Principles of Mechanical Measurement
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Module -11
Motion Measurement
Lecture - 02
Vibro-, velo- & accelerometer

Hello everyone. Welcome back to the 2nd lecture of our week number 11, where we are talking about the measurement of motion. Or basically, we are talking about vibration sensing in terms of the measurement of displacement, velocity and acceleration of any vibrating element.

Now, in the previous lecture we had a quite smallest discussion, where we just introduced the vibrometers and accelerometers. And discussed about the basic operating principle in terms of some mathematical calculations where we have seen that most of the vibration sensing instruments can be viewed in the form of a spring mass damper combination. And their interplay generally gives us to a way of sensing the vibration of an instrument.

Today also we are going to finish up on that discussion through another quite a bit smallest discussion lecture.

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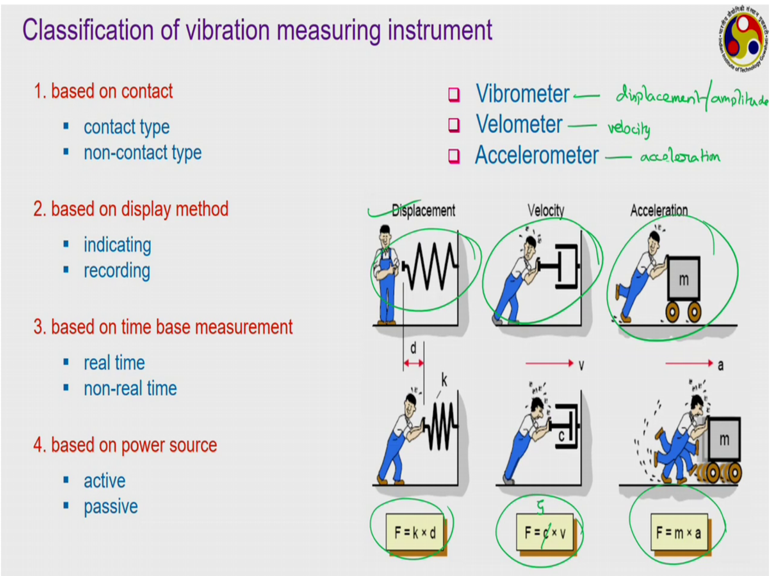

So, to start with I would like to classify the vibration measuring instruments following different types of categories. Like the first type of classification that we can have is based upon the contact. The contact type or non-contact type. The contact, as the name suggests the contact type means where we can take the instrument in contact with the vibrating member whereas, there may be several situations which is, when the when it is not feasible or suggestible to take the instrument in contact with the vibrating member.

So, we have to go for a non-contact type measurement. While contact type instruments are generally cheaper because there we can use any instrument which can sense the vibration. And can directly attach it to the local zone or region or surface where you want to measure the vibration. For non-contact type cases we have to use some kind of indirect measurement like, we generally have to go for an optical or some magnetic based measurement for vibration.

Another type of classification can be based upon the display method. As the name suggests, indicating means where we are interested or to get the reading directly on some kind of screen. Generally, indicating type of method or indicating type of instruments we use when we are not interested about a continuous monitoring, rather just one odd occurrence. Or just for a very brief instant of time we are interested to know the oscillation amplitude or vibration amplitude and acceleration. And then we go for the indicating kind of instrument.

However, if our interest is to record it for a prolonged duration of time to store the data somewhere maybe in some digital form. Then, we have to go for the recording type of option. Here, we have to operate it for a prolonged duration of time. So, that we can have a decent data set which can be subjected to subsequent data processing. The time based measurement, where we can have a real time and non-real time. Real time means, that is somewhat similar to the recording case, where we want to get a real time measurement of vibration and in non-real time just one odd occurrence for a very brief instant of time something. Say, a device is operating at a, under steady state over a prolonged period of time and occasion we just want to check the vibration level of the instrument.

So, we go for the non-real time type measurement where we do not have to bother too much about the long data set. We just take one reading just ensure it is satisfactory level or within permissible limit and then we go back to the work. However, in case of real time measurement, we do have to record the data over a long period of time. And finally, is based upon power source. If the instrument has a power source inbuilt in it, then we call that an active device whereas, if it does not require any separate power source, we call it a passive device.

Now, in the last lecture I mentioned about two terms, vibrometer and accelerometer. However, when you are talking about the motion sensing actually used three terms, vibrometer, velometer and accelerometer. Vibrometer and velometer are quite similar in terms of their working principle and we shall be seeing that shortly. However, they are, these two names are used, vibrometer is definitely a much more common name. And as I mentioned during the last lecture, vibrometer generally we assign with the name vibrometer, the term vibrometer we assign when we are looking to get velocity measurement.

But, truly speaking the term vibrometer we assign to the situation when our objective is not to measure velocity, but actually displacement. And with the small the modification of the vibrometer, mostly in the calibration scale then the same instrument can be used to get a direct reading of the velocity. And then, we do not call it a vibrometer, we call it a velometer. So, the vibration amplitude or displacement is given by vibrometer. Whereas, when we get the vibration velocity, then we call it a velometer. And as the term accelerometer suggests, it is the one that is used for measurement of acceleration. It has slightly different working principle compared to the vibrometer or velometer.

But, vibrometer and velometer I repeat has the same working principle. Only difference is, in terms of the scale that we attach to the instrument and subsequently what reading we extract or what information we extract from the instruments. If we think from a spring mass damper point of view then, the vibration sensing or rather when our objective is to sense the displacement then, we focus more on the spring. Because, as we know when the force associated with the spring is, the displacement times the spring constant and. So, the spring force it is directly proportional to the displacement and therefore, following the spring we can get a measurement of the displacement.

So, vibrometer mostly concerns the use of the spring whereas, what about velocity? So, that has to be concerned with this damper because the force associated with the damping is generally the velocity times the damping coefficient. Here, c is written in this graphics, but actually this as per our symbol this is the zeta, the damping coefficient. So, the damping force is proportional to the velocity and therefore, the damper is the most important component in case of a velometer and in case of accelerometer, we focus on inertial force because for the inertial force is mass times acceleration.

So, the mass is the most important component in term for an accelerometer. Therefore, a spring mass damper assembly, each of the three components has their own importance depending on which parameter we want as the output. I repeat therefore, for a vibrometer where you are looking for displacement or amplitude measurement. We focus more on the spring or we take the reading from the spring. In case of an velometer when you are looking to get the velocity, we focus on the damper. And in case of an accelerometer when we want to get the acceleration we focus more on the mass.

Now, let us see the difference between this vibrometer-velometer combination and the accelerometer. Again, using a little bit of mathematical analysis which we have done during in the last lecture.

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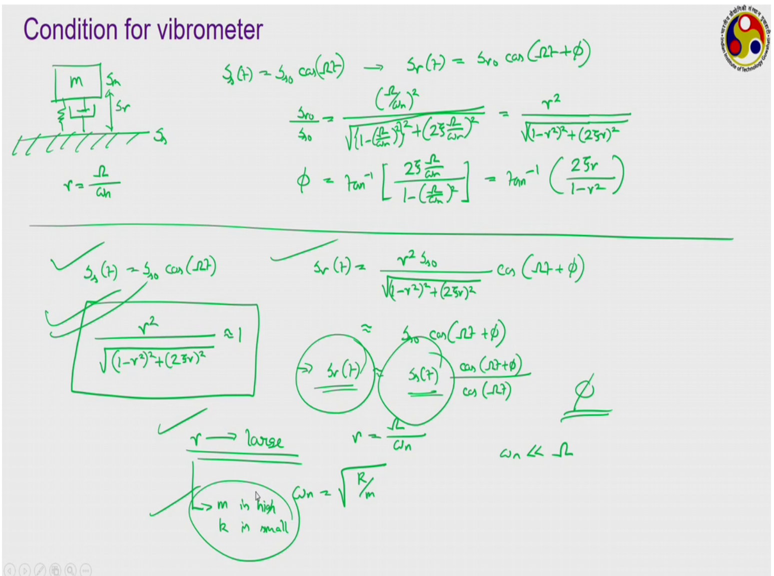

First the condition for the vibrometer, but before I directly go to the vibrometer just think about the analysis that we have done in the previous lecture where we considered a simple mass and a simple mass which is connected with some vibrating member. Say this one may be the surface where we are looking to measure the vibration. This is the mass that we have, we have the spring in between and we have the damper also connected to this.

So, this spring mass damper combination gives a sensing of the vibration that we are looking to get. We use these symbols S s was used for the surface where we want to get the measurement and S m for the mass. And this in between, the difference between this was referred as S r, which is the relative displacement of the mass with respect to the surface. So, this is the one relation that we have developed is S r t ok. Now, before that I should mention that we have assumed a simple harmonic motion for the surface which is given as S s t is equal to S s naught into cos.

We did not use this symbol. We use this particular symbol, cos omega t where this capital omega refers to the frequency of the imposed vibration and t is time. And this lead to, through analyzing this system as a second standard second order assembly subjected to a periodic signal. Then, we obtained S r t as S r naught into cos of omega t plus phi, where this S r naught was calculated as or sometimes we write this as S r naught by S s naught. Was identified to be something like this, omega upon omega n whole square, where omega is the natural frequency and whole root of 1 minus omega upon omega n whole square. Whole square this, plus twice zeta omega sorry, omega upon omega n whole square. Here, omega n is the natural frequency.

So, zeta upon omega n is some kind of frequency ratio. So, let us indicate this one as r, which is frequency ratio that is the frequency of the impulse vibration to the natural frequency of the system. And zeta is the damping coefficient ratio. So, in terms of r if we simplify then, we get a much simpler waveform to deal with, r square root over 1 minus r square whole square plus 2 zeta r whole square.

So, this is S r o upon S s o or the magnitude of this resultant vibration. And phi is the corresponding phase lag which is given as, tan inverse of 2 zeta omega upon omega n divided by 1 minus omega upon omega n whole square. Or if we use the symbol r that is for frequency ratio, we get this one to be as tan inverse 2 zeta r by 1 minus r square. So, we know the amplitude and phase lag for the resultant signal.

Now, if we want to use this for a vibrometer then, there is situation is quite simple. Just I write this in terms of their components and up to this part is a repetition of what we have done in the previous class. So, now, the imposed signal has a displacement of this much because S is a direct symbol of displacement. So, this is the displacement that we are looking to measure. And at the output side, what we are getting? We are getting S r t is equal to r square into S s o root over 1 minus r square whole square plus 2 zeta r whole square cos of omega t plus phi. I am just repeating the earlier sentence.

Now, if in a certain situation even were careful you just note carefully. In a certain situation if we have r square upon this term, that is 1 minus r square whole square plus 2 zeta r whole square over root of this. This is nearly equal to 1. Then, what we have? As this S r t, this is equal to S s o into cos of omega t plus phi. Or if we compare with this particular form then, we have S r t nearly equal to S s t into cos of omega t plus phi divided by cos of omega t.

So, therefore, when this particular condition is being satisfied that is this particular ratio is very close to 1. Then, the resultant signal, at least the displacement of the resultant signal quite follows the imposed signal S s. This is the resultant signal, this is the imposed signal which follows the so, the resultant signal follows the displacement, imposed displacement quite well with a phase lag of phi and. So, this particular thing can be identified as the condition for a vibrometer.

So, whenever you are designing a vibrometer we have to ensure that this particular condition is being satisfied. Now, you can see this, this particular condition can satisfied when in this r, there is a frequency ratio is large. We have to ensure that the frequency ratio is very large. Now, that is possible, as r is a ratio of the imposed frequency to the natural frequency. So, this particular r can be large only when this omega n is much greater than the imposed frequency. That is, a natural frequency of a system has to be much greater than the imposed frequency.

Now, what is the relation for omega n? We know omega n is equal to root over k by m. So, let me write it properly it is root over k by m where k is a spring constant and m is the mass. So, we want this omega n to be very large that is we want very high natural frequency of the system. And that is possible, that is this particular situation is possible when the, we have either the mass is very high or k is small, that is the spring is stiff. So, the condition for a vibrometer is the mass has to be very small and the stiffness has to be quite low that is the value of the k has to be quite low. Or I should not say the spring is stiff, I should say the k should be small that is the spring has low stiffness.

So, high mass and low stiffness is the required condition for a vibrator measurement. The result of actually this combination is a quite bulky system because we are talking about a larger mass and also a small value of k accordingly the thing, the quite stiff spring, low stiffness we are talking about. So, the system generally is larger in mass, but in inertial the condition for using a spring mass damper combination to you as a vibrometer is this thing. That is this ratio of r square upon root over 1 minus r square whole square plus 2 zeta r whole square that has to be quite close to 1.

Then only the resultant displacement, this S r follows the imposed displacement, it is S s with a certain phase lag, but follows quite well apart from this phase lag phi. Of course, the value of the phase lag can also be controlled by controlling the damping coefficient ratio.

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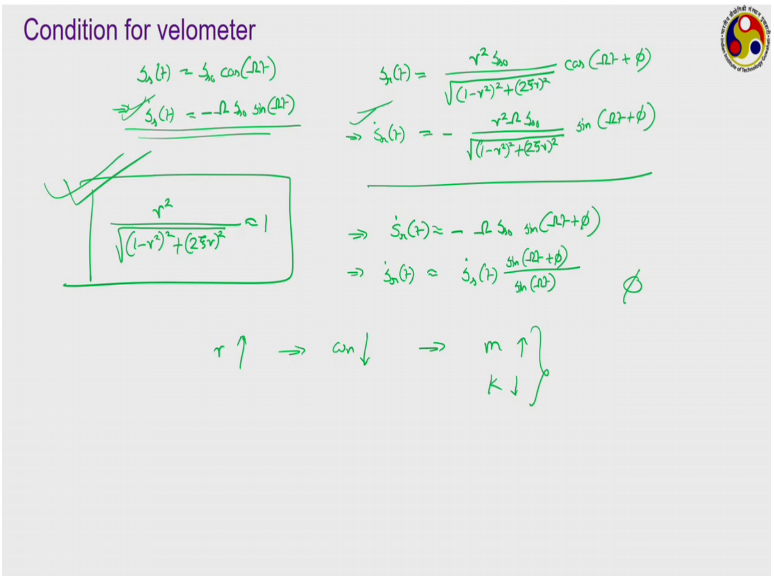

Now, we move to a velometer, for a velometer so, we again used our condition. We have our imposed displacement S s t is equal to S s naught cos. So, this is the imposed displacement. Then, imposed velocity is the time derivative of this particular thing which becomes minus omega S s o sin omega t.

Now, look at the resultant part. In the resultant side what we have? We have S r t like the expression that we have written shortly back in the previous slide. If I just look at the previous slide, this is the expression that I am talking about. So, if I write it again we have r square into S s o into root over of 1 minus r square whole square plus 2 zeta r whole square cos of omega t plus phi. So, this was the resultant displacement.

Now, if we differentiate it with respect to time, we get the resultant velocity. So, if you differentiate with respect to time then what we are going to get? We are going to get minus of r square omega S s o into root over 1 minus r square whole square plus 2 zeta r whole square into sin of omega t plus phi. So, compare this particular form with this particular form. This is what we are looking to measure. This is what we are getting from your system.

So, in a situation when again the same term which we had for a vibrometer that is r square upon the square root of 1 minus r square whole square plus 2 zeta r whole square. This is nearly equal to 1 then, what we have in this case? So, we have S r dot is equal to or I should say nearly equal to because we have because we are using this nearly equal to condition is equal to minus.

So, omega into S s o, into sin of omega t plus phi. If you compare with in this particular form then we can write this one as or we can say. This resultant velocity will be equal to into phi by sin omega t. That is the resultant viscosity or resultant velocity rather. Resultant velocity will be able to follow the imposed velocity with a with a phase lag which is again the same phase lag phi that we are talking about.

So, this is the condition that we got earlier for vibrometer. The same condition has to be applied if we want to operate this as a velometer. That is this r has to be very high and r can be high when either m is high or. Or I should say when r can be high then the corresponding condition the omega n, this is possible when r is large. So, omega m should be quite small and omega m can be quite small only when the mass is large. Or k is small or preferably both combined.

So, whatever is a condition for a vibrometer, the same is the condition for a velometer. That is why in the previous lecture I have not mentioned the term velometer. I talked I mentioned the term only vibrometer. The same instrument can be used for a vibrometer or as a vibrometer or as a velometer, the condition being, we have to keep this particular ratio quite close to 1. And that is possible either by increasing the mass or by using a low stiffness spring. Only difference is that, in case of a vibrometer the output is scaled in terms of displacement whereas, in case of a velometer the output has to be scaled in terms of velocity, that is all.

If we can provide a proper calibrated scaling which can easily be done through the proper calibration then, the same instrument can be interchangeably used as a vibrometer or velometer. Now, let us check the condition for an accelerometer.

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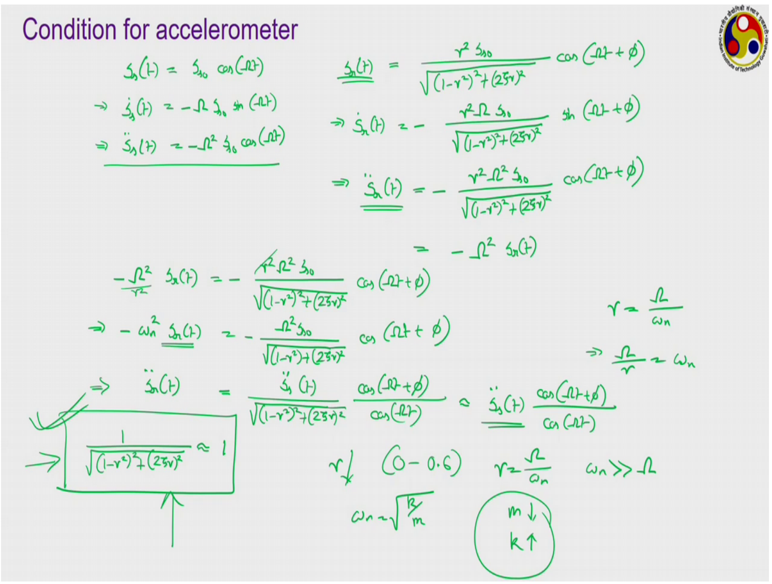

So, again we first check the imposed part. We know that the imposed displacement S s t is equal to S s naught cos of omega t. So, correspondingly imposed velocity is equal to minus omega S s naught sin omega t which you used in the previous slide for a velometer. But now, our objective is on acceleration.

So, as we are differentiating it once more that is the velocity part is being differentiated with respect to time again. So, we have minus omega square S s o and this sin becomes cos again, cos of omega t. So, this is the imposed acceleration of the vibrating member. Now, look at our instrument. So, the resultant that we have got S r t that was r square into S s o by root over 1 minus r square whole square plus 2 zeta r whole square cos of omega t plus phi.

So, if we differentiate it with respect to time once like we got in the previous slide, S dot r t. So, this will become minus r square omega S s naught root over 1 minus r square whole square plus 2 zeta r whole square into sin omega t plus phi. This is the form that we have used in the previous slide, this particular form. But now, as we are looking for imposed acceleration you have got, we are looking for the resultant acceleration.

So, we have to differentiate it once more with respect to time to get the S r double dot. So, this will become now, minus r square omega square S s o by root over 1 minus r square whole square plus 2 zeta r whole square cos omega t plus phi. Now, again we know that our ok. If we compare this particular form with this particular one, we can write this one as minus omega square of S r t. So, minus omega square Ss r t is the one that we have got.

If we compare this particular part. Now, from the output side you have to understand that in the output side we are only getting the displacement of the mass that we have inside your instrument. So, though we are looking to measure acceleration somehow we have to relate that to the displacement of the mass. So, if we compare this, that is this omega square S r t the displacement is equal to minus r square omega square S s o to root over 1 minus r square whole square plus 2 zeta r whole square cos omega t plus phi.

And we divide everything by r square. That is we remove this r square and divide this by r square. Now, as per the definition our r is omega upon omega n. So, therefore, omega upon r is equal to omega n only, the natural frequency of your instrument. So, we have minus omega n square S r t is equal to minus of omega square S s o to root over 1 minus r square plus 2 zeta r whole square omega t plus phi and if we now relate this one to this particular imposed acceleration.

So, omega square S s o we already have. And let us replace this one as S double dot s t by root over 1 minus r square whole square plus 2 zeta r whole square. Here, this omega square S s o we are replacing using this equation or minus omega square S s o. So, into cos of omega t plus phi by cos of omega t. Then, what should be the condition for this S r resultant displacement to follow this imposed acceleration? Then, if we impose this condition that is 1 upon root over 1 minus r square whole square plus 2 zeta r whole square.

If we can assume this to be nearly equal to 1, then what we have? Then, this particular situation becomes S s double dot t cos of omega t plus phi by cos of omega t. That is the resultant displacement or the resultant displacement which we can also write in terms of say, resultant acceleration. Resultant acceleration is going to follow the imposed acceleration with a phase lag phi of course, if we have this particular condition satisfied.

Remember the form that we had in the previous slide. There we had a r square in the numerator for vibrometer or velometer. Here, the denominator is the same, but there is no r square in the numerator. So, this is the condition for an accelerometer to or for an instrument for that same spring mass damper assembly to act as an accelerometer. So, this condition is possible when the r is small. Like in the previous case our condition was r has to be large. Here, our condition is we can take, for a given value of zeta you can check from here, we need to have small value of r; practically, r general is limited between 0 to 0.6.

Now, if r is small means r is equal to omega upon omega m n. That means, the omega n has to be large, that or I should say and for r to be small this natural frequency has to be much larger than the imposed frequency. Now, look at the condition that we had here. Actually, I made a mistake while writing this. For a vibrometer we want r to be large. So, this omega n has to be much smaller compared to omega and correspondingly we have this condition. We want omega n to be small for a vibrometer or velometer whereas, for accelerometer omega n has to be much larger. And how omega n can be larger? Omega n being root over k upon m.

So, omega n can be large only if either mass is small or the stiffness is larger, just the opposite condition for this. So, for an instrument to act as a vibrometer or velometer, we want the mass to be large or the spring stiffness to be small, resulting in a bulky instrument. Whereas, for it to act as an accelerometer, we want the mass to be small and the stiffness to be large, resulting in a smaller instrument. And then the same by playing around with the value of this mass and this spring is, this spring's stiffness. We can use the same instrument either as a vibrometer or velometer or as an accelerometer.

But, the condition that keeps on changing which we can identify from this for the accelerometer. So, that is the way we can mathematically get the criterion for designing either a vibrometer or an accelerometer. And generally, it comes to be a, an interplay or I should say you have to play around with the value of the mass and the spring stiffness to get this.

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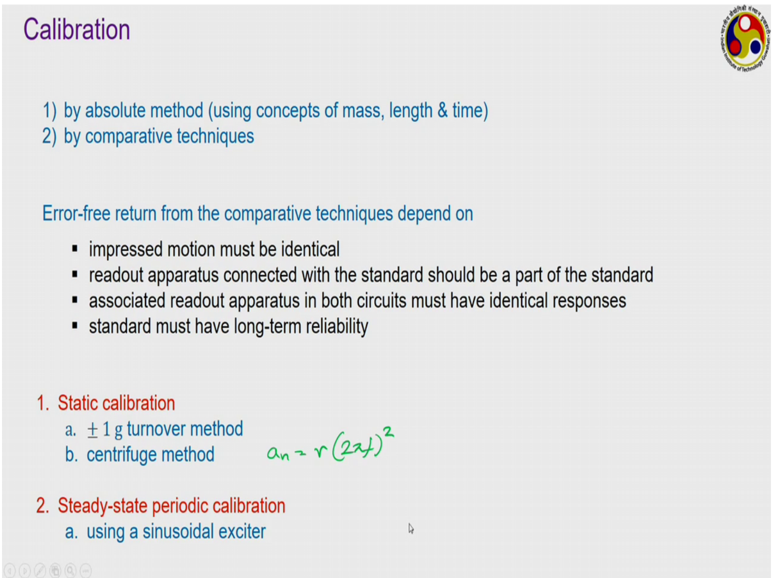

Now, let us quickly check the way that we generally calibrate an instrument because I have mentioned, the same instrument can be used as a vibrometer or velometer.

But, depending on what kind of calibration we are doing, we generally have certain kind of output scale which is either calibrated in terms of velocity or in terms of displacement. If the former is a situation, that is it is calibrated in terms of velocity, we use it as a velometer. Whereas, when it is calibrated in terms of displacement, we call it a vibrometer. And the most common method of calibration, actually the all the methods of calibration can be categorized into two category, two parts.

One is by using absolute method. We are using the, we use a concept of the definite, the fundamental units, definition of fundamental units that is mass, length or time. Or the general common one, the comparative techniques. In case of a comparative techniques, we compare the vibration of the member that we are looking to analyze with the with some standard equipment. And their vibration levels are compared from where we generally try to get a calibration.

Because, if your instrument is vibrating with a particular frequency, the standard one generally keep on varying till we reach the resonant kind of situation. Both of when both of them starts to vibrate with the same frequency. And then we can identify the frequency of the vibrating member from this. But, in order to get an error free return from the comparative technique, we generally need to follow or we generally have to be concerned about four different factors.

Firstly, the impressed motion between the standard and your subject must be identical. That has to be identical, if the nature of imposed motion is different, then we have to use some separate standard. Then, the readout apparatus for the standard particularly is preferable to be a part of the standard self. That is, it should be attached with the standard and preferably be a part of the standard. Otherwise, we can say, if it is a part of the standard the entire system can be traceable.

Then, the associated readout apparatus for both circuit must have identical responses. That is very important because you know that whatever may be the primary sensing instrument or characteristic of the primary sensing instrument, ultimately everything comes to the secondary side. What your secondary transducer is doing which is the readout apparatus here. So, both should have identical secondary transducer. Or I should say the dynamic characteristic of the readout apparatus for both the standard and your subject should be identical. And the standard must have long term reliability that is true for any kind of standard, forget about vibration.

For any measurement standard, it must have long term reliability so that you can keep on using for different kinds of instruments. Now, calibration can be categorized into two parts. One is static calibration and other is steady-state periodic calibration. In case of static calibration, we can have two kinds of methods. One is plus minus 1 g turnover. That is a very simple situation where the particularly low range accelerometers are calibrated following this way. Where we just we just rotate the accelerometer upside down.

Like if your accelerometer is like this, we just rotate it upside down. Then, how much is the change in the effective gravitational acceleration? In this case, actually both cases gravity is acting vertically downwards. But, in this case if we consider it, the action to be minus g, in this case it is to be like a plus g. If we consider this, if we consider the direction coordinate direction for always pointing towards the tip of this accelerometer, then in this case your gravity is minus g.

Now, it is plus g. So, total change is 2 g amount. And how the system responds from there? We get a calibration. This is called plus minus 1 g turnover method. The other one is the centrifuge method. In case of a centrifuge method, we generally have a rotating table, the vibrating member is kept on the rotating table. As the table is rotated with a particular frequency, from there we try to calculate the mass. The, like the acceleration towards the center of rotation can be represented like this, means the normal component of acceleration towards the center of the can generally be written something like this.

Where r is the radius of that rotating table and f is the table rotation speed or corresponding frequency you can say. So, from there we can get some kind of calibration. The other is steady-state periodic calibration. In case of a steady-state periodically, we generally use a sinusoidal exciter. That is, we excite our system with a known frequency and accordingly see the response. Not necessarily we have to impose a sinusoidal signal, it generally has to be a periodic signal.

Steady-state periodic calibration probably is more popular compared to the other methods. So, that takes us to the last topic of this week where we just briefly talk about the exciters.

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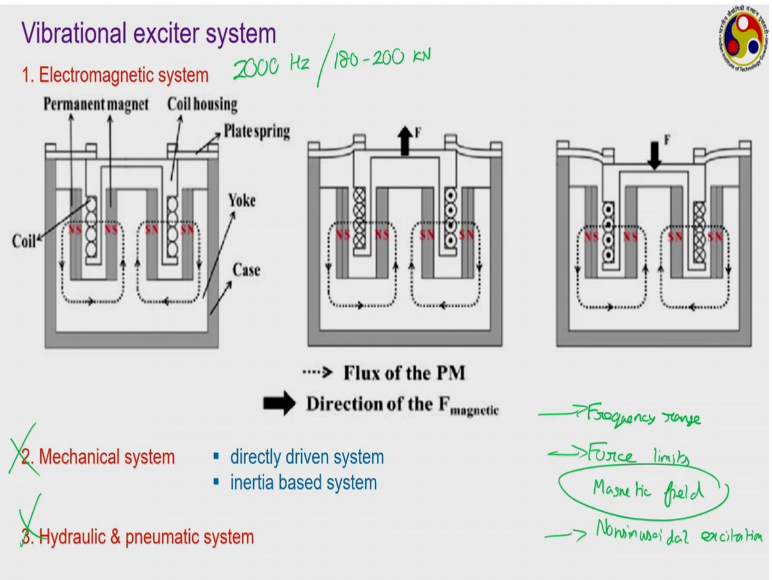

Vibration exciter systems are the systems which are used to impose vibration on certain member. Now, exciter system can be of different kinds. And depending upon the working principle, but three of them are very common. Particularly, the most popular one is the electromagnetic system.

In case of electromagnetic system as shown here, we have one permanent magnet. Like here just the shown the shaded one is the permanent magnet here. And in between the permanent magnet, we have some coils placed. So, this coils when there is no electricity, there is only one magnetic field created by the permanent magnet. However, as soon as we switch on the electricity, current starts flowing through the coil. Accordingly, another magnetic field is created. And both by varying the current we can easily change the design or also rather I should say the magnetic flux corresponding to this magnet as well.

Now, look at the dotted line that is shown. It is the flux, direction of the flux created by the permanent magnet. And when in this situation, when the current is flowing through this, the F magnetic, the magnetic force is acting in this particular direction. So, these two creates some kind of interplay and this interplay leads to an vibration of the member where we are looking to subject this. Quite often this vibration exciter systems are also called shaker.

So, electromagnetic shaker is a very popular one. Another one can be mechanical systems. In case of mechanical systems, we generally can have either a directly driven system or an inertia based system. In general, the case it is quite similar to what we talked in a previous slide regarding calibration. We have a vibrating table or rotating table and which is rotated at a certain with a certain rpm using the mechanical linkages. And then, using some crank or connecting rod assembly, we can easily control the speed of this rotation. And from there, we can get a certain level of excitation of the object which is kept on top of this rotating table.

Another type of mechanical shaker or mechanical system where you use the counter rotating masses. To apply the driving force we generally have 2 mass with a certain ratio. And they are rotate in opposite direction which leads to this. If someone, I am not going into the detail of any one of them because these are all adverse levels or practical level topics. Just giving you more than names which we are concerned about and the final one is hydraulic and pneumatic system which as the name suggest you can understand. The hydraulic one operates with some fluid liquid and pneumatic is generally using some high pressure gases, using which it creates the vibration.

Now, if we can briefly compare between these three kinds of shakers then, the electromagnetic one is the. There are several ways we can compare. Actually, the first one, first type of comparison is based upon the range of frequency. That we can consider. The largest level of frequency or upper frequency levels can be achieved with this electromagnetic one. Over there for electromagnetic shaker we can go for very high pressure or very high speed.

We can go something in the range of easily 200 Hertz which is not possible with a mechanical or hydraulic and pneumatic systems. So, if we are looking for high frequency, electromagnetic one is the largest one or most preferable one. We can also have force limits. What level of force that we are looking for? They can, electromagnetic once again can give you very high pressure in the range of 180 to 200 kilo Newton or very high level of force.

So, as we are having an electrical magnet involved there in forms of this coils. So, by changing the current flowing through the coils, we can also change the force produced. The net output force produced. And therefore, it is much easier to control the electromagnetic one. The force produced by a mechanical shaker also can be controlled by controlling the rotational speed of the rotating cable. But, mechanical shakers are particularly susceptible to several kind of prime mover losses. Maybe there are many frictional losses because of presence of bearings and several other linkages into the system.

So, chances of losses are much more in mechanical system. What can be the issue with the hydraulic systems? As we are talking about either some liquid or high pressure gases. So, there will be lots of valves and connecting pipelines and corresponding joints which are always susceptible to leaks. The presence of magnetic fields is another area, we can combine the magnetic field, electromagnetic shaker requires a relatively very intense magnetic field.

So, we have to be very careful. This one definitely is applicable only for the electromagnetic one because magnetic field is not there in the other two. But we, because of the presence of magnetic field, we have to be very careful. The voltage induced by the magnetic field can itself be a problem. And if that gets reflected in the final output signal then that has to we have to be very careful because, the final output signal or final output processor does not have the option of signal separating the effect produced by this imposed voltage.

And finally, another one that we generally are interested in to compare is non sinusoidal excitation. Now, in non sinusoidal excitation the we, the excitation that we are imposing on the member, we prefer that to be periodic, ideally a sinusoidal signal. Now, producing a sinusoidal signal or any other waveform, that is the easiest with the with which one? What do you feel? Definitely the electromagnetic one because there we can easily control the waveform again by controlling the interaction between the two fields. And it is very extremely difficult for both these two.

So, electromagnetic system that is why is a advantageous in terms of this point, this point and also in terms of this point. However, this is something that we have to be careful of while using an electromagnetic exciter system.

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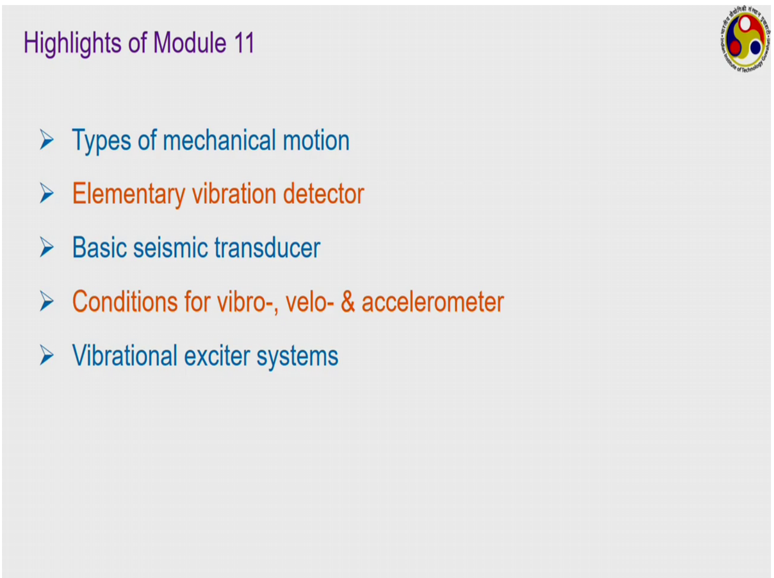

So, that takes us towards the end of a very brief discussion on vibration sensing instruments. Vibration is a topic of extreme importance in any mechanical design and also in civil designs but, this particular course being focused on more an introductory level initiation or more initial initiation level of means different measurement systems.

So, we have kept ourselves only to very introductory or preliminary discussion about vibration sensors. So, here we have talked about the different kinds of mechanical motion then, elementary vibration detectors in the form of wages etcetera. Then, we talked about the basic seismic transducer, the mass spring damper assembly. And we did the mathematical analysis. From there we have identified the conditions for the system to act as a vibro or velometer or accelerometer. Like for, we know that for vibro and velometer, we need to have the omega n, natural frequency to be very small. And the natural frequency can be small only when the mass is large and k is small whereas, for accelerometer we want the natural frequency to be high.

And the natural frequency can be high when the mass is small or k is high. And finally, we briefly touched upon that the vibrational excited systems. So, that takes us towards the end of this module 11. In the next week we shall be having the final lecture of this particular course, where we shall be discussing about quite a few stray topics. Not insisting ourselves to any particular parameter measurement. Rather, we shall be talking about 3 or 4 different parameters which are of wide practical importance. So, till then take care, good bye.