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

Lecture - 54
Tool Conditioning Monitoring

Well in this lecture, actually, I am going to discuss a case study on tool condition monitoring, this is out of a given a research which you did at IIT, Kharagpur, again close to 2 decades ago and in fact, this was the study which we are doing when I first discovered the power of MCSA. So, I will describe that and then I tell you how certain techniques can be used to diagnose a fault and if it is a model based system how it can be used for fault prognosis ok.

Of course the technology or the techniques today available for tool condition monitoring are many like visual based inspection ok, but then today we thought of looking at it in a very broads way including larger scope.

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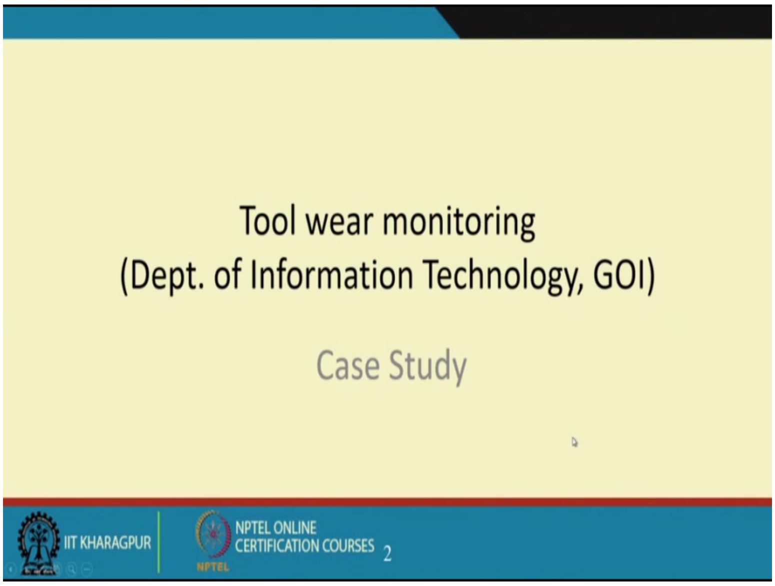

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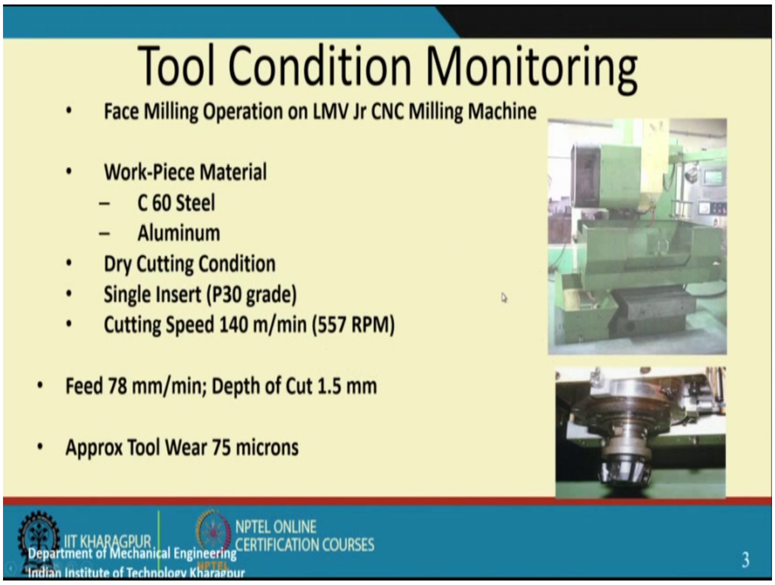

And let me tell you; what this was done, this was an sponsor research which we did supported by the ministry and then if you look here, I have a milling machine ok, vertical milling machine.

Where we machined both steel and aluminium of course, the cutting tool no cutting fluid was used dry cutting condition in the cutting tool there are options of multiple level multiple inserts, but then we only used a single insert a cutting speed was around this range speed feed and depth of cut was maintained feed at 78 millimeters per minute depth of cut at 1.5 mm and approximate tool where to begin with was 75 microns ok.

So, this machine was instrumented with many sensors ok, I will come to the sensors here.

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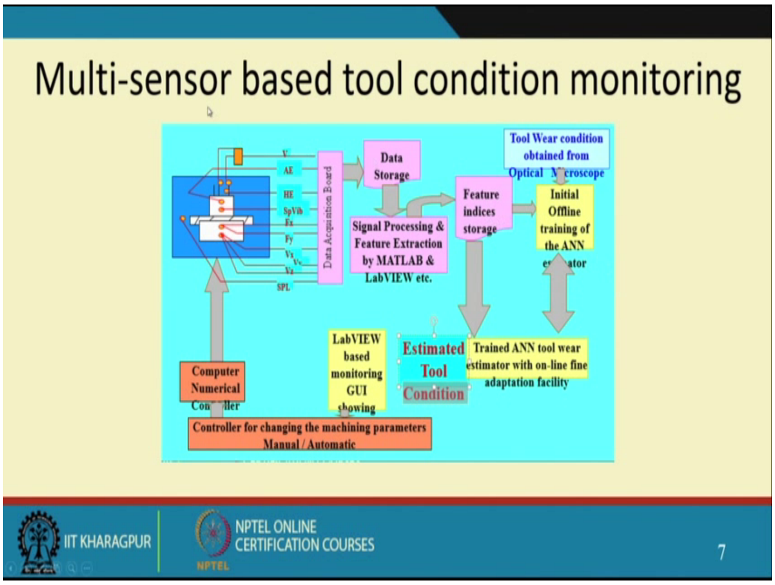

So, this was a multi sensor based tool condition monitoring work where within, I have this machine here and the idea behind this is why are you doing this tool condition monitoring because what you know. So, happened if the tools condition is very blunt it is not sharp I may be damaging the tool or damaging the work piece ok.

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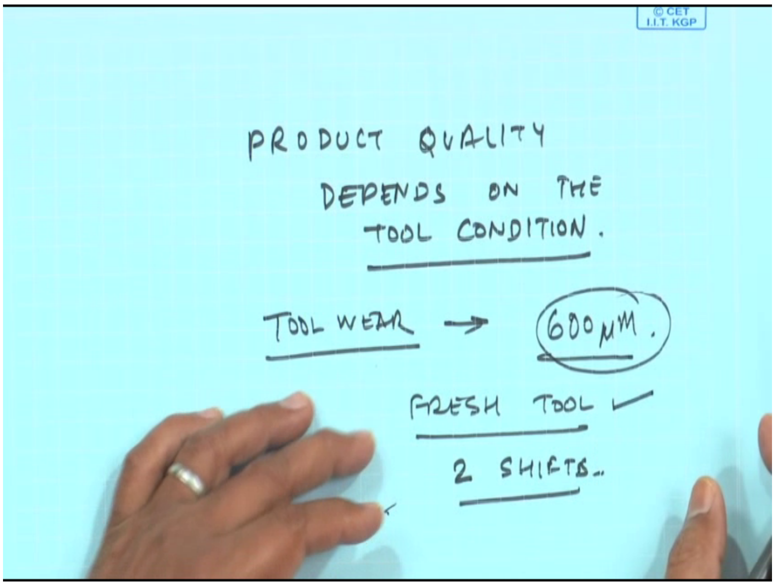

My product quality is going to deteriorate depends on the tool condition ok. So, the flank wear of tool wear which we will discuss usually beyond 600 microns. So, you are manufacturing specialist will say is time for the tool is blunt and it is to be replaced. So, in a large production plant if you will see you, only day in and day out, when there are doing machining operations, how do you know that time has come for the tool to get replaced ok.

So, they usually go from the operators experience that you know every tool which is a fresh tool which is put is maybe for the same operating conditions is replaced after every two shifts ok, but sometimes the tool may be good tool may have lot of remaining life. So, we may not be optimally utilizing the tool. .

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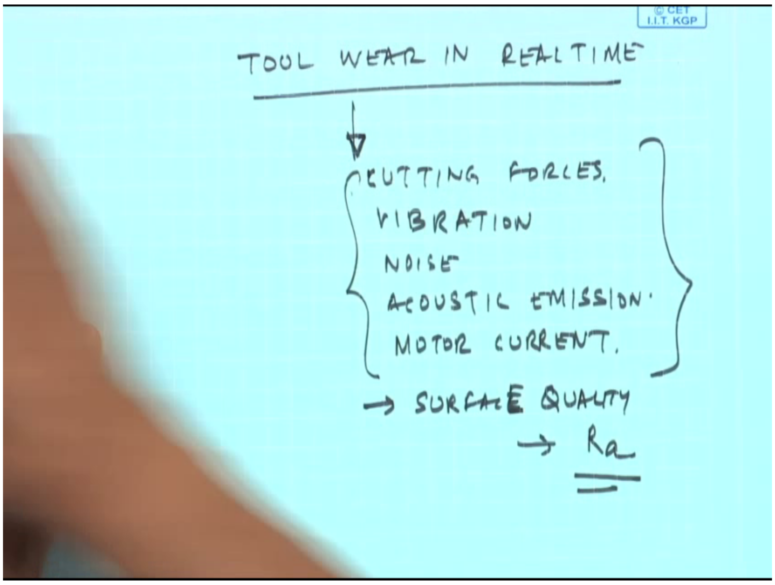

So, to optimal optimally utilize the tool we need to know it is tool wear in real time ok. So, what is this tool wear going to do tool wear is going to generate with the tool is blunt it, it will generate more cutting forces cutting forces would increase we can very related a to a blunt knife and a sharp knife.

Imagine you are trying to cut an apple with a very sharp knife and the same apple with a blunt knife, you require an less force with a sharp knife. So, similarly with a sharp tool here cutting forces would be less ok. So, if your forces are high there could be vibrations, there could be noise, there could be acoustic emission load on the motor, the motor current could increase of course, I can also a measure some method the surface quality by maybe surface roughness by an R a value.

We saw we all this parameters. So, this is what we did in this experiment we measured all this signals the acoustic emission in the springal vibrations the cutting forces the vibrations the noise level the voltage and current drawn by the motor and acquired all the signals and extracted the features and develop the program where we selected the features out of this signals and stood them in inputs at the same time we also after every run every pass of the cutting tool in a it is a milling machine.

So, every pass of the cutting tool yeah we measure also the tool wear. So, then we mapped the tool wear with all this measured features and developed a model based on artificial neural network ANN.

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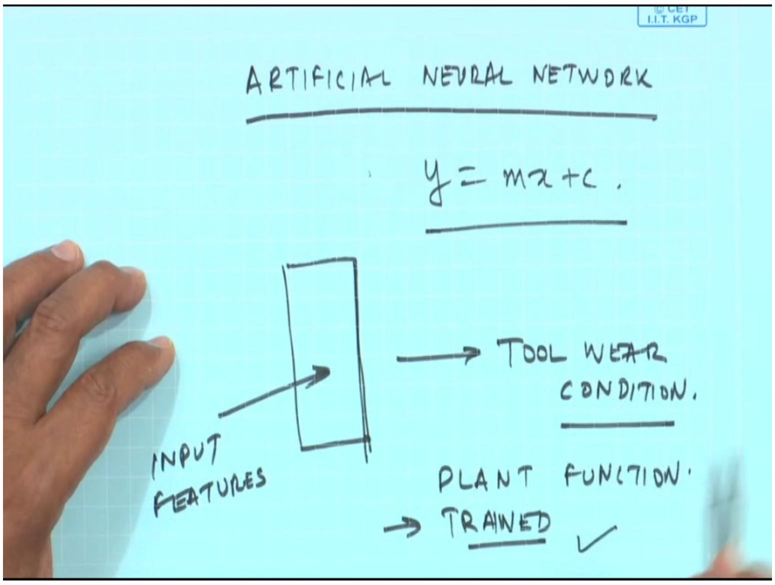

This work, we did about the two decades ago and today you know people are talking about many soft learning techniques are there like you know your a support vector machines you know, we will today are talking about in a data analytics in a big way ok, but these technologies do exist, you know I say y is equal to mx plus c you know existed long ago ok.

So, so, when people studied y is equal to m x plus c where they are not doing data analytics they were in the sense, today, only thing as I have what is happened computers are there. So, that we can do many things accurately large number of datas and more accurately ok. So, data analytics for that matter is not new outsides the old wine in a new bottle we as a mechanical engineer root say that ok.

My friends may disagree, but anyway. so, what we did is we mapped all the input features to the tool wear condition and developed a plan function which was trained like you do in a little door and then lens forth what happens if you have a trained plan function out of, then ANN model for any input features it can very easily predict the tool wear. So, we estimate the tool wear by having a online adoption facilities.

Now, in a tool condition monitoring how is this going to help say for example, once you know the tool were you can take control over the machine and maybe reduce the tool the depth of cut reduce the speed of operation.

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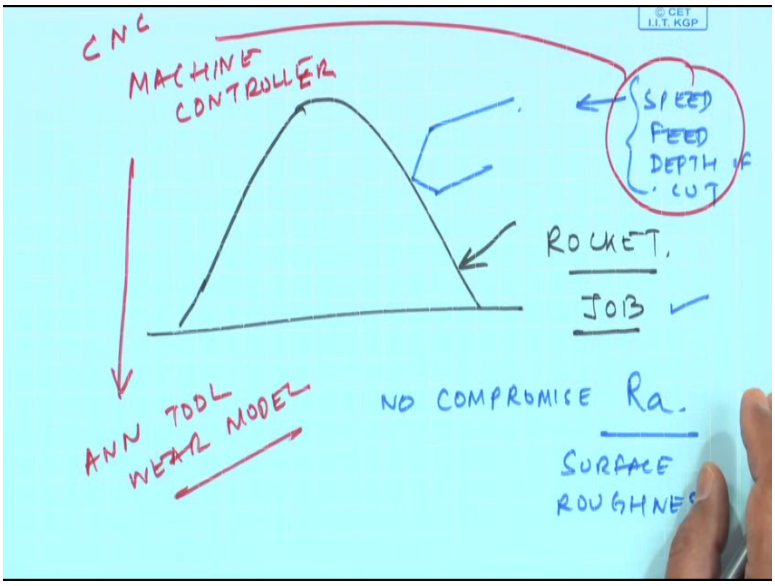

Sometimes you know large machining one of them machining a dome of a rocket. So, it is one of a kind job, I do not want my blunt cutting tool to damage these surface. So, in such a condition what you can do, you can reduce the speed feed depth of cut. So, that at least the job gets done complete the job at lower rates, but nevertheless no compromise on the surface roughness.

So, this command on the machines controller here machine CNC machine controller could be given the appropriate command bases from your ANN tool were in a model ok. So, you get the complete picture, I measure the missions condition, I know the present tool were for the machines conditions developed the plant which is trained and now, when I do not know the tool wear from my machines a conditions, I can predict the tool wear and then take control. So, that the even at a load tool wear or a blend tool I can complete the job whatever with the case.

So, this is what we did in this research project which was a multidiscipline multi departmental project.

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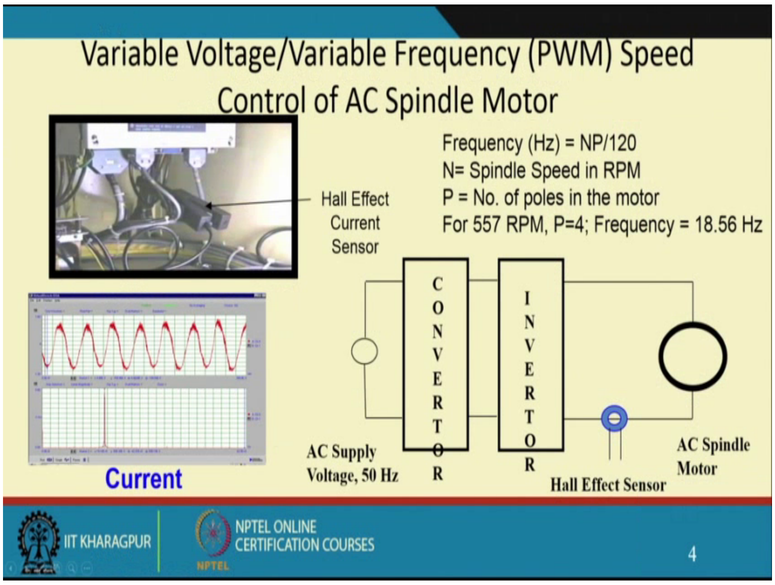

So, just a give you an view now you all know about motor current now. So, this is this Hall Effect sensor used because this had a very well frequency dry if ok. So, you put an hall effect sensor where in we could change the speed of the motor spindle motor by changing by frequency and you will see for no load case when there is nothing being machine the current is nicely a sign wave and I have a single component ok.

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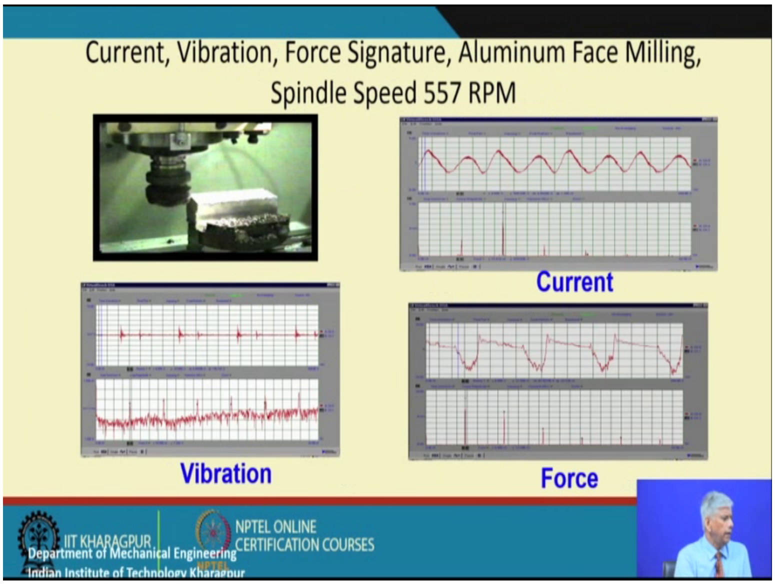

And of course, I was telling you this machining operation we monitor the current by the hall effect sensor we monitor the spindle vibrations and we measured also the force by putting this work piece on a cutting tool force dynamometer ok. So, every time the single tooth comes in contact with the surface there is a force and comes out.

So, this force seen which are looks like this and there is a periodic impact every time the cutting tool comes in contact with the work piece. So, there are impacts and they you can see the frequency of this spindle from this spacing here, but I want to draw your attention to this way from here the current is no longer sinusoidal current has got a modulated and I had told you in the class on motor current signature at analysis. So, there is a load on this spindle motor because of the cutting forces or because your machining and aluminium work piece.

So, because of this modulation there are you will see sidebands around the cutting around the supply frequency to the electrical motor. So, you see this two side bands in there amplitude give us a clue as to an external load is coming on to this spindle motor and in this case this is external load was because of machining aluminium and we were initially surprised twenty years ago when we saw that we when the same scenario when we started to machine steel the modulus and increased because; obviously, the forces have increased the vibration has increased because steel being a much harder material to cut then aluminium.

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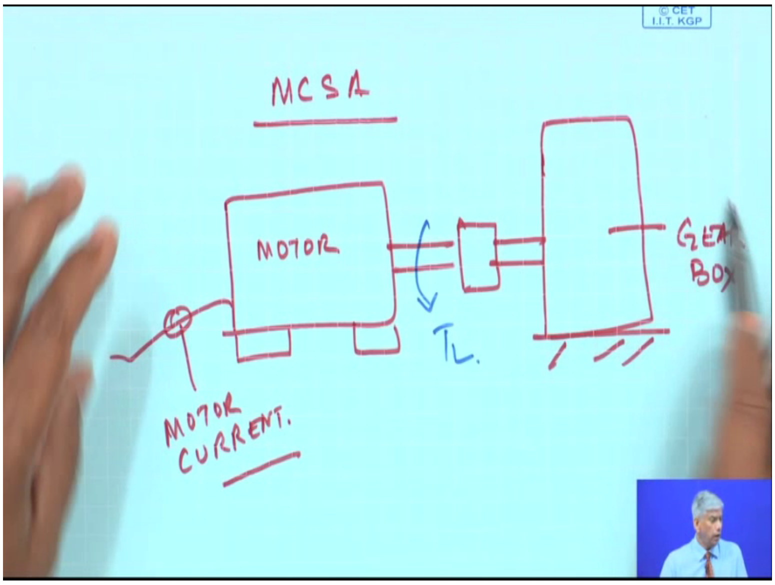

So, just give us a clue why not we use MCSA to find out falls in mechanical system being driven by electrical motors. So, then and now we studied gearbox and so on which I had discussed earlier ok, but this research was our origin of finding out MCSA ok. So, any load torque which comes because of a defect and in this particular case it is because we are missing steel. So, we have current force vibration and then we have other features.

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And this facility this system which we developed we tested at a gearbox manufacturing facility online on a CNC machine, we instrumented, we developed this algorithm in our labs we implemented, it an online gear manufacturing facility.

So, you can see twenty years ago how the systems look like we have to carry and isolate scope large desktop with all the signal conditioning amplifiers and filters, but today everything can be done even on a small laptop little DAQ all this could be done ok.

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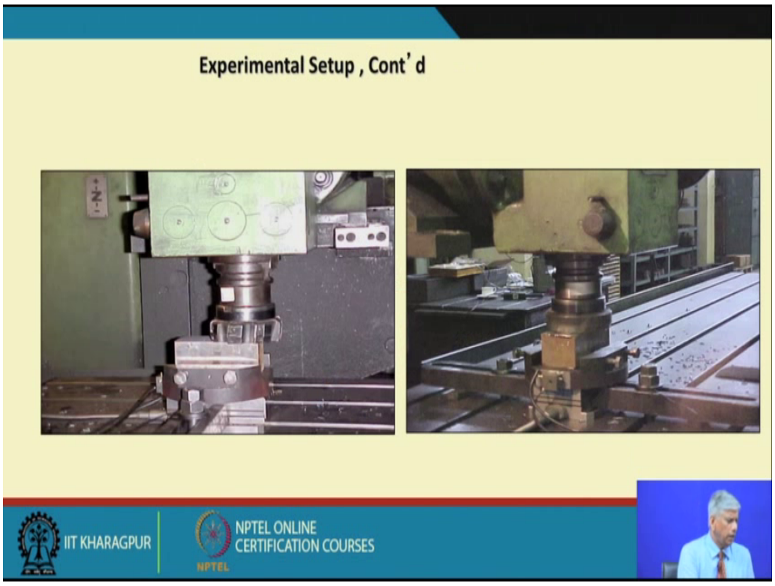

And then again you can see a close up view of this spindle where in we quickly mounted the accelerometer here on the cutting tool where is the cutting tool force dynamometer onto with this workplaces set ok.

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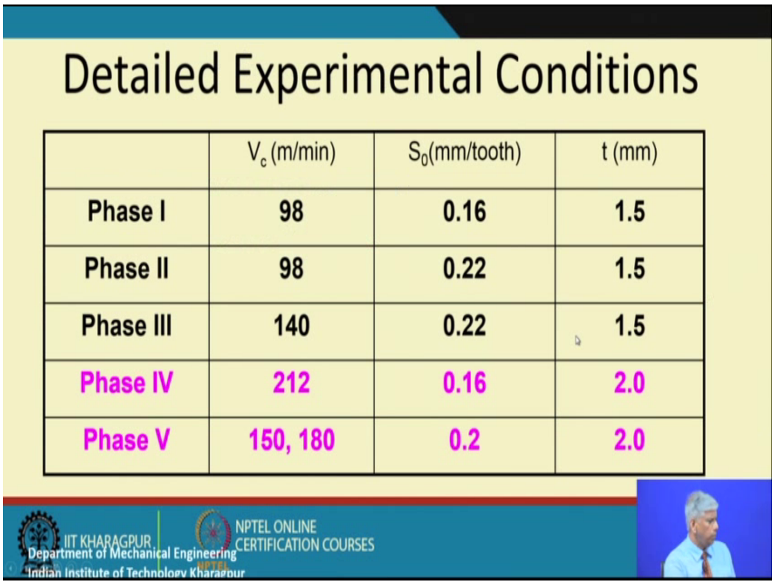
Detailed Experimental Conditions

	V_c (m/min)	S_0(mm/tooth)	t (mm)
Phase I	98	0.16	1.5
Phase II	98	0.22	1.5
Phase III	140	0.22	1.5
Phase IV	212	0.16	2.0
Phase V	150, 180	0.2	2.0

And then we measured all the parameter. So, there are different phases where in we had the feed rate the depth of cut and the speed.

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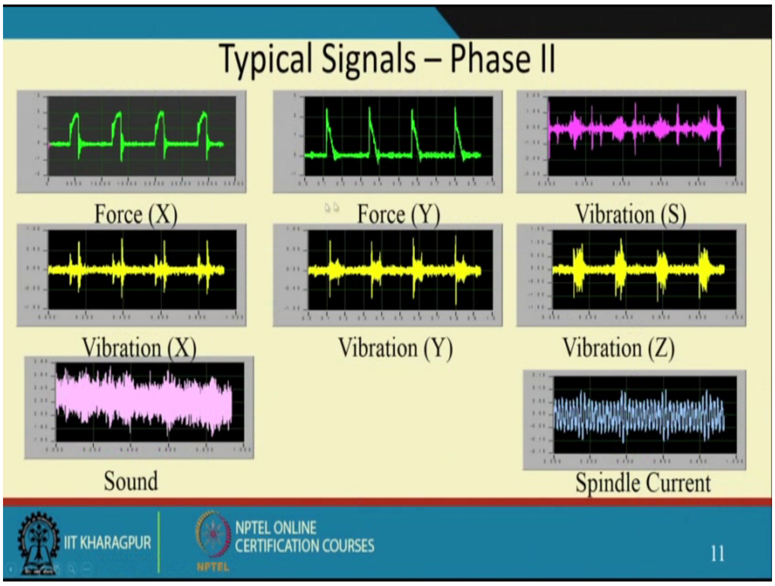

So, for different machining conditions we captured all the machine parameters and this is the typical signals. So, you have the force signals the vibration signals spindle vibrations, the machine vibration signals the noise signals which I have told us sound and the spindle current, etcetera. So, once we get the signals, you will recall, I had told you in signal domain analysis whenever we have a signal we will extract the features.

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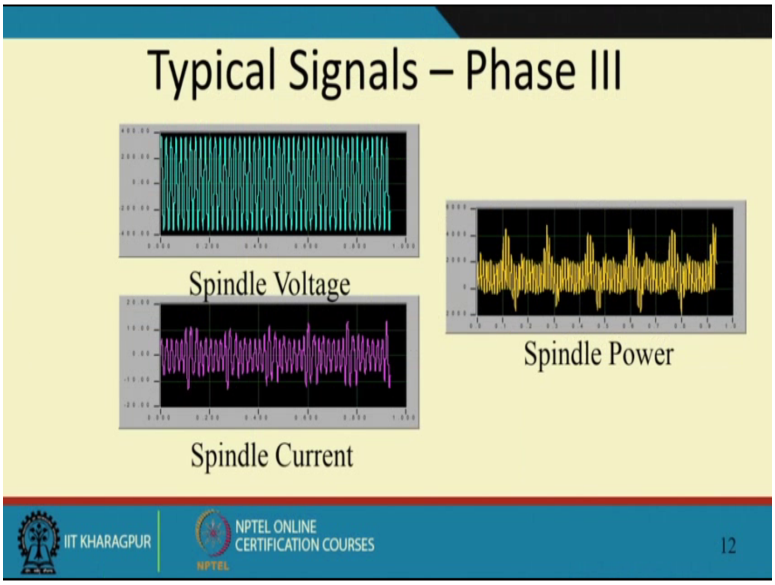

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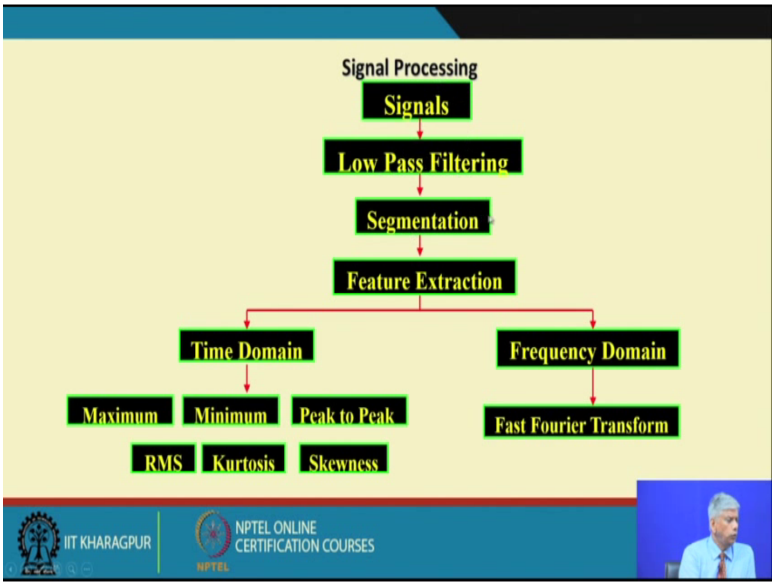

So, we did extract the features and so, we did lot of filtering to remove the artifacts in the signal which were which was not of interest to us and we segmented it and I will show you this is my next slides and we did this features extraction only in the time domain.

We did not even going to the frequency domain because this is lot of information in the time domain signal itself these are pretty much stationery signals to the machine is running at a constant speed. So, this features one they were extracted we could map to an artificial neural network program.

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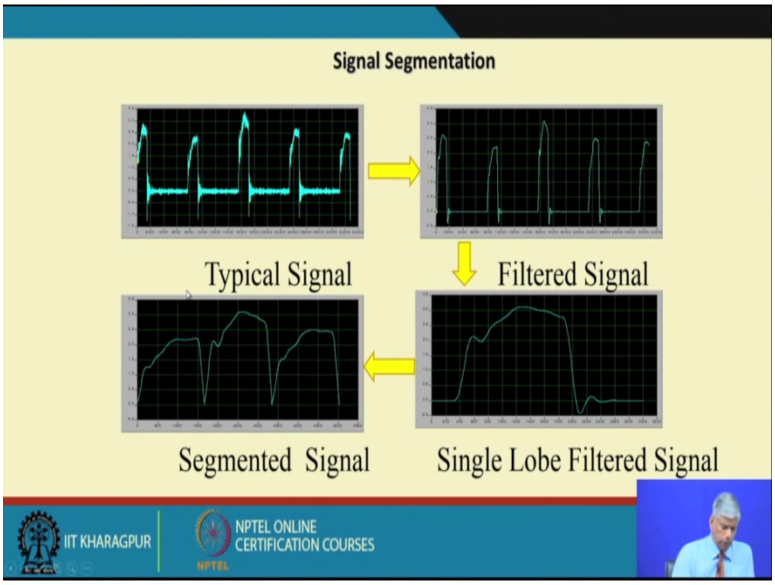

So, a typical signal as you can see, it has lot of noise over it. So, we did a low pass filtering and then this is the filtered signal, ok, I am in where we have remove the high higher frequency effects and then you will see this, there is no information.

So, we magnified one lob we remove the lobs the, this lull period and spag them together the segmented signal.

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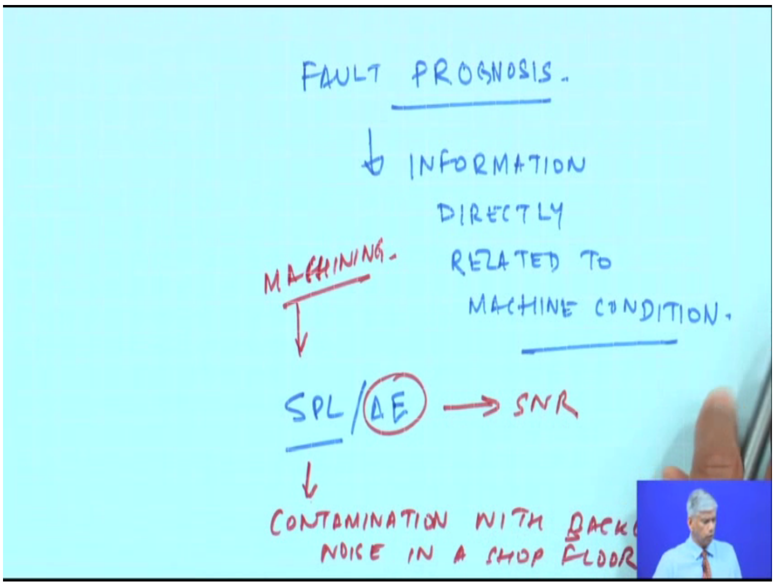

So, this is something judiciously we have to use when you are doing models for fault prognosis. So, carry information which is directly related to machine condition keep this in mind ok, there is no point you know taking this signal here, this lull period and trying to find out what is wrong with the machine ok.

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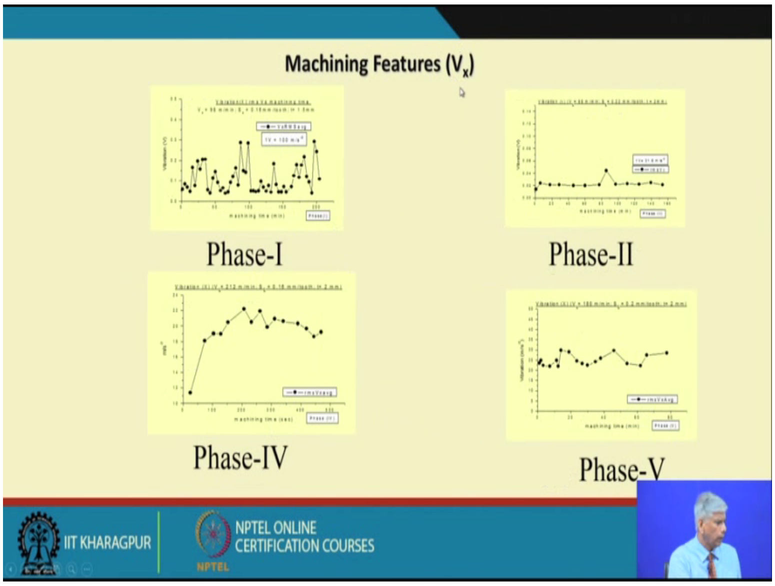

So, such feature extraction was done and then we measured with machining time, all the different parameters as you will see these are all real experimental data. So, which time; obviously, all these parameters increase subject to the experimental variations errors and limited phase one phase, three phase, four these are all in different machines and different locations and so on. So, you lot of study was done just to demonstrate that such a system is possible this was in the x direction again in the y direction and then this is the a vibration again ok.

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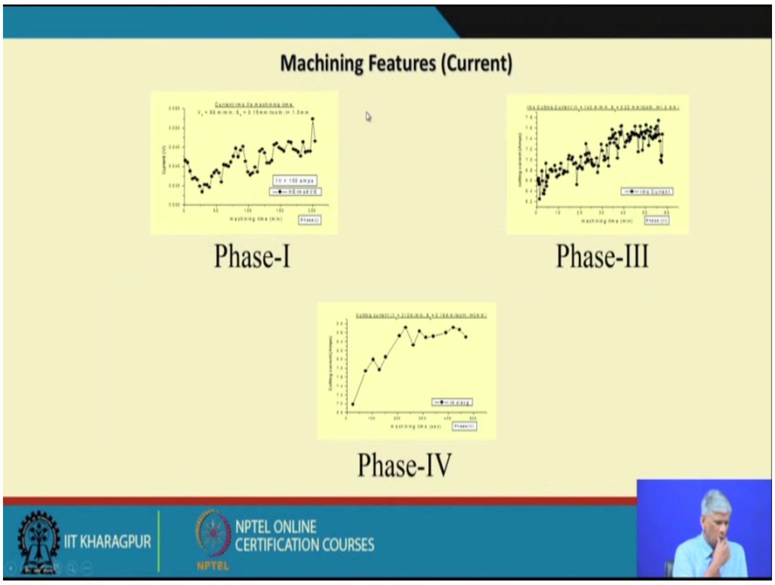

So, once you and of course, the machining features current.

So, one such features were drawn and as we these are all against machining time in seconds.

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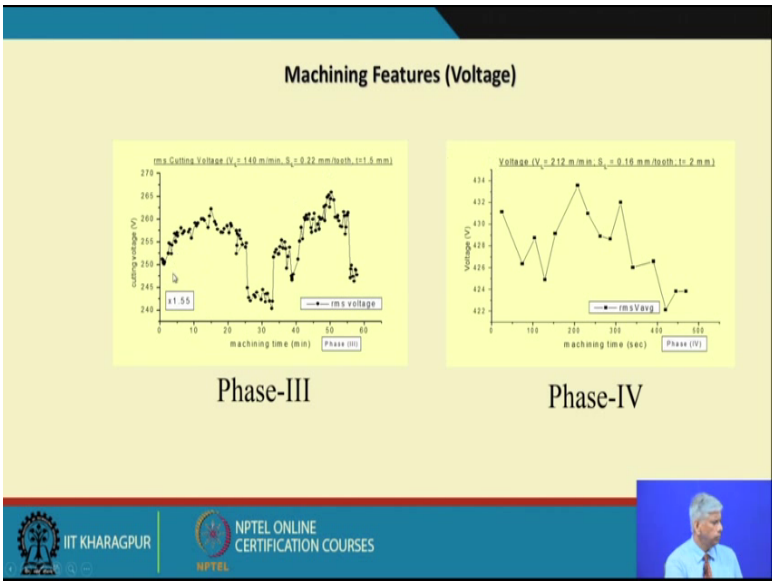

So, again the voltage because you know there could be some variations and so on power machining.

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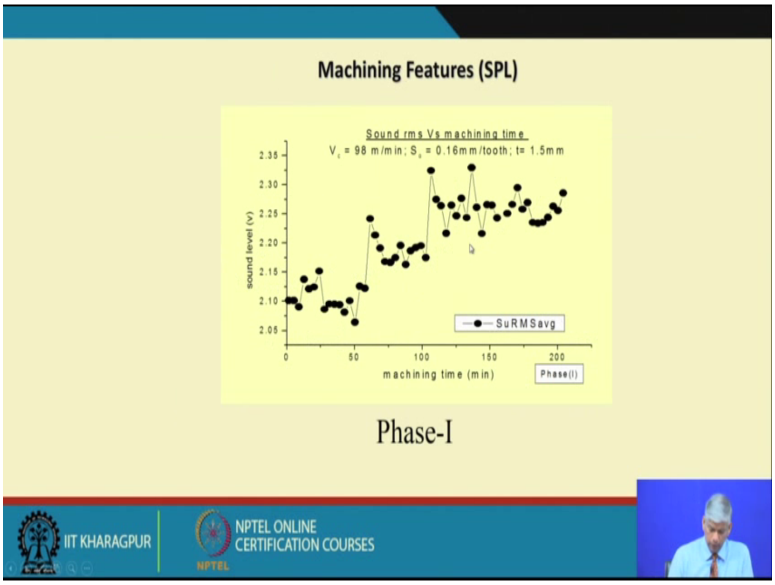

Feature some pressure level some of the parameters from this experiment we were not happy with SPL and acoustic emission for two reasons SPL was contamination with background noise in shop floor, it becomes difficult to monitor the background noise in a shop floor and what influence the machining has rather even acoustic emission there was issues with SNR.

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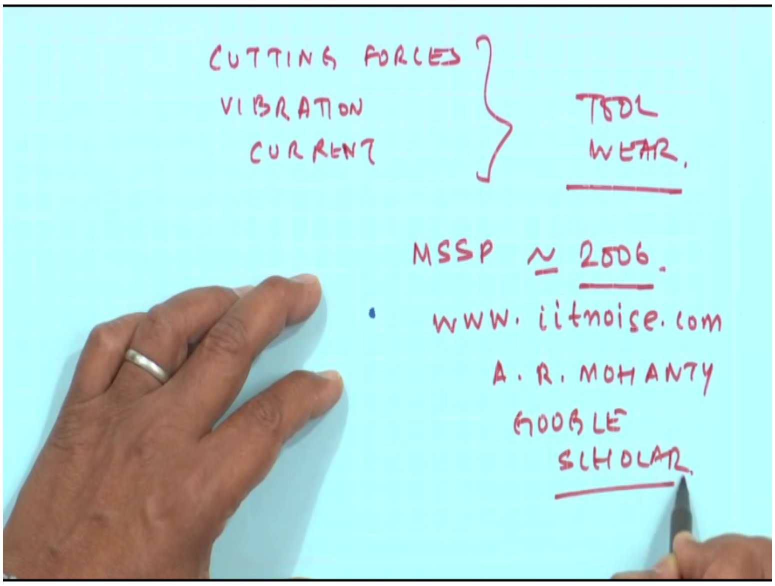

So, some of the good candidates for us where actually cutting forces, vibration and current, we saw we the tool wear by the way this work of ours is there in a publication in mechanical systems and signal processing somewhere in 2006, at believe, but you can refer to my website on my Google scholar, if you do a search A R Mohanty, in Google Scholar, you can get the reference to this paper and those of you who want to download it can do that or asking for a complimentary copy.

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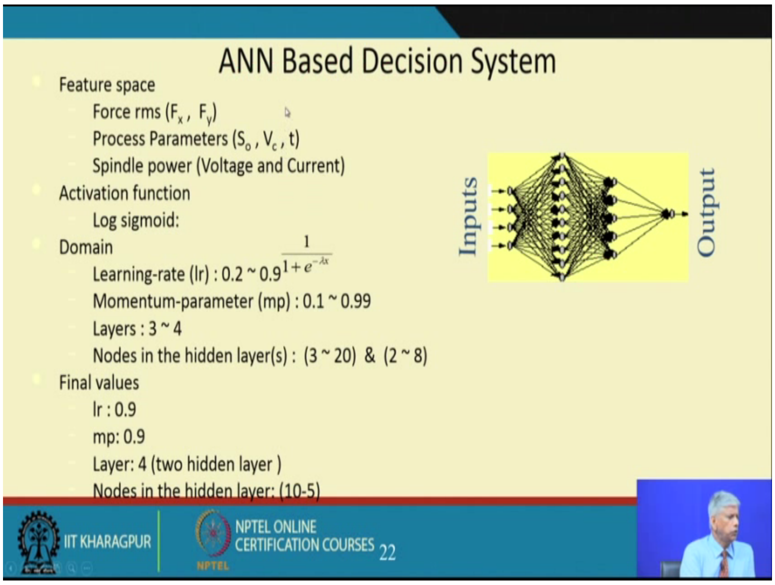

So, this is the artificial neural network based decision system which we used. So, the parameters where the forces process parameters speed depth of cut machining time spindle power and then certain log sigma del activation function was used in the ANN model and we were our three four players and every nodes in the hidden layers with played around with all those these may couple of students got there and a masters degree out of it believe one of them got an award out of and this is work.

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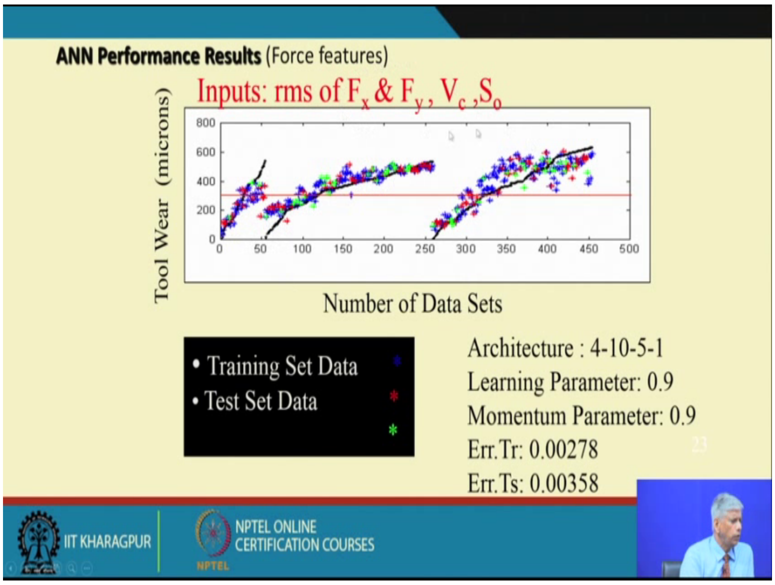

So, the tool were for different data sets, when the tool were with the different data sets when we took the training data set and the test data set.

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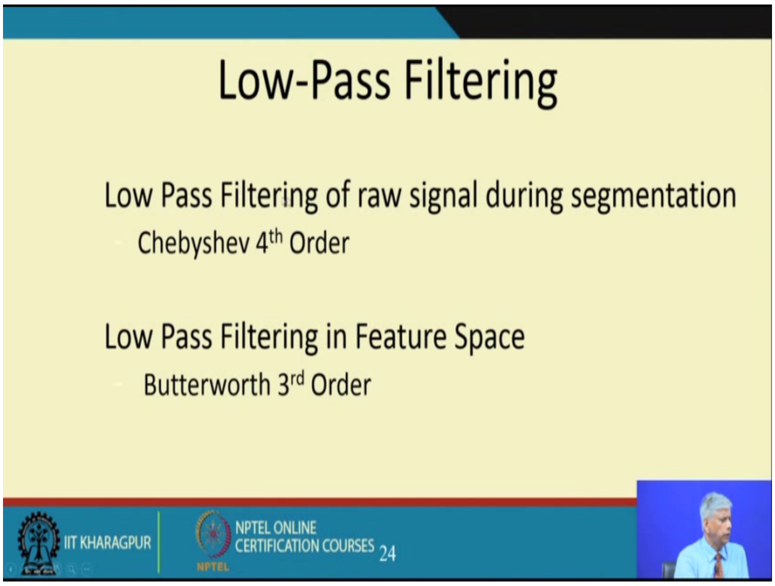

So, there is a good amount of correlation between the training and the testing we tried this parameters and of course, for the low pass filtering by used a Chebyshev fourth order filter and in feature space we used a Butterworth third order filter ok.

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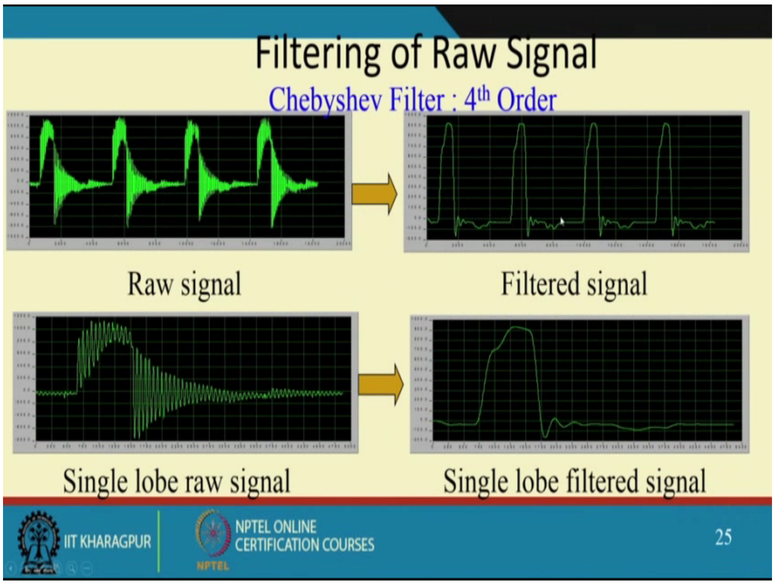

So, this is the output of a filtered signal the raw signal ok, filtered lobe signal lobe raw signal filtered lobe signal.

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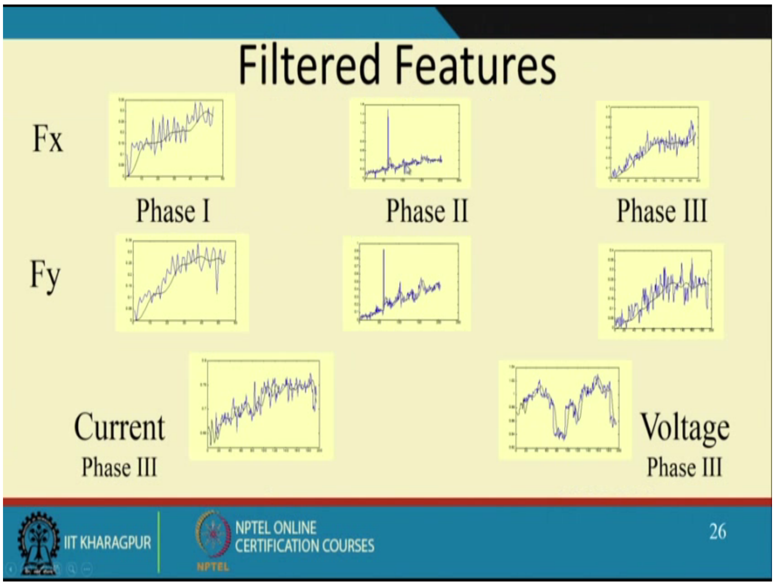

So, you see the effect of filtering lot of high frequency effects can be removed. So, filtered features gave us good meaningful information because see as a steeling you computers will only work on data input.

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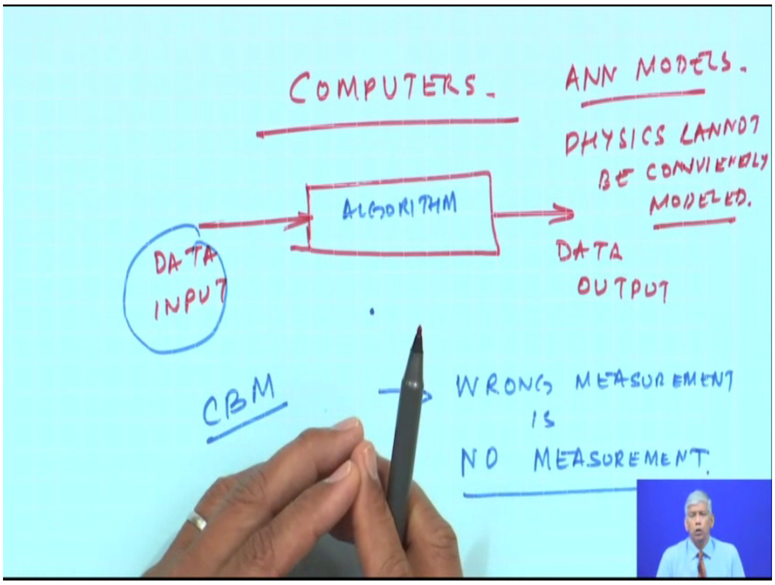

They will produce a data output or an algorithm based on an algorithm and all such if you are algorithm is fixed we have to be careful in the type of data. So, in CBM I believe always do not measure, if it is a wrong measurement wrong measurement is no measurement ok.

So, please keep that in mind. So, as we would see here this higher frequency signals physically occur reasons could be many, but for our model we are not interested in this higher frequency signals I can give this model same signal to a computer and develop a model, but it is not useful it is not helpful. So, to understand the physics you know make it very simple. So, that we understand it and by the way you may be asking why do we use ANN because many a times what happens ANN's are helpful or models are helpful such soft computing models are helpful when the physics cannot be convenient modeled ok.

So, if a physics cannot be modeled do not I mean in break a head of course, now today in rotor dynamics lot of modeled based systems are coming up or for diagnosis and progmasis, but when I am talking about a large steel plant where you are designing in a blast furnace modeling a blast furnace or in the case in the present case CNC machine, it becomes humanly impossible to perfectly have a physics based modeled for a CNC machine or for a blast furnace. So, sometimes this is soft computing models help of and then we took ANN as an example to model and come up with their fault prognosis modeled where in we can find out the tool were ok.

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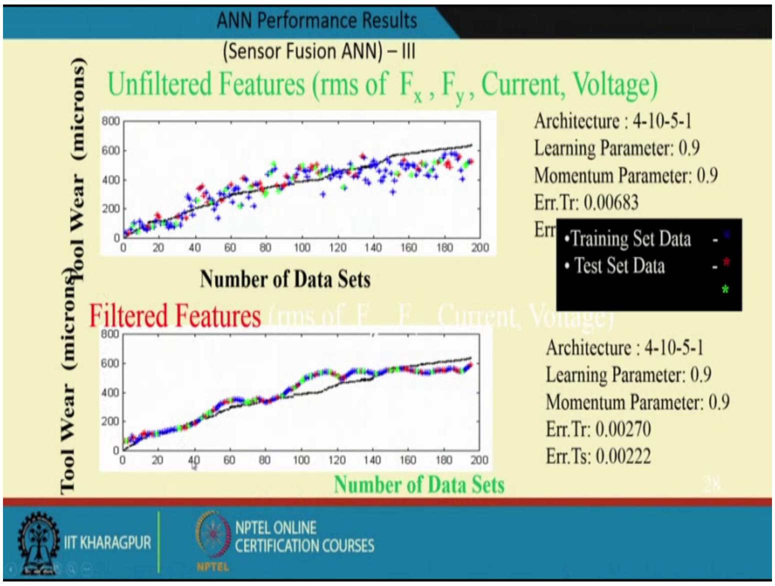

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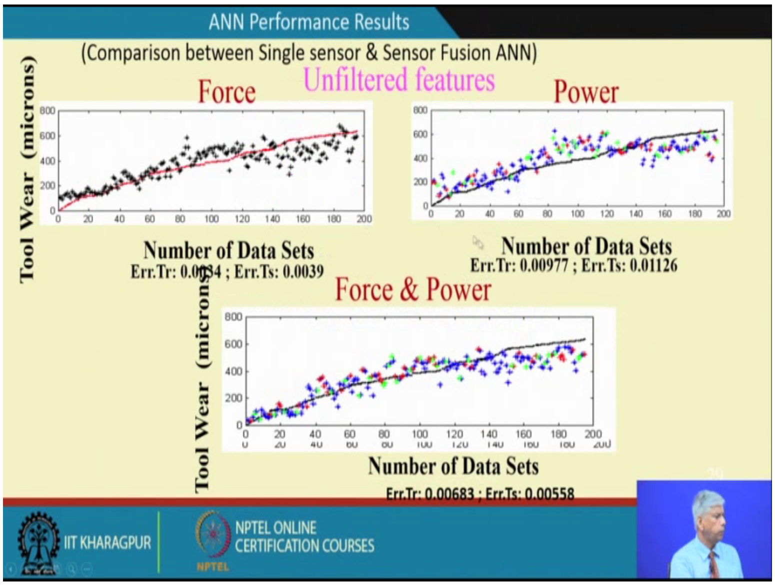

So, we could predict the tool wear within the data sets and there is good amount of predictions with force power and so on ok. .

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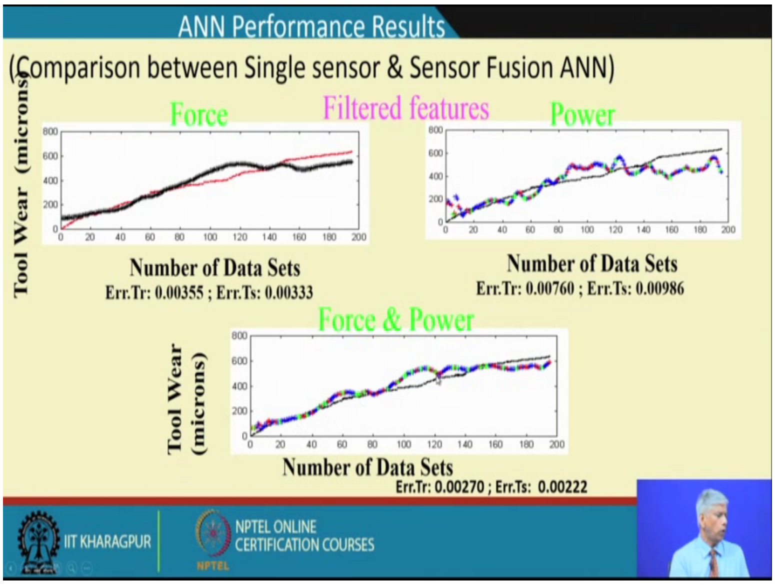

So, you can refer to that paper. So, now, what happens once I measure the force and power out of this machine I can very easily say well that is your tool were and at 600 microns in it you replace the tool. So, this is the power of such ANN.

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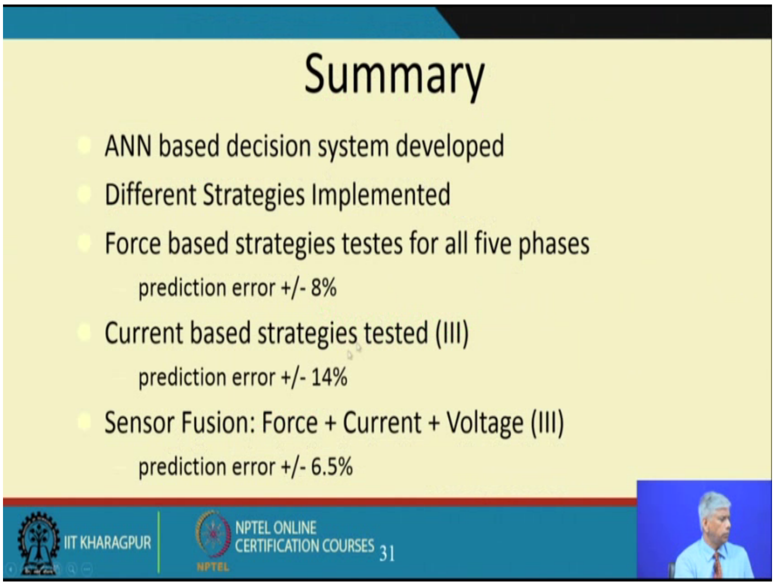

So, in summary we developed an ANN based systems where the prediction error improved, when we had senor fusion, when we had force current and voltage and so on ok.

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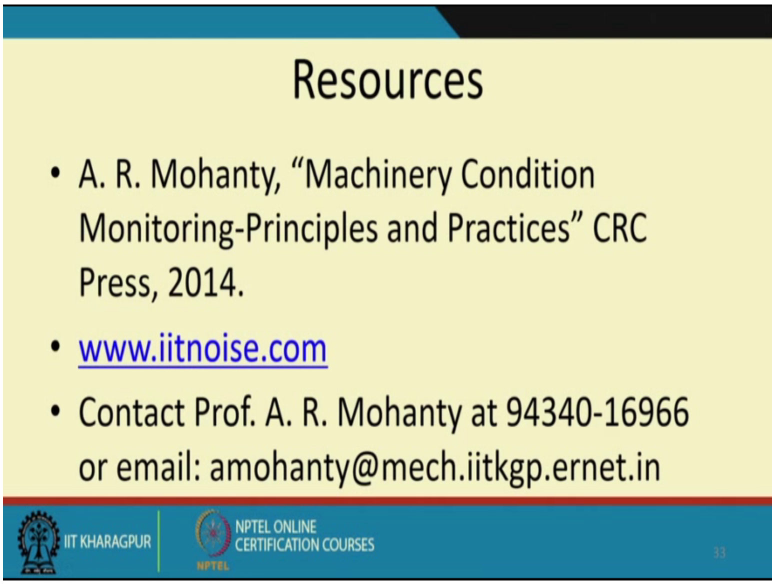

So, more of this, we can find in website and also in my book.

Thank you.