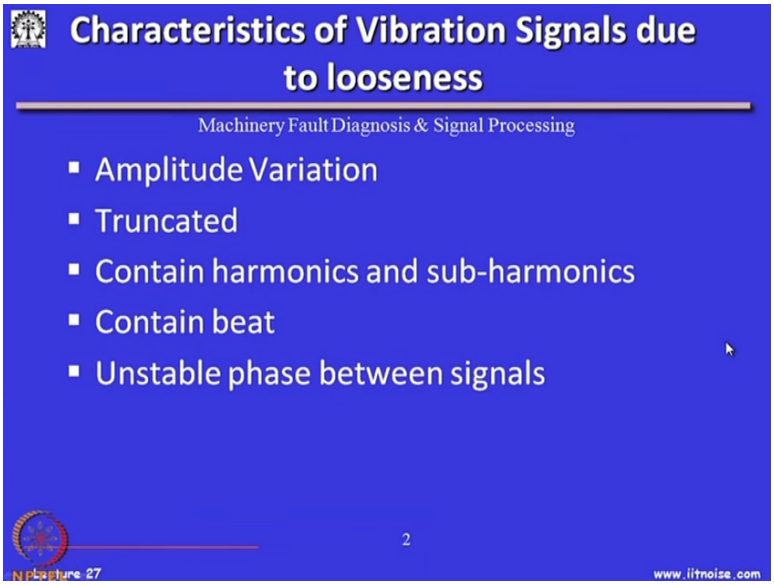
Machinery fault diagnosis and signal processing
Prof. A.R.Mohanty
Department of Civil Engineering
Indian Institute of Technology – Kharaghpur

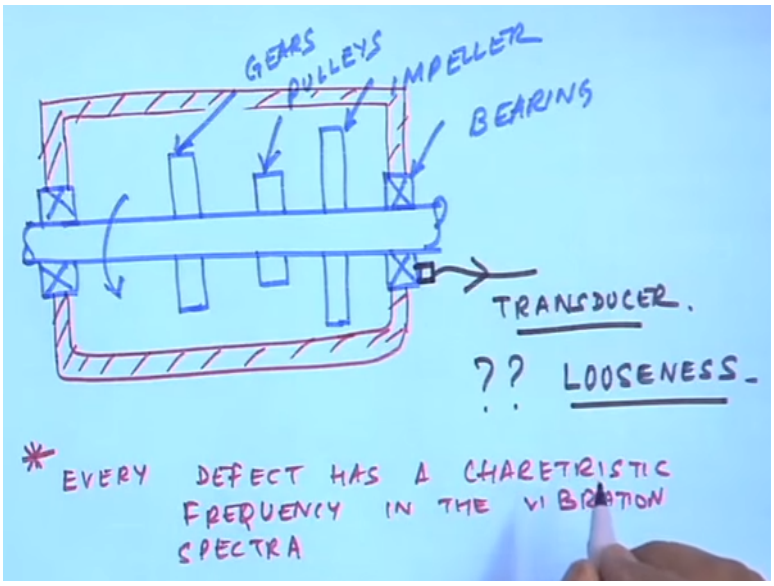
Module No # 06
Lecture No # 27
Looseness and Rub Detection

In machinery condition monitoring we come across many defect machine defects like unbalancing misalignment bearing defects, gear defects which we have discussed in some other previous classes. Another important defects called in machines is a looseness and rubs so in this class we are going to focus on looseness and rub detection what is the characteristics of such defects and how through vibration analysis such defects can be distinguish.

(Refer Slide Time: 00:56)



(Refer Slide Time: 01:05)



Well what is this looseness we are talking about so if you think of a machine basically any machine has many such rotating shafts which are supported on bearings okay. And this bearing could be anti-friction or general bearings and this shafts maybe caring gear pulley sort of impellers so all this components could be there may be one of them could be there or all of them could be there okay.

And this shaft is rotating now obviously if this was in a machine this should be in casing should be housed in casing and so on and perhaps near the location of the axle of the bearing we may be picking up a vibration signal okay we may be picking up ah vibration signal from transducers now it is this characteristics of the signal which we measure by putting an transducer near the bearing locations and from this how do we identify looseness these are obtained.

Just to recap you know in machinery condition monitoring wherein we are using vibration analysis the fact that vibration analysis is so far hole is for the fact that every defect has a characteristic frequency in the vibration spectra. And this is the most important fact for which this vibration signature is very powerful, convenient, easy implement in finding out fault in machines.

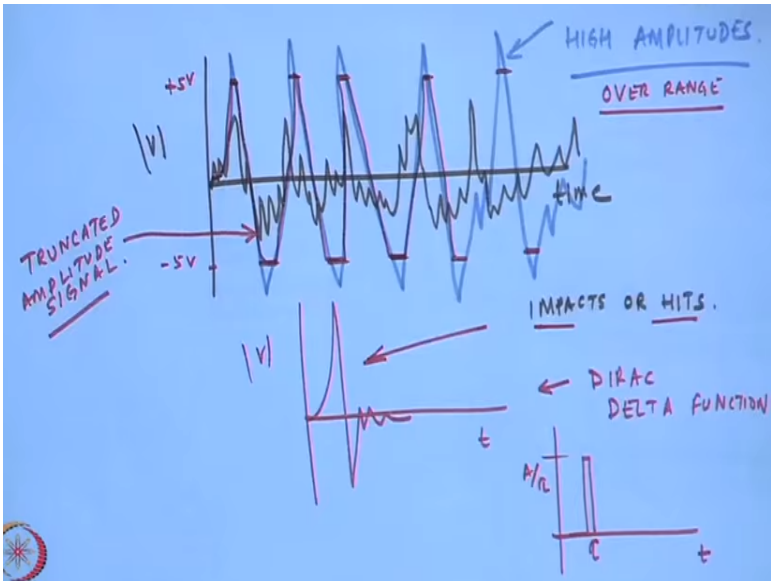
We all know that when we see about bearings fault new how the characteristic defect frequencies of the bearings showed up in the spectra we know about the misalignments how the axial components of the 2X vibration frequency showed up more prominently than the other and gear

show side bands along the two machine frequency in you will talk about will talk about fluid machineries particularly in fans, blowers, pumps, turbines.

How the frame pass or blade pass shows up in the frequency spectra similarly the question is what happens because of the looseness and then how do you detect? As I was telling you here the characteristics of vibration signals due to looseness there will be significant amplitude variation this signals in the time domain look truncated I will explain one of them they will be having certain harmonics sub harmonics.

And then there could be a beating of the signal and the unstable phase between signals you will see each one of them one by one.

(Refer Slide Time: 05:25)



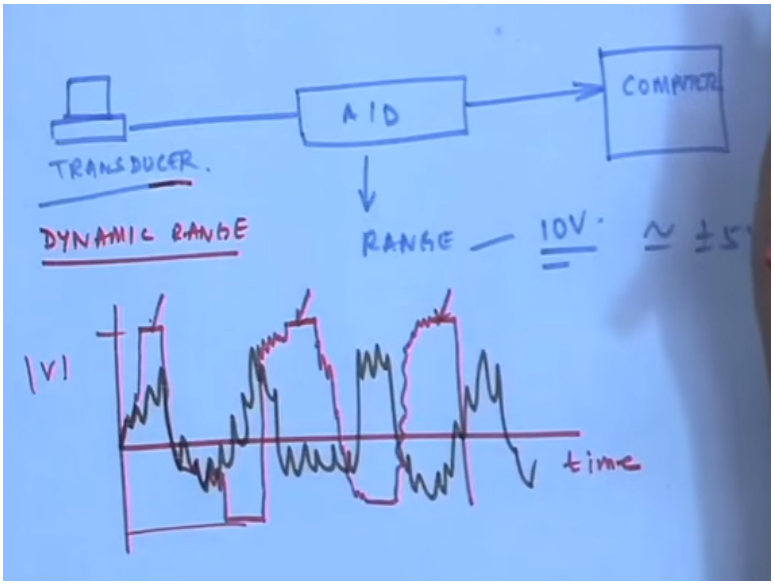
Say for example if things are loose what happens the components will be flying around all the places so there would be hitting against each other so there will be series of impacts or hits. So if we look at the time domain signal of a normal signal is this something normal thermal signal so what happens when there is an impact or hit you all know the characteristics signal of an hit is something like a impulse and actually mathematically represent them with a DIRAC delta function when we do the indication define at the response.

It is something like this time period tow I may be amplitude by A / tow like that and this exist only for a short duration of time and this is the mathematical representation of an impact by this

is what the real world signal looks like because of an impact and imagine such a signal such impacts or occurring of a time signal because of a the looseness. So what will happen is this amplitude would go blow up okay and so on.

So first of all these are high amplitudes significant variations now in vibration monitoring you know that once we have the transducer this is followed by a data acquisition system.

(Refer Slide Time: 07:38)



And in the data acquisition system I will back to this later in the transducer I have a A to D system and then of course we have a digital signal which goes to a computer and this is my transducer there is a range of this A to D system and this could be maybe 10 volts maximum range we can have or plus minus 5 volt. But what happens if this transducers are of very wide dynamic range it must have happen because of the impact.

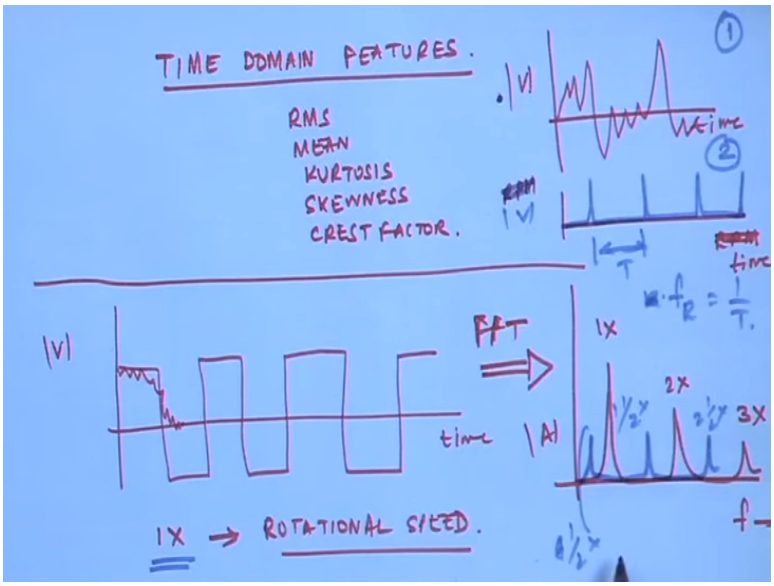
Because there is no physical device which is controlled this amplitude there is no limit to control it if we have a impact because of a looseness because we are going to produce a high vibration signal okay. And this is limited by the dynamic range of the transducer okay sometime it may go beyond the dynamic range it may over range so it may be a case where I will over range go beyond the capacity of the transducer okay.

In such a case what happens these signals will truncated because my A to D system will turns to + 5 volt and this remains – 5 volt. So the A to D card you will not try to understand anything

beyond + 5 or – 5. So my signal will look truncated if I draw in the so this is the red one is the truncated amplitude signal so such a signal appear in the time domain vary at measurement because of the impacts or impulses which occurred due to looseness.

So first draw them again so these are signal which can very easily we seen on an oscilloscope for example my normal periodic stationary signal at of a machine could look something like this. But the truncated signal could so these are the limits so what happens they look like chop signals or truncated signals. So looking by the physical nature of these signal characteristics of course how do I know in an automated system it is not possible to look at us signal.

(Refer Slide Time: 11:32)



So we have to study the time domain features some of the time domain features are meant RMS, MEAN, KURTOSIS, SKEWNESS, CREST factor etc. We studied about this in some of the earlier classes on time domain signal analysis and you know by now how to calculate this parameter. So the characteristics of truncated signal to be different have in a different KURTOSIS, SKEWNESS and CREST factor and in the time domain they will look like truncated like I showed you in the earlier red plots this kind of plots I showed you here.

This is how this are the characteristics of the truncated time domain signals and they will look something very close to may be a square with okay. And with some signals with some oscillations so on so if somebody was going to do an frequency domain analysis of such signals

and the normal method of doing such signal domain analysis a frequency domain analysis is by FFT process.

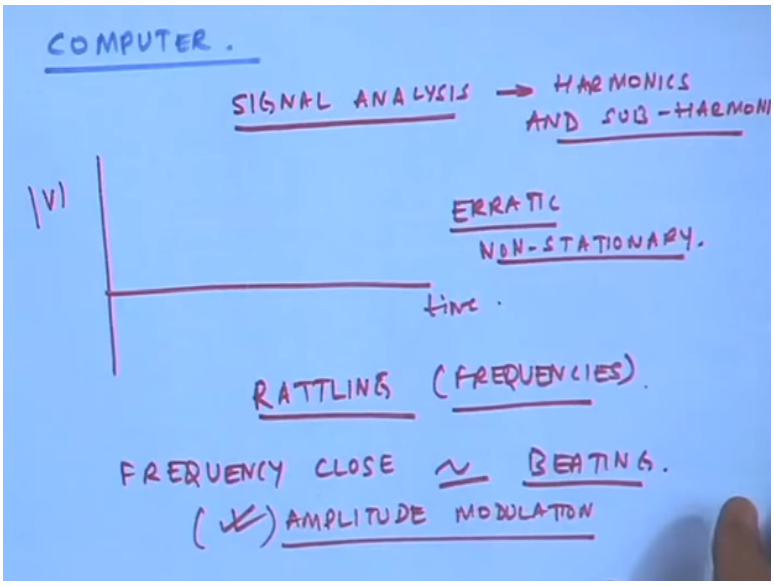
You will see lot of this is a typical 1X, 2X, 3X by 1X I mean the normal rotational speed and you will see again one thing I should derive the point that in vibration mode is essential that whenever we are doing vibration monitoring beat in the laboratory beat in the field it is very very important can be implied that you are always measuring the rotational speed okay it is a good practice many time when you go to the industry you know people assume that the machine is running at 1440 RPM or it running at 2900 RPM etc.

That is fine that is what the motor ratings says okay if you have no knowledge about the speed of the machine that is good to follow however wherever possible try to install a rotating speed measuring device like a reluctant probe like an optical tachometer like a laser way system. So that any time whenever you are measuring the vibration you also have the corresponding RPM trace this also of course in a time signal RPM.

And how you will usually get a peak from voltage and this is a time period and the rotational speed FS or FR = 1 / T okay. So it is always good to measure of course vibration and then the rotational speed because once we have the rotational speed we will get a good estimate of 1X and then you will 2X, 3X etc., but the characteristics of such signals in the frequency domain is that we will get harmonious to lot of fraction harmonious okay maybe 1 half X, 1 half X, 2 and half X and so on.

And maybe even fractional one third X one sixth X and so on so these are the because they end of the day your this FFT analyzer is being done by a computer.

(Refer Slide Time: 16:09)

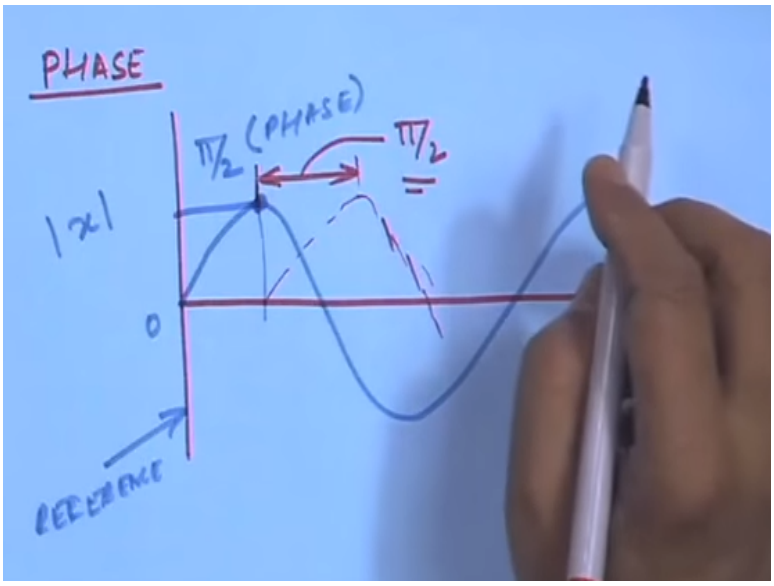


And this computer does not know where the machine as the looseness or not okay it is the signal which it has the computer wants to analyze we interpret that there is a looseness. So this interpretation how the signal is only by a mathematical process between the signal analyzers which gives s harmonics and sub harmonics okay. This is what is given by the computer the harmonics and the sub harmonics so as long as the signal looks something which will give us harmonics sub harmonics.

We then interpret there is a looseness in the system otherwise this computer will not be able to tell whether there is looseness that is where the signal analysis comes in the help. And again because is looseness suddenly a component may get stuck so it may be loose the moment early it may frozen it may get jammed with some other loose device. So this signals are very erratic you can say to some extent they are non-stationary.

And of course because you know the rattling this rattling maybe at frequencies which are close to each other okay. Say if frequency is close I will get what is known as the I will beating occurring okay. And once beating occurs we will have a amplitude modulation well I not have a amplitude modulation but the same look like amplitude modulation okay and then look has they are independent these two frequencies which are rattling in close to each other produce and they are independent they will produce beats and then look like amplitude moderated signals okay.

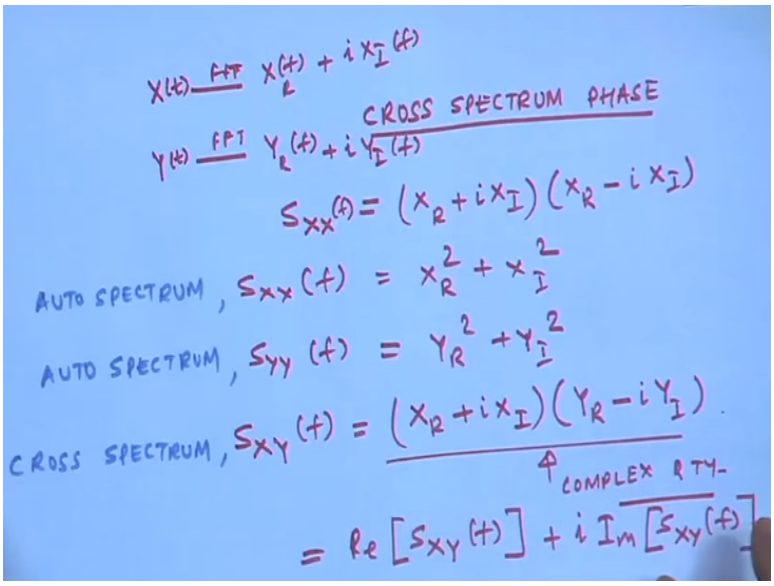
(Refer Side Time: 19:07)



Now we did not mention something about phase is a very relative term for define phase if this is my some signal X. So if this is Pie / 2 the first this is my reference the first occurrence of an maximum amplitude from the reference plane and this is the phase my question is if I have many signals okay say another signal there is of course the phase difference between I will not draw another signal may be I have just okay.

There is a phase difference may be the between the blue signal and this is the phase difference phase is always relative so when I said here Pie / 2 this blue one it is with reference to this plane but between these two signals there is again a phase difference of pie / 2. So in when you do signal analysis the unstable phase between signals now what do you mean by unstable phase between signals.

(Refer Slide Time: 20:52)

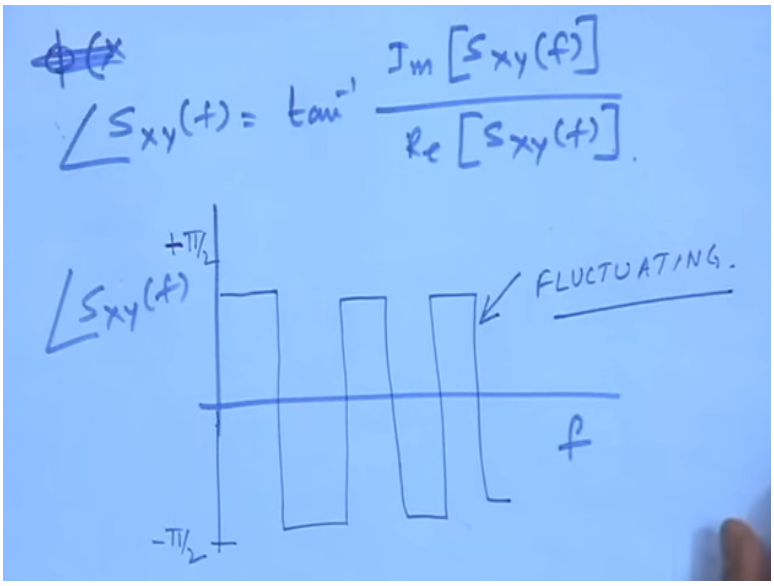


So when I talk about two signals okay when I talk about two signals X and Y how do I find out the phase of these two signals. So what I can do is there is a process known as the cross spectrum phase so in an FFT analyzer I can always find out the auto spectrum SXX which is nothing but so this shows signal was if I do a FFT of a signal was XT and I do a signal FFT I will get the signal which in the frequency domain will have and similarly I will have one Y real in the frequency domain + imagine part of Y imagine in the frequency domain.

So SXX I will remove the FC here this all in frequency domain and this will be XR + I XI times the conjugate and this will be XR square + XI square. So this is the auto spectrum X similarly auto spectrum of Y will be square but there is another component which is known as the cross spectrum between SXYF is nothing but XR + IXI times YR – IYI and you will see that this is a complex quantity okay.

And this will have I will not go into the details of this so this will have a real part of SXYF + imaginary part SXF and so on. So the magnitude will be nothing the cross spectrum this is the auto spectrum and other words this is the power spectrum the unit as squared and this is the cross spectrum. The reason I am telling you this is how in the FFT analyzers the phase between few signals are calculated.

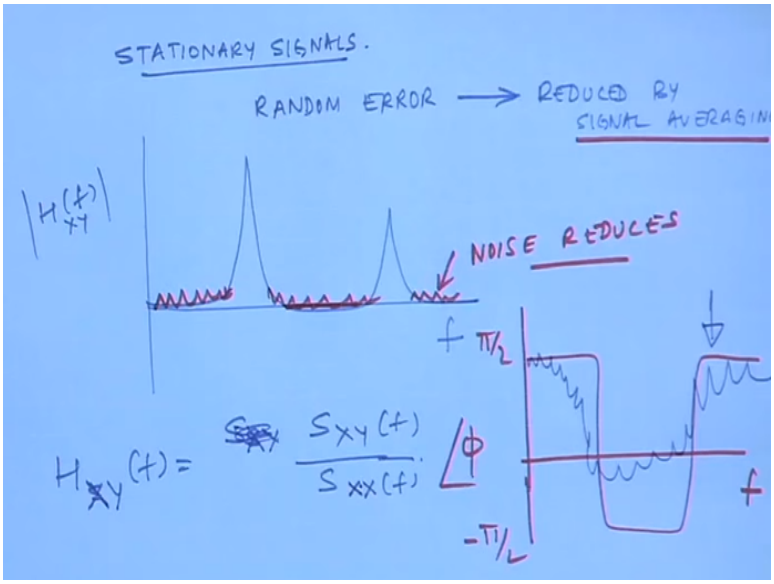
(Refer Slide Time: 24:22)



Phase between signal X and Y Pie X or Pie R of the spectrum XY F is nothing but tan inverse imaginary of SXYF by the real part of FXYF and from this equation if you multiply by them we can find out the real and imagine. So this phase angle which is a functions of frequency this phase angle which is the function of frequency will actually vary with time and this will be from + Pie / 2 to – pie / 2 okay and then this will be vary.

And this variation for a stationary signal and this depends on how many signal occurred and this is fluctuating.

(Refer Slide Time: 26:03)



And usually for stationary signals when in signal processing the random error in measurement is actually reduced by signal averaging. So what I mean to say is suppose I am finding out the transfer function by the way the transfer function between this two signal HXYF is nothing but the auto spectrum sorry okay and this is again a complex quantity and these are all the functions of frequency.

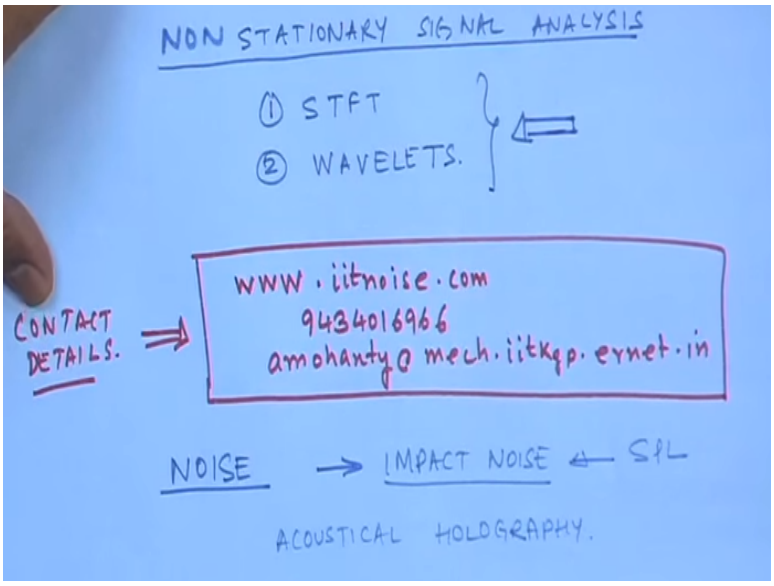
We have to careful about function of frequency conjugate and then this magnitude will look something like this okay and with averaging there will lot of such noises which will reduce noise reduces by signal averaging. Now similarly for this if you look at the phase also is pretty noisily defined phase of the transfer function. However when you such analysis between two signals which are coming from a machine where there is lot of looseness will see that this phase there will be lot of make no such because if you do a average signal we will not get any meaningful information.

And that is what I mean by unstable phase by this signal and these are clear indications that the system as looseness so through signal looking at the signal in the time domain I will see very very high amplitude over load occurring repeatedly overload occurring though you what is known as then auto ranging etc., but if you look at the signals in the time domain their features may be very high they mean the RMS value will be high but again in the frequency domain a very easy way to find out such defects is the occurrence of a harmonics sub harmonics.

And the reason behind harmonics and sub harmonics is because of the fact at the signals almost look like the square waves they truncated the waves and then because if things are rattling moving around they will be lot of beating occurring and then there will be unstable phase between the signals because these signals are have no constant base of signal in the time domain. I mean in one instance one variation signal is coming out of another distance another variation signal is coming out because of impact as occurred.

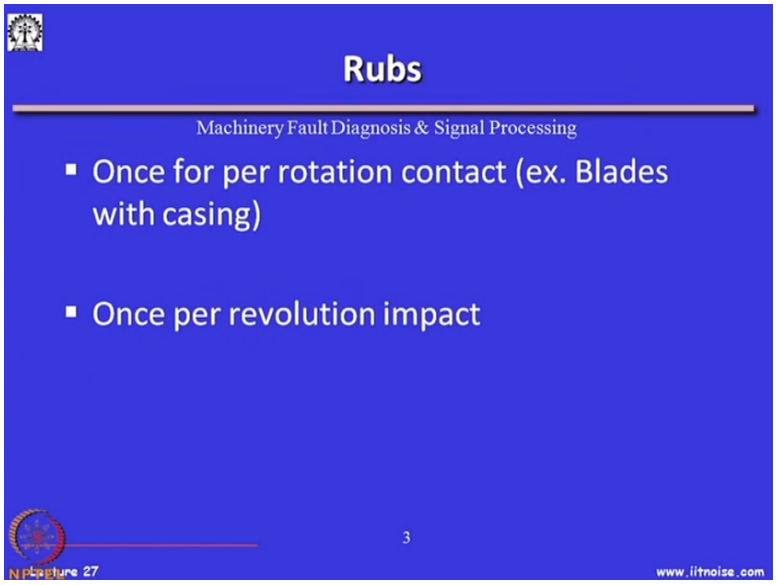
So they are all give us to a signal which has lost is test is another definition by which we can also find out looseness.

(Refer Slide Time: 30:11)



Now once we have all the techniques of a non-stationary signal analysis can be done to detect such defects okay. And what are the stationary signal analysis we will go to them okay.

(Refer Slide Time: 30:37)

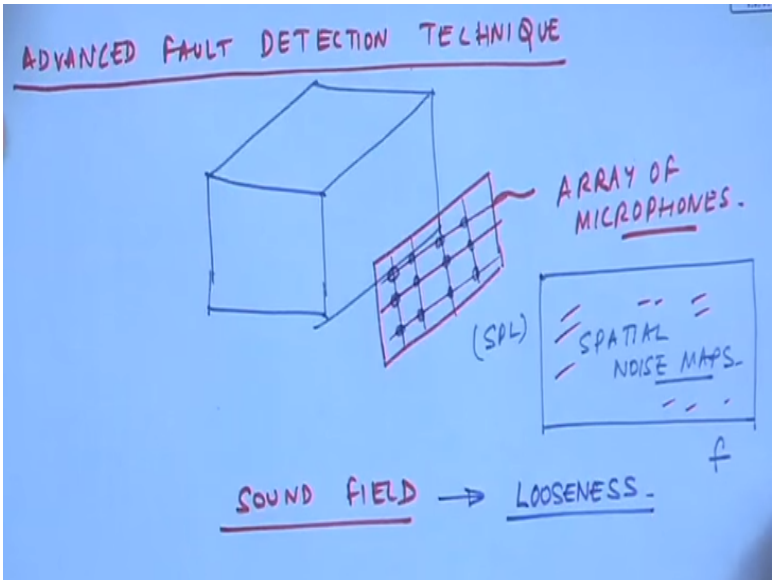


I will before that I will before coming to rub conclude this in the sense in the non-stationary signal analysis we can do what is known as the STFC what I can do what is known as the wavelets okay. And these are the two important techniques which can be used to find out looseness though in this course I will not go into the details being the very basic course on STF and wavelets I will not go into details of this.

But however if you want to know more about this we can refer to my website iitnoise.com or you can contact me my mobile or you can email me these are my contact details if you want to know more about these a constitutional signal analysis STFT and wavelets but this is not in the domain of this course however this being in the well if anybody is interested to know about the more about the constutionary signal analysis they can contact me at this website or to my mobile or email.

Now another very important characteristic of this looseness signal is that they will be associated with noise okay. Because things are hitting against each other so there will be impact noise okay and these noise can again be captured by a certain process which I told is SPL but now a days techniques are acoustical holography are available by which this sound feel can be detected.

(Refer Slide Time: 33:17)

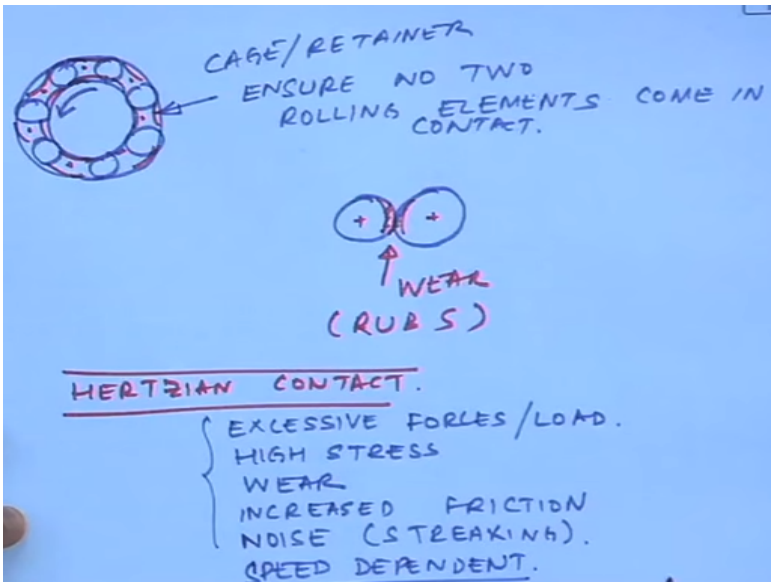


Say for example I have a machine okay and there has been some defect inside so it is radiating noise so what I can do I can bring about another plane around it I can do the noise measurement either through an array of microphones. I manage this microphones are located at every grid location and they can we can do a official transformation of the sound feel by using such an acoustical holography technique.

And if there are defects in the machine okay and then the noise will be removed then the noise can be very very high level and if I look at the sound feel okay for every frequency I can get some maps spatial noise maps okay. And because these are non-stationary these maps are going

to change okay and this is an advanced fault detection technique which is being used to know from the sound field what is the noise we choose getting generated okay.

(Refer Slide Time: 35:59)



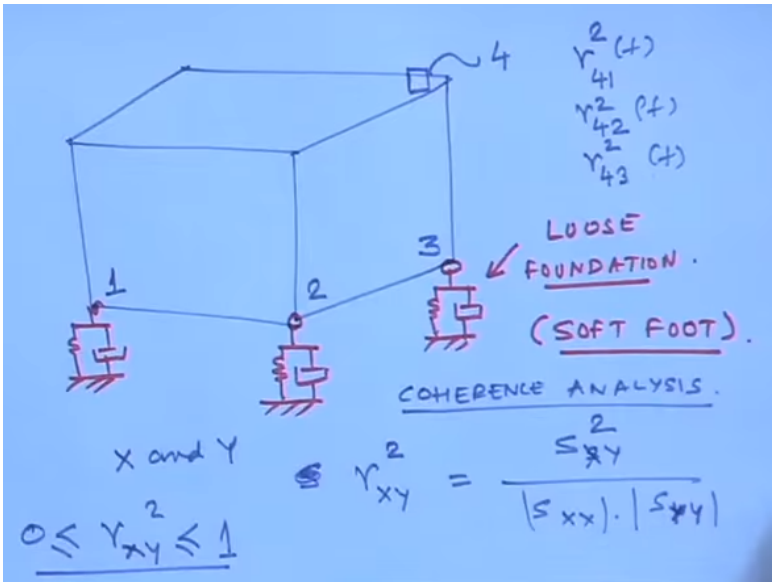
And we can then detect looseness in a system but sometimes we purposefully have things made loose for example rolling element bearing okay there is a cage or the turner which sits on the between the retainers these retainers are the reverted however their free to rotate or the purpose of the returner is ensure no to rolling elements coming contact okay. But then they are loosely rotating at the shaft is rotating they will be spinning at their frequencies.

So they will come to their retainer were not their at the cage or the retainer if this cage or retainer was not present what would happen is these two rolling elements would come and contact with each other and that happens if when is there two balls spinning at high speed and come and contact with each other there will be lot of wear they will get be formed and then they will not perfectly round and then they will have a more friction and then more noise and more vibration.

So that is what we are coming to the next topic of about rubs okay and if this things are rotating so we should avoid coming back to this rubs. So in a machinery if anything is contacting each other rotating device contacting each other they will rub again each other so rubs will occur and I just told you the case of the rolling element bearing were if the cage or retainer shown in red was not present these two rolling elements when they were spinning and rotating they would come to and touch each other and then they will be sever wear because of hertzian contact.

Because of hertzian contact would be developed and again the same phenomena will occur there will be because of this excessive forces load they will be high stress there will be where increased friction and then there will be of course noise kind of a streaking noise. So this would happen okay and they will be speed dependent okay and this kind of happens okay

(Refer Slide Time: 40:10)

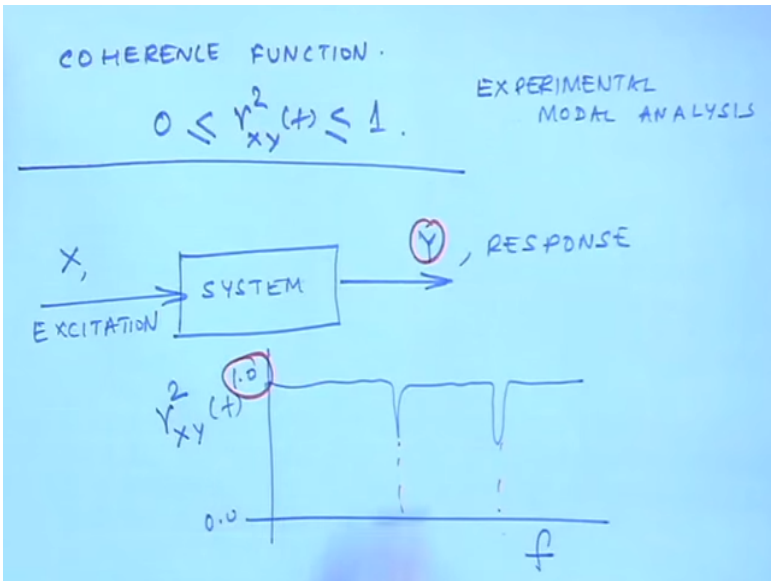


So we should avoid these rubs to be occurring and then I will while I was talking about rubs I will also tell you when I talk about machine many times these looseness will also introduce that two parts either rotating or sliding or stationary come in contact each other okay and these machines are usually I have not drawing the other side which is hidden usually are having foundation.

So because of this foundation being loose we call this is as a soft foot now soft foot can be very easily determine what is known as an coherence analysis okay. And how this is done is suppose I will just name them 1, 2, 3 and suppose I have another transducer at location 4. So what i will do between transducers 4 and 1, 4 and 2, 4 and 3 I will find out what is known as coherence function and what is how is this coherence function between any two signals X and Y denoted as so gamma X, Y is nothing but SXY . SXX times SYY okay.

And this actually denoted by a square and the value of this is 0 XY square less than equal to 1 and this is known as the coherence function.

(Refer Slide Time: 43:01)



So the value of frequency domain so when I measured in this case when I measure the coherence oaky you will see this may be this loose say for example this loose number 3 is loose or having a shaft this could be of the order you know this could be 1, 2, 4 1 two of may be 5, 6 and you will see that the vibration at 3 is nowhere related at 4 because they are not connected to this system.

Because this could be very low so this gives us indication that something is wrong with machine this foot and then it is not producing a coherence signal at 3, 4 is not because of 3. So these says a coherent function actually relates one signal to another and just by measuring I can measure them simultaneously and then measure them by a dual channel signal analyzer one at a time you know like suppose here axis 4 could ones one, ones two, ones three and then it could be doing this computation.

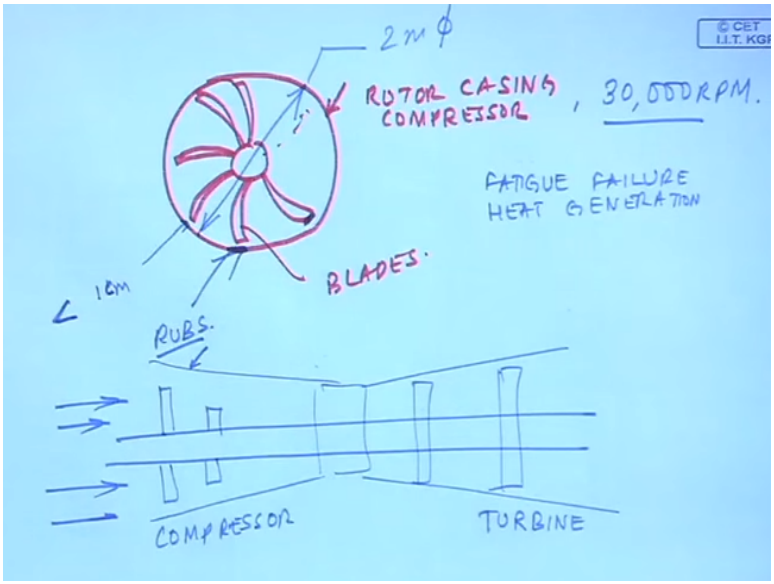
Of course the modern FFT analyzer have this functions built in so you can measure the coherence and if there is a soft foot the coherence would be poor in the given frequency domain. So this is another way such coherences can be detected and then in fact coherence also as a very important application in experimental model analysis because if have a system mechanical system or a machine.

Suppose if I am getting some output Y the response because of some input X is the excitation and to know whether this system I can measure gamma X and if this value is I know mostly that

the response is because of the excitation and most of you know signal processing or vibration you know this will be the resonance because at resonance you require very less force to excite or to get a response or that is there are dips in the function.

So this means that the response Y is only because of X if I have good coherence okay and this is actually used in experimental model analysis. I will not go into this in detail but coming back to the phenomena of the rub because looseness create rub. So the characteristics of this rub is once for per reverse contact for example blades with casing.

(Refer Slide Time: 46:38)

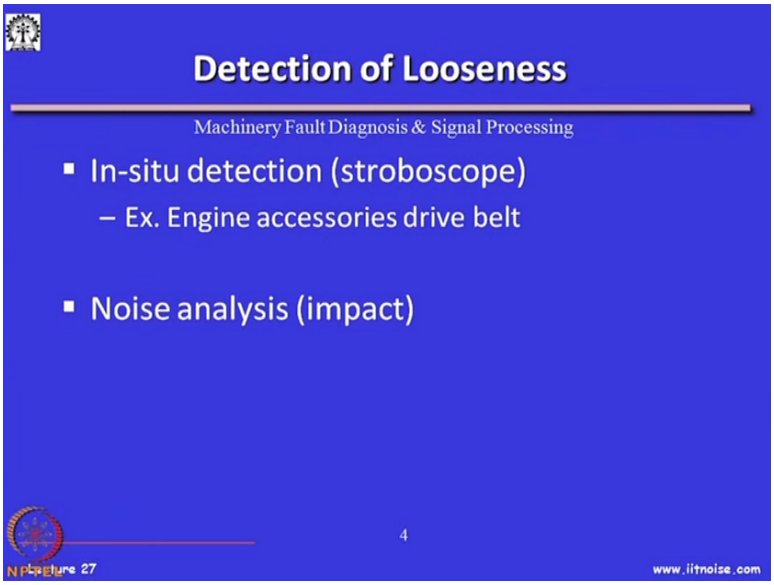


And rub as lot of detrimental effects for example if you think of a turbine of a aircraft the compressor which looks like this in the outside rub blades. I will not draw the entire set of blades okay and so on and this is the rotor casing or the compressor casing and these are the sets of blades. Imagine because of a misalignment this touches this edges touches this casing so if there is a rub there will be fatigue failure there could be high heat generation.

So though the tolerance are very close and move less than 1 centimeter in a gas turbine engine or from a 2 meter diameter this could be about 2 meter diameter and then this is less than 1 centimeter and these things rotate at turbine there may be 30,000 RPM. So you can imagine this series consequence they may have if the blades tough either so this rubs are to be avoided and this could be because of my bearings which are supporting the long shaft because in an aircraft engine the series of okay blades.

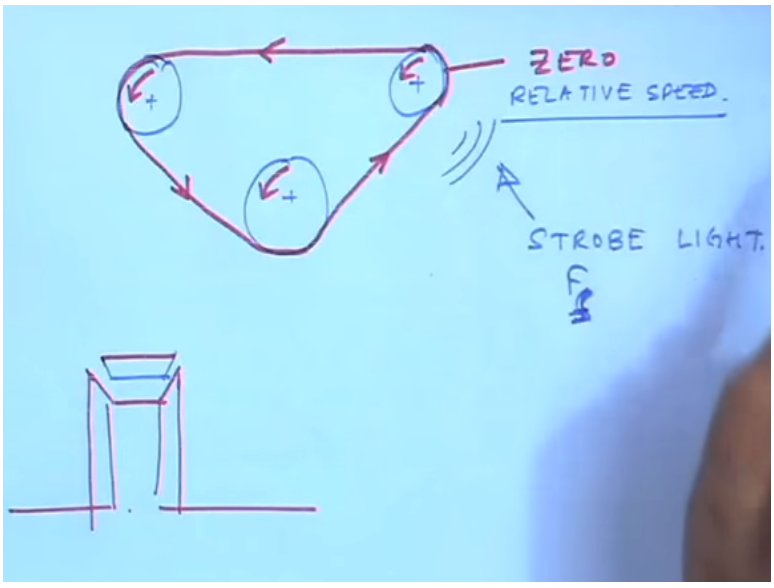
The low pressure compressor the high pressure compressor the combustor and the turbines okay of course which works on the principle of the brittle cycle particularly gas turbines. So I will have air flowing in okay and then combustion in the gas and get the thrust but imagine if this casings touch with each other so we should avoid you may be in the class of turbines I will show you a picture of how this compressor blades look like and close there are.

(Refer Slide Time: 49:33)



So this as to be taken care of now some of this because this is loose and rubs they interrelated how do you detect this looseness.

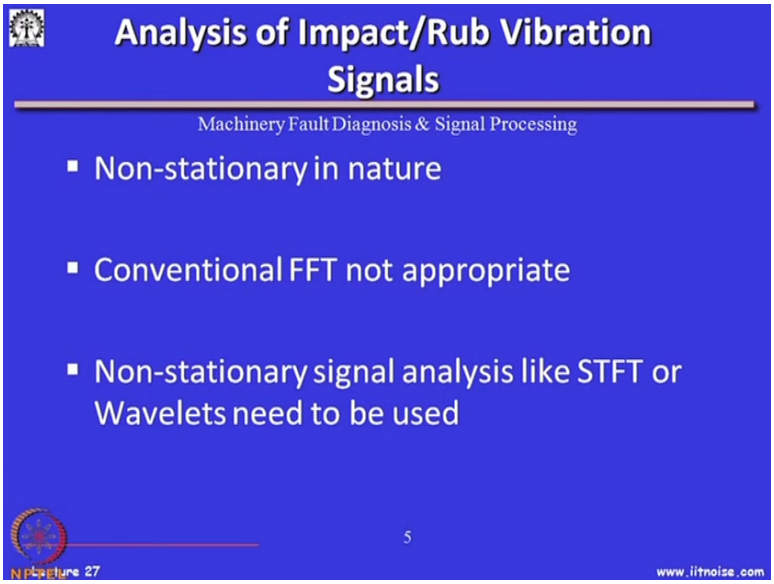
(Refer Slide Time: 49:45)



Many times many systems what happen the series of belts okay and then there will be series of pulleys and there will belts going all over the system and they are all rotating in a particular direction in a linear speed. So if the belt was not slipping of the pulley was not loose what would happen the relative speed between them is 0 okay. And this can be very easily detected by a what is known as a flash the strobe light.

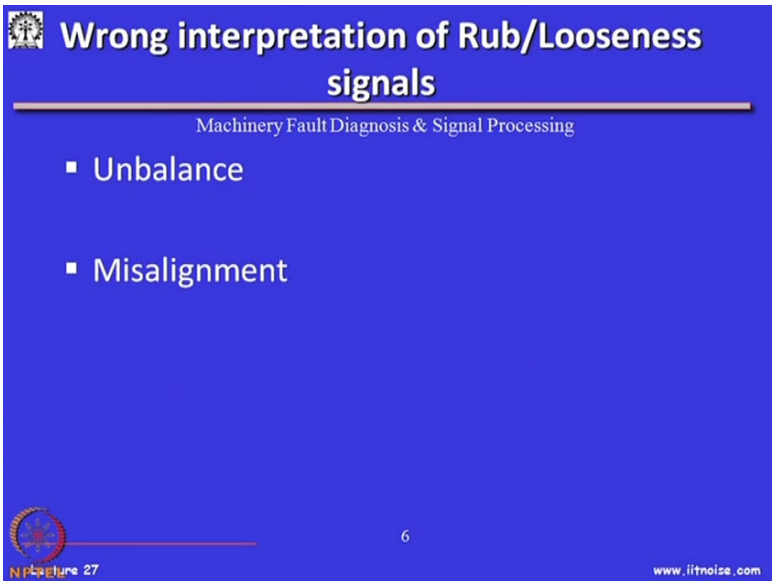
So basically you flash at a frequency okay which is equal to the rotational speed so the belt would look to be stationary on the pulley okay. So I have exaggerated this gap so between this the belt would look and such can be used to detect a laziness. If where not stationery this would gradually look to this sliding I mean those of you would have of the particular engine fan belt if it is slipping over the pulley they shoot a strobe light on to the engine fan and belt and find off this kind of things.

(Refer Slide Time: 51:58)



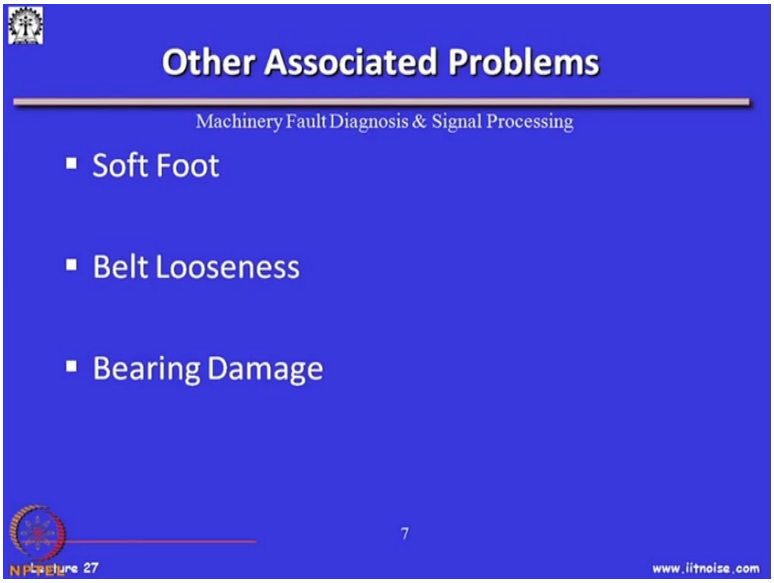
So this analysis of impact and rub vibration signals which are created because of a the looseness or non-stationary in nature and conventional effective is not appropriate non-stationary signal analysis like STFT or wavelets need to be used.

(Refer Slide Time: 52:22)



And another important thing we have keep in mind usually because of a rub which has occurred because of the loose signal because of a loose component they will manifest as vibration access vibration and because this 1X will be high people many times misunderstand them as unbalance and misalignment. So we have to be careful against that while measuring such rubs because of loose componential in a machinery.

(Refer Slide Time: 53:00)



So associated problem like I told you soft foot looseness and bearing damages may lock if there is loose components go undetected they will give excessive forces on to the bearings and then there will be problem okay bearing and eventually damage. So one lead to other end and that is

the most important thing in condition monitoring if you are not careful the very first time you may the disease may develop more severe disease difficult for diagnose okay thank you