Vibration Control

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Module - 4
Vibration Generation Mechanism
Lecture - 4
Field Balancing of Rigid/Flexible Rotors

Hi, this is Dr. S.P Harsha from mechanical and industrial department IIT Roorkee. In the course of vibration and control we are discussing about the vibration generation mechanism and in the previous lectures we, discussed about the source classification, we discussed about the self-excited vibrations. And even in the last lecture we, discussed about the flow induced vibrations, that what exactly the mechanism is there. How do we analyse? How do we you know like first see, the physical nature of the source, and what exactly the mathematical descriptions are there of these generation features.

In this class also we are going to discuss about the vibration generation mechanism, towards the flux, the field balancing of rigid oblique flexible rotors, because we know that which, we have already discuss by the way. That, if we have the rotor on balance, irrespective of nature rigid or flexible, it has a clear impact on the vibration generations in the entire machines. And this generation, vibration generation is so you know like the transmission is so fast that it is straightaway affecting the performance of other components as well.

So, when we are talking about the vibration in the rotating machinery. It is a common feature that, there is a result due to this vibration in terms of the mechanical faults. Including the mass unbalance, the coupled misalignment, the loose components and may be many other causes, which we can simply feature to justify that why the vibrations are there in the rotating machinery.

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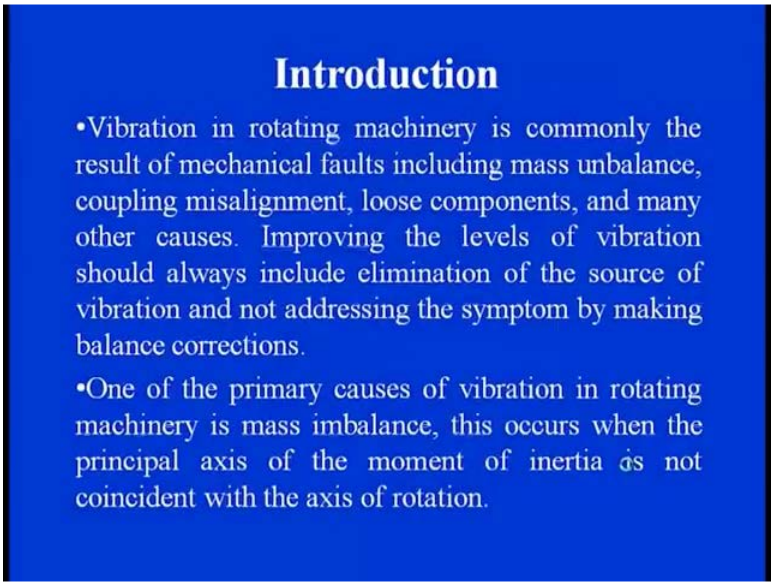

And even in the improving of the levels of vibration should always be include, the elimination of the source vibration, not you see addressing the symptoms, but also we need to make the balance, of the entire you see. Say, the mass balance, the misalignment reduction or any you see you know like the tightness of the component with these balance corrections.

But one of the basic and primary cause of the vibration in the rotating machinery is the mass unbalance and it occurs mainly due to, when the principle axis is of the moment of inertia is not coinciding with the axis of rotation. There are various reasons for that, because we know that if there is a deviation in the principle axis of our moment of mass, moment of inertia due to various reason from the axis of rotation, then it is creating some kind of the non-uniform mass distribution. And which results in the mass unbalance.

So, when we are talking about the rigid rotor. So, for the rigid rotor the imbalance is usually eliminated by adding or even subtracting sometimes rather, we are saying the correcting masses, into two distinct planes, in such a way that it is you know like realign and re-centre realign. Means, it has to realign and re-centred the principle axis along with the axis of rotation because until and unless if you are not able to realign and re-centre the our rotational axis, then certainly you see here the corrections are not proper.

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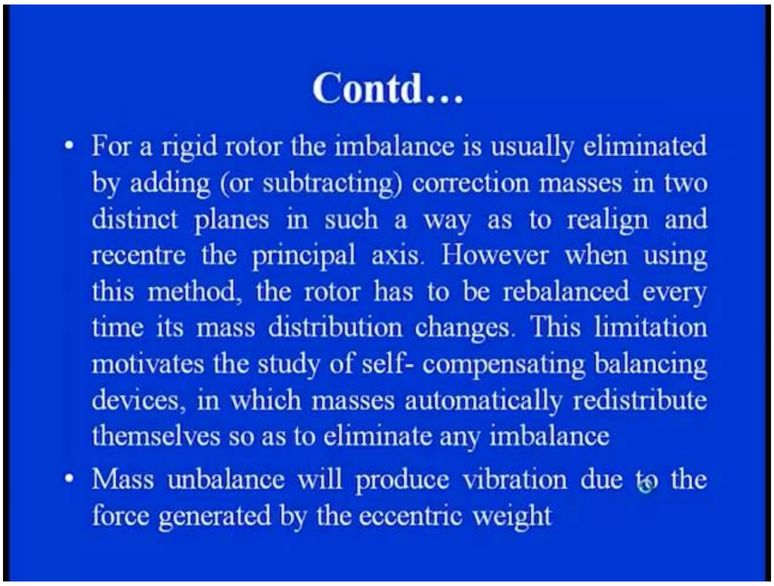

Even sometimes this method where the rotor has to be rebalanced, every time the mass distribution is changing and this non uniform or the different distribution of masses is creating some kind of you see the self-excited vibrations. Even sometimes we can say that, this limitation is also, motivates that the self-compensating balancing devices in which you see the masses are automatically redistributed themselves.

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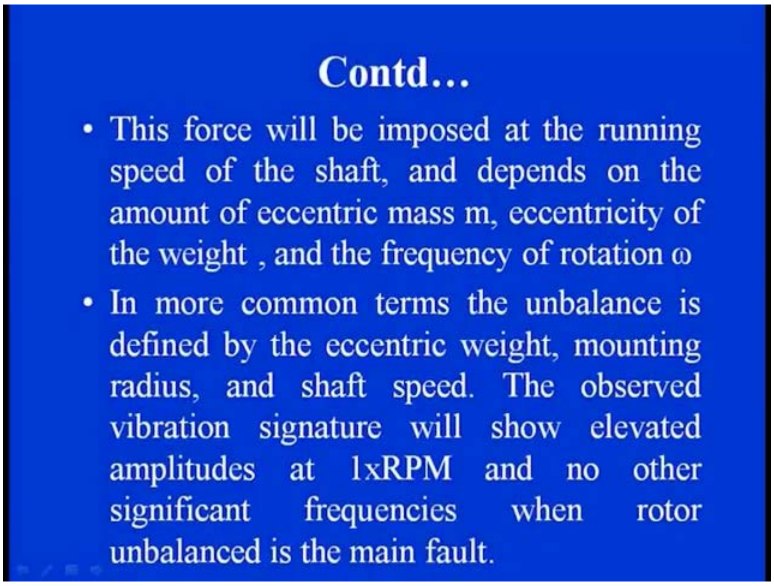

You can also at least reduce not absolutely eliminate, but reduce any kind of imbalance. And mass unbalance can also produce vibration due to the force generated by the eccentric weight, because this eccentricity causes again the kind of deviation of the axis of rotation and the principle axis rotation of the moment of inertia. So, these eccentric forces will be imposed at the running speed at the shaft and it is absolutely depending on the amount of eccentric mass and the eccentricity of weight and the frequency of the rotation. M E omega square. So, as you see the speed of rotor or the you know like the shaft is increasing these forces are of main significant.

So, in most common terms the unbalance is defined, by the eccentric weight mounting radius and the shaft speed. As we discussed and in the vibration signature, they have a clear indications or their presence is very clear at the elevated amplitude at 1 x R P M. With these you see here no other significant frequencies are being coming when the rotor unbalance is there because they are so significant that the excitations due to this is always dominant in the vibration signature.

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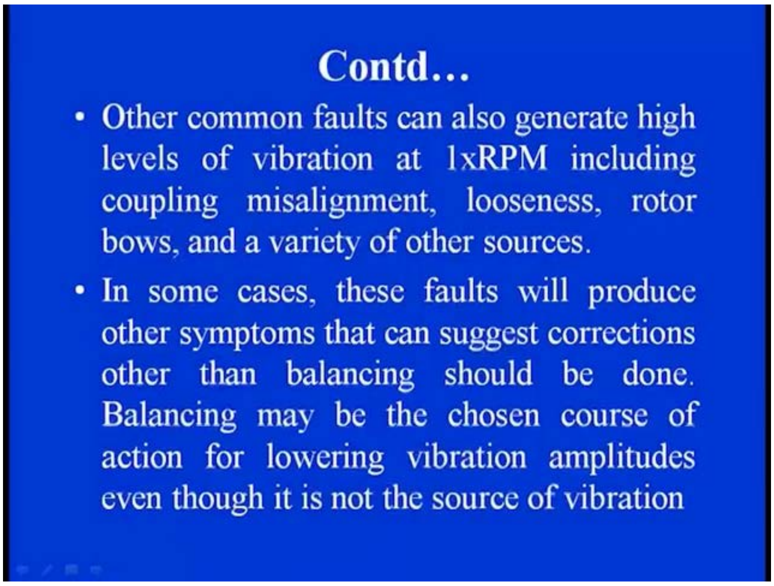

Other faults can generate you see the high level of vibrations which can even include this 1 x R P M. Like the coupled misalignment, because when the misalignments are there they are not you see the proper aligning features are there. Even the looseness, even the rotor bows when there is a bend in there or other variety of the sources they can also cause these things.

But in some cases their faults will either you see a different kind of symptoms are there because the different kind of corrective measures are there for that to balance the system.

And balancing may be chosen the course of action for lowering the vibration amplitude even though it is not the source of vibration. So, sometimes you see this is one of the common corrective measure, which one can adopt in any of the condition like the you know like the unbalance or the you know like the eccentricity features or even you see we when we have a misalignment feature or the looseness.

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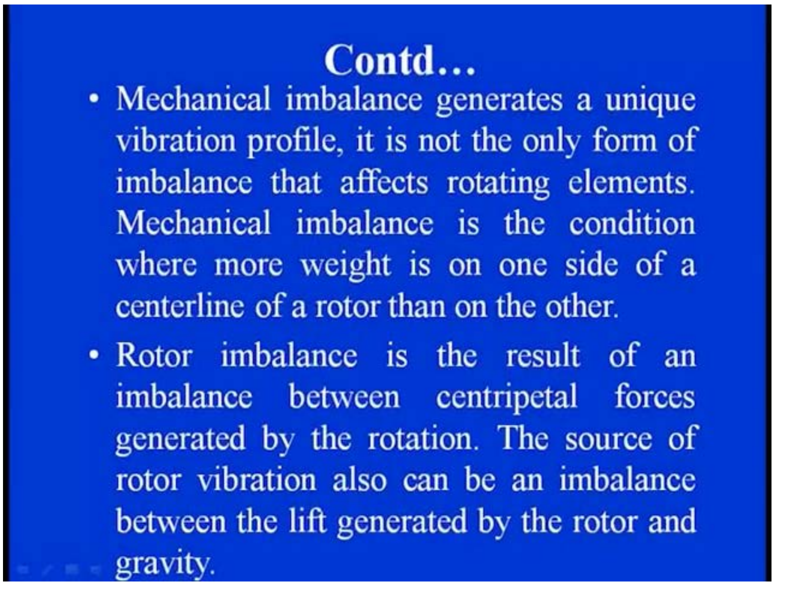

The mechanical imbalance generates a unique vibration profile as we discussed and it is not only the form of imbalance that affects the rotating element. But also you see here it is the distribution, that how you see the systems are being affected with the distribution of this mass. And mechanical imbalance is the condition when more weight is on one side and through which you see the centre line of the rotor is being affected with the main line of the moment of inertia. So, rotor imbalance is the result of imbalances between the centripetal forces generated by the rotation and the other forces in terms of the inertia.

The source of rotor vibration also we can say, provide the imbalance between the lift generated by the rotor and the gravity and because of that you see the deviations are there in the axis's. So, we can say that these centripetal forces are so significant that whatever, you see the other forces the lift forces cannot provide the proper support to the system to cancel out these things.

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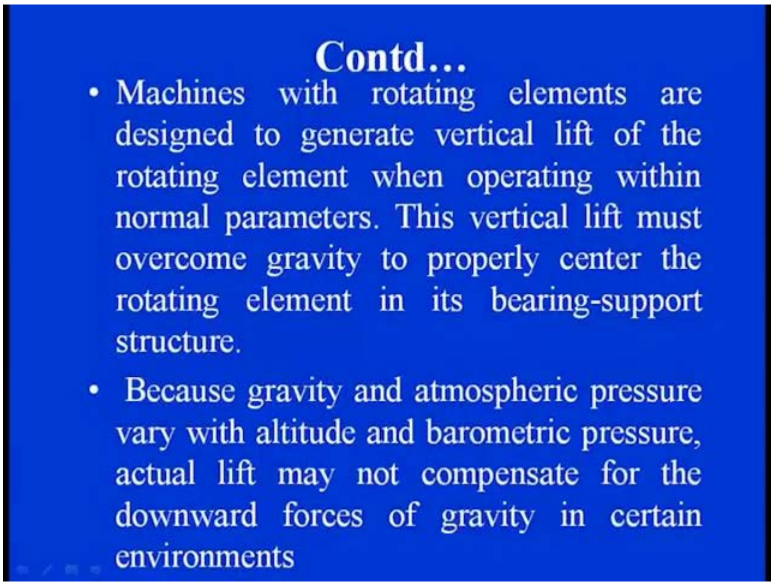

So, the machines with the rotating elements are just designed to generate the vertical lift of the rotating element when operating within the normal parameters, because this vertical lift must overcome the gravity to gravity to properly centred the rotating element at exactly at the bearing support. So, that you see here there is no misalignment in between these two centre lines. And since, the gravity and the atmospheric pressure vary with the altitude and the barometric pressure, the actual lift cannot be absolutely compensate for the downward forces of the gravity.

In certain environments where you see, we know that these forces are being varied according to the gravity and the atmospheric pressures. And, the deviation of the actual lift from the designated lift can also be significant and at that time you see here, the rotor is creating so much imbalance in that. So, unbalance in the rotor can result, an uneven distribution of mass and this causes the huge vibrations in the system.

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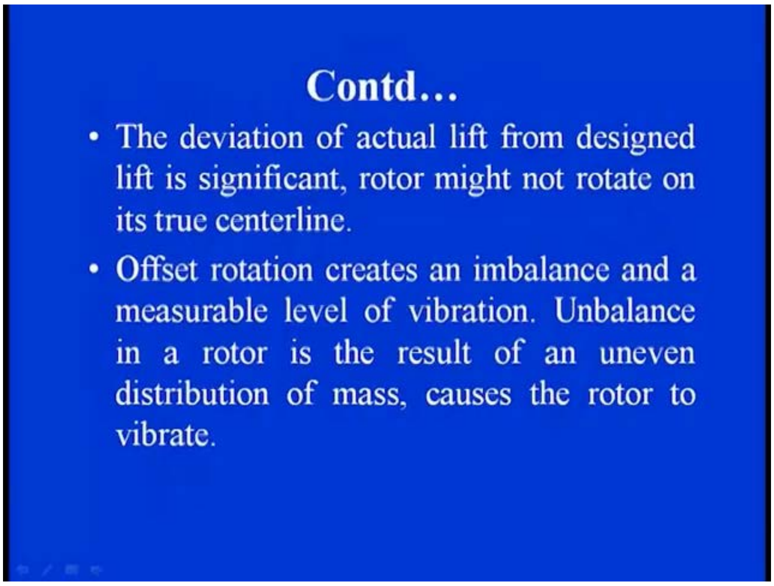

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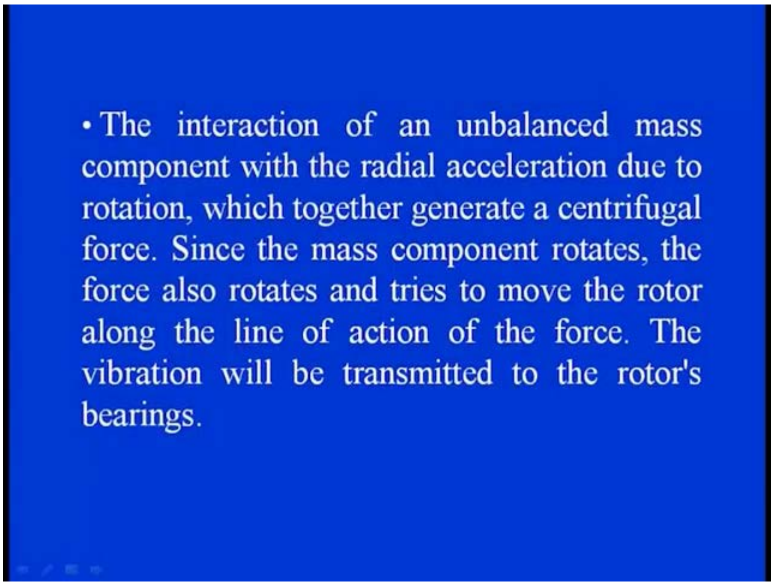

And the interaction of these unbalance mass component with the radial acceleration due to the rotation, can generate the centrifugal forces of the significant kind. And since, the mass component rotates. The force the force also rotates and tries to move towards the rotor along the line of action of the force. And, this creates the huge transmission, means the rapid you know like transmission of the huge forces and they are straightaway transmitting to the bearings. And then there is a clear damage of the bearings because of these vibrations.

So, you see these were the various physical conditions along with the basic physics involved in the rotor vibrations. We know that when, any features are there irrespective of unbalanced, misalignment, looseness, there is a clear exciting frequencies and there is a clear huge amount of we can say the forces are being generated of centrifugal and centripetal and centrifugal type.

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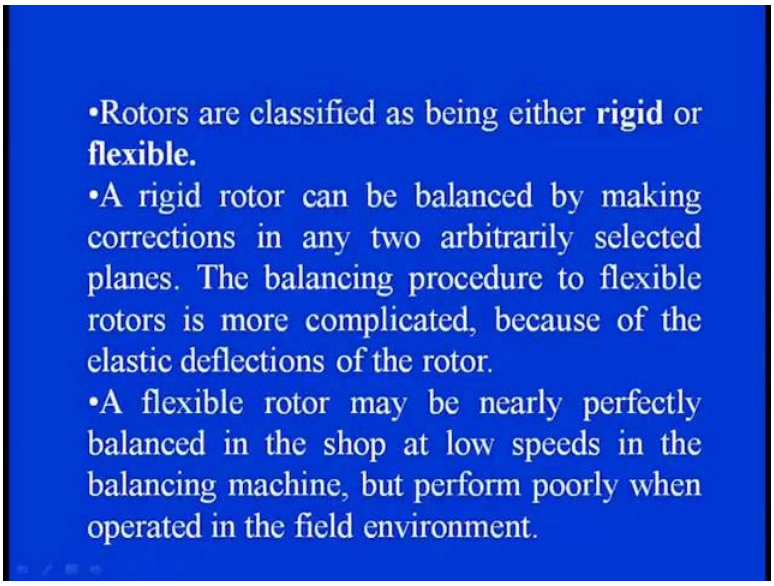

So, when we are talking about the rotors, we need to first describe the rotors either it is a rigid or the flexible one. A rigid rotor can be balanced by making correction in any two arbitrary selected planes because this is a rigid in which not much deformations are there. The flexible means, at the contact points there are significant deformations. Even at the higher harmonics mode there are clear, you know like the different mode shapes, clear deviations are there all along the rotor feature.

When we are trying to make the balancing practices there in the rigid rotor then we need to make the correction in the two arbitrary selected place. And the balancing procedure to flexible rotors because of the more deviation or the complicated deviation is really becomes very complicated because the elastic deformation in the rotor is so significant at the localised points at any first or any higher harmonic nodes.

So, the flexible rotor may be nearly perfectly balanced in the shop at the lowest speed using the balancing machine, but perform very poorly when they are operating in the field environment because the various forces which are of the non-linear nature, cannot be simulate absolutely in the field environment. But in the shop, when the balancing machines are being used and all they are absolutely, ok, because of the low speed.

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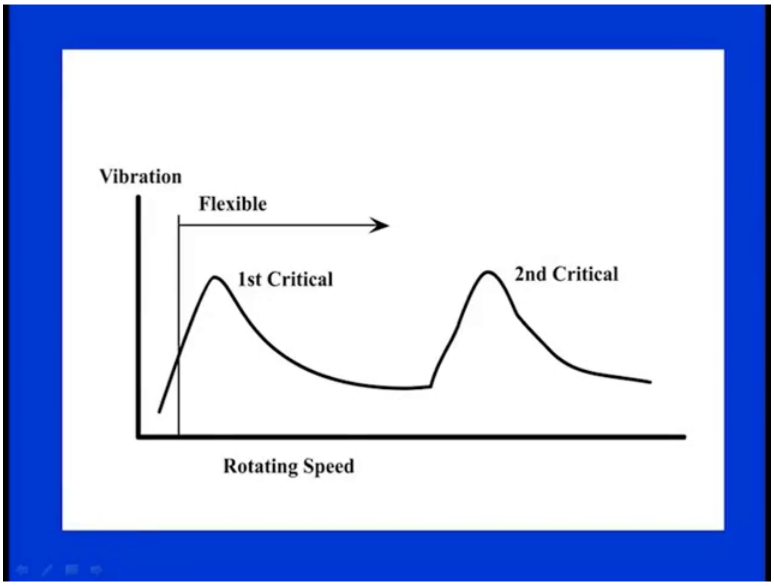

As, you can see here on the diagram the rotating speed and the vibration diagram, is clearly showing that, it is clear from the first critical to second critical speed the flexibility is of so non-linear in the nature, that even if we want to put or if you want to balance the things, put the masses or balancing the things the things are not uniform in its own nature. So, flexibility in the rotor is causing a variety of, you know like the stiffness variation or the different deformation at the localised region. And because of that you see the vibration criterion is not so uniform.

So, the first thing is coming the balancing, is the field balancing because that is what you see the environment is. So, it is nothing but the process of balancing a rotor in its own bearing because the bearing supports are there and supporting structure, rather than the balancing machine because we need to apply at the localised region, that you see, how we can adjust the mass unbalance in the rotor or any kind of you see the source at the rotor itself in the field. And once the balanced rotor has been mounted in its housing, on the you know like we can say, the bearings. In absolutely actual field then, we do not have to balance the entire machine forever. Once we can achieve these things.

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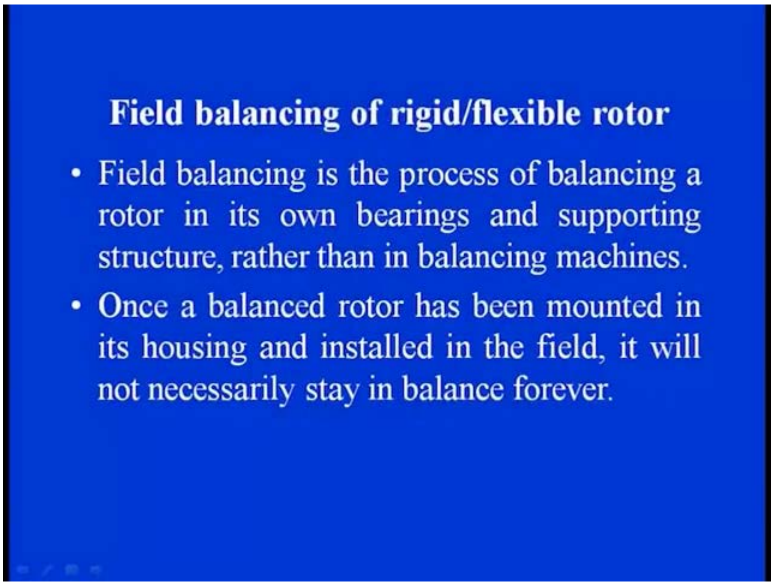

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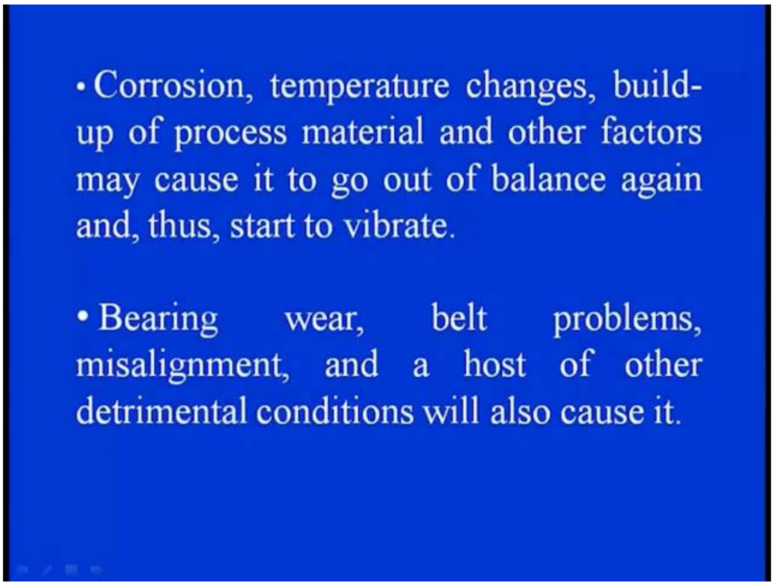

But there are other you know factors of the field which can immediately effect and have a greater impact on these rotor vibration. The corrosion, the temperature changes, build-up processes of the material and other factor. They have a clear cause through which the rotor is just gone out from the balancing feature and again start vibrating. The others are the bearing wear, because of the wear features in the bearing elements, the belt problems, the misalignment problem and there are other detrimental conditions, can also lead to the rotor vibration in its own nature. So, when we are talking about this.

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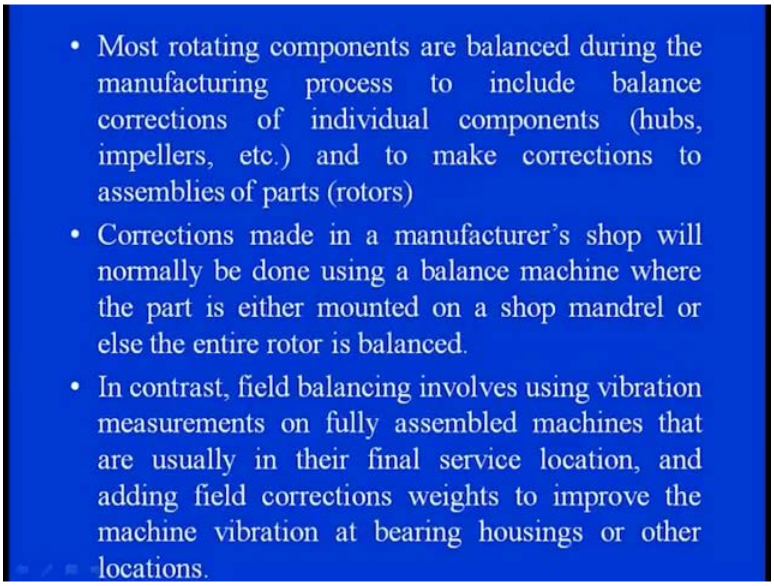

We know that, most of the rotating components are balanced during the manufacturing process only because at that time you see here, like the hubs or impellers, with the individual components. We can straightaway put some kind of, you see the correction during the assembly of these parts to the rotors. And the correction made in the manufacturers shop will normally be done using the balancing machine because; we know that the entire structure can be straightaway balanced using all the criteria's. Where either the part is mounted on the shop, we can say mandrel or the entire rotor is absolutely balanced.

In contrast the field balancing involves, absolutely the vibration measurement, is giving the proper input on fully assembled machine that are usually being coming to the final service location. And being you see you know like, we need to add the field correction weights to improve the machine vibration, at even the bearing housing or any other locations there itself. So, that is why we are saying that the field balancing is nothing but the localised balancing feature is straightaway we need to impact on the rotor itself.

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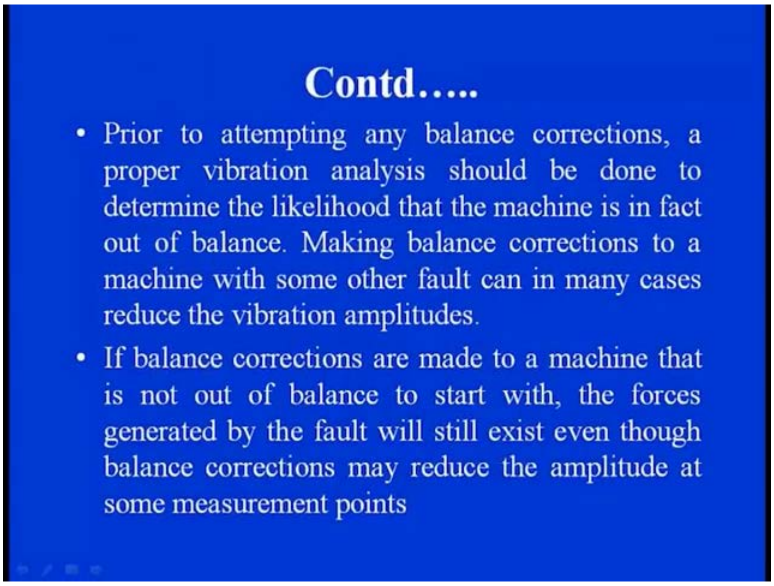

Prior to attempt any balancing correction, a proper vibration analysis is very important, because that is clearly giving the indication of the vibrations in their vibration structure signature. Even they are clearly relating the exciting dedicated frequency and the corresponding amplitude. So, that we can see the how much significance is there of these effect on the rotor vibration. And by making balancing corrections to the machine some other faults may also be reduced, which can also reduce the vibration amplitudes.

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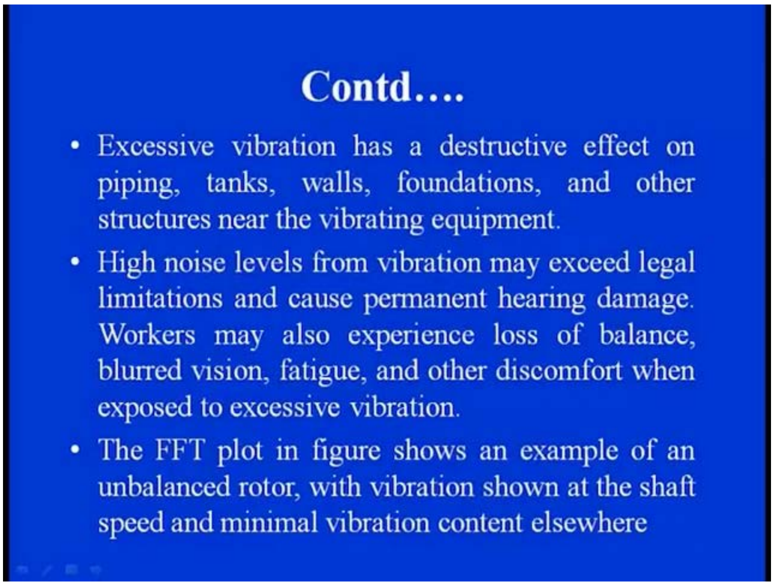

So, if the balancing corrections are to be made to any kind of machine, that means you see here, we need to start not only the balancing of the machine itself. But also, whatever the forces which are being generated during the rotation, we can straightaway balance those things and we can reduce the amplitude features of the vibration.

An excessive vibration clearly have a destructive effect on not only on the machine itself of its own nature, but also you see here the surrounding pipes, tanks, walls, foundation in any other structure which is closely bounded to the machine itself . So, that means you see here the environment is also being damaged by this. And high noise levels which are being generated from this excessive vibration, also having a clear impact on the human beings who are clearly working for these things because of this. You see you know like these sound effect, the worker may also experience loss of we can say the hearing, the balance, the blurred vision, the fatigue means the discomfort level we can say when they are exposing to the excessive amount of vibrations.

So, this is you see one of the drastic cause when the rotor unbalance which are creating you see the huge amount of vibration, not only they are damaging the machine itself, but they are also having a clear damage, clear you see the untoward effects to the human being. So, first of all we need to check it out in the field, what is the vibration signature is. And for that, the vibration signatures are of two main. We can say domain one we can capture in the time domain and we can convert into the frequency domain.

So, fast Fourier transformation based on the Fourier service is clearly showing, the specific dedicated peak in its signature analysis due to the unbalanced router. And then you see here we can find out that what exactly the significance of this amplitude or the exciting frequencies are...

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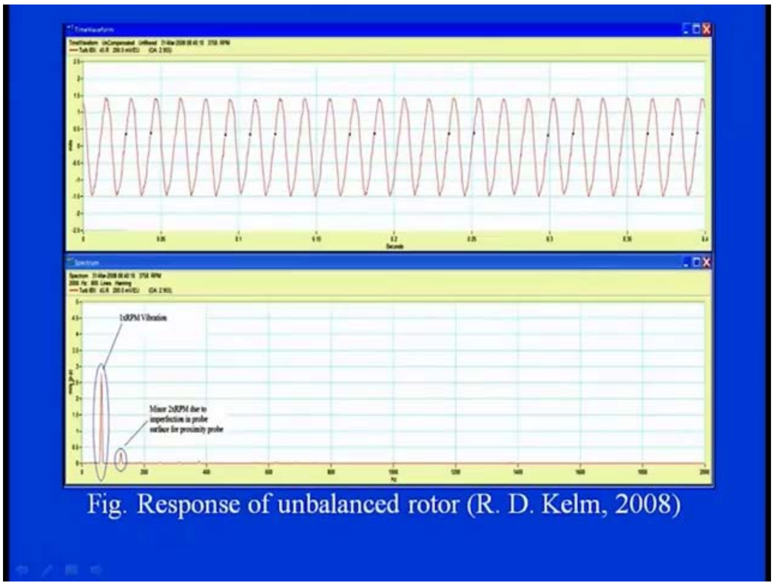

Fig. Response of unbalanced rotor (R. D. Kelm, 2008)

So, you see here this is what it is. As I told you that there are two domain, one the time domain, so this is what the time domains are. It is clearly showing the variation of the displacement with respect to time of the vibration signature. But sometimes you see here, the vibration in you know like which is being caused by these reasons, have is having you see you know like a different kind of signature. So, it is not easy to analyse the variety of features in that time responses. So, we need to go to the frequency response. Also, in the lower figure the frequency response clearly shows that, you see, if we have 1 peak and that too you see it is absolutely 1 x that means the unbalance is significant.

And this, another peak which is showing is just you see noise elements are there so we need to adopt the different filter to cancel out this noise. So, you see the entire vibration signature in the fast Fourier transformation, is simply relating the exciting frequency and the amplitude of this vibration is and when we are doing this once you get to know that we need to first put what is the unit of measure.

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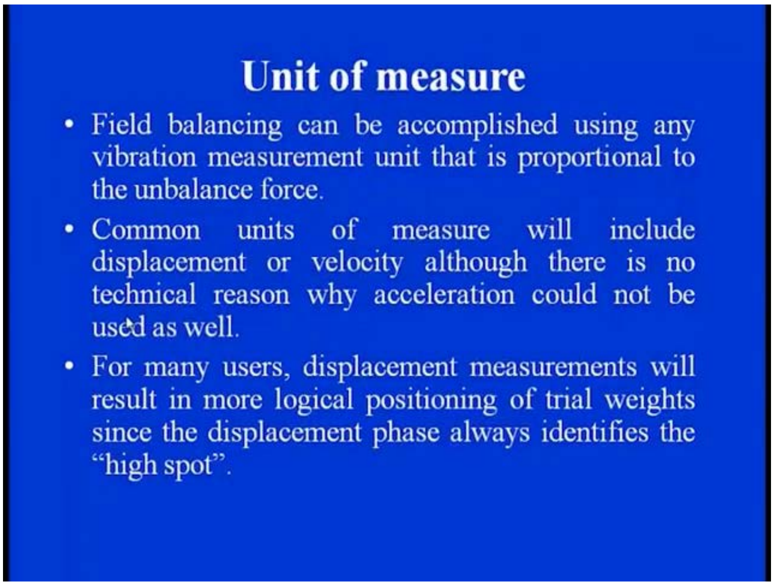

In the field balancing, it can be accomplished using any vibration measurement that is proportional to the unbalanced force. And the common unit which we are you know like including in this, is sometimes the displacement or the velocity. Although, there is no you see you know like the technical reason why the acceleration is not you know like added. But sometimes we are going with the displacement and a velocity because if you are doing this, we know that the displacement velocity and acceleration they have their own frequency dependent criteria.

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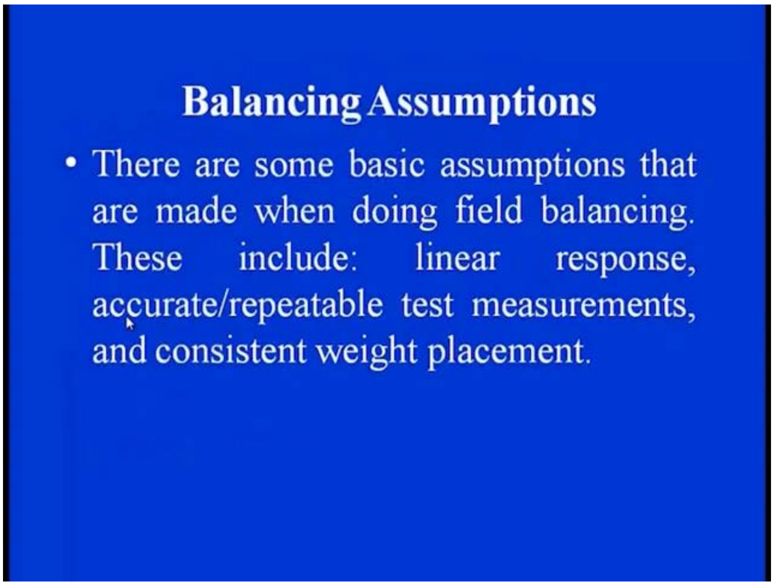

So, for many users the displacement measurement will result, is more logical positioning of the trial weights. Since, the displacement phase is always being identifies as the high spot. So, that is you see some reasons are there for many users when they are using that. There are some basic assumptions, which needs to be framed out for field balancing. They are like linear response, the accurate or you know like the repeatable test measurements and consistent weight placements. So, these things you see you know like which needs to be put during you see their balancing assumptions.

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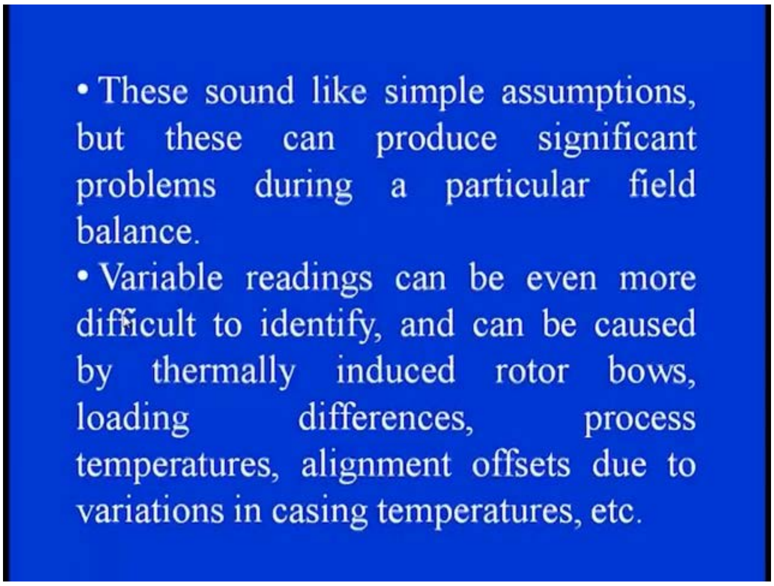

So, these simply you know like sound like the simple assumptions. But they are producing the significant problems during a particular field balance. So, we need to assume that. And variable readings can be even more difficult to identify, that what is the basic cause. Like you see whether, it is you know like caused by thermally induced rotor bows, loading differences, the different processes involved in that or even there are different alignment offsets are there due to the variation of the casing temperature or what exactly. So, you know like when these variable readings are being coming into this signature, the interpretation is really difficult to go for the accurate cause of this vibration.

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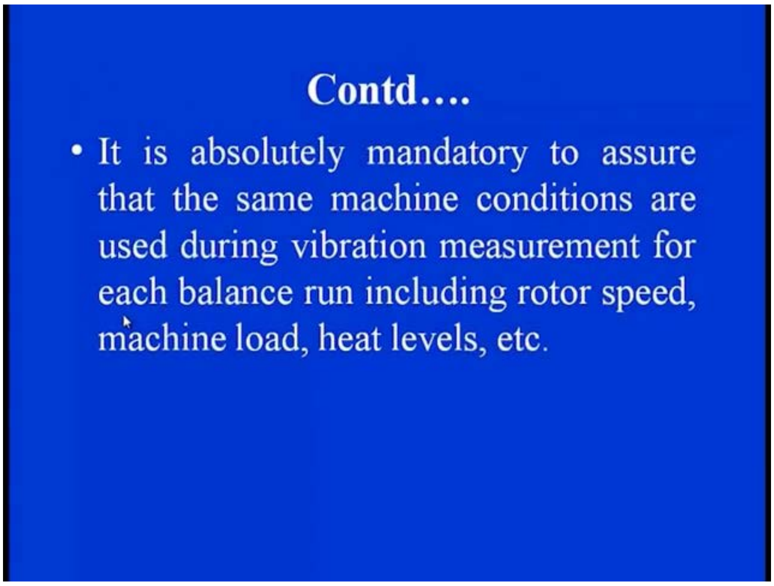

So, it is absolutely mandatory to assure that some of the machine conditions are being used during the vibration measurement for even balancing, just to run, includes a rotor speed, machine load, heat levels these has to be checked out and has to be framed in a steady state manner. So, that we can go towards the actual cause of this and we can analyse it accordingly.

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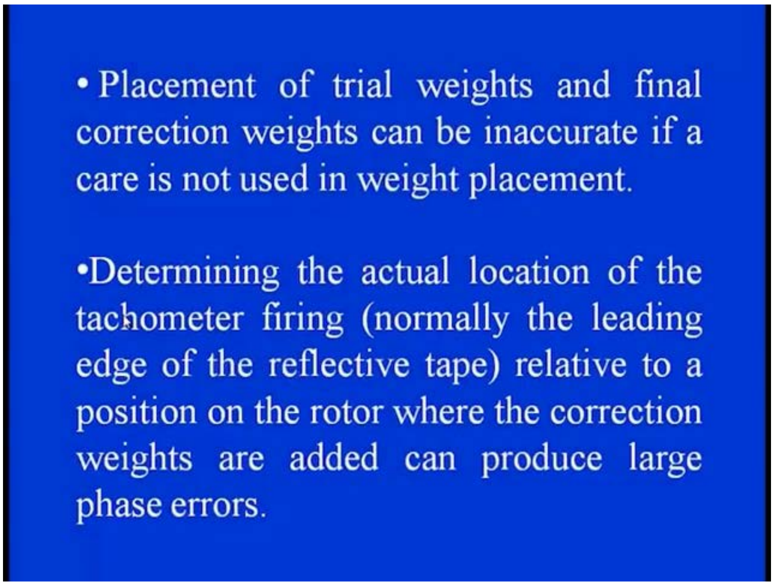

So, the placement of the trial weights and the final correction weights can also be inaccurate, if the case is not used in the weight placement side. And to determine the actual location of the, we can say the tachometer firing, means you know like for checking out you see the speed of that, which normally you know like leading towards the edge of the reflective tape, relative to the position of rotor, is always giving a different kind of variations. And here you see the correction weights can also add a different kind of phase differences in such things. So, it is really you know like some of the complicated features which are being emerged out, when such things are being happening with the tachometer or with the different weight arrangements.

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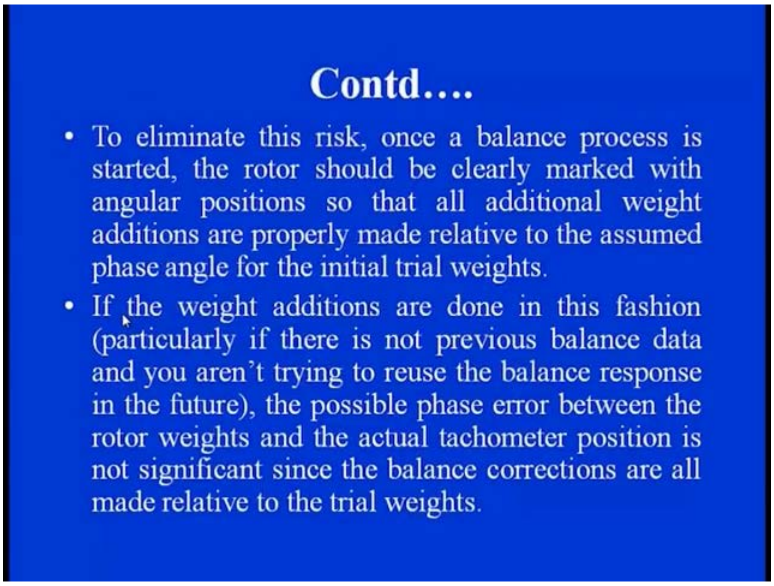

So, to eliminate this risk, once the balance process started the rotor should be clearly marked with the angular position. So, that all additional weight which are being added at the properly if we properly placed they made a relative you know like feature to the assumed phase angle with the initial trial weights. So, that you see a proper correction can be easily made. If the weight additions are being done in this fashion then, we can say that the possible phase error between the rotor weight and actual this tachometer position can be even you see make the proper corrections there itself.

So, what i mean to say that, even when we are saying that the balancing data, the previous balancing data, which are not being there, but if you want to go for the new balancing feature, we can immediately find out that, what exactly the phase errors are there between the rotor weights and the actual tachometer position, which is sometimes not even the significant when the balancing is to be done based on a real trial weights.

But sometimes it is really significant, when we see that a clear phase differences are there due to these reasons.

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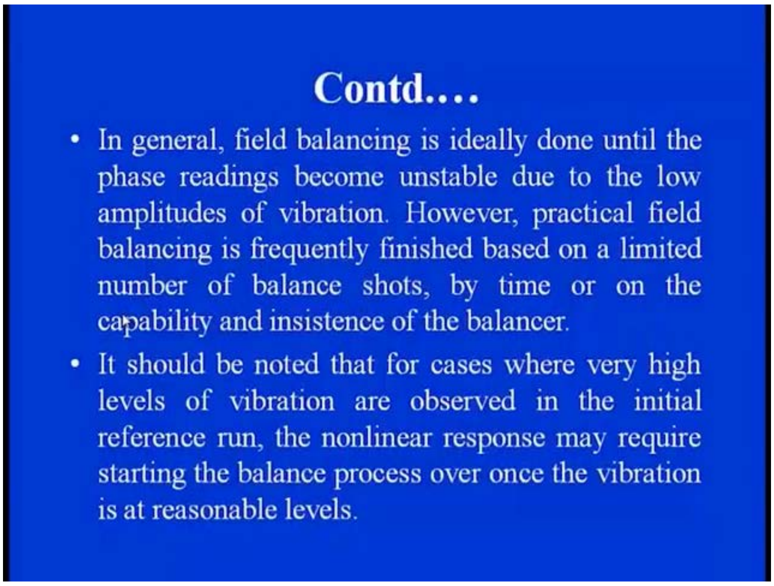

So, in general the field balancing is ideally done until the phase readings becomes unstable due to the low amplitude of the vibrations. That is why using sometimes we are doing this. And practical field balancing is frequently finished based on the limited number of balancing shots by the time or we can say on capability and the insistence of the balancer. We can also find that when the high level of vibrations are being there with the initial reference run the non-linear process has to be analysed, because we know that the things are more of non-linear and we cannot assume the linearity at that point of time.

So, there are various equipments of the field balancing feature. Like the indicators and the measuring devices. In those things and although these devices are sometime we are saying the portable balancing machine, because you see on the side we can immediately apply those things and we can find out. But they never provide the direct readout of the amount and the location of unbalanced sometimes.

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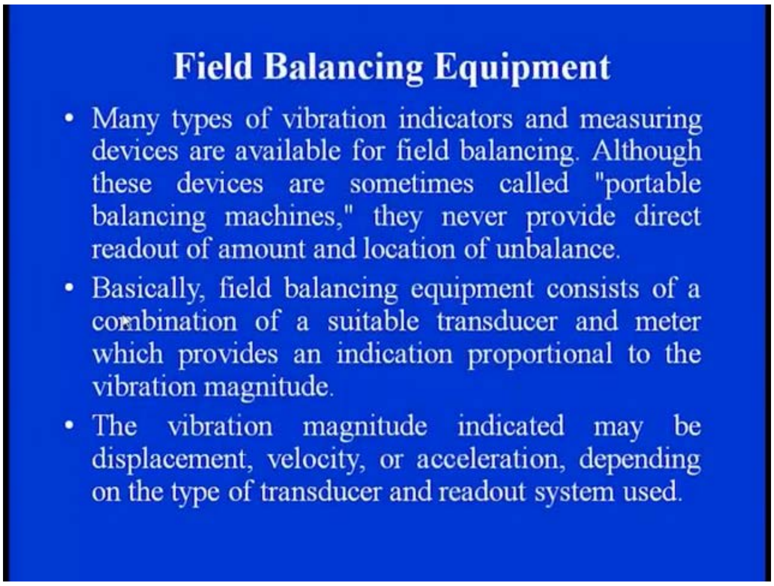

Basically, field balancing equipment consist of the combination of suitable transducer, so that we can find out the relative displacement of this, a meter which provides the indication proportional to the balancing magnitude in terms of say the displacement probes are there, the velocity probes are there. And sometimes even we are using now the accelerometers for that.

It can gives the clear reading of the excitation features in terms of displacement velocity and acceleration because ultimately you see here, our main focus is to see the cause and the amount of vibration which is being generated on exactly on the field. Due to the field conditions or due to some the left out you see here you know like the unbalances, which is being there.

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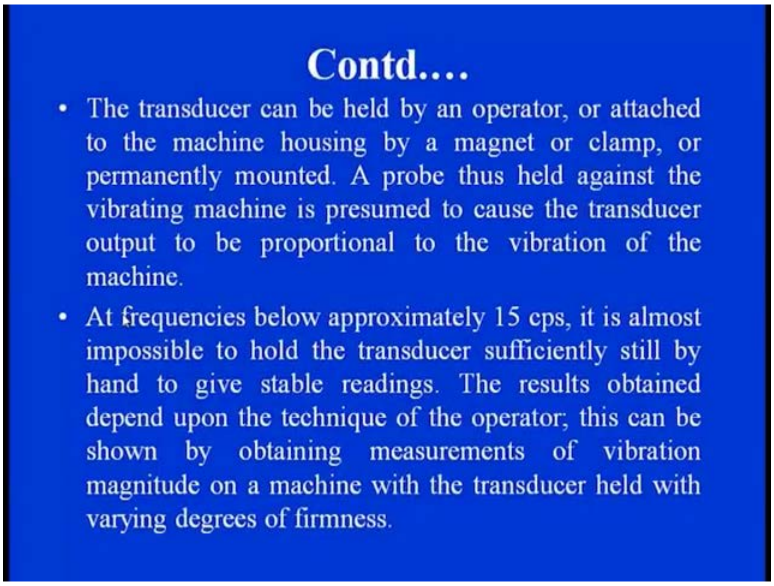

So, transducer can held by operator or attached to any machine housing by any kind of clamp, magnet or anything you see here. And then probe you see you know like held against the vibration machine, is presumed to cause the transducer output, which is proportional to the vibration of the machine. So, sometimes you see here the results which are being obtained due to that is absolutely depending upon the technique of the operator.

And even sometimes you see here we can see that the magnitude which is being there of the machine vibration with the transducer is always giving you know like the variety of the firmness in this. So, again you see here when we are putting the transducer we have to be very careful that what exactly the locations are of this. And how we are measuring, how exactly the impact of these. Is there any looseness there in between? You see the transducer putting and the reading itself. So, you know like it causes various things. So, transducers have the initial we can say the internal seismic mountings and should not be used where the frequency of the vibration being measured is less than the three times of natural frequencies of the transducer is because this is always responds to all the vibration, which is being subjected and within the useful frequency range of transducer.

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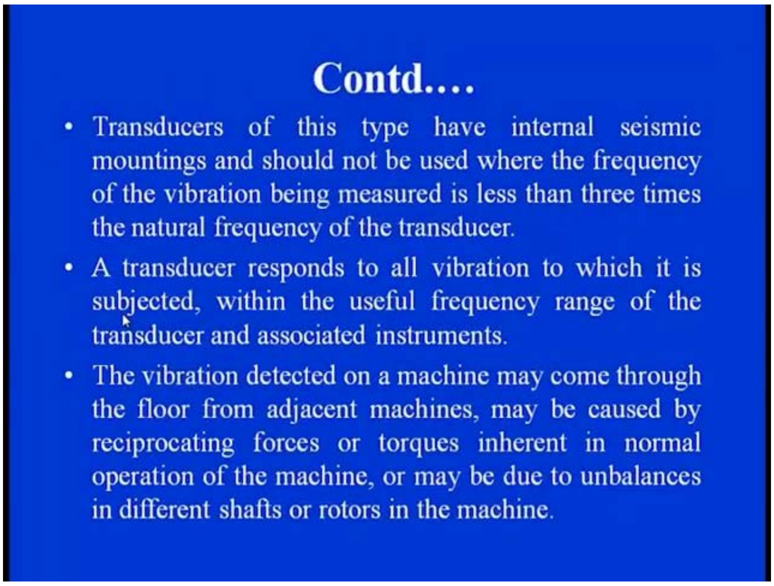

We cannot exactly framed out in this and we need to put appropriate instrumentation according to the natural frequency of vibration because the vibration detected on the machine may come through the floor from the adjacent machine. And, may also caused by reciprocating or any kind of you know like the rotating forces or the torque inherent in the machine at the normal operations of the machine or may be due to unbalances in the different shaft of the or the rotors in the machine.

And then you see here the variety of the excitations are coming in that, and the transducer at that time is not be in a appropriate way to find out the actual you know like the displacement in this. So, simple vibration indicator cannot discriminate between the various vibrations, until and unless the magnitude at one frequency is considerably greater than the other frequencies are. And that is why you see we have to be very careful while choosing of this equipment.

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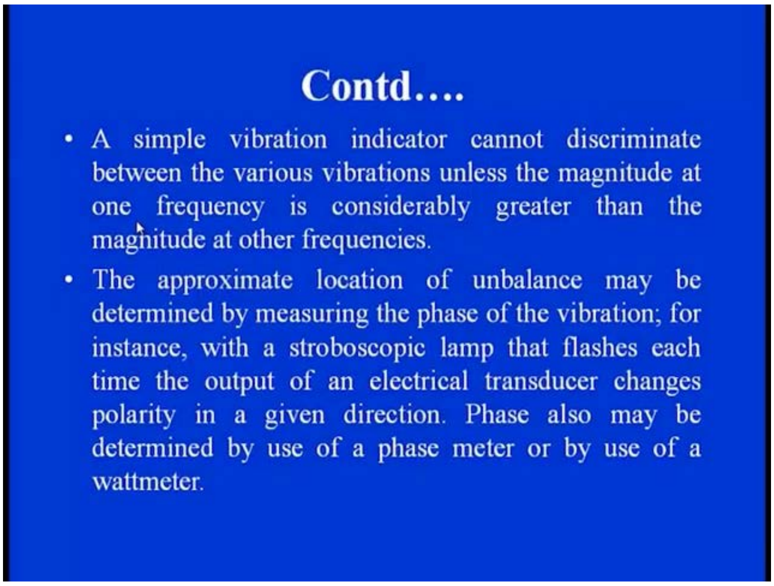

Second, as we discussed any appropriate level of the location of unbalance can be simply determined by measuring the phase of the vibration. For instance say the stroboscope lamp that flashes each time the output of electric transducer changes polarity in the given direction. And then accordingly we can simply determined that how exactly the phase meter or you see the watt meters are being given appropriate readings in that way.

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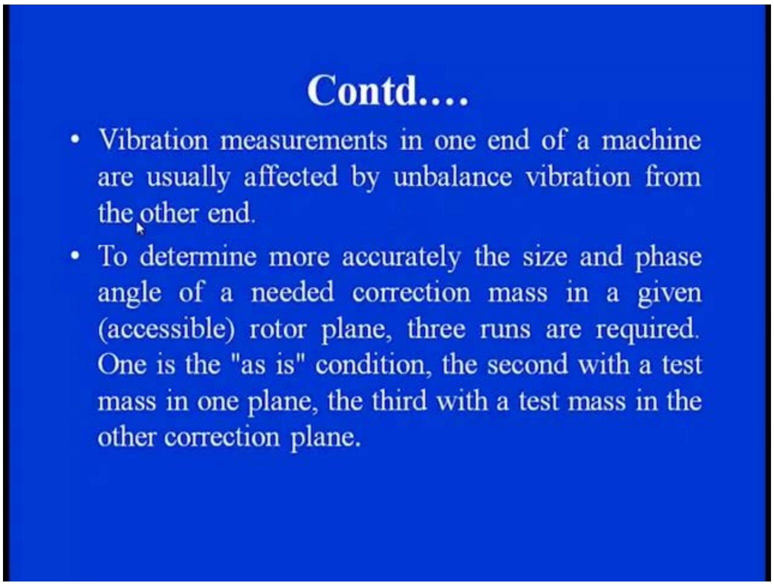

So, vibration measurement in one end of the machines are usually affected by unbalanced vibration from the other end. That is very common feature is that? So, to determine more accurately the size and the phase angle, of a needed corrected mass, one has to assess the rotor plane and three runs at least to be required to find out. Just you know like to find out the conditions and the corrections in the appropriate correction plane.

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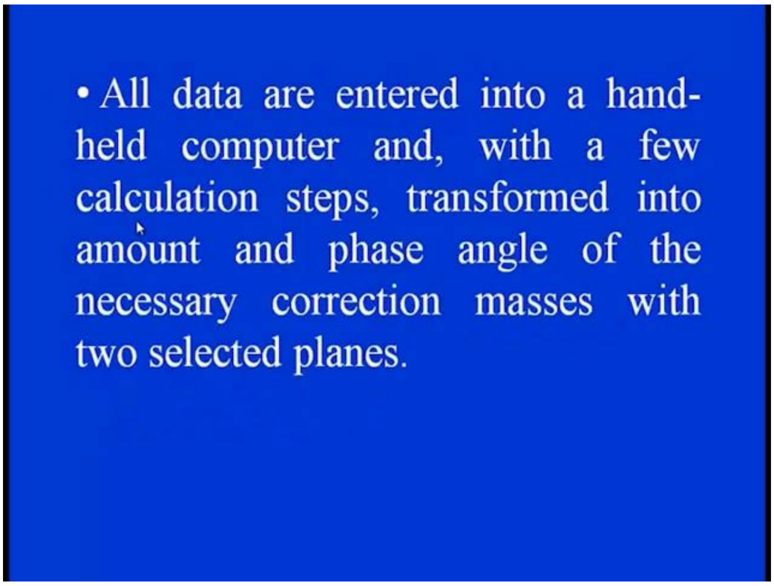

In all the data which are being entered into the system, just gives you see a clear transformation of the phase angle and the necessary correction masses with the phases at the selected planes itself. So, as we discussed that you see here in the field balancing the instrumentation, the location and proper compatibility of the situation is essentially required to check it out this. So, as we have discussing about the weight we are we can put the masses and we can be framed out you see, the principle axis and the rotating axis should be coincide. So, how the weight corrections are to be adopted?

Because, you see the balancing which is being done on the weight correction. There are various ways through which we can adopt that. So, when we are performing the field balancing, we need to generally describe, that what exactly the desirable level is there of that. So, that we can make the trial weights, just to move in such a way that, it can be easily mount mounted or the removed once the final weights are being determined because it is not that you see here, once we put the you know like, once we frame the masses there itself. And even the phase differences in other things are being coming out.

Then, we need to only add we cannot remove or something like that. Such, situations should be avoided.

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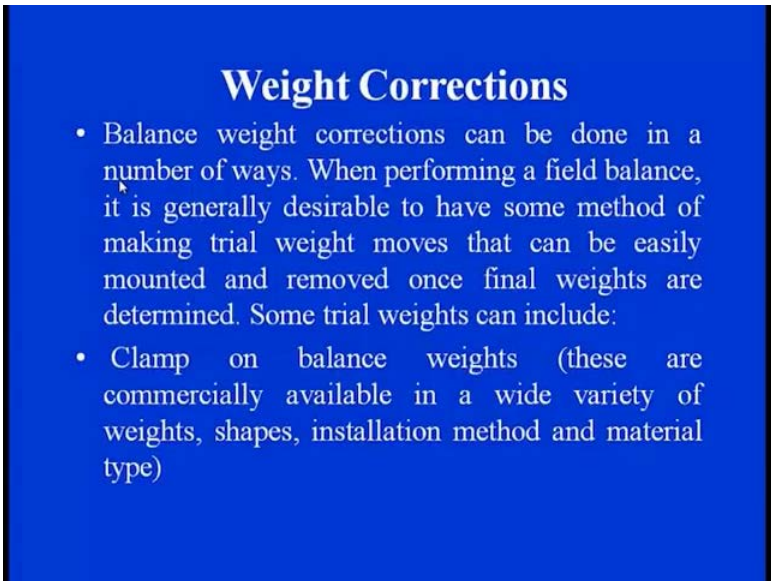

Like clamp on the balanced weight sometimes we are saying that you see the wide variety of weights. Even the weight we need to check it out what exactly the level of the weights. In terms of masses, the shapes, the installation methods, and second is the material because sometimes when we are adding the weight they are also providing some kind of material damping according to the material type.

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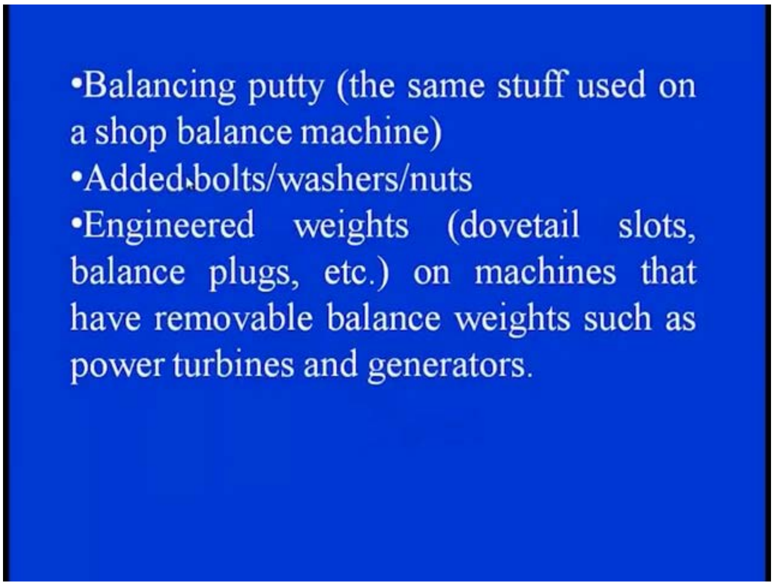

So, we need to check it out you see here what is the specific weight is required in what size. So, that you see these centric features of both centre lines should be properly added in this way. The balancing putty that means sometimes you see you know like we can say the shop balancing machine, it should be properly put. The added bolts or washers and nuts, these are also one of the essential component which has to be there.

So, either the bolts or the washers or the nuts, we need to check the effect of these on the on the entire balancing feature by the weights. Or else we can say that the slots the balancing plugs which are termed as the engineering weights on the machine, that have to be removable balanced weight. In the terms of we can say the power turbines or generators, so that whatever the weights weight-adjustment which are being required in the different conditions can be added or can be modified accordingly.

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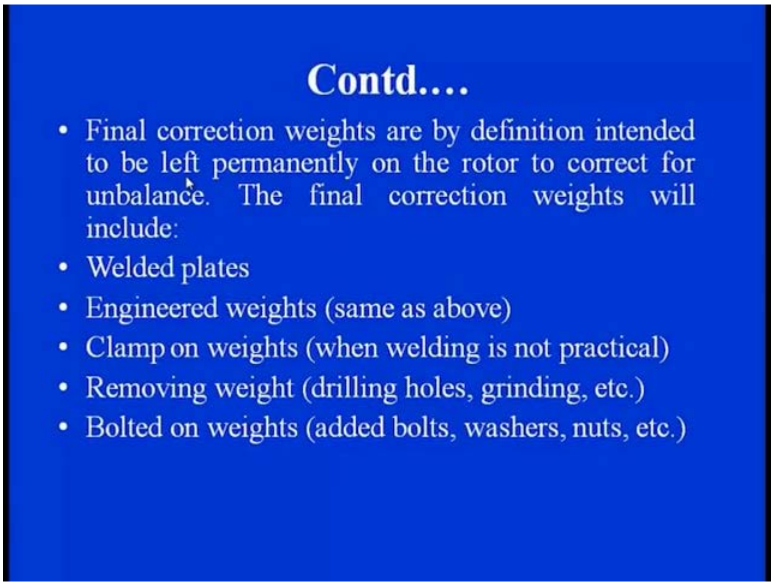

So, the field correction weights are certainly you know like we can say these are the dedicated weight, which are being permanently you know like we can say left out those things when the corrections are to be featured out due to the unbalance part. And the final correction weights can also include the welded plates because once you find out yeah this is what my entire features are and this much know you see the unbalance is there in the huge turbine or power generated rotors. We can, because we know that the nuts or the bolts are sometimes is during the oscillation, they can be loosened. So, we can use the welded plates.

We can use even as we discussed the engineering weights for that. We can see when the welding is not practical, because of various reasons. We can go for the clamping action for that. Even we can remove the weight by various ways, by simply grinding the surface or even by drilling the holes. Even you see here when we are when we see that the vibration mode shapes are not significant across these surfaces. And even at the higher harmonic modes, the bolted can also be the added bolts or added washers nuts can also be put as the weights to the system.

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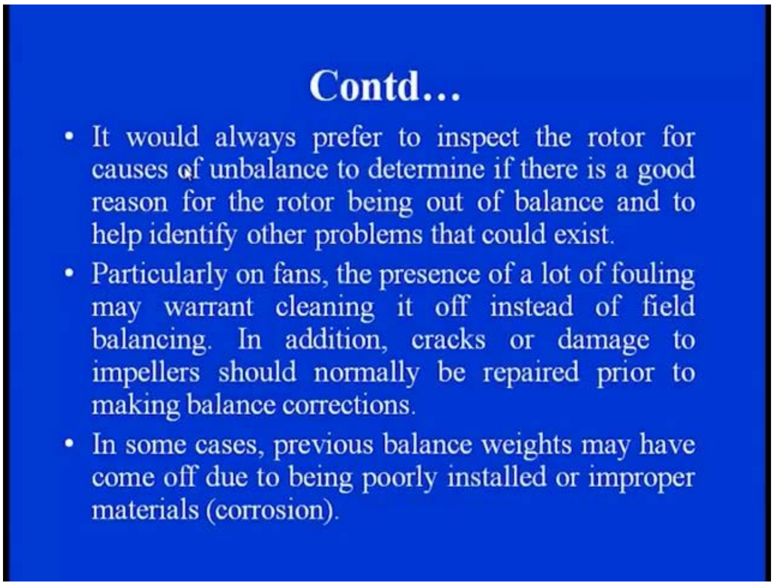

It would always be preferable to inspect the rotor for the cause of unbalance which is to be determined. If there is a good reason for the rotor being out of balance, then we need to go and see the entire conditions rather to make a proper you know like the correction at the time of this. And particularly on the fans, the presence of lot of you know like the fouling may warrant a cleaning it off instead of the field balancing. Or else the cracks or the damage to the impeller should normally be repaired prior to make the balancing corrections, because you see because of that there is a clear deviation in the entire material properties which is being supported to the entire structure.

And we have a different kind of excitations there. So, in some cases previous balancing may weights which is being there you see may have also become due to the poorly installed or even sometimes you see you know like the corrosion other effect. They can also you know like create some kind of the loosened feature and they may also create some kind of unbalance.

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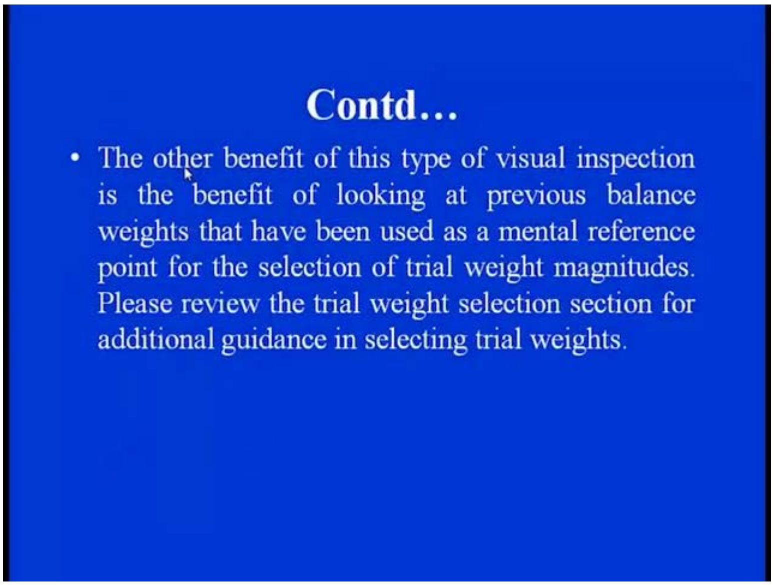

So, the other benefit of this type of visual inspection, is just giving that what the previous weight situations are, so that the selection of the trial weights can be appropriately chosen. To just check it out to see the balancing features in that.

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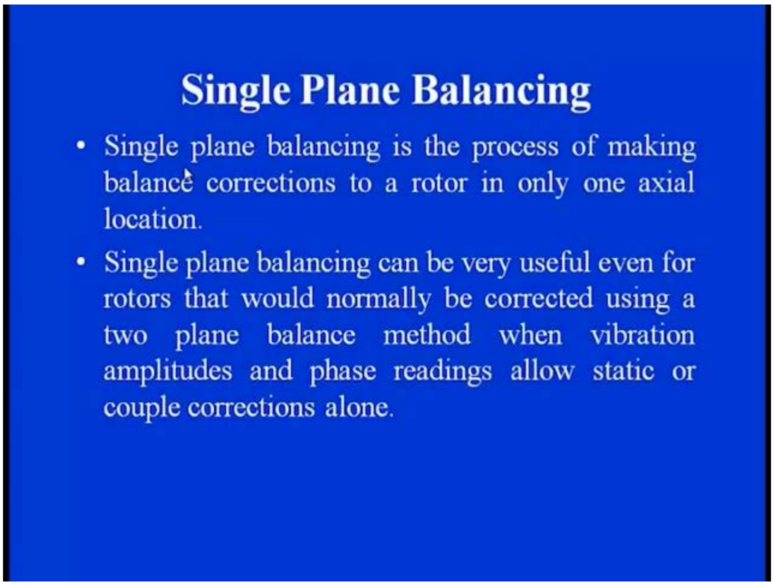

So, the first category in the balancing is the single plane balancing. And this is the process of making balancing correction to the rotor just with the consideration of one axial location. And it is very useful even for the rotors that would be normally corrected using two-plane balancing generally, when the vibration amplitude and the phase readings are just allowing the static and the coupled correction alone. So, when we have this situation in which you know like the static corrections or the coupled corrections can be done separately. So, instead of adopting the general methodology of the two-plane balancing method for the rotor the single plane itself is very effective and can give you accurate results for that.

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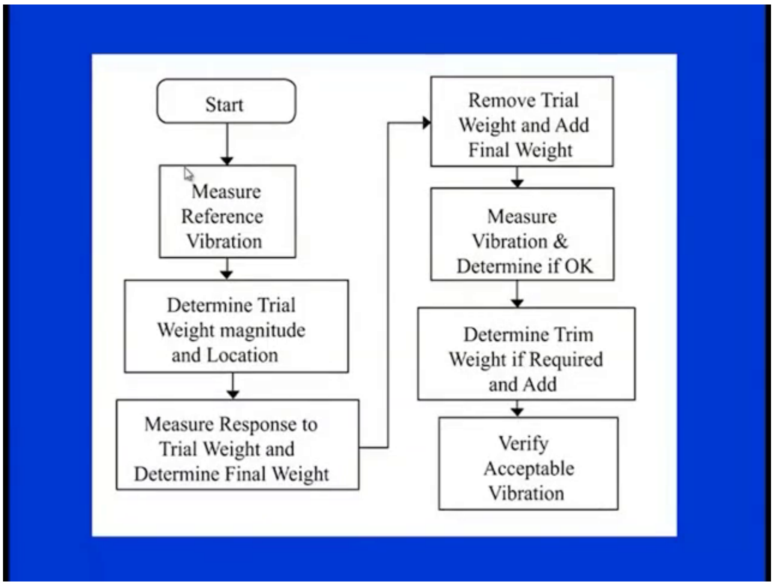

So, this is what the process is. We need to measure first the reference vibrations from this, that you see what exactly the reference vibration levels are there with that. Need to determine the trial weight magnitudes and the appropriate location where the weights are to be installed. Then again needs to go to measure the responses. To the from the trial weights and find the find what exactly the optimum weight through which we can suppress the vibrations. Then we need to remove the trial weights and we need to add the final condition of the weights are.

Then again we need to check the vibration responses and if this is, okay, that yeah, we are now getting the desirable level of balancing features. Then we need to determine the trim weight, which is to be you know like required or any added feature is there. Then we need to find out or to verify the acceptable level of vibrations are... So, this is what you see the extended process which needs to be adopted for doing the final corrections in that. Now, we are going the another way of doing the balancing for the flexible rotor. And we know that when the flexibility is there in the rotor, it is very complicated to do the balancing even at the localised region in the field part.

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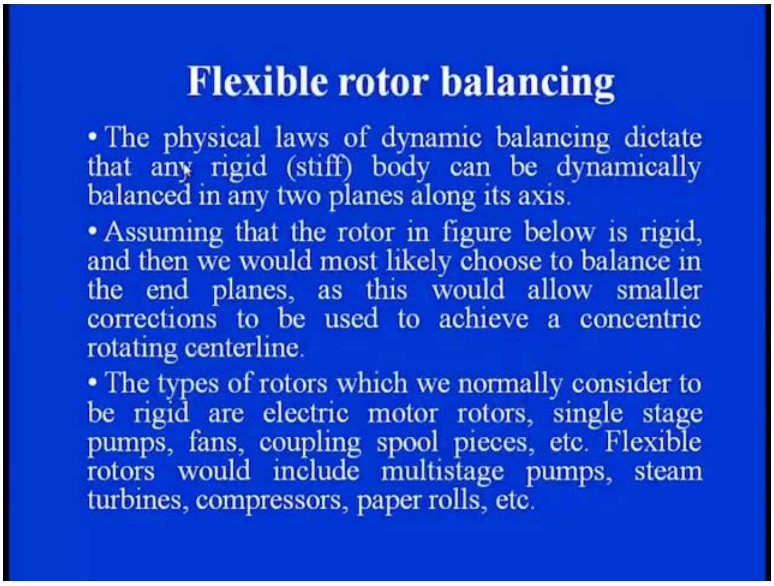

So, the physical loss of dynamic balancing just dictates, that any rigid or the stiff body can be easily dynamically balanced just by the two plane along its axis. And you because we know that whatever the deformation or even you see the less amount of deformation which is being available, it can be easily handled. Assuming that the rotor in you know like in these kind of situation is rigid, and we just want to choose the balancing features in that we need to take the end planes, which would allow us a small correction to use to achieve the concentric feature of these two centres in the rotating centre lines.

This type of rotor which normally considered to be rigid are the elastic motor. The whatever you know like the electric motor rotors are there. The single stage pumps, fans, coupling spools, whatever you see the pieces are there. They are absolutely comes under you see the rigid features of the rotor because we know that whatever the rotating features are being coming out under these conditions, they can be treated as the stiff body or the rigid rotor are.

But flexible rotors have also you see you know like significant applications like in the multi staging pump, like the steam turbines, the compressors, the paper rolls, because you see until and unless the flexibility is not being provided with any impact forces there is a clear damage because of the high power transmission or heavy loads or the high speed even applications there.

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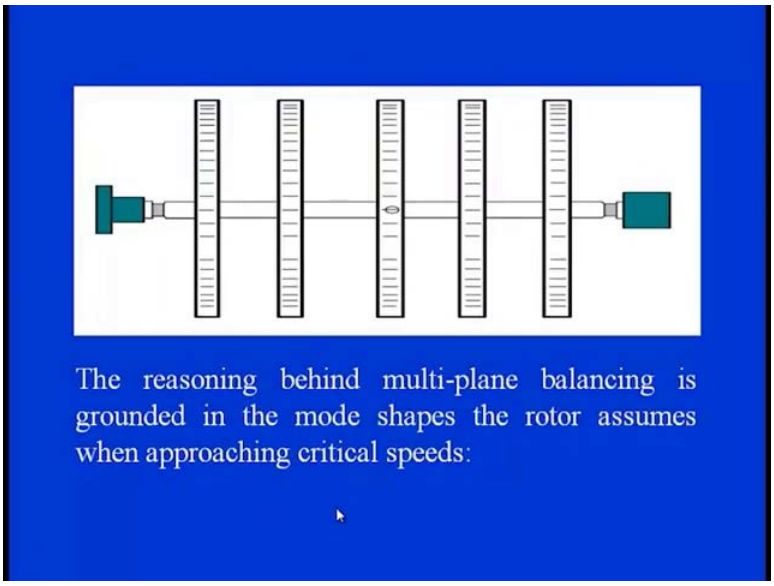

So, the reason behind the multi-plane balancing is just you see that we have the different mode shapes in the rotor. So, we need to adopt the multi-plane balancing to appropriately attack on the variety of the shapes in the different mode shapes, when they are approaching to the critical speed. So, you can see on that we have a clear you see the variation you know like multi-plane balancing features are there. We can adopt all these part just to suppress a typical location of the vibration modes at the different you see the critical speeds.

So, you can see that we have clear feature and that is why we are adopting that. When we have a rigid mode shape, there is no deviation in the entire structure of the rotor. It is a clear straight one. But when we are going towards the first second or third critical shapes, we know that we have the various axial mode shape, radial mode shape, even we can say binding ((Refer Time: 41:10)) mode shape, we have you see the shear mode shape.

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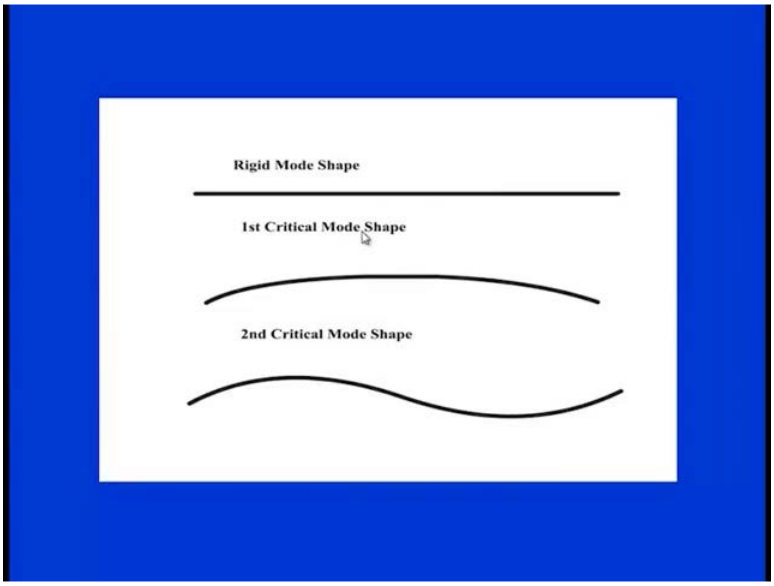

All these feature are all these features are being featured out, when the rotor is rotating at the different critical speeds. So, you can see that the first critical speed, we have a different you see in the entire shape is like that. So, we need to adopt a different kind of methodology. When we are on the second critical shape you see here. We have a wave feature and a different corrections are to be needed there itself.

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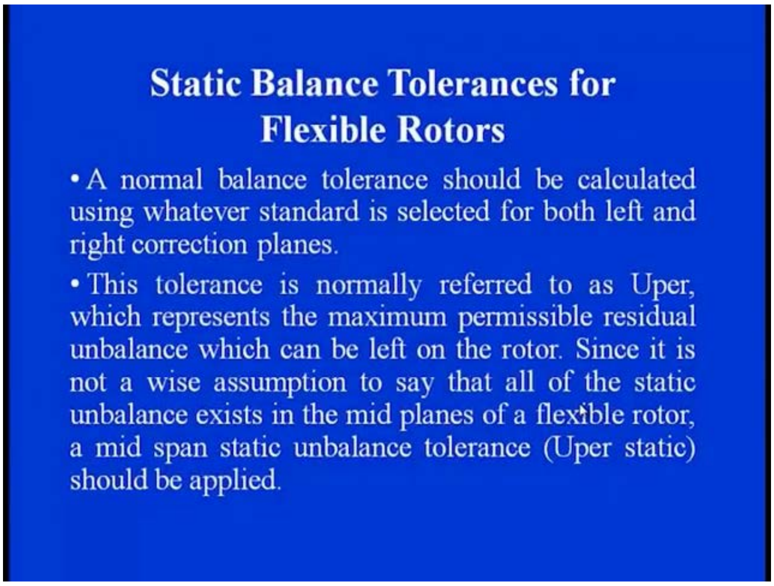

So, a static balancing tolerance is for flexible rotors when we are just talking about these we need we need to first put, the normal balancing tolerances. That how you know like the amplitude of these tolerances are. And then we need to select both left and right correction planes to make balance of that. So, sometimes this you know like tolerance is referred to, you know like the Uper or we can say that you see you know like what exactly the permissible residual unbalances are there. You know like from left hand side or right hand side.

And accordingly, we can simply find out that what exactly the unbalances are there in between the flexible rotor plane and you see what exactly the mid span. Is being you know like variations are there at the mid span. So, that we can find out that what exactly the upper static or the lower static tolerances are there. And accordingly, we can apply the weights you know like towards these sides.

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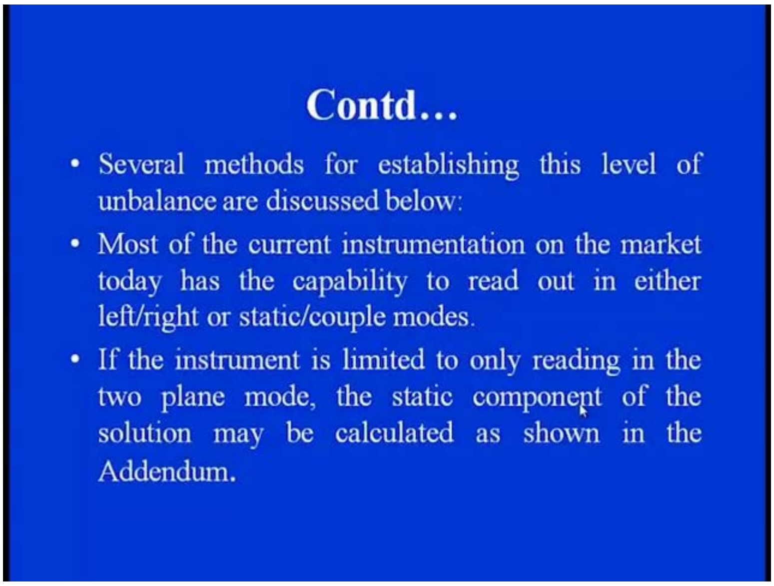

So, we can adopt even various methods for stabilising the level of unbalance in the flexible rotor, and most of the current instrumentation which is simply there, as that how we can adopt, the different weights at the two different planes. When they are even the static or the coupled modes or even you know like we are just going with the left and right side. But even you see they are giving clear feature of the two plane mode, the static component and the dynamic component in these two features.

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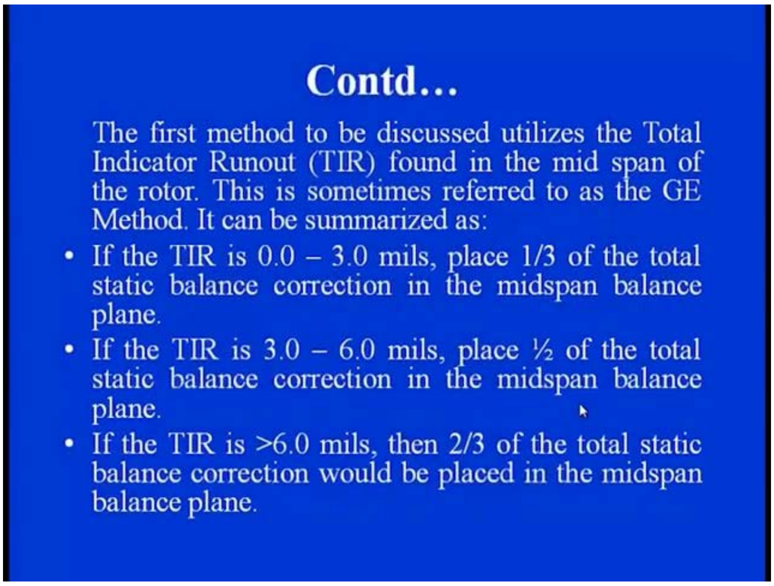

So, if we if you are just looking towards that, we know that the method which we are adopting is totally based on the Total Indicator Runout, T I R at the mid span. We can summarise all these things towards, you know like the various features. One if the T I R is in between 0 to 3 mils, means you know like we need to put one third place. There you see you know like the balancing corrections is to be required from the mid balancing plane. And if it is you see in between 3 to 6 mils. That means you see we need to move exactly half of that means the static balancing plane corrections are to be required absolutely at the middle point.

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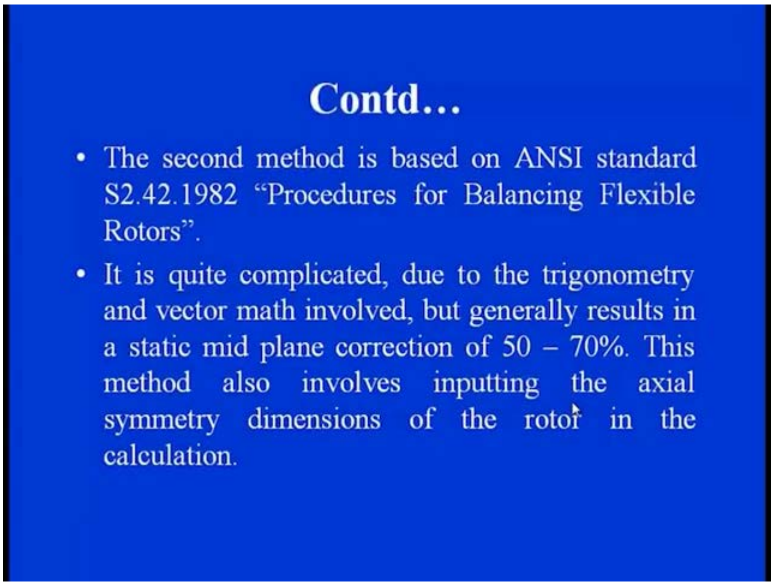

If this is just crossing the 6 then we need to go on the other side, right hand side. The two-third of the total static balancing plane and the correction has to be put there itself. So, this you see the total indicating run out is clearly giving the indication about the requirement of the balancing features.

And then, you see we can adopt accordingly in this way. The second method which is you know like very standard method is the American national standard instrumentation, A N S I standard S2 42 1982 in which there are various processes, of the balancing of flexible rotors are being documented. That can be adopted according to the situation, the type of loading and you see what are the operating conditions are there. But again you see it is very complicated due to the trigonometry and the vector method involved in this in these standards. But generally you see we can find that, you know like a static mid plate correction up to 50 percent – 70 percent can be achieved with these two things.

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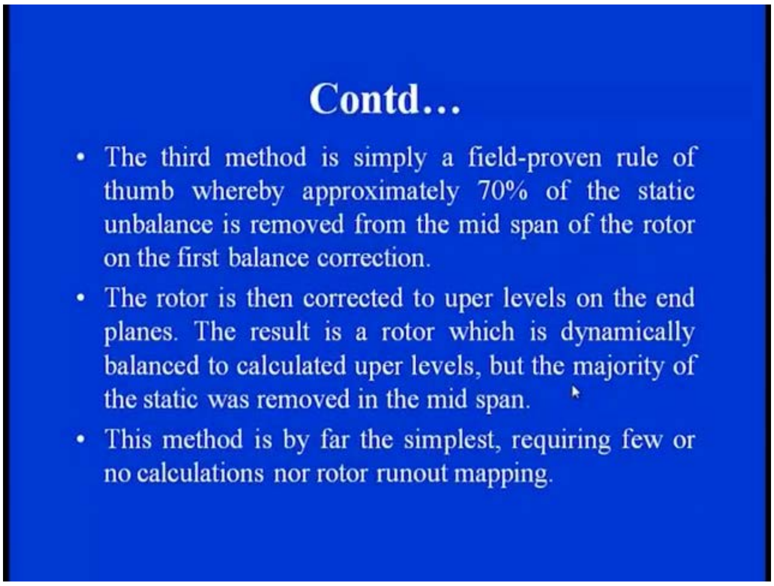

And then you see here you know like, the third method is very simple and field proven rule or we can say some kind of thumb rule is there. Where at least you can get the 70 percent of the static unbalance can be achieved by removing from mid span of the rotor in the first balancing correction. Then the rotor is also corrected, at up to the higher level or the upper level of the tolerances.

And these results in the rotor which is dynamically balanced when the dynamic coupled are there to calculate it to calculate up to the upper levels. And when you see we can say that when the static feature the static unbalance is simply removed out. So, this is something we can say a very standard method and sometimes you see on the field balancing we are adopting that. In the last feature which is one so one of the responses of the vibration signature.

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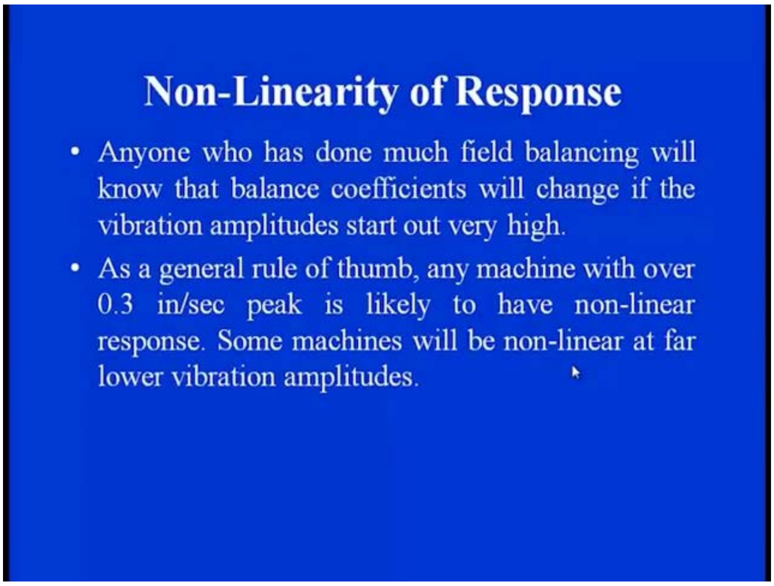

So, we can say that when the things are being non-linear nonlinearity in the responses. So, the field balance when we are doing, we need to check it out the balance coefficient. When they are changing, we know that the vibration amplitudes also be changing rapidly. When we are adopting you see some of the methodology, any machine with 0.3 inch per second or you see you know like is a showing the peak. That means you see here it has some kind of nonlinearity, geometric, material, boundary condition nonlinearities are there. These you see you know like the lower ((Refer Time: 46:43)) amplitude vibrations, is also showing some kind of you see the different variations in that.

So, that piece that you see here, the standard method of the balancing can also result in continual overshoot or undershoot with successive weight calculation as the balancing coefficients change. Unless a method is used to re-calculate the balancing coefficient to remove the nonlinearity existed in that.

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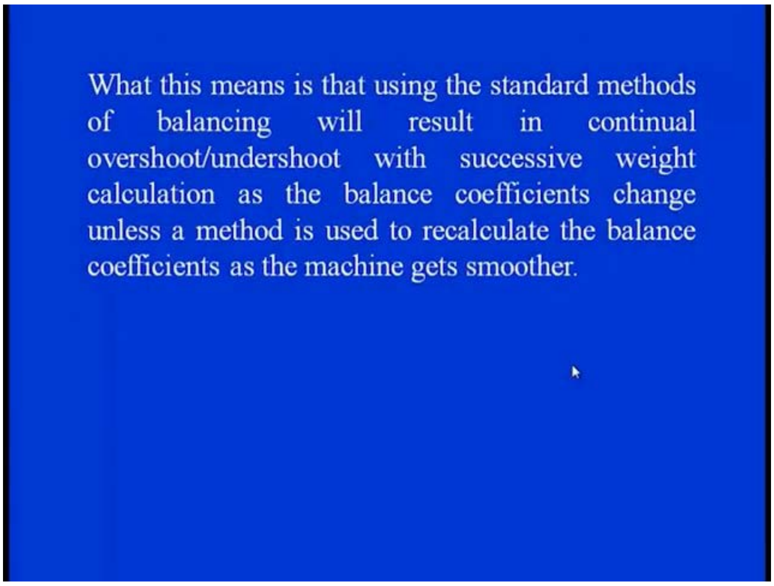

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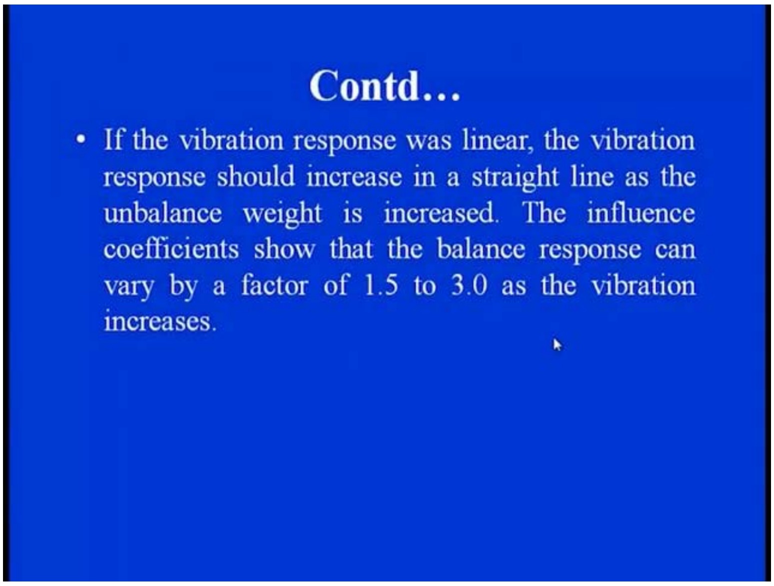

And if, the vibration responses is linear there is no problem because you see there is a increment is quite straight line and the unbalance you see weight can be increased accordingly. So, there is a straight influence coefficients are there through which, we can simply put the various factor in which the vibration generations are there.

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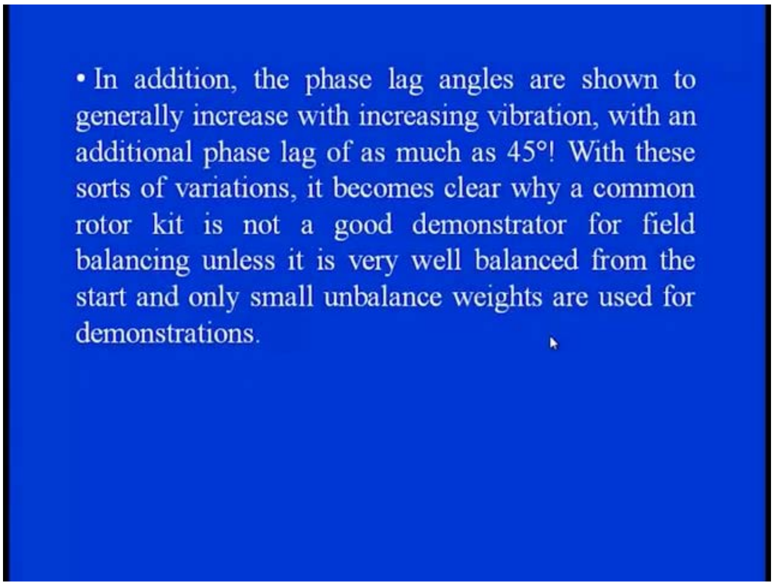

The phase laying angles which you see you know like, changing with changing of the vibration, can also be put that you see up to 45 degree. The phases are becomes you know like the linear variation as the vibrations are there. And accordingly we can add the weights to balance out these things.

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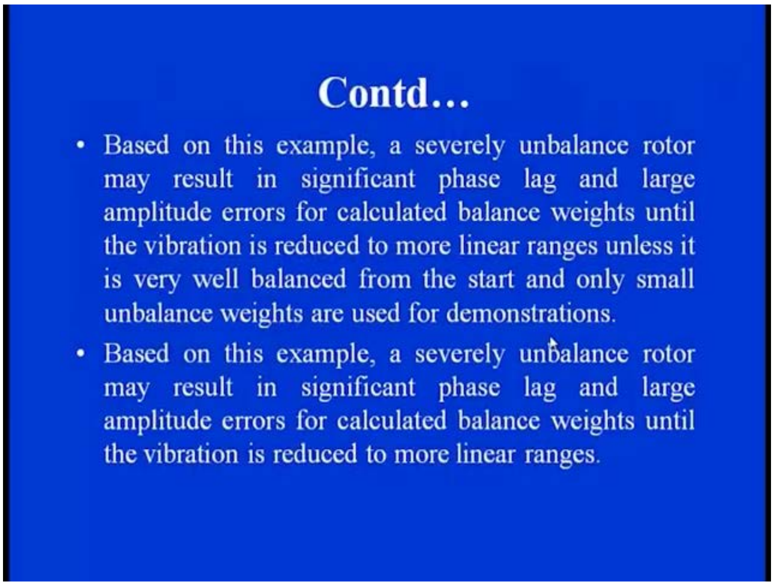

But a severely unbalanced rotor may also result in the significant phase lag and the huge amplitude errors, when we are calculating, just based on the previous calculation. If you want to reduce those things then we need to go and check it out. What the unbalanced weights are there, you know like which you know like which are creating you see the different phase lags. We need to check it out the nonlinearity existed in the vibrations.

So, we need to first you see check it out whether, there is a significant phase lag and large amplitude errors are there, then we need to just go first to bring the entire non-linear responses to the linear one. Then we can put that these weights to bring down the entire centre lines.

So, you see here first the treatment of the nonlinearity is to be required. To bring down the system responses to the linear and to reduce the amplitude errors and large you see you know like the unbalanced weight errors there itself. Then we can brought down towards that. So, this lecture is more of you see when we are trying to do the balancing of the unbalanced rotor at the field.

When we are operating those things, we need to adopt a practical methodology due to the service condition, due to the operating condition, due to the boundary conditions. We can say and we have various options for that and accordingly we can brought down, the entire vibration signature. Along with the phases along with the transmission in the rotor, rotor-unbalanced, misalignment, looseness or anything you see here.

So, there is a standard processes are there. Now, you see even the codes are being also available to adopt those things. So, in the next lecture now, we are going to see the vibration generation mechanism from the system itself. And then we are going to discuss about the various damping models in those things.

Thank you.