Lecture – 04
Fault Diagnostics and Prognostics

Well, in this lecture, we will talk about fault diagnostics and prognostics. By now we have an idea on the three different types of maintenance, being periodic maintenance or preventive maintenance, then we have the predictive maintenance or what is known as condition based maintenance and then we have the reactive maintenance. And in the last part just we saw how FMECA could be used to identify the critical equipment or machinery or operation so that, our maintenance efforts needs to be strengthened and we need to put more maintenance efforts.

Now, in this lecture I will be introducing you to certain definitions of fault diagnosis; because as you would have seen I have found out by FMECA a critical machine, well the next question is so what? All obvious question comes to everybody's mind is know I have done maintenance and of course, in always monitoring its condition through an online condition monitoring technique, but people always ask how can I find out if a fault has occurred what kind of fault has occurred, which component to the machine has failed and if it has failed or if it is deteriorating how long is it going to last till the machine totally fails because you will see.
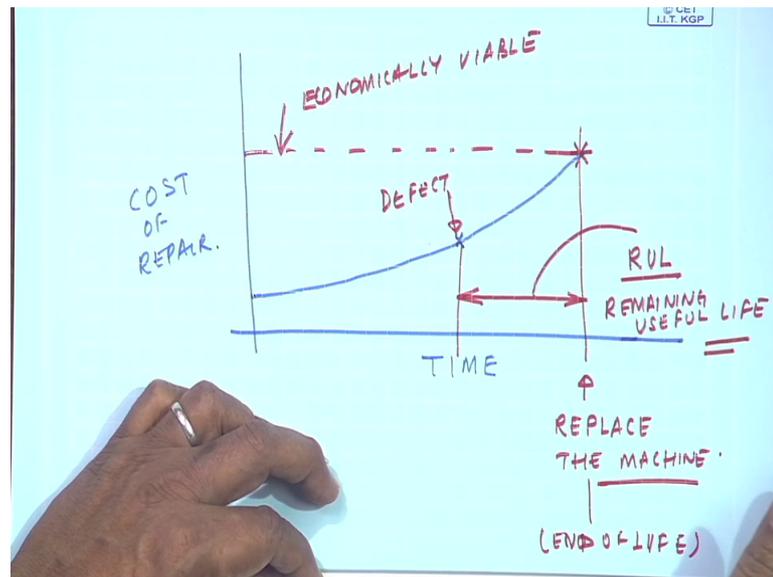
 With time there is always a cost if the machines is being maintained with time because the; we are interior increases the cost of repair perhaps, but time would come when I will reach a point, where this is not economically viable to repair this.

So, this point I can say now it time to replace the machine. I will just give you an example, there have been instances where gold mines in our country people have not gone had an mine, gold further mine because the mind depth has increased to certain levels such a level that it is not economic to mine gold from so much underground and then people think know well, it is not economically viable. So, end of the day why are we maintaining this you know if you recall in the very first or second lecture are told about profitability.

So, if I manufacture a good, and if I do not make profit out of it, you know I will run on a business. So, to ensure that I manufacture quality goods, I have to have my machinery running at their desired specification. So, I have to produce components at they are you known as, but within the tolerance limits of the designers and so on. But all these things will get affected if my machine which are manufacturing them are not perfectly maintained and so on. So, there are certain terms associated with this fault diagnosis and then; obviously, people always ask at any given point of time for example, if I have found a defect at this location in time and at this time. If I decide that this is my end of

the life, people would be wondering what is this rule of the machine that is known as a remaining useful life of this machine.

So, but then we will see how this is done. So, before I go into I will give you.
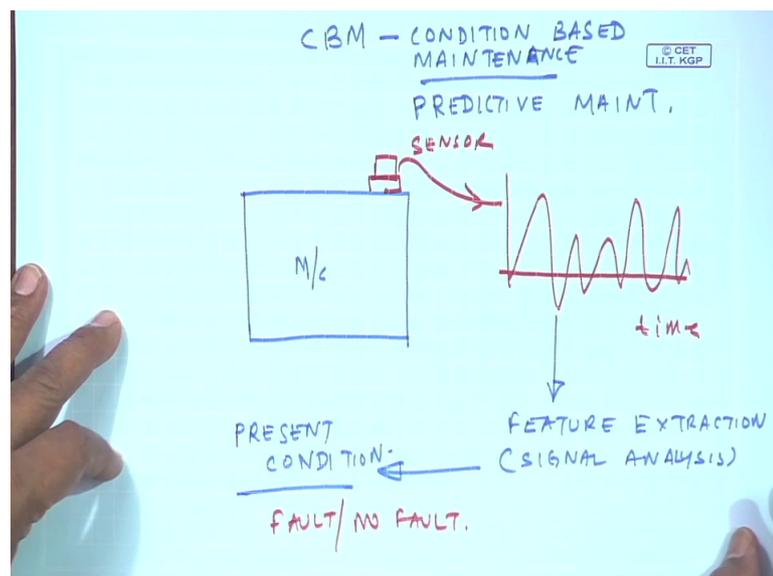
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Some elements of the CBM because we will in this class, focus on condition based maintenance, and then which is also known as predictive maintenance.

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And then so for doing predictive maintenance I need to put in a sensor some sensor, and then I will have this data reading with time, some data I will do a feature extraction or I will do this signal analysis, and try to understand the machines present condition. By present condition I will say whether there is a fault or there is no fault.

So, this is what with time our machine evolves, but if I this operation is done see for example, I am with time, I am monitoring a particular feature.

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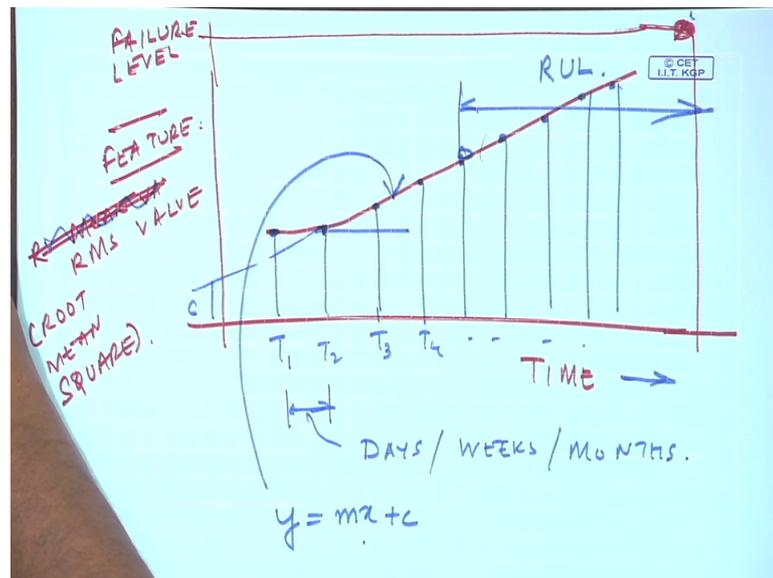
My future means a particular feature of this signal for example, we will understand mean value of the signal or RMS value of the signal nothing, but root mean square value of the signal.

Now, if I just plot this, this is at some time T 1 another time T 2 this are the values, and suddenly I see that with time this is increasing; obviously, on higher value of this value means the machine is having a defect they are all different Ts and so on. Well who is doing this this is at any given instance I in time my machine is running, I put a sensor get a signal find out it RMS value at time equal to T 1, next I do the same thing at time equal to T 2 T 3 and so on.

So, what happens this frequency is up to you know, it could be days, it could be weeks, it could be months. So, this is known as the trending and you see it was come to the point that you know I will my machine would have failed if the level this is my failure level.

So, once it reaches this it is a failure level. So, you see for a simple system if I can draw the equation for the straight line y is equal to mx plus c, where c is this intercept here and y becomes this level here, and m is the slope of this line and x is time. So, at any given time was if this equation to the straight line is known I can find out at what x or in this case what time t, it is going to reach this level.

So, at any given instant if this equation is known to me I can find out at distances; what is the RUL. So, in CBM or the prognostics health management cycle if one needs to put sensors needs to collect the data, do some pre posting and extract the future classify default weather they are what kind of classes, they belong to whether they are multiple severe and so on and prediction of fault evolution C, through this example I give you a very small like this simple example of one parameter which is going linearly with time and then I can find out what is the RUL, but it is not so simple in real world, and then you will see in the next lecture how certain machine learning techniques are being used to find out the remaining useful life of a plan.

Because end of the day I have diagnosed.

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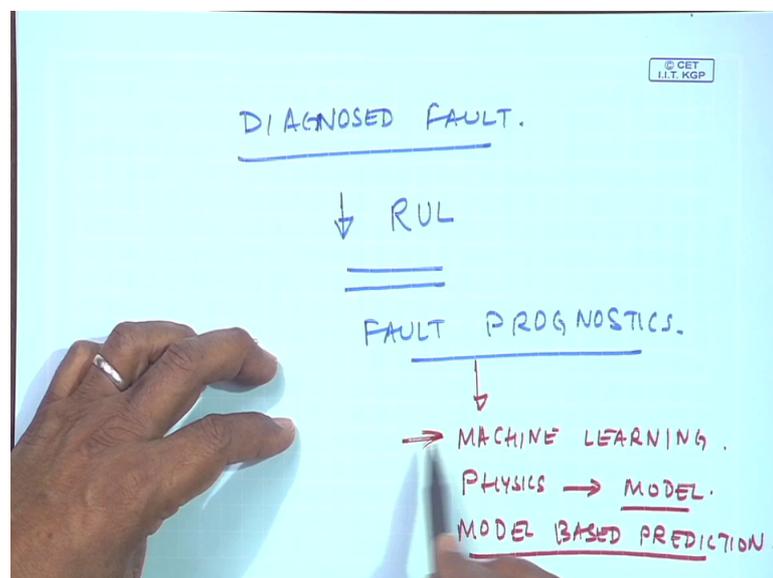
This fault I have found out the reasons why this fault is occurred, but the question is next people ask what is the RUL and that is what is known as fault prognostics, and to do fault prognostics today the state of the art is people are there used you know machine

learning algorithm or from the physics of the problem we can develop model and used model based for prediction model based prediction.

I am sure these models have to be accurate, sometimes you know physics is not enough or physics is not well understood because the system is so complex that certain machine learning algorithms has to be a used and so on. I will just give you an example I think of a nuclear plant, nobody would have waited for a nuclear plant to fail to actually see that know what is going to happen and what is it say or allow a defect to occur and predict and see you what the remaining useful life is are all done through nicely developed software models of the plant simulation and models of the plant.

So, in many systems from the physics a good model is developed and sometimes to supplement the model, certain machine learning techniques like neural network support vector machines are used. So, that we have a robust model by which we can looking at the past history of the defects in the machine we can predict the future. I am sure know everybody one if you visit a terminally ill patient in the hospital, everybody wonders and asked the doctor know what is the lie expected life of this patient and so on. Similarly in a machine also we try to use the past data obtained from sensors in this machine, and see how we can find out the for in the machine.

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So, certain definitions is what we need to know. So, for diagnosis means detecting isolating and identifying an impending or incipient failure condition and the affected

components of system is still operational even though at a degraded mode. Many times a defect has occurred that does not totally impair the machine it will be still running, but then the fact that I have identified is very very important and you will see a lot of this data analytics we are talking about or signal feature extraction, help us find out the defect in the machine.

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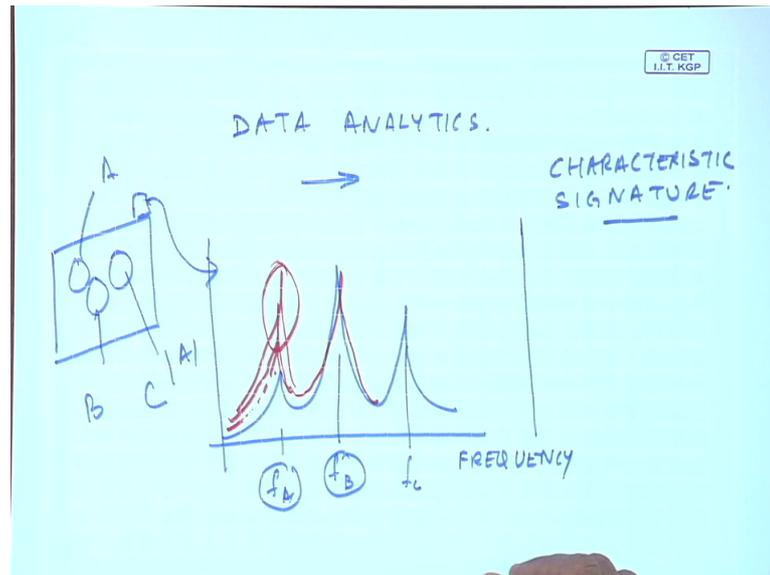
Because let me tell you how CBM is going to happen or occur. See suppose I have a machine with different components A, B ,C and if I do the of a capture the signal and do an analysis you will so happen this may be corresponds to frequency of A, frequency of B, frequency of C.

So, if I take the signal and of course, it by the way this is a running machine. So, if I take this signal out of the transducer put up this machine, which has ABC components, the signal in the frequency domain certain amplitude will have a certain amplitude at this distinct frequency. So, A corresponds to the component A, B components to component B C component fc compare corresponds to component C. So, every component in this machine has its characteristic signature or frequency in this spectrum. Like every human being has a characteristic signature; every machine component also has a characteristic signature and which we are trying to measure and relate.

So, this is component A has failed maybe with time it is going to increase. So, this is what and this will all be same. So, you see in this spectrum at different time instances if I

produce such spectrums I will know that the A component A has fail. So, I would be able to detect that from such an analysis that component n my machine has failed, I can take measures either to identify it or isolated or even get a impendent A replaced because I have identified that the fault in this machine is because of a failure in component A. And imagine a large cement plant for example, in the cement plant we have some critical components like a gearbox like a (Refer Time: 17:51) etcetera.

Student: Sir.

If you have understood that the;

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Motor electrical motor then the cement plant has the critical is having the problem, we always can plan in advance and get this critical electrical motors stored in her inventory as because as soon as our defect has become severe we can replace it. So, this would also save us time and so on.

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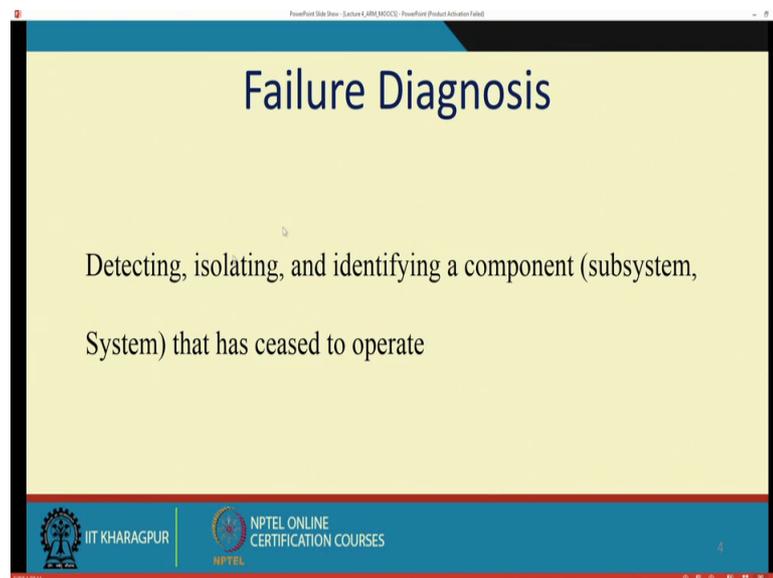
So, failure is different than for diagnosis failure diagnosis is detecting isolating and identifying a component that has ceased to operate because the failure has occurred and many a times as the condition mounting know consultants or experts we are called when this has happened machine has failed, and then know we are asked know what was the

reason while the machine failed, and that is what we do what is known as an failure analysis.

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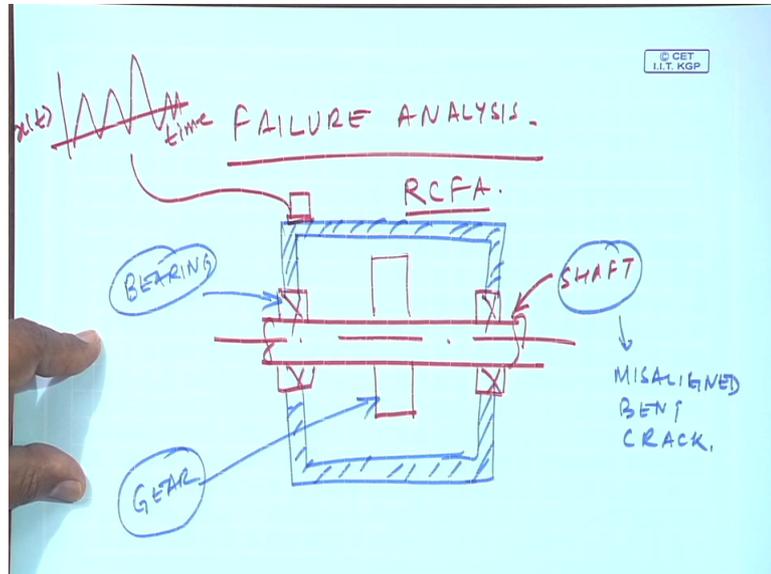
We will cover about this in the later chapters little lectures on failure analysis. Despite are best maintenance efforts or failure is occurred.

So, how do I find out the root cause of this failure; root cause of failure RCFA root casually it analysis we need to find out.

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Fault an abnormal operating condition is detected and reported today the sensors are so smartly available, that the machines itself to the right data analytics will indicate that a failure has occurred or what kind of corrections needs to be taken and so on.

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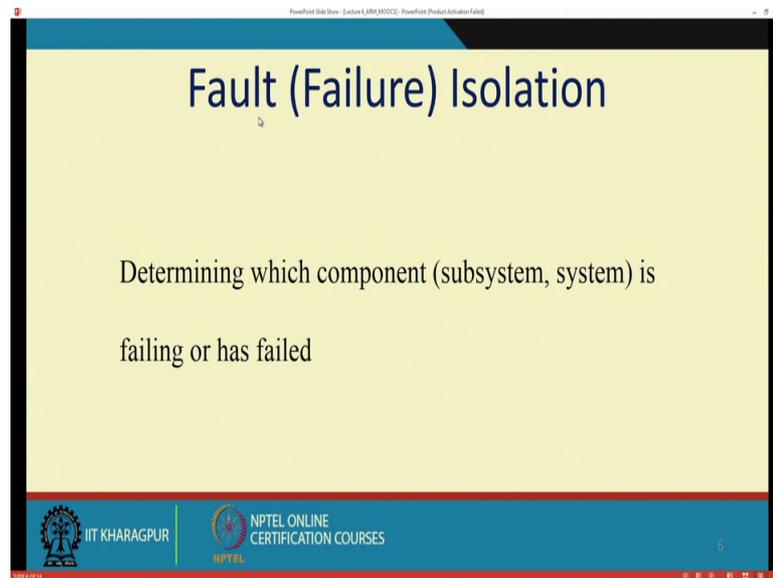
So, another definition is fault isolation. So, determining which component subsystem is failing or has failed.

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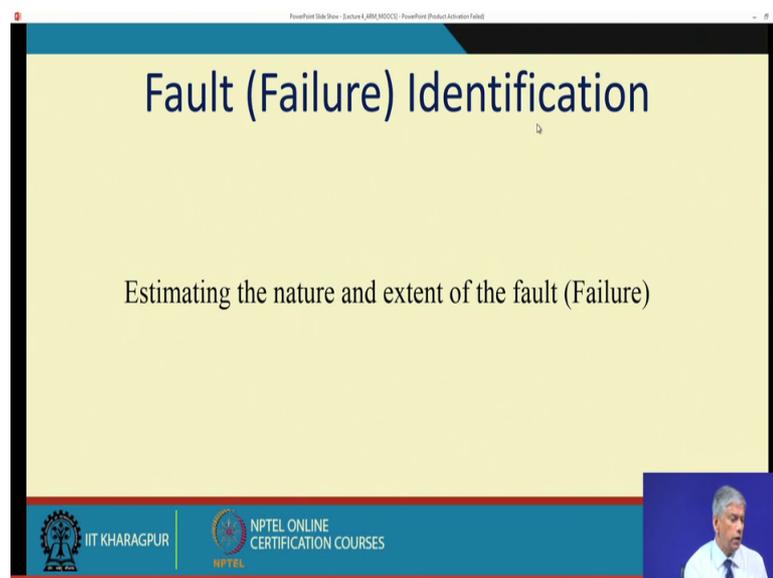
Now, fault identification estimating the nature and extent of the fault, this is also sometimes it may important because when we are talking about the RUL, this

information is going to help us well how much into the till it fails we are into in the time domain.

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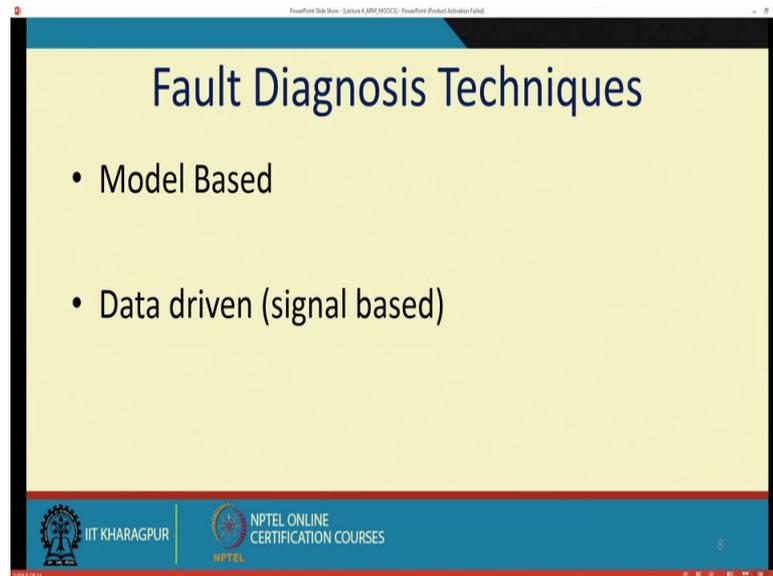
So, certain fault diagnosis techniques exist today, and the most popular being the data driven or the signal based which are I told you right in the beginning, we have a machine for a transducer get some signal analyze it see the characteristic frequency spectrum and then try to correlate with the machine component. But many a times I will be not allowed to get a signal from a failed machine, a nuclear reactor is a very good example.

So, there we have to develop lot of models; models based on the physics of the problem models sometimes so complicated that sometimes physics does not help us. So, we have to do some studies reading a using techniques like neuronal network etcetera, and I will I will show you an example in the next class how neuronal network can be used to prognost the fault in or a tool where.

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So, certain data driven fault classification one is you know stored fault pattern library is in a fault classification so; that means, the characteristic defect signatures are already there. So, one can do a comparison for example, when you talk about machine, I have a shaft, which is having gear supported on the bearing and there is a casing. That the casing on the. So, this machine there are three components; one is shaft, other is the bearing and gear.

We shall put a vibration transducer here require some signal, and I analyze it some xt see the failure in the bearing has a characteristic frequencies, failure in a gear has a characteristic frequency, failure in the shaft in the same in the terms being sharpened misaligned shaft being bent shaft having a crack. So, all these have a definite pattern and so in fact, today software are available which are very generic, it could be using it in any rotating machines, this machine could be a electrical motor could be a gearbox could be a palm, but the feature is the same know we have the shaft bearings gears and so on.

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Another is looking the feature vectors and a lot of studies today are going on using neural networks support vector machines fuzzy logic Bayesian networks and so on to diagnosed default. So, a lot of data driven techniques are being used to find out faults and we will see how this can be done.

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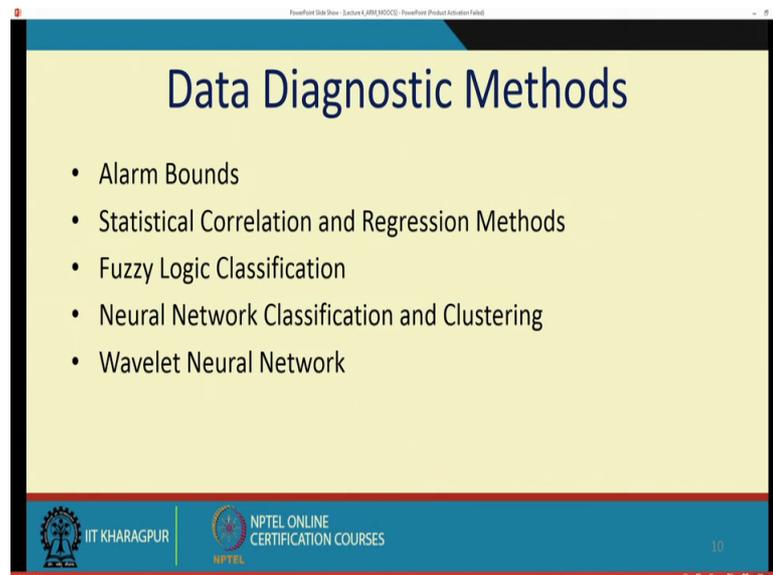
But then in certain diagnostic methods we also with time we can have certain band this is my usually this is my upper band.

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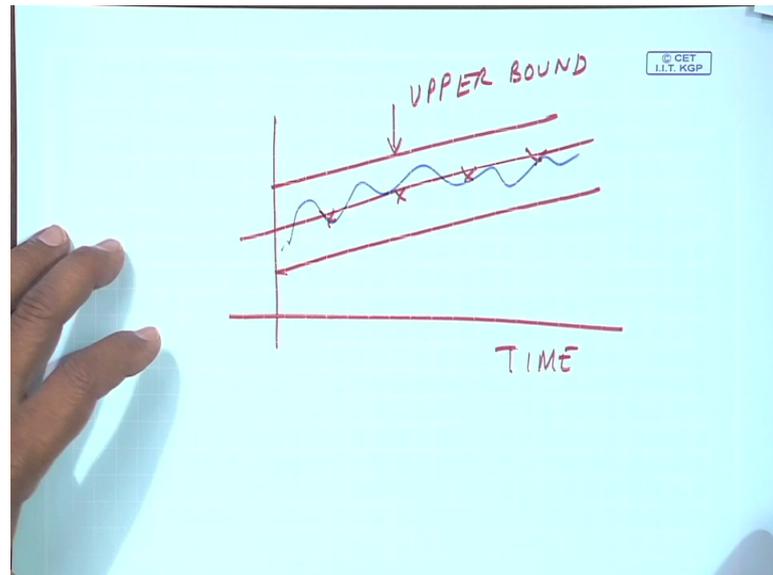
So, should failure occurs we put some upper bound? So, within this bound if there is a failure I may not get worried about. So, this could be changing and there is a lower bound. So, which time?

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So, this kind of bounds are also there in the software there are many data driven diagnostic methods, storm statistical correlation regression methods, fuzzy logic neural network and so on.

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But there are also many physical model based methods, I will just give you one example of how crack has occurred in a component like the shell of a rotary kill casing of a gearbox and which is subjected to fatigue loading know, this is the load cycle. So, this the crack propagation the crack depth depends on certain material properties and these powers are there. So, this is the; a famous a Paris equation, there is a time taken for the crack to grow.

So, we can use such models to estimate that after what time the crack would have come to a level which is not possible to be managed and then of course, today lot of numerical techniques like finite element analysis are being used for model based diagnostics, and that can be used to find out the faults in any structure which has a crack. But such physical model based I was just giving the case of a crack, today for rotor dynamics a lot of work people are doing on model based techniques for finding out faults in rotor bearing systems using the technique of finite element method to model the system and of course, update the models with realistic experimental data and so on.

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So, once robot robust models are available it is very easy to prognosis default. So, prognosis is the ability to predict accurately and precisely the remaining useful life of a fail component. See if I have a model I can always use that model to do what is known as the forecasting.
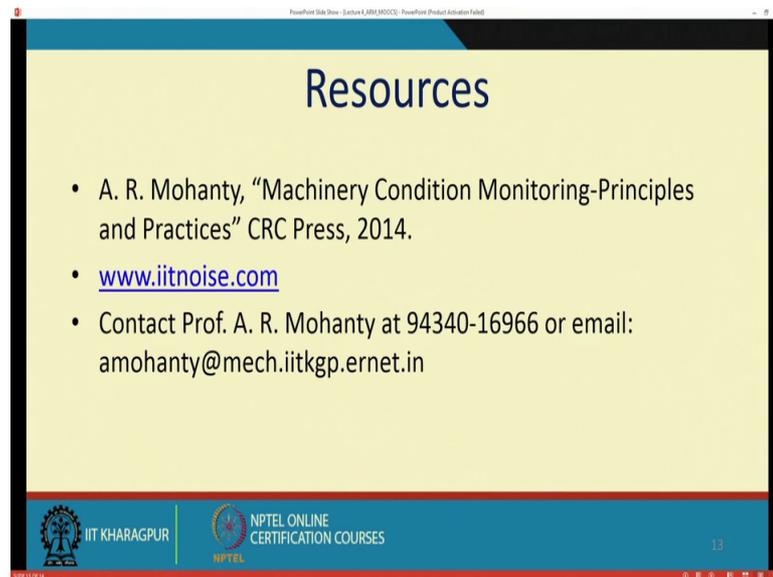
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So, prognostics is nothing, but what is known as the fault forecast for to determine RUL. And models will help us or even sometimes you know doing on filtering, we can have an adaptive filter which will let you know also looking at the past history.

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So, more resources on this can be found in my book and you can contact me our email or my phone.

Thank you.