Machinery Fault Diagnosis and Signal Processing
Prof. A. R. Mohanty
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 32
Vibration Monitoring

Ah in the last class we discussed about accelerometers and particularly, how they are used for vibration measurements along with eddy current proximity probe and so, on. Well today, we will discuss in this class about vibration monitoring. As you know 70 percent of the cases of machinery condition monitoring are done through vibration measurements and monitoring. So, we will see what are the real issues when one goes to measure or monitor vibrations of machine.

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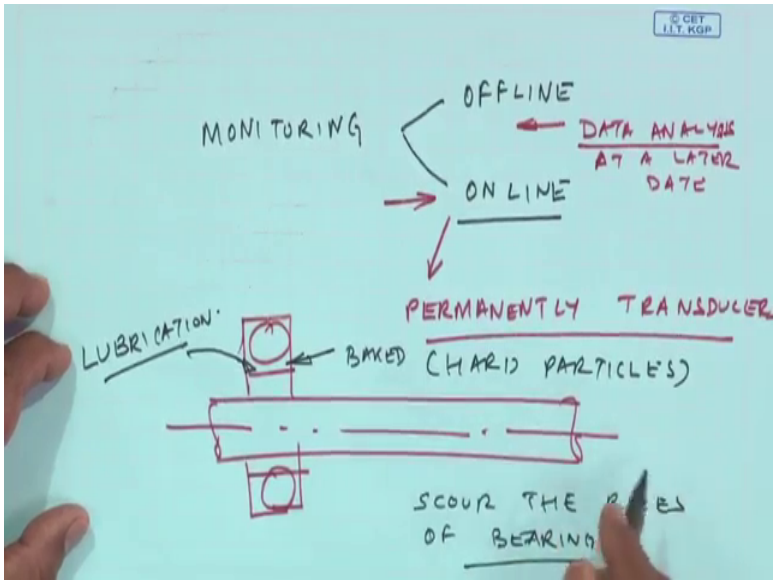

So, this monitoring, as I told you right in the beginning can be 2 methods, one is offline, another is online. So, in time monitoring what we have we have permanently mounted transducers. offline they could be permanent, but data analysis is done at a later date. So, for critical machines one has to do online monitoring because in real time one gets to understand what is the condition of the machine component?

For example, though we have not studied bearings. I will just tell you a fact now see as you know, machines have rotating shafts which are supported on bearings and then similar in this side. So, what happens this bearings those of you know about ball bearings

they have a layer of lubrication. So, the bearing temperature increases because of friction this lubrication may get baked. and they will form hard particles which will score the races score the races of the bearings and eventually damage the bearing to avoid this not to happen or to avoid that you know this temperature rise does not occur.

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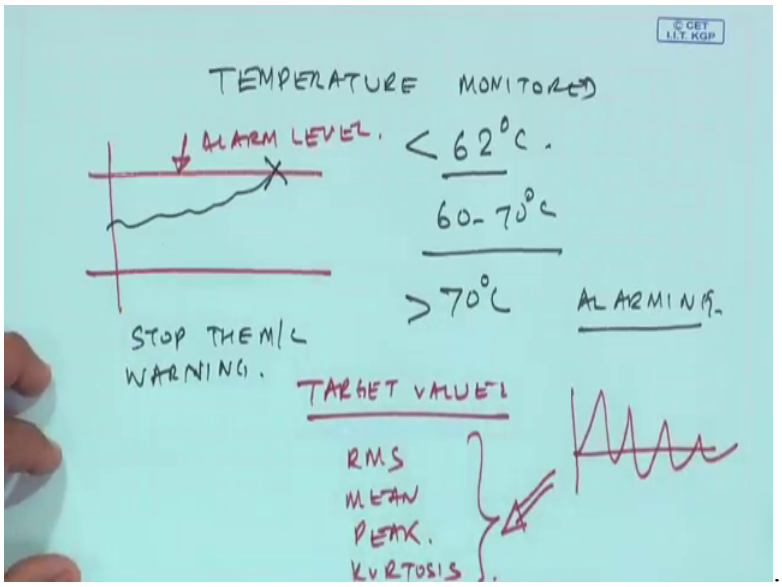

Always in industry, the temperature of bearing is monitored and usually the industry practices many industries have it has to be less than 62 degree celsius. You know somewhere around 60 to 70 degree celsius and beyond 70 degree celsius it is an alarm level alarming conditions. So, this was just to give you an example. Suppose, we are doing online monitoring of any parameter, there are certain target values which has been set. So, these parameters. It could be like, what do I mean by parameters? It could be the time domain features of the signal like the RMS value the mean value the peak value etcetera ok.

Or even kurtosis we all know about this right now. So, any signal which has been captured online and analysed and it is parameters determined. We can set pre-set conditions that this is the alarm level. and I would not let the parameter which I am in measuring go up to this point. So, then it will either ensure certain safeguard methods like you know stop the machine or given warning sign to the operator that this machine needs to be fixed. So, these are the cases where online monitoring is been done and the measured data is compared or targeted against a set value and depending on the

conditions on a machine could be stopped and alarm could be given and so on. So, in vibration monitoring actually what happens.

When we have online monitoring offline monitoring, people depending on the criticality of the machine somebody may do an online monitoring and offline monitoring, but.

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If you see the industrial scenario of vibration monitoring for example, this is a part of a cement plant, wherein this is the torsion shaft which is being driven from a speed reduced gearbox and there is the pinion gear here which is matched with the ring gear of the kill.

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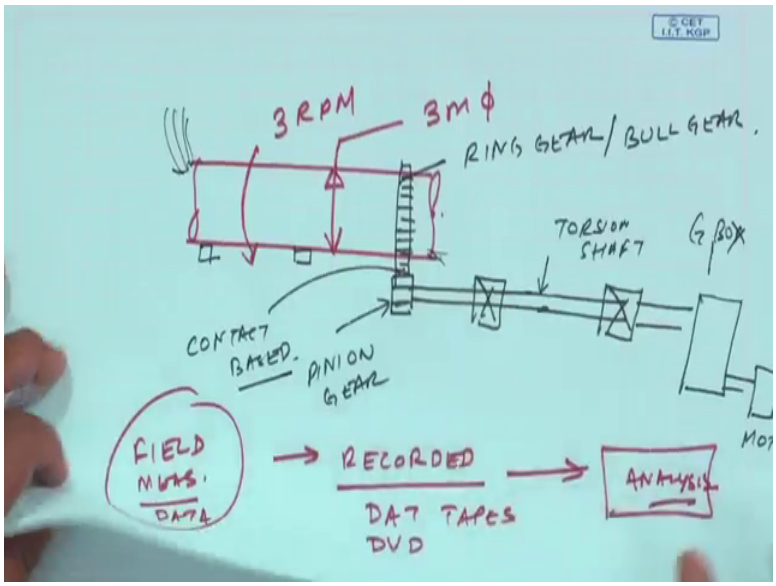

So, I will if I was to draw this one view, which is rotating about 3 RPM very slow RPM and this diameter is about maybe 3 meter and. So, if this is rotating there are sort of gear and of course, these are all supported on bearings cycles. So, if I have a ring here all around it and on to this I put a pinion gear which is driven by this is put in the bearing long bearing. and then there could be a gearbox which has been driven by a motor.

So, this is my gearbox, motor, torsion shaft, the weak structural member here and then there is the pinion gear and the ring here or the bull gear, as it is known. So, what happens you know, the this raw material is put and there is a gradient here this drum slowly rotates and then the they are ground by grinding media of just kept in the shell and then the dry cement comes out., but the question here is you know you can understand the complexity of such operations. If somebody was going to do monitoring of this insitive because this very dusty this environment is very dusty and we cannot be sitting there and doing an analysis.

So, if you will see here while we are doing this monitoring we had put an accelerometer on the bearing housing supporting the pin here and then this accelerometer cables if you see here are being taken and then usually measurements from the field or field data are recorded. and we did discuss about dat tapes or even nowadays DVDs and then they will come to the station where analysis could be done. And this is why did we record it?

because the environment is not conducive enough not comfortable enough for anybody to do any serious analysis this is one aspects of doing it and.

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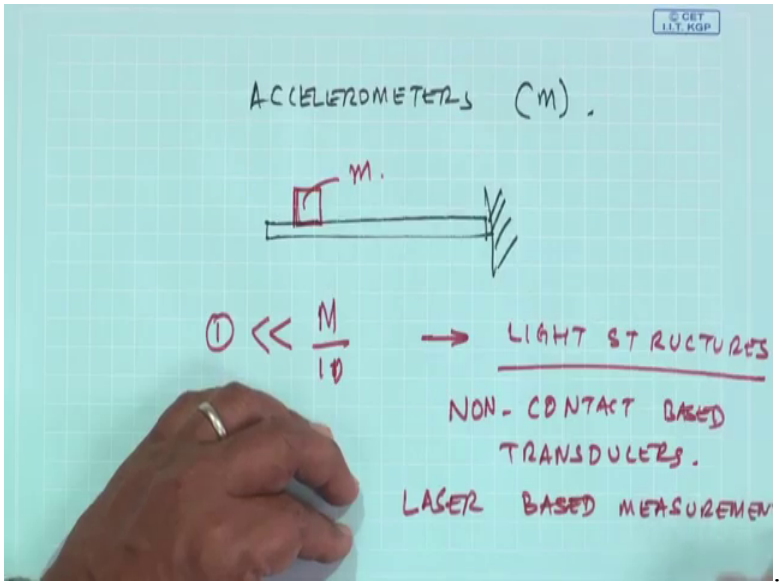

This was monitored by what is known as an contact based measurements and when we talked about contact based measurements, you know this accelerometers have a mass some mass. Now, imagine if I am measuring the vibration of a very thin structure and if I put a heavy transducer of some mass n the transducer mass is going to affect the dynamics.

So, I have loading the transducers loading the system. So, I must have an accelerometer which is less than much much less than one tenth the original mass of the system where I am measuring vibrations ok, but then this is always not possible for light structures ok. So, for light structures we need to have non-contact based transducers for vibrating monitoring. and this is actually done by what is known as laser based measurements. So, how does this laser based measurements work? Let me just briefly explain to you.

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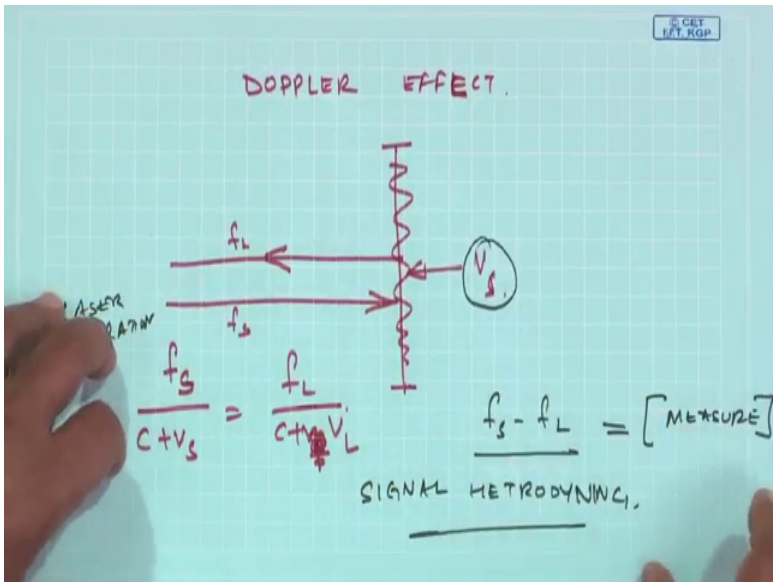

You all know, what is this doppler effect ; that means, if I have a source structure which is vibrating ok. If I shoot a laser beam with have V ok. Fs by C plus VS is fL y C plus VL ok. So, what happens if I am sending a laser beam because of these vibrations? it is going to get reflected back. Now, this frequency shift because of the vibration of the source or whatever you call it of course, you have to make sure that the right sign conventions are there. I am not going to the details of the sign convention here, but in essence what happens if I shoot a high light beam laser beam onto a surface which is vibrating with a velocity VS I will get a frequency of the laser beam reflected back fl.

Which is related by this equation and then by knowing the difference fs minus fL ok. I can measure this how do I do it? there are optical heterodyning measures, because as you I knew as you know by now laser beams are light waves of very, very high frequencies and; obviously, to find out the frequency shift we need to have what is known as signal heterodyning. So, just to recap know these things which we had discussed earlier. So, signal heterodyning is used to find out the frequency of the reflected wave by eh and then we can find out the source vibration of this velocity. vibration of this body which is vibrating and whose vibration.

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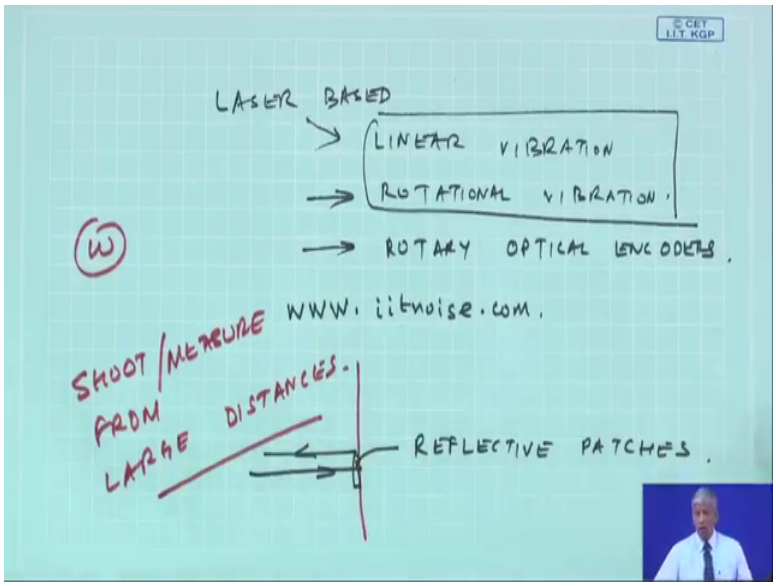

We need to measure such laser based measurements can be used both for linear vibration and for rotational vibration and also we will see.

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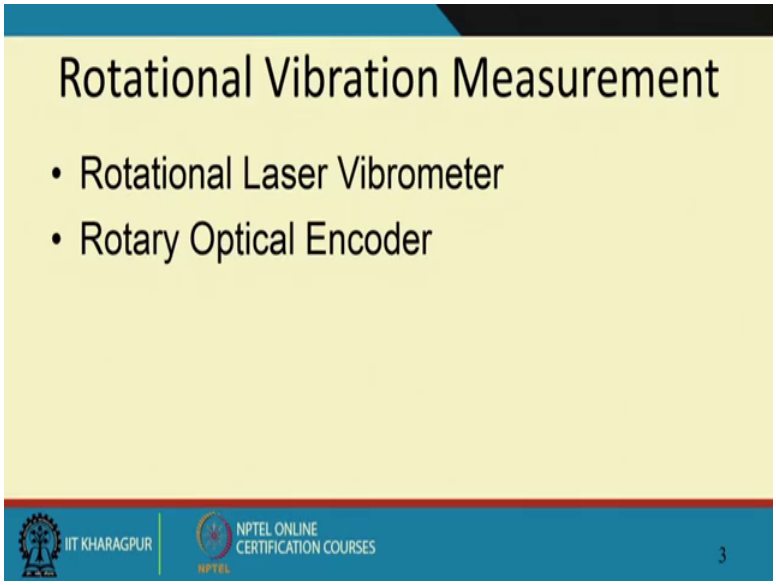

So, if you see for rotational vibration meter.

I had talked about rotational vibration and of course, there is another very easy way which we have done some work at IIT Kharagpur on optical encoders. By the way, to know more about some of these you can visit my website WWW IIT noise dot com and in my Google scholar you will see some of the literatures on the how rotary optical

encoders have been used to measure the rotational speeds of engines to find out the firing frequency of engines and so on. But, today here we will focus more on the linear vibration measurements and rotational vibration measurements by lasers.

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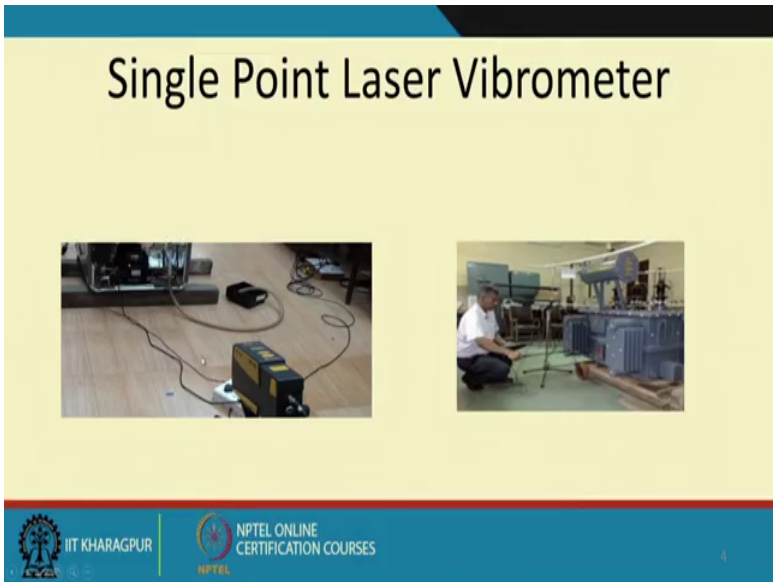

So, you see this is a single part laser which is being used to measure the vibration of a compressor of a refrigerator. Imagine, if this compressor is very small of course, you know compressor because of it is operation there will be a lot of heat generation to this surface many of you would have felt in your domestic refrigerators that the compressor shell is very hot. And it is not desirable to touch it of course, you know today we have charged accelerometers which can be put on such compressors to measure the vibration, but you know this being a light shell structure the accelerometer which we put here may load this structure.

So, this is a laser vibrant, vibrant meter being focused on to a surface wherein the laser beam is reflected and some things I must tell you many surfaces are very dull. So, they will not reflect a laser light. So, what they do people put reflective patches. So, that you will get a reflected laser a light back and then we can measure through signal heterodyning optically and the frequency shift Doppler shift and then find out the velocity at which this shell is vibrating.

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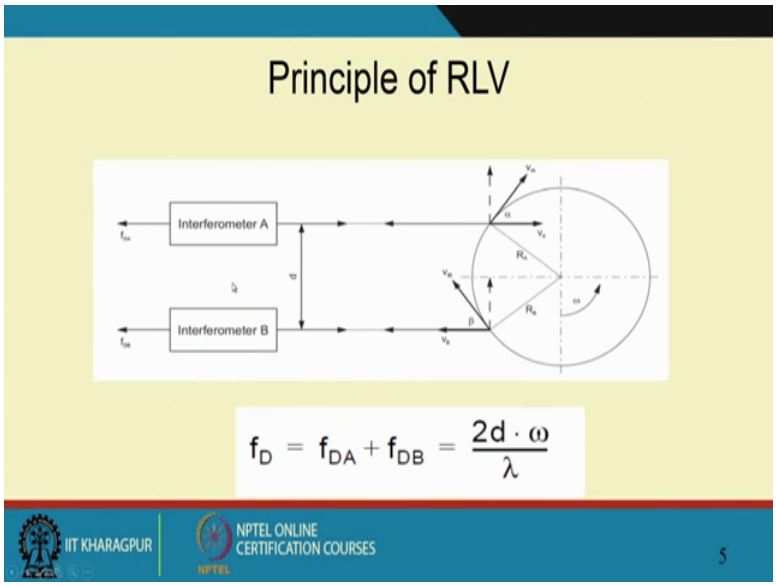

Now, I have 2 laser beams ok. I have a laser beams A laser beam B and this is the principle behind the working of a rotational laser vibrant meter. So, if this is a shaft onto which it is this laser beams are focused with the separation distance of d, but this separation distance they have to be identical ok. Because, the signal to strength should be balanced. And so, that I will have a reflected and a eh component here VB and VA and so on. And by this equation, you will see that the Doppler frequency shift which is measured in the heterodyne analyser is a function of the rotational speed of the shaft and the suppressant distance and the wavelength of the laser beam.

So, anywhere if I shoot 2 laser beams onto the rotating shaft I can find out this omega. The best part about this rotational laser vibrant meter is and also for the linear vibration measure is I can shoot or measure from large distances imagine you have to measure.

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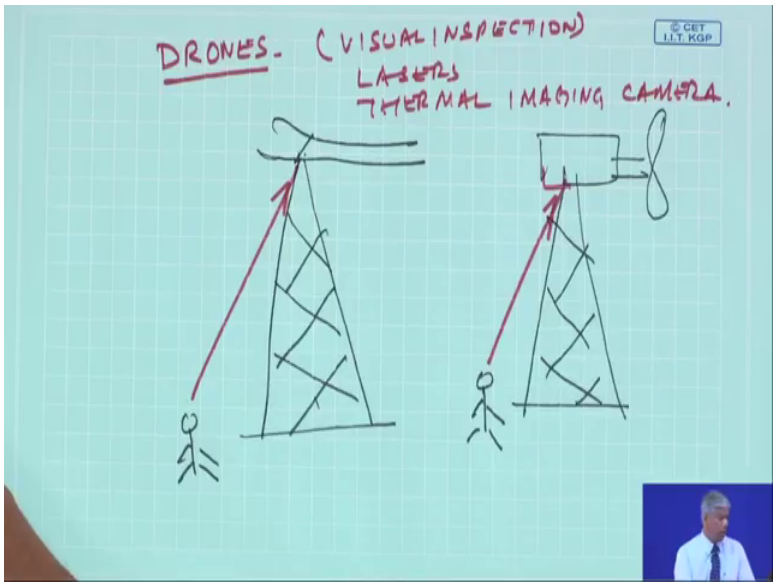

The vibration on top of a large tower. it could be a transmission tower, it could be an windmill etcetera and you are standing here ; obviously, in such cases one is not. So, you can have a laser beam and shoot and reflect back. Of course, today let me tell you the technology you know you all must be hearing about drones people have started to use drones for; obviously, for visual inspection and the drones could carry lasers could carry thermal-imaging camera. to measure at locations where (Refer time: 18:00) humanly it is time consuming it is dangerous and so on.

If you if you look into or see in north sea ok. In the of Europe and between you know Germany and UK in the north sea. You are in Denmark areas you will see in the ocean there are a lot of wind turbines being put there in place. So, it is a challenge to measure or monitor the condition of the gearboxes etcetera of this wind turbines. So, you know traditionally they go by helicopter and you have to be very skilful operator or pilot of the helicopter to you know place the equipment below or drop somebody there to go and inspect visually.

So, these are all very time consuming dangerous and this technology, now and of course, later on. I will tell you of another technique which is a motor current signature analysis by that how remotely we can also monitor the conditions of the machine without even actually physically going there or touching them or contacting them. So, to summary to summarize you know we could use drones having cameras for visual inspection having

lasers or vibration based measurements or having thermal imaging camera. For the heat temperature detection and then of course, I can have a motor current signature analysis.

Where I can monitor the current ok. So, one thing about the lasers is the focusing distance ok.

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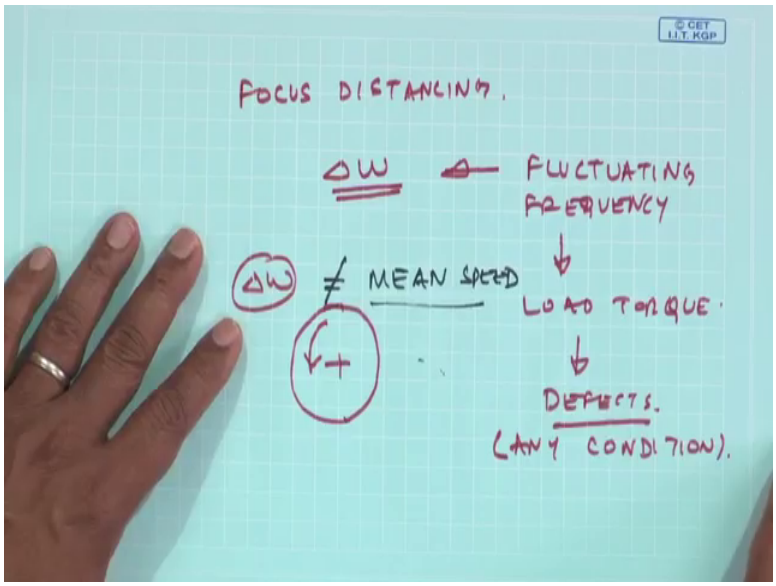

Sometimes this is known as the standoff distance and the beam separation.

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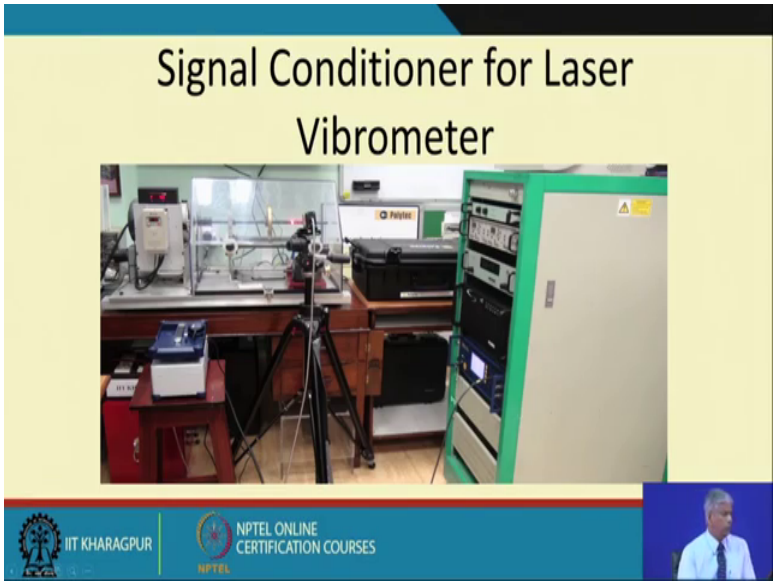

So, this is a view in our laboratory if you will see here these are shaft and Africans see here there are actually 2 laser beams you know you I someone this diagram they are not able to see it maybe in another diagram. So, this is the laser head where laser Vibrometer is being put and there is a lot of signal conditioning we require and you will get either the entire time series of this velocity and which you can later on do any analysis yeah.

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And here, if you see there zoom picture here you will see 2 dots this corresponds to those 2 laser beams which are being put on the shaft. So, you can very easily measure the speed and actually in many condition mounting. It is not the mean speed it is the fluctuation speed and this fluctuating frequency are because of the load torque, which is because of the defects I say defects or any conditions.

Any conditions if I change the load on the system. I will be coming with a different frequency so; obviously, momentarily the shaft which is rotating will have a change in it is speed. This is not equal to the mean speed which we would measure with a tachometer etcetera ok. We will talk about these later on. So, it is this kind of conditions which help us by our using rotational laser vibrometer to find out the different frequencies in systems.

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This is another view of their rotational laser vibrometer you know and this these systems are very expensive compared to the traditional linear based vibration measurements. Using accelerometers or optical encoders nevertheless they are advantageous because they are non-conducting and you can measure them from a distance.

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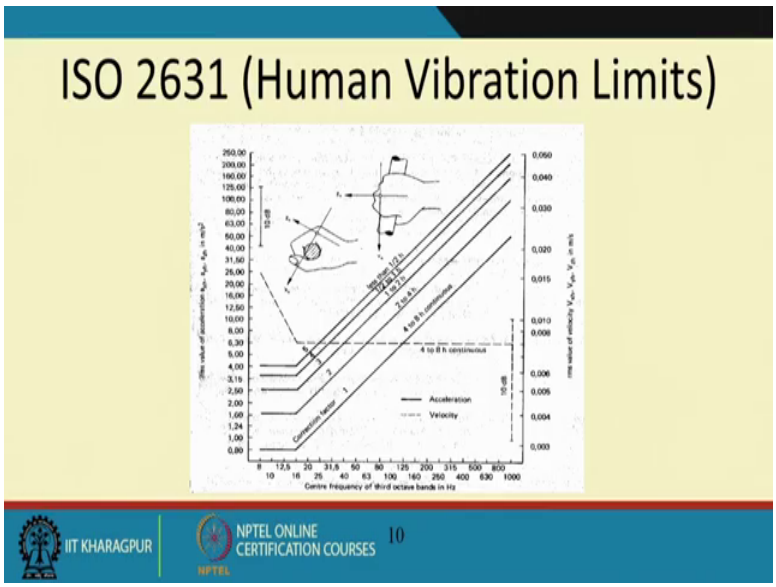

Now, I did mention in your earlier classes that what is the limit of this vibration levels. And why at all we measured these vibrations one of course, is to find out the defects in machine. By the signature analysis of the measure vibrations, but even I must tell you if

you are making a product or designing a product or developing a product like for example.

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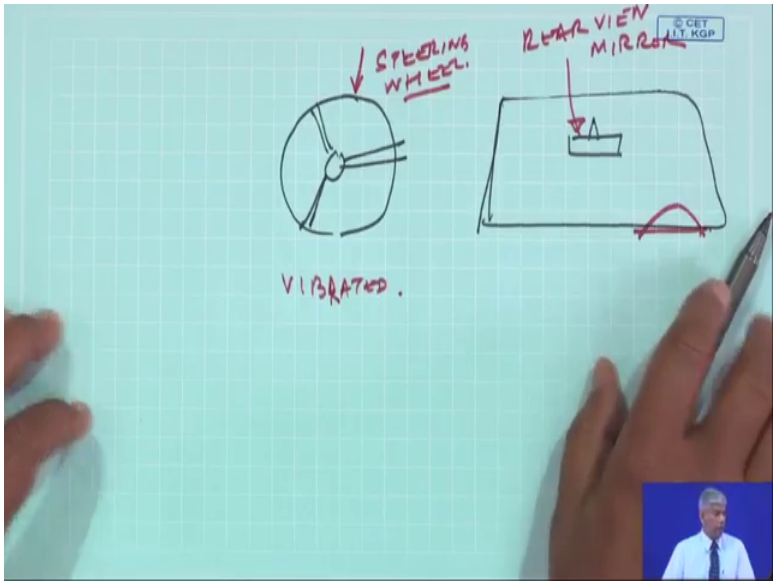

Even the steering wheel of an automobile which has been designed or the even the rear view mirror which is being put in an automobile steering wheel.

So, this is your rear view mirror this is your steering wheel. So, a designer would have good done a good job, but imagine if somebody was holding the steering wheel and it always vibrated ok. I will give you another example is this you know people doing jackhammering.

So, persons are holding on to certain devices handled measuring equipment portable power tools like drills grinders saws jackhammers. Now, imagine again if your rear view mirror always shook while you are driving the car it would be very difficult annoying for a person whose trying to focus on the rear view mirror, but the mirror is shaking because of a bad oscillation and so on. So, there are limits as to because you know if you are exposed your body or a RMS are exposed to high levels of vibrations you will have nervous disorder.

So, there are ISO standards as to what are the frequencies? And what is the hour or time to which you can be subjected to the maximum levels of vibration in particular direction?

So, today there are essentially vibration based transducers which are used are available for measuring this equipment vibration and then one has to be careful about it.

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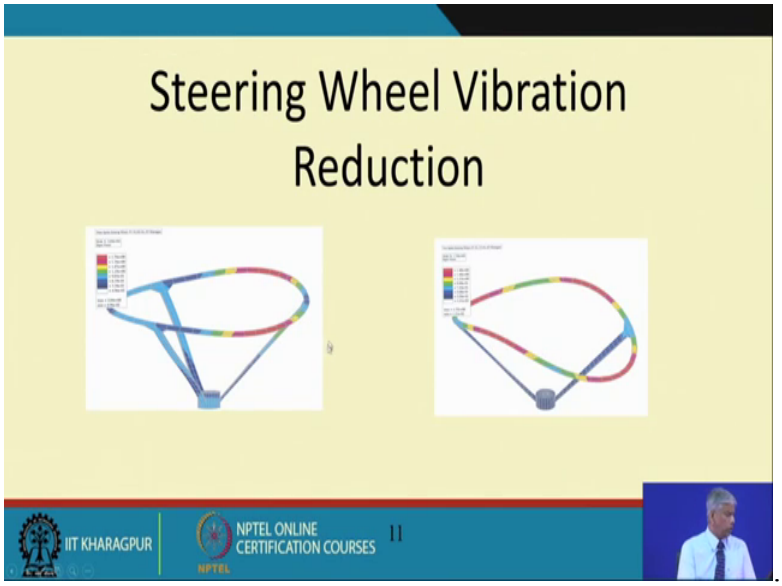

So, this is one work which we did I thought I must share with you that an some company they had a tractor as soon as the tractor engine idle there was excessive vibration. And then later on, we realized through analysis that the natural frequency of the steering wheel actually matched to the one of the engine firing frequencies during the idling. So, of course, we could not change the engine. So, what we did is you know through analysis we shifted the natural frequency of the design of the steering wheel. And thus, reduce shifted the natural frequency and avoided the condition of resonance.

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So, that the vibration level reduced and this is the example of that same tractor which has been used for the measurements.

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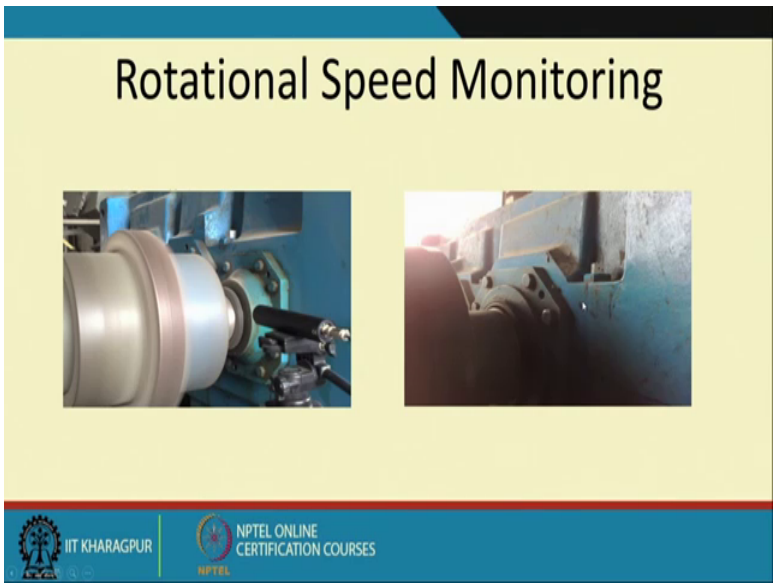

Of course you know when I talked about vibration based measurements of course, in the next class we will be talking about rotational speed measurements, but then we will discuss more of this in detail later on, but this is just in an industrial system where the laser sorry the optical tackle meters are being used for measuring the speed.

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And in industry many times people will not allow you to put anything a tap on to their surface.

So, usually I put a pre tap to a block of aluminium on and then I just glue them there and then I mount my accelerometers for measurements.

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This is the bolted onto which I have glued my block onto which I have screwed this tri axial accelerometer. So, this is a good practice to have in your kit when you are going to do vibration based measurements to carry some of these mounting blocks with you. And

they are very easy to make, but only thing you have to sure make sure that the surfaces are nicely machined.

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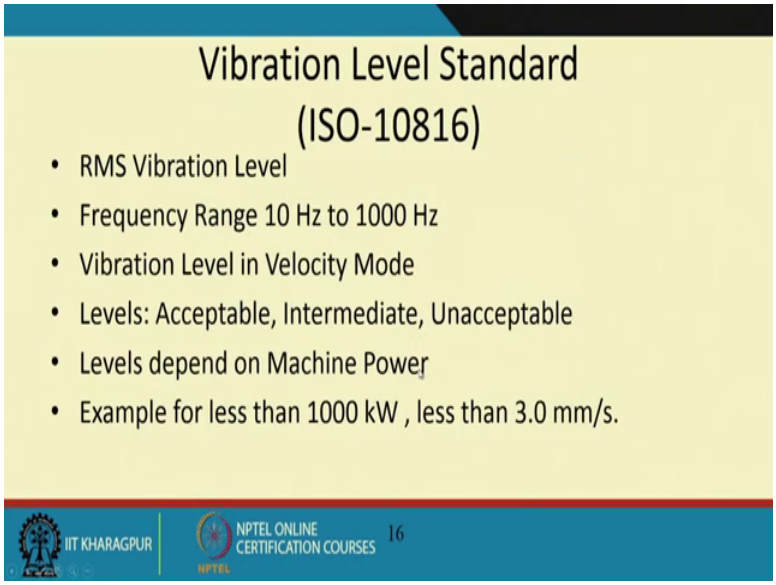

So, there is an ISO 10816 standards people can look up to. So, the vibration level is measured in RMS the frequency range is from 10 to thousand hertz vibration level is measured in the velocity mode there are 3 different levels of this overall RMS vibration level depending on the power of the machine which is given in this ISO standards. So, people can know whether my machine is acceptable not acceptable requires immediate maintenance. By this for example, a good thumb roll is for a thousand kilowatt machine the vibration level of the RMS velocity should be less than 3 mille meters per second.

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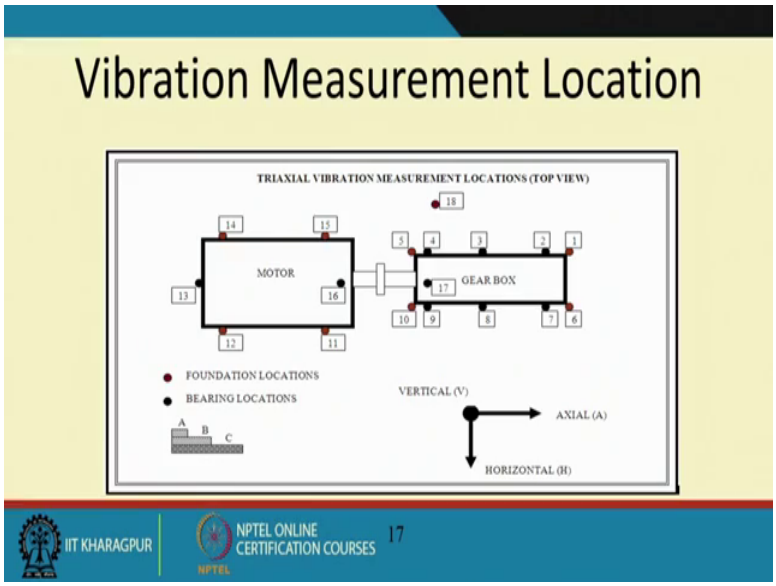

These are some of the locations where we need to put the transducers because everybody needs to know where do I put the transducer. When you know I am doing a vibration monitoring it is usually the bearing locations or the foundation locations and..

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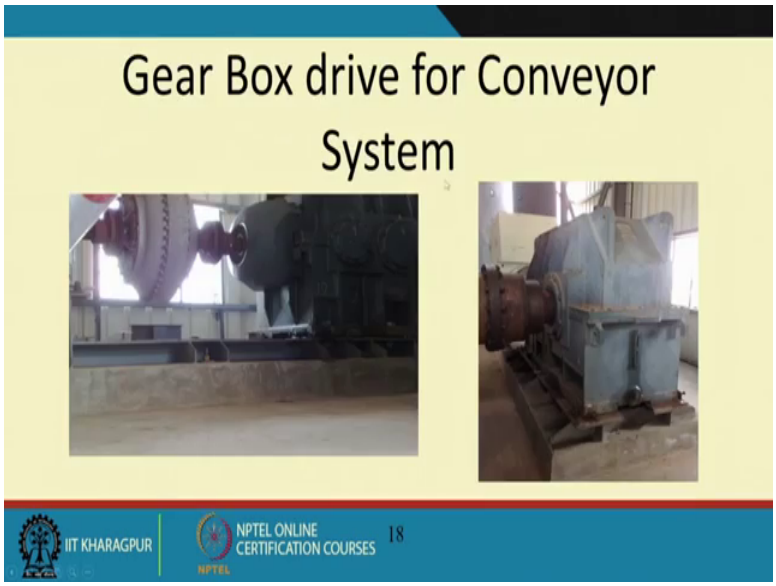

So, on I will discuss more of this.

In So, on I will discuss more of this, the next class and these are some of the example in gear boxes in conveyer system where.

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We are measuring vibrations I just to give you an view a ship loading our raw material into a conveyor system and there is a loaders here crane operated. So, they can scoop from the hull of the ship or drop into the hull of the ship, but these are these conveying systems. Imagine, if these are not monitored if there is a problem with the conveying system your ship is not able to either load or unload. They will create a lot of ripple effect because other ships cannot come into the jetty and so on.

So, you can understand the severity of the problem and imagine, in our country if we are you know importing coal good quality, coal exporting, iron ore. And if our ports get blocked because or somebody did not do a good job in monitoring the vibration levels of a conveyor system what kind of disastrous consequences it can have in our economy? Its so, you can really understand the importance of vibration monitoring and so on.

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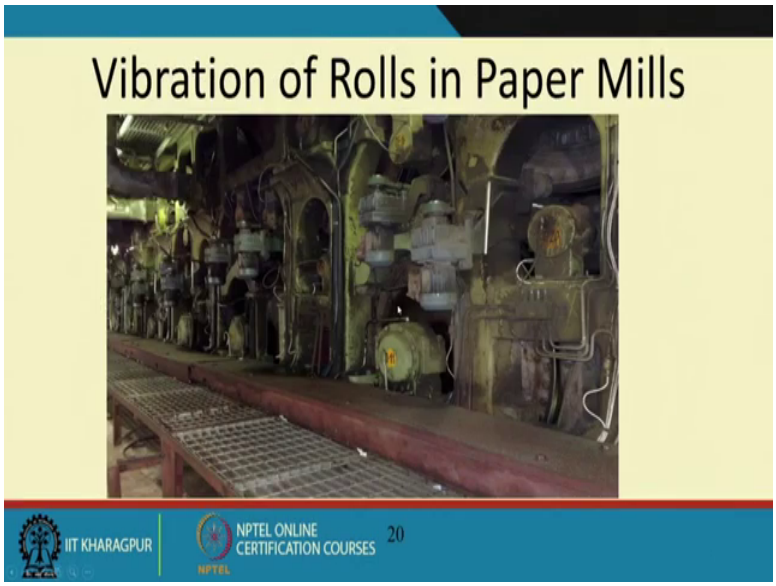

This is a permanently monitored transducer see all the steel cabling.

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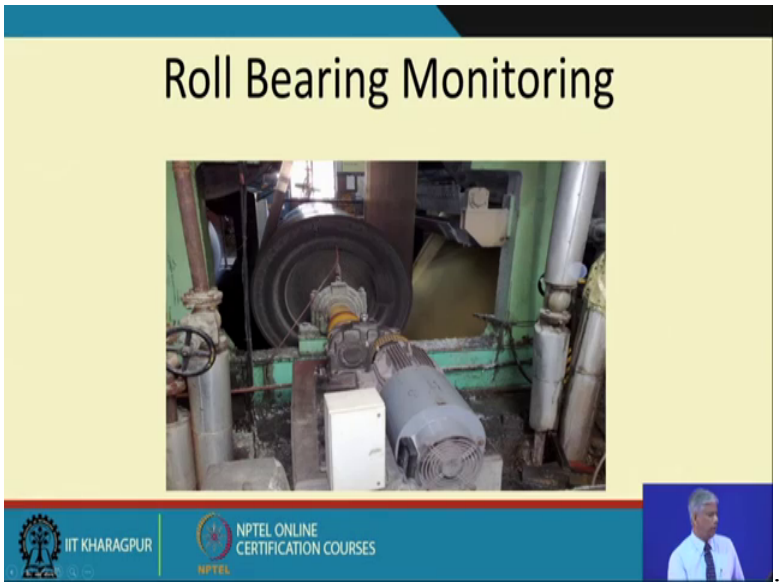

Which you see for vibration monitoring in a paper mill rolling bearing vibration monitoring ah. Sometimes speed measurements are being done which I will discuss in the next class.

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And then you know of course, you can have a control room where and everything comes onto a GUI and the operator. Nowadays, does not have to do go to a machine individually, but jun these are the junction boxes you can just monitor any machines he want. And today the state of the art is that they will even the signals will even come to your mobile apps.

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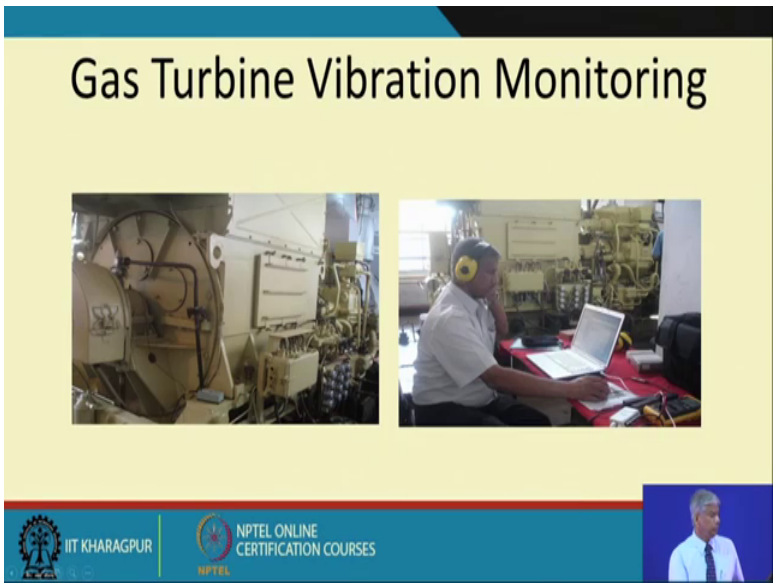

And this is where we are doing also the gas turbine monitoring and so on.

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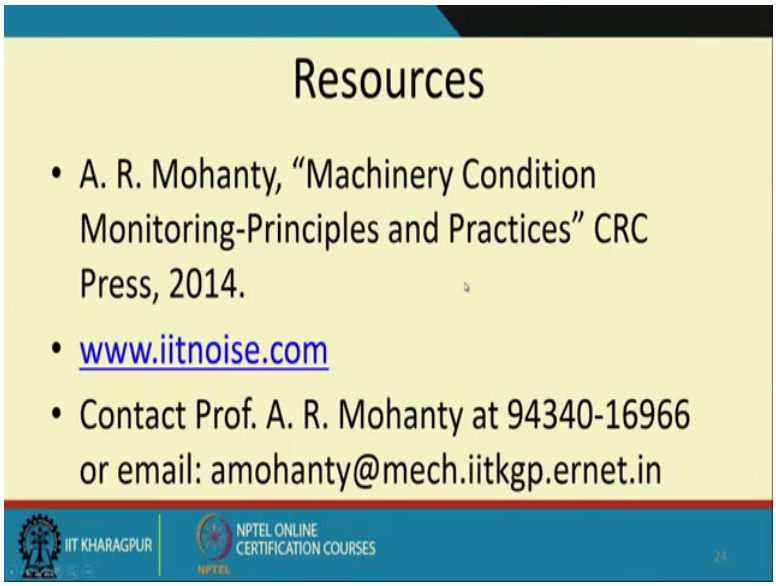

So, more of this you will see some of the case studies in my book on machinery condition monitoring.

Thank you.