Machinery Fault Diagnosis and Signal Processing
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Lecture – 44

IC Engines

Here in this class, I will talk about how do you detect faults in IC engines, as you will see or as you all know, IC engines are very important prime movers driving the motor cars motor vehicles because you know, today, people are talking about electric vehicles, we will talk about electric motors maybe next week, how you find faults with electric motors, but IC engines per say very easily, there are certain techniques which you know my vibration mountain, we can measure and if you think of an IC engine of course.

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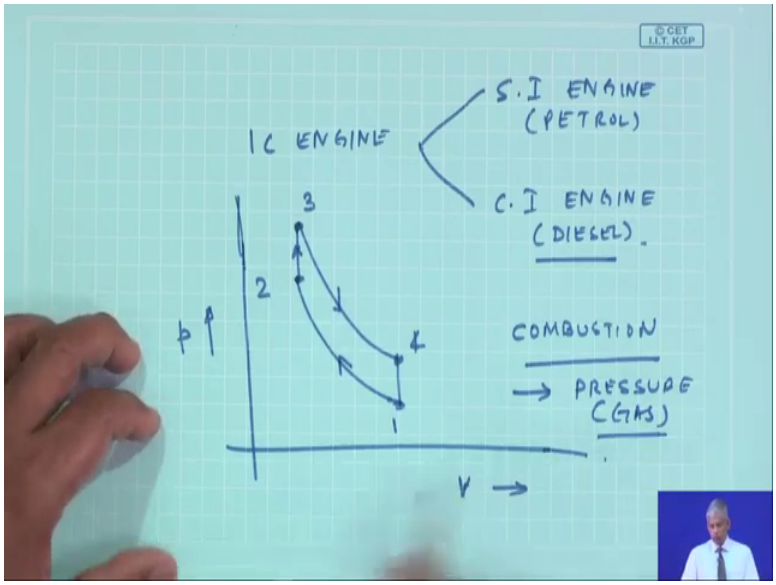

If you classify IC engines, there are through broad classification the SI engines in the patrol spark ignition engine and the CI engine and the diesel engine the compression ignition engines ok.

So, if you look at the pv diagram of a nice engine, any engine for that matter this of course, work done from the engine is the area enclosed by this curve, but as you all know in any of this engine for this foreign petrol engine the because of combustion of the fuel we get an pressure which we call as the gas pressure.

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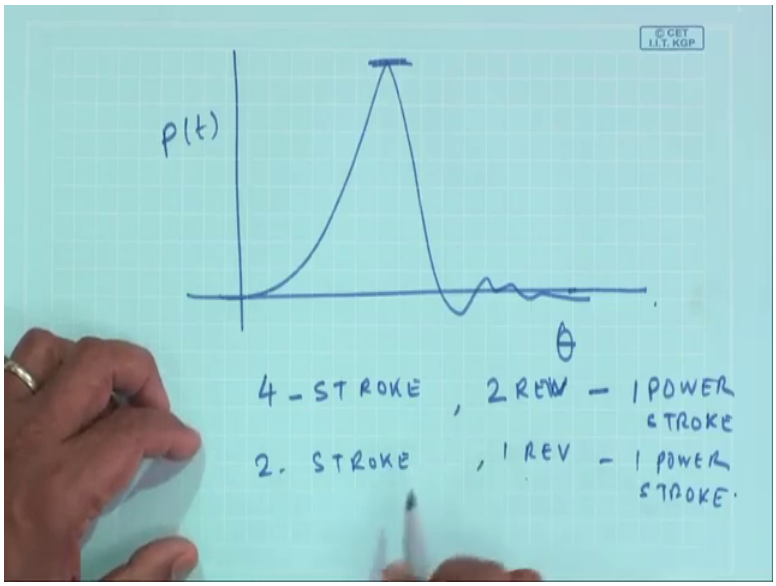

And this is the prime mover this combustion of the fuel is responsible for giving rise to a pressure and it is this pressure which is responsible for the power and so on and then of course, in 4 stroke engine, we have for every 2 revolutions 1 power stroke and for a 2 stroke engine, we have for every revolution on power stroke.

So, because of this combustion it is a force gas force which is coming on to the lesson if I have a cylinder ok, this gas force because of the pressure and of course, this will this will lead to you know and so on ok.

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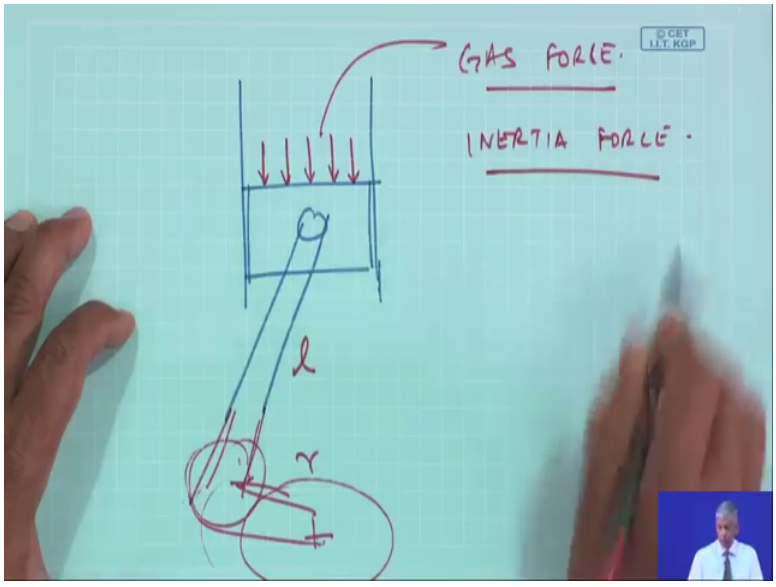

I will have of course, there will a. So, and any but it is what happens this gas force and of course, because of the slenderness ratio I will also have the inertia force in the system.

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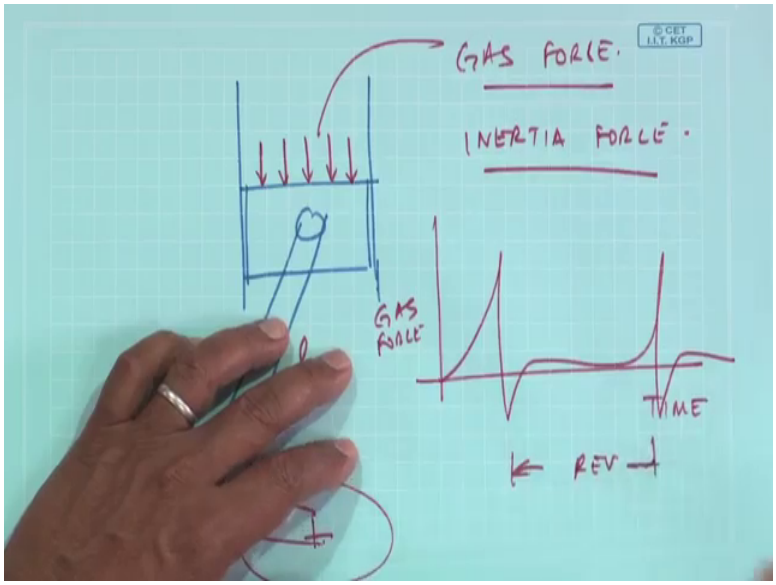

So, this force as a function of time is dependent on the every revolution, I will have per cylinder this.

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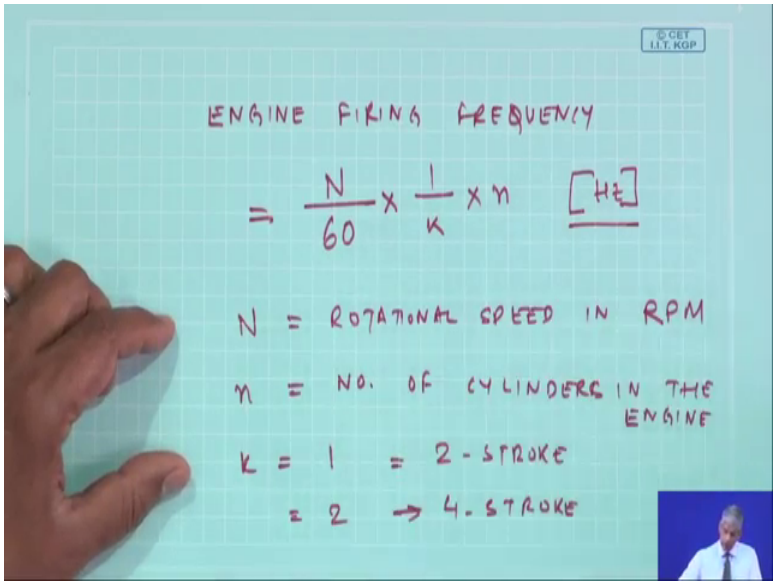

So, the frequency of this gas force is what is known as the engine firing frequency which is nothing, but where n is rotational speed in RPM. RPM is revolutions per minute and small n is number of cylinders in the engine and of course, k is equal to 1 for it is 2

stroke engine is equal to 2 for a 4 stroke engine and this engine firing frequency will, then given in hertz. So, for every engine you can find out this.

Now, this essentially means that all the cylinders in the engine are firing. So, if you so, how do you monitor the health of an engine I could monitor the cylinder combustion pressure, but as you know the cylinder combustion takes place inside the cylinder and the cylinders are held in the engine block and there are high forces.

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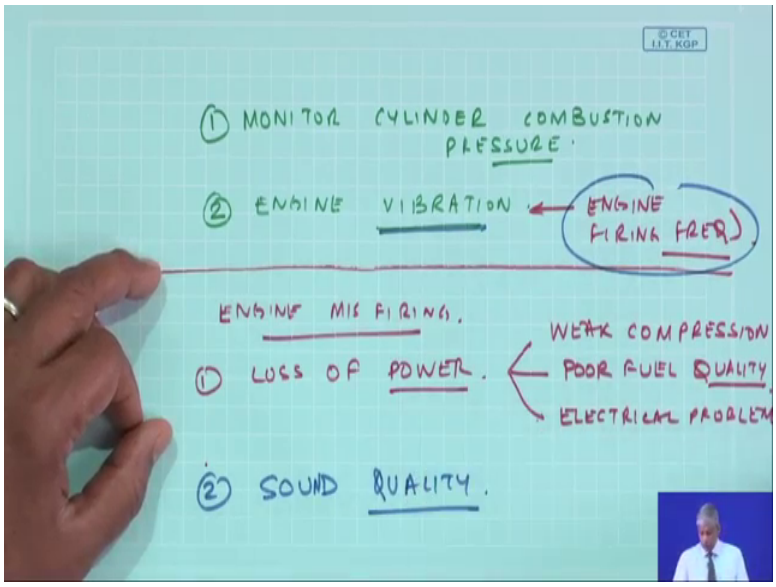

And so, from the to measure the cylinder pressure we actually have the pressure sensors which has to be put inside the cylinder which can withstand the high pressures and high temperatures which occur inside the combustion chamber or alternately we can measure the engine vibration ok.

So, if you monitor the engine vibrations; obviously, at more speeds been more rate of combustion and more pressure in a given time. So, the vibrations level would increase, but then if you do the frequency domain analysis of the vibration signal you can also deter the engine firing frequencies ok. So, this could be direct, but before I get into how to detect it what are the possible force which can occur in an some of this picture has not come here and a, I will show you an engine here limit you go back yeah it is come down.

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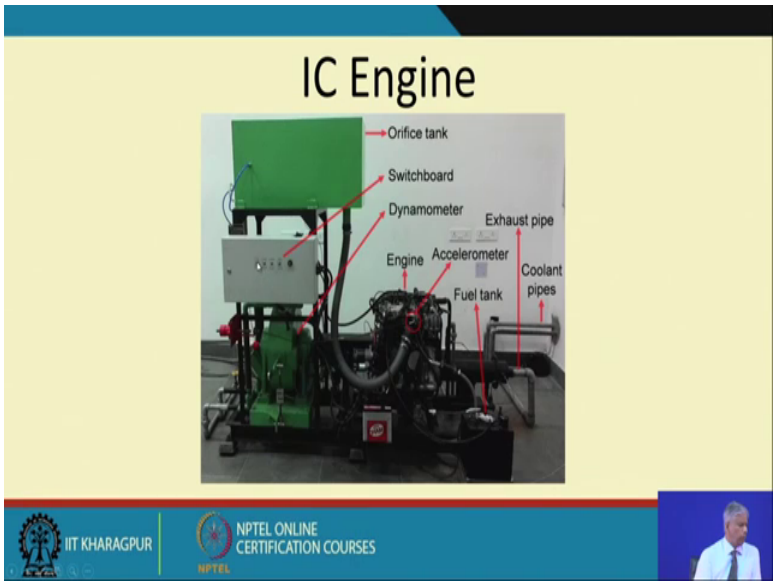

So, this is are typical engine where you will see in our laboratory this is a 4 cylinder engine which is coupled to a dynamometer and there are 4 cylinders there are 4 switches here which can switch off the electrical supply to the spark plug of this engine. So, that I can create a fault by what is known as engine misfiring and of course, you will see there is an water cooled engine.

So, that the coolant pipes the exhaust pipe and so on. So, one in this case studies, you will see here is an accelerometer to measure the engine vibrations of course, this cylinder

has a lot of instrumentation. So, this engine has a lot of instrumentations as well and there is a pressure sensors mounted inside the cylinder to measure the engine pressure.

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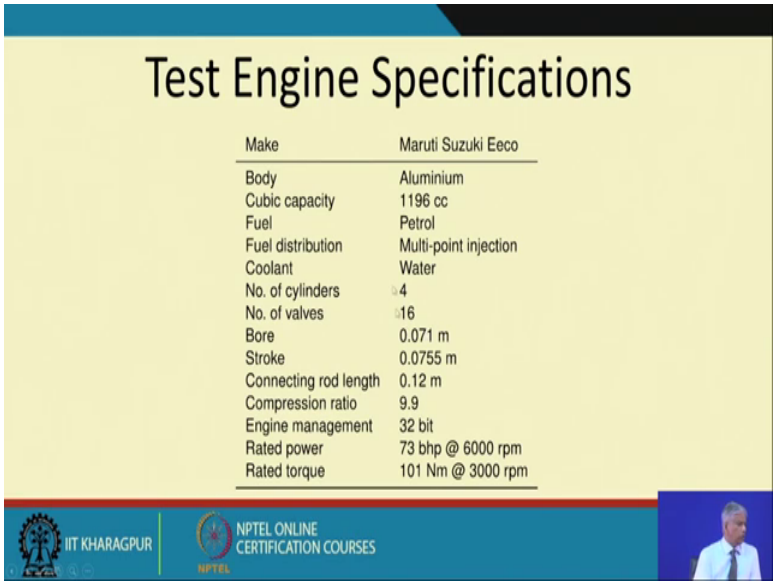

So, this is the specification of this engine the total cubic capacity is about 1200 ccs, it is a petrol multi point injection water volt engine number of cylinders is 4 with 4 valves per cylinder and compression ratio is 9.9, it is this you there rated power is about 73 BHP at 6000 rpm and 101 Newton meter at 3000 rpm. So, what are the typical faults which can occur in a nice engine of course, one is loss of power loss of power could be because of many reasons weak compression weak compression occurs because there will be lot of blow by and the cylinder rings have worn not so much that there is a lot of clearances between the piston and the cylinder walls.

So, loss of power could be because of this poor fuel quality and both the quantity as well engine misfiring because of an electrical problem. So, all this would happen of course, because and of course, you know this would lead to if you have mountain the engine vibration this would lead to change in the engine firing frequencies or change in the vibrations and of course, also what is known as this sound quality which you perceive would also change and you would see In lot of the engine manufacturer even new engines.

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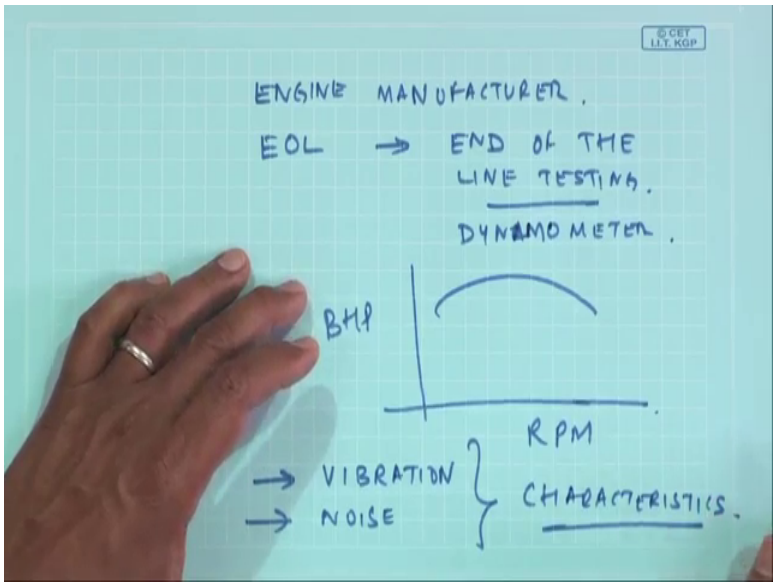

They do what is known as EOL and of the line testing maybe on a dynamometer to see the RPM which is the BHP curve, whether it is producing as for the design specs, but sometimes even monitoring the vibration or the noise and looking at the characteristics you can find out the faults in the system.

In fact, I was approached by a company in South India, two wheeler manufacturer to develop such a system and at given them the idea of using sound quality and the more details you can see in my website ok.

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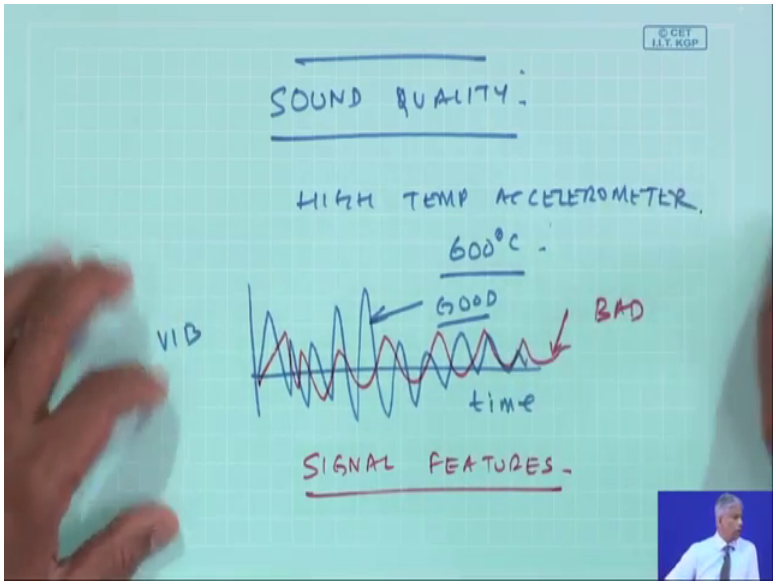

So, here what we have done in this particular case in our laboratory we have put a microphone inside an enclosure made around this engine and that is why one of my students was since graduated whose operating the engine and these are fellow, we are recording all the signals coming out of this engine onto a tape recorder for subsequent analysis and find out they cast its characteristic qualities of the signals when a defect has occurred and we could artificially induce defense by switching on and off the engine.

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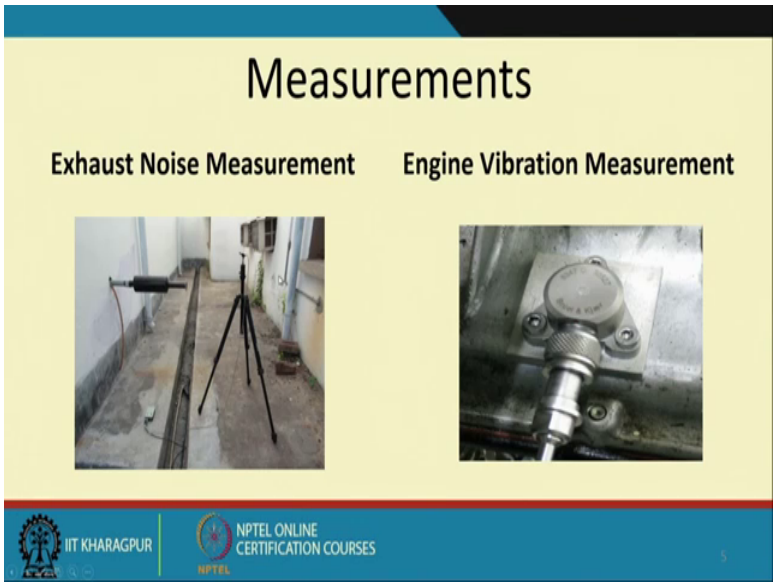

And at the exhaust side we have a muffler and then we have put a microphone here to measure the exhaust noise and in this particular example, we did not measure the cylinder pressure rather measured the engine vibration by a high temperature accelerometer, by the way this accelerometer is very costly and you can measure all the way up to 600 degree Celsius using such an accelerometer and you can see because of high temperature all this cablings arrow all metallic sealed in metals.

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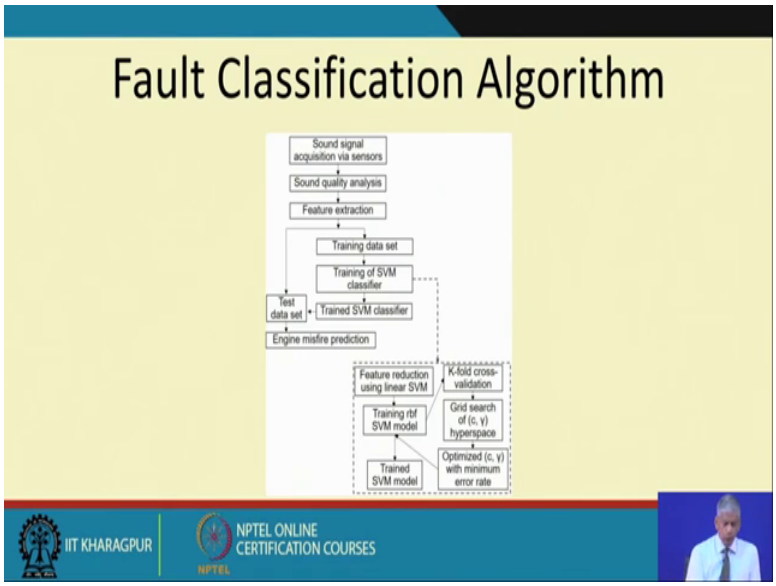

So, once we have got the signal we used for those of you who are interested because you know I will get a time domains signal beet vibration a good engine or a bad engine this is maybe bad or a good sometimes to the naked eye such signals are very difficult to distinguish. So, we can use certain signal features and we can classify the faults here in this example we took the sound signals.

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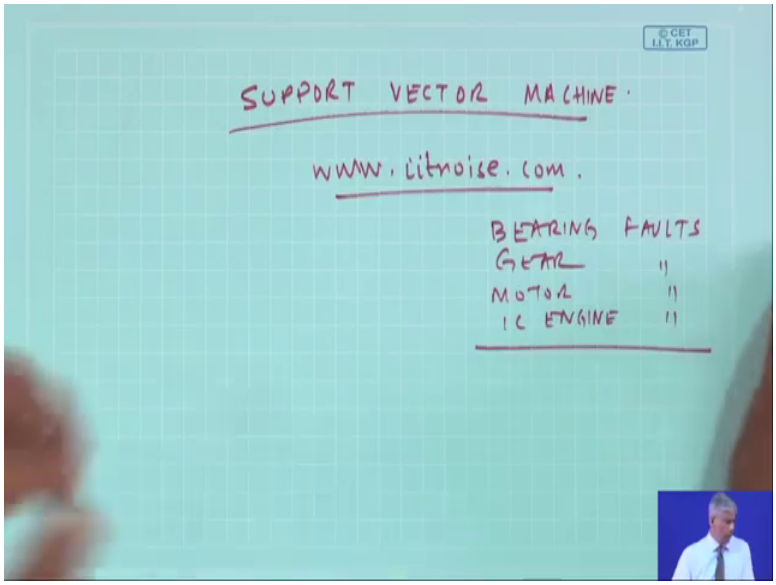

So, by a method which is very popular nowadays the support vector machine for a classifications and more details about this, you can find in my website on some of the

general publications in this area applied to find out finding out bearing fault gear faults motor faults of course, IC engine faults and these are techniques.

So, I will not go into the details of this, but all I need to say is I need to measure this signals do certain feature extraction and use an SVM to detect healthy engine from a non healthy engine the reason, I am saying this is you know vibration is we have to put a transducer.

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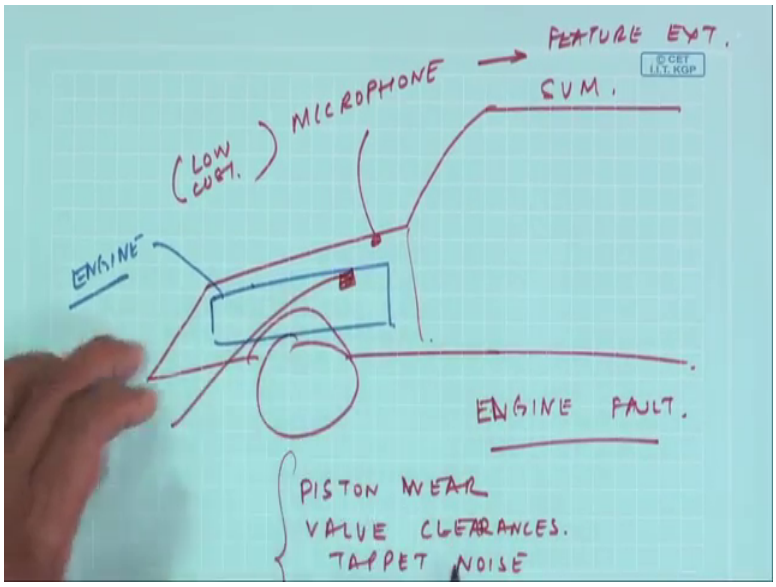

But imagine in a automobile my engine is placed somewhere here imagine, if I put in the hood microphone a very low cost microphone and I have I am giving you this ideas you know, I have not patented them, but this because there is nothing novel and patenting it, but somebody could implement this in an industry that we put a microphone and have the future extracted and use an SVM fault classifier to intimate to the driver that there is an engine fault.

Because this is very cost effective because you know a driver sometimes if it is not he is not experienced he or she is not experienced may not right away feel the loss in the power because of some malfunction in the engine, but this abnormal change in the noise characteristics is a good indicator to what kind of faults would have occurred in this engine of course, you know, I am not going to the details of the engine for example, there could be piston wear, there could be valve clearances tappet noise.

So, all these could be very easily quantified because in issue the engine is covered and is nicely and closed the contamination from outside noise is not there and this being airborne lot of the structure borne issues which are there with the traditional vibration measurements because if I put a vibration transducer here it is going to measure all sorts of vibrations; because of the suspension because of the engine because of the transmission.

So, this becomes a very complex signal compared to a noise signal which is just there inside this hood of the engine ok. So, this is an area where somebody can look into to monitor the health of this engine.

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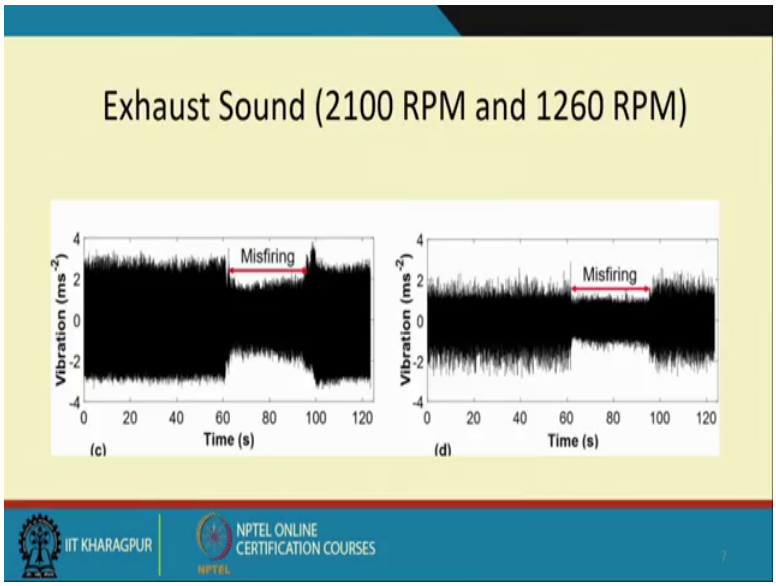

So, I will give you an example in this case here of course, in this laboratory as a case study we ran the engine at many different RPMs and I have just given you two representative rpms one being at twenty one hundred RPM another being at twelve sixty RPM and the vibration was collected by that accelerometer measured by the accelerometer for about two minutes and I must tell you that this is a normal engine and we artificially misfired one cylinder.

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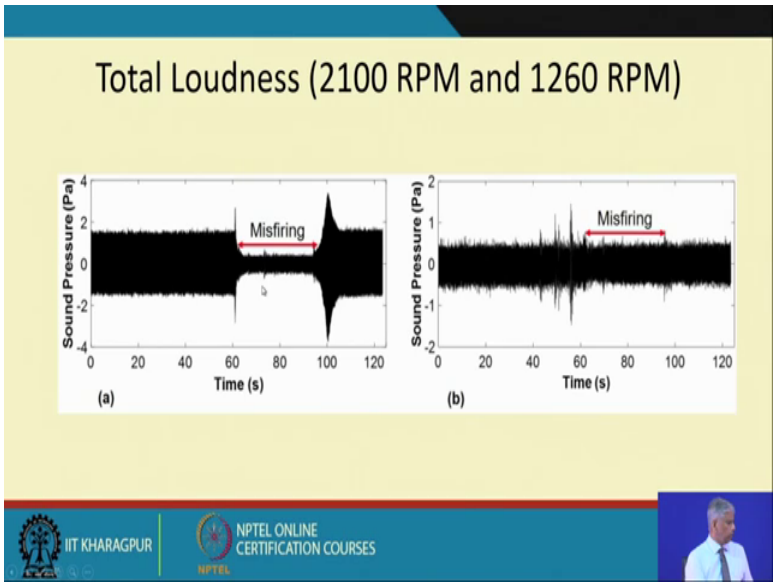

So, you can see right away there is a typo here, the should be a sound pressure here sound pressure here. So, you see the sound pressure here there will be the case of misfiring at a low RPM, there is a misfiring, but the sound, we are not able to detect visually in the time history both the amplitudes are low as compared to the sound pressure which drastically reduces at high RPM because of misfiring and at the end of about thirty seconds we again switched on the engine.

So, once you switched on engine the sound shot up and then it reduces. So, what somebody is driving it will be very difficult to distinguish between firing and misfiring, but then if you have an algorithm wherein you extract the features and do an SVM and you can do it and you see this is the case of an engine vibration when we have misfiring occurring this is at a higher RPM and this at a lower RPM.

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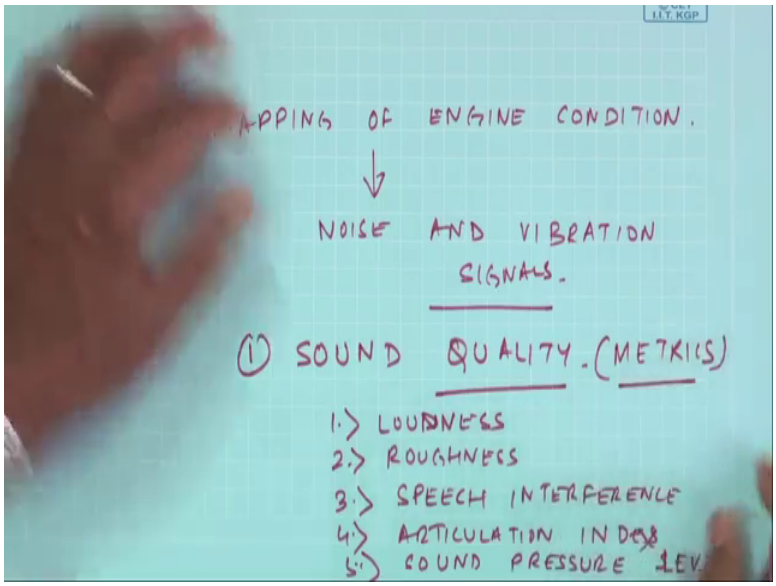

So, if somebody maps mapping of engine condition to the noise and vibration signals you can find out the engine conditions and I must give an example today, people are looking to sound quality.

So, sound quality is nothing, but objective matrix for subjectively evaluating a sound now when I say something is good something is bad now somebody may says, it is noisy somebody, somebody else may say it is not noisy. So, this becomes very subjective somebody may like a sound somebody may not like a sound, but there is a scientific method by which the sound which here from any machine beat an engine beat appliance. It can be quantified by a few objectives like the loudness like the roughness like the speech interference articulation index etcetera of course; we all know the sound pressure level. So, far we have talked about only sound pressure level.

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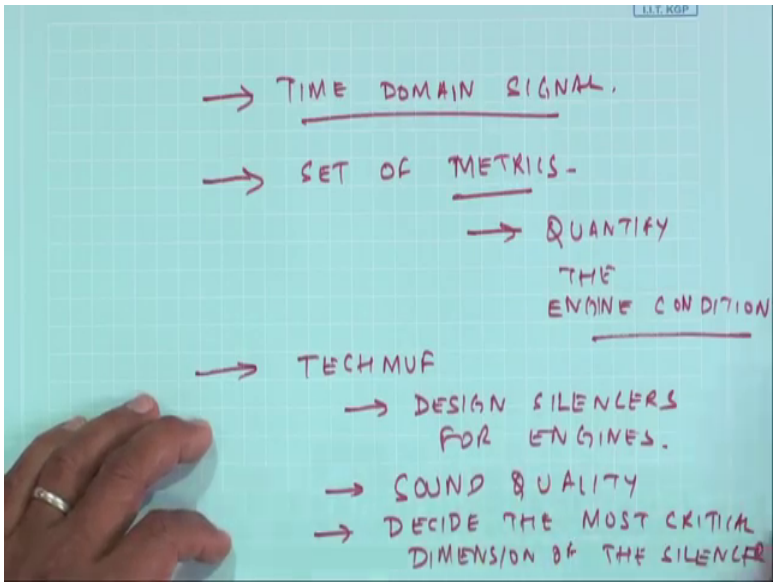

So, there are sound quality matrix which can be measured from the time n domain signal and you can have a set of matrix which will quantify the engine condition ok. This is possible and this is a they are in for mini machines and an operator or a manufacturer can design systems where in such set of matrix can be done and we have also had IIT, Kharagpur used a software called tech mop to design silencers for engines and used sound quality to decide the most critical dimension of the silencer.

So, which will tell us which is the best parameter; the designer should play around with the silencer design. So, that they sound the best. So, such research areas are being pursued by people throughout the world in and in the industry to use sound quality as a means to find out, I just give an example in this class on how sound quality can be used to detect engine misfiring and earlier, I told you how rotary optical encoder could be used to measure the change in the rotational speed because of the misfiring and detect the engine misfiring frequencies.

You can use lot of signal processing algorithms like the empirical more decomposition to find out features from signals which are highly non stationary and where you do not require really long time length of data which is sometimes require when you are analyzing stationary signals.

So, lot of algorithms are coming up in the world of machinery condition monitoring empirical more decomposition being one at the same time, lot of miniaturization in

instrumentation embedded systems embedded sensors are coming up which can help us diagnose faults in mechanical systems.

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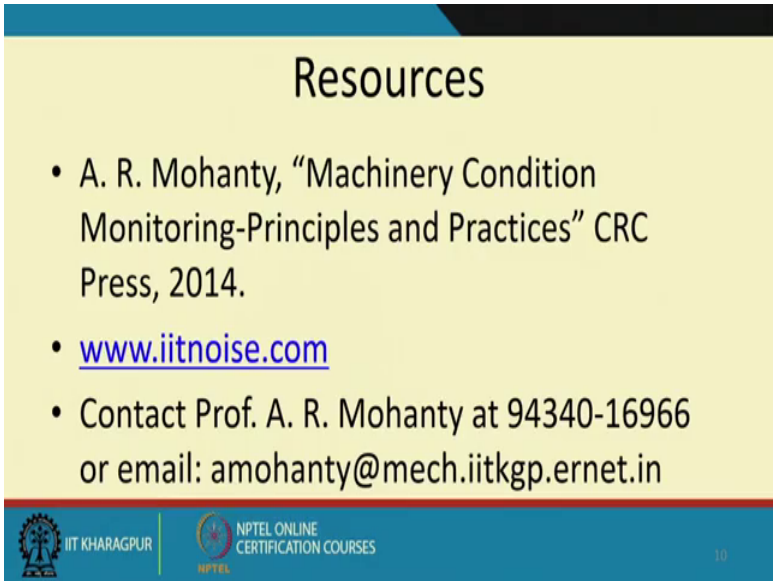

So, some of these examples you will find in my book as well.

Thank you.