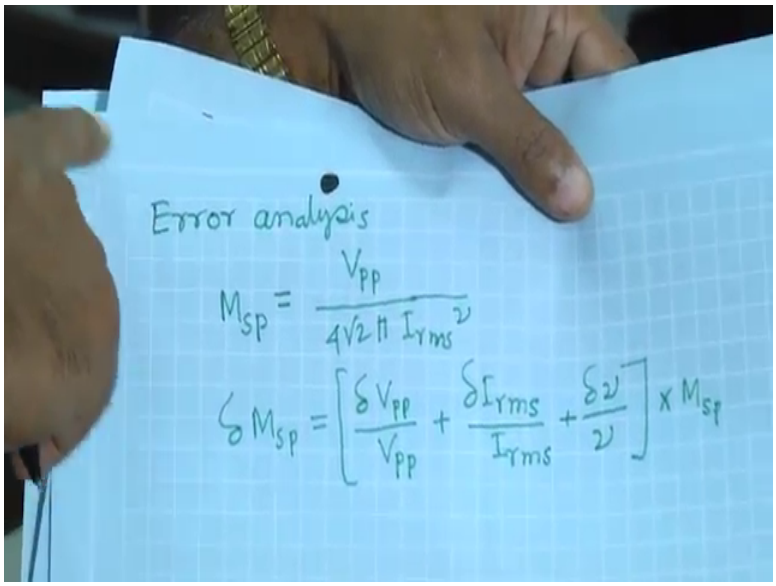

So, I thing yes and if you want to calculate the error, so this is the error working formula, and error there del V pp by V pp plus in error in I, and then error in nu ok. So, all delta nu, delta I, delta p, you know we have noted down just put it. And just choose a particular angle, what that angle you have mutually inductance, and what is the error on this mutual event, then just tell ok. So, I think, I completely, I described this experiment, I think very easy and small experiment, very good experiment ok. So, I think, I will stop here.

Thank you for your attention.