

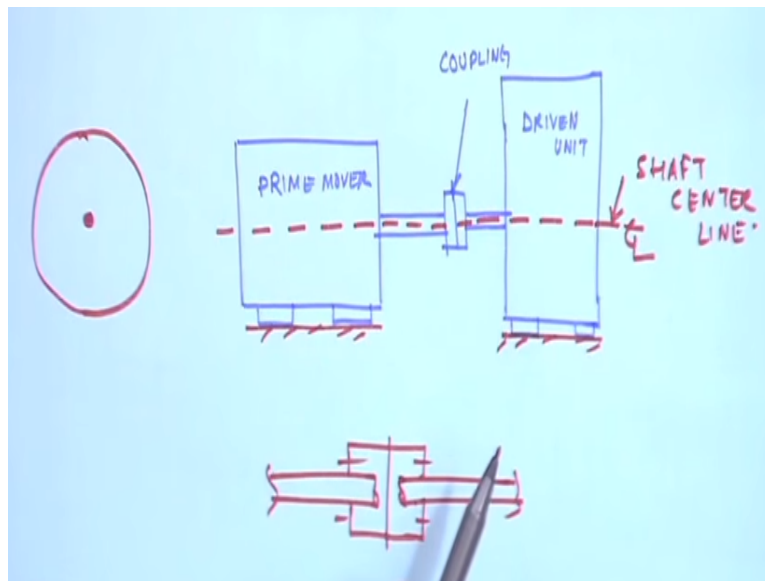
Machinery fault diagnosis and signal processing
Prof. A.R.Mohanty
Department of Civil Engineering
Indian Institute of Technology – Kharagpur

Module No # 05
Lecture No # 25
Misalignment Detection

This is the lecture on misalignment detection like we had the last class discussed about unbalance deduction and how balancing can be done to prevent unbalances but if you look at mechanical systems there are many types of mechanical faults which can happen one of course is a unbalance which we have discuss and the next most series is the occurrence of misalignment between two shafts.

And of course there are related defect to misalignment like eccentricity of rotor shaft being banned or bored and may be cocked rotor and then because of misalignment why things becomes loose what happen if the foundation has become loose and what we know as shaft food foundation. So how this occursion machine we are going to discuss in this class and then what is the methods to deduct them and then also tell about something how about reduce the occurrence of misalignment etc., in the system.

(Refer Slide Time: 01:32)

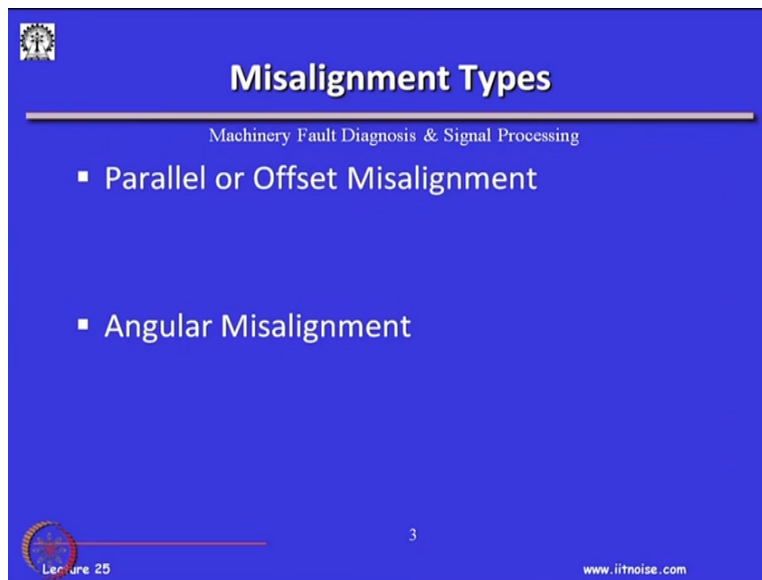


So I was to talk about misalignment essentially in any planned as you know basically we have two systems one is the prime over and other is the mechanical unit or the driven unit okay. This

is the prime mover and this is the driven unit and this is the coupling and most important point here is they are center line of the shaft here. So basically in this dashed red line is the center line between the prime mover and the driven unit and they have to be in a straight line horizontal to the ground.

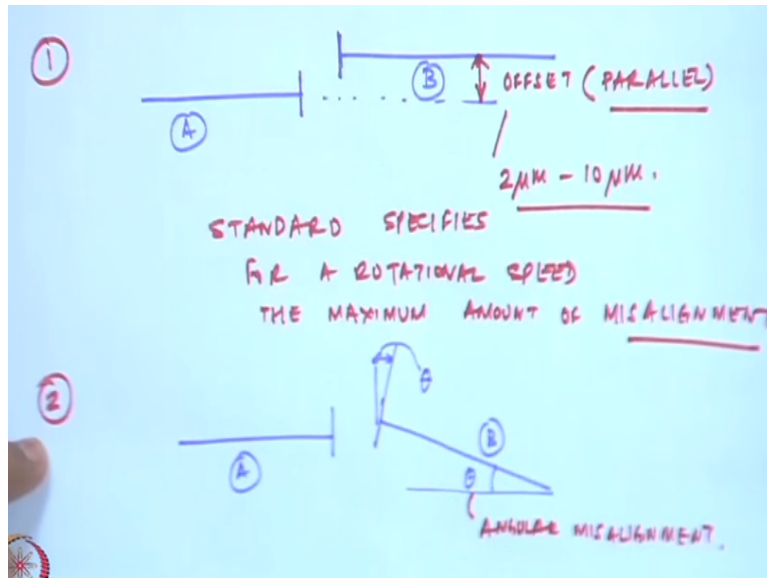
If you look in the vertical plane or if you look in the side view they should make projection okay. Now if this does not happen how do you maintain this coupling basically brings about the two shafts together basically this two shafts brought together by this coupling of I have exaggerated it and then there bolted the parts of the coupling or bolted and then this shafts are held together. So if this are not held together will have certain problems okay.

(Refer Slide Time: 03:52)



I will come to a disruption as to in the laboratory how we have to discuss this alignment but before that there are two series types of misalignment which occur in the shaft system.

(Refer Slide Time: 04:12)

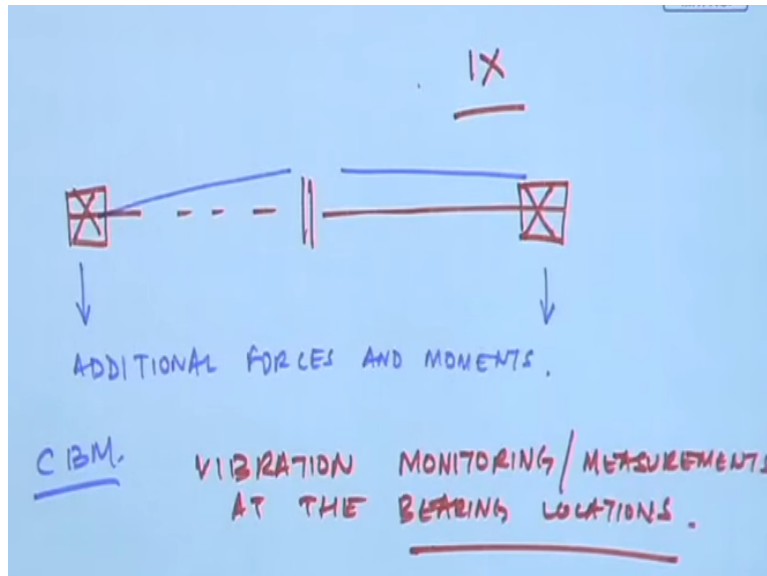


Suppose I say this is shaft A and shaft B by misalignment I mean in that shaft A and shaft B and this is the end of the coupling okay phase of the coupling. This is the one scenario wherein shaft is offset the access is offset and this is known as to be but they are parallel okay this amount of offset could be about you know 2 to 10 microns or more depends on the speed of the machine.

In fact there is a standard which specifies for a rotation speed the maximum amount of misalignment and this are available in handbooks. So if it is a 500 RPM this will happens if it is a 1500 RPM will be some other value and so on. So in one case we have what is known as the parallel or offset misalignment in another case we have the shafts at an angle to each other okay. Sin theta shaft A, Shaft B so this is what is known as the angler misalignment which is of offset of misalignment and the angler misalignment.

So what happens in such a cases this will give rise to certain forces in the bearings because as you know the shaft systems are supported n bearings.

(Refer Slide Time: 06:46)



This is my coupling they are supporting on bearings okay if they misaligned either angular or offset they gives to give rise to additional forces and moments at the bearings so we will have a failure or the bearing because of misalignments and then we notice a defect because in a the excessive vibration at the bearings but there is a excessive vibration in bearings you know people are mislead that they will say that the bearing as fault but the problem is the misalignment created a fault in the bearing.

Or in the previous case like we had seen unbalances which went undetected created a problem at the bearings by giving an excessive loads if letting loads to the bearings, bearings are going to fail. So to monitor a misalignment we need to look into to this certain special characteristic of misalignment which I will discuss later on the class but usually people in the industry are alarmed by having excessive vibration to the bearing.

Everywhere that is the problem we will face while doing a CBM because we do vibration monitoring or measurements at the bearing vacations invariably. Because people say that the bearing is at fault because bearing is vibrating excessively that is and then if this went unnoticed that the bearing would fail and then people will say the bearing failed my machine failed.

But actually the reasons could be something as reasons could be the misalignment which went unnoticed which was not corrected give rise to this kind of an excessive force in the bearing and then the bearing failed or unbalance which we went undetected. Give rise to excessive forces in

the bearings. So to diagnose or detect fault in misalignment we need some certain special vibration monitoring or signature analysis and then typical characteristic of misalignment or something which we will see in the vibration spectrum or spectra measure at the bearings locations.

In a invariably when the shaft is rotating at you will have a vibration at 1X okay but there will be some other components or other frequencies like 2X, 3X, 4X and so on when you see high levels of harmones or an excessive vibration in particular direction we may be sure that this is misalignment.

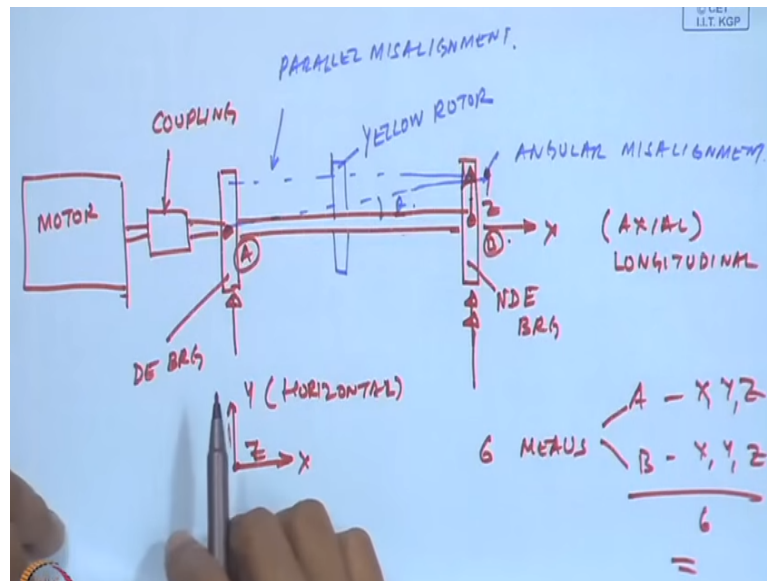
(Refer Slide Time: 10:09)



So let me tell you what we did to study the misalignment in the laboratory okay. This is the setup which we are using in the laboratory and then infact using this setup to demonstrate other defects like the eccentricity like the bend shaft the rubbing in the shaft the cocked rotor etc., basically here you will see here this the motor the prime mover in this case and this rotor on a shaft support at two bearing one bearing here and another bearing here which is my system and this black one is coupling okay.

So by introduce misalignment we have this dials here which could be turn around and this system could be loosened and so that we push other both of them away and create an offset misalignment or if I just push one of them by holding constant when I can create and angler misalignment basically to explain it to again.

(Refer Slide Time: 11:18)

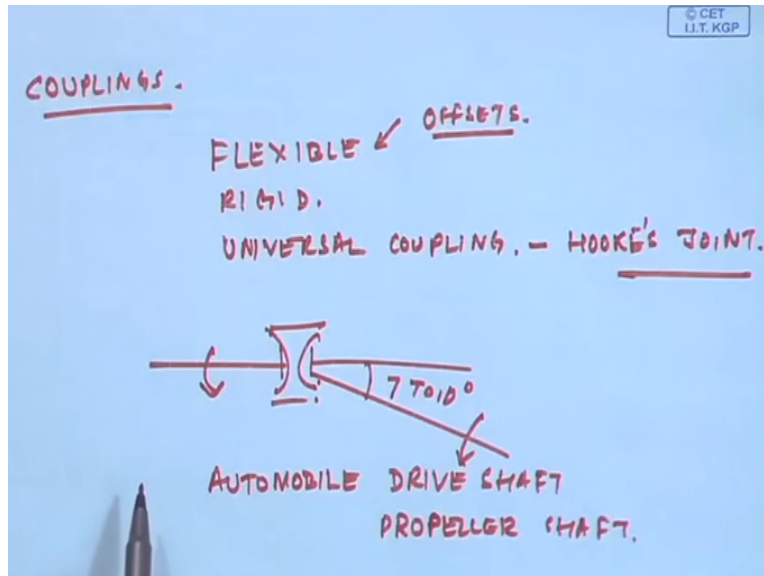


If you look at the top view the system this is the top view this is motor this is the coupling, this is the driven bearing this is the N Driven bearing and this it he yellow rotor. So in a in fact you see this to wide dials here okay this dials this one dial here and another dial here these two white dials they could be turned okay and then I can force this move it so that I create an angler misalignment and if I move or if I move both of them I can create a parallel misalignment okay.

Now to measure the vibrations I can measure at each of the bearing location in X, Y and Z directions. Similarly here in X, Y and Z direction okay so this kind of vibration measurements can be done and basically this is my actual direction along the longitudinal axis Y happens to be horizontal firstly I have moved it here this point but this is actually at location A and location B okay.

So basically I have 6 measurements in location A, X, Y, Z location B, X, Y, Z and I have to total 6. So this kind of vibration measurements can be done in any machine okay in this to notice that angler misalignment we are not moving point A. Now this misalignment amount of misalignment does depend on the flexibility of the coupling that is very very important.

(Refer Slide Time: 14:33)



Couplings play a major role in the prevention of misalignment you would have heard of this flexible coupling, Rigid coupling or the universal coupling okay. Basically in flexible coupling there are there are elements gap which will take small amount of offset can be accommodated okay. Rigid couplings are do not allow per say any offsets but then there are universal coupling wherein these angles could be as high as you know 7 to 10 degrees okay.

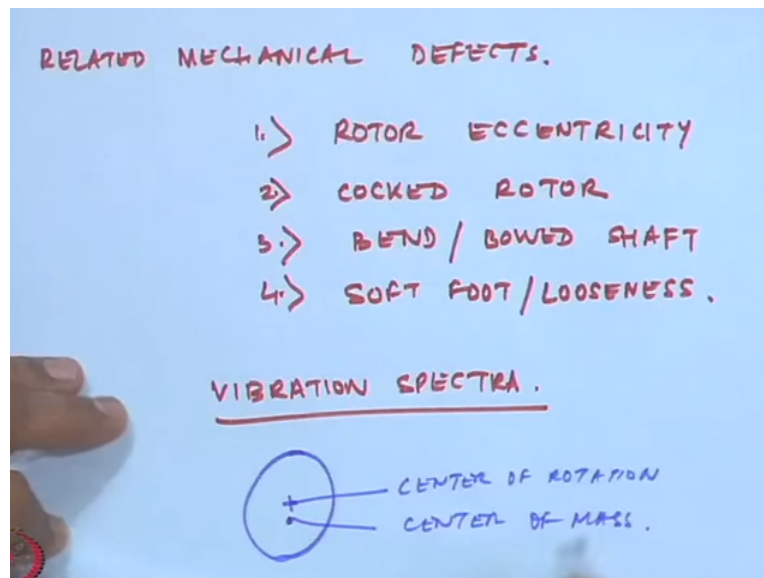
A good example of universal coupling what we known as hook joints is in the automobile drive shaft as sometime it is known as the propeller shaft. They can take good amount of angler misalignment okay so the couplings play major role to accommodate such parallel or offset or angler misalignment between the driver and the driven unit okay. But despite having these couplings we will still see lot of forces and moments coming on the bearing locations.

I mean why at all misalignment is a series issue in machinery because for the fact that misalignment will load the system. So when I give a part to a machine to run it am unnecessary wasting this energy to rotate a misalign shaft for rotating the misalignment shaft and the perfectly normal and misalign shaft I will require power to rotate the normal or perfectly okay shaft then compared to a misalignment shaft.

So I do not want to waste power and the other effect is if misalignment goes unnoticed for a prolonger time the forces and the moment occurring and ports are going to increase the bearings

are eventually going to fail and last clearance may occur in bearing and then things will loose and so on.

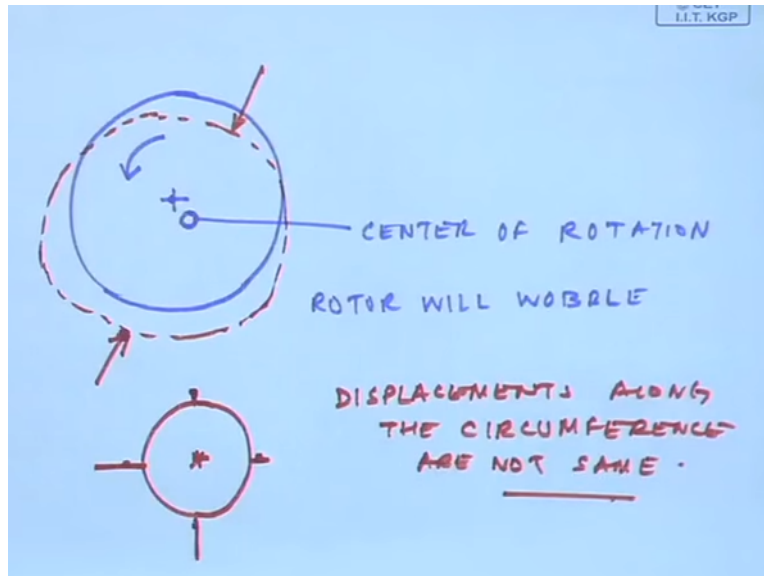
(Refer Slide Time: 17:38)



So once we are talking about misalignment some of the related issues with the other mechanical defect R related mechanical defects one is rotor eccentricity other is cocked rotor, bend or bowed shaft, soft foot or looseness. We are going to discuss about soft foot and looseness in few classes down the road but the reason I wanted to tell you is you know once we look into the vibration spectra this signature R they defects like rotor eccentricity cocked rotor bend bowed shaft or almost very similar at times.

So we should not be mislead as to a misalignment as occurred okay though there are misalignment can be deducted and then separated out but particularly at high speed the behavior is almost similar and then we should or at least know what would we mean by rotor eccentricity. For example if you look at the rotor by rotor eccentricity mean the rotor center of mass is not at its center or rotation.

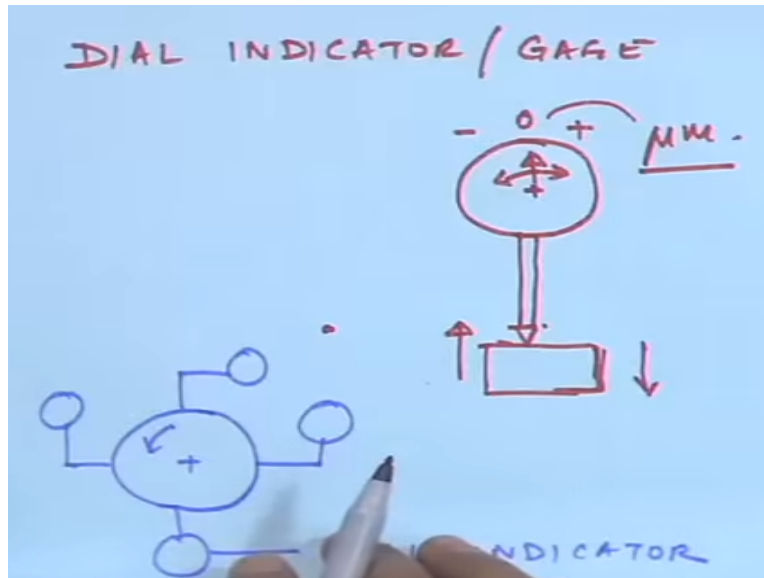
(Refer Slide Time: 20:02)



The another way to look at it is maybe I should draw I have a large disc okay this is my center of mass but I am rotating the whole as made here and this is my center of rotation. So you can understand the rotor is going to wobble and make lips like a thing at some point if I okay this some point I will have large forces a large displacement and less displacement okay.

If this was a perfectly balanced an eccentric rotor the displacement at location like they are called you know 12 o clock position, 3 O clock position, 6 O clock or 9 O clock position will be same okay but if they are eccentric or the center of rotation is not at this mass center there will be warbling and level will be less compared to other and here may be another level this is more compared to this okay.

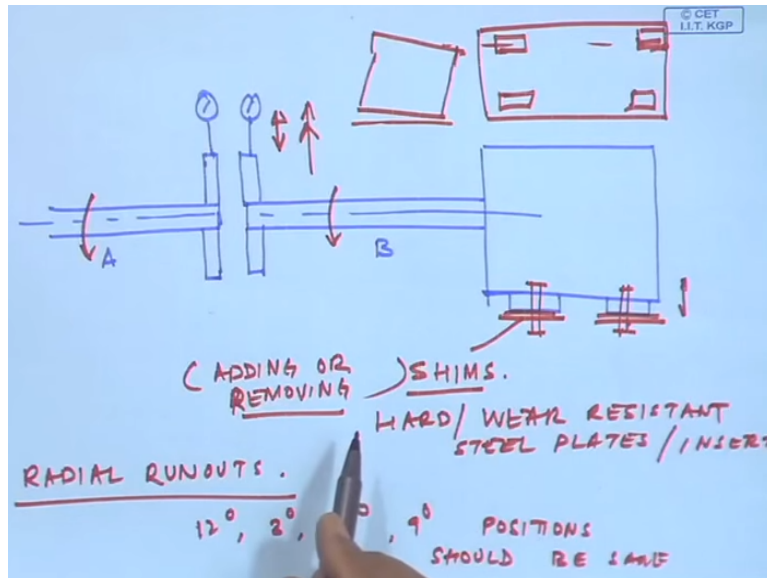
(Refer Slide Time: 22:24)



So the displacements along the circumference are not same okay and this is because of this eccentricity and the rotor okay. It is very easy to measure okay and there is an instrument all of you would have been familiar must have it is a very common instrument in the lab that is a Dial indicator or a gauge basically it is a spring rotator style off okay spring inside it and then we will have a indicator which is either it could be 0 here plus in this direction here minus in this direction okay.

And in this styles contacted contacting on a surface this surface is going to have a motion this way so it is showing and this direction if it going to have more position in this direction so the swing other direction okay. And this readouts are usually in micron so a dial indicator gauge can be put on a rotor which is rotating at this locations this is basically the dial indicator. So by knowing the measurements in the dial indicators at this full locations on the circumferences one can decide the amount of offset has occurred.

(Refer Slide Time: 24:00)



And usually these measurements are taken on the flange which is there monitored in the shaft if I have a shaft because the shafts only meet and the coupling okay. If I was to align this two shafts A and B whatever motion this going to happen this also going to have the same motion. So I can see the dial gage reading here I can read the dial gage reading here I can see the dial gage reading on this sources and then as I rotate it they should all cut the same reading okay if not we will have to play around the system and that is how I will tell you for example.

And this system we see that the level in this as increased in particular direction okay so in fact in all of this foundation there are very thick steel plates which are known as SHIMS. SHIMS are very hard wear resistance steel plates or inserts which are induced right at the time of installation and then we put the foundation bolts similarly by removing adding or removing shims this can be taken care.

And in this system we had the provision of putting shims at this locations so look here we can remove this is the foundation of the bearing and then shims could be introduced okay and then we can align them as to they are in perfect displacements okay. So this kind of shimming is done right at the foundation by measuring the radial run outs and this distances that we measure are going to run as the radial run outs.

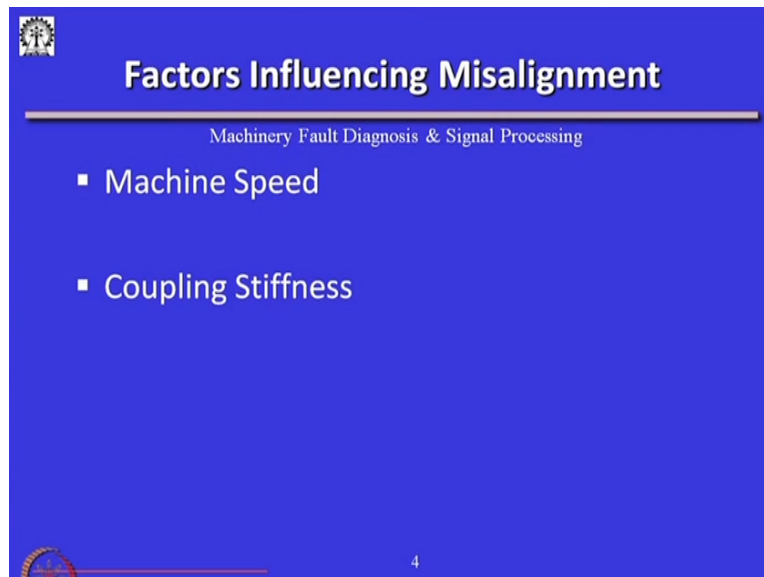
The radial run outs in the 12 O clock position, 3 O clock, 6 O clock, 9 O clock positions should be same. So they are concentrate okay and other relatively between shaft A and shaft B they

should be also same and if they are not we have to play around with the shims to adjust the level okay maybe this is only in the horizontal in the vertical plane you have to move something in the horizontal plane as well okay.

We have in the top view I have shims here shims here I have shims here I have shims here if I add or remove in one plane I can reduce the angler we can make an understand if there are this is at a locations this location is elevated compared to this this will be having a rotation like this and this plane will be like this okay and this gives rise to what is known as the angler misalignment.

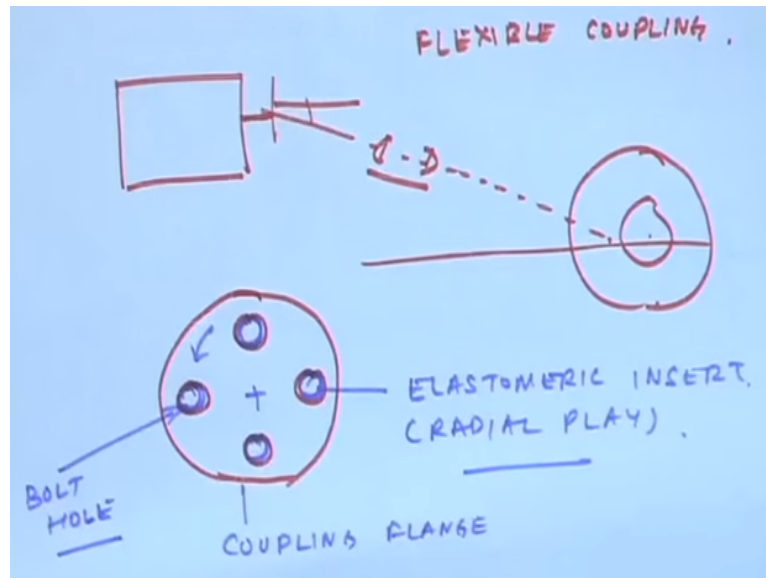
So by adding and removing shims I can take care of the misalignment by either reducing the radial run outs or in both the angler sense or in the normal vertical or horizontal sense.

(Refer Slide Time: 28:33)



So what are the factors which affect the misalignment of course one is the machine speed. Because the machine speed is high the forces will be high and the misalignment could be that coupling stiffness plays very important role in the misalignment as you have seen we allow a flexible coupling or a hooks coupling to accommodate certain misalignment required by our functionality example in our automobile shaft.

(Refer Slide Time: 29:06)



The reason we give a misalignment hooks joined is because of the fact that this is my wheel and engine is here. So my output shaft is are location is driving shaft so to account for this kind of angler division of the we have to give rise to a coupling which can take care off. And that is what done by actually the hooks joint or universal joint so misalignments are required and sometimes it has they have to be suppose reduced in a rigid machine and that is where the coupling stiffness placed into accounts so that is why we have flexible coupling.

In a flexible coupling if you look and the bolt holes I have just four bolt holes in every bolt there will be provision to have an elastomeric insert okay which can take little bit of radial play and reduce the amount of misalignment. This are there kept in the machine to take care off.

(Refer Slide Time: 31:02)



Effects of Misalignment

Machinery Fault Diagnosis & Signal Processing

- Additional forces and moments at the bearing locations
- Additional power consumption
- Fatigue loading of the system
- Pre-mature failure of the system and components



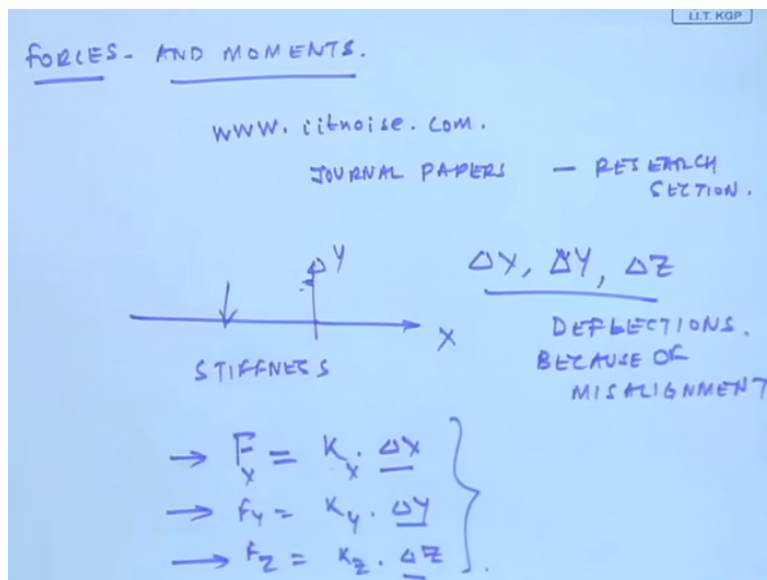
Lecture 25

5

www.iitnoise.com

Now what are the effects of misalignment so additional forces and moments of the bearing locations okay.

(Refer Slide Time: 31:12)

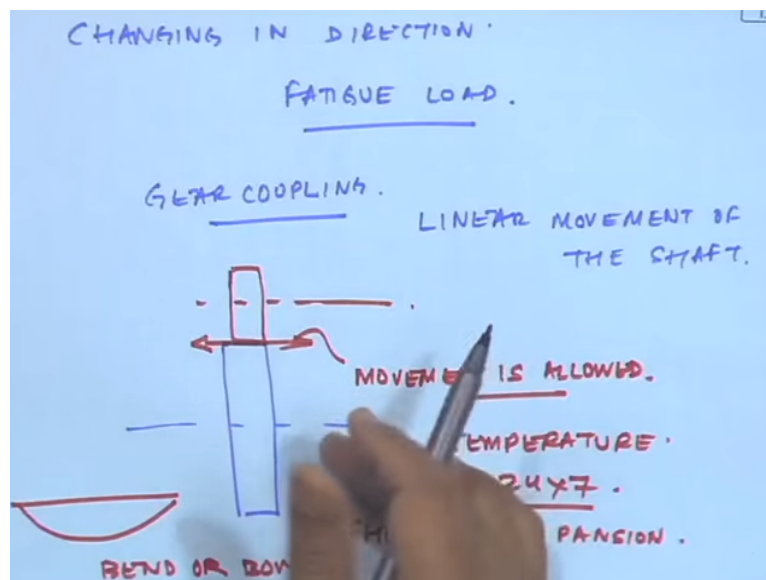


And this forces can be calculated okay forces and moments and this class on the preliminary condition based monitoring I am not going to the details on this forces and moments are derived but out of the research work this are there and the published paper and if we can visit this website of ours IIT noise.com wherein you can refer to the journal papers in the research section and then see the papers on the misalignment basically this misalignment in systems which are caring normal shaft as to crack shaft etc.,

How these forces and moments are computed? And why because if we look into X axis and Y axis there will be deflections of δX δY and if you are looking at three dimension data is that so these deflections because of misalignments and the system already has stiffness so as $F = K \times \delta X$ F_{XY} is different K_y . So these δX δY δZ are because of misalignment the system as stiffness K_X , K_Y , K_Z .

So we are going to get additional forces affects F_Y , F_Z and of course depending on the length we have a moment and this couple. So additional forces and moments do happen at the bearing locations because of misalignment. Obviously if these additional forces are coming they will oppose the system. So once they oppose your load you are going to have additional spark on the machine and the system and then because of these forces are changing in directions at every rotation.

(Refer Slide Time: 34:11)



They will induce fatigue load so the problem gets bounded so you see small δX which has gone unnoticed will fatigue our systems are going to fail much earlier than they were designed or designed for. So to avoid such fatigue failure because of misalignment we have to ensure that these δX , δY , δZ are kept to a minimum.

(Refer Slide Time: 34:51)



How can effects of Minor Alignment be Mitigated

Machinery Fault Diagnosis & Signal Processing

- Flexible Couplings
- Universal Coupling (Hooke's joint)
- Gear Coupling
- Alignment (Checking by Measurements)
 - Leveling by introduction of Shims



Lecture 25

www.iitnoise.com

So how can this minor alignment be mitigated of course you know we just discussed about flexible couplings and then we have the universal coupling and the industry we have lot of high power transmitted or converted we have what is known as the gear coupling. Gear coupling allows for certain angle in linear moment of the shaft for example if we think of the one gear one thing like this okay and another here.

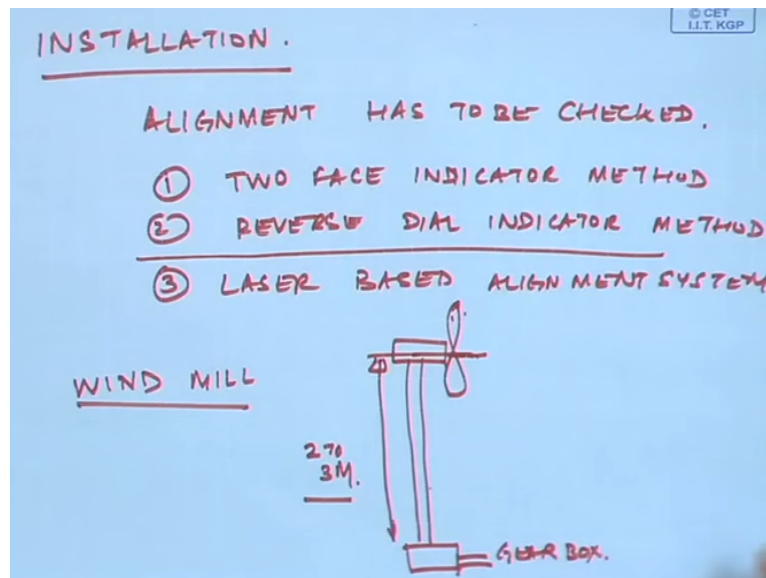
So they want to okay so there will be a slight amount of movement is allowed this is essential because of temperature particularly in industries you know we have the systems rotating almost round the clock 24 by 7 okay. And of course there is an amount of force conviction are of there are blowers in the in the motors okay which cool the bearings sometimes we have the large gear boxes.

Gear boxes the temperatures becomes very hot so there will be small amount of thermal expansion. Now things we are held rigidly both the driven unit and driver unit and held rigidly and then the shafts underwent thermal expansion and if there is no space or no allowance for this expansion to take of this linear movement they are going to bend because of this shaft are going to bend or bow.

So allow for such thermal expansions usually gear couplings are used which will by the once the thermal expansion happens they will expand and then they will slide this could be fluid will know very few microns but not the left they are going to take care of this. Now even before this

is done from this happens later on we are running the systems but once what happens when you are installing in the system.

(Refer Slide Time: 37:57)

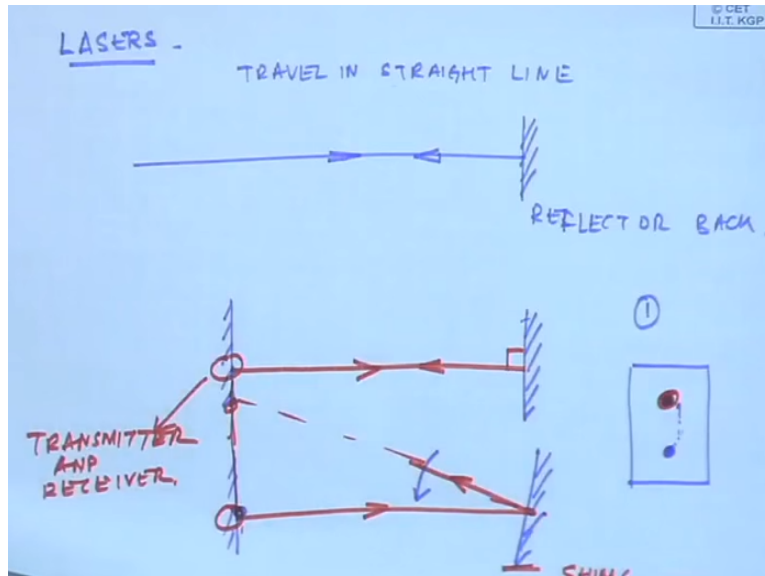


During installation alignment has to be checked and this is very important and the traditional methods are using dial indicators what is known as the two face indicator method another is the reverse dial indicator method. Of course this where preferred method in the industry wherein you measure the radial run outs in the four different locations that is 12 O clock, 3 O clock and 9 O clock locations.

And then try to estimate the average radial run out and try to use either in the vertical plane or in the horizontal plane or across the foundation access as the distress. And then another method is distress dial indicator method with very popular but off late people are using what is the known as the laser based alignment system. This is for the fact that because of the previous first two examples first two methods two phase or reverse dial indicator our meetings and the two shafts are very close to each other.

So that we can take dial engage readings through a common shaft but imagine in a case of may be a windmill okay. Where the longs shaft and then we have the gear box here okay and then the alignment here and then we have the fan here and this is a coupling here and this this could be about 2 to 3 meters. How do you align such a system?

(Refer Slide Time: 40:46)

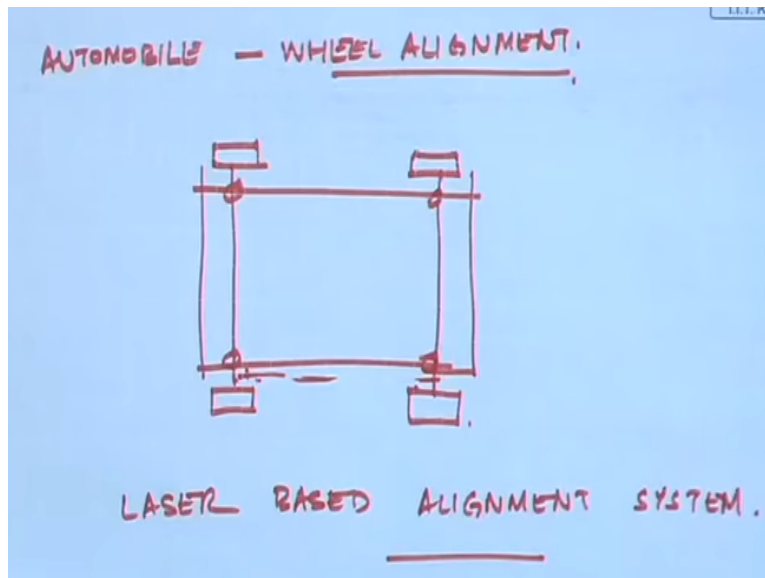


Okay and that is where lasers are helpful because lasers can travel straight line in straight line and we have put a reflector and they want to reflect back okay. So imagine if I have a two systems one this was one flange and another flange so one scenario second scenario is and this is okay and first case if I shoot a laser beam okay it is normal incident so it is going to reflect back and this case shoot a laser beam it is not normal.

So this is not a normal we are going to come out somewhere like this okay so if I have this is my laser transmitter is here. Transmitter and receiver okay I should see a single dot its going in and coming in and another way if I put a mirror here okay at some point for exaggerated it I will be getting two points so I can play around with the shims at this locations such I align it and then bring it back so that they all well learn to one point so in of the mirror plane one is this dot and another is this dot.

So I have to play around so that this both the dots come together both the dots together so the laser along are very helpful in this regards.

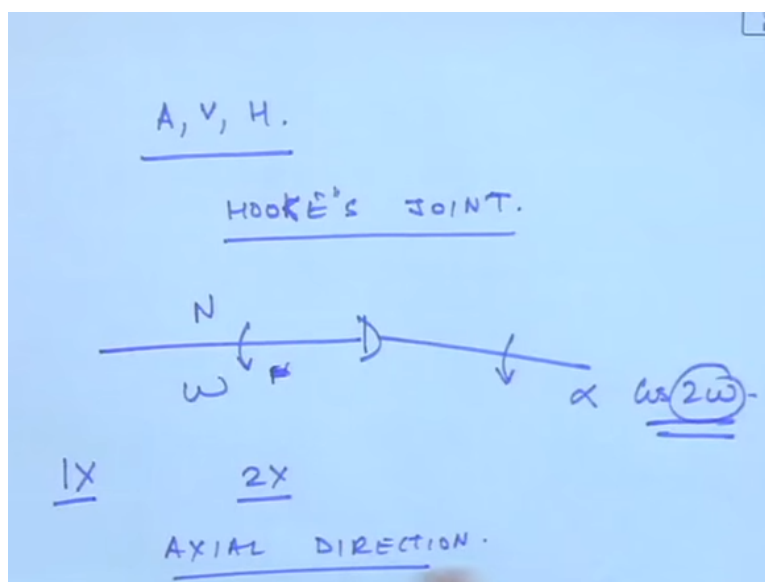
(Refer Slide Time: 43:27)



And particularly we would have seen that when you go to an automobile garage okay. The four wheels of the shafts sorry of the vehicles have to be aligned okay basically they use this laser alignment systems they have a reflector they have a mirror and then they will make sure and then here they can change the camera angle and there are adjustments bolts wherein they can adjust the chamber first two angles sure that the wheels are aligned.

So the same laser technique laser based alignment system is very popular to do machinery alignments okay. Now I will come to what is the best way to find out whether a misalignment is occurred in a system through vibration monitoring okay.

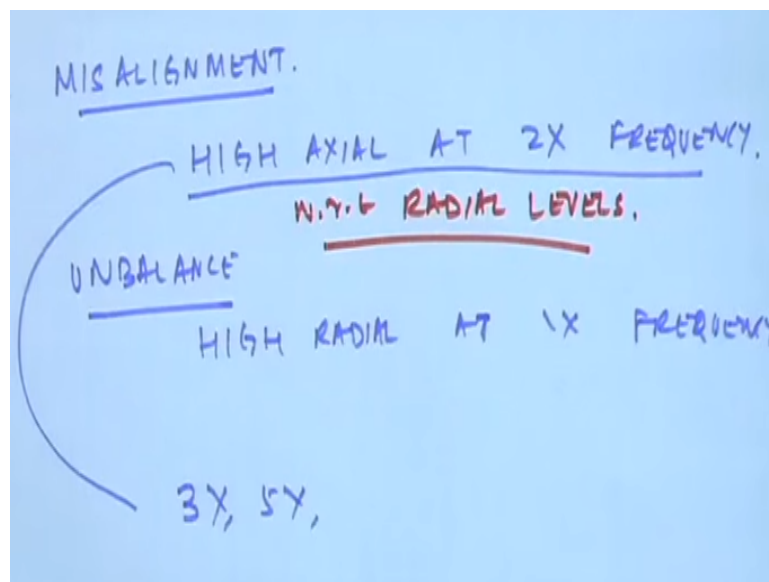
(Refer Slide Time: 44:57)



In this what we do as I was telling we will measure at any location the axial vertical and horizontal vibration locations and if you see go back to the equations of flexible coupling or the hooke's coupling okay. If I have a input shaft N and if I put a hooke joint the output shaft is actually a function of this is rotating at ω this output this is a speed the output shaft speed.

So this proportional to two ω okay so this two ω comes so if I am rotating at 1X because misalignment I will have a strong vibration at its 2X in the axial direction. So this is the most important diagnostic indicator in a vibration spectrum.

(Refer Slide Time: 46:08)



Whenever we have a misalignment as i post to the unbalance it was strongly radial here it is high axial at 2X frequency. If you recall unbalance was high radial at 1X frequency but let me just caution you very theoretical in the sense high axial at 2X vibrations when we go to the lab we see 3X, 5X sometimes we see event high radials okay when there is a intercity with misalignment.

So one as to be careful though if you go to any hands books on condition monitoring or any trade guidelines they usually give a machine rate trouble shooting chart at which says you know we have to you now if it is high axial and in 2X frequencies it is misalignment its well and good and one has to be careful then that is not necessary always true okay.

(Refer Slide Time: 47:38)



Misalignment Detection by Vibration Measurements

Machinery Fault Diagnosis & Signal Processing

- Generally a high axial level of vibration compared to radial levels
- Usually higher vibration at 2X frequency (Exception sometimes parallel misalignment)



Lecture 25

8

www.iitnoise.com

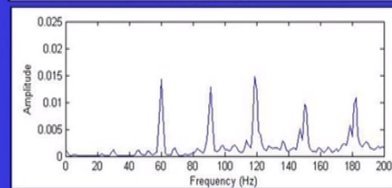
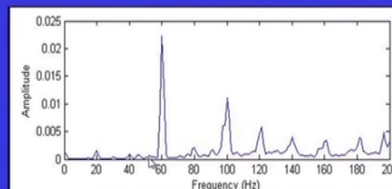
So misalignment detection by vibration measurements generally a high axial level of vibration compare to radial levels okay compared to radial levels that is the good way to look at it in comparisons with respect to radial levels but sometimes exceptions are there at a parallel misalignments and so on.

(Refer Slide Time: 48:14)



Axial Vibration for Misaligned case

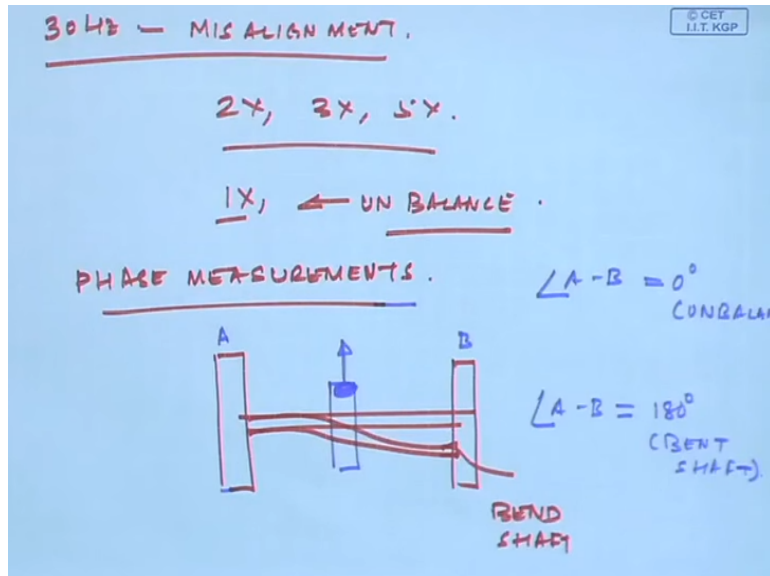
Machinery Fault Diagnosis & Signal Processing



Lecture 25

www.iitnoise.com

(Refer Slide Time: 48:27)



And now what I am going to show you is this is the case where in we had the vibrating machinery rotating at 30 hertz okay and then we had a different amounts of misalignments of course this is all measured as axial directions. And we will see usually 2X sometime close to this 3X and 5X is occurring okay. So what I mean to say is always it is now right to say that always only 2X will come.

But this is characteristics different in the case of unbalance in unbalance we will very rarely see things beyond 1X okay. Of course another thing is we have to take care of phase measurements phase measurements do help us for example I have talked about the bend shaft because in a bearings I have a shaft which has a rotor and if there is a unbalance mass I will see the vibration at bearing A and B or in phase.

So if $\angle A-B =$ almost 0 degree in case of unbalance okay if the shaft was bend in this diagram I am exaggerating this bend shaft you will see we have bend shaft this will close to about 180 degree. So these are characteristics of the phase measurements or the characteristics of the vibration spectra when an case of misalignment as occurred okay. So to summarize in this class on misalignment deduction we studied about how misalignment occurs and why sometime we have to purposefully give misalignment.

So that this thermal expansions between systems can take places and that is why the industries we have lot of coupling in the automobiles we have the hooke's joint because of the large angler

deviations between the engine live shaft and the grand shaft and the propeller shaft or the vehicle. Sometimes we allow misalignment because of misalignment defects through few microns and that can be accommodated by flexible couplings okay but despite or best intentions or giving gear coupling hooke's joint, flexible coupling.

The misalignment as you have seen we will give rise to excessive forces or moments and these forces and moments are time varying and their periodic and reduce fatigue loads at the bearing. So bearings are eventually going to get subjected to excessive forces because of misalignment and again because of misalignment because these forces have come we are unnecessarily using extra energy to overcome these resisting forces.

So the park and then also increases because of misalignment in an effect this misalignment as determined effect into the health of the machine which has to be avoided. To deduct misalignment basically at slow speed we can turn around the systems the shafts at the phases and measure the radial run outs there are run outs should be same both the systems that is the driven the driving unit if they are not there are run outs we can play around by inserting shims at the foundation locations.

So that and then we can raise or lower the foundations as to requirement amount of microns measured in the radial run outs and once we have done that we misalign the system. But for the systems unknown to us misalignment does occur it occurs in machine and then to identify misalignment is to look into the 2X axial vibrations in the vibration spectrum measure at the bearings.

Typically to distinguish themselves from unbalance and unbalance we have high radial at the 1X direction of course when there is overall balance we have seen there could be also the axial components but usually in the case of misalignment into the 2X axial direction of vibration which is very high okay. Thank you