Vibration Control

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Module - 8
Vibration Measurement Techniques
Lecture - 1
Basics of Vibration Measurement System

Hi, this is Dr. S.P Harsha from Mechanical and Industrial Department, IIT, Roorkee. In the course of Vibration Control, now we are going to start last module which is absolutely based on the Vibration Measurement Techniques. In that you see here first we would like to discuss about the basics of that how we can measure the dynamic parameters what are the instruments particular, which should be there to measure those basic dynamic parameters.

And what exactly the nature of these you know the vibration features are basically, till now you see here we mainly discussed about the vibrations the causes of you see the vibrations, and the sum together. How we can reduce the vibration you see here at this source or at the receiver end or during the transmission path, then we adopted the two main we can say techniques, one is the isolation means the when isolators or absorbers are there we can say these are the passive vibration control devices.

And the second which we discussed about the active vibration control, in which we mainly discussed about the sensor, and the actuator feature at the same time we discussed about the materials. The smart materials, through which we can reduce the vibration either by you know like just putting some adding some kind of damping or just by you know like, creating some kind of you know like the actuated force exactly opposite to the vibrating excitation forces. Then we solved some of the numerical problems, that how we can adopt those devices through which we can control the vibration excitations. So, now you see here in this lecture we are going to discuss about the basics of the vibration measurement techniques.

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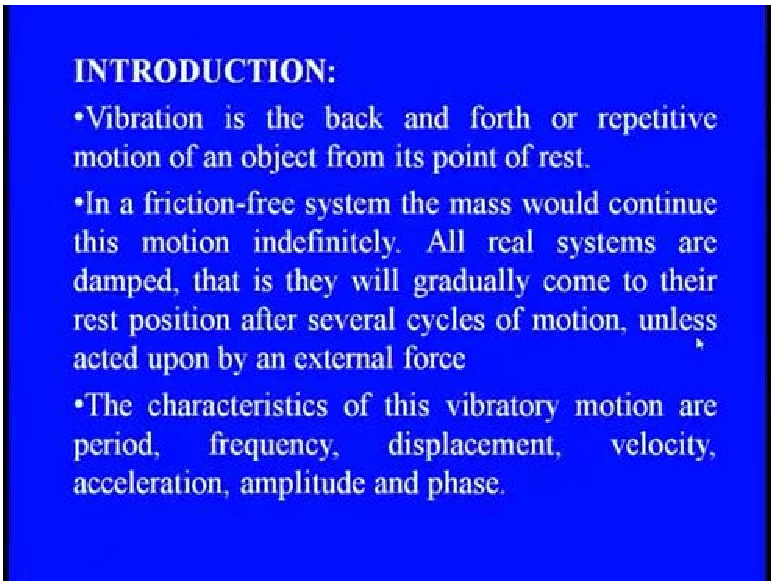

So, if we talk about the vibration then we know that it is nothing but the you know like the back and forth or some kind of repetitive motions of an object from the point of rest or some the mean position. And when we are talking about the friction free systems, we know that the mass would you know like continuously will oscillate or move you know like without having any kind of obstructions.

But, when we are talking about the real systems we know that, there are damping through which you see here you know like the vibration is gradually die out. You know like and the rest positions are coming even after several cycles of the motion, even you see you know like, we can say that whatever the system inherent natures are. But, if we are acting any external excitation force, then certainly you see here it will add some kind of more energy in the excitation features and we will have more vibrations, that is what the basic nature of the vibration is.

So, if you want to characterize the vibratory motion, then we know that we can only characterize using the period of vibration or in other terms we can say the frequency that what exactly, you know like the frequency features are there. Whether, the system is exciting at the low frequency or high frequency, just like you see we discussed about the human vibration and we know that this is absolutely starting from 0.5 Hertz, where the motion sickness is there.

To at the most you see 80 to 100 Hertz, where we know that the discomfort level right from you see the heart or we can say our brain or whatever the muscles are there, you know like right from the leg or at the hand part you see they are all you see they have the their own natural frequencies for that. So, the discomfort can be created at the low frequency, and even the high frequency excitations like you see the machines are there, whether the spindle is rotating or any you know like the bearing or the gears are being under the rotating features.

The excitation frequencies are almost in terms of thousands Hertz, means in terms of the kilohertz rather we can say this. So, this is one way to characterize the vibration, second is the amplitude, the amplitude means you see here whether the displacement or velocity or acceleration these are the 3 parameters, through which of their amplitude is here, through which we can describe the real characteristics of the vibrations.

And the last is the phase, when we are trying to relate those things, we know that not only the time derivative features are there, but even if we have the harmonic or any kind of you see the motion, then the phase differences are also being there with that. So, from frequency amplitude phase or a period you see through you know like with the using of this key concept, we can you know like characterize the vibratory motion.

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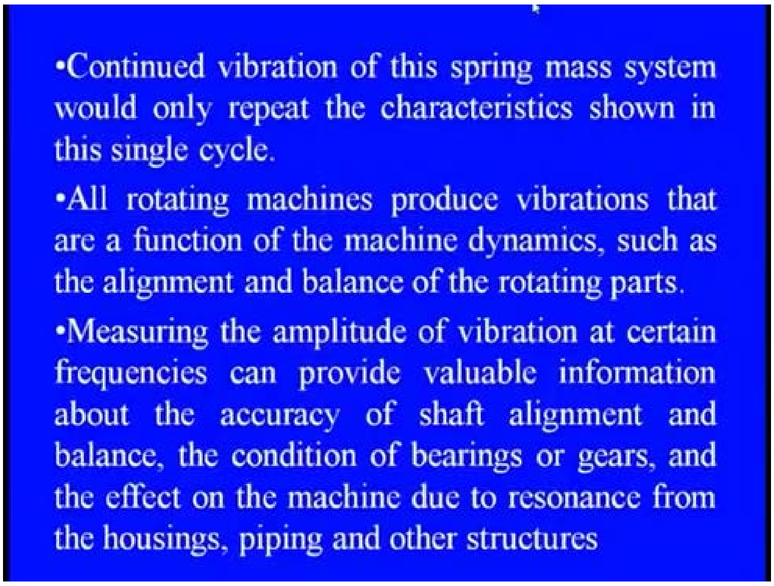

The continued vibration of this spring mass system would then you see you know like, we then have the repetition features in the characteristic part using the various cycles.

And all the machines which are producing vibrations are simply the functions of these machine dynamic parameters, and when we are talking about the machine dynamics we know that the key features are the alignment and the balancing of these rotating masses.

Because, the measuring of the amplitude of vibration at certain frequencies are simply providing the valuable information about the accuracy of shaft alignment, and also you see the balancing condition of these. We can say the rotating masses, like the bearings like gears or we can say the effect of this machine, due to resonance from housing piping and other structures. And when these devices are under exciting forces, we know that a clear exciting frequencies are being coming out through the transmission features of the machine, and we can measure and we can characterize rather the kind of excitations from that.

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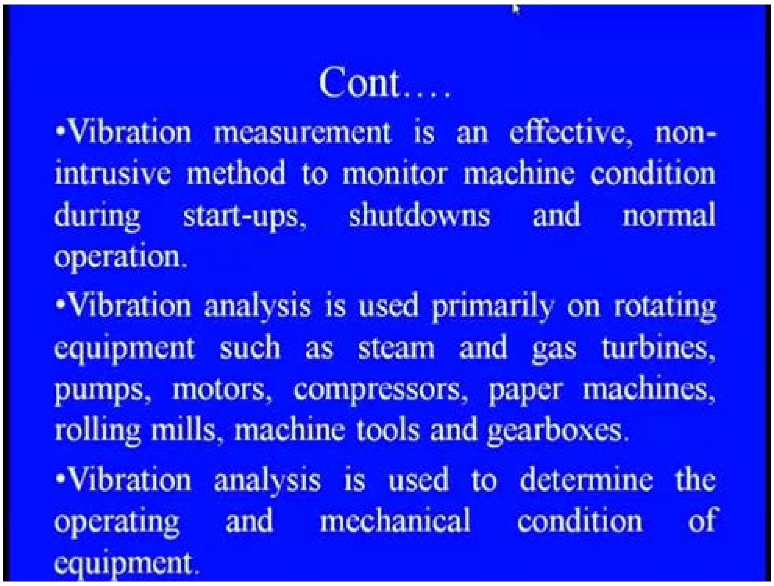

So, vibration measurement is an effective non-intrusive method to monitor the machine condition during start-ups, when the transient feature of the vibrations are there during shut down and during normal operations. So, we know that when the start-ups and shut downs are there, this is one of the important part that you see that how we can measure the transient form of the vibrations, and when the steady state feature is there under normal operations, how we can monitor the machine health using measurement of vibration.

Because, when we are saying that the machine is under running operation; that means, the dynamic feature of the machines are there; that means, there is a motion feature in the machine. And when there is a motion in the machine, one of the best technique to identify the fault or to locate the fault at any specific part of the machine or the machine itself the health condition, the vibration is the significant we can say you know like vibration signature is the significant part to do this.

So, vibration analysis is used primarily on the rotating equipment, right from you see you know like we can say the steam and gas turbines, pumps, rotors, compressors, paper, machines, rolling mills, machine, tools gear box. Right from small machine to the heavier machines for even power production of more than 1000 megawatt, by a single unit like you see the super critical boilers, and super critical thermo thermal power plants are there, where, a single unit can generate more than you see 900 megawatt, and then we can assume that what the huge rotors are there, and what kind of you see the thrust. And you know like the journal bearings are there at which the huge kind of exciting forces are being generated, and we have the huge amount of vibrations or we can say you know like the sounds are there.

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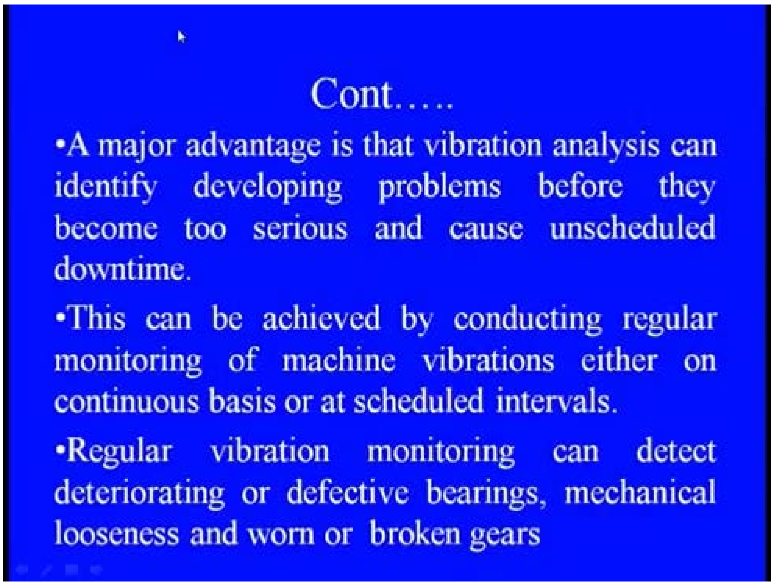

So, vibration analysis is used to determine the operating and the mechanical conditions of the equipment. So, major advantage in that you see the vibration analysis can simply identify the developing problems before, they become too serious and cause the unscheduled downtime of the entire system. And simply you know like we are achieving these by conducting regular monitoring, we are saying that the periodic maintenance feature.

We are always trying to measure the level of vibration and the exciting frequencies, that what kinds of you see the dedicated exciting frequencies are there in the spectrum. And what is the vibration amplitude associated with these you know like the dedicated frequency, we could easily figure out that these mechanical vibration either we are doing the continuous bases, means the online fall diagnosis or on the periodic maintenance feature it is clearly indicating the health of system.

So, regular vibration monitoring can detect deterioration or any defective part in the various rotating components right from the bearings, the mechanical looseness or even the worn or any broken gears or the shaft. Whether, it is a line shaft, any kind of misalignment is there unbalanced features are there, or various other rotating features or component through, which you see these excitations are being coming there itself.

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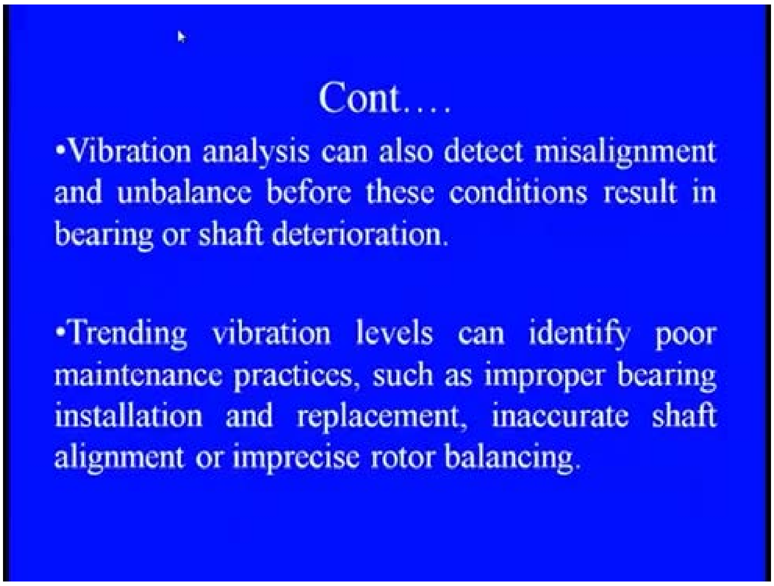

So, vibration analysis can also detect as i told you the misalignment and unbalanced, which are nothing but you see here it is a clear deterioration of bearing or the shaft part. So, trending vibration levels can identify the poor maintenance practices, such like you see in we can say the improper bearing installation or replacement improper lubrication adopted. So, that you see here the wear and tear is more, inaccurate shaft alignment even improper we can say imprecise rotor balancing, and you see here the gear meshing part means you know like the axial these axial features of the gear mounted shaft.

Then there is a meshing part and there is a huge impact forces are being created or generated at the meshing of these gear part, or even when the gears are being mating what is the lubrication features which are not being appropriate. And at that time you see whatever the film thickness, which are being generated is not able to or it is not sufficient to take the energy back and we have the huge kind of vibrations at that point.

So, these are the possible you know like causes, and that is why you see the vibration measurement is one of the important part prior to go for the control adoptions. So, that is why this part is more important than, you even know like adopting the vibration this control technology or you know like this method, that we should first try to featured out that what exactly the vibration part is. So, when we are just going for the basic characteristic of vibration, we know that you see first of all we need to check it out through these sensors, that you see how we can measure accurately the vibration and what exactly the characteristics are there.

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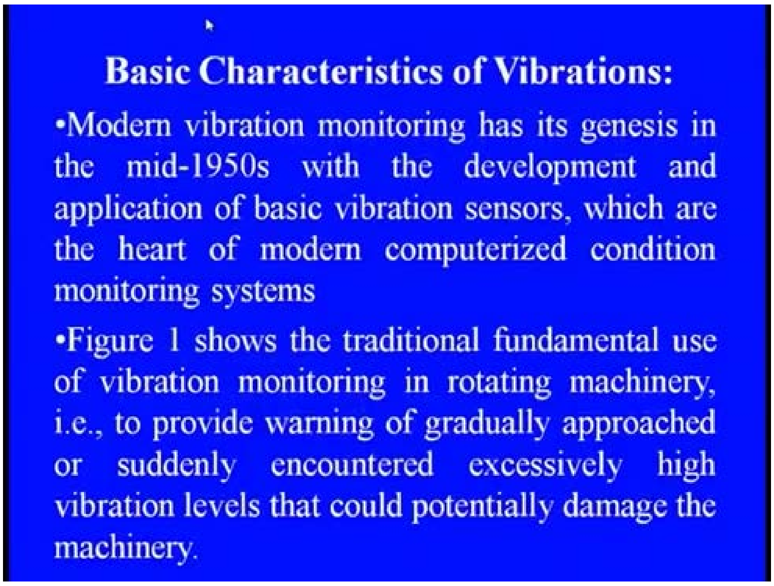

So, modern vibration monitoring has it is genesis in the you know like, we can say in mid 50’s with the development and application of basic vibration sensors, which is the heart of the modern computerized, fault monitoring or condition monitoring or health monitoring system of the machine. So, we can say that if you are just going with the basic fundamentals of the vibration monitoring, in any of the rotating machine. We know that these are simply providing a warning of a gradual approached or suddenly we can say encountered excessively high vibration level.

This is nothing but you see you know like the by high vibration level, means whatever the oscillatory features of these you know like the masses. If it becomes more and creating you see you know like more kind of you see the frequency part, or we can say more kind of you see the sound generation is being created; that means, you see here somewhere there is some problem. And, because of that this huge amount of you see the exciting energy, or exciting forces are being generated, so that can be straightaway monitored out and that can potentially damage the entire machinery itself.

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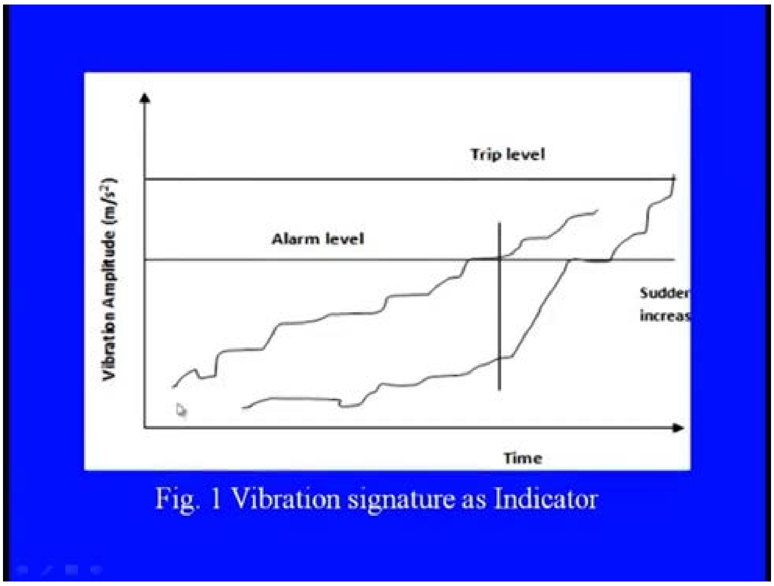

Fig. 1 Vibration signature as Indicator

So, if you see this diagram, it is clearly saying that the vibration amplitude this is showing in terms of acceleration, when you see the masses are being under you know like the motional feature. And you see the this you know the acceleration part is coming then you see the vibration acceleration with the time, when the machine is you know like just producing the vibration acceleration of this level. We can say this is what the comfort level no problems are there, because when the machine is in the rotating part or translating part or any kind of motion certainly due to the inertia forces.

We have these you know like we can say the varying compliance, feature of this vibration the self-excited vibrations we can say, but when the things are being you know like just increasing. That means, there is some you know like the additional features, due to misalignment unbalanced or due to various other reasons the defective part in the bearing gears or the you know like we can say the shaft. Due to that you know like this vibration is continuously increasing; that means, you see the exciting forces are quite dominating as the normal forces.

So, you see here we can put the alarming situation just based on the transmission, and you see here whether this vibration, you know like the this amplitude or the energy at that point you see here is now damaging the other we can say whatever the components. So, this is what the alarming situation, and once it is being you know like approached up to that point it can be tripped there, so the entire machine is now at the shut down. So, there is you see we can again recheck that which part is inducing this vibration, or which part is creating you see this huge sound.

We can straightaway treat or cure that or else the second phase is when you see you know like these are being operating, and you see over the time it is not showing any indication. That you see that sudden vibration this vibration is increasing, but due to some fault or due to some you know like fault may be of any nature, may be some defects may be some you see you know like these aligned problem unbalanced problem.

Anything you see here at the rotating component, there is a sudden increase, and this sudden increase is creating huge amount of we can say you know like the force is there itself or the exciting energy, which shoots me you know like when it is just approaching up to alarming level, we need to trip the part. So, vibration is one of the best indicator for these machines, where the you know like the motion or rotating reciprocating, anything is one of the key part for any processing you know like the machine itself.

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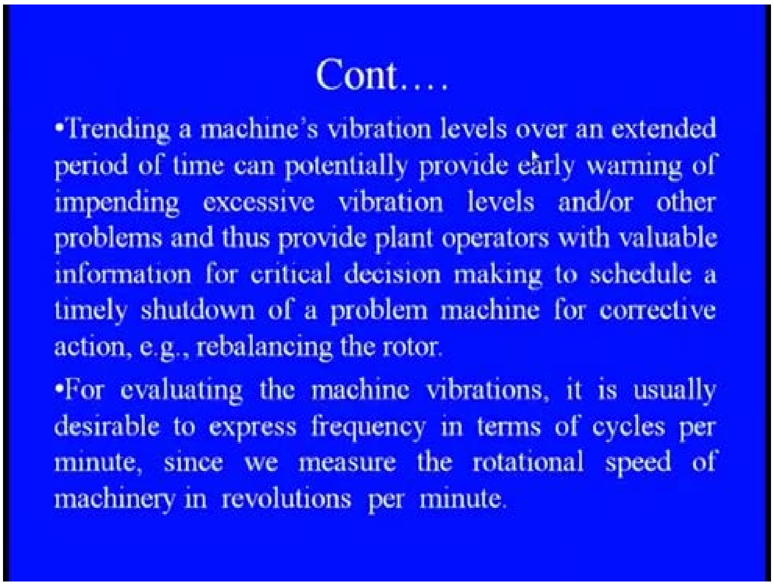

So, it is a good indicator for identify the health of the entire machine itself, so trending the machine vibration level over an extended period of time, can potentially provide the early warning of the impending excessive vibration level on the other problems. And thus provide plant operator, with the valuable information for critical decision making to schedule timely shut down of the problem machine for corrective action. That means, you see here if whatever the problems are there with the machine, can be immediately either replaced can be repaired or can be maintained properly for the specific time of that.

So, for evaluating of machine vibration, first we need to see that what exactly the desired level of the frequencies are there, and then you see here what exactly our amplitude which we can effectively control at that point or whatever the amplitude which are being generating. We can say this is the usual form of the amplitude at the particular frequencies, so if we can measure, these you see you know like we can say the rotational speed of machinery with this rpm part. That we can calculate you see the dedicated frequency which we are saying that, you see these are the frequency which can come, when any rotational features are there the rotor bearing gears shaft whatever.

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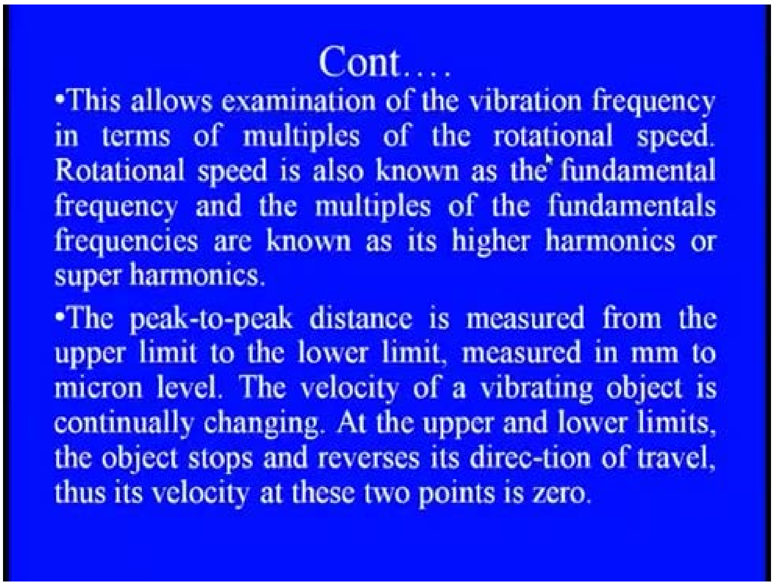

So, once we do that certainly this allows the examination of vibration frequency in terms of the multiples of these rotational frequencies, and we can say the rotational speed is also which is nothing but you see the fundamental frequency. And whatever the multiples are coming of these fundamental frequencies, we can say these are the higher harmonics or the super harmonic joules of that. Even, sometimes system is also exciting say half of the natural frequency, one fourth of the natural frequency, one eighth of the natural frequency, three fourth of the natural frequency, this is also harmonic.

Harmonics of these you know like the natural frequency, but at the sub harmonic system. So, we can get you see here whether the system is absolutely exciting at the natural frequency, means the resonant condition in the sub harmonic region, super harmonic region and then we discussed that you see how we can adopt the control strategy accordingly.

So, the vibration measurement is one of the specific and informative tool, to adopt the corrective measures against that. The peak to peak distance, which can be measured from the upper limit and lower limit is nothing but you see we can say you know like right from the microns level to any of the level. And it is clearly showing that how much total displacement is there of the rotating or you see the vibrating mass, and this is what the displacement and the velocity of vibrating object is continuously changing.

The upper and lower limit of the object stops, and reverse it in the we can say direction of the travel, simply providing it is velocity at these 2 point. And then in between that you see here, we can say what the variations are there of the velocity, when it is approached to the 0, the upper and lower feature.

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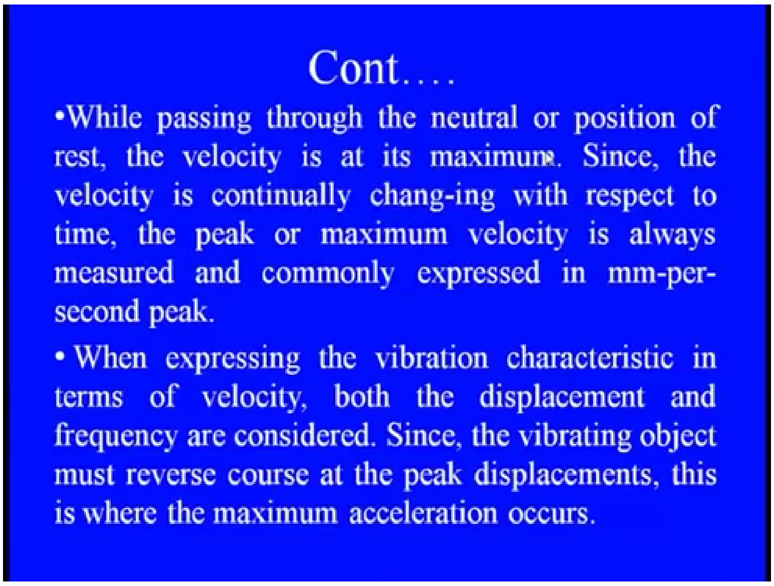

So, while passing through the natural or we can that this neutral or the position of the rest the velocity is at maximum, and since the velocity we know that you know like the nature of the velocity and in continuous changing with respect to the time. The peak or maximum velocity is always measured, which gives the more the informative feature, and it is commonly expressed, in terms of you see you know like the millimeter per second or whatever it is at the peak part.

And when we are trying to express the vibration characteristics in terms of velocity both the displacement, and the frequencies are being considered, because we as we discussed. That the frequency is this velocity of any simple harmonic or the periodic vibration is absolutely depending on the amplitude, that what exactly the amplitude of these velocities are there, but also the frequency term.

Linearly depending on both the parameters, and since the vibration object must reverse you know like course of the actions at the peak displacement, this is always where you see where the maximum accelerations are occurring. So, we need to consider right from you see the you know like we can say the displacement, means the maximum amplitude and the frequency for the measurement of velocity in that.

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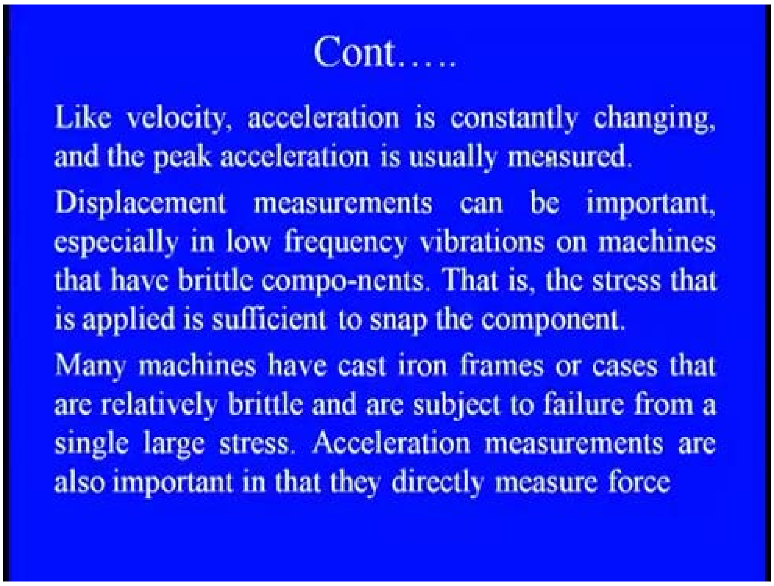

So, you know like velocity acceleration is also continuously changing, and the peak acceleration is usually measured, so this is the third parameter of the dynamic system in which you see here the out of 3. The 2 in which you see we are simply measuring the peak part, peak velocity and peak acceleration, so displacement measurement can be importantly you know like can be importantly done. Because, especially in the lower frequency vibrations on the machine, which have you see you know like we can say the brittle components.

These always you see you know like, because we know that the brittle components are harder and they are providing good damping part, the displacement must be measured not the not the velocity and acceleration. Because, they can provide you rather you know like, we can say good kind of the accurate kind of the exciting part, the frequency part. And we can say that you see when we are talking about these brittle components, the stress that is applied is sufficiently, you know like to step the component.

And whatever the variations are there, that can be easily measured using this any of the displacement part l b d t or something the strain part or like that. So, many machines, which have you know like the cast iron frames or the cases, they are relatively brittle and are subjected to failure from the single large stress. So, acceleration measurement is also one of the important feature, because they are measuring the force part that how much you know like the inertial forces are there, when the mass is rotating.

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And excessive force can lead to improper lubrication in various bearings or gear and that is resulting in the failure. So, dynamic force which are being created by the vibration of due to any rotating member, can be directly measured using the acceleration feature of that rotating mass. And you see we can find out that how much you know like the these inertial forces are being there, which can cause the failure part.

So, generally a machine can withstand up to 8 times of the designed, we can say static value before bearing failure occurs, so we can say that we need to check it out that this is general trained you see here. So, we can say that what exactly you see the kind of forces which are being generated, during the rotational feature or any oscillating feature, and also you see you know like it seems that sometimes whatever the small unbalances are there they can also create. The huge dynamic force and even it is transmitted at the you know like the faster way, because of their robust connections even at the overloading part of bearing or at gears or at the shaft part.

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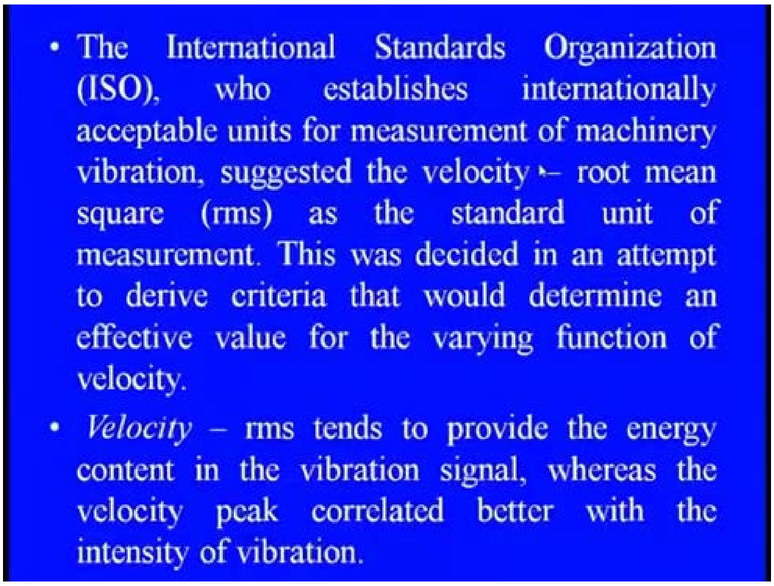

So, ultimately we need to focus on that what exactly the international standard organizations are there, through which we need to find out the measurement, what are the you know like the acceptable features are there for measurement of vibrations. So, for a velocity we can say that, or for these you know like the dynamic parameters the r m s is one of the specific term or the unit, which can be used directly.

Because, based on you know like these levels of this vibration in terms of rms part, can at least find out you see you know like the what is the level of this vibration is, during this root mean square value of these part. So, when we are talking about velocity then rms tends to provide the energy content in the vibration signal, whereas the velocity peak can correlate better with the intensity of vibration.

So, this is what the things are, when we are talking about the root mean square trained of the velocity, then it is simply providing the energy that, how much energy is being contained in the velocity signal of the vibration vibrating feature. But, when we are talking about the peak to peak value the maximum value, then you see you know like we can rather see the intensity of these vibration in that.

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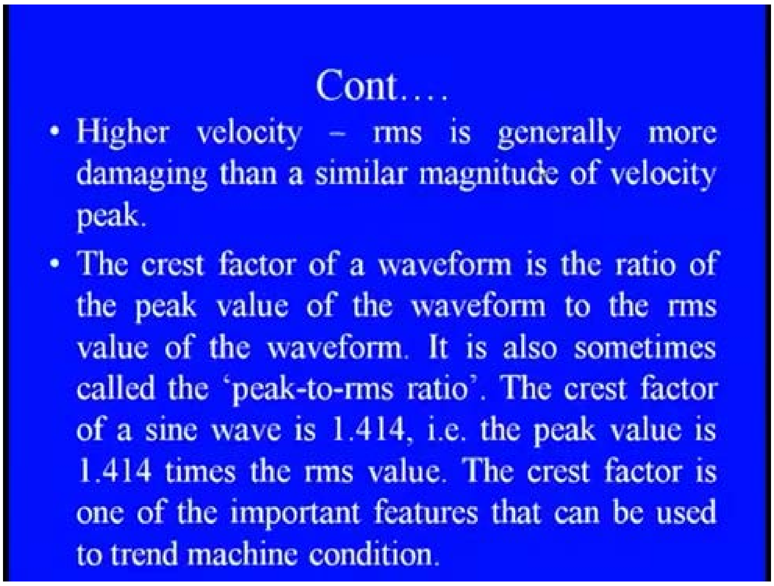

So, when we are talking about the higher velocity, that means the rms is generally more damaging, than a similar magnitude of this velocity at the peak level. So, again you see we can straightaway go to the various you know the factors, which are related to the wave form, so crest factor is there in that. The crest factor of wave form is nothing but the relation between you know like the peak value of wave form to the rms value, and sometimes we are saying that this is the peak to rms ratio of the crest ratio.

So, crest factor of this sine wave generally, we are taking as one point you know like 414, you know square out of 2, and the peak value 1.414 times the r m s value is appropriate you see in such cases. So, crest factor is one of the important feature, that can be used to train the machine condition straightaway, because it is relating the rms and the peak value.

So, when we are talking about you know like these velocity or you know like, when we are talking about the acceleration, we need to see that that you know like, whether we are talking in terms of the just forces or the energy transformation. Because, you see when we are talking about acceleration which is nothing but the rate of change of velocity, it is simply referring to spring mass body. Where, the acceleration of mass is at maximum you know like at the extreme limit of the travel, where velocity of mass is absolutely 0, so how we can relate in terms of the energy or in terms of the forces together.

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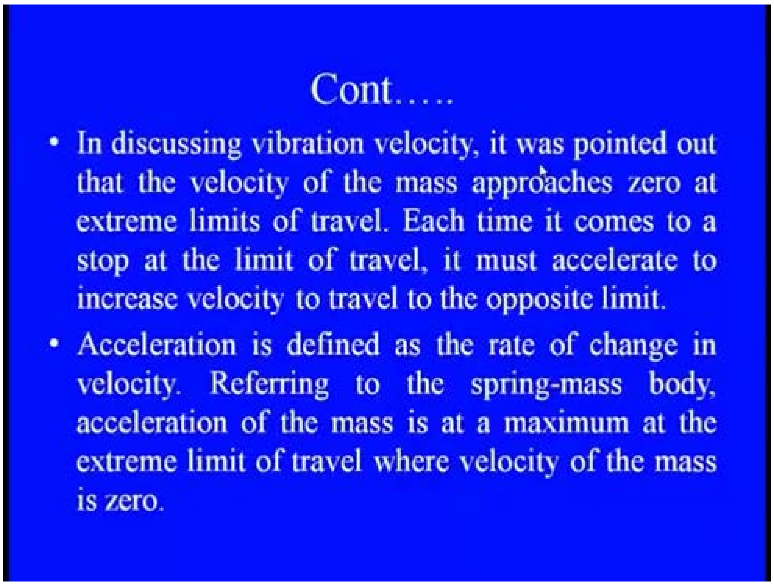

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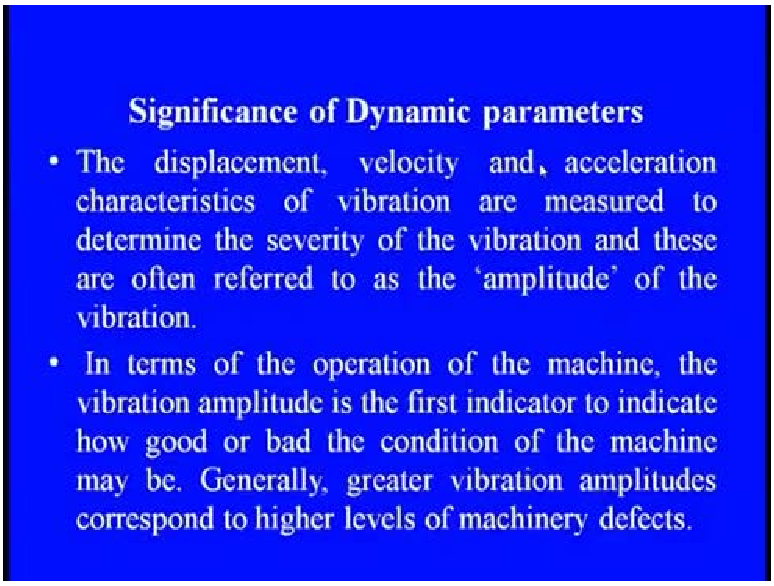

So, first the significance of the dynamic parameters, so the displacement velocity or acceleration, which are we are saying that these are the key parameters needs to characterize you see here. And in such a way that we just want to you know feature out the vibration, and we want to measure just to determine the severity of these vibrations.

And these are often referred to the amplitude of that, because whatever the amplitude of these 3 quantities are there, they are generally saying that the amplitude of the vibrations. So, in terms of the operation of machine, the machine amplitude is the first indicator to indicate, how good or bad the condition of machine is, or we can say that whatever the greater vibration amplitudes means the higher level of machinery defects are there.

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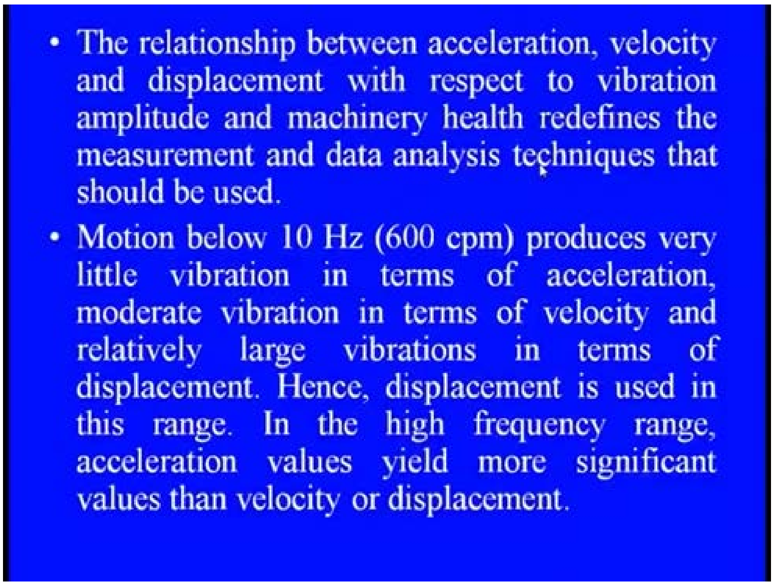

So, we can say that we can simply set the relationship between the acceleration velocity and displacement, with respect to you see the amplitude and the machinery health which redefines the measurement in data analysis technique. You know like, what exactly you see you know like these details of these signals are and based on that, you see here we can correlate that.

So, if we are talking about you see you know like the machine, which is say exciting below 10 Hertz which can produce the we can say you know like very little vibration terms of acceleration moderate vibration in terms of velocity, and relatively large vibration in terms of displacement. So, displacement is used in the in this range and in high frequency region acceleration value yield more significant than velocity or the displacement, because when we are talking about high frequency.

If you are talking about displacement, we know that if it is a simple harmonic motion x equals to a sine omega t. So, this displacement which is clearly showing the amplitude and the sinusoidal feature, is just showing you see the frequency dependency in the sine omega t, whatever you see the you know like the sinusoidal features are there. But, when we are talking about the velocity this is clearly showing the amplitude, and the linearly dependency on the frequency.

So, a omega cos omega t is there, and when we are talking about the acceleration, it is absolutely minus a omega square sine omega t; that means, you see here the acceleration not only depending on the amplitude, but also you see the omega square. So, when we are talking about the high frequency zone or the ranges acceleration is the only parameter, which will clearly characterize in a correct manner about the vibration significance.

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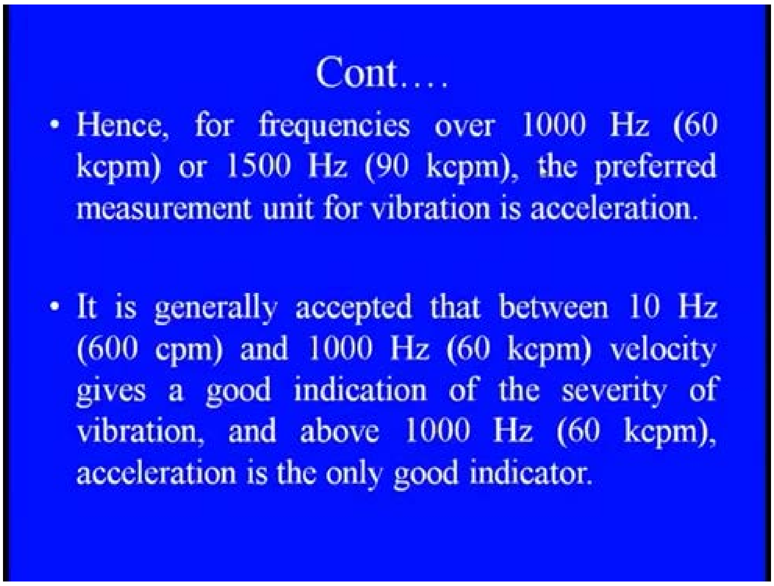

So, you see here when we are talking about the frequency over the range of one kilo hertz, or we can say 60 you know like kcpm or even more than you see 1.5 kilohertz the preferred measurement is absolutely the acceleration. And it is generally accepted that up to ten Hertz or we can say you know like the thousand Hertz, the velocity is a clear indication the good indication for severity of vibration.

And above we can say you know like this 1 kilohertz the acceleration, and below 10 Hertz, we can whatever you see you know like the deforming features are there or we can say you know like for as we discussed about the these brittle material or cast iron. When you see the low frequency excitations are there, the displacement is a good part and that is why you see here for controlling low frequency vibration.

We are always adopting the spring for controlling high frequency vibration, we are adopting the masses and we have we just want you know like go to the resonant condition. Certainly the damper is one of the key feature for you know like controlling at that point of time to absorb the vibration excitation.

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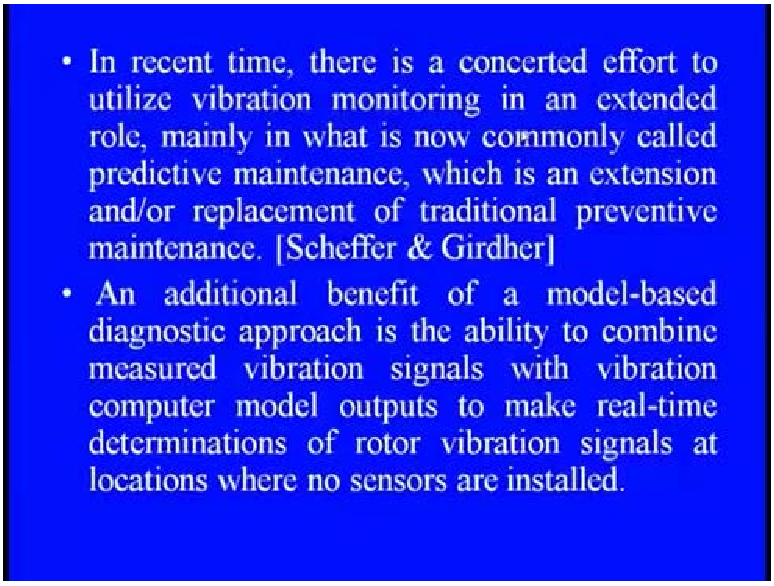

So, in recent time there is a you know like simply concentrated effort to utilize the vibration monitoring in such a extended way, that how we can just predict. The vibration level based on what the sophisticated these you know like the equipments are being available, and this is absolutely based on these sensors, whether we are using displacement this velocity or acceleration measurement devices.

So, you see here, when we are talking about the model based diagnostic approach, which has the ability to combine the measurement signal with the vibration. We can say whatever the outputs to make the real time you know like the determinations of rotor vibration, or any kind of things can simply give the severity level the alarming situation, and you see here what the comforting zones for health monitoring systems.

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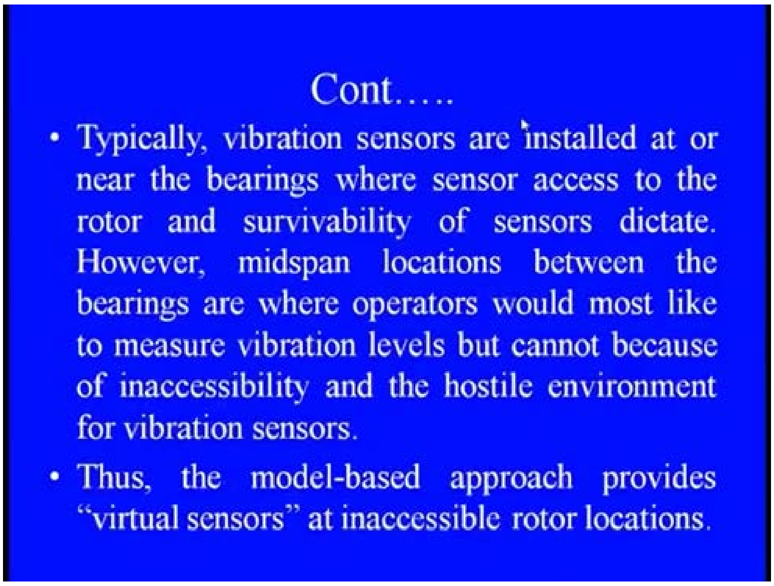

And when, we are talking about the installation means you see here where the vibration sensor to be installed, they are generally installed near the bearings, where you see you know like the accelerometer or any these probes are being installed there, Else, we can say that, wherever you see you know like, these kind of the rotating devices are there whatever the closed by positions are there.

We can install those things, but we know that you know like whatever, these mid span locations between the bearings, where the operator would most like to measure the vibration level, but cannot, because you see the inaccessibility or the hostile environment for the vibration sensor. We need to see that what exactly the static means the housing positions are there, where we can keep and we can get these vibrations, because these vibrations are transmitted.

As, we discussed through this structural member, and because of this structural damping sometimes we are not able to correctly configure these inertial forces, or whatever the dynamic forces which are being excited at the point of excitations. So, this model based approach, for we can say you know like which is providing the virtual sensors are inaccessible, for this rotor or the bearing locations to accurately.

Say, you see if you have a defect at the bearing or some inner rays or somewhere where in gauge, then it starting you know like inducing the vibration, we cannot even put the gauge there itself. We need to put the gauge at some static position, so that the vibration can be measured, but when the exciting the source of excitation and the measurement part. There is you see you know like the structural members are being connected, and as I told you some material damping or the structural damping can be act against this kind of excitation, and it is really hard to find out the clear excitation feature at the source part.

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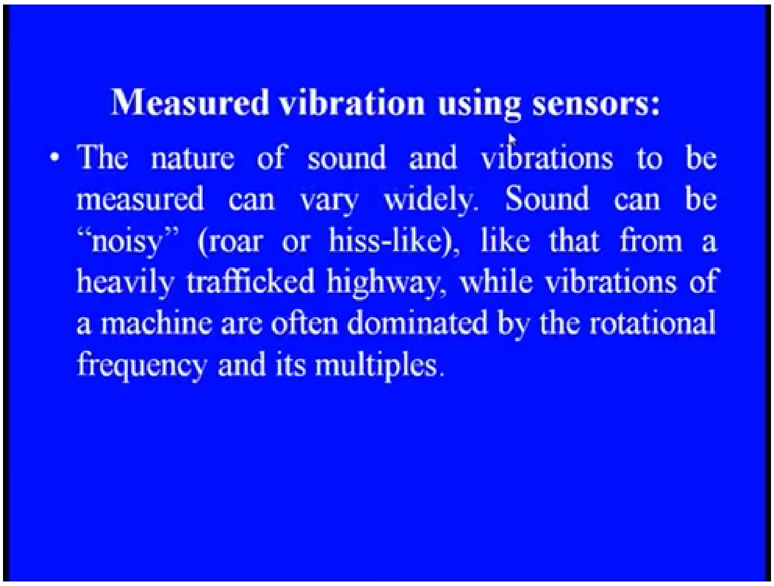

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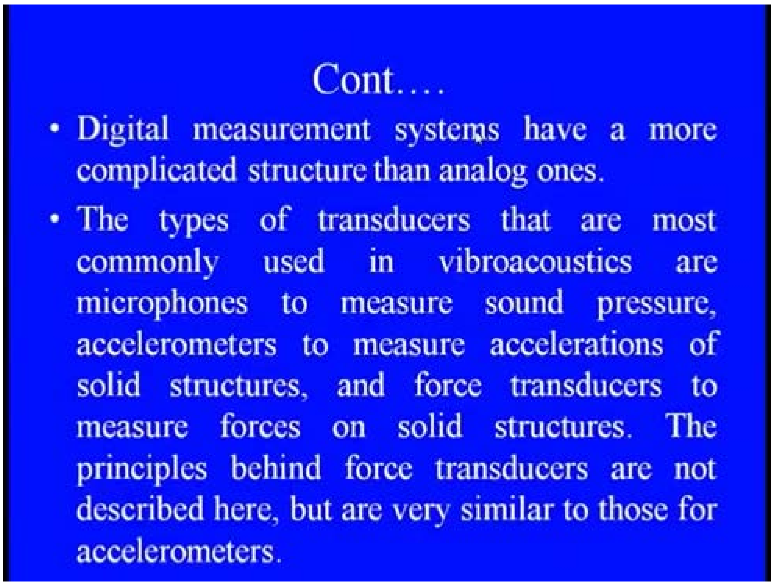

So, you see here when we are trying to measure the vibration using these sensors, we need to first found that, what exactly you see the kind of you know like the vibration, fee the signature which is being coming in these. You know like we have the vibration these capturing signals, and then you see here how we can you know like see that how many peaks are there in the vibration signature, through which we can characterize the vibrations.

So, digital measurement system, which we are generally using you know like, but you see they are always more complicated structure than the analogue ones, and the types of transducers, which are being you know like using for you know like systems. Sometimes, we are using the vibroacoustic like you see the microphone to measure the sound pressure, accelerometer to measure the acceleration of the solid structure, or the force transducer to measure the forces, in the solid which are being generally used and coupled with that. And the principle behind force transducer are not to describe, but mainly you see here to see that, how you see the forces are being there, you know like generated because even we can get those inertial forces through the accelerometer also.

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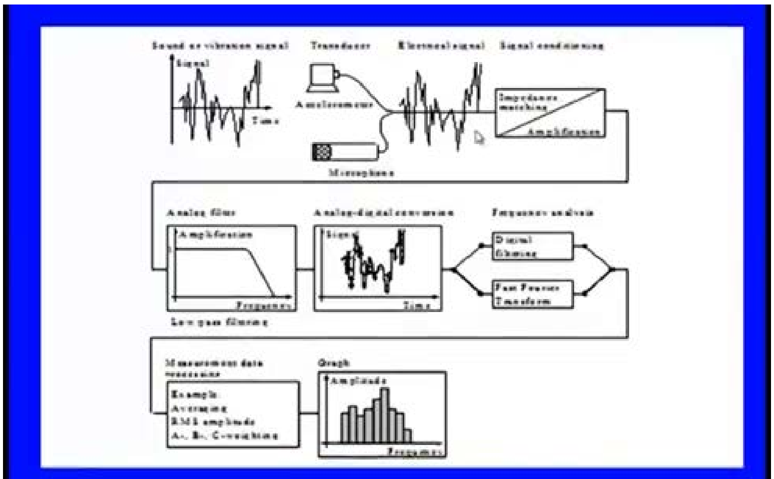

Fig. 2 Flow chart of a digital, single-channel measurement system [1]

So, this is what it is we can see that, in which you see you know like these wherever you see the positions are there, we can put these you know like the microphones or the accelerometer. This is what my main transducer, and through that I can get that you see these signals or even you see, when we have such kind of things with this, you know like the digital this filtering, we can get you see you know like the frequency peak the FFT.

So, this is my time domain, this is my frequency domain and it can clearly give that what kind of you see the exciting frequencies, again we can get the responses in the 2 main domains. As, we discussed already in our initial lectures the time domain is clearly giving the variation of the vibration amplitude in terms of the displacement velocity, and acceleration. The FFT, which is nothing but you see we are using the key information of the time domain part, and we are trying to convert this, in the stationary wave form from time domain to frequency domain using the Fourier transformation.

And that is why frequency domain information is simply used to say that fast Fourier transformation, discrete Fourier transformation, sort in STFT also, short term Fourier transformation and anything, which is being required. Sometimes STFT is being used for you know like if any additional peak is there because of some abrupt changes, and the transient feature is coming which is not the stationary part. We can use either the wavelet or any kind of signal processing unit for these you know like to featured out, the non-stationary form of this signal part, so you know like we can characterized these you know like various the signal processing part.

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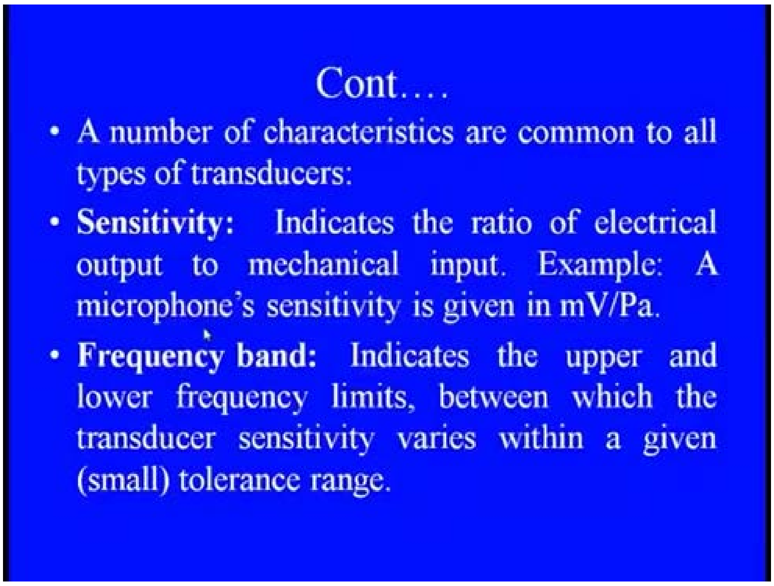

But, the one of the you know like the important characteristic, which are being commonly used for all the type of transducers are first the sensitivity, the sensitivity is simply indicating the ratio of electrical output to mechanical input. Second is the frequency band that what exactly, you see the upper and lower frequency limits are there.

So, that we can simply put that this is what you see my transducer sensitivity, which is varies you see, right from you know like within this part. So, this is what my tolerance range is there for that, and octave bands are there for you know like we can say this the third octave band and all.

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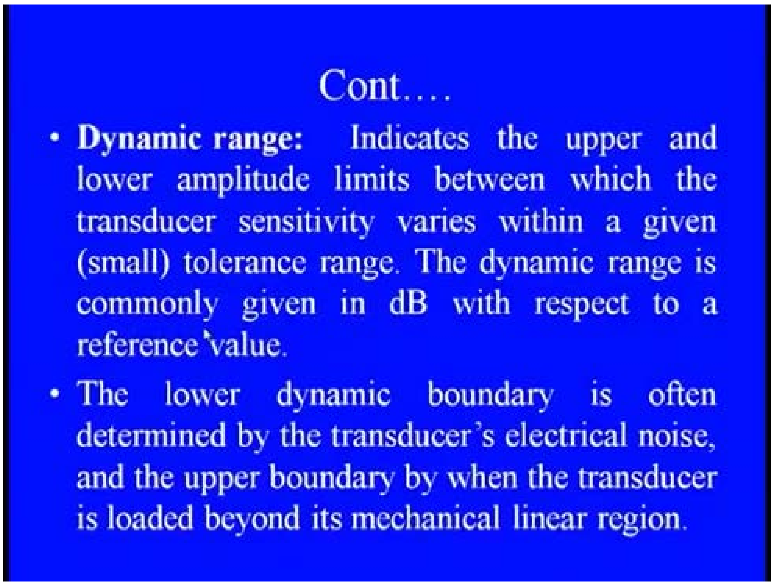

The dynamic range, which is simply indicating the lower and this upper limit of the amplitude in between the transducer sensitivity varies within the given tolerance range. And the dynamic range is commonly you know like being there in that decibel sound, the decibel part with respect to the reference value. So, the lower dynamic boundary is simply you know like determining by transducers electric noise, and the upper these you know like we can say dynamic boundary of the transducers, when it is being loaded beyond the mechanical linear regions that can be get. So, the first part is coming, which is the accelerometers accelerometers, nowadays is one of the you know like the fascinating device, which is based on mainly as we discussed the piezoelectric base.

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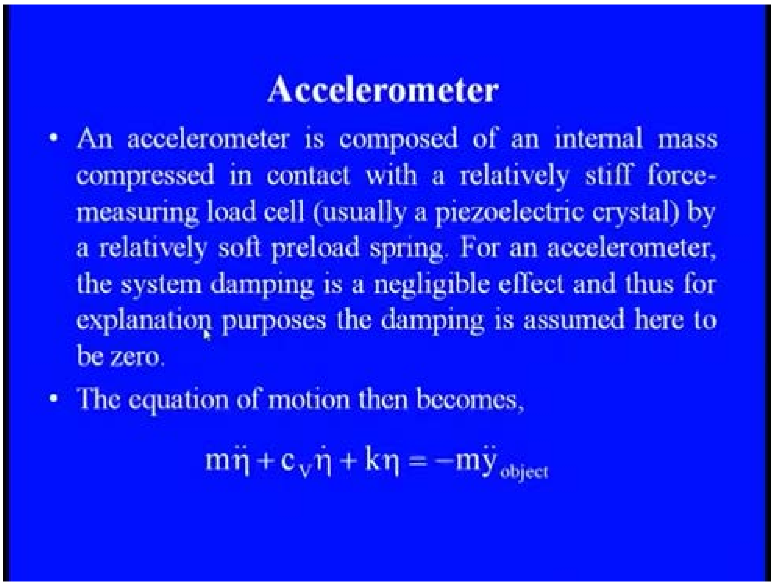

So, when we are talking about the accelerometer, the system damping is almost you know like having the negligible effect, thus for we can say that. We can simply use these you know like the accelerometers, which is based on you see the piezoelectric level, having the equation of motion m, say this one m eta double dot plus c v eta dot plus k eta equals to minus m y object.

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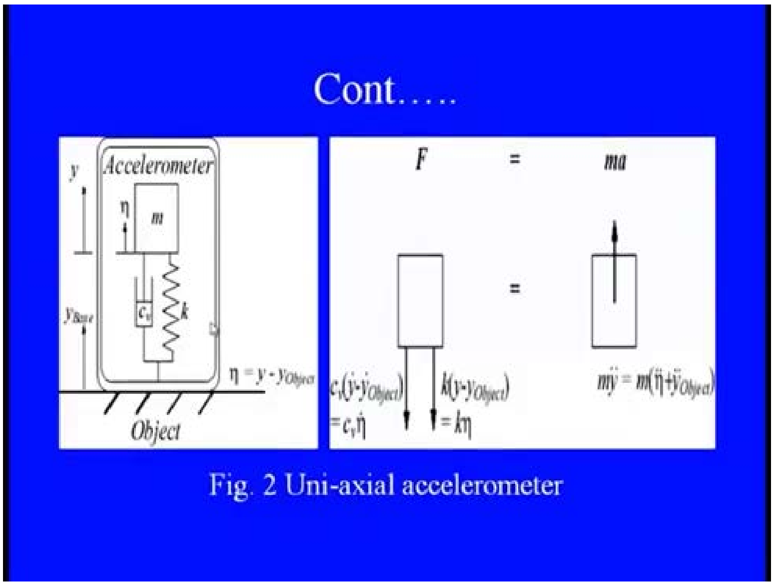

This equation is simply you know like forming of that one, we have the object where the vibrations are there, and this has you see the you know like the displacement of this y.

And you see this accelerometer which is being putting on that one you see here, so we have the y base, y base is nothing but the displacement of the base, which is being now you know like sensed by this accelerometer. And in this you see here, this accelerometer is also moving along with our base, and in that accelerometer we have the stiffness kcv is nothing but the damping, and the mass which is being there in the accelerometer has you see you know like the movement is the eta.

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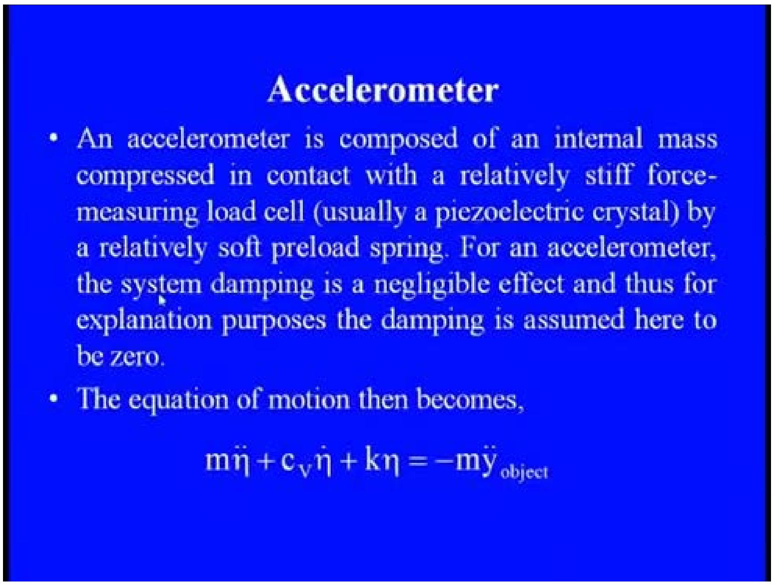

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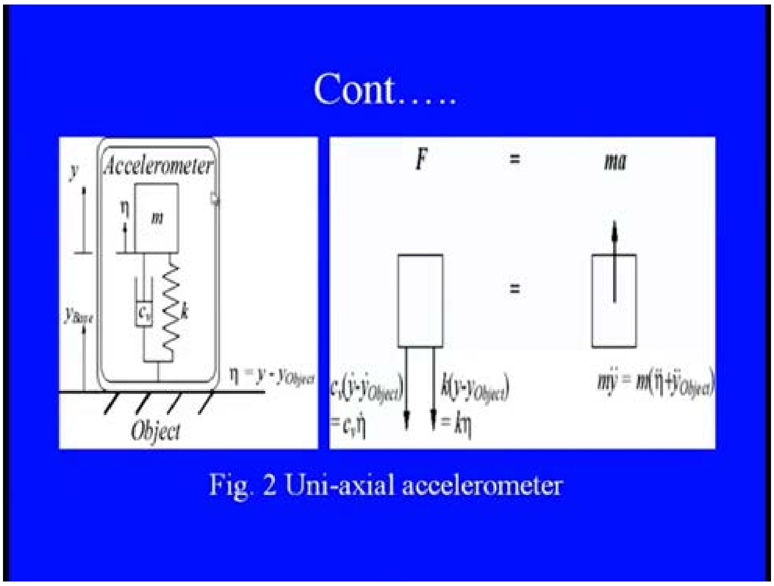

Fig. 2 Uni-axial accelerometer

So, that is why previously which I shown you see, was m eta dot that is you see the inertial force within the accelerometer device, and then c v this damping and restoring forces of the our accelerometers are. So, when we are trying to make the balance of this say eta which is nothing but equals to y minus y object, when we are trying to make the forced balanced condition. We have you see m y double dot equals to m into you see eta double dot n y plus y object double dot that is what you see the total overall impact of this part, into you see which is making balance of m into acceleration.

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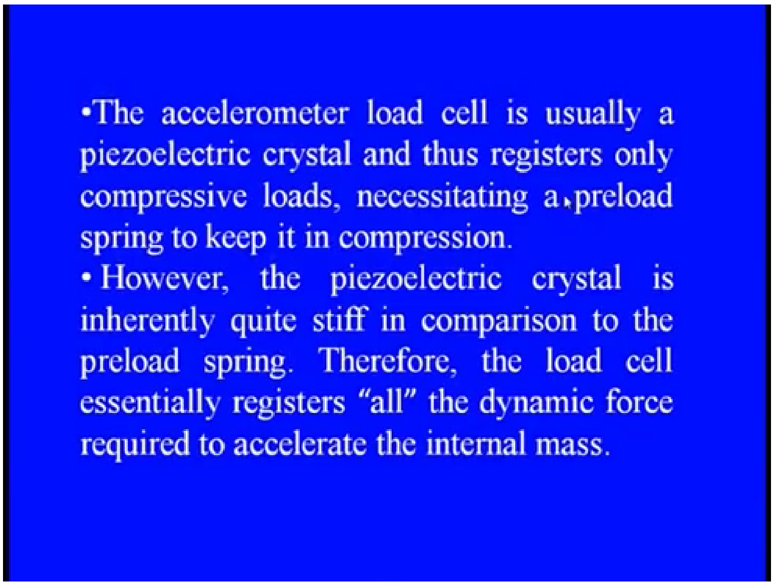

So, accelerometer load cell is usually you see you know like having a piezoelectric crystals, and you know like they are simply registering a compressive load, which is necessary we can say a preload kind of spring to keep it in compressive part. So, we have you see the spring and the damper on which you see we have the mass, which is always keeping in the compressive or the preloading feature.

And the piezoelectric crystal which has you know like inherent, you see the inherently property with a quite stiff part in comparison to the other preload spring. So, we can say that the load cell essentially register all the dynamic forces, required to accelerate the inertial the internal masses towards that. So, this is what you see you know like, as we already discussed about the piezoelectric features, and how you see the pjt, these piezoelectric accelerometers are being used effectively to measure the accelerometer in that.

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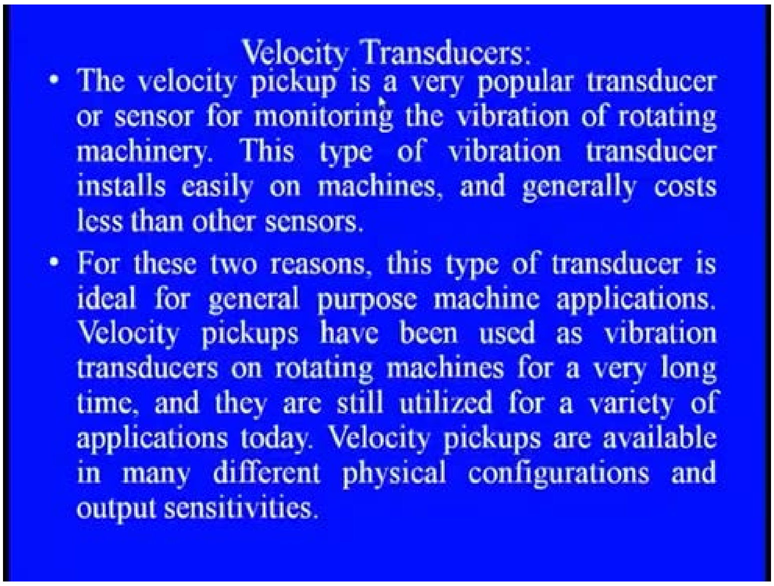

The second part is in this is velocity transducers, so velocity pickups are very popular transducers or we can say you know like for monitoring the vibration of any rotating machinery, because we know that it can be straightaway installed on the machine easily. And you see its very low castings compared to the accelerometer, so for these two reasons we can say that generally, we are using you see you know like the velocity probe straight away or and we can keep. You know like, just we can use as a vibration transducer, and straight away keep on the rotating machinery for even for longer time, and can be utilized for variety of these you know like the configurated machines.

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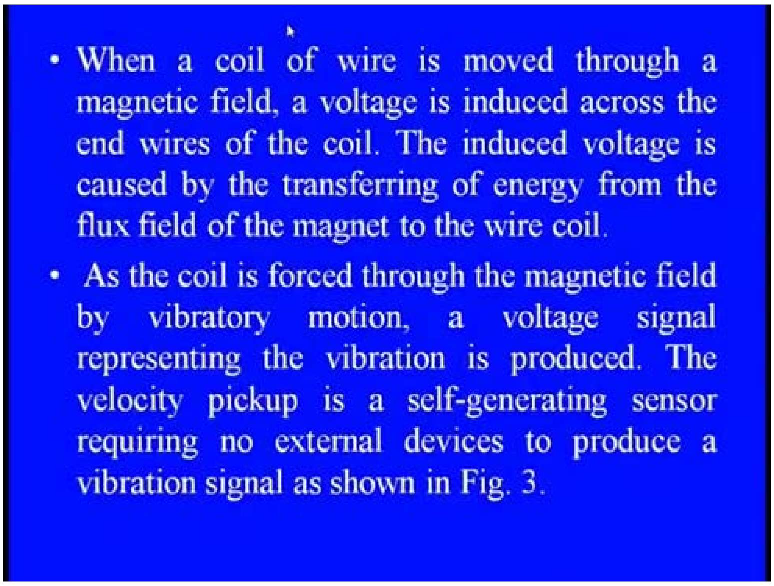

So, in that when a coil of wire is being moved through a magnetic field a voltage is induced across the end of you know across these, you know like the end of the wires of the coil. And this induced voltage is caused by you see you know like the transferring of the energy from fixed, this whatever the flux field you know like just you know like to the magnet to the wire coiled.

So, whatever the flux which is being you know like just we can say flux fields are there, exactly at the this magnetic point, they are being you know like they are right from to this point to you know like the this coiled wire. And as the coil is forced through the magnetic field, by any vibrating or you know any kind of you see the injective motion a voltage signal which is representing the vibration. You know like the produced vibration is being transmitted, and this velocity pickup is nothing but the self-generating sensor required, you know like no other any external device and it is being transmitted there itself.

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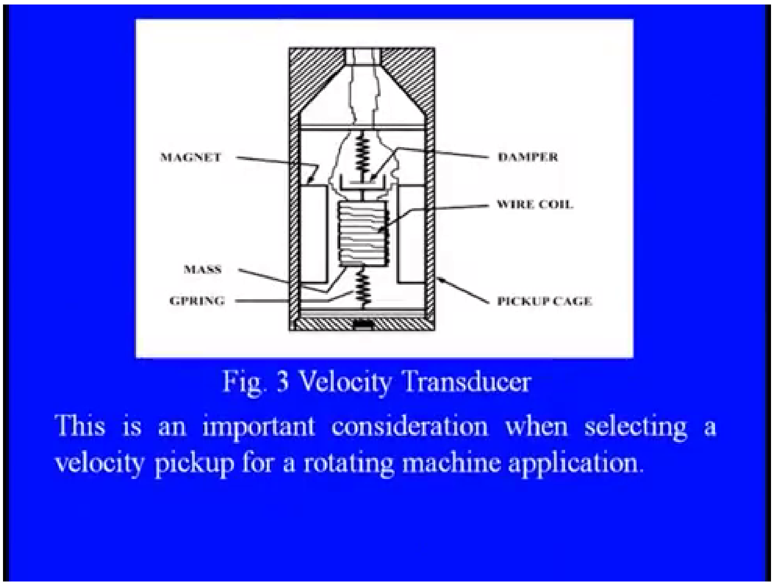

So, you see here you know like the corresponding vibration signal can be generated, as you can see in this diagram that here we have the spring and whenever it is being coming it is being straightaway go to the wire coiled. So, in that wire coiled you see here whatever the things are being coming straightaway it will pickup, and then it is being transmitted through this.

So, you see here and in all along that you see we have the damper and this coil, which is there in between the magnets is immediately you see sensed that, and then it is being transmitted through these you know like whatever the damper, and the spring devices and then we can measure that. So, this is you see you know like one of the important, we can say vibration pickups are there using this velocity pickup we can say probes.

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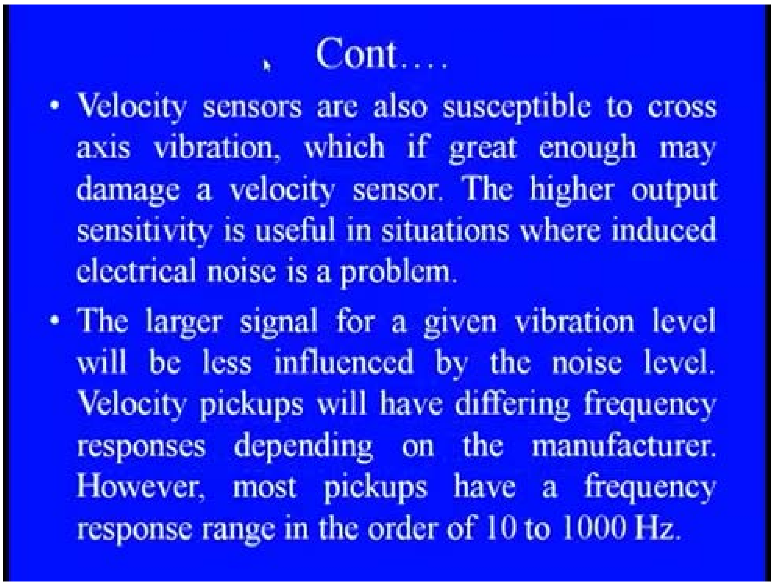

So, velocity sensors are always you see you know like, we can say susceptible to cross the vibration features even in that you see here, whenever we are trying to see that if the higher output sensitivity is there. Where you know like the electric noise is creating the useful, is creating the huge problem these pickups are always being useful. So, for larger signal and for you know like whatever the vibration level is quite high, as compared to this noise level the velocity pickups have, you know like the different frequency responses which are absolutely depending on.

You see that what exactly, the sensitivity level is given in these velocity probes, but most of the peaks you know like these most of the pickups of these velocity probes. That they can be easily work within the this frequency response range, right from 10 hertz to we as I told you the 1 kilo hertz, but in, but nowadays you see here we have a right from uniaxial, biaxial, and even triaxial accelerometers are there.

And you see even these accelerometers, which are absolutely based on these piezoelectric base, they are absolutely even sensitive and they can provide, because they are the calibrated one. And they are providing absolutely you know like the accurate information, in any of the accesses with you see whatever the this pjt acceleration features are.

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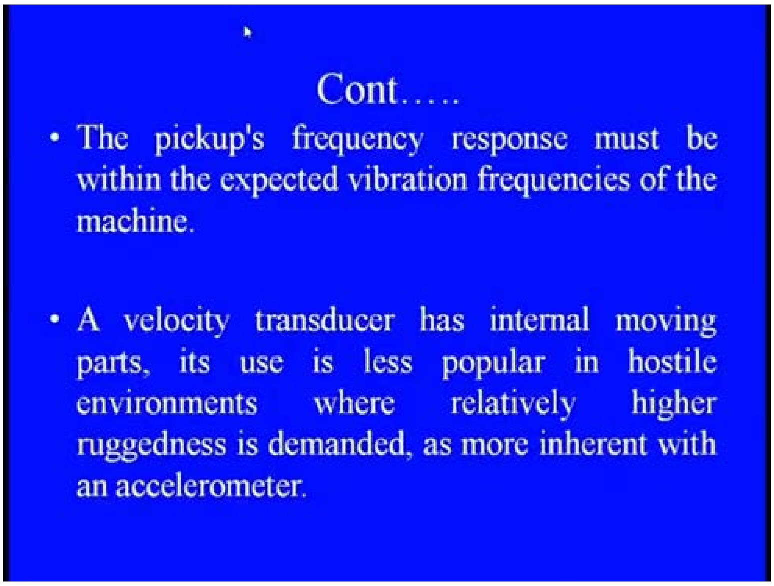

So, you see you know like the pickup frequency response, when we are talking about the velocity probe, then you see you know like we can get straightaway from the velocity pickups within the. You know like we can say expected vibration frequency of the machine, and we know that the velocity transducer, which has the you know like the internal moving part, and you know like that cannot be given accurate reading in any hostile environment.

Because, we know that when the these movements are there certainly, you see here this hostile environment or you know like some kind of huge amplitude is creating the problems within that. And that is why you see here the as I told you the accelerometers are the perfect one for measuring this, if we are talking about the displacement transducers.

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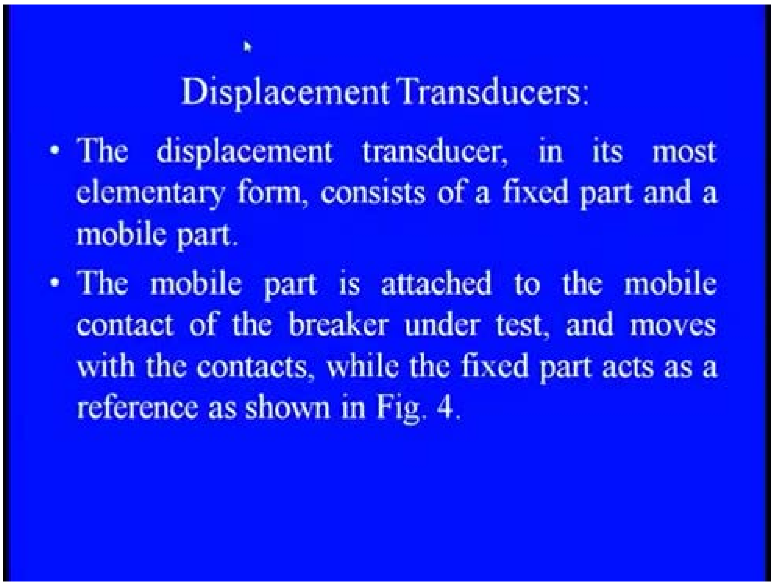

We know that there are variety of the displacement these probes are being there, in which we have the fixed and movable part, and we know that the movable part is absolutely attached to these we can say the this entire unit with the breaker part. And when it is moving with the contacts, we know that you know like the fixed part is absolutely acting as a reference end, we can get you see what the differences are there.

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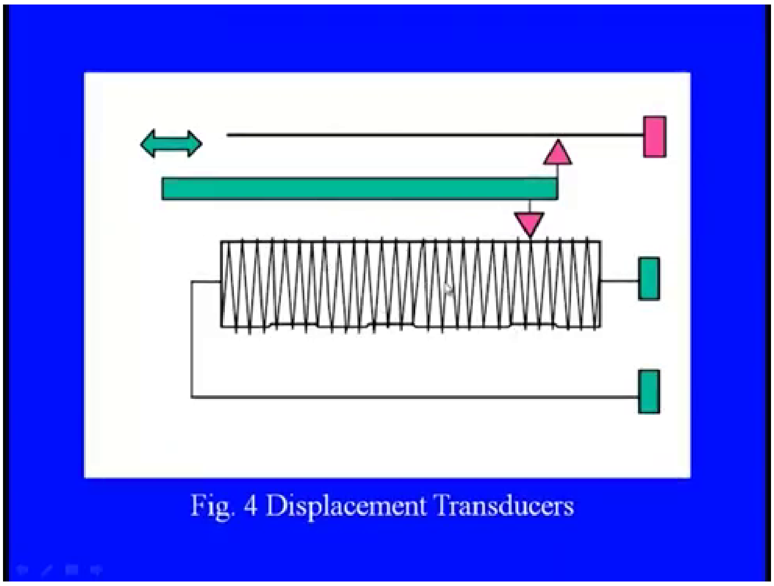

Fig. 4 Displacement Transducers

So, you can see this one, we have the fixed part and the movable, and they are being rested on that, so whatever the movements are there you see under the load conditions we can see the differences and we can get the displacement or this one. And even you see here, we can get the deformation with the using of a strain gauges l v d t's and all through that you see, we can find out you see what exactly, you see you know like the strained features are there towards that.

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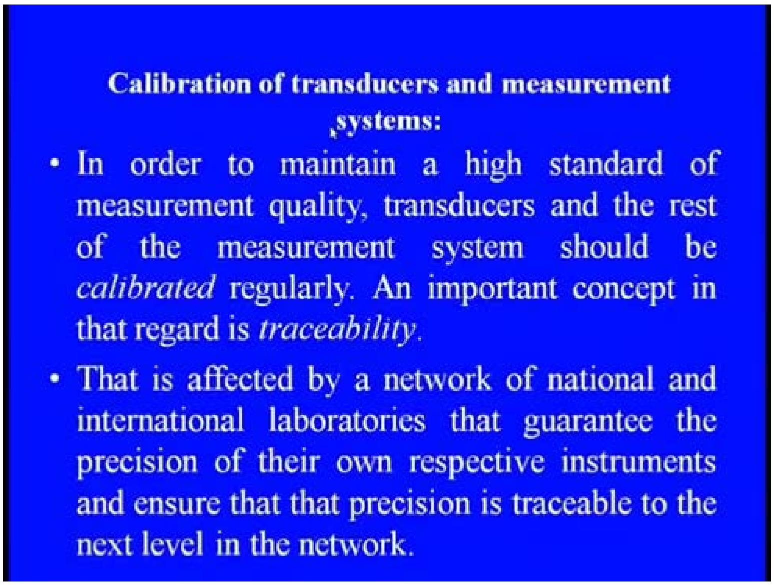

The last part in this chapter is the calibration, the calibration of transducer for accurate measurement system is one of the essential feature, because we just want to maintain the high standard of the measurement quality. The transducers, which are absolutely you see you know like first calibrated and second part is the traceability, so you see here you know like we can say when the things are being working. We need to check it out that whether you know like the instrument, which should be you know like a first the calibrated should be there, and then you see here we need to trace that what actually the problems are.

So, in practices we are always going with the regular calibrations of the equipment, and we need to find out that you see here you know like we need to just put that you see, what exactly the calibrated measurement values are there.

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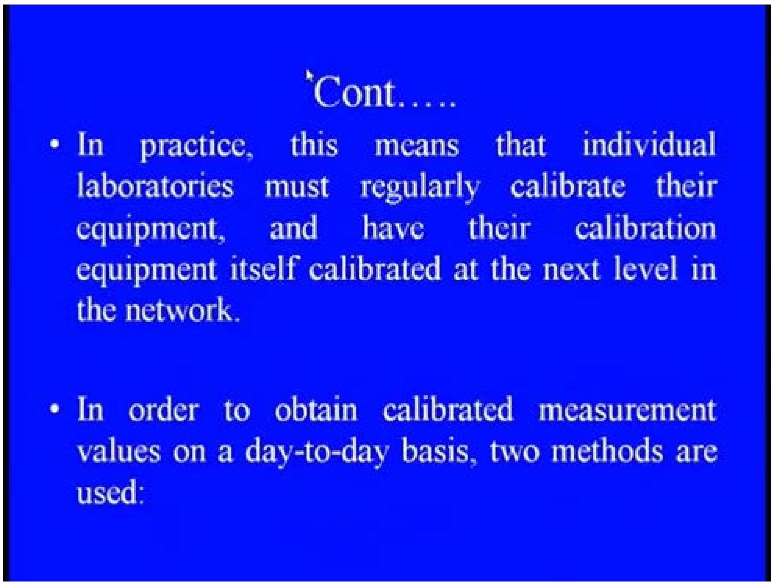

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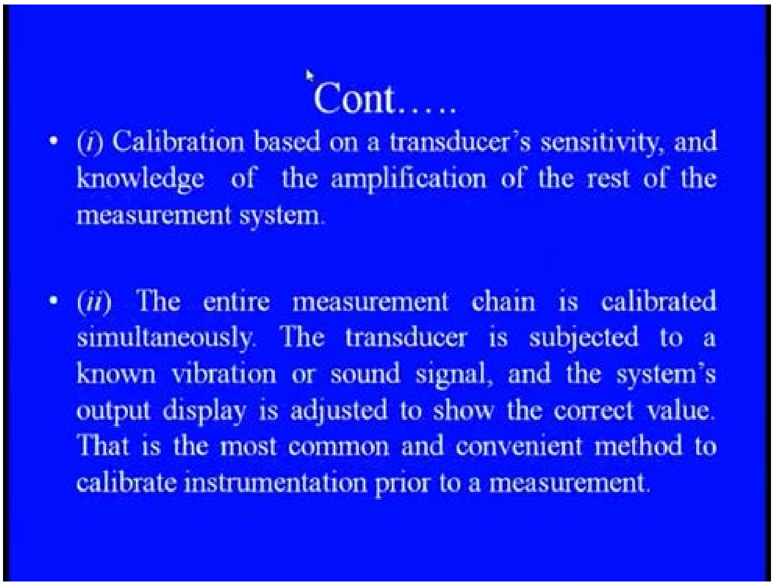

And in this you see here we can go with the two main phases, one the calibration based on the transducer sensitivity, in which we need to see that weather the calibrator is absolutely there, within the given sensitivity level or not. And in the knowledge of the amplification of the rest of the measurement system is you know like one of the important feature.

And second is the entire measurement chain is calibrated simultaneously, and the transducer is subjected to the known vibration or the sound signal. And then the system output can be checked that whether, we are getting the correct value the desired value or not, and otherwise you see here whatever the corrective measures are being taken.

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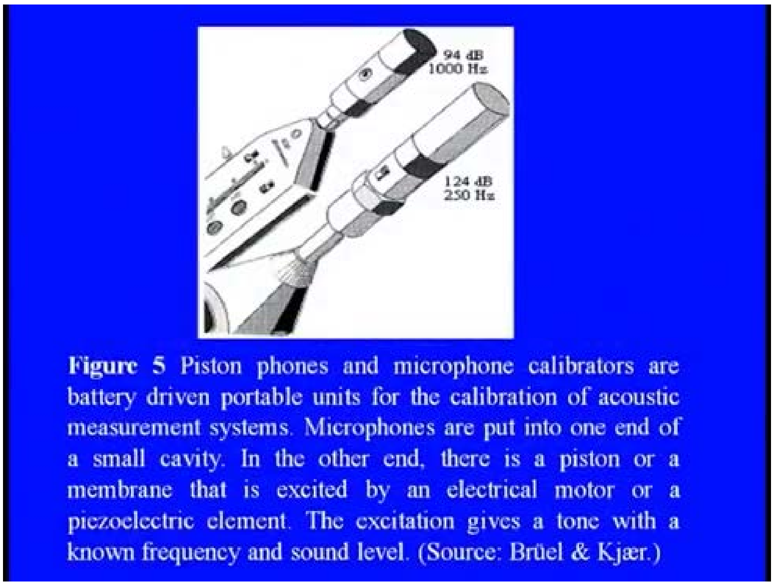

Figure 5 Piston phones and microphone calibrators are battery driven portable units for the calibration of acoustic measurement systems. Microphones are put into one end of a small cavity. In the other end, there is a piston or a membrane that is excited by an electrical motor or a piezoelectric element. The excitation gives a tone with a known frequency and sound level. (Source: Brüel & Kjær.)

So, this is the most common and convenient method which we are always being using for calibrating instrument prior to go for the measurement feature, so you see this is one thing we know the standard value. And then you see here when we are exciting or when we are giving the sound values say in the first part, if it is 120 d b or 250 Hertz, then we are just putting if you can calibrate using this sound level meter of 124 d b.

If we can calculate if we can measure using this, you know like the frequency part a 250 Hertz, this is absolutely if it is not then you see we need to check it out that, what exactly you see you know like the other features are there, through which we can calibrate. So, one is the standard one or the known value, one is you see where we need to calibrate, we can get we can check the output of that, and we can check the error of this.

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Figure 6 To calibrate a vibration measurement system, there are portable, battery-driven electrodynamic vibrators, that generate vibrations of a known frequency and amplitude. (Photo: Brüel & Kjær.)

Lastly even to calibrate the vibration measurement in nowadays you see here, they are absolutely you know like we are using the portable battery driven electrodynamic vibrators, through which we can excite at the known frequency and amplitude. And we can see that whether we are measuring through these accelerometer or velocity probe or anything you see of the same level of frequency or the amplitude or not. If any error is there we need to make a proper corrective measures in that, so we can calibrate through this way.

So, you know like there are lots of you see you know calibration devices are there, and we can prior to go for measurement we can check. So, in this lecture, we mainly discussed about that you see what the basics of the vibration measurements, what is the need of the vibration measurement, because you see here the controlled strategy can be adopted, but prior to that we need to know the values.

We need to know the vibration features of the entire structure is and once you can featured out, once you can characterize the vibration then it is very easy to adopt the proper corrective measure to control the vibrations. And for that as we discussed there are three main devices, one is the accelerometer, second is the velocity probe or the displacement probe can be adopted accordingly. So, in the next lecture we are going to discuss, about these you see that how in the measurement technique, how we can go for you know like these, how we can featured out these vibration signals and then how we can characterize those things.

Thank you.