Machinery fault diagnosis and signal processing
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Module No # 07
Lecture No # 35
Motor Current Signature Analysis

In last class we discussed about faults in electrical motors and transformers and how through current monitoring we could find out the defects in the motor in particular the rotor bar cases are this static eccentricity and the end I discussed about how faults could be detected in the bearings of a motor. From that you will get a clue as to bearings is the mechanical system in the motor.

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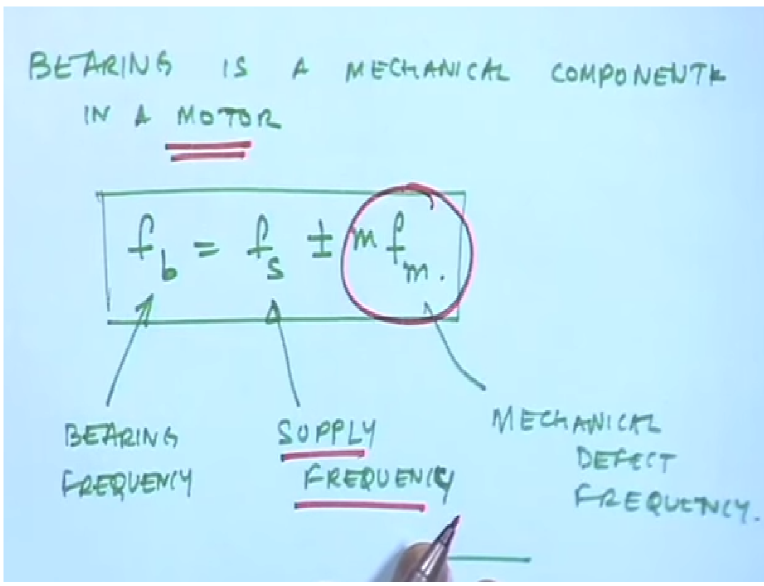

Our mechanical component is a mechanical component in a motor and essentially this bearing fault was nothing but the supply frequency plus minus the mechanical frequency okay. This gives us a clue that if I have any mechanical defects we can see in a system where it is being driven by an electrical motor. By looking at the motor current spectrum I can see side bands around the supply frequency.

I will repeat that again if I have system driven by an electrical motor and the systems mechanical system has defects okay so this is how the defects frequencies are given. So if I now monitor the frequencies of the electrical motor I will see these defect frequencies come as side bands around the supply frequency. We will see the genesis of how this happens when an electrical motor and you will be see the how powerful this technique case for the fact that is non-intrusive need not go near to mechanical unit.

Like I was telling you in last class remotely at my control room I just accessing the conductors which are carrying current to the electrical motor I can be able to find out the faults in them.

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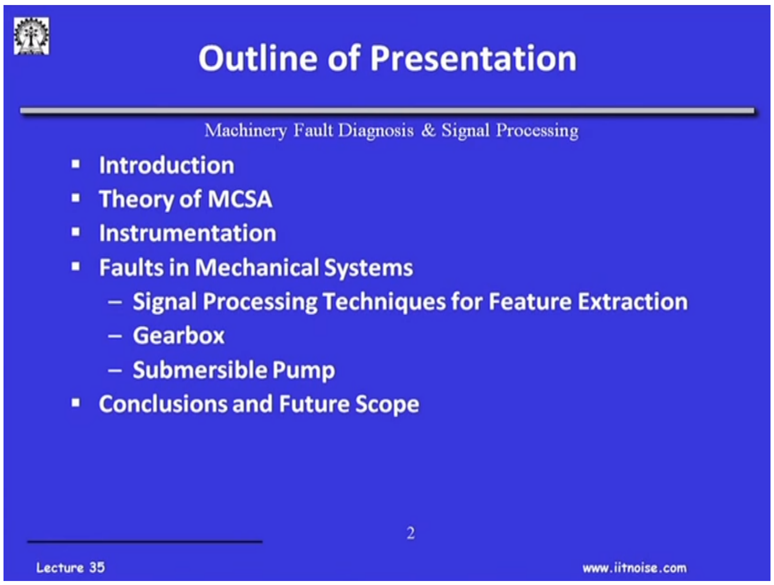

So in this lecture on motor current signature analysis I will basically tell you about the theory of MCSA method analysis. And I will be proud to say that we at IIT Kharaghpur has been pioneer in this. Last 15 years we have done this and many of our publication on our effort worldwide and we have we are the first to find out fault I gears or gear boxes which are driven by the electrical motors.

Actually not by monitoring the vibrations one of the gear box but just by monitoring the current drawn by the electrical motor driven the gear box we can find out the faults in the gear box. Imagine now I will just give you a wild imagine now that you have to measure a find out the faults in the power plant were in you do not have any access you have basically physically do not go there to mount your transduction.

But you have the access to the current carrying conductors to the critical motors or operating at the different valves, gear boxes, pumps etc and that is how you can do them. Think of a submersible pump wherein the pump is underground obviously you cannot put a recent transducers going underground but can definitely access the current carrying connect to the motors which is driven to the submersible pump and thus be able to monitor the effect of the motor.

In fact in this class I will telling you about the theory of the motor current signature analysis and particularly how signal processing can be used to find out the faults in the system and I will tell you about the two case studies one about the gear box and another one is regarding the submersible pump and tell you the features of a motor current signature analysis. I believe in the years to come motor current signature about a decade ago motor current signature analysis is very much in an nation reserve stage.

But now it is in fact there are combustion projects which are come out where in you can fit on a system and then you can find out the fault only through current monitoring I believe in the future we using wireless techniques in motor current signature analysis you could be measure remote of places very convenient.

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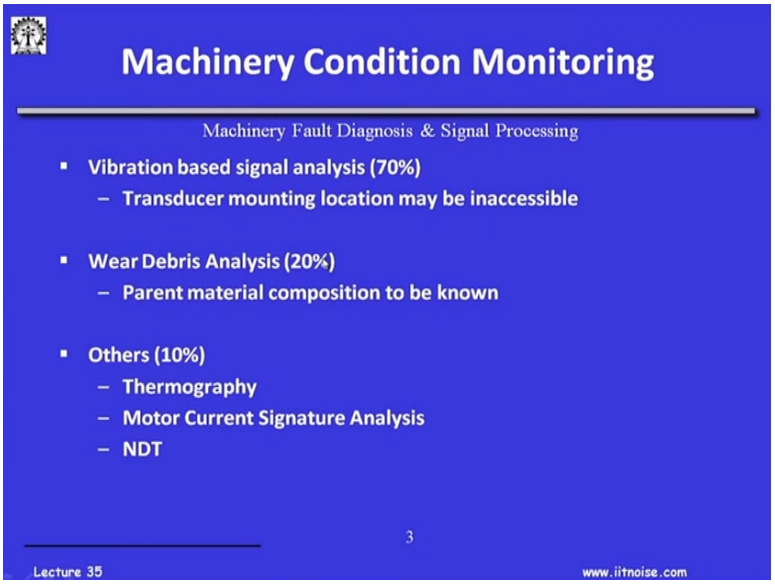

So we all know this by now in this class that we were somewhere here we know the 70% of the vibration monitoring wear debris analysis parent material composition to be known but this motor current signature analysis is upcoming field of CBM.

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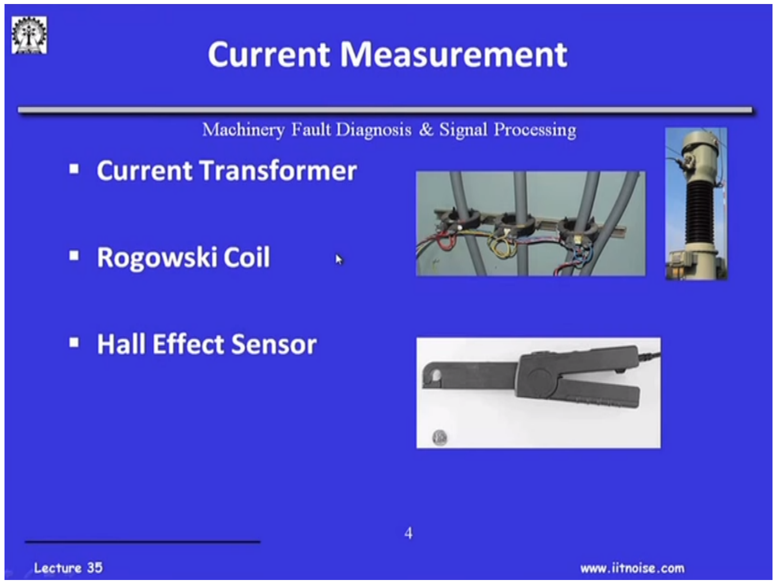

Of course the essential elements in this motor current signature analysis is based on the fact that the current have to be measured. Current cannot be measured by an (()) (06:25) cannot give RMS value and utmost with load or defect only the value we form the magnitude of the current is going to change. But I have no clue when somebody says my diameters reads 10 amperes I do not know it is 10 amperes need sign wave or 10 amperes need modulated.

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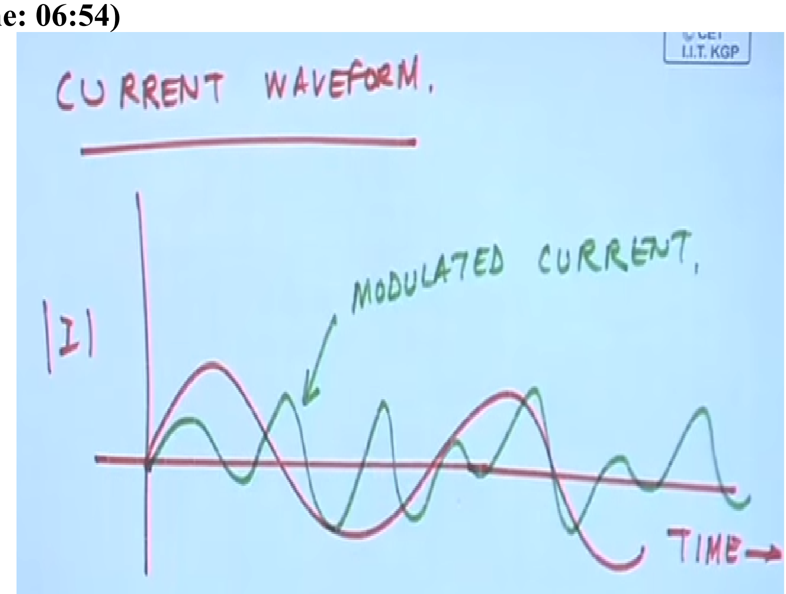

Or 10 ampere with lot of peaks I do not know that so once I see the current wave form to being with in oscilloscope and then do it frequency analysis i get a better idea. So everything depends on this current waveform okay current could be as need as this modulated as this this is how the modulated current is actual method modulated current. This statistical parameters or this two pumps may be similar some of the statistical parameters could be the same.

So we should not bring this slade that looking at the single number that they are at the same current but if you look at the wave form look at the frequency content they are different. And this frequency content is actually the indicator in the fault in the system okay. In fact people use all of the sensors like this wherein we pull the conductors here and this are current transformer. Basically current transformers are used to measure basically very high current in a tarn ratio is on 1000 is to 1.

We cannot measure the 1000 ampere current because the voltage inducer will be large so we will have a transformer to reduce the magnitude and that is how when you go to the any plants they CD coils just to reduce the turn ratio so that meter can used to display and the same meter can be used to measure 100 ampere, 1000 ampere of current same to measure the 1 ampere of current. But when we measure the 1000 ampere of current we have to give a step drawn transformer and that is where the current transformer are used.

And particularly a field is Rogowski coil are used but we will using all of its sensor because so they have a wide frequency range and as you will see this green signal here the frequency contained of this signal is different.

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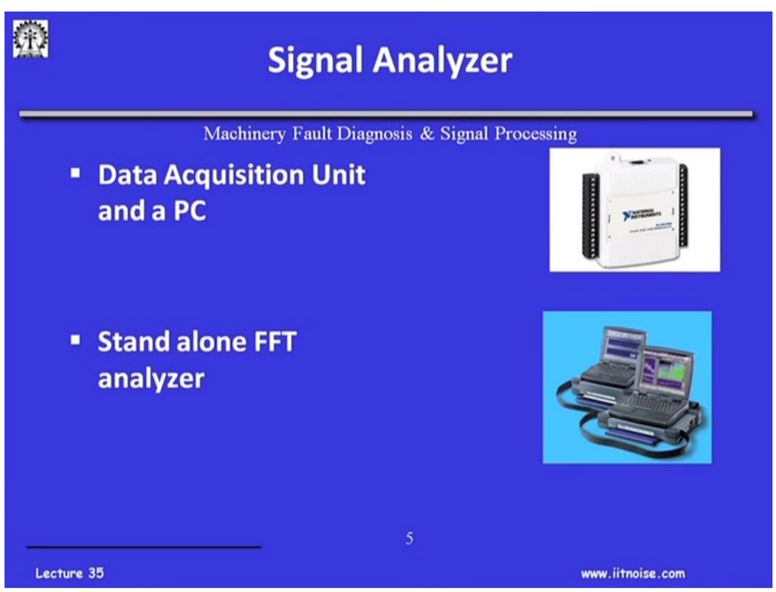

And then this is very cheap all you have is the data like is an unit which will carry the conductors and then are used one of the analyzer as of like we have in the laboratory then you use it and then do the current analysis.

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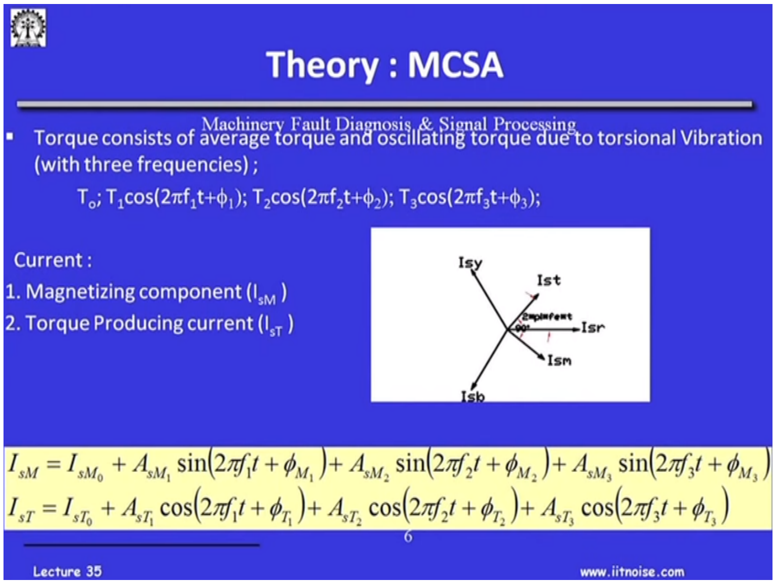

But now let us go the theory of the motor current signature analysis and we will see why this is important. Basically I am talking about the current which is there in a motor so for example in a motor I have three phases T1, T2, T3 okay all level simply look into here. So there will be two types of current in the motor one in the current which will be responsible for producing the magnetic field okay in this stator.

And other 90% to it which will occur responsible for producing the torque and which is rotating the rotor of the motor. Now if there are three defects at frequencies F1, F2, F3 these are three mechanical defects which have taken and basically they have this three torques responsible for this defects produces three torques T1, T2, T3.

If I sum them up one is the static component of the magnetic first equation here is this magnetic component the DC component and the time varying component because of F1, F2, F3 and quadrature to it is the torque producing current IST which is given by this okay. Now if I just add them up there are similar you can taken also any one of them to demonstrate okay.

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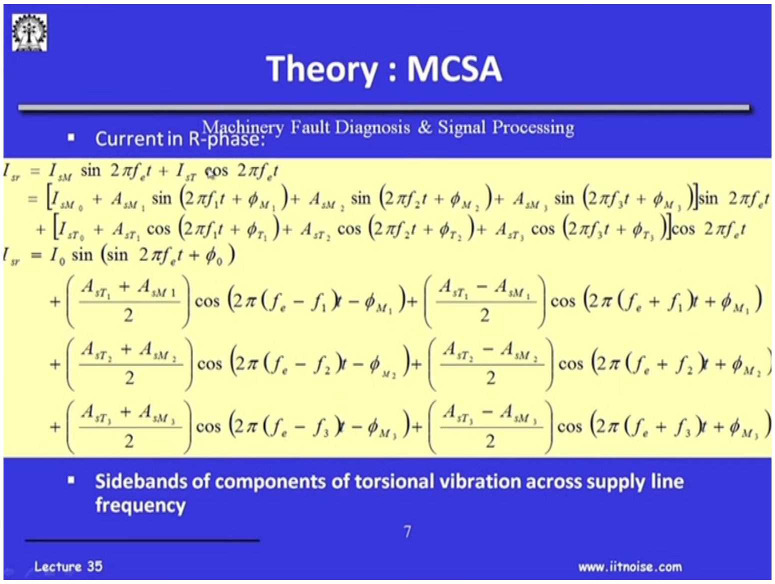

Now if I see the current in any one phase if I add them up it will nothing but the component of this two together in the respective phase if I just add them up the magnetic current the torque producing current if I add them together like this I will come up with an expression wherein I will get cosine Fe – F1, Fe + F1, Fe – F2, Fe + F2, Fe – F3, Fe + F3. Where Fe is the supply frequency and F1, F2, F3 is the defect frequency.

So if you see the current which is add in the R phase you know there are RYV3 phases in any one phase the current drawn is no longer I0 sight to I2 by FT FET but these components.

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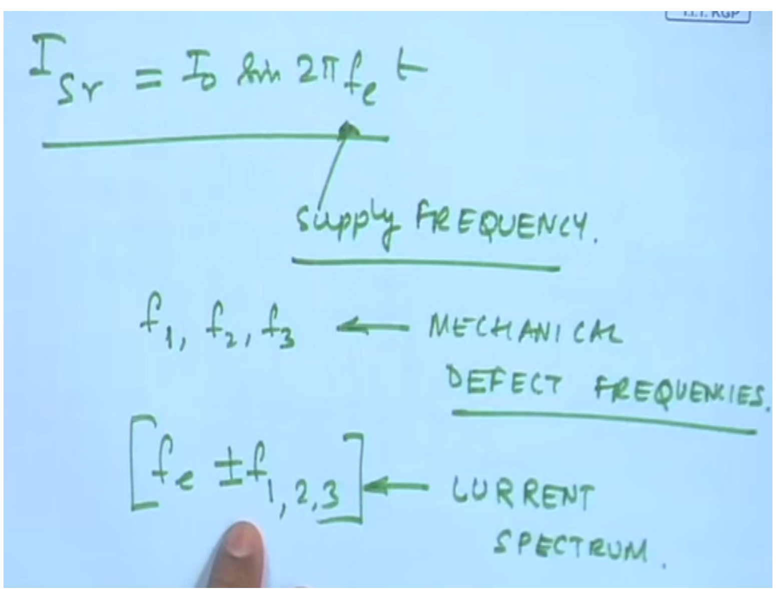

So these becomes ISR is I naught Sin 2 pie FET would have been my ideal case okay where the this is the supply frequency okay. But as soon as I have the defect frequencies F1, F2, F3 these are my mechanical defect frequencies I will have components of Fe frequencies F1 or F2 or F3 in the current spectrum okay. And looking at this I will know whether if these come around the basically they are modulating these torques which created because of a fault is modulating the current.

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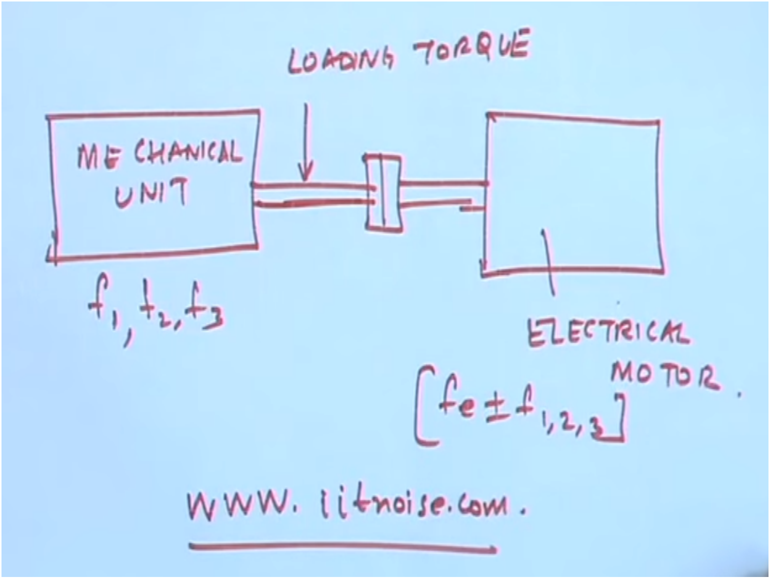

And because of modulation again I am (()) (13:40) so in effect if I have explain you through a flow chart. I have a mechanical unit which is coupled with motor is this mechanical units have defect F1, F2, F3 anything. They are basically going to produce a loading torque okay and this load torque is responsible for drawing the current because there is load torque because the flex is going to change.

So the rotor has been given to a load torque so I need to produce an contracting torque to this load so that motor is going to run and these as to be at this frequencies because they have FE plus minus F1,2,3. So the current drawn will be having this kind of characteristics okay. So side bands are components for torsional vibration across supply line frequency is the strongest indicator or the faults in the mechanical system.

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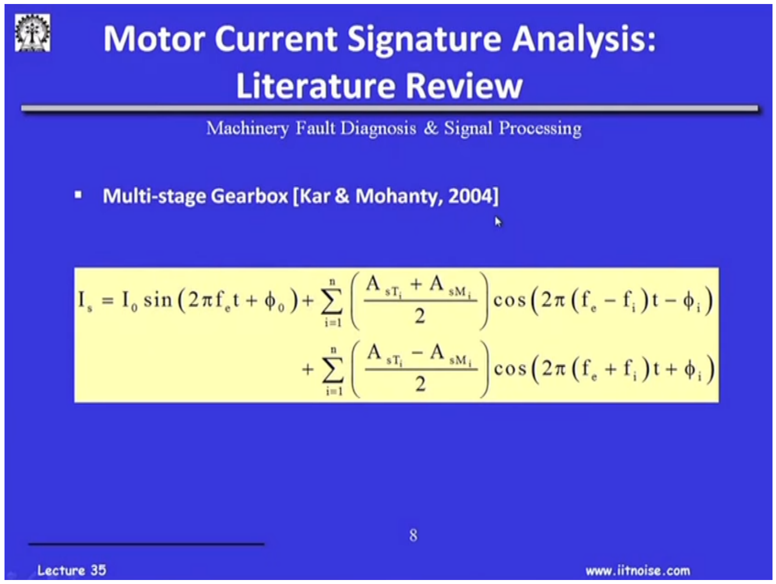

Because torsional vibration are created because of this form so we have a present at this in our one of the paper. In fact you can go to one of our website IITnoise.com to see a more about our research findings and you can see some of the detail of the literature so there are reference papers regarding the motor currency signature analysis which you are doing since the two thousand okay.

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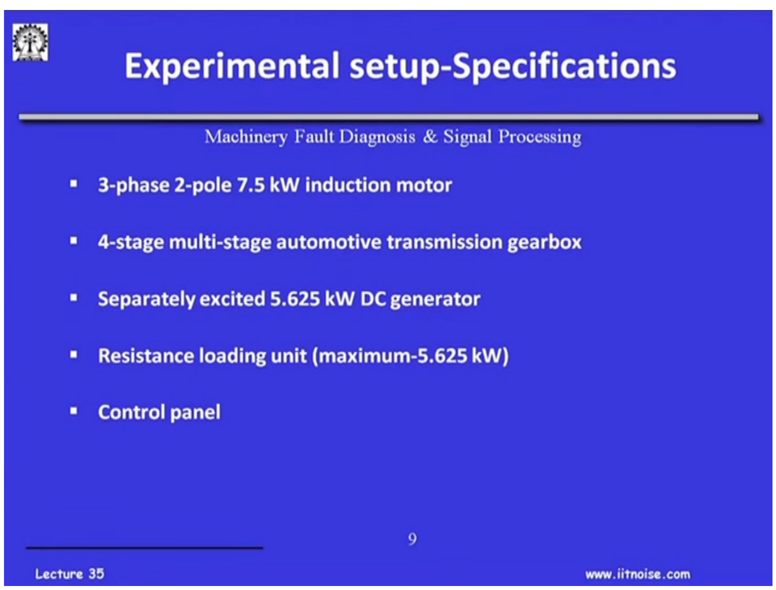

So in fact I will now describe about the experimental setup in the laboratory would explain how motor current signature analysis is used to find out fault in electrical motor so in this case what we have is the three phase two poles 7.5 kilowatt induction motor. Which is actually driving a four stage multi stage automotive gearbox transmission gear box from a car. And this gear box is driving a generator and by giving an resistance load to the generator loads.

Is typical setup in a lab we are able to load the motor through by loading the generator so this experiments initially we did that at single speed. Now we are provisions we can though we have drive also we can do this study at different speeds. But most important is that we artificially created faults in the gear box in the automobile gear box and then we know the characteristics frequencies as a faults.

Basically around gear machine frequencies and then we have different load conditions by loading the generator we load the gear box we then analyze the current okay. And then found out that the gear machine frequencies were actually showing as side plants of the current being drawn by the electrical motor.

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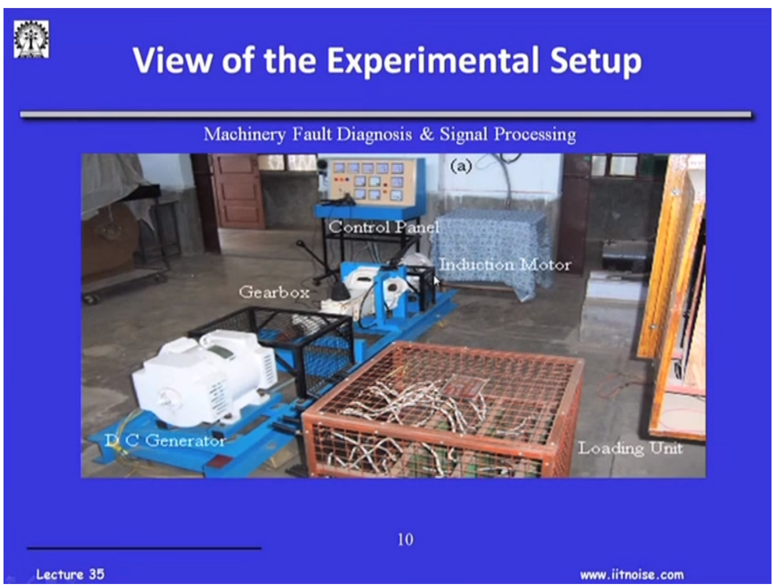

And this is the setup which we add in the laboratory this is an induction motor which is driving an automobile as you can see this is the car gear box we have the coupling and DC generator and the loading unit from resistance bank when the control panel you will see three hall effect sensors because initially we were measuring the three phases. And since this is the balance supply later on we just used a single oil effect sensor.

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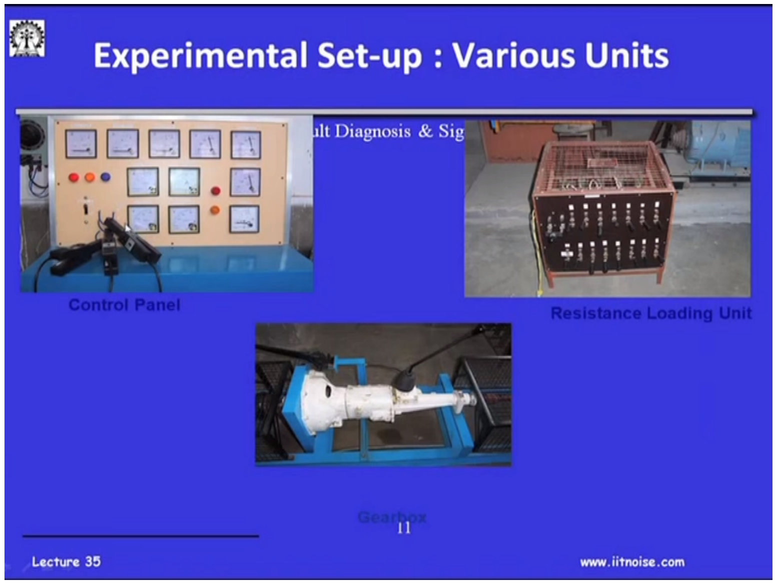

I will have the closer view you can see the three hall effect its hall of three gear box and this are automobile gear box were in we could remove the gears and then put in defect from the gear and then run it.

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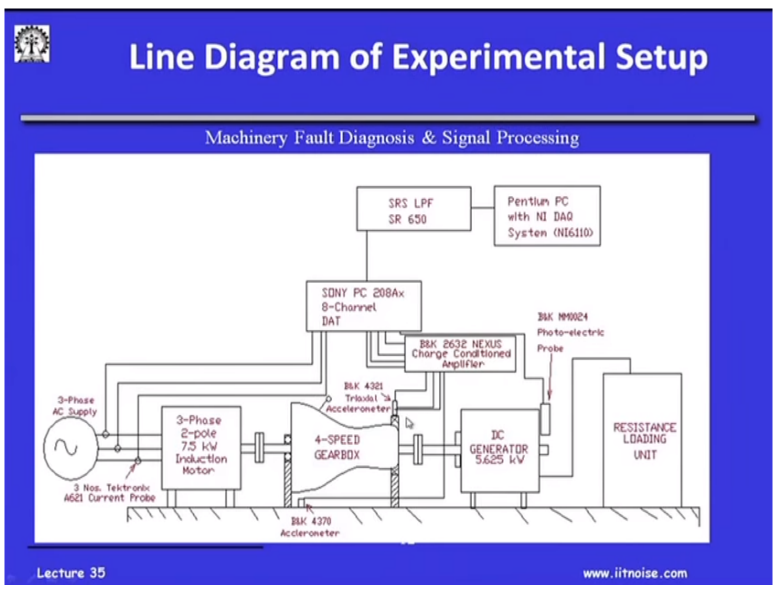

And this is just give an idea of the experimental we have a three phase two pole induction motor driving a four stage gear box driving a generator. Generator is being loaded and we have current probes supply frequencies as supply current and then of course to correlate or to find out the faults we also used a efficient transducer and try the accelerometer here. And we recorded all of them in a tape recorder and then to get into a data basis system where we did the analysis.

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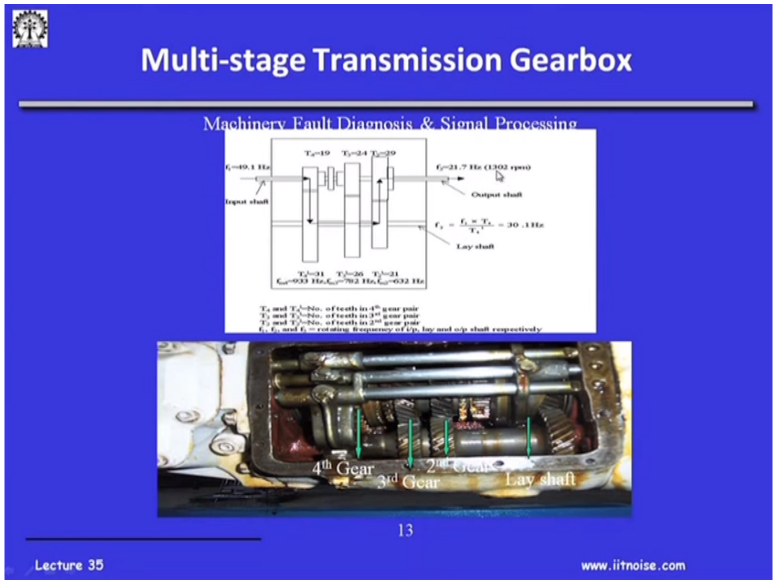

And this is the internal of the gear box this is the four stage gear box so this is if my speed was 49.1 hertz and this is the lay shaft and this is the output shaft and then the fourth gear as an 19T, third gear 24T, second gear 29 T. So we can find out the machine we operated at second gear and that we can calculate the output shaft speed for a supply frequency of 49.1 hertz that is close to about 3000 RPM you know and then we are having because of the reduction we are having the output shaft of the second gear is 39.1 is this hertz and output is only 1302 RPM.

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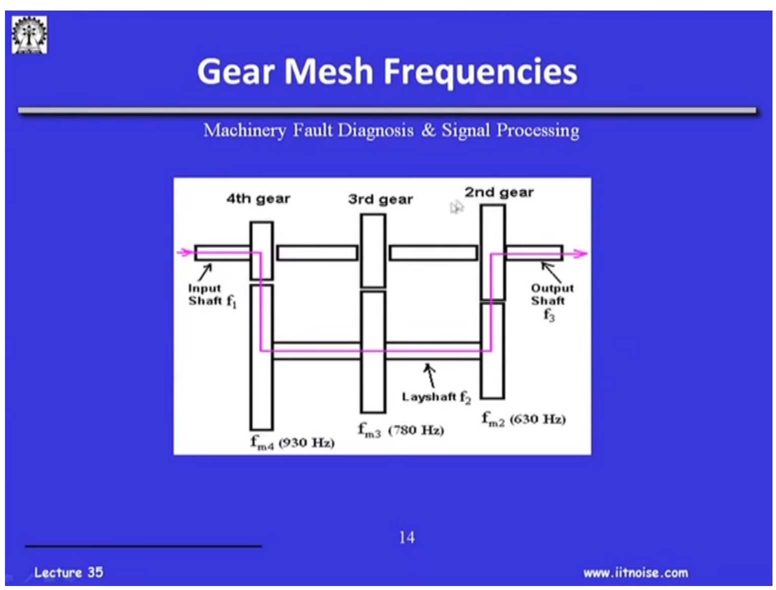

So when we run in second gear the gear machine frequency is 630 hertz and third gear it is 780 and the fourth gear is 930 hertz.

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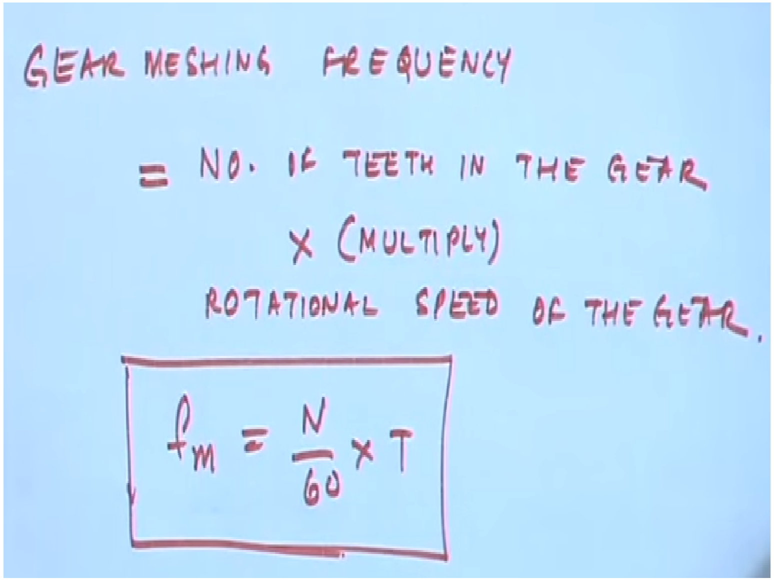

Gear machine is nothing but this times just not confuse so FM is nothing but F /60 times T for the linear spear gears okay.

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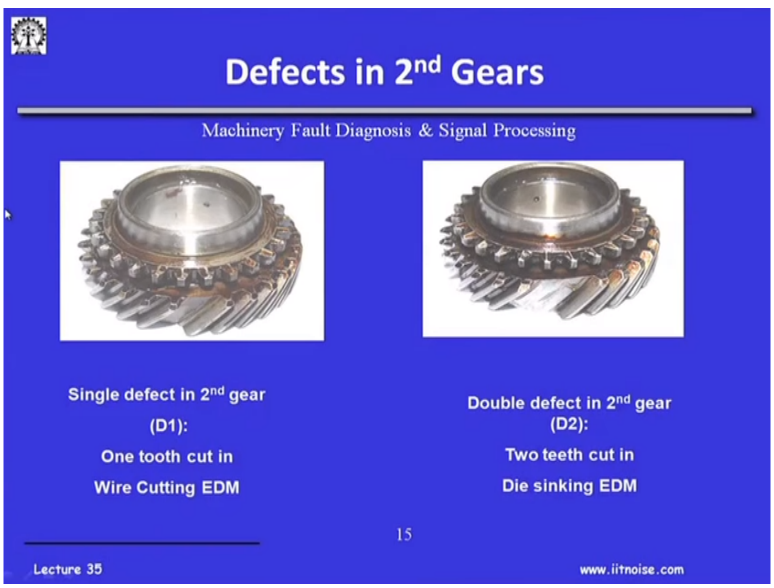

So this are the view of the gear which we introduce defects in the second gears. In one case we remove one complete tooth and this are very hard so we use an wire cutting ADM okay and we remove too teeth okay by die sinking EDM and then we again put them back in the gear box.

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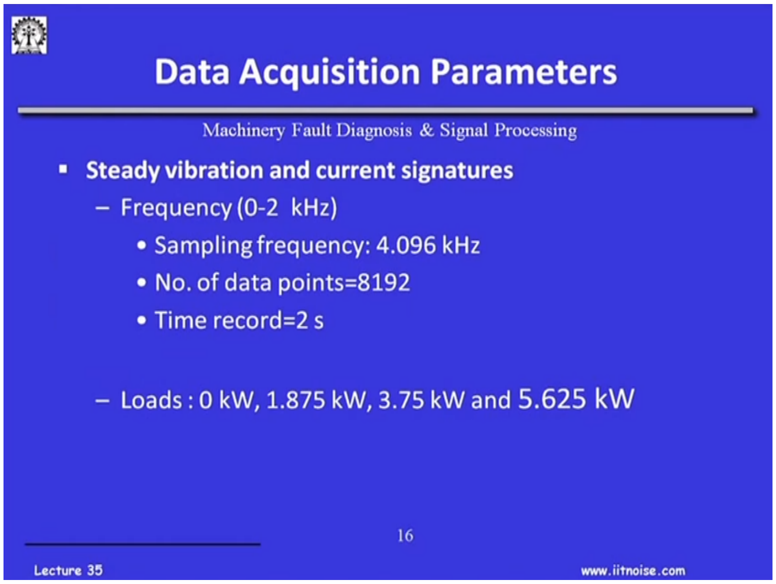

So some of them detect diagnosis parameters we studied our focus was 0 to 2 kilohertz. Sampling frequency was 4.096 hertz no of data points was 8192 data points time record was 2 seconds of the data which we took and then we have applied no load at you know this is the full load about 5.625 half load quarter load etc and then we measure the current spectra and then the lot of signal processing to find out the defect in the gears.

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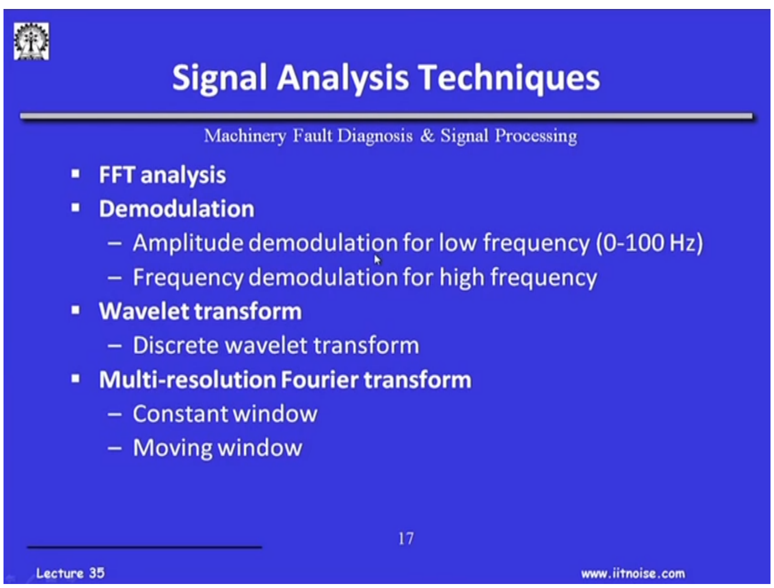

So some of the signal processing techniques which we are used we know the FFT analysis normal FFT analysis but as you know all this signals become modulated. So we have to do demodulation okay and in this class we mostly giving examples from the demodulation though there are other techniques of signal processing which are not there in the scope of the class regarding wavelet transform multi resolution fourier transform which could be used to find out the signal features of signals which are non-stationary.

And some of this signal of this gear box are non-stationary but we are not going to discuss about them in this class but I will just show you the amplitude demodulated current.

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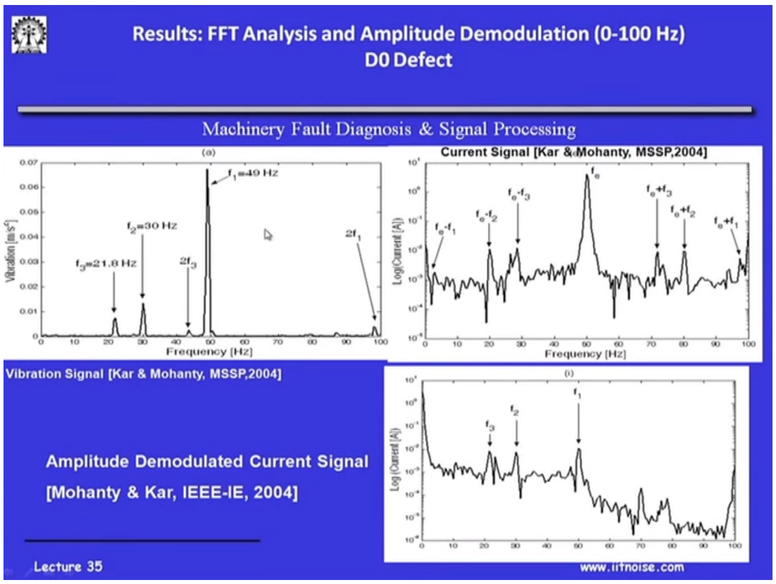

And this is what is there if you see this these are the publication this where we had this publications done. And you will see just as a comparison FFT analysis and amplitude demodulation D0 defect this is no defect in gear box. If I do the vibration monitoring by putting the transeal on the table of the gear box am seeing the F1 is the input speed F3 is the output speed and F2 as the second gear layer shaft speed.

These are pretty much available in the oil spectrum as I was expected but if I look at the current signal you will see around the 50 hertz okay. If we I will see FE + F3, FE + F2, FE + F1 they all this side bands come up okay. The side bands are because of the modulation obviously they are modulated and to find out this side bands I did at demodulation and this demodulation you will see F1, F2, F3 sticking off.

And with load or with defects severity this amplitudes are am going to increase so nowadays there are commercial indicators based on this algorithms where people just use on a pump on a motor on a mechanical linear driven by a gear box they what F1, F2, F3 and they put lot of signal processing features to is to find out how much is magnitude of F1 compared to the no defect case as the magnitude of F1 increase F2 increase and then they will setup triggers and alarms is to tell you that there is a fault in mechanical system okay.

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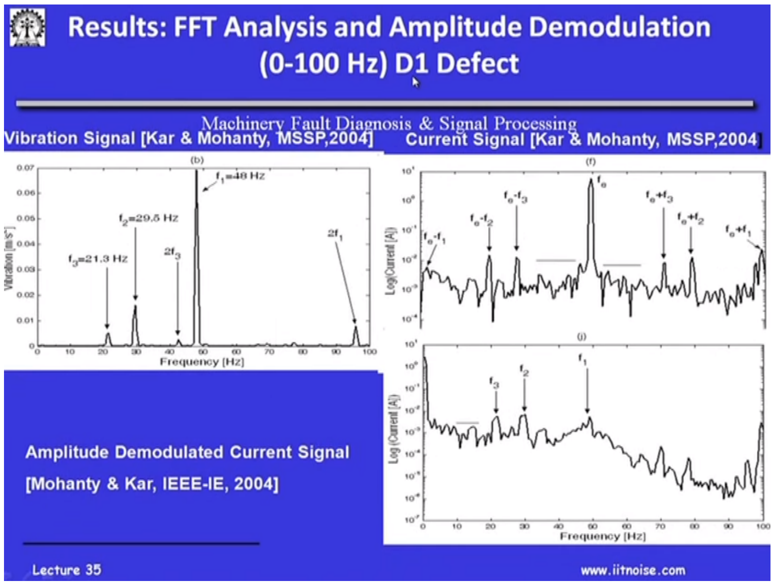

Now as you see with defect the D1 same frequency use the severity of vibration increases severity of amplitudes also in a F1, F2, F3 are increasing okay. So imagine in a current if the current we are able to get the mechanical frequencies of the system which is been driven by the motor you can see the power of such an unit. Now imagine we do not have to go inside yet mine to close to the gear box inside undergo to the pump.

And sitting in the control room measuring the current doing this kind of analysis and all do is find out the amplitudes are F1, F2, F3 in the current spectrum okay.

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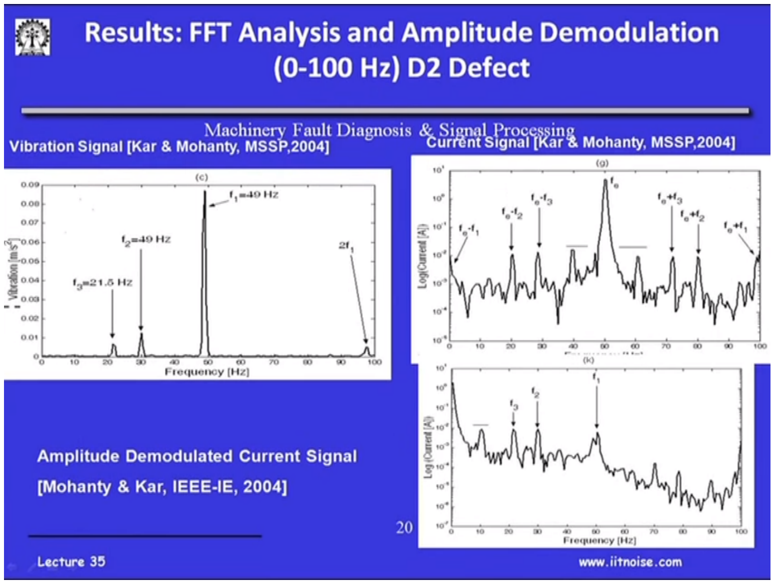

Similarly again with the defects severity D2 is where when we have two teeth they removed we can see the amplitudes again going up okay. And these are because of side bands so key catches the torque or the defect is going to modulate. Modulation means current will be having side bands and side have to be detected by modulation and the amplitude of side band will increase with the defects severity.

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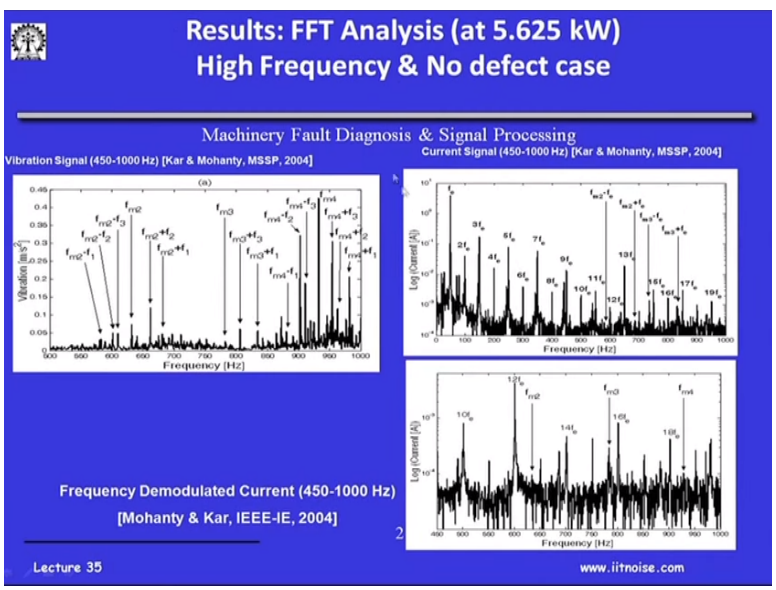

Of course we also saw the high frequencies we want to see around the gear machine frequency earlier case was 0 to 100 hertz but if you recall this second gear mass a gear machine frequency around 630 hertz. So you will see lot of side bands around gear machine frequencies of course they look gibberish right now. But we have to right kind of frequencies and then we have frequency detectors in them algorithm and I will only looking for these frequencies and monitoring the amplitude we will do a good job in easy mode in current signature analysis.

But because of this came out of our research am showing all the possible scenario's which are available I could be monitoring the fourth gear and third gear of the second gear depending on frequency FN.

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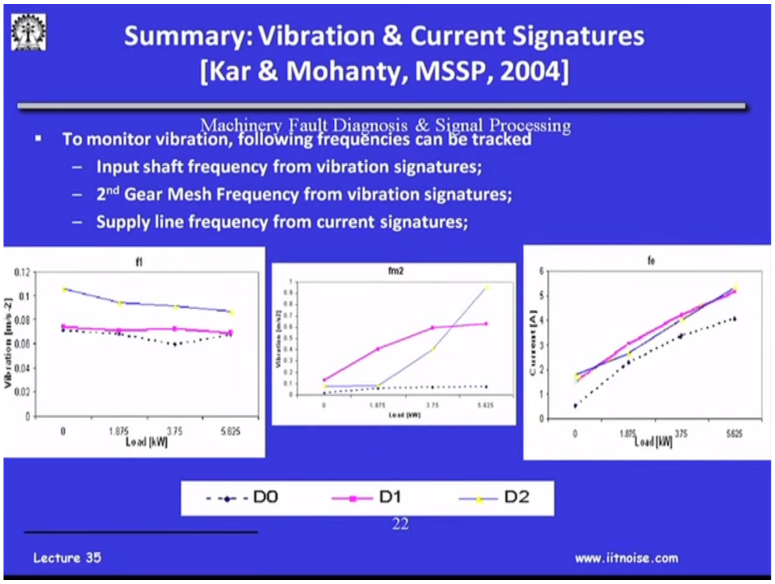

This is just to summarize what we have found out in the vibration current signatures we will see the monitor following frequencies is going to be tracked. Input shaft frequencies from vibration signatures if I am from vibration signatures. Second gear mesh frequency from vibration signatures supply line frequency from current signatures this is the vibration and then defect how the current will bear D0, D1, D2 because current gives an good indicator.

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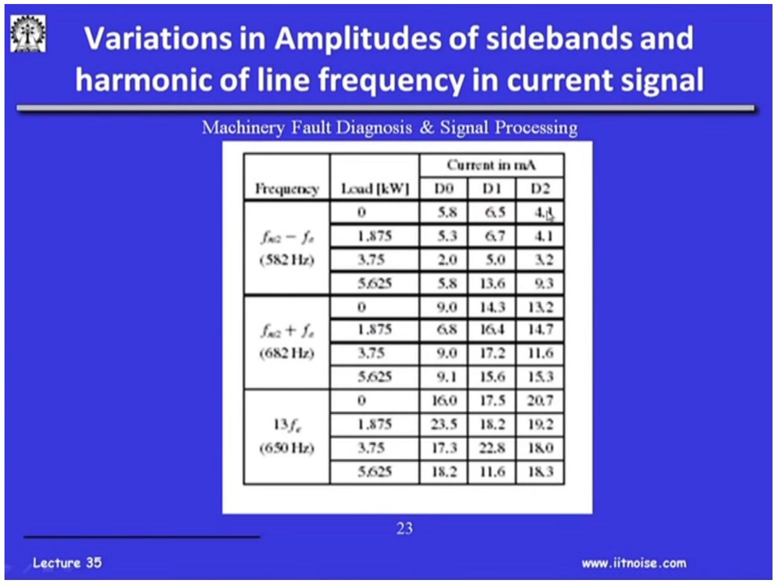

Frequency	Load [kW]	Current in mA		
		D0	D1	D2
$f_{m2} - f_e$ (582 Hz)	0	5.8	6.5	4.1
	1.875	5.3	6.7	4.1
	3.75	2.0	5.0	3.2
	5.625	5.8	13.6	9.3
$f_{m2} + f_e$ (682 Hz)	0	9.0	14.3	13.2
	1.875	6.8	16.4	14.7
	3.75	9.0	17.2	11.6
	5.625	9.1	15.6	15.3
$13f_e$ (650 Hz)	0	16.0	17.5	20.7
	1.875	23.5	18.2	19.2
	3.75	17.3	22.8	18.0
	5.625	18.2	11.6	18.3

And of course you know now you can also do there are many algorithm to do reasons in amplitude of side band and harmonic of line frequency in current signal. With amplitudes of side bands are going to increase because it is in second gear frequency FM 2 is 630 plus minus 50 hertz okay – 50 + 50 and so on okay.

So you will with defects severity amplitude keep on increasing so this one what is the results I was telling but this only demonstrate that any mechanical unit can be used I mean it can be detected or estimated by monitoring the current being drawn by that motor which is driving the unit.

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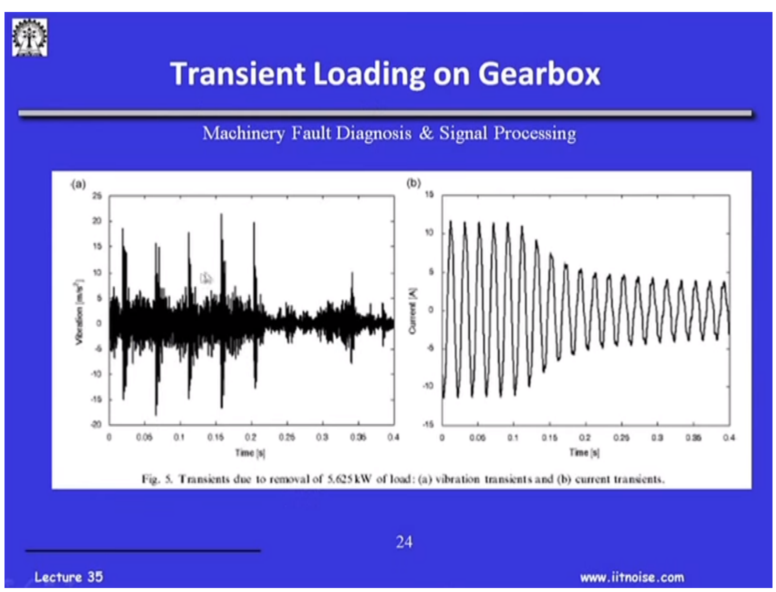

Of course we could do the transient loads also to do the because the loads are transient the speeds are transient this will become non transient signal I will not go into details of the non-stationary signal but certain algorithm can be developed.

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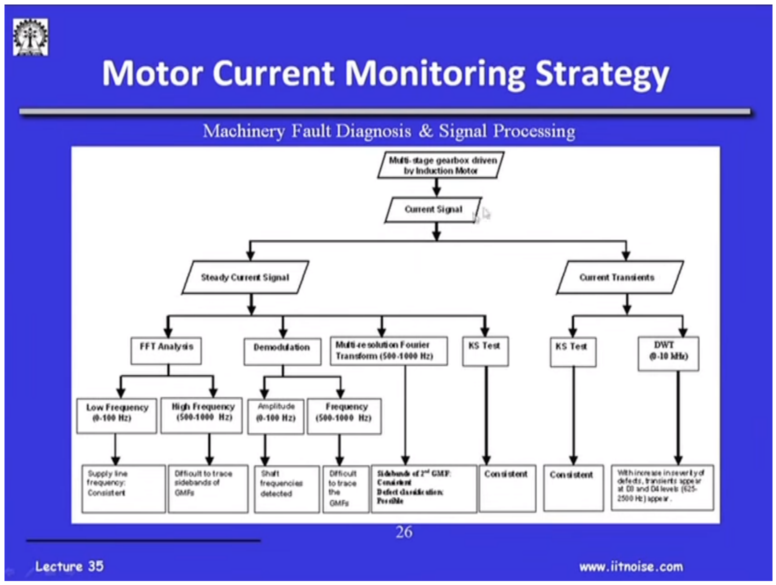

And this actually gives you the motor current monitoring strategy which is being used in a for a MCSA it can have a study current signal and current transient. We are not discussing about current transient occur initially switching on the machine or switching of the machine but a steady state current signature we can do a FFT analysis sometimes it is difficult to understand the side bands in the normal FFT analysis because of the this things become modulated.

But once you do the demodulation we would have seen the shaft frequencies detected but of course in high frequency modulation because of the gibbering of high frequency signal it becomes difficult to signal gear machine frequencies but then there are other methods like the multi resolution transform shown to know loan more about the this retail there in our research publications which you can see you can very easily see this bands of the second gear you can see and the defects can be very easily classified okay.

With this kind of our introduction to motor current signature analysis in fact many of the early classes when I talked about fault prognosis which we did in the case of machine in a lathe machine were in we wanted to prognosis on a cutting tool knife fault we did in fact on the experiment on lathe machine where in the we monitor the motor current of the lathe machine once it was cutting element of aluminum and steel and you know this is about maybe a 15 years old now.

We have seen that how this current in lathe machine changes once it machine steel once it is machine aluminum and then we found out that this current definitely carries information regarding though down the lathe spin. And so a defect also give a load and the load will reflect in the curve so my monitoring analysis current we can find out fault in this case in the gear box in the previous we found out faults in the lathe machine.

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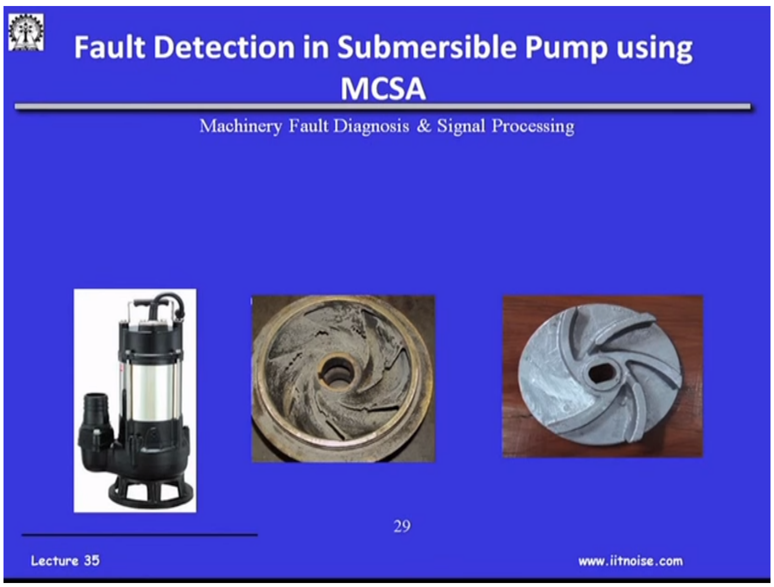

And we took it out little further in the sense went tired and started to use this technique to find out fault detection in submersible pump and this is currently also we are doing this kind of a research to find out a faults in a submersible pumps. Where in if you see here this is a submersible pumps which is drain type but there are many submersible pumps.

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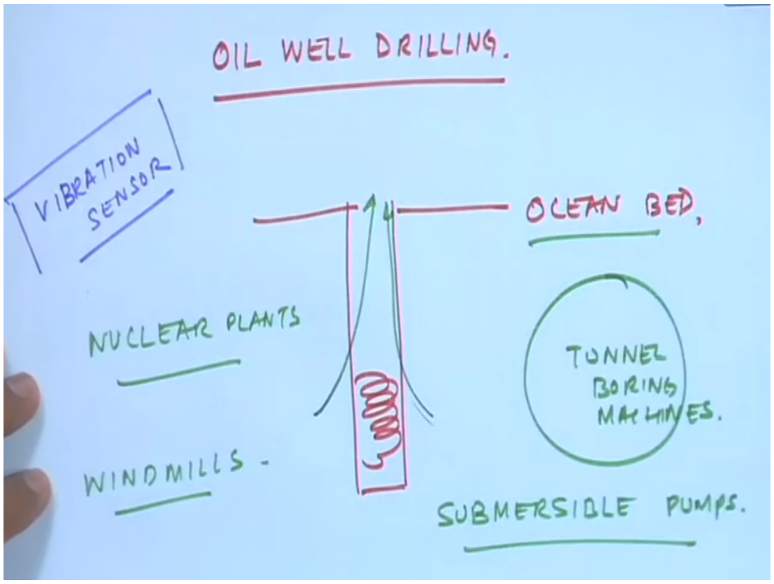

And if you think of may be oil well drilling okay imagine we spend crores of rupees to drill under the ocean bed okay and they are continuously being drilled of course if a and there is one if we drill and then we have of course there are share pressure the oil gush out and pipe and the tap it of an tap the crud line.

But once we are drilling it may be 50 meters 100 meters below the bed and if the motor is developed and some fault how do you monitor it large tunnel boring machines. Submersible pumps oil drilling nuclear plants wind mills. Basically think of scenario's where we are not able to position or vibration sensor. So MCSA is were relief in such a case we can use MCSA to find out the faults.

So here in the laboratory in fact we are here doing research in this area to finding out more signal processing algorithm is to finding out more signal processing algorithms to find these we just better. So we have an there are actually 6 radial vanes in this pumps and you will see we should have removed one of the vanes here okay because we wanted to do again artificial induce and see what are the effects of these on the pump function and again through motor current signature analysis where we can measure it.

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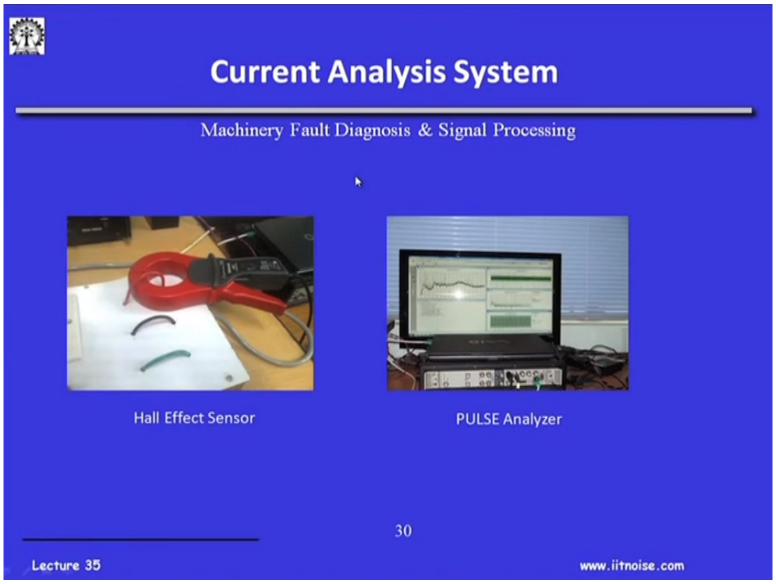

Again we drop this pump through a VFD drive and then we have this hall effect sensor okay so which is used to measure the current and then we have this analyzers system where in you can we can see the current time history and then you see the current spectrum.

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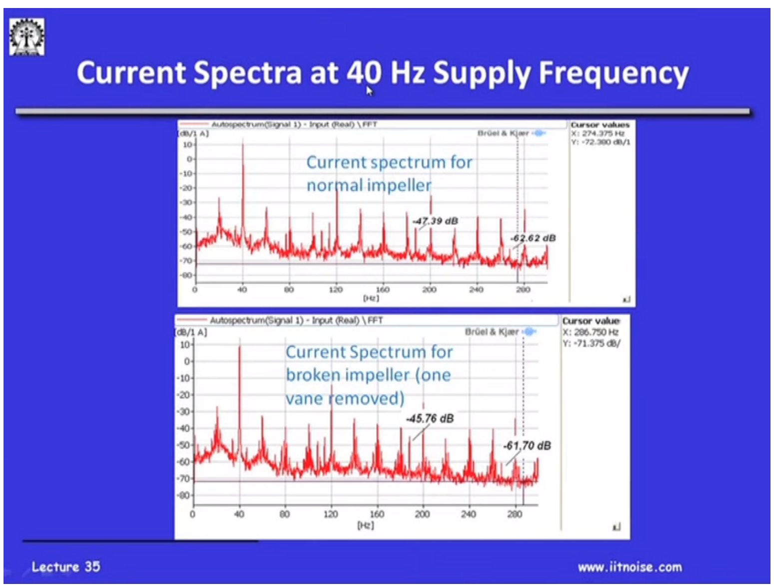

And you see this at a 40 hertz power supply frequency the current spectrum for a normal impeller is given like this you will see many frequencies is coming up and we can see at a particular gear meshing frequency because you now again in pumps like we have in case of gear mesh and gear boxes.

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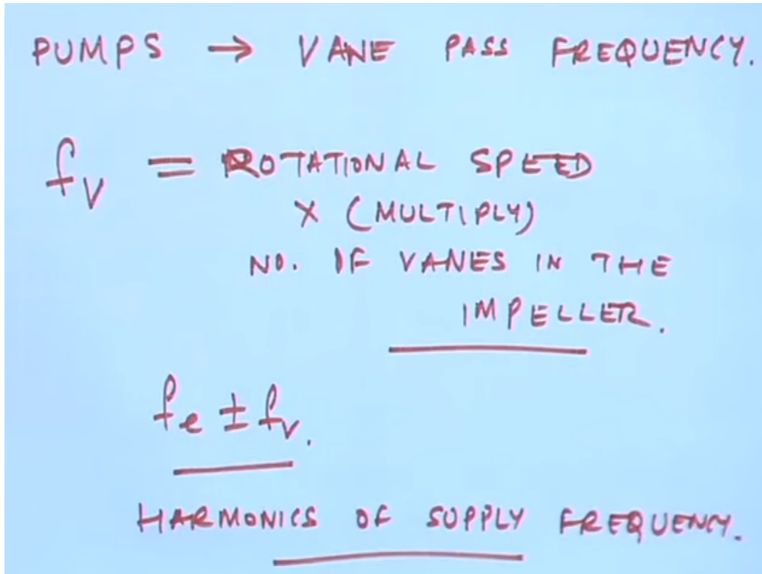

We have the vane gear meshing frequency in pumps we have what is known as the vane pass frequency which is nothing but rotational speed times multiply the number of vanes in the impeller. So again if this vane pass frequency is given by a FV I will FE plus minus FV or the other way also. And this is what is there in the frequency spectrum and there will be lot of harmonics in fact in this signal you will see lot of harmonic multiples are there harmonic of supply frequency.

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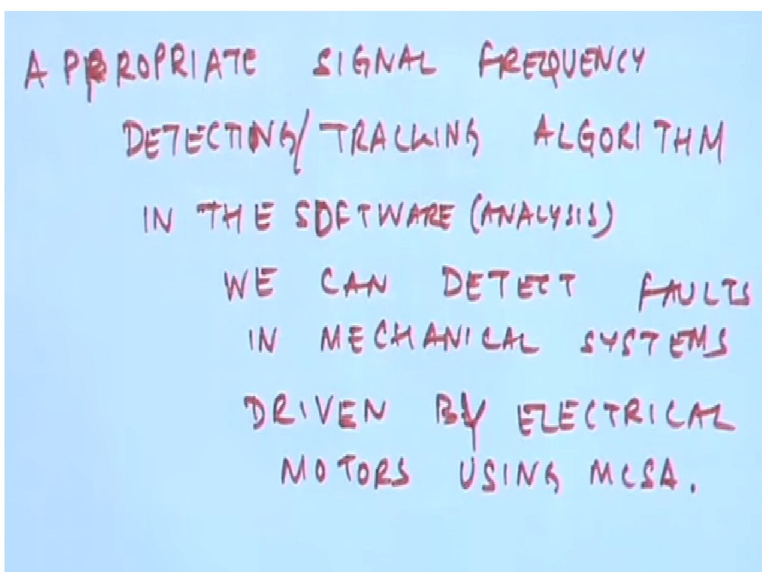

If you have the MCSA you will have the appropriate signal frequency detecting or cracking algorithm in the software in the analysis software we can detect faults in mechanical systems driven by electrical motors using okay if we answer is very very important you may not get just monitoring the peak at the supply frequency you may not get that okay.

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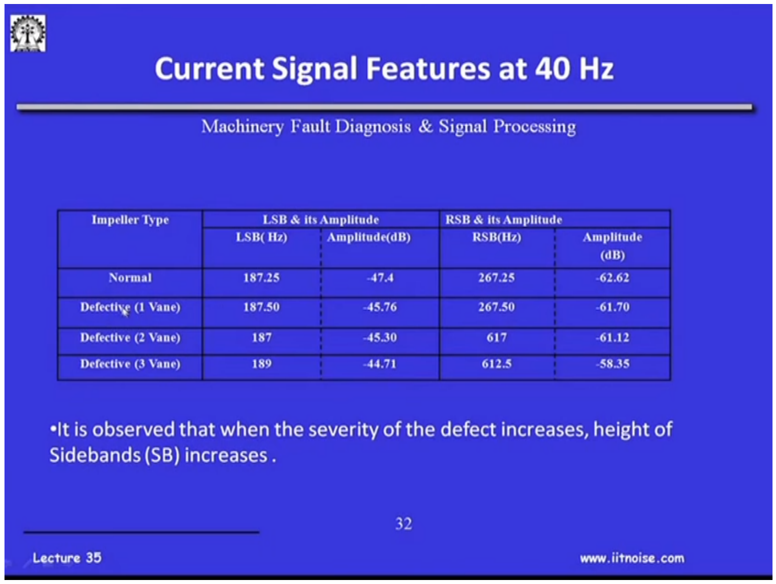

So in this example at 40 hertz we again had defects of 1 vane remove, 2 vane remove, 3 vane remove and then we see this side vend values okay at these frequencies okay the lower side band and the left hand band and the right side band and their amplitude to see it is observed that it is severity of the defect increases of the side band increase because you will see from – 47.4 it becomes – 44.71 from -62 it become – 58.35.

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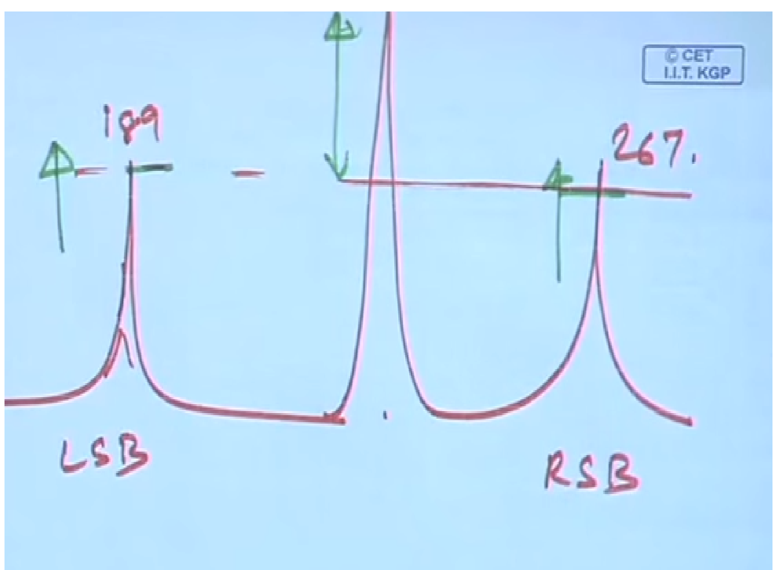

That means around the supply frequency of so this around 189 so these values are going to increase okay and then another case was 267 this is the right side band this is the left side band. So once the defect severity increases they will increase if somebody monitoring this ratio so you can develop many algorithms. I monitor this ratios or I monitor this differences if this differences go beyond lot of certain value i know there is fault okay.

So many algorithms can be developed as I was telling you just by having algorithms better algorithms to detect can find out the fault in this mechanical system okay.

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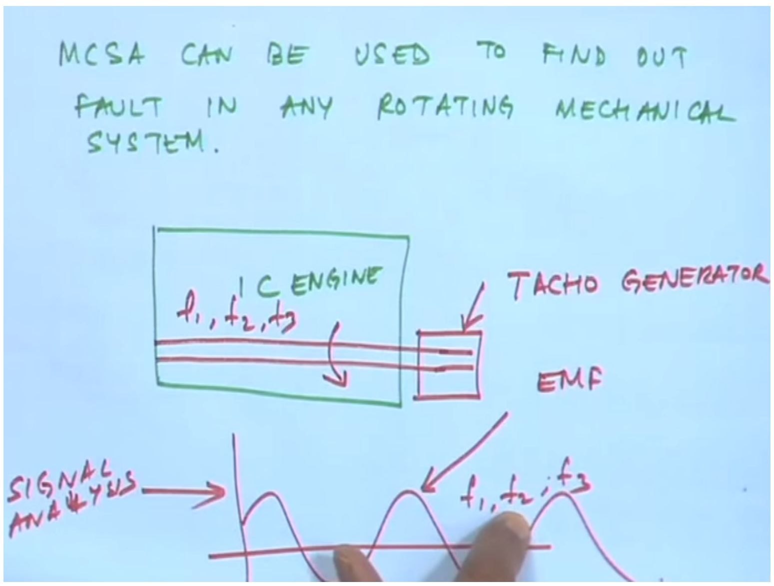

Now another technique how MCSA is powerful to find out faults in any mechanical system okay. Imagine now I have an IC engine okay now somebody ask me how do I use MCSA to find out fault in this IC engine all I can do is I know we have a crank shaft to this you use a tacho you put a tacho generator so because of rotational tacho generator is going to produce an EMF okay.

So if you this EMF will have the defect mechanical frequencies of the system will be there buried in this. If you do a signal analysis on this EMF which is generated by the tacho generator coupled to the mechanical system which is rotating I can find out the fault in the mechanical system.

In fact we IIT Kharaghpur have a patent on this system this orbit these are in invention which we have done that by using by tacho generator on any rotating system is just attach it and then we have used in successfully and the monitoring they have the gas turbines okay we have that for the case of gas turbines.

That we can find out fault in any mechanical system IC engine gas turbine etc., here I do not have motor driving changing. IC engine I just couple it to a tacho generator because the tacho generator is rotating and the rotational power here is the crank shaft which is being driven which is prime mover in this case and then I am saying the a EMF which I having lot of ripples and all these characteristics frequencies round to show up hat defects from show up in this spectrum.

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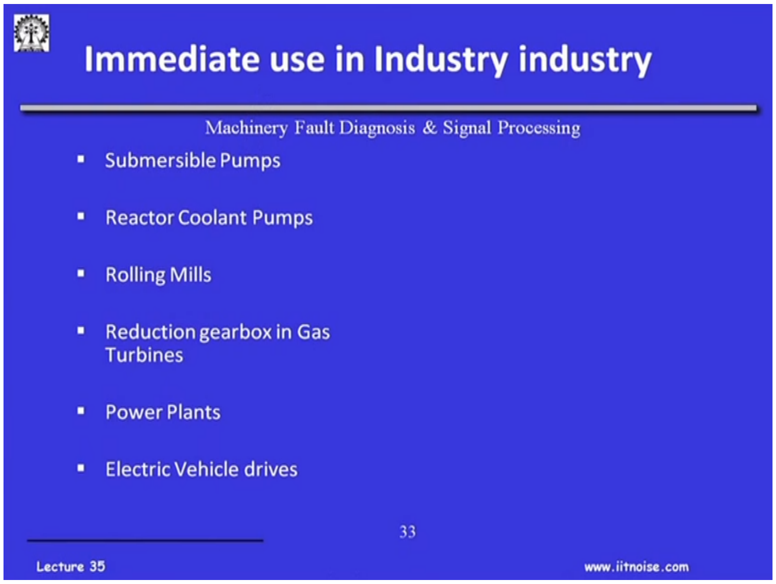

So you can realize the power of the motor current signature analysis it is a very powerful clean neat technology provided you do a measurement right and you are signal processing right. Submersible pumps we just saw the example our reactor coolant pumps so we cannot go inside reactors so we can monitor the coolant pups particularly coolant pumps are very critical to net reactors.

Now that is where they control the temperature of the reactor I mean you know what happens in japan okay because there is a cooling pumps did not function they got faded the reactor no way had a controllable reaction so this is very important. Rolling mills there are lot of motors which are driving the rolls so if one of the motor phase it is going to have a series of aspect on the rolling reduction.

Reduction gear boxes in gas turbines power plants no it is good candidate for motor current signature analysis is this way electrical vehicles which are moving around basically they are high power battery driven call wherein we have a motor basically driving the wheels okay. And if there is defect in this electrical motor I am going to have a problem f this motors drive a gear box and gear box with the speed reduction driving wheels.

So I can have some sort of an monitoring mechanisms in that think of the attraction drives in locomotive there else again the DC motors is you know here we talk about AC motor even if we have DC motors the same thing would happen only thing there will be ripples after remove the DC current you will be finding lot of ripples and this ripples do contain the frequencies of the defect frequency of the mechanical system which are being driven by such unit okay.

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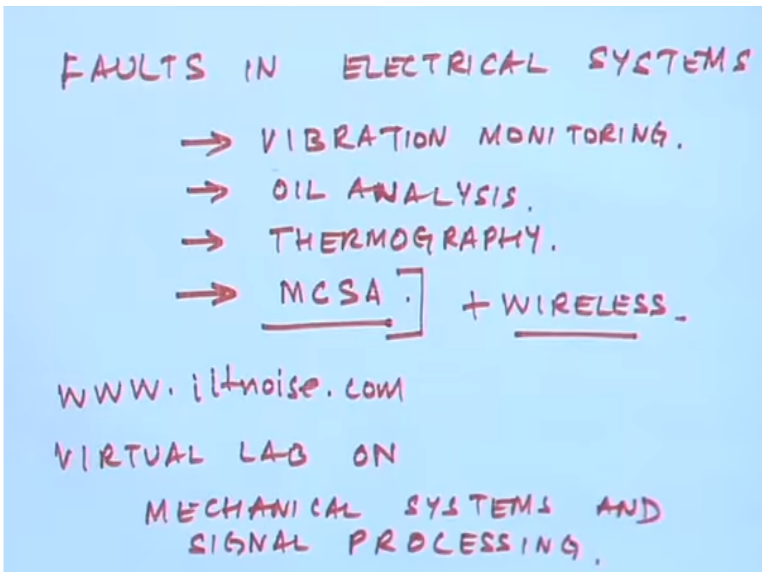

So in conclusion if I talk about the previous class faults in electrical systems of course nobody asking me to use the vibration monitoring still do vibration monitoring I can do oil analysis particularly for the case of transformers I can thermography something which you are going to study in this subsequent few lectures. Because there will be lot of heat generation in contacts and then we will use a or MCSA to find faults in electrical motors and also faults in mechanical systems.

And I believe if I use MCSA + wireless techniques in fact we have done a experiments on using MCSA in wireless and if you go to our website and then if you see the experiments on the virtual lab on mechanical systems you will see virtual lab. In fact you will see the virtual lab on mechanical systems and signal processing you will find out there are two experiment one on using MCSA to find out faults in gear boxes another is to find out faults through MCSA and wireless techniques in industrial blowers okay thank you.