Theory and Practice of Rotor Dynamics
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Module - 9
Condition Monitoring of Rotors
Lecture - 42
Condition Based Monitoring

In previous lecture, we discussed condition monitoring of a rotating machinery basically, we try to see whether various kind of faults which reflects in a vibration signal. How, we can able to detect the a various kind of faults in rotating machinery by just looking into the signal, either it is in time domain or frequency domain or whether it is orbit plot or, may be waterfall or cascade plot? So, these are the various forms of plots, which we require for analyzing the vibration signal, so that we can able to identify or locate or basically we can able to detect the fault in various kind of machine elements.

Now, in today we will be extending the condition monitoring in more broader prospective, especially condition based monitoring we will be introducing this particular subject in more broader way. And we will try to see, what are the various tools are available to perform this and what are the research directions, which are there in this particular subject. Then we will see a few case studies at the end of this particular lecture.

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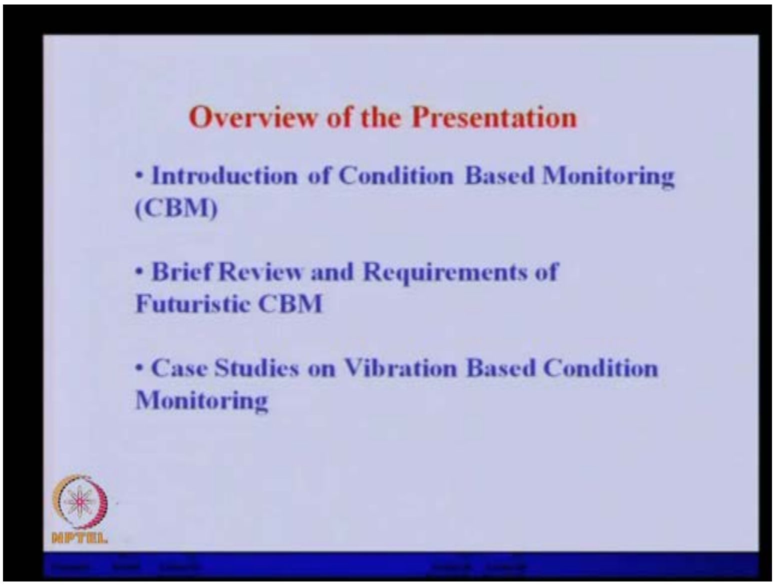

So, in this initially, this is the overview of the condition overview of the presentation in which, we will be introducing the condition based monitoring. Even we will give some brief review specially, of the requirement of this condition monitoring few case studies we will try to see at the end.

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So, coming to the condition monitoring of industry obviously any industry we need to capture various kind of signals, as there is a vibration signal or temperature pressure noise various kind of signal we need to capture. Then those signal we need to store in computer and try to analyze those signal, and try to correlate various kind of faults which may appear in this kind of machinery. Then we can have some kind of data base based on that, we will be having some kind of expert in the form of may be heuristic expert in which we can able to correlate the symptom of the fault, and the whatever fault reflects what kind of symptoms.

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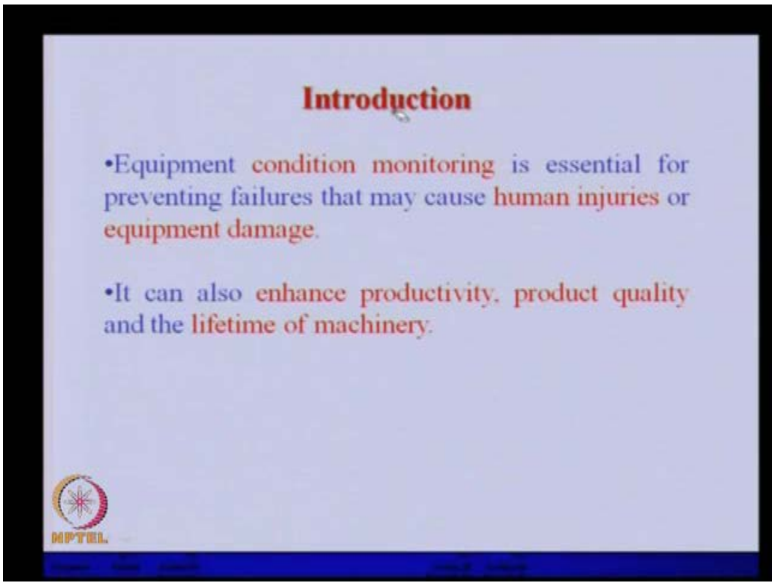

So, to introduce this particular subject the equipment condition monitoring is essentially to prevent the failures that may cause human injury, or equipment damage. So, obviously it can also enhance productivity if we are maintaining the machine properly, product quality will be good life of the machinery will be more.

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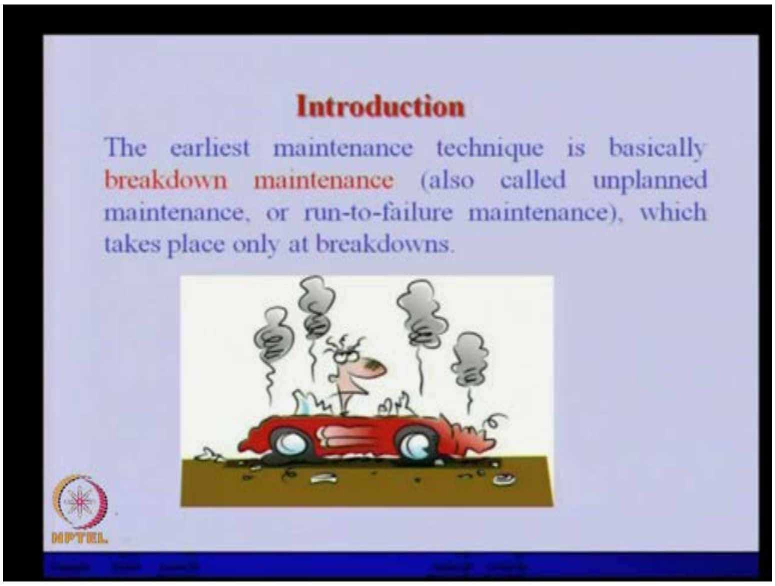

This is the breakdown maintenance, so earlier in the maintenance technique was basically the breakdown maintenance, also called the unplanned maintenance or run to failure maintenance, which take place only at breakdowns. So, when the machine worth failed then we are calling for the maintenance, so that is call it a breakdown maintenance.

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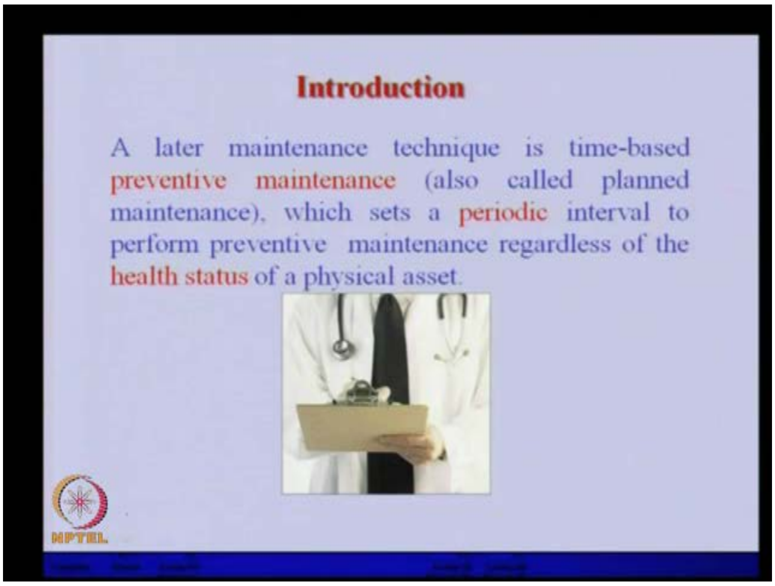

Later maintenance technique is the time based preventive maintenance also called planned maintenance, which sets a period interval periodic interval to perform preventive maintenance regardless of the health status of the physical asset. So, whether the machine is fine or not we schedule the maintenance and then we stop the machine, and do the maintenance that is called preventive maintenance. But, with this we unnecessarily stop the machine. If machine is healthy and so loss of, loss of economy will take place because of this.

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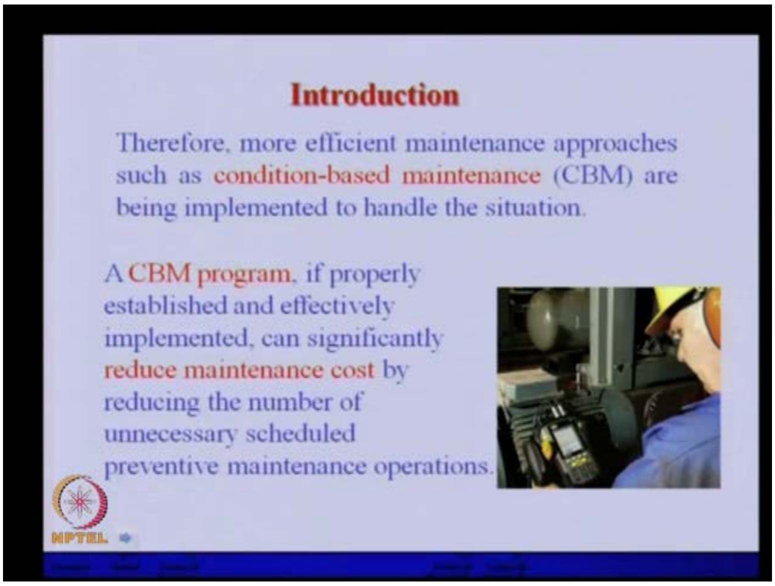

Therefore, more efficient maintenance approaches such as, condition based maintenance are being implemented to handle the situation. A CBM, or condition based maintenance if properly established an effectively implemented, can significantly reduce maintenance cost by reducing the number of unnecessary scheduled preventive maintenance operations. So, you can able to see that through some monitoring technique, we can able to see the condition of the machine, and if there is unexpected signal coming in into this kind of gadgets. Then, we can able to plan the maintenance.

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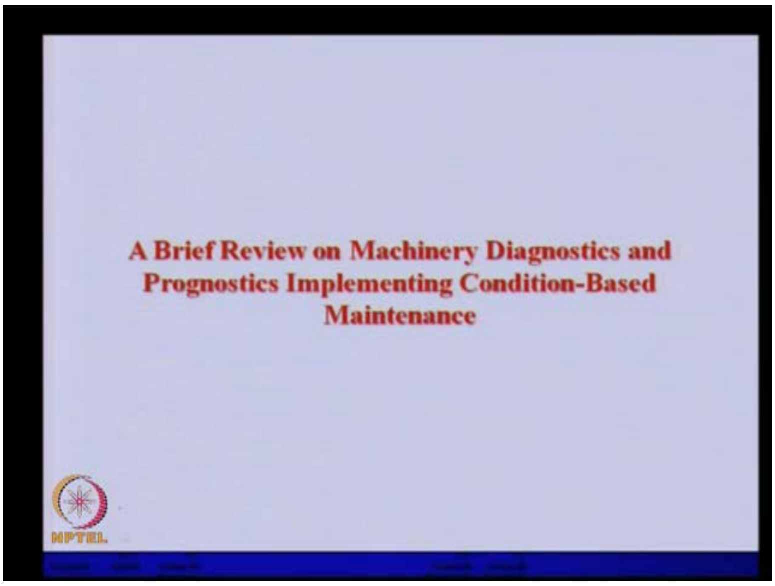

Now, we will be briefly doing the machinery diagnostics and prognostic, and implementing condition based maintenance. In, this diagnostics refer to the basically finding what kind of fault is that, what is the severity of the fault. Prognostic is whether we can able to pre priory we can able to have some indication, that the false are impending or is coming into the machine, if we can able to detect that will be a real challenge.

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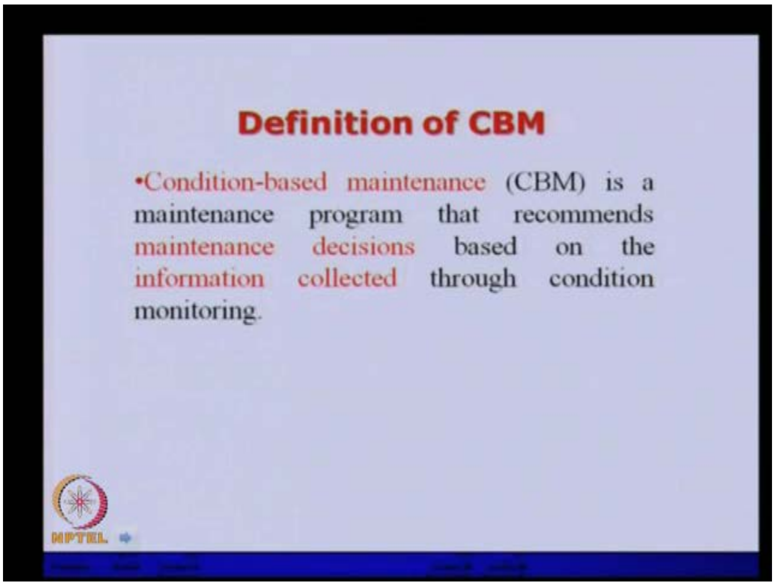

So, abstract definition of the condition based monitoring is a maintenance program that recommends maintenance decisions based on the information collected through condition monitoring. So, based on information only we plan the maintenance not as a scheduled maintenance one.

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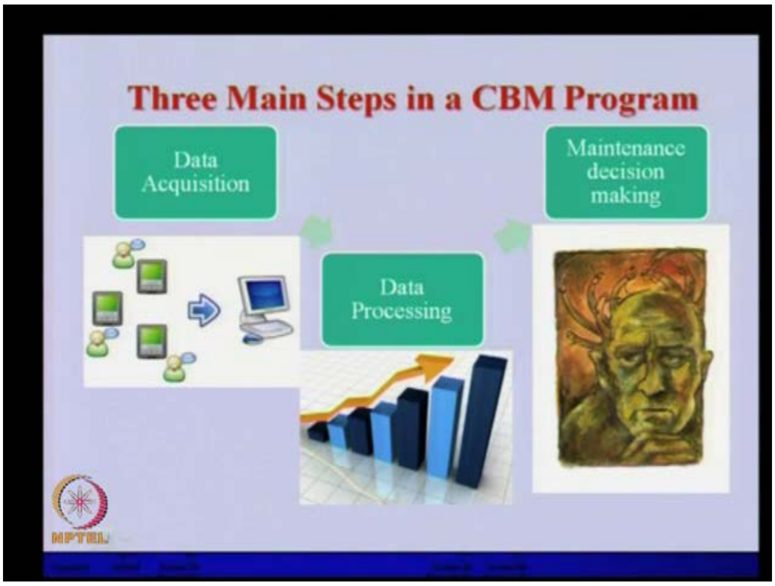

So, in this there are three basic component in the condition based maintenance program, one is the data acquisition. So, we collect the data at from various sensors and then we store that in a computer. Second, is the data processing; so once we have collected a huge amount of data, we need to put them in a proper form and we need to plot them in bar chart or other kind of formats, in which the analysis of the data can be done easily. So, that is the third one, so once we have done the data processing; then the most crucial part is the maintenance decision making. So, once we have the data then the experts will analyze the data, and then make the decision for the maintenance.

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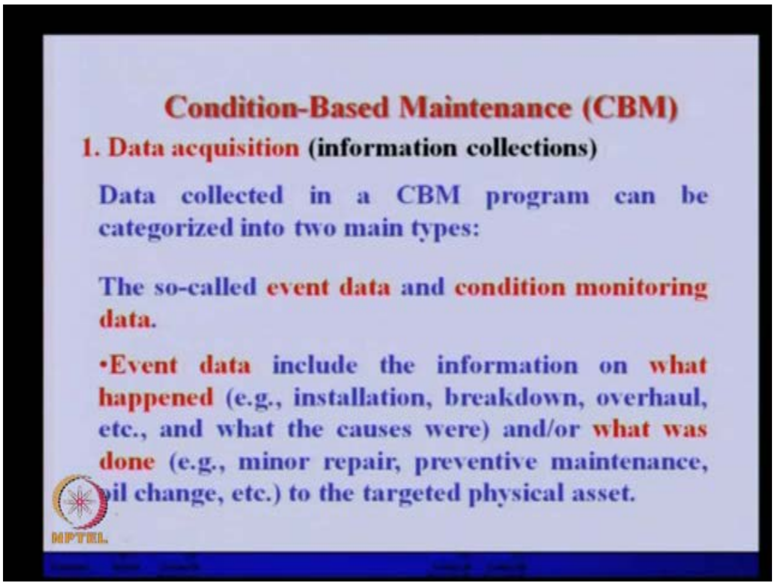

So, condition based monitoring, so we will go in more detail of those three components of the condition based monitoring. So, one is the information collection so data collected in CBM program, can be categorized into two main types. One is the so called event data, and condition monitoring data. So there are two types of data. So, event data is that include the information on what, on what happened as the installation breakdown overhaul. What the causes were, so what happened? What the causes were, so that is the some kind of event, and or what was done minor repair preventive maintenance oil change, to the targeted physical asset? So, this is some kind of event which will form the basis of the data acquisition.

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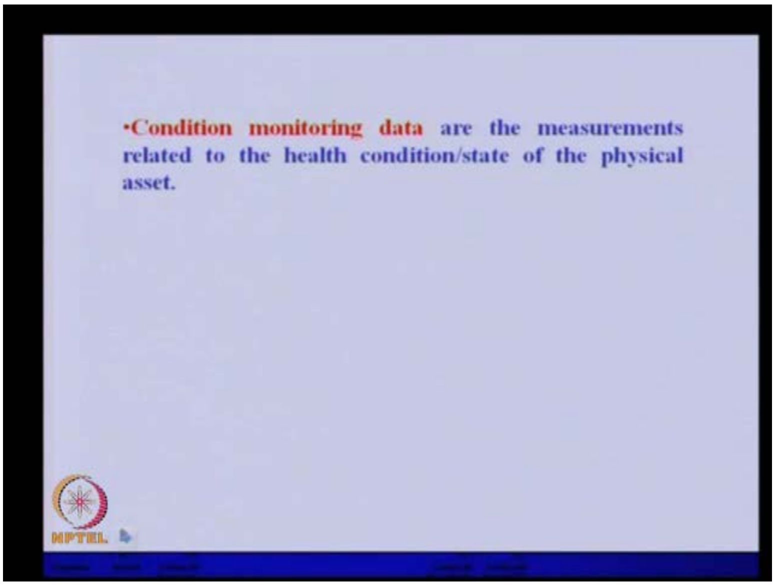

That, is event data apart from this we will be having condition monitoring data. These, are measurement related to the health condition state of the physical assets like vibration, temperature, pressure, noise. These, are the data which we collect that is that fall under the condition monitoring data.

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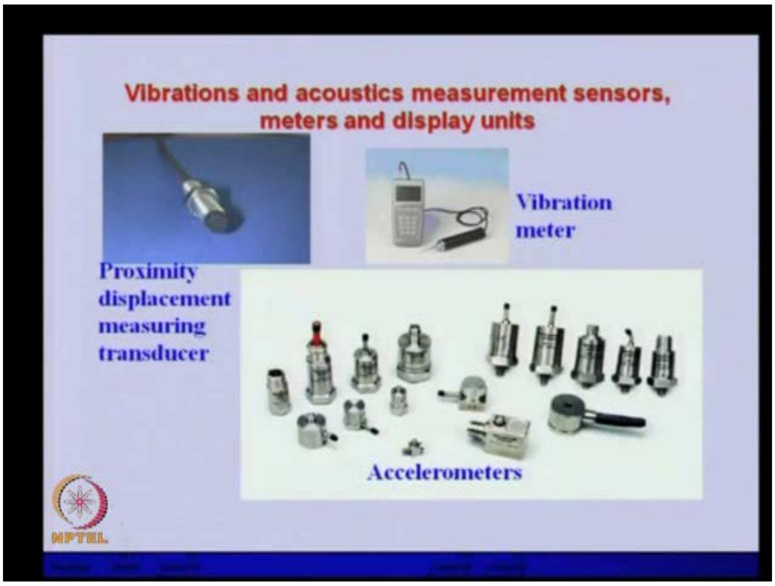

Then, to collect this data we have various kinds of sensors and this we can able to see that, this is one of the displacement measuring proximity probes. There, variety of accelerometer which so basically these are physio electric based accelerometer, which gives vibration signal or the signal voltage signal corresponding to the proportional to the acceleration of the body on, which they have been mounted. So, there are various kind of mounting like these are you can able to see, this is a base creditor wholes are there. So, this we need to fix on to the body, or sometimes we can able to glue it. So, various kind of mounting, we can we can have in this kind of sensors, this hand held vibration meter in which we can able to get either the level of vibration node. So, simple RMS value or that kind of information's, we can able to get about the vibration with this vibration meter.

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Apart from this, the acoustic measurement is very important. So, those are the typical various shape, various size of the sensors the microphones and depending on upon the application their choice will be decided. This is the sound meter so this can measure the various parameter of the sound, like power of the sound.

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This is another kind of an instrument, which is called impact hammer or modal hammer. So, sometimes we need to give some kind of a small force to the machinery, and corresponding to this what is the change in the vibration we want to monitor? This is the purpose of this particular modal hammer the advantage of this is, what particular impulse we are giving to the machinery. We can able to that also we can able to measure it, because there is a force measurement sensor is attached here. The tip of the hammer, we can have variety of tips like, rubber tip or aluminium tip or, steel tip and depending upon what kind of frequency range we want to impart this tips can be chosen.

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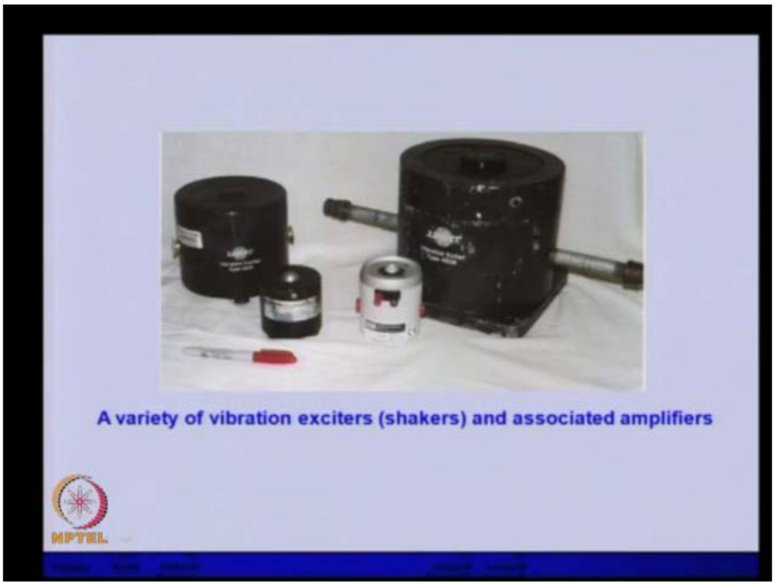

This is another kind of instrument, which is called vibration exciter so or shakers. So, in this variety of shape various size of the shaker we can have, depending upon what kind of machinery we want to excite. So, with this we can able to excite the machinery externally, and we can able to choose either the frequency of excitation or amplitude of that we can able to choose. Or even what kind of excitation force, we want to give we had sinusoidal or two frequency signal or multi frequency signal or random signal. So, depending upon the application, we can able to excite and then we can able to measure corresponding change in the vibration, that basically we can be used to find the condition of the machine.

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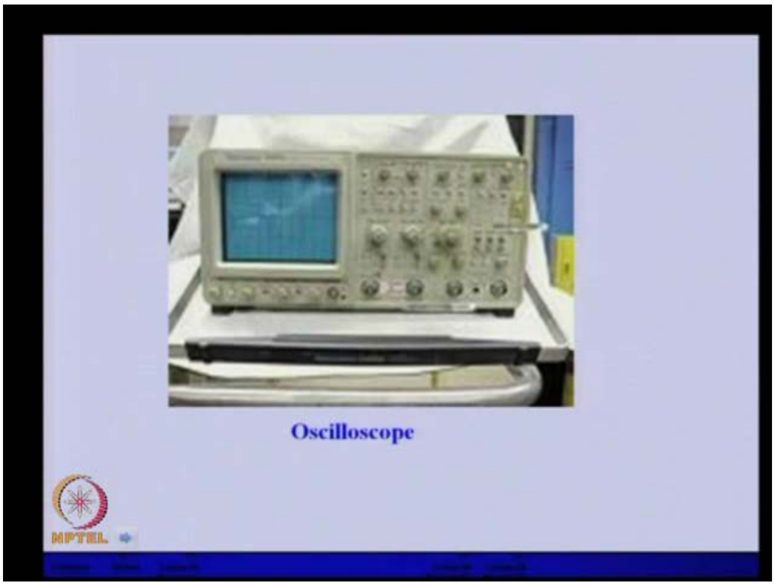

This is for displaying the whatever the vibration signal captured through this these sensors. We can able to display the signal on this kind of screen that is the oscilloscope. Generally, it is it displays signal in time domain. But, frequency domain signal also can be seen in this.

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Apart from this there is another advance analyzer that a spectrum analyzer in which exhaustive analysis in the frequency domain of this time signal can be done.

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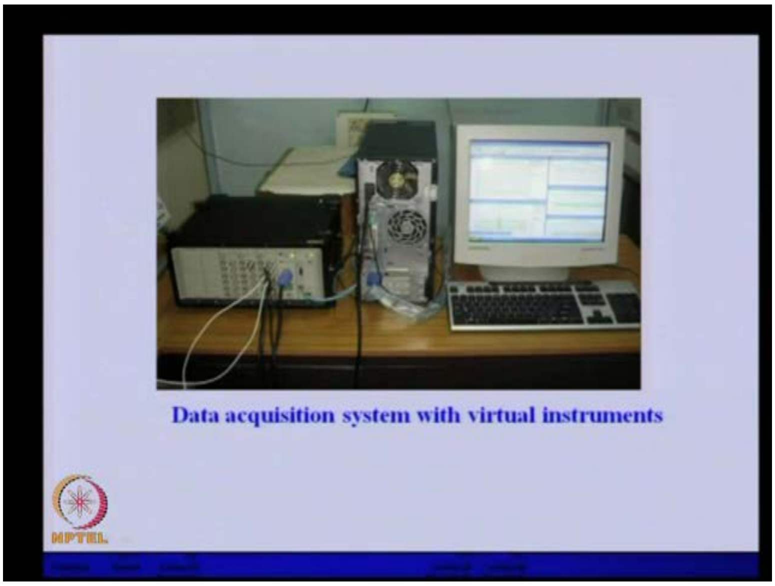

Various form of the signal in the frequency domain can be plotted apart from the FFT simple FFT. Or if required, we can able to transfer the data into the computer through a data acquisition system, and here we can have some kind of virtual instrument. So, depending upon the need what kind of processing we want to do, we can able to make our own instrument virtually.

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This will display various form of the signal which we want to monitor, so this is very handy. But, whatever the signals we are capturing we can able to directly process it, and display on the screen directly online signal we can able to see it is in this kind of virtual instruments. Sometimes to pin point what kind of fault is giving what kind of signatures, and what kind of frequency? This kind of laboratory instrument, we can able to develop, or fabricate in which various rotating components like this is a rotor with two discs. This is a belt pulley arrangement, gearbox. So, rigid prorating mechanism, so various kinds of machine components we can able to design and fabricate.

If you want to see the signature analysis of various kinds of faults, we can introduce in this. And, we can able to capture them in isolation of other kind of faults, so that we can study a particular fault in more deep unlike even various kind of faults in the motor, either it is a machine fault of the motor or electrical fault of the motor. That, we can able to study may we you can take out the current information from this kind of a setup, and even the current can indicate, what kind of faults are appearing in the motor? This kind of testing can be built to simulate the fault experimentally in your laboratory.

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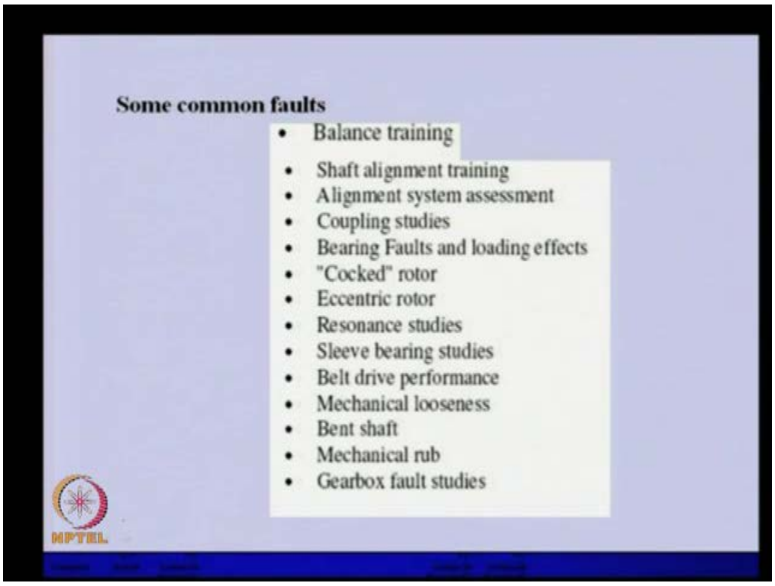

So, these are the various kind of faults generally as we have discussed in the previous lecture also various kind of faults. We can have, and every fault gives a unique frequency in the vibration spectrum and with the help of that unit frequency, we can able to identify which kind of fault has appeared in a particular machine.

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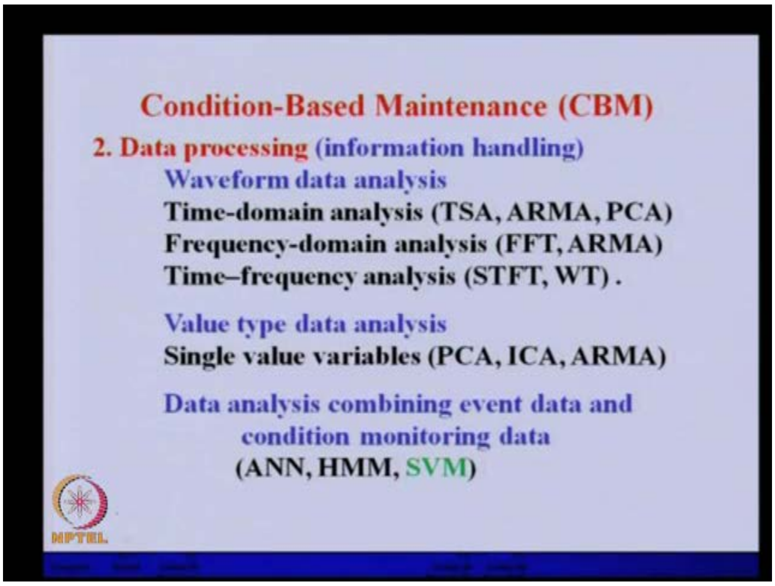

Now, coming back to the data processing that was the data capturing the second stage is the data processing, in the condition based maintenance. So, this is the information handling stage of the condition based maintenance, so we have wave form data analysis, so in the waveform we can have time domain analysis. So, various techniques are available. I will be explaining this in the subsequent slide frequency domain analysis, FFT, ARMA model, these are auto regressive moving average model.

These, are all time domain or frequency domain models time frequency analysis that is, where we transform a short time frequency transform. This kinds of a techniques are available to analyze the waveform data such as in a vibrations. Another is the value type data like single value variable that temperature, or pressure in which we get at one particular time may be one value. So, that kind of data also we can collect.

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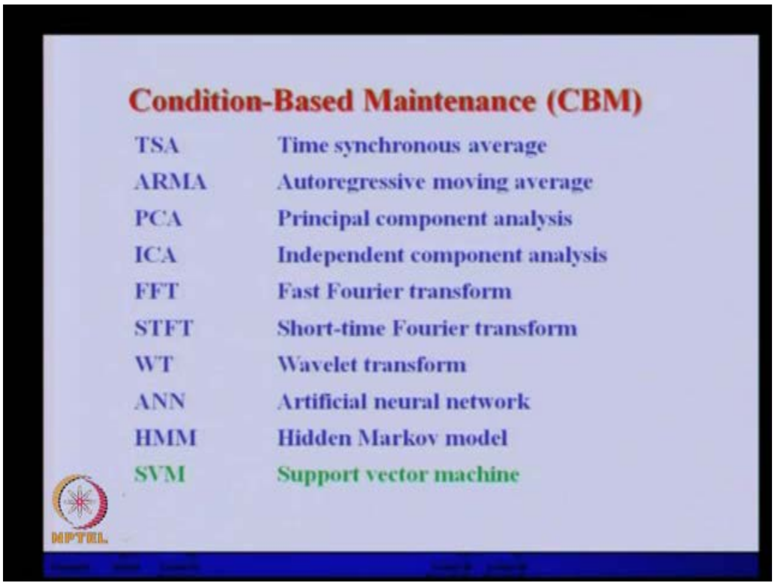

There are various methods which are available to analyze this, so various methods which I have described there are listed here. So, describing each of them is beyond the scope of this particular lecture. But, some of them will be knowing like Fourier, fast Fourier transform, short time Fourier transform, wavelet transform, artificial neural network, hidden Markov model, support vector machining.

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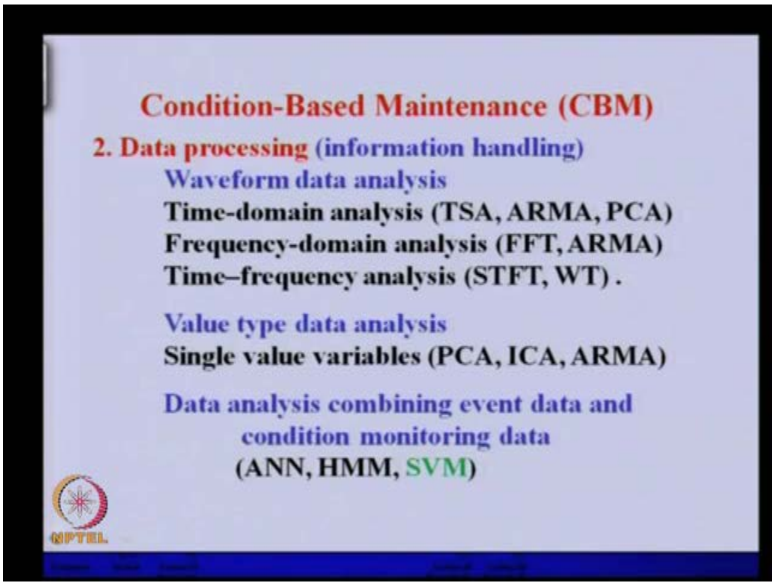

So, these are various techniques by which we can able to process the data and we can have some kind of expert data base with us, then data analysis combining even data and the conditional condition monitoring data. So, event and the condition monitoring data both, we can able to combined because that is very important need for information. So, various artificial intelligent data processing techniques are there. These, are the techniques, which I described in the subsequent slide. So, these can be used for processing of the data to take out the information from the enormous amount of data which comes from the machinery.

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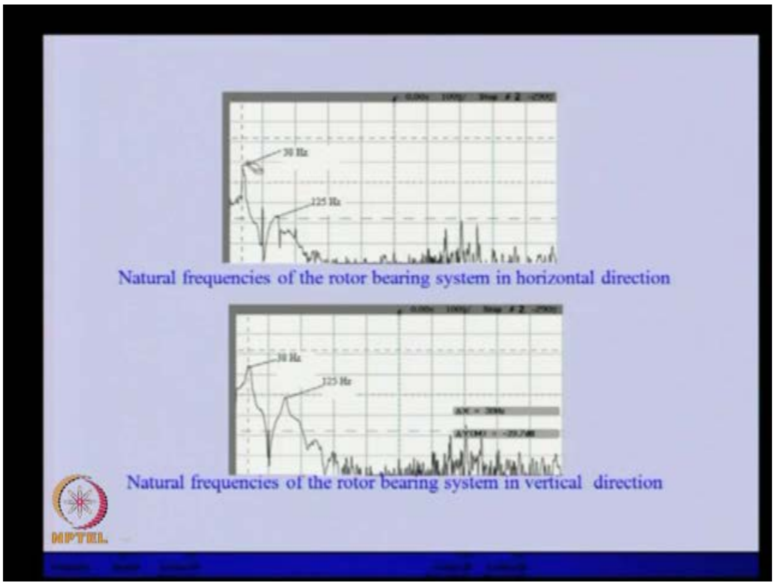

Some, data like frequency domain data free vibration analysis, we can able to perform we can able to pin point what are the natural frequency of the system.

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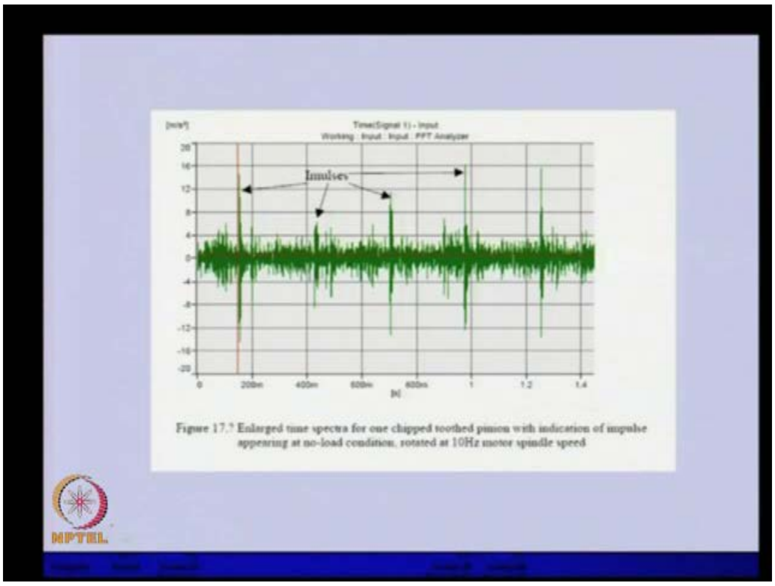

So, predominant peak we can able to collect and that will be our data base, or as we have seen in the previous lecture for gear, if we have check tooth of gear then we can have these kind of impulses, so those information's can be collected.

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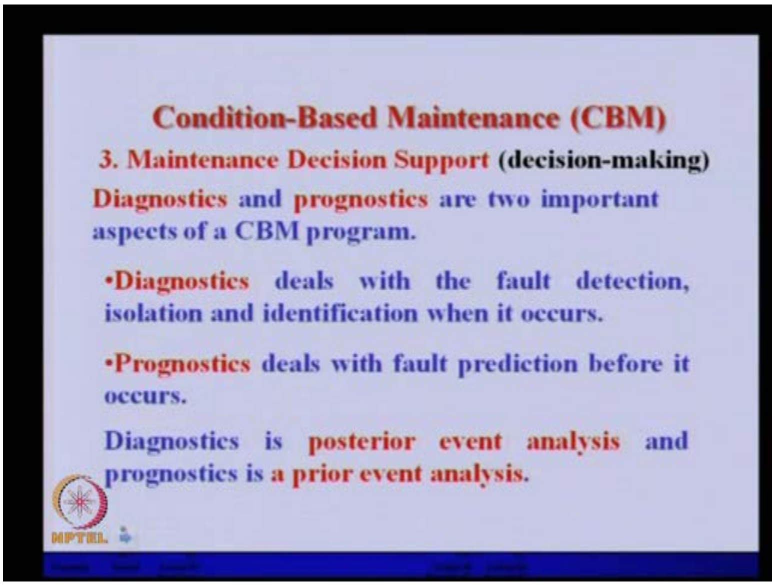

These, are the some of the data type but we can have a more of such type. Then, the third stage which is most crucial one maintenance decision support, that is the decision making process. So, diagnostic and prognostics are the two important aspect of condition based monitoring program, so these are the two main component in this third stage which is most crucial stage. So, diagnostic deal with the fault detection, isolation and identification when it occurs, so basically detection equalizing that and finding the severity of that, and prognostic deals with the fault prediction before it occurs.

So, whether we can have a technique before the fault appears into the system or at the beginning at very beginning of the fault appearance, whether we can able to diagnose that or prognostic we can able to find that there is a fault appearing that will be the most challenging task. So, diagnostic is a posterior event analysis and prognostic is a prior event. So, before it happens, we need to predicate that. Then we can able to so together with this two, we will be having a complete condition based maintenance program.

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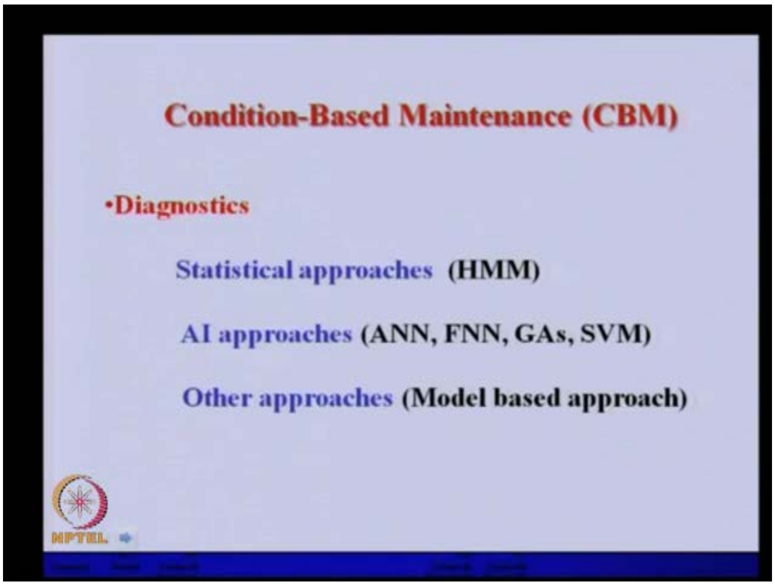

So, diagnostics we have different statistical approaches like hidden Marco process, artificial intelligent approaches, artificial mirror network, genetical rhythm, support vector machine. Other applications like model based because various kind of fault like, unbalance misalignment. We can have mathematical model of that, and once we are measuring the vibration from the actual system, we can able to comfort the mathematical model with the vibration signal. Try to find out whether the fault is there or, if it is there how much is the severity of the fault or the quantification of the fault. We can able to do with the model based approach, which is actually real research which is taking place in the present day on the rotor dynamics field.

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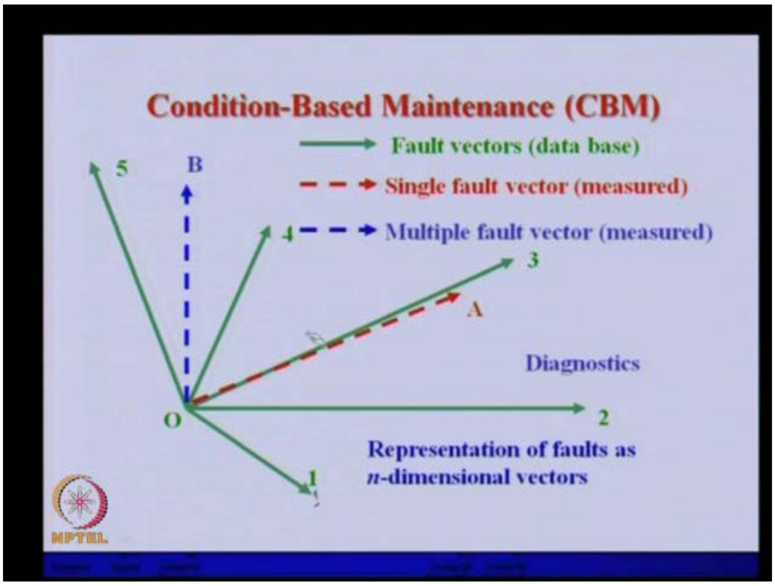

So, this is a very obstruct way how we can able to basically diagnose the faults so in this particular case we have one we have, we have collected various data from the machine. And, let us say there are n number of such data and those data in mathematics, we can able to represent as a n dimensional vector. So, if you have any vector n number of data, those data may be pressure temperature vibration RMS value various data. We can have, and we can put them in as a vector in that will in a n dimensional space, it will occupy one particular vector direction.

Then, so in this particular case what we will be doing we will be introducing one fault in a machine at a time, and we will be finding key what is the change of these vectors are taking place. These, vectors are changing obviously their orientation in the n dimensional space will change. So, the first one is may be corresponding to one particular kind of fault this one is for one kind of fault, this is for second fault. Similarly, we can have third fault state vector, fourth fault in the machine. So, we need to introduce this kind of fault as I shown earlier some kind of fault simulator, in which we can introduce the fault one at a time.

We can able to collect the data, that will be the data base corresponding to various kind of faults. So, these are the 5 type of faults if a particular machine can have, we can able to first generate this kind of data base. And, once we have this 5 data base for 5 different fault then if let us say some unknown fault appears into the system, then if we have measured all the data, and if we plotted in this particular data base space. Let us say this red one is for unknown fault, we measured it and you can able to see that it is close to the fault 3.

So, that means it is representing that whatever the fault is there in the system. Which, is unknown to the user it is actually from database it is predicting that there is a fault 3 in the a particular machine, this is this will happen when there is a single fault, so the matching of these two vectors will be quite close. But, if a vector comes like this so obviously in this particular case it is not aligning with any of the fault, but they are close to 4 and 5. So, we can able to attach some kind of a probability along with the, because the fault 4 and 5 both are there is a possibility.

But we can able to attach the probability of the four is this much and may be 60 percent, and 40 percent for the 5. That kind of based on the vector we can able to stimulate the probability of the fault. If, there are multiple faults appearing in that particular machine, so it is a very obstruct definition how we can able to identify the fault using this enormous amount of data. So, this kind of a technique can be used to predict the fault in a machine.

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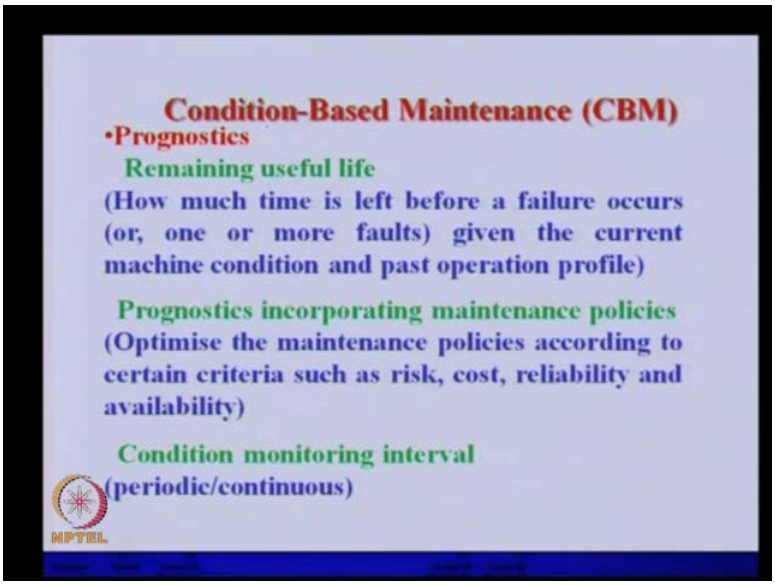

Now, coming to the prognostics there are several things which we can able to predict like, remaining useful life of the machine. So, how much time it is left before a failure occurs or one, or more faults appears given the current machine condition, and the past operation profile. Once, we have the condition based data based on that and previous history of the machine, whether we can able to predict the remaining useful life of the machine. This is very pertinent prognostic production, will be there for a machine.

Apart from this prognostics incorporating maintenance policies, optimise the maintenance policies according to the certain criteria such as risk, cost, reliability and availability. So, this if we can able to integrate the prognostic along with the maintenance policy that could, that will be very useful. Then, third is the condition monitoring intervals periodic continuous so depending upon type of machine and critically of the machine, we can able to decide whether particular machine require a periodic monitoring or continuous monitoring.

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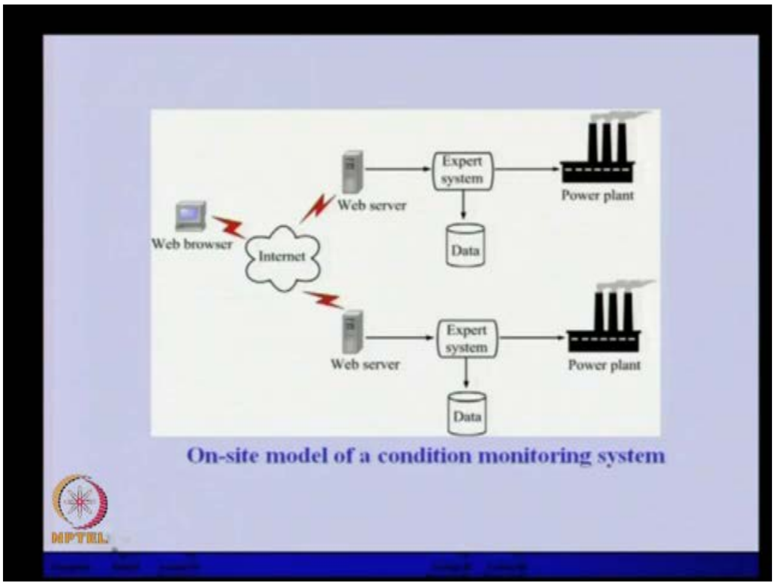

This is a typical on set model of a condition monitoring system, in which there is a power plants or different locations, we are extracting the data from this various kind of data so we are storing at one place. And, there is a expert system based on the data base of the history of the plant. This data base and the whatever the online data which is coming to the system through net can go to various web servers. From there experts can view this and they can see the condition of the machine. If there is some unusual case they can able to pin point that there is some fault is as already appeared in some machine component, or some sub plant or it is going to happen. So, that kind of interface we can able to built from such large systems.

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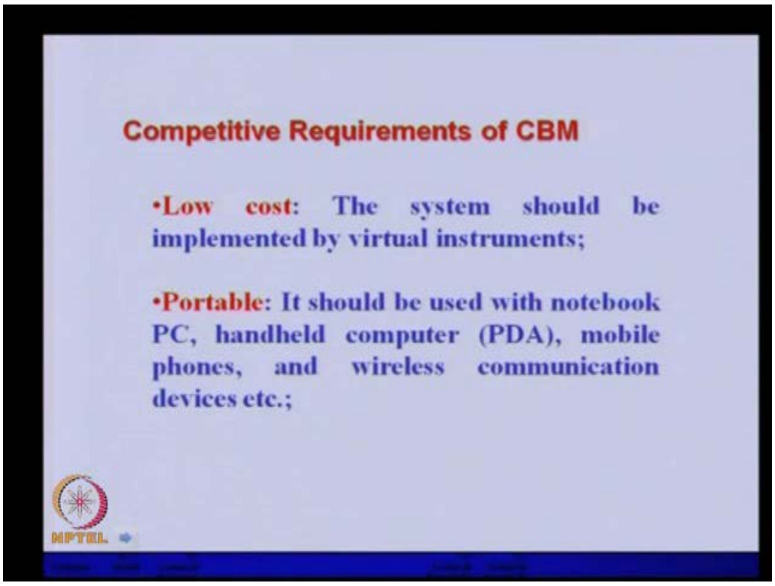

Apart from this, is some other requirement of the condition based monitoring which we may look into, that the one is the cost the low cost the system should be implemented by virtual instruments. So, it should we should have low cost of the CBM program portable it should be useful, again I am repeating portable it should be used with notebook PC, handheld computer, mobile phones, wireless communication. Easy to, use detection of fault via instant exact wavelet analysis active noise cancellation and 3D trend plot.

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These, are some other requirements automatic report generation and alarm, condition monitoring using automatic logging function, web and mobile based remote sensing and monitoring, user friendly training video for self learning. So, these are some of the requirement of CBM should have. Now, after discussing very general topic the on the condition based monitoring, again we will take up some case studies. So, to start with we will take case study of a gear in which various kind of faults, I have been introduced. Based on the vibration signature the type of fault and the deduction of the fault will be doing it.

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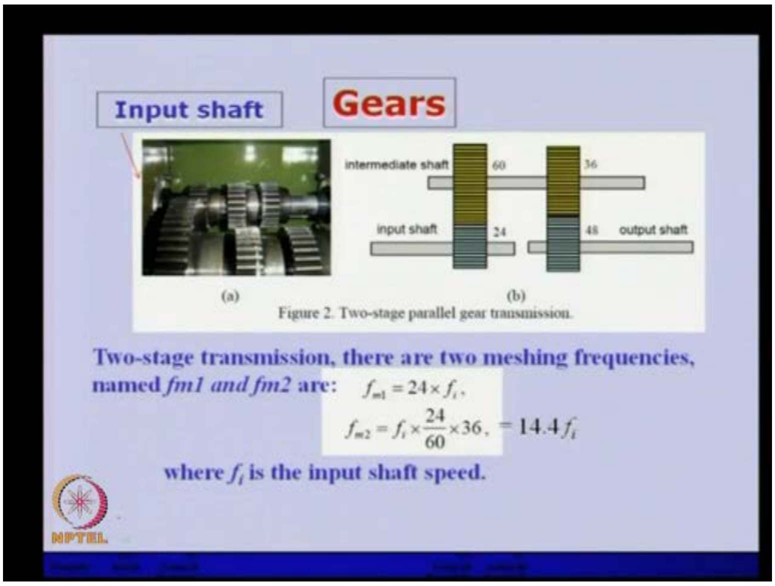

So, in this particular case we have a double stage gear so we can able to see this is the input gear and this is the line diagram of that gear. So, input shaft there is a pin end 24 teeth is there and then this is a gear 60 teeth, then the second stage in which 36 and 46 are there number of teeth, so this is the output shaft. Now, two stage transmission there are two machine frequencies because one between these two gear and another between these two gear. These are named as f 1, f m 1, and f m 2.

We can able to calculate this so first is between these two, that is so the input shaft speed is this 1 f i and if you multiply by the number of teeth of the union, we will get the f 1 will get the f m 1. So, this is one of the tooth meshing frequency we could have taken this t number of teeth, and the speed of the shaft this one we could have got the same value. Another gear is this one, so in this you can able to see that the speed of this particular gear, we are taking the speed of this gear and the number of teeth of this.

So, this is the reduction with in the first stage and if we multiply with the number of teeth of this, we will get the tooth meshing frequency for the second pair. So, tooth meshing frequency is for pair not for a particular gear, this is for first pair and the second pair. So, we have this two tooth meshing frequency we should expect in the vibration and spectra apart from the rotational frequency of the input shaft.

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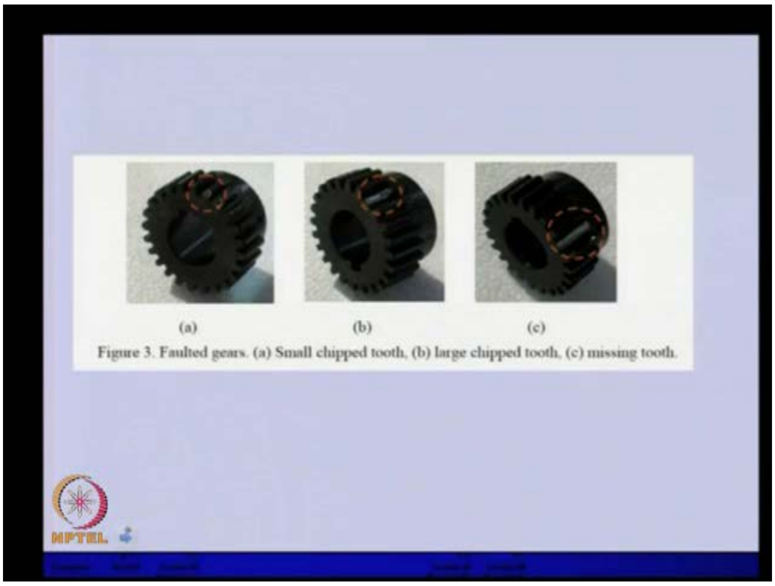

These, are the various gears and especially the fault so you can able to see in the first one a small chip tooth. So, a small tooth has been chipped off this is a large chip tooth has been removed and another one in which the whole teeth has been removed. So, they are three level of fault in which all of them are having fault related with the tooth of the gear.

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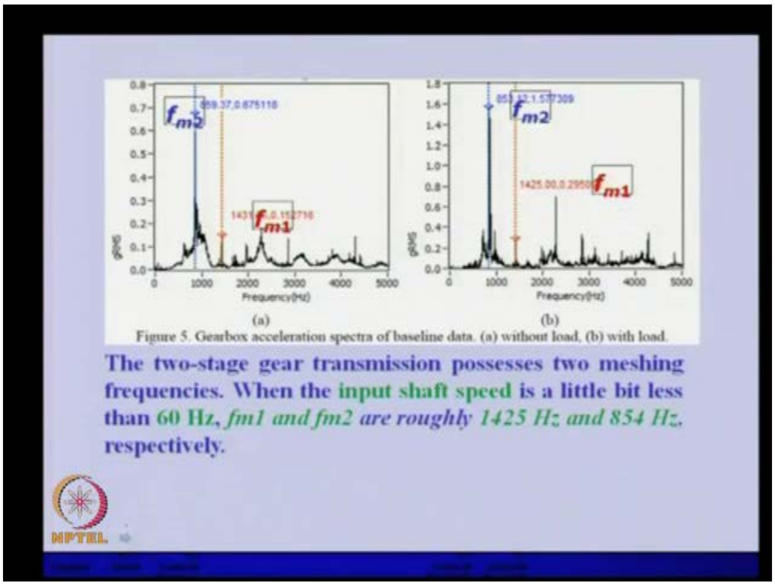

This is a typical signal, this is the gear box acceleration spectra of baseline data first is without load, and second one is with load. As, pointed out earlier whatever the dynamics is going on at the gear will reflect at the bearing location, or the bearing location is, because bearing is mounted on gear box. So, we can able to take the signal from there. That will reflect the dynamics of the gear. So, this is a typical signal so you can able to see the f, so first gear mesh frequency there is a peak for second one there is a large peak. Here also, we have the value is around 4 to 5 that means this is the first one, 4 to 1 is this one red one, and this f m 2 is this one that is 853 around, so this is for f m 2 and this is for f and f m 1.

Apart from that, there will be some other peaks corresponding to the structure of the gearbox and other things. But we must see try to see the peaks is basically this is a cursor which is showing the red line, but this peak is small you can able to see the peak size is small but this is red dots are the cursor. So, in this two stage gear transmission possess two meshing frequency are there two stages are there, so when the input shaft speed is little bit less that is 60 hertz for this has been measured f. The, first and second mesh frequencies are roughly 1425 and 854. So, you can able to see that, these are matching with the actual experimental data. So, this is one and this is 1, so the theoretically calculated, and the experimentally measured frequencies are matching.

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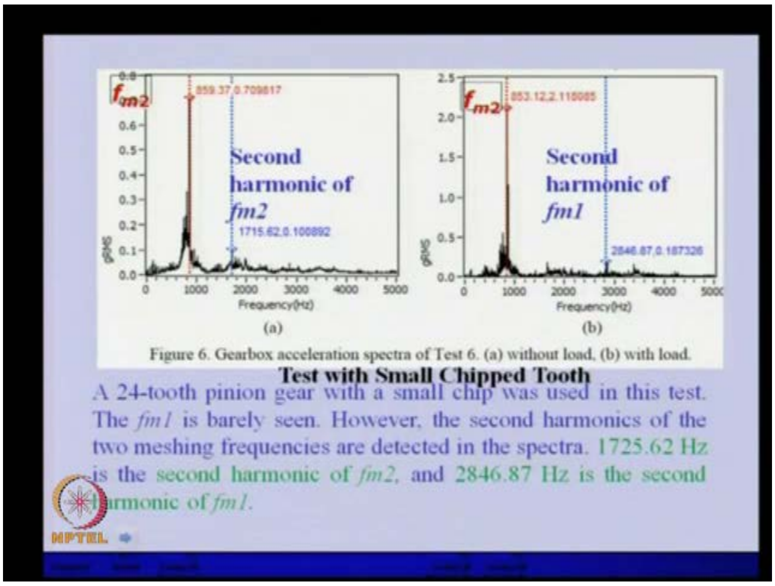

Then, this is with test with a small chip tooth so with this obviously we except the amplitude of the vibrations will increase. In, this we can able to see a 24 tooth pinion gear with a smaller chipped chip was used in this test, the f m 1 is barely seen so this is not visible here. However, the second harmonics of the two meshing frequencies are detected. So, basically you can able to we are not seen the first harmonic, but second harmonic of this particular mesh frequencies are appearing in the spectra. So, the 1725 that is this one and the second harmonic of this is 2846, 24 you can able to see here. So, some higher multiples of the harmonic of the mesh frequencies are visible, but fm 2 is more predominant, but f m 1 is not that much predominant. But, second harmonics are peaking up.

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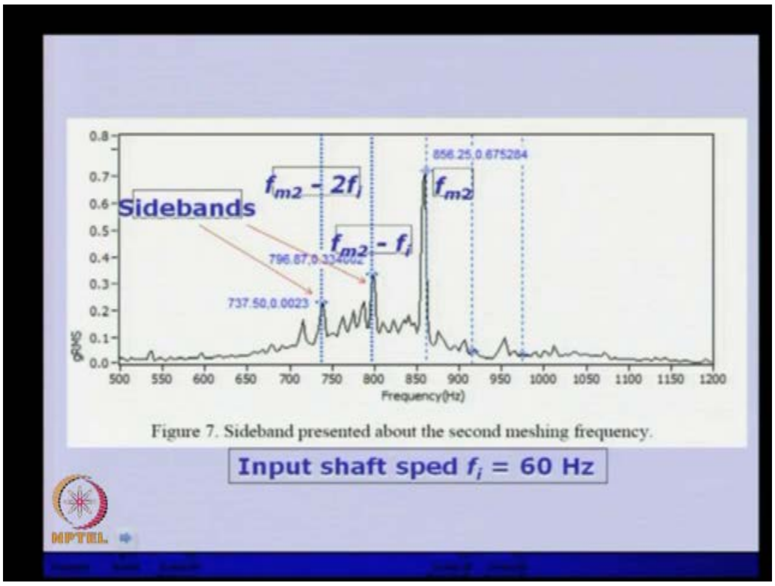

So, then the next is you can able to see the sideband presented about the second meshing frequency. So, we have this is the second mesh frequency this is the sideband, so you can able to see this is coming from the modulation of the rotational speed of the input shaft. The, difference between this frequency and the shaft frequency is giving as a sideband similarly, multiple of that so f m 2 minus 2 f i. This we already seen in the previous lecture, in that we can have one carrier frequency modulated frequency, then we can have this kind of sideband but in one side only that sidebands are more predominant.

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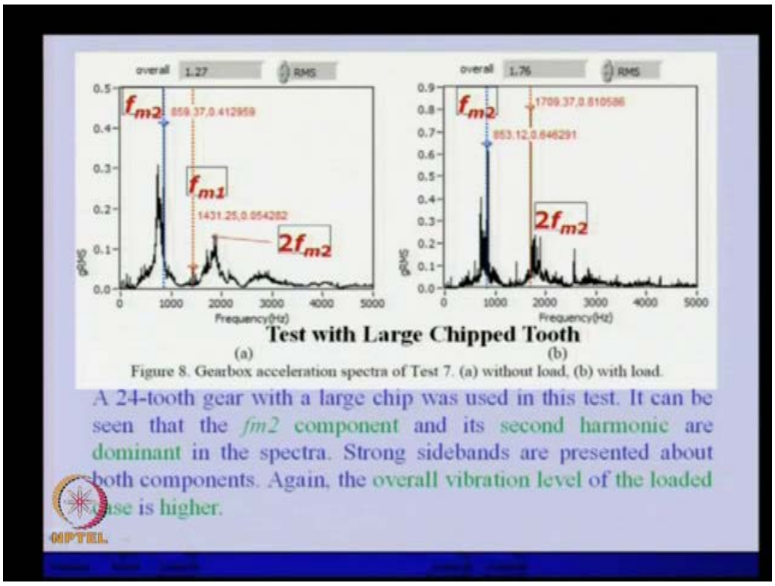

For, this particular case the shaft speed is 60 hertz in this particular case, now this particular signal is with large chip tooth the previous signal was for small chip tooth. So, in this you can able see that the 24 tooth gear with a largest chip was used in this test it can be seen, that the fm 2 component. It is second harmonics are dominant in the spectra that means this is f m 2.

But, second harmonic this is first harmonic of f m 2 so they are predominant, f 1 f m 1 is not that much predominant here also. Strong sidebands are presented about both components, so sidebands are also there we will see the zoom view of this also. Again, the overall vibration level of the loaded case is higher. Even the vibration signal level, if you see this will be higher as compare to the previous one.

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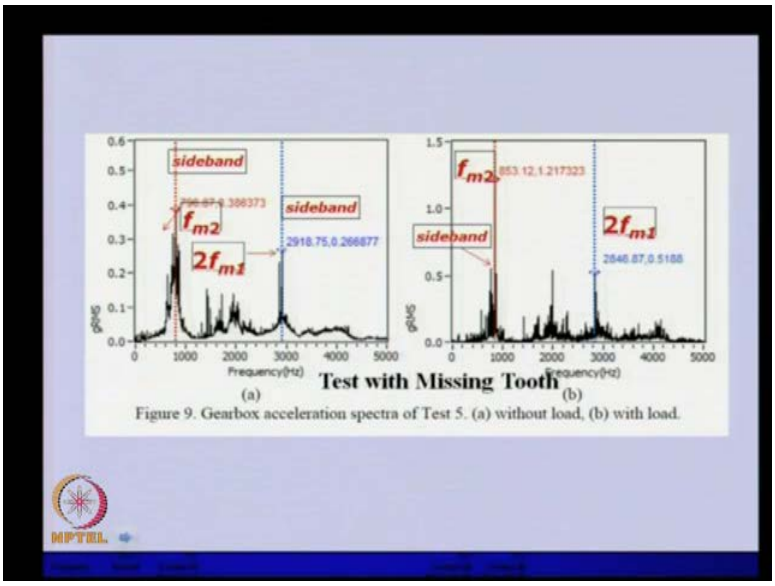

So, this is with the missing tooth the more severe fault in which, the tooth itself is removed completely.

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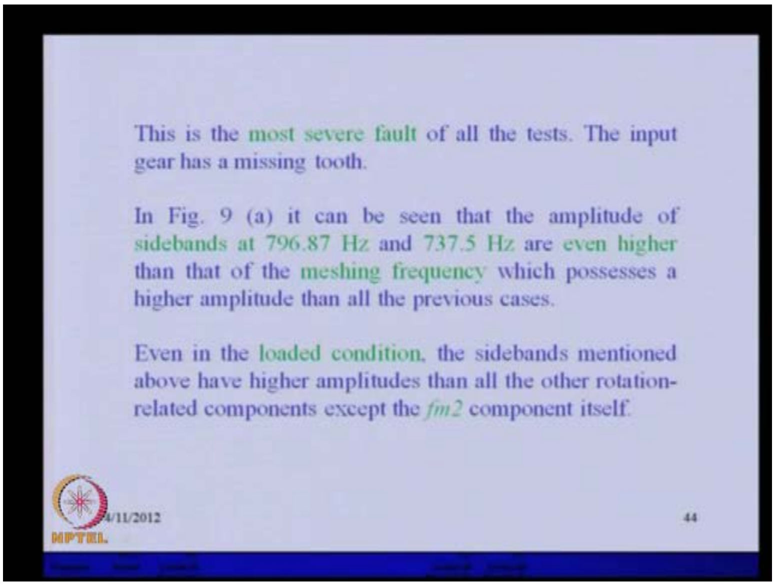

So, in this you can able to see. Let us so this is the most severe fault of all tests the input gear has a missing tooth, in the previous figure. It can be seen that the amplitude of a sideband 796 and 736 or even higher than the meshing frequency.

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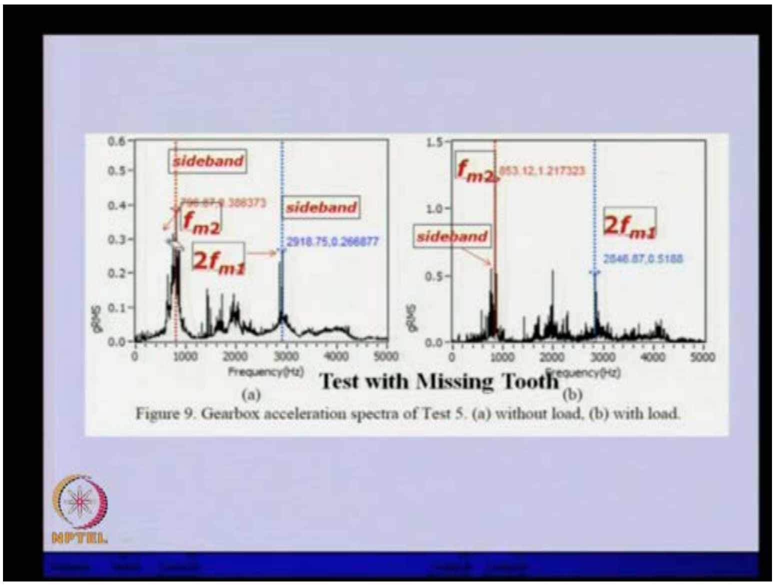

So, 796; so in this f m 2 is more predominant but there are sidebands, they are quite predominant here also. Here, sideband is more predominant you can able to see it 853 these are, these are sidebands fm 1 is present here. Here, the second harmonic of the fm 1 is more predominant, so this kind of modulation can take place.

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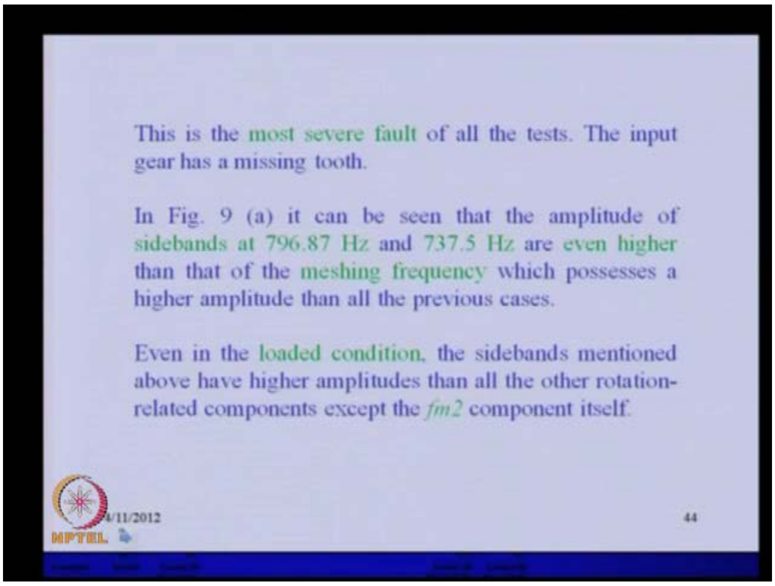

In, such even in the loaded condition the sidebands mentioned above have higher amplitude, than all other rotational related component except fm 2 component itself. So, sideband is one particular phenomena, which we could able to observed in such kind of fault.

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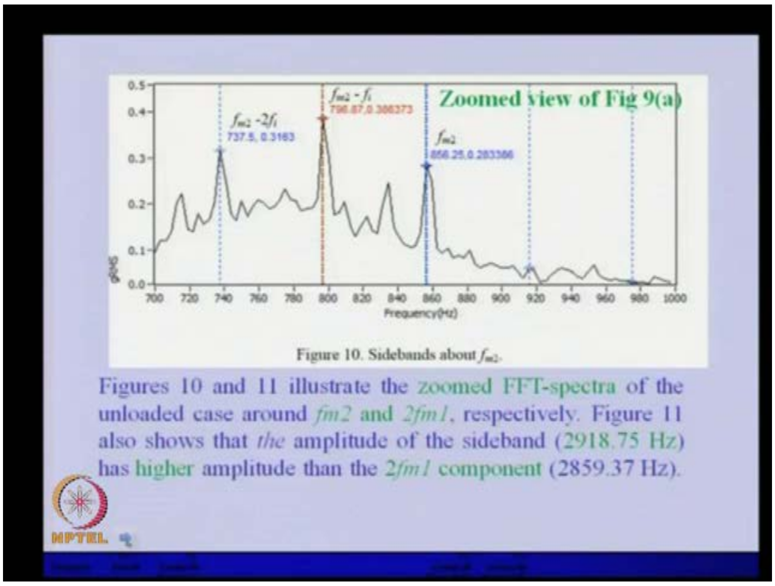

This is the basically zoom view of the previous slide, so in this you can able to see that this is the f m 2 there is a modulated frequency, that is sideband f m 2 minus f i corresponding to the spin speed of the shaft. This is a f m 2 minus 2 twice of f i. So, these are the sidebands which are predominant more than the, actual this tooth meshing frequency because of the severity of the fault.

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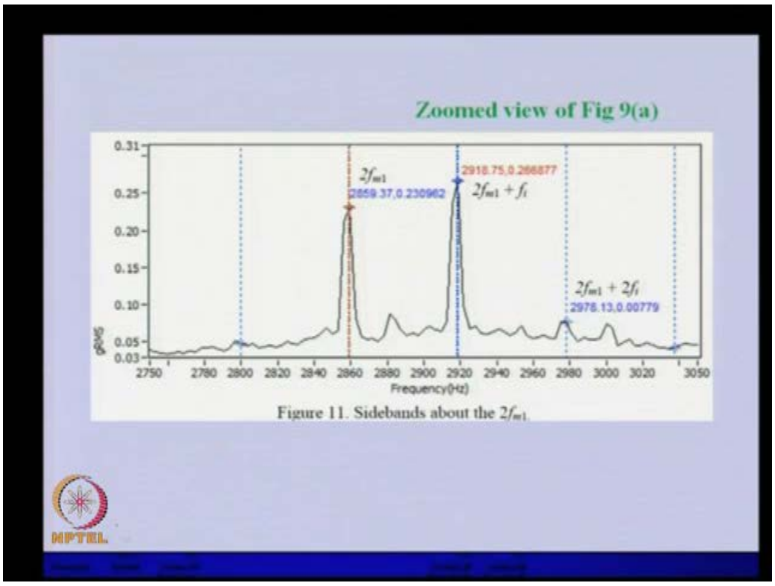

This is another zoom view of the same figure, so in this you can able to see f additionally we have 2fm 1, that is in the higher range we have shown here and the sideband. So, sideband is more predominant than the actual tooth meshing frequency of the first tooth meshing frequency. Here, it has been modulated even this is the higher harmonics of the tooth meshing frequency, second harmonic of the tooth meshing frequency, and sideband of that here also the higher side sidebands twice of spin speed of the shaft. Now, we will take up some more case studies especially, of the fans which are there in the industry.

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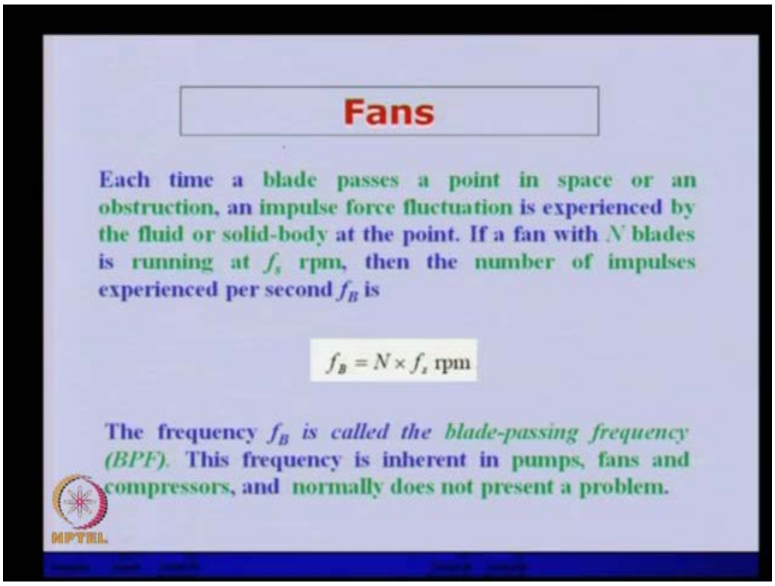

So, in this particular case we were describing about the industrial fans so each time a blade passes a point in space or an obstruction, an impulse force fluctuation is experienced by the fluid or the solid-body at the point. If a fan with N blades is running at f s rpm, then the number of impulses experienced per second will be N there is a number of blade into the speed of the fan.

So, this is the this is called the blade passing frequency, as we have the tooth meshing frequency similar to that blade passing frequency is there BPF. This frequency is inherent in pumps, fans and compressor normally it does not present a problem. So, normally it will not create any problem, but if there is some fault, then we can have the difficulty in the in this particular frequency.

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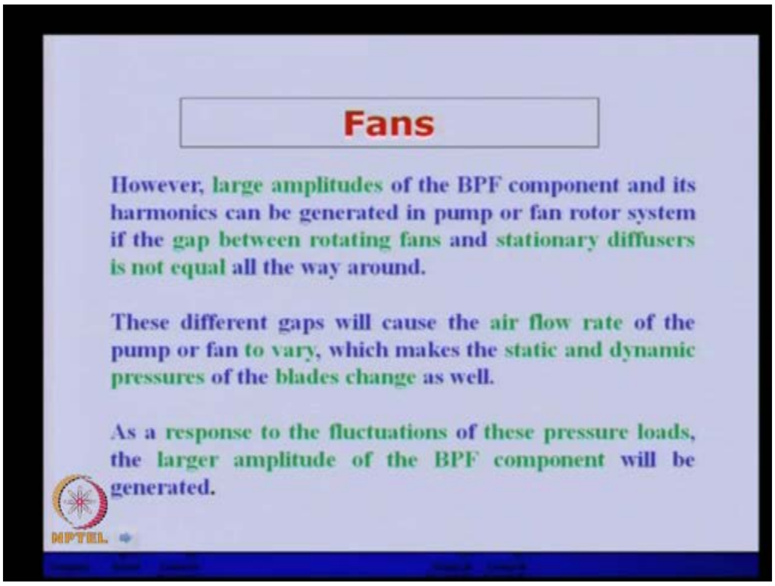

However, large amplitude of BPF component and its harmonics can be generated in pumps or fan rotor system, if gap between rotating fan and the stationary diffusers is not equal and all not equal all way around. So, in the whole circumference if that gap is not equal then we can have this kind of large amplitude at this blade passing frequency. These, difference different gaps will cause air flow rate of the pump, or fan to vary which makes the static and dynamic pressures of the blade changes as well. As a response to the fluctuation of these pressure loads, the larger amplitude of the BPF component will be generated.

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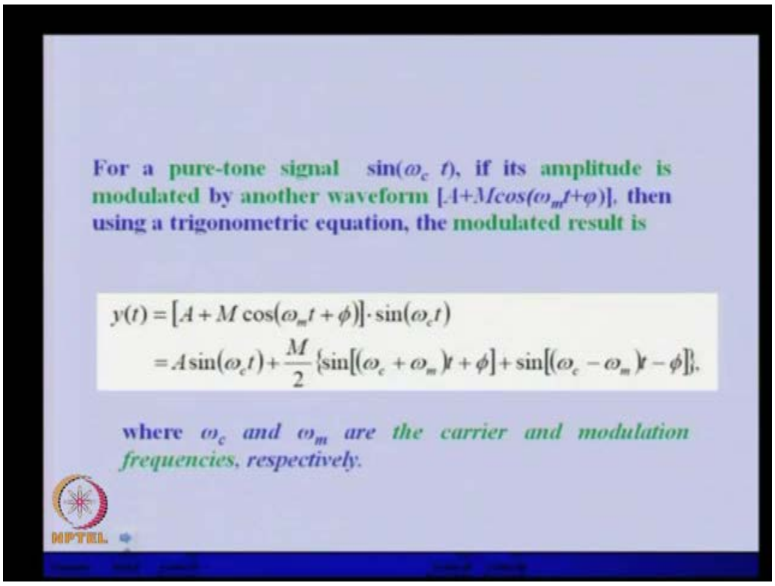

So, for a pure tone signal that let us say this is a signal sin omega t, if its amplitude is modulated by another waveform like this. Then, using trigonometric equation we can able to see that, there will be not only then add and subtract of these two frequency modulation will take place. So, here as we have explained earlier also omega c is the carrier frequency, and omega m is the modulation frequency. So, we can able to see in the sidebands in such system.

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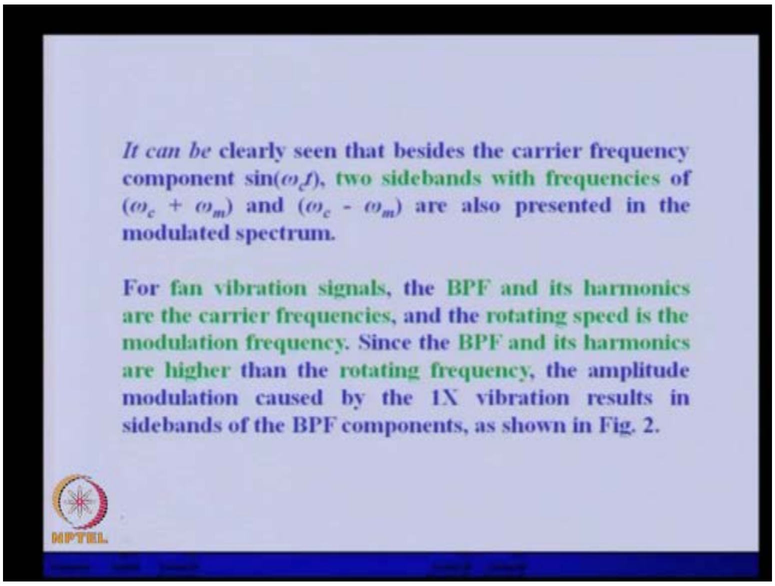

So, it is it can be clearly seen that the beside the carrier frequency component two sidebands with frequency of the summation of two frequency, and difference of this frequency are also present in the modulated spectrum. For fan vibration signals, the BPF and its harmonics are the carrier frequency, and the rotating speed is the modulation frequency. Since, the BPF and its harmonics are higher than the rotating frequency, the amplitude modulation caused by 1X vibration result in sidebands of BPF components, as shown in the next figure.

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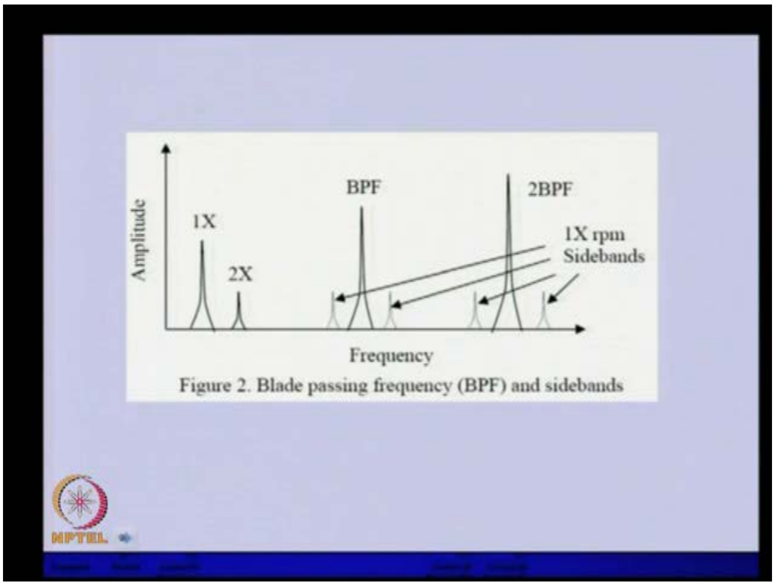

So, you can able to see that this is the BPF, and there are sidebands corresponding to 1X r p m of the rotor speed. This is the second BPF, higher harmonics of that and we have sidebands of that, and these are due to the unbalance 1 X and 2 X corresponding to the rotor speed this is a typical fan.

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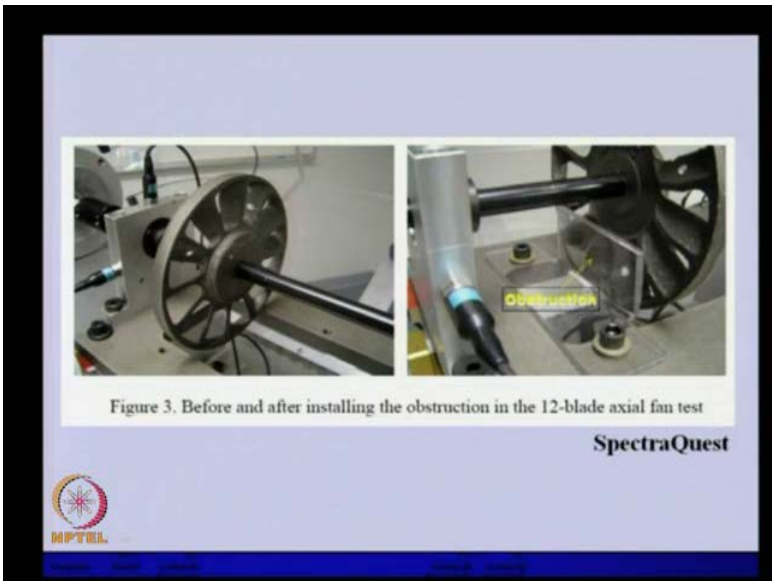

So, before and after installation the observation in the 12 blade axial fan so there are 12 blade axial fan, in this we put this is taken form a spectra quest lecture nodes. So, this is the obstruction, which was put here so that, we can get some kind of disturbance.

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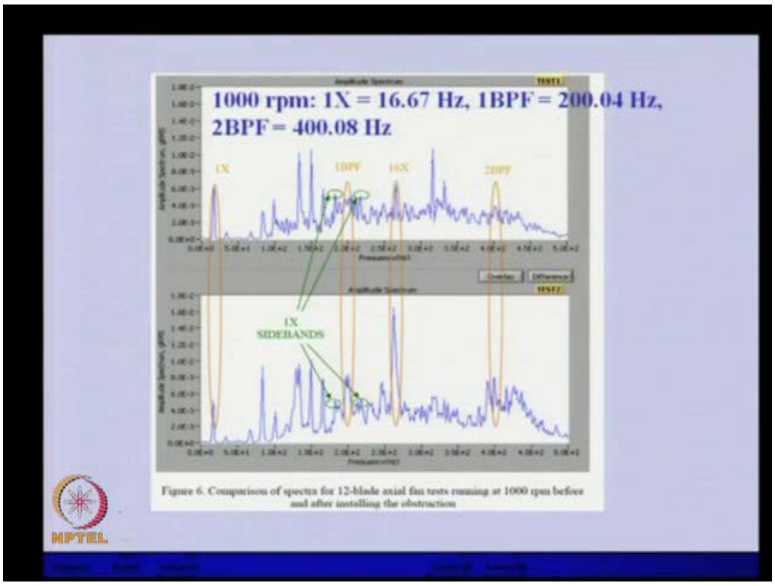

This is a typical signal in this so you can able to see there is a 1 X 1 blade passing frequency is this one, and there are sidebands to that this is component of the 16 X of the rotational speed this is twice of the blade passing frequency peaks. So, this kind of a spectrum you can able to except from such blades in the present lecture. I gave a brief introduction to the condition based monitoring, which itself is a big subject and research area.

So, in a single lecture it is very difficult to cover all the aspect of the condition based monitoring, but I try to give various basic component of that particular condition based monitoring. In, which obviously the first component is the collection of the data, second is the analysis of the data, third is decision making based on whatever the data we collected and analyzed. So, that was the overall over view of the condition based monitoring we presented in the present lecture.

Apart from that, if you more case studies on gears and fans we presented and we try to see, that how this condition based monitoring are especially looking into the signal we can able to detect the fault in the a rotating machinery. With this, we basically conclude this particular subject of rotor dynamics lecture, so generally this particular subject is taught as elective in our institute. These particular lectures generally we cover in 40 to 42 lectures.

But, with the power point presentation we could able to put more information and more illustrations in these lectures, and hopefully it will be useful for the students as well as practicing engineers in India and all over the world. Now I would like to acknowledge some of the people who were behind this preparation of these lectures. So, basically you can able to see all the M. Tech students and PhD students, who took rotor dynamics course under me from 1999 up to 2012.

They contributed in this particular subject, their discussion with them were very helpful. Because of the motivation from them only, I could able to develop this particular lecture notes. Apart from this video recording and editing staff at CET, they were very helpful in recording and editing of this particular video lectures. I am, thankful to all of them apart from my family obviously, because without their presence I cannot able to concentrate on developing this particular course, so I acknowledge them also.