**Machinery Fault Diagnosis and Signal Processing**
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**Lecture - 46**
**Principles of Motor Current Signature Analysis**

Yeah, in this 10th week we have must talk about some other techniques of condition monitoring other than vibration analysis which we had seen so far and particularly we will be discussing about you know how electrical motor current signature analysis can also be used for fault detection, we will talk about thermal imaging wear debris analysis oil analysis and later on in the 11th week we will talk about other NDT techniques like acoustic emission ultrasonic's x rays and so on.

So, well coming to this lecture on principle of motor current signature analysis.

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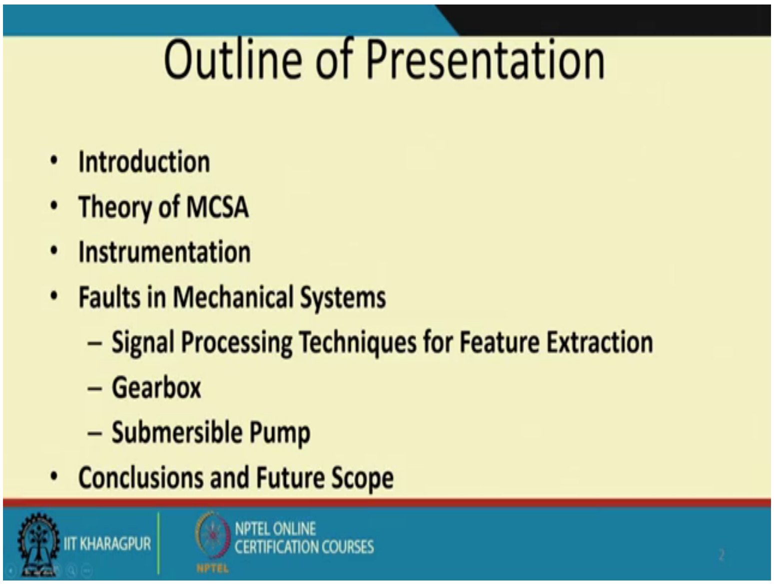


This is primarily what I will be discussing today like what is the theory behind motor current signature analysis and why it is important and why it becomes helpful to use MCSA to find out faults in rotating machines, the associated instrumentation and then basically I will be seeing how MCSA could be used to find out faults in the gearbox submersible pump and perhaps we can use MCSA to find out faults in any mechanical system being driven by an electrical motor.

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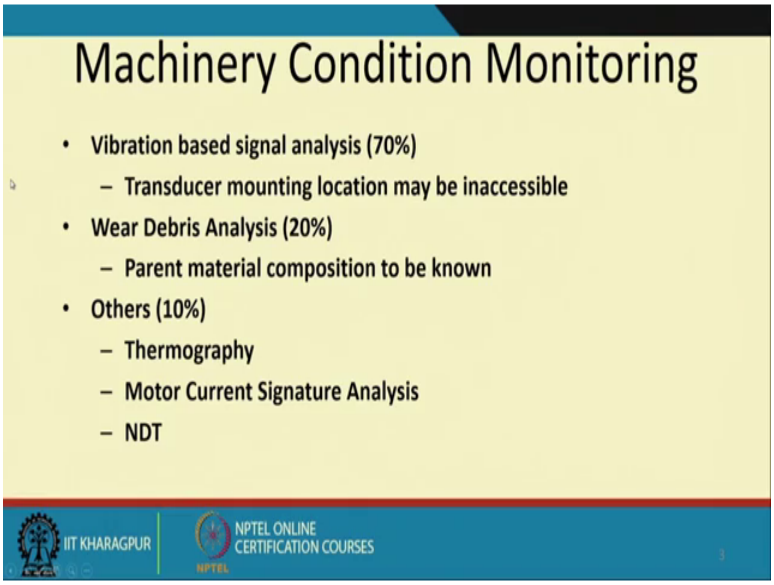


So, as you all know by now that nearly 70 percent of the monitoring is usually done in by vibration and that is the statistics throughout the world, but the problem with vibration based signal analysis is sometimes we may have problem locating the transducers or mounting the transducers in the sense, the I will give an example may imagine I have to measure the vibration of a gearbox of a wind turbine which is perhaps you know 50 metres above the ground.

It is not convenient humanly to monitor at such remote locations or in other words also underground because, in today the technology is such that once the accelerometer or vibration transducer is permanently mounted at the location we can have wifi or wireless transmission to transmit, the signal in packets and analyse the signals at the receiver station. That is a new technique which has come up which is aiding many of these vibration based signal analysis we will talk about these in the future scope of machinery condition monitoring.

But coming back to the slide the other techniques are wear debris analysis where in the parent material composition is to be known, so that if we see the wear particle relating to the parent material we can say that which component is wearing out we will be discussing this later in this week, but some of the other techniques which are becoming very popular is thermograph through thermal imaging and the most important one which we are going to discuss is the motor current signature analysis, which is a very promising technique which has come up I would say primarily because, of the research we have done at IIT Kharagpur in the last two decades we started somewhere in the mid nineties and then we continued working this and we now have a patent on using any electromagnetic device to find out the faults in a rotating machine.

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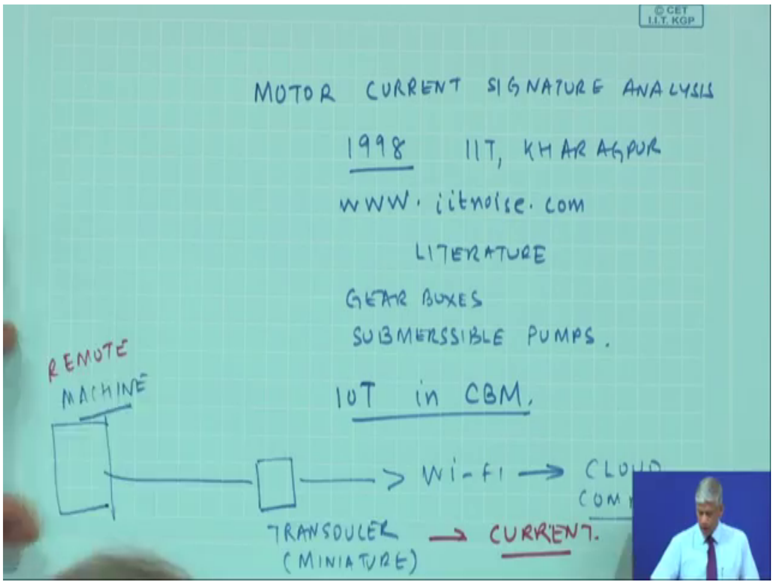


So, this motor current signature analysis close to exactly about 2 decades ago we in IIT Kharagpur came across the technique and we have developed many algorithms where MCSA can be used to find out faults in mechanical systems. So, you can go to my website or to my Google scholar, to see the relevant literature in this area for finding out faults in gearboxes submersible pumps.

So, today people when people are talking about IOT of devices IOT in CBM, the technology is such that we can have a transducer where miniature Wi-Fi cloud computing, wherein the transducer is remote from the machine this is my machine.

So, in the sense that anywhere we want to measure the condition of a machine, all I need to have the transistor accessing the current and then we can translate by Wi-Fi and all the analysis can be done on the cloud and that is the technology which is prevalent today.

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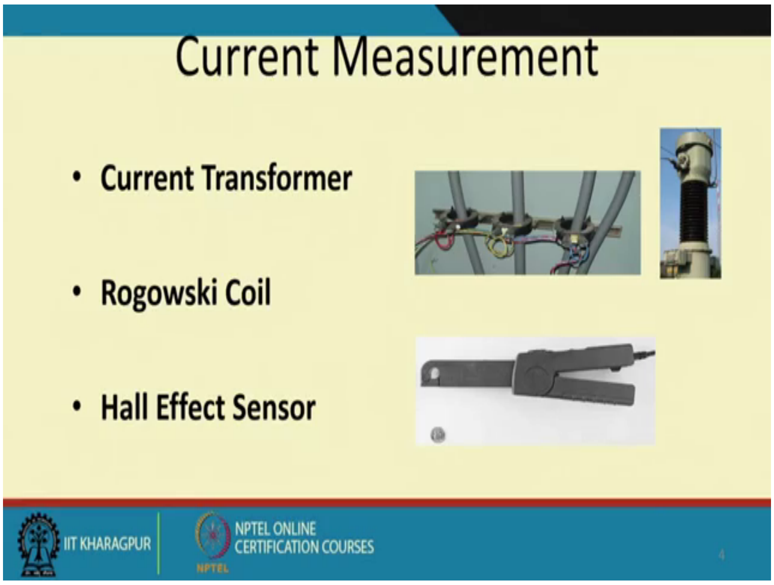


So, let me come to the theory of MCSA well before that I need to measure current ok. So, we can use a current transformer or a Rogowski coil, but we will talk about this Hall Effect sensor wherein; suppose this is my current waveform ok. If there is a defect and usually a prime mover like an electrical motor is actually driving a mechanical unit, this could be a gearbox example or a pump etc, but then this motor is fed with conductor wherein I can measure it.

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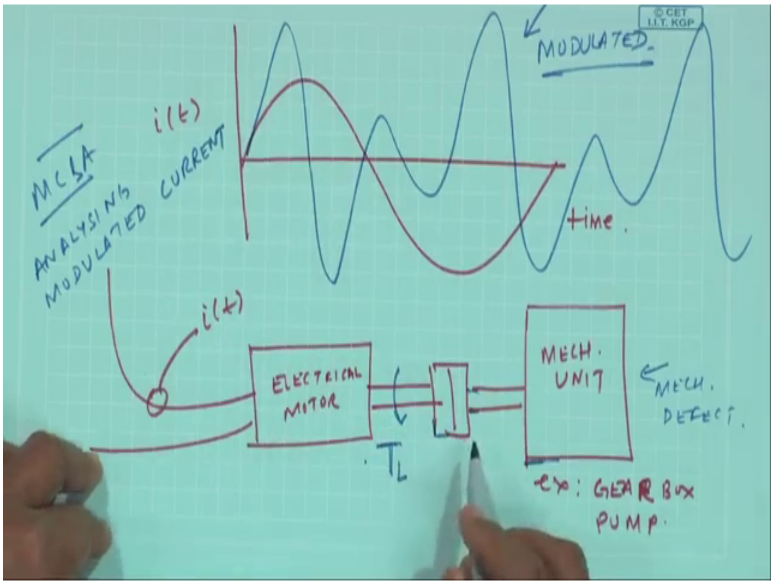

So, if there is any defect in this motor in this mechanical unit, it is going to influence as a load torque on the motor. So, imagine the motor is being subjected to a load torque because of a mechanical defect. Now if the motor is subjected to a defect which is at a different frequency than the rotational frequency, the motor current may and will get modulated. So, the key to finding out fault in MCSA is actually analyzing the modulated current drawn by the motor.

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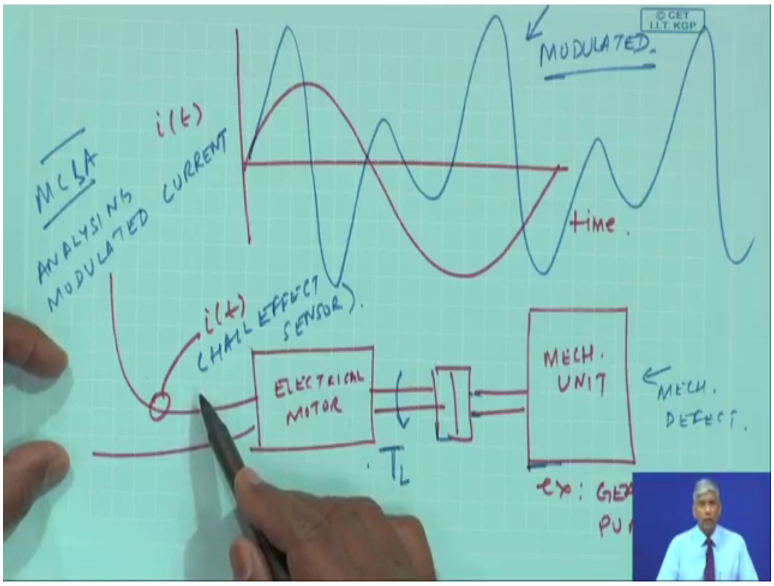


Now imagine it could be a unit very far off this current carrying conductor could be accessible usually a Hall Effect sensor. Well Hall Effect sensor is a special semiconductor device ok.

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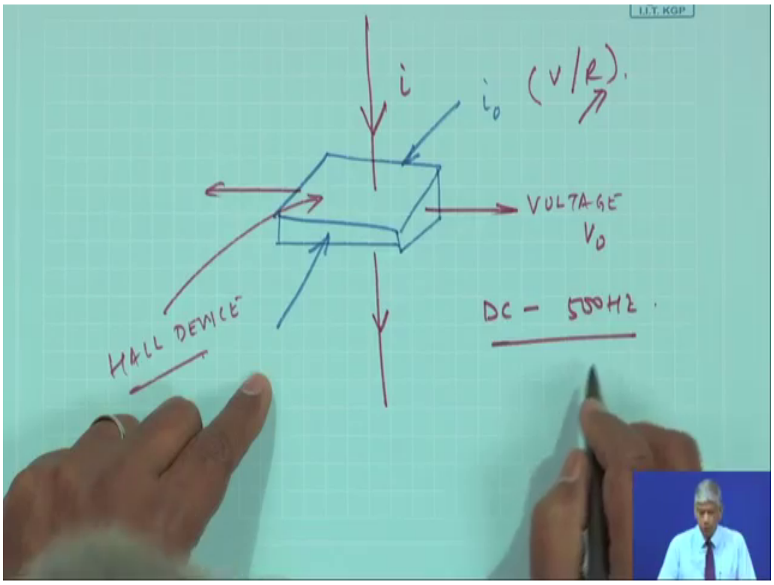


Wherein if a current carrying conductor is flowing through this hall effect sensor if I give a current some current I naught, because of the magnetic field produced by this flowing current which I want to measure I will get a voltage and this is usually a hall device a semiconductor ok.

So, this becomes very popular in the sense all devices somewhere kept here and all we need to do is put a current carrying conductor through this hall device and then we will get a voltage. So, we need to give a current so basically we need to have a voltage source across a resistance where I can vary the resistance. So, that I can nullify it this output voltage should be 0 and there is no current. So, this arrangement is can be done and there is an knob here which can help you to calibrate the Hall Effect sensor.

But the essential advantage of using a Hall Effect sensor that I can measure all the way from DC to about 500 hertz and that is the current frequency ok. So, MCSA becomes very simple that I all I need to do for this motor is if I put an hall effect sensor motor, could be you know 100 meters away from you we need not even walk up to the motor to put a virus and sensor all I need to do is have access to the current carrying conductor or the motor and then access it.

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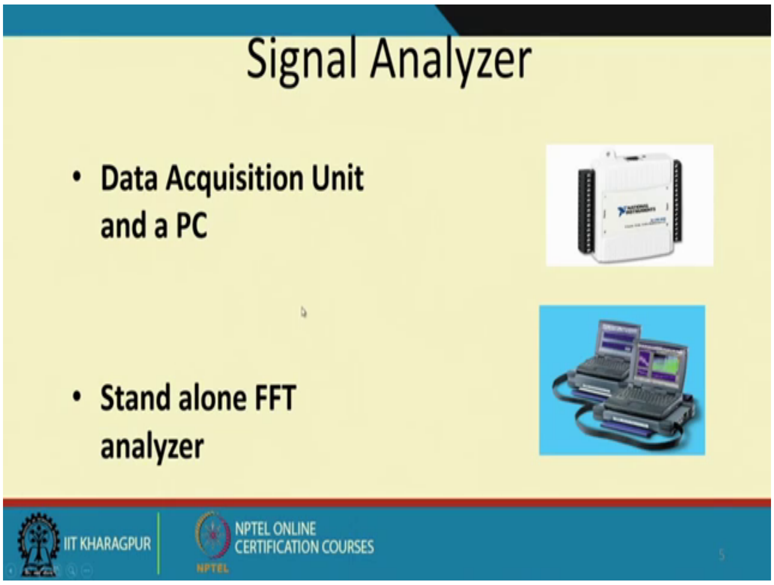


So, in terms of the signal analysis equipment, all I require is a data acquisition unit because is a very slow signal 500 hertz; I can I can capture with the data acquisition unit and I can have an standalone FFT analyzer or a laptop. So, comparatively this is a very cheap setup compared to the traditional vibration transducer. So, basically all you need to have is a computer with a data it can DAQ and Hall Effect sensor.

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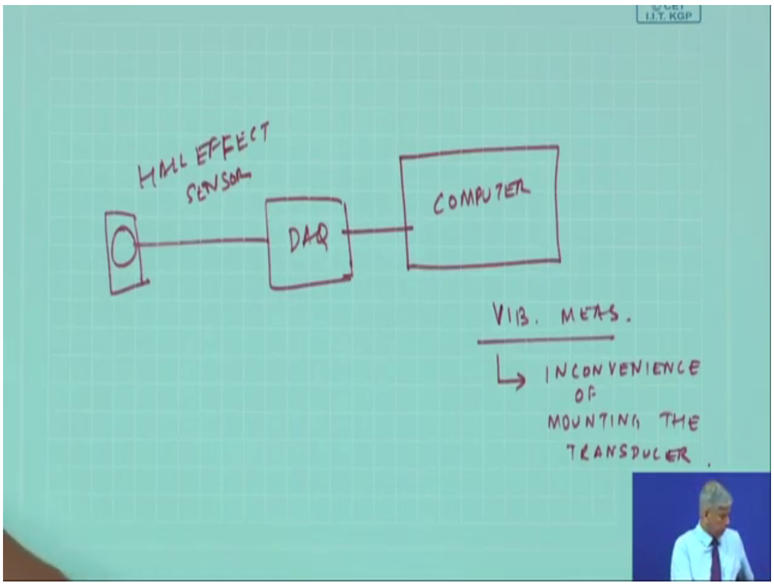

So, this is a very cheap method very cost-effective compared to vibration measurements because, the vibration measurement the essential problem is inconvenience of mounting the transducer, so this is becoming very popular the motor current signature analysis.

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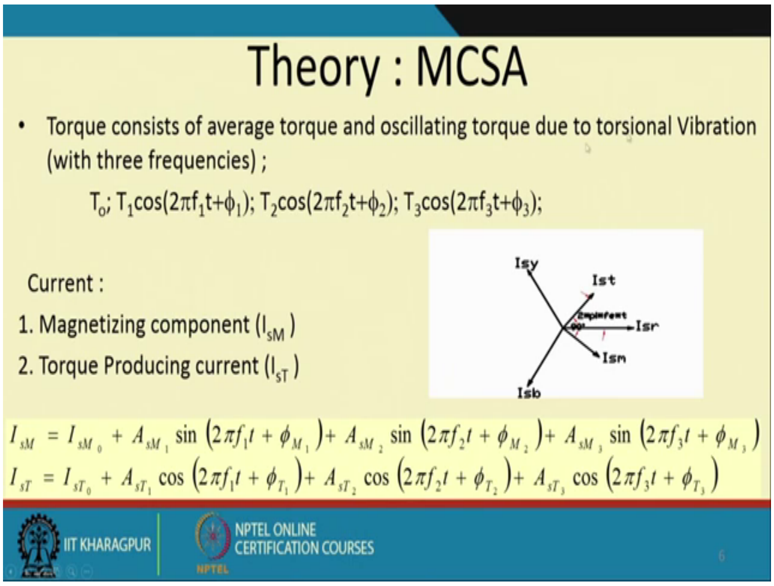


Now, let us look into the theory of motor current signature analysis as to why it is beneficial or why it is able to sense, now look at this the torque which I discussed as TL on the electric motor this is due to the oscillating torque due to torsional vibration, now what is this torsional vibration?

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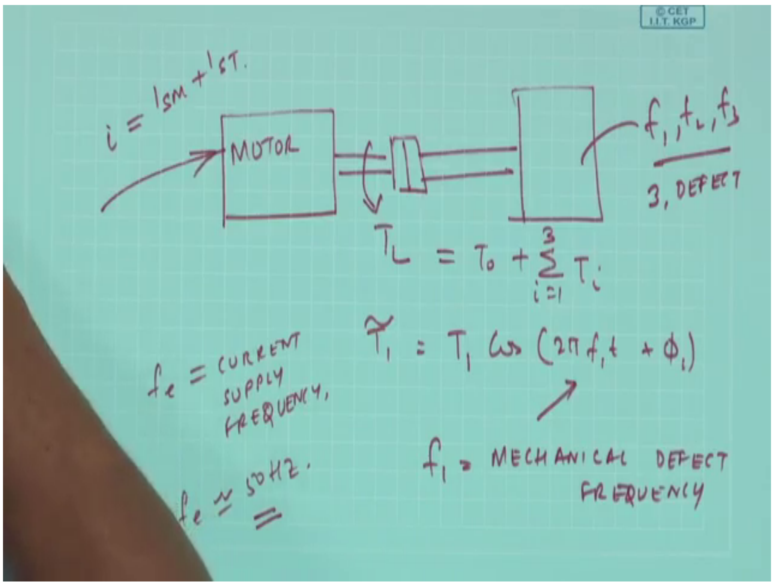

So, this motor which I am talking about suppose it is driving a mechanical unit, it is being given a load torque. Suppose there are this torque is a constant component plus some T i is equal to 1 2 3 this case where T i is may be some constant cosine 2 pi f 1 T plus pi 1, where f 1 is the mechanical defect frequency.

So, in this diagram say f 1 f 2 f 3 are the 3 defect frequencies, which could be because of a gear which could be because of a bearing etc. So, in a sense this defects are going to give a load torque on the motor now the current drawn by this motor essentially has two components, one is the magnetizing component and other is the torque producing component because, the current drawn by this motor will be in a particular phase magnetic plus torque. So, magnetic current will produce the we will they will they will all get modulated, they all are 90 degree out of phase ISM and IST and then I have written here ISR ISY ISB because, these are the three phases of the motor we will discuss any one phase.

So, in any particular phase you see the magnetizing component is given by a sine function and the torque producing component which is 90 degree phase difference with the magnetizing component is given by a cosine component. So, these are the two current components being drawn by the motor.

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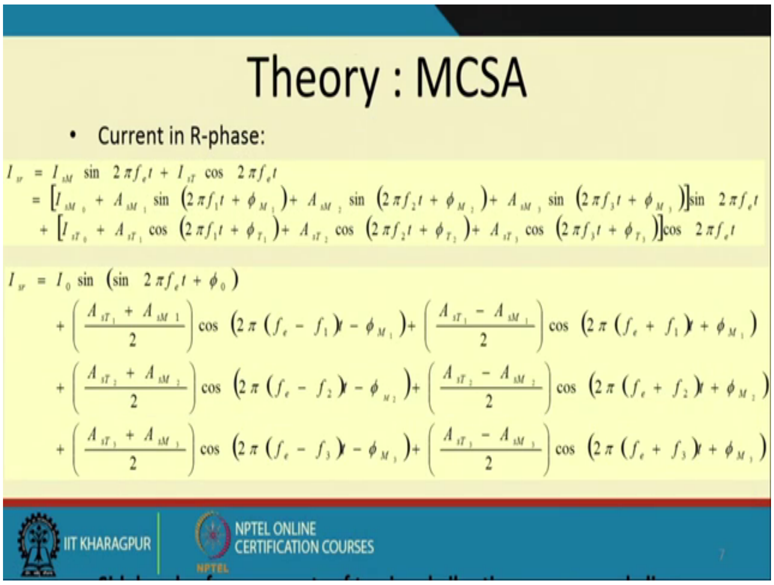


Now, so in any particular phase for example, in our phase if I add the magnetizing component and the torque producing component if I add them up sine and cosine, I will come up with an expression the total current drawn will be certain amplitude, but most important is it has terms like f e minus f 1, where f e is the current supply frequency. For example, in our country f e is 50 hertz in united state it is 60 hertz well, but this is the constant current frequency which is at the supply side.

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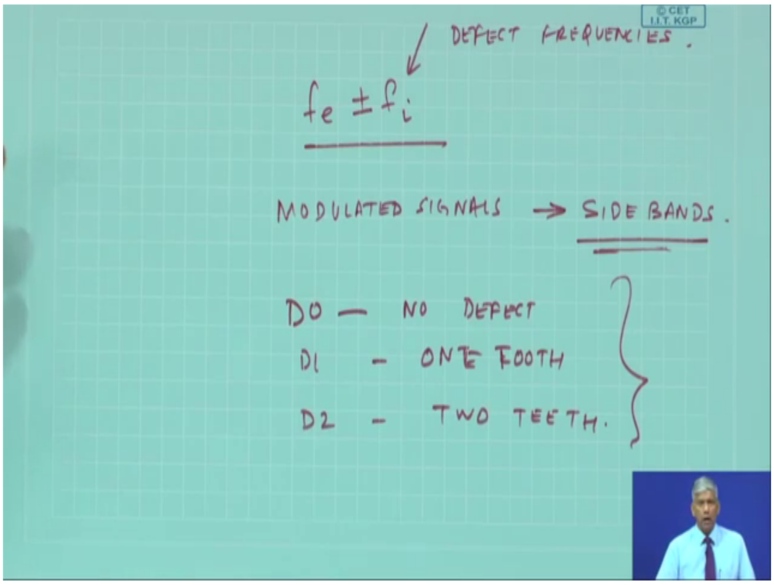


So, you see this f e minus f 1 f e plus f 1, the supply current frequency basically gets modulated and this is the defect frequencies. In fact, this is the reason why I can measure current to detect these frequencies. So, basically all it boils down because sidebands are there you can pretty well say that they are modulated, because as you know modulated signals in the spectrum will give you side bands.

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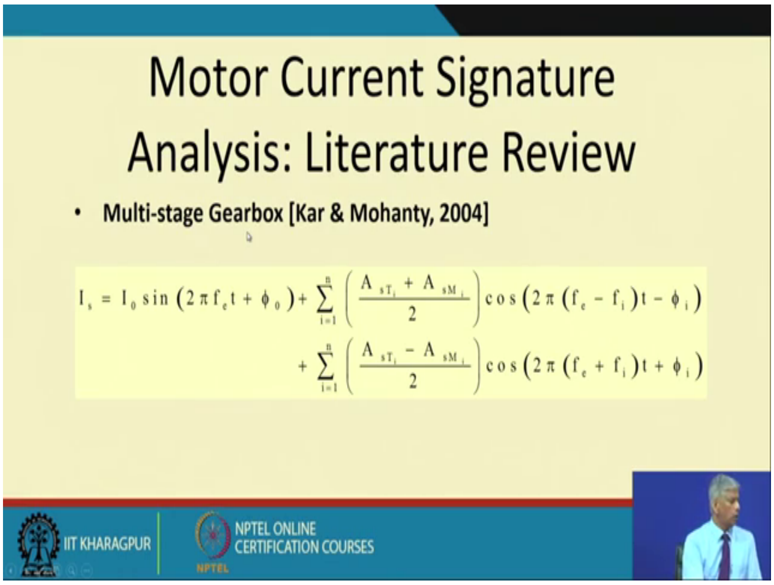


So in fact, if you go back to our Google scholar you will see these literatures and the entire theory behind these so basically.

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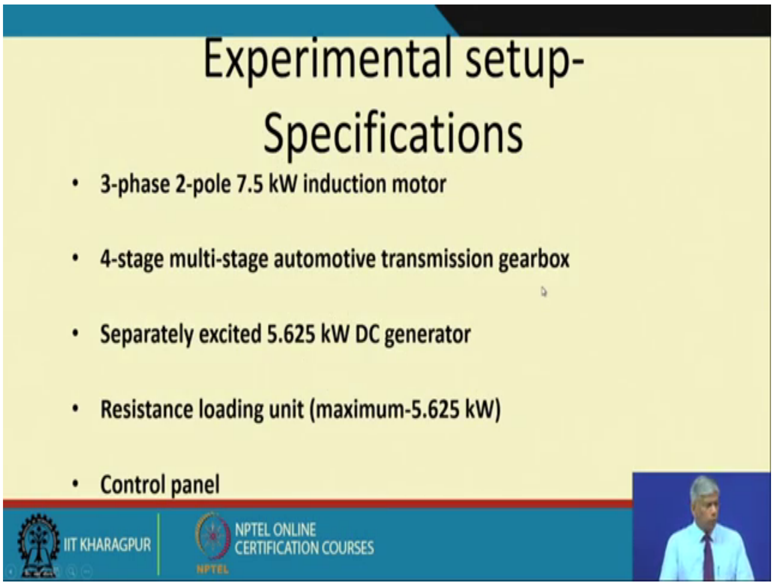


Now, to demonstrate this motor current signature analysis on a gearbox, I am going to briefly go over an experimental setup which you did in the lab. So, this is a 3 phase 2 pole 7.5 kilometre induction motor, which is driving an 4 stage automotive gearbox which is this gearbox is connected to a generator which will and because this generator is rotating the armature is rotating at the generator voltage and this could be loaded by a resistance loading.

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The view of the experimental setup which we have in the laboratory, so motor gearbox generator and the loading unit and you can see the hall effort sensors here which are measuring the currents in the 3 phases and then this is the resistance unit and then we have the gearbox here right.

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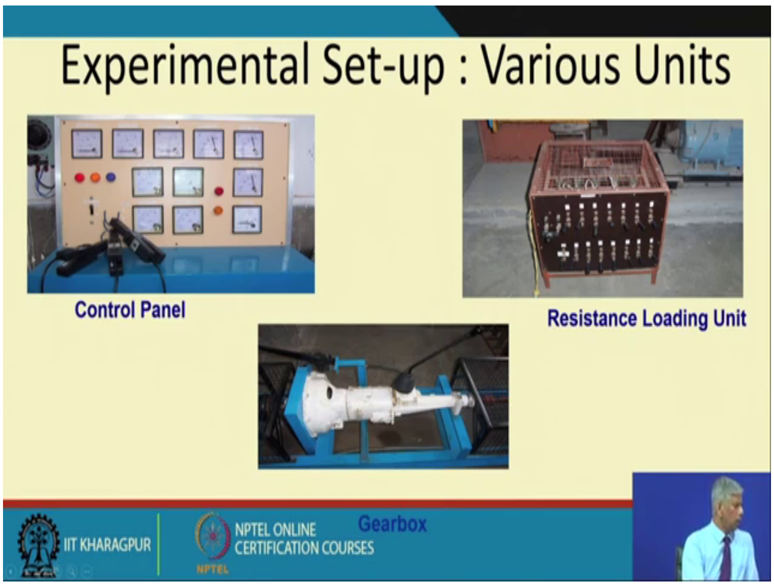

Then, automobile gearbox; where, I can induce defective gears. And then, see the current drawn by the electric motor.

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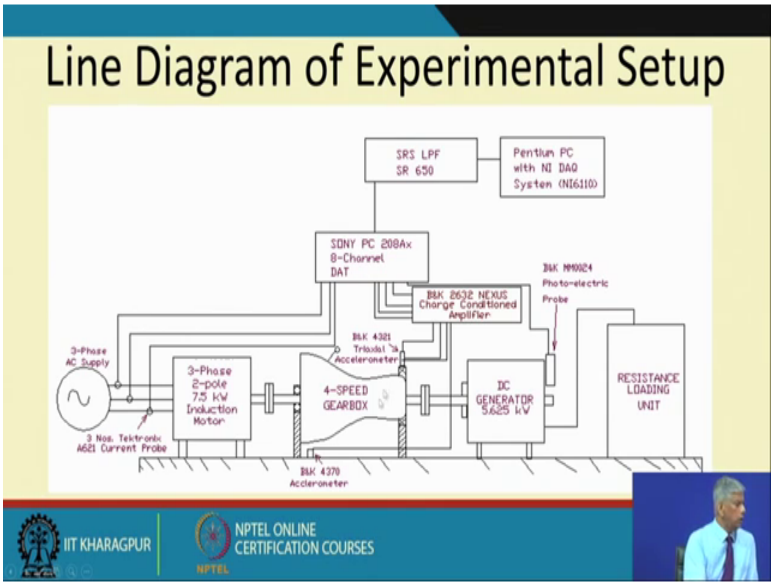


So, this is just to give you an overview of the experimental setup which we did, so this is a the motor driving the gearbox and then this gearbox is connected to a generator and generated has loading unit and because and then in the supply side we have 3 hall effect sensors to measure the 3 phases of the current and then because we wanted to establish that whatever conclusions we come or obtain from the current we also need to substantiate that or validate that with vibration measurements. So, we put a tri-axial accelerometer and also an uniaxial accelerometer on the frame.

We collected all the signals on the tape recorder and analyzed them in a DAQ system and of course we also monitored the motor rotational speed within the photoelectric pro.

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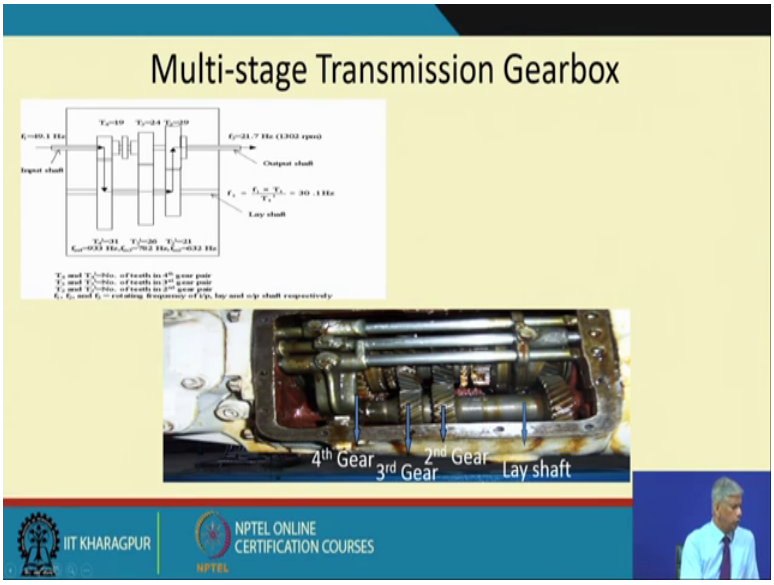


So, this is the view of the gearbox the automobile gearbox then fourth gear third gear second gear. So, we operated with the second gear and then wherein we will artificially remove the gear seated defects and put it back. So, if you look at this signal like this supply speed is 49.1 hertz is the input shaft and when we are running in second gear the second gear output shaft comes out of this and then the defective the gear machine frequencies etc are given here.

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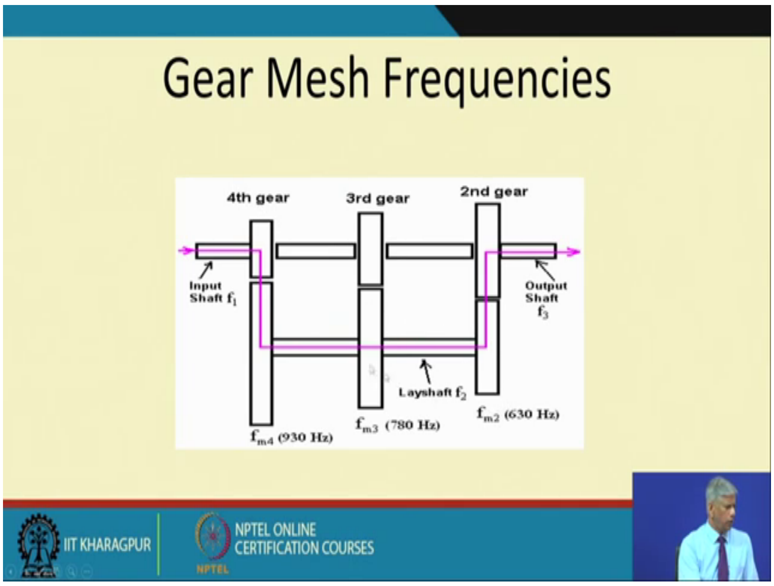

So, when it is running out in gear the gear machine frequency is 630 hertz and this is how the defects in the gear look like, we which we call as D1 is one tooth remove from the gear we use an wire cut in EDM to remove this gear and then D2 is the removing 2 gears and of course D 0 is no defect.

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So, we have two cases D 0 no defect in the gear D 1 is one tooth removed and D 2 is two teeth removed. So, all these conditions we ran the gearbox at different speeds measured the current measured the virus and send then all the conclusions which we have got.

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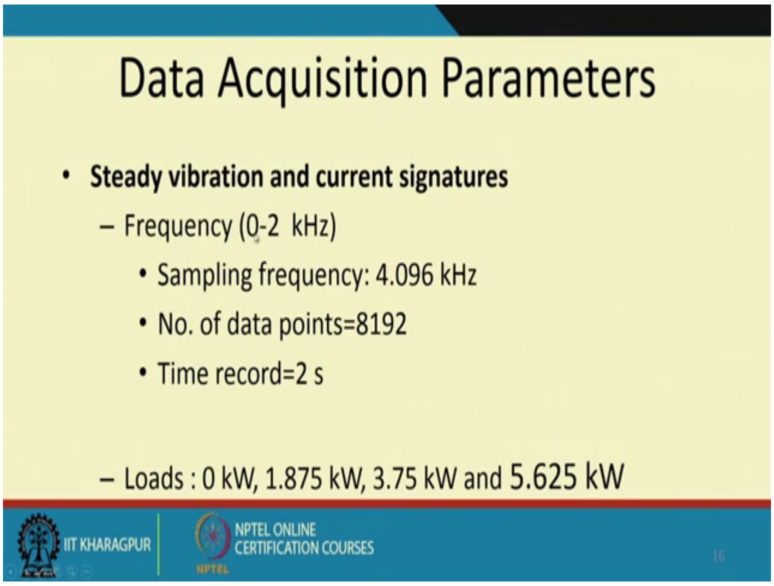
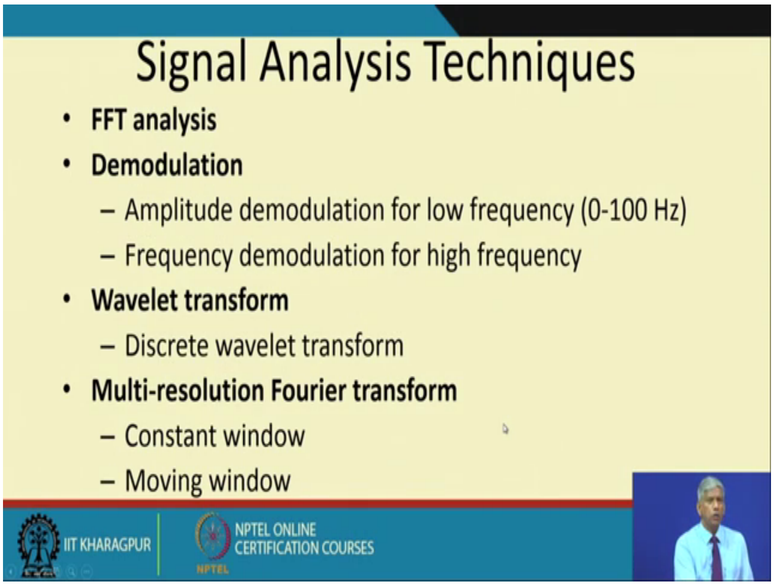


Now, another thing which you notice here even the frequency range is not very high, unlike if you have to find out the faults and bearings or gearboxes where we had to have an higher frequency range, it is not required in monitoring current signatures 0 to 2 kill hertz is good enough we sample at 4.096 kilohertz, the total time record was 2 seconds the gearbox was run at different load conditions 0 kilowatt and these kilowatts 1.875 to 5.625, because in the resistance unit there were units where we could switch in the circuits or resistances to introduce the gears.

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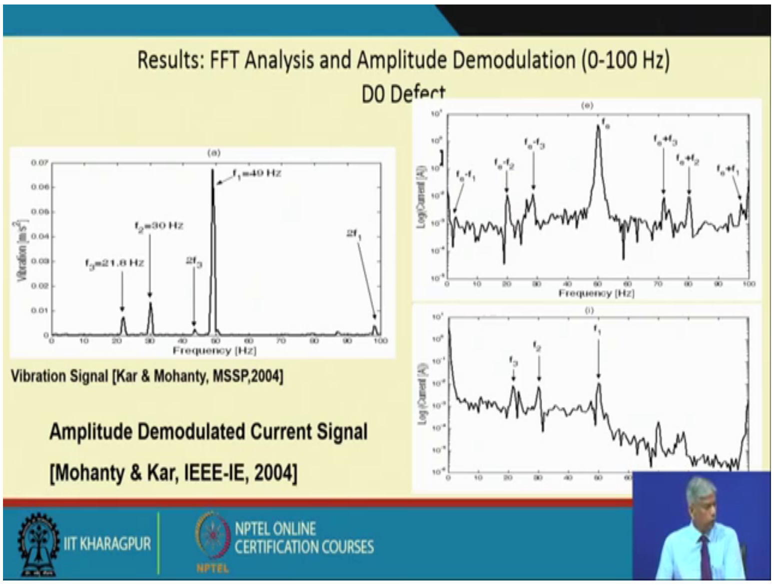


So, once this signal has been acquired from the DAQ system into my computer I need to do some sort of an analysis, the conventional FFT analysis sometimes it becomes problematic because, of the low signal to noise ratio and then we may not be able to capture these signals. But if we do d modulate the signals we can very easily calculate the an identify the different frequencies and if there are transients as if the gearbox or the mechanical unit is not running at constant speed, we could use some of the non-stationary signal analysis techniques as well.

But this is the case wherein we see FFT analysis and amplitude demodulation from 0 to 100 hertz. So, this is the virus and signal obtained from this gearbox wherein I can see all the input frequencies and that is what is expected ok; but when we first time did our analysis because, we were excited to see that the side bands around the supply frequency f is 50 hertz is the supply frequency, I can see these peaks and then if we do the these are the modulations side bands are there. So, if I do modulate the amplitude modulated signal I can very easily see f 1, f 2, f 3 and if the severity of the defect increases these amplitudes of these frequencies would increase and that is the tell-tale sign that a defect has occurred.

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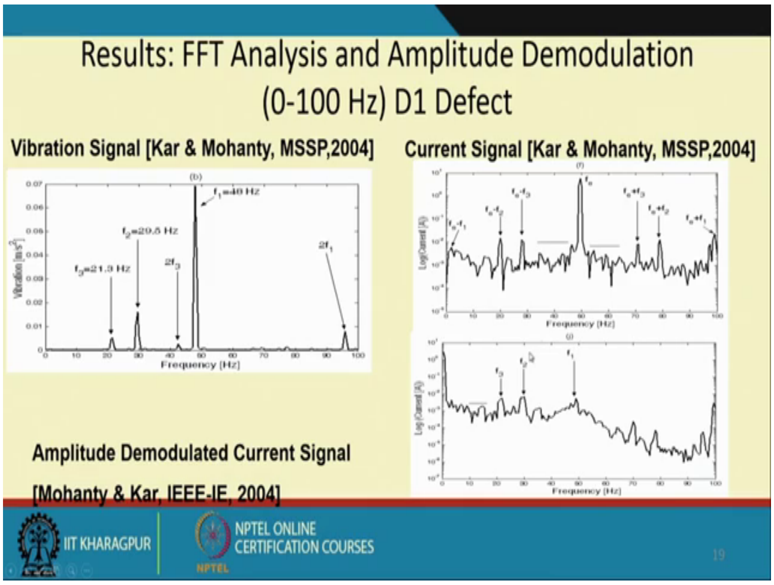
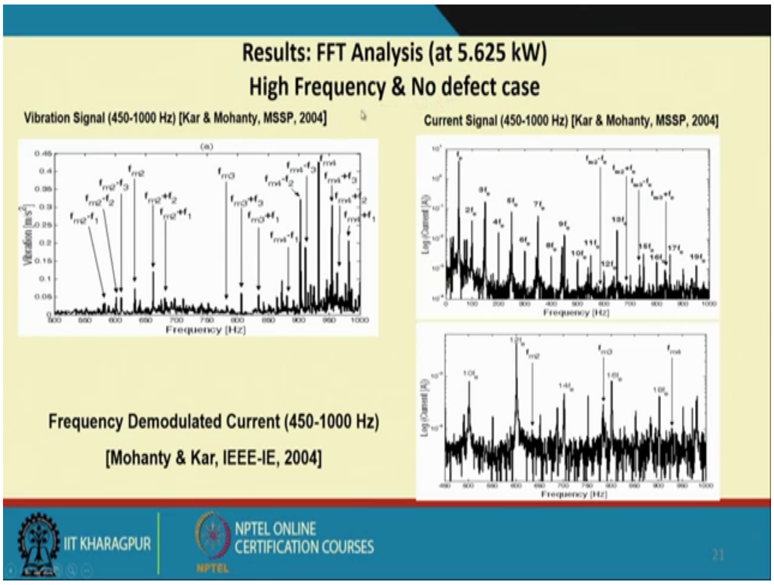



So, we did this with D1 defect where there is one teeth removed we did this with D2 defect and then of course we did this with many high frequencies, wherein for the frequency modulated signal if there is any speed fluctuation we could see the gear machine around certain order of the gear machine frequencies because the GMF is very high.

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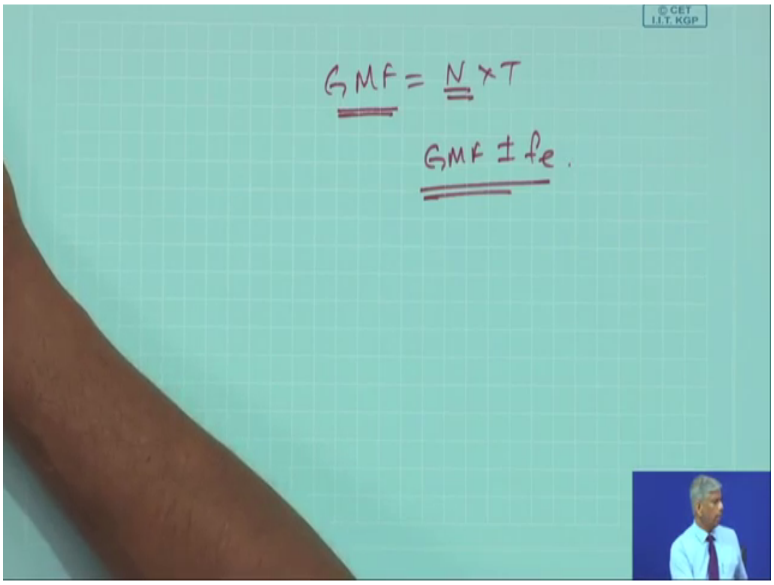


So, GMF is rpm times number of teeth the speed changes the GMF would change and then the GMF plus minus f e was also visible and these are usually high frequencies ok.

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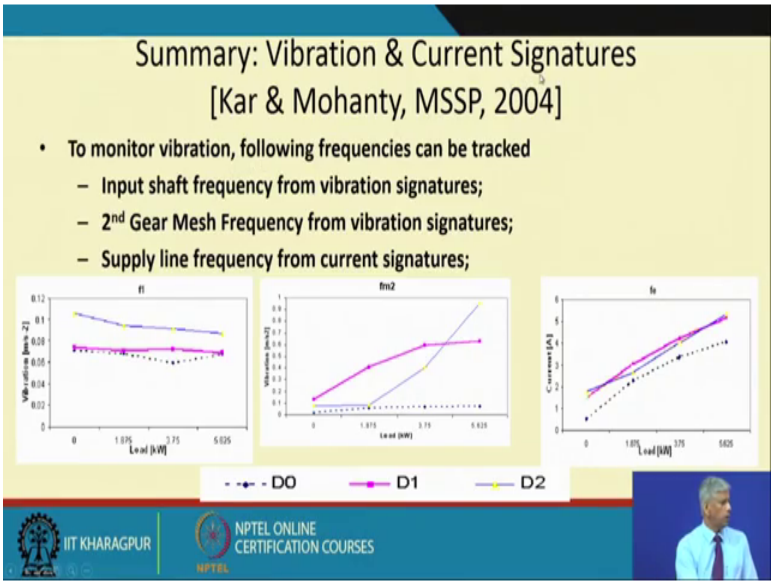


So, just a summary of the vibration and current signatures to monitor vibrations input gear shaft frequencies from viruses and sequences can be measured; gear meshing frequencies need to be monitored. So, we did that with the input shaft the gear meshing frequency and the supply frequency ok, of course with load the supply current amplitude will also change.

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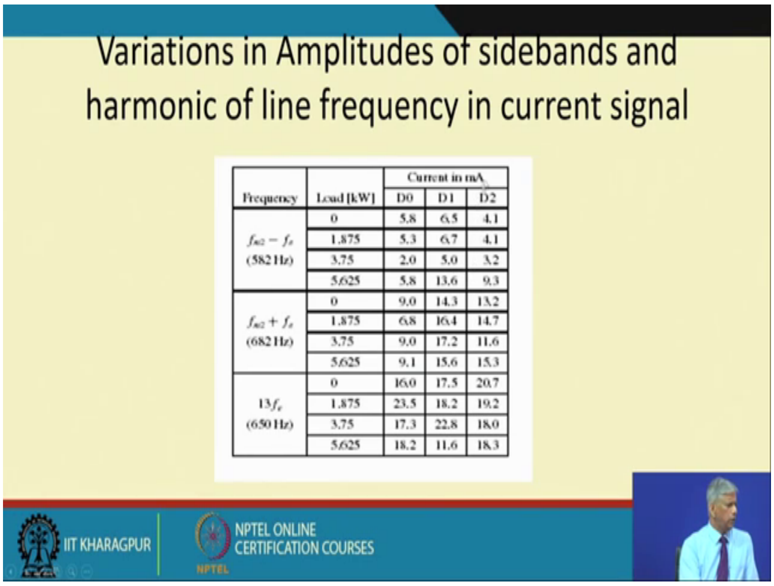


| Frequency | Load [kW] | Current in mA | | |
|---|---|---|---|---|
| | | D0 | D1 | D2 |
| $f_{m2} - f_e$ (582 Hz) | 0 | 5.8 | 6.5 | 4.1 |
| | 1.875 | 5.3 | 6.7 | 4.1 |
| | 3.75 | 2.0 | 5.0 | 3.2 |
| | 5.625 | 5.8 | 13.6 | 9.3 |
| $f_{m2} + f_e$ (682 Hz) | 0 | 9.0 | 14.3 | 13.2 |
| | 1.875 | 6.8 | 16.4 | 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 |

So, if you see in terms of the mainly ampere, the variations in the sidebands for the defect gears with the severity of the defects they would increase fm 2 plus minus f e and then thirteen f e these frequencies are sure.

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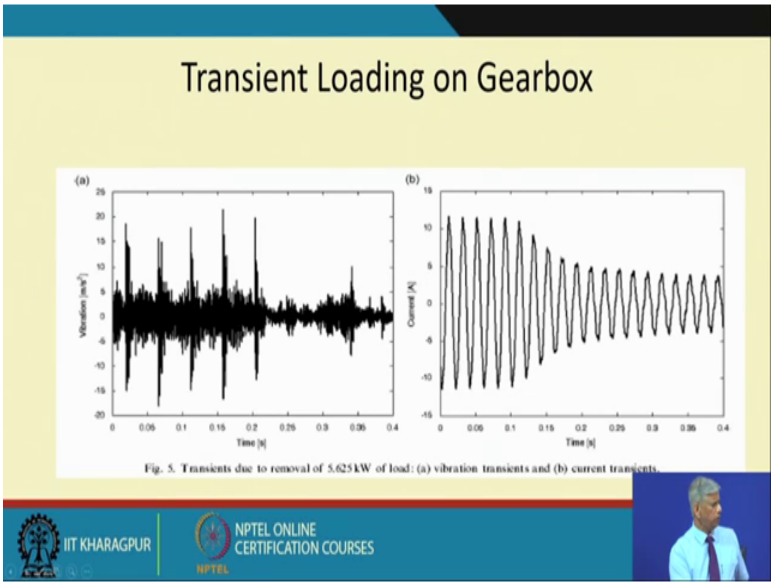


So, if there is transients the current would change and then this can be done through non stationary signal analysis.

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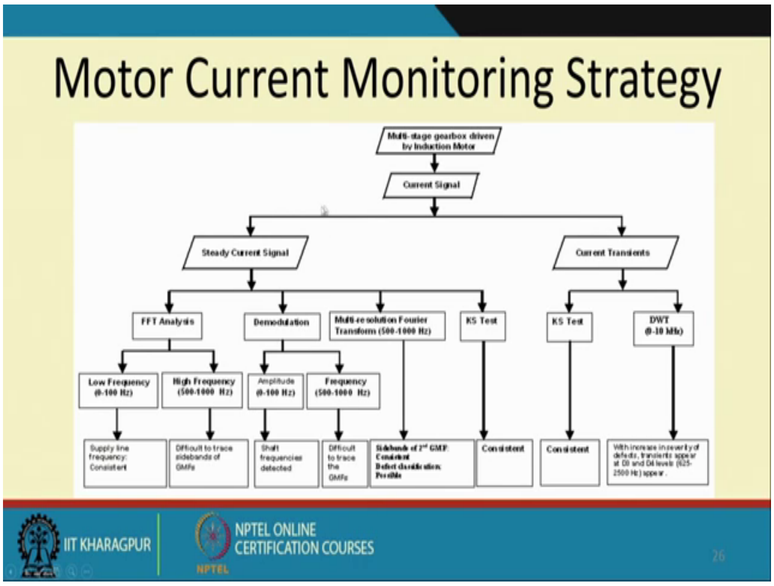


So, a complete strategy for monitoring the gearbox faults is given in this chart here and the details you can find in (Refer Time: 25:59) ok.

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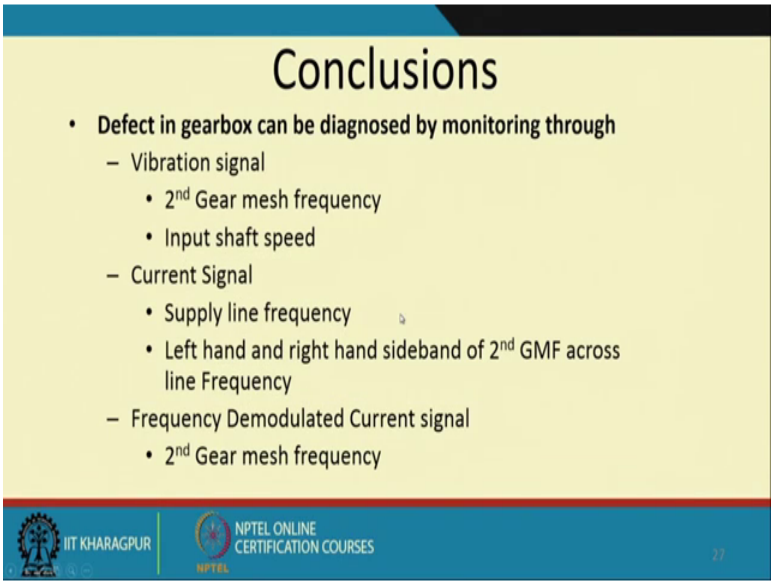


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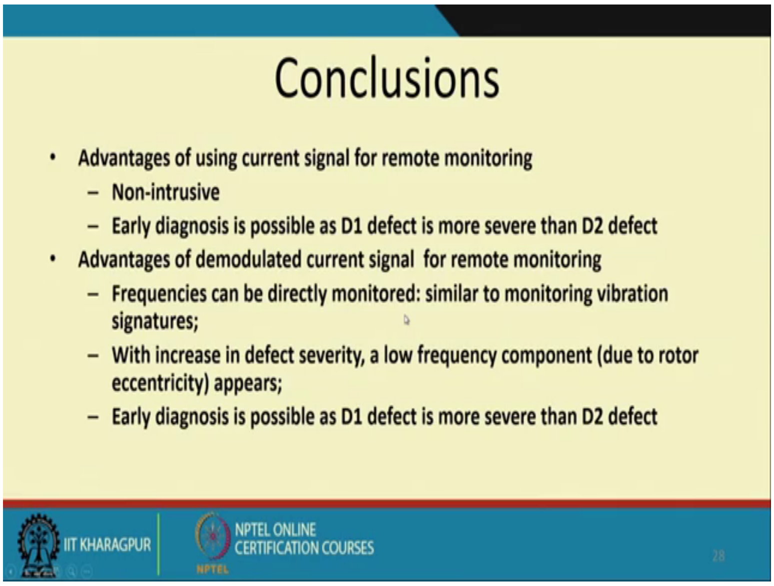

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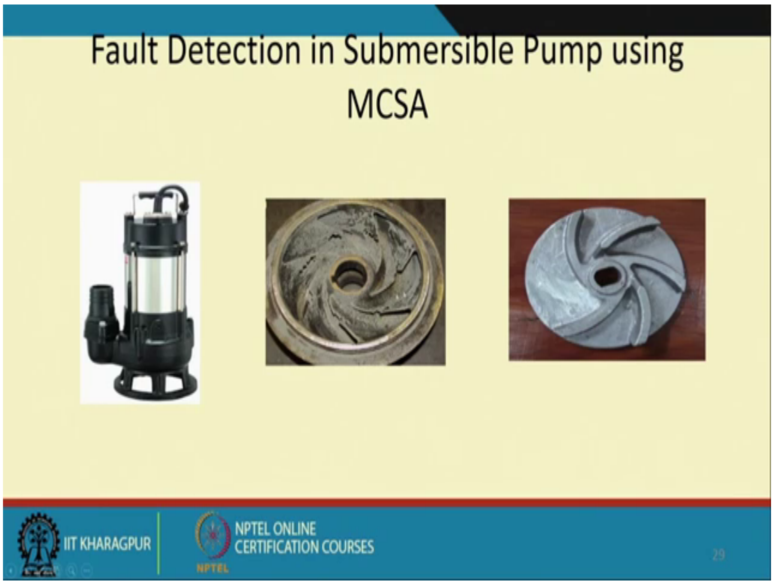


The similar thing which we did for the submersible pump also where we removed artificially the veins and then this was done at different impeller conditions.

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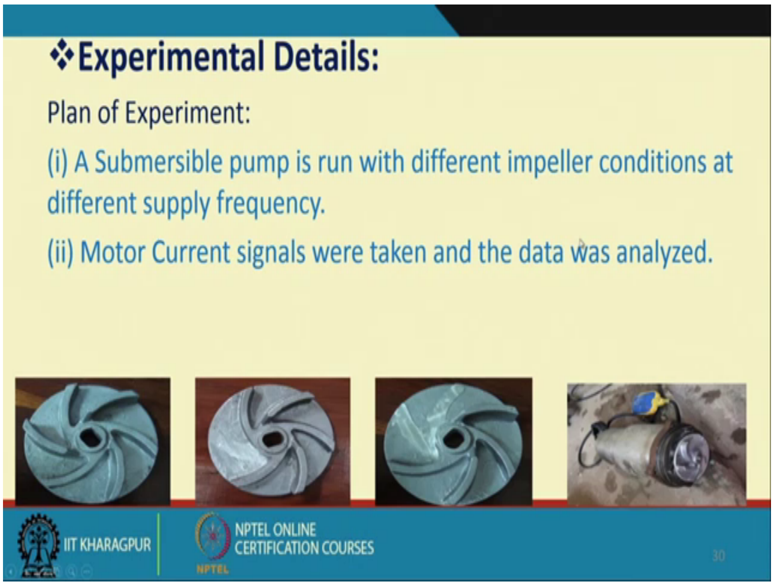


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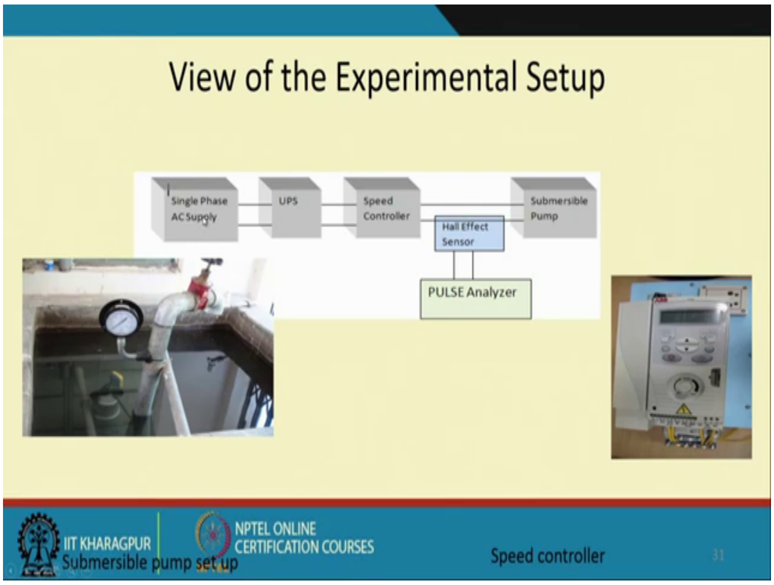


Similarly supply frequency speed controller and the Hall Effect sensor will measure in the analysis.

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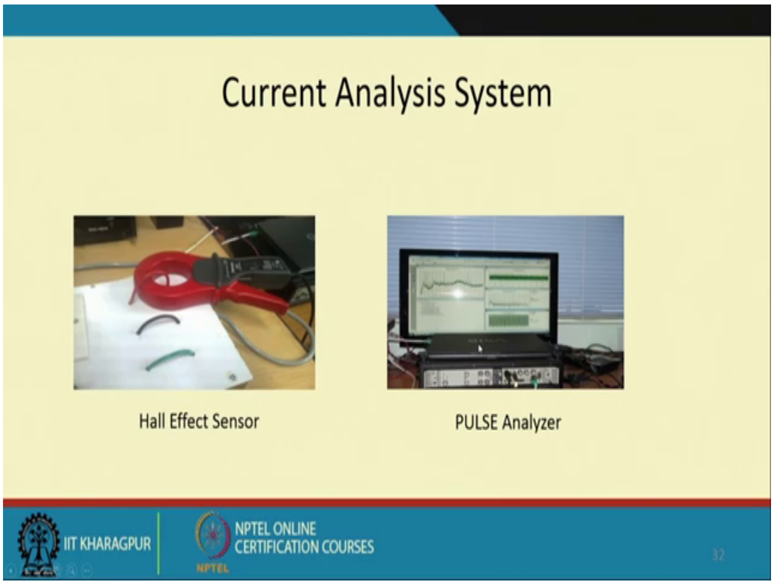


Ok and then we can see the current spectra at 40 hertz supply frequency.

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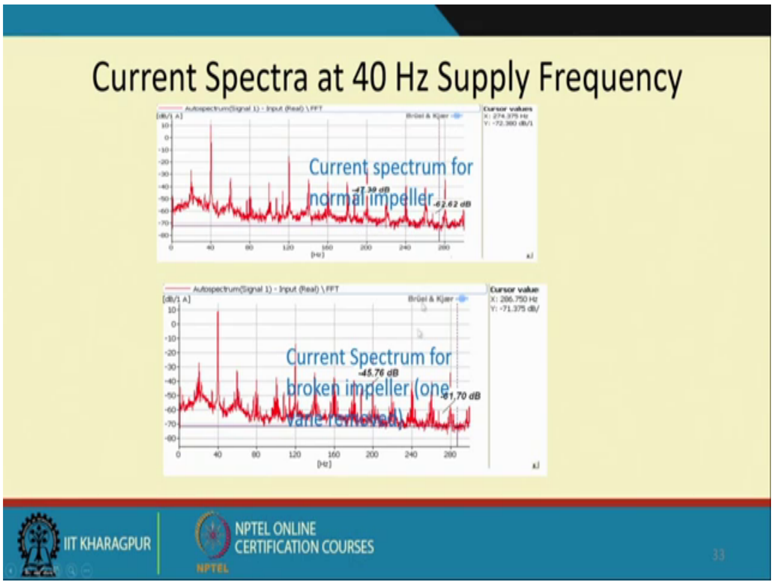


There will be lot of sidebands because of the broken bar impeller.

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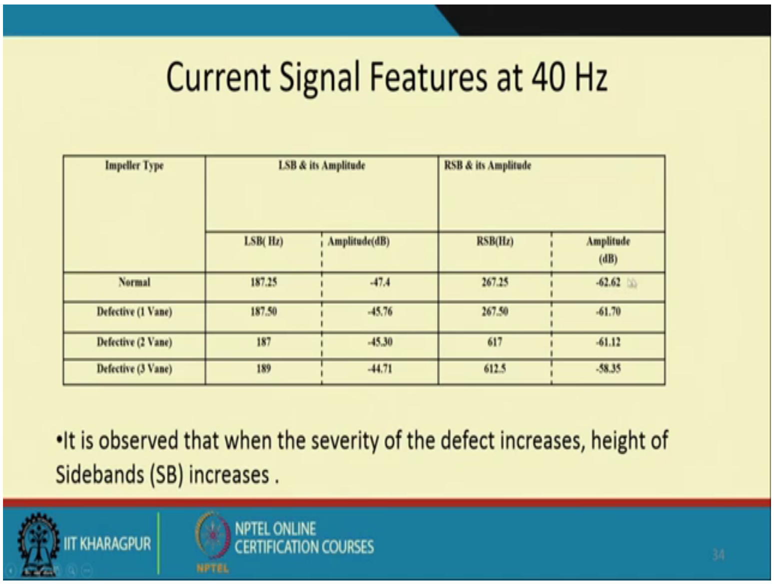
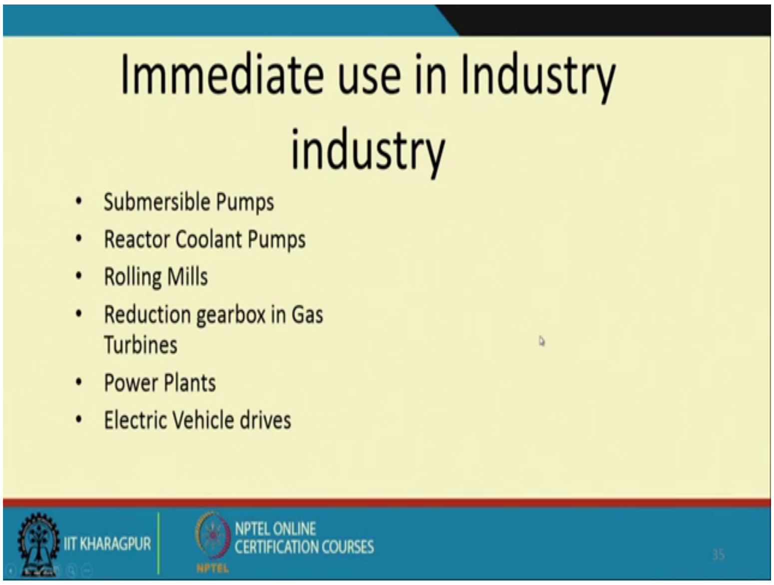



| Impeller Type | LSB & its Amplitude | | RSB & its Amplitude | |
|---|---|---|---|---|
| | LSB( Hz) | Amplitude(dB) | RSB(Hz) | Amplitude (dB) |
| Normal | 187.25 | -47.4 | 267.25 | -62.62 |
| Defective (1 Vane) | 187.50 | -45.76 | 267.50 | -61.70 |
| Defective (2 Vane) | 187 | -45.30 | 617 | -61.12 |
| Defective (3 Vane) | 189 | -44.71 | 612.5 | -58.35 |

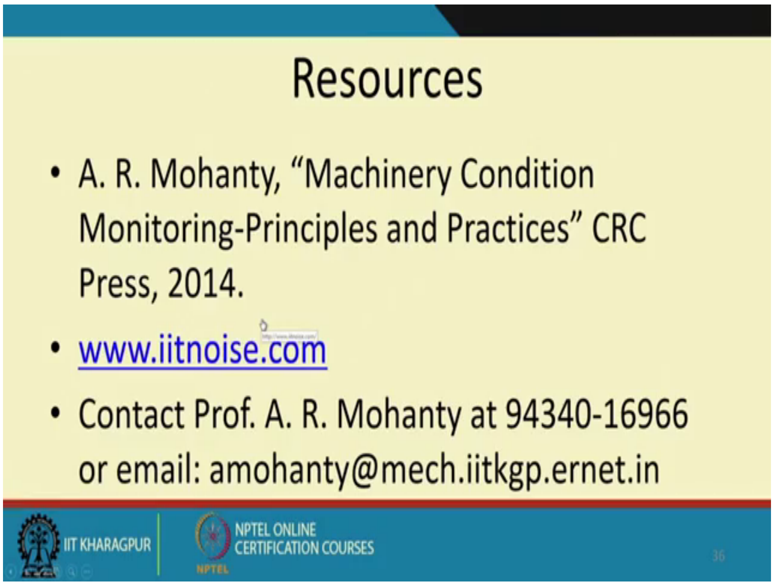
So, again by monitoring the severity of the defect increases with the height at the sideband increases, so this could be done.

(Refer Slide Time: 26:46)




So, immediate used to the Indian industry is because, MCSA is remotely we can do we can use them in submersible pumps, reactor cooling pumps and in some nuclear reactor and rolling mills in large reduction gearboxes in gas turbines power plants and even today in electric drive vehicles.

(Refer Slide Time: 27:06)




So, more of these you can find in my book and particularly if I go if you go to our website we will see many of these conditions there and the literature associated literature.

Thank you.