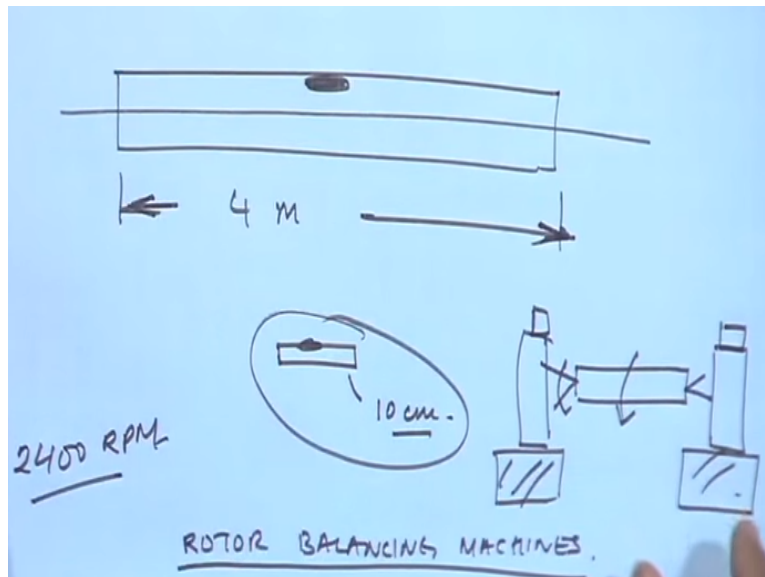


Machinery fault diagnosis and signal processing
Prof. A.R.Mohanty
Department of Civil Engineering
Indian Institute of Technology – Kharagpur

Module No # 05
Lecture No # 24
Field Balancing

In this lecture we are going to talk about field balancing well as you saw in the last class that balancing is necessary to remove this amount of unbalance which you have in the shaft because the unbalance is going to leave to the fatigue failure of the rotating system and so on but these rotor shafts can be of many different sizes and lengths or weights and lengths.

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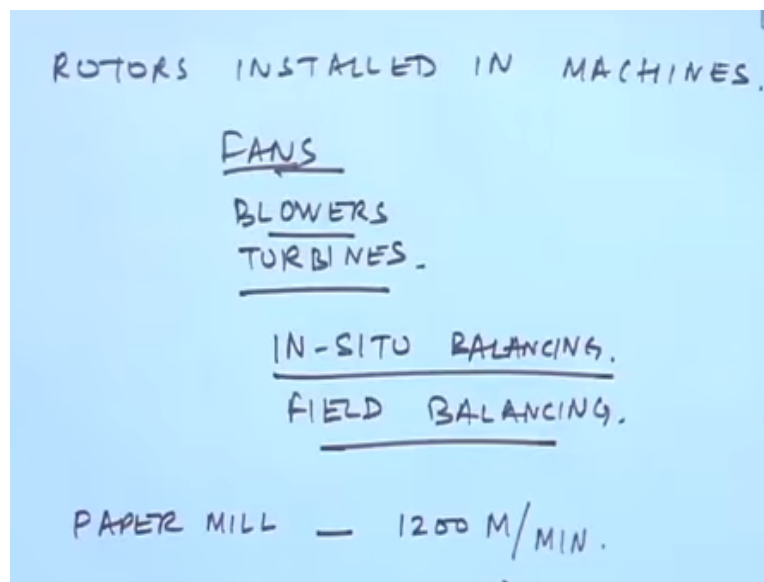
I can have a very large rotor okay this could be as long as 4 meters okay or as small may be may be 10 centimeter okay and as you can imagine if we have a large rotor of 4 meter length they cannot be treated as rigid they will flexible they will be critical speeds but still again in class also we are going to discuss about the first critical speed frequencies operational frequencies below the first critical speeds okay.

But to balance the masses we can always bring in a shaft or a short shaft or a small shaft small rotor into a machine wherein we have to spindles okay and one spindle is rotating on the supporting wherein I put a rotor and then have a and then balance it. So these are the rotor

balancing machines such rotor balancing machines are available in the market where table top rotor machine or balancing machine taking how the size of the studio.

And wherein you bring in a rotor supported between two spindles one spindles allow to rotate it and then there are (()) (02:45) which will measure the vibrations and with a vector calculation find out the vector of unbalance vector and then find out the correction mass. But in this class we are not going to talk about such rotor balancing machine. This machine are available in the market wherein we can balance to as high as 2400 RPM and so on.

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But am talking about the cases wherein in the industry we have a rotors installed in machines like in fans, blowers okay turbines obviously for large fans, blowers, turbines I cannot bring to lab or into mount it into such balancing machines. So in this cases we have to balance at this site or IN-SITU balancing as to be done what is known as field balancing.

So in this class we are talk about how such field balancing of rotors which are already present in fans, blowers, turbines which are installed in a rigid foundation in a plant how do I balance them okay.

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Just to give an example this is a case of paper mill you can see this is the this roll here this roll rotates at a felt which is going this roll and there is a roll on the top roll on the side and then many more rolls as I was telling you in a paper mill or a paper plant there are about 100 to 200 similar rolls of length of 4 meters and particularly in a paper mill the linear speed of the papers coming out.

And then this is the felt on which the pulp is coming out pulp will be spread and then on a pulp as I was telling you full of water and there will be lots of press so its downstream where in finally eventually we will have papers and then which are dried extreme dried on the roller because inside the rollers we will have a heated steam going in and they will drive and in paper mills typical speed linear speed is about 1200 meters per minute.

That means in one minute we are having 1200 meters of paper coming out okay and if there is an amount of unbalance on the shaft many things can happen I need has happen in few paper mills have been because of an unbalance this bearings are going to have a fitting failure once this bearings fail this roll is going to fall, fail and fall this falling rolls may damage few other rolls and the because this is a very continuous serial process.

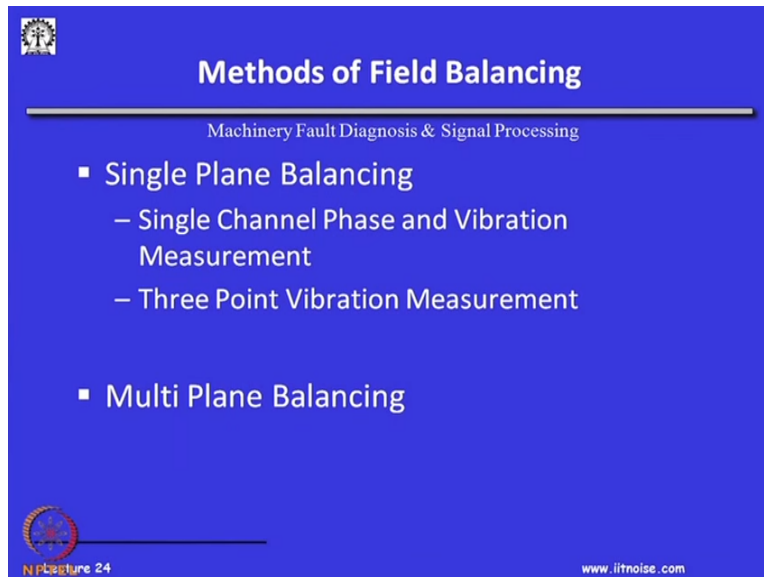
If one role breaks their entire production has come to a standstill unless you repair it so in fact that is the reason why all this bearings in paper mill are very critical and they are monitored real time round the clock by having preinstalled sensors on this bearings and where in around the

clock they monitor the variation levels coming on the bearing okay. By which they can also deduct what is the possible causing of the bearings or faults is it because of unbalance is it because of something got deposited because of some sludge getting the seals here.

We are not proper and then sludge got into the bearings and the heating was so high that the lubricated bearings and the grease or the lubricants burnt and the black carbon residue hard particle and that particle went into the part and damage the bearing. So as I was telling this is the dominos effect one affects the other okay. So but imagine such a role cannot be brought to the shop to the balanced.

And many cases such rolls when they are initially unnaturally balance at the long or manufacturing machine as well wherein a we can we have the process of rotating it and time of rotating supporting it on bearing. But in a plant where already such rolls are rotating and existing how do you balance them is the problem we have in hand.

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The slide is titled "Methods of Field Balancing" and is part of a presentation on "Machinery Fault Diagnosis & Signal Processing". It lists two main methods: "Single Plane Balancing" and "Multi Plane Balancing". Under "Single Plane Balancing", there are two sub-points: "Single Channel Phase and Vibration Measurement" and "Three Point Vibration Measurement". The slide also features a small logo in the top left corner, a circular diagram in the bottom left corner, and the text "NPTEL Lecture 24" and "www.litnoise.com" in the bottom left and right corners respectively.

Methods of Field Balancing

Machinery Fault Diagnosis & Signal Processing

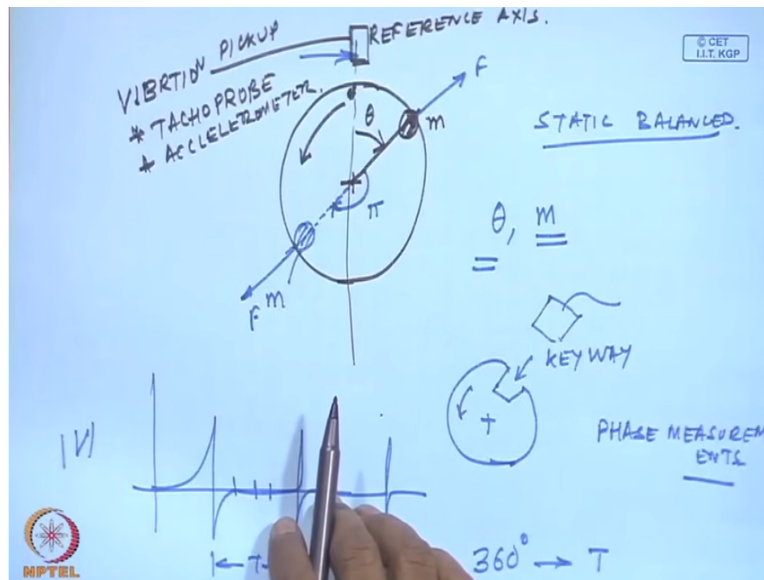
- Single Plane Balancing
 - Single Channel Phase and Vibration Measurement
 - Three Point Vibration Measurement
- Multi Plane Balancing

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So again we will see what are the methods of field balancing one is as I was telling as in case of the static balancing. We will do the single plane balancing wherein we measure the amount of unbalance and put a balancing mass or a compensating mass 180 degree from the unbalance mass and then the balance it.

So that is either it through a single channel phase and vibration measurement or through a three point version measurement is what we have going to discuss in this class and am not going to talk about multiple in balancing in this class but there are many commercial software which are available wherein all need to do is measure the bearing vibrations at the both the outward in ward and outward bearings or both the bearings.

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And then the software once you give the amount of unbalance of direction locations the software is going to tell you and which correction plane what kind of unbalance is to be put at what degrees because in methods of balancing the very important in balancing is from a reference axis okay this very important what is this theta and what is this? Amount of unbalance once I know the amount of unbalance and location my job is done then next what I have to do is at another location this is Pie I will put correction mass.

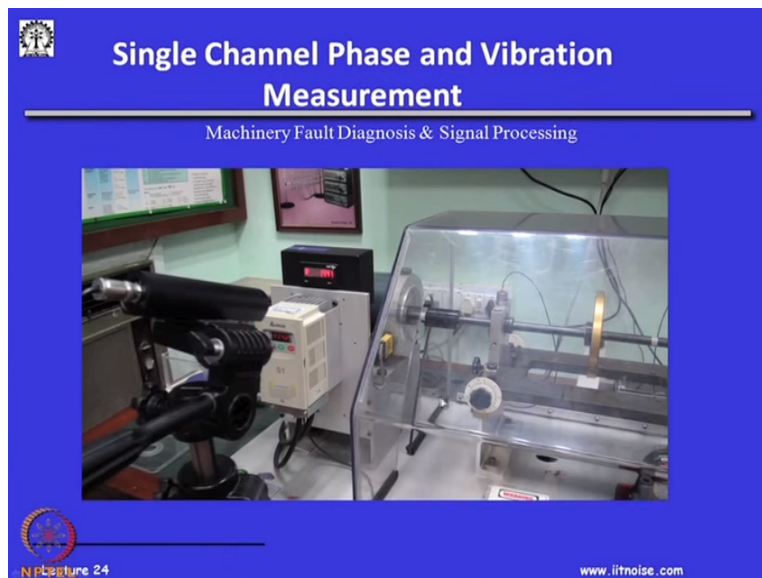
And then the forces will balance and I would have done static balancing ratio but the problem is so I have two unknown one is theta and other is M and then I have to define my reference axis. Because when a shaft is rotating usually people take in a shaft we have the use the key and as I was telling you when you talk about the case of velocity transducer whenever I put a transducer along the key way and this shaft rotates for every rotation am going to get a pulse.

And this is the time period and if I know the speed I know this corresponds to 360 degrees at the time period one time period. So I can define at what time period at the refer axis. So this is how

phase measurements are done which respects to the with resource to the variation which could be a tacho probe which could be an accelerometer as well because wherever the unbalance mass comes below this am going to have a high evaluation.

Say that again if I have unbalance mass coming here I am going to have a high level of vibration okay this means that my unbalance is at this location okay. How much away from this the unbalance we deduct it and I will show you how this is done.

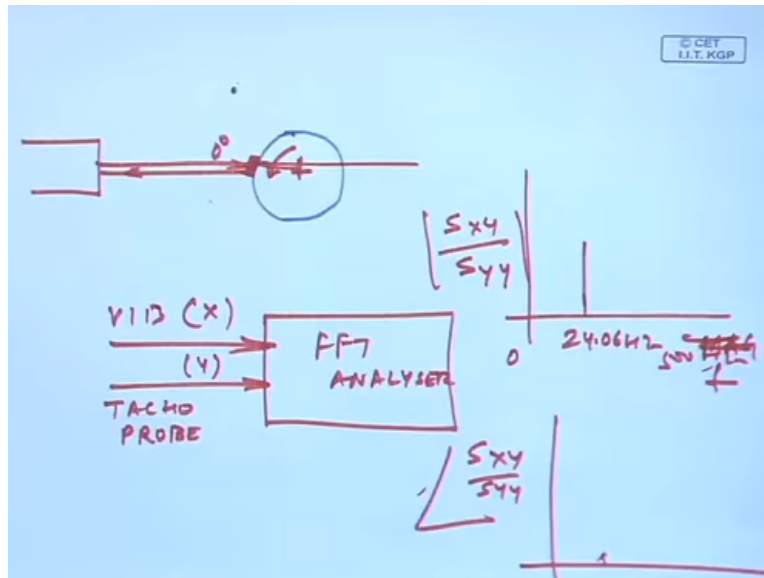
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So first we will discuss about the single channel phase and vibration measurement. I will just show you what I have here is a this is a motor you can see here this is a motor and this is one this is a coupling here black one is the coupling and then I have a bearing one of the bearing you cannot see the other bearings here and this is a shaft on which we have a rotor okay this to being with perfective balanced.

We created an unbalance putting an bolt on to the rotor so we created an artificial unbalance and you will see here I have measured I have put one accelerometer in the vertical direction to measure the acceleration of the vibration and this is the tacho probe okay which will shoot on to the shaft here which has a reflecting tape.

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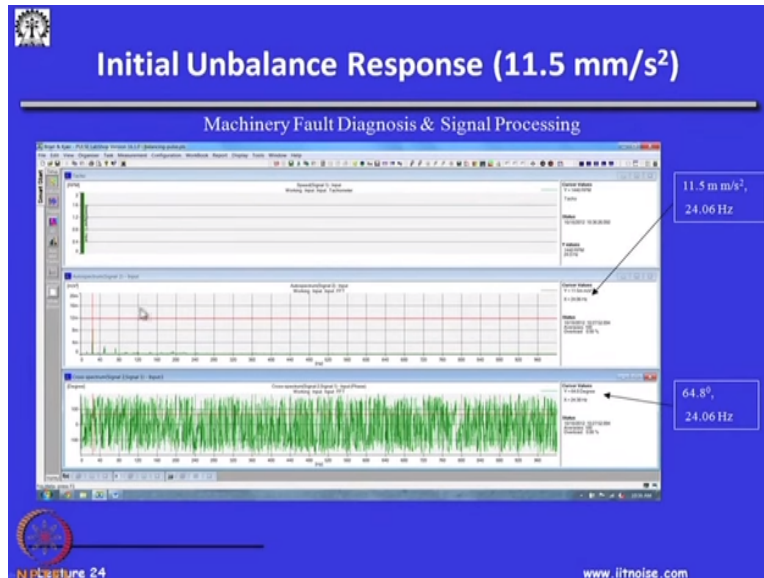


And then we will measure the RPM or know when then because when tacho probe I basically on the shaft I have a reflective tape thin reflective tape. So this tacho probe shoot the light beam and then its gets reflected when the shaft is rotating. Okay so that will give the this is 0 degrees as start from 0 degrees in this location okay and then when it comes to next cycle an unauthorized degree has occurred so it is rotating.

And at the same distance I have in fact this shaft yeah you can see here a marker here okay this is the reflective tape that means this is 0 degree okay. And a right a 0 degrees I have put my unbalance here mass this happens to be the case when I could have put it in any way but there is always a related phase between this RPM detector and the accelerometer that is fixed okay.

So whenever I measure this the phase is always of this is respect to this okay and that is fixed so initially I give an unbalance at 0 degree I put some mass of unbalance and made the system unbalance and then measure the vibration level okay.

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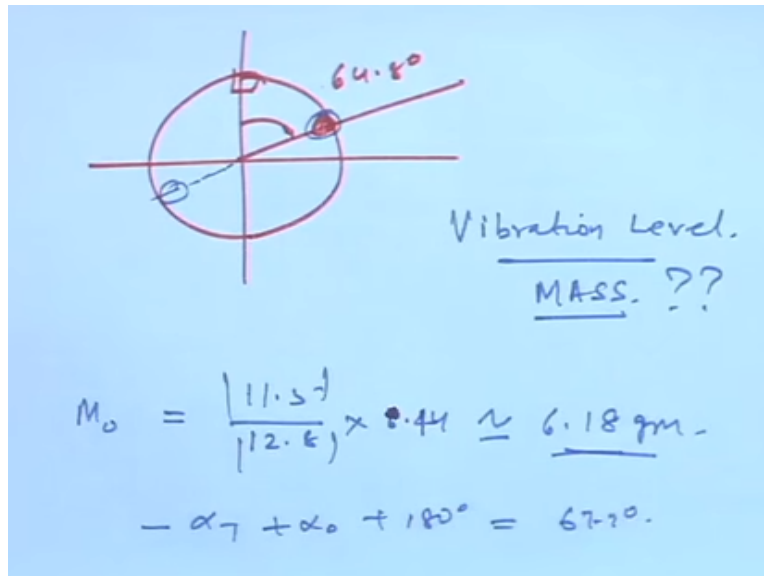


And what we did is here in initial unbalance response okay this is the vibration has recorded by the accelerometer mounted in the vertical direction and this was wrong at 1440 RPM and then we got a 24.06 hertz and the initial version level is 11.5 millimeter per seconds square okay now with the FFT analyzer. I am giving 1 as the vibration and one as the Tacho probe so channel X, Channel Y what I have done here is basically plotted as SXY okay.

I am try see the response of the vibration see the respective couple of so this will have a complex quantity this will have a magnitude frequency this is magnitude and also I will have the phase of okay and this phase you will see all those lines up to measure from 0 to 500 hertz but I am operating at 24.06 hertz okay.

And if you look here there is a very strong component coming at 1 hertz in a frequency the red cursor here this is a vertical cursor and the peak is somewhere here at 24.06 I have 11.5 millimeter per second square is the level of vibration measured by the accelerometer okay and that the same frequency am measuring the phase angle. Phase between the vibration and the RPM indicator is 64.8 degree so this is my initial phase.

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So this gives me let some clue as to what or how or where the unbalance is located with the reference to the measured acceleration okay. So okay now this is initially now I have to find out what is this amount of unbalance and then how much mass I need to give. So this gives the vibration level but it does not tell me what is the mass and that is what I need to do.

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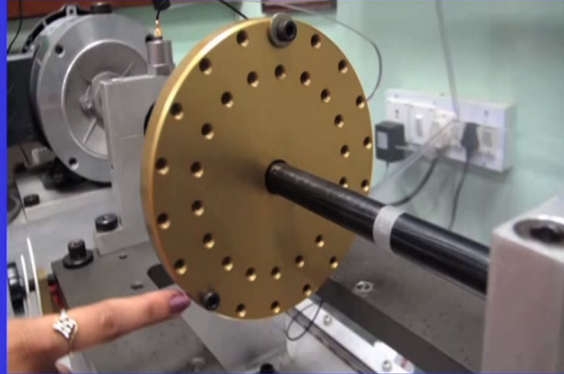
So the very first step once I have measured the unbalance response and know the phase angle with respect to the rotational speed and the acceleration I have to give a trial mass. I will give a known mass of about the 6.14 gram just measured it here and then I will attach it at some location.

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Trial Mass

Machinery Fault Diagnosis & Signal Processing



So this was my initial unbalance at another location I have put 6.14 as the trial mass okay. And then in another way I put the accelerometer am measuring and of course I did the tacho probe. So I have just put an unbalance mass am sorry a trial mass of known weight of 6.14 gram okay. And then I need to again rotate again at the same location I will measure the vibration and the phase angle.

Now this vibration as come become 12.8 because of the trial mass and the phase angle at the same frequency it become 121 degrees Okay this is all I need to do.

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Compensation Mass and Angle (6.18 gm, 67.7°)

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$$M_o = (V_o/V_T)M_T$$

Compensation Mass

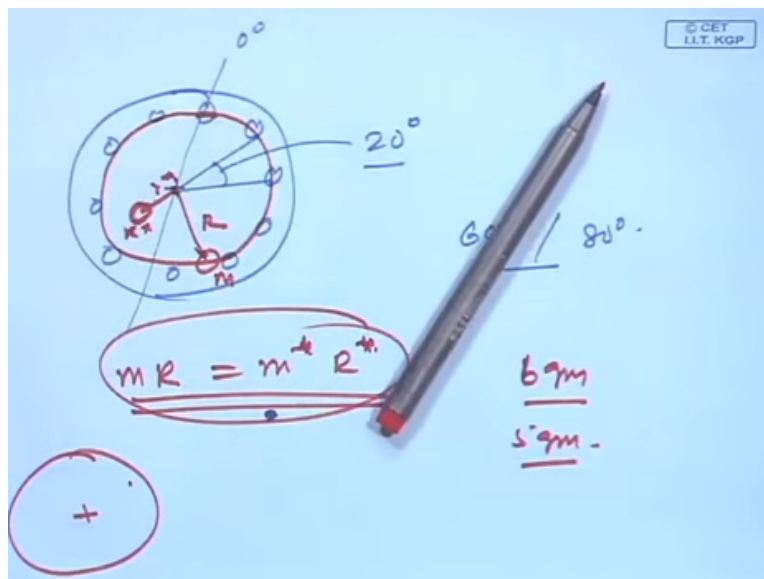
$$\alpha_{comp} = -\alpha_T + \alpha_0 + 180^\circ$$

Compensation angle measured from
Trial Mass Axis



So this has to be put again at another direction is this alpha compensation is given by alpha T whatever I would have got this angle 121 degree and then alpha naught was my initial and then 180 degree and this happens to be 67.7 degree measure from the trial mass access okay. And once we know this we then put it back at that location and then we got the residual unbalance to about 6.02 the same location the balance amount got reduced.

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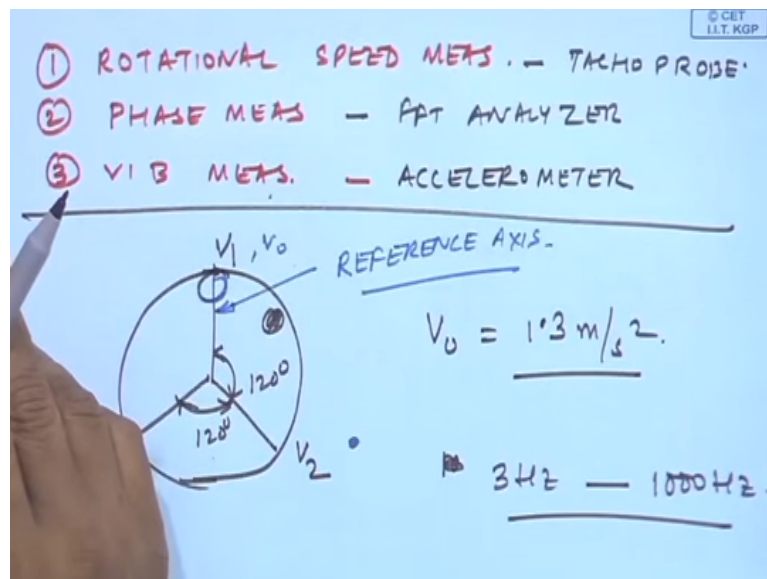
Say this disc there are actually holes around this okay and this holes are placed at about there are 18 holes are about 20 degrees. So if I calculate the 0 degrees if I calculate any angle it has to be multiples of 0 degrees I got some reading as 67.7 degrees. So either I put it at a 60 degree mark or a 80 degree mark because of this problem the residual unbalance is not quite less okay.

But this is very important that this are all happen in practice also there is one location another is regarding the radius the amount of the unbalance okay. $MR = M \text{ star } R \text{ star}$ okay I can have a higher mass put at a lesser distance at create a same kind of effect this also there. So radially I can change and then selected about the play around the mass also because if suppose it comes with the mass of 6 grams but I only have 5 gram of unbalance mass weights to put so I can put it at radius by maintaining the relationship okay.

So this are practical limitations as to where to put the unbalance mass at which radius and how much of unbalance is to put and for this is this problem we in the lab we did not get more than less than 6.02 this is of problem placing the mass at the calculated angle because the rotors did not allow us look at this are because this are all at 20 degrees at around 80 degree. So if the angle comes somewhere here problem I cannot put it that is where the problem is.

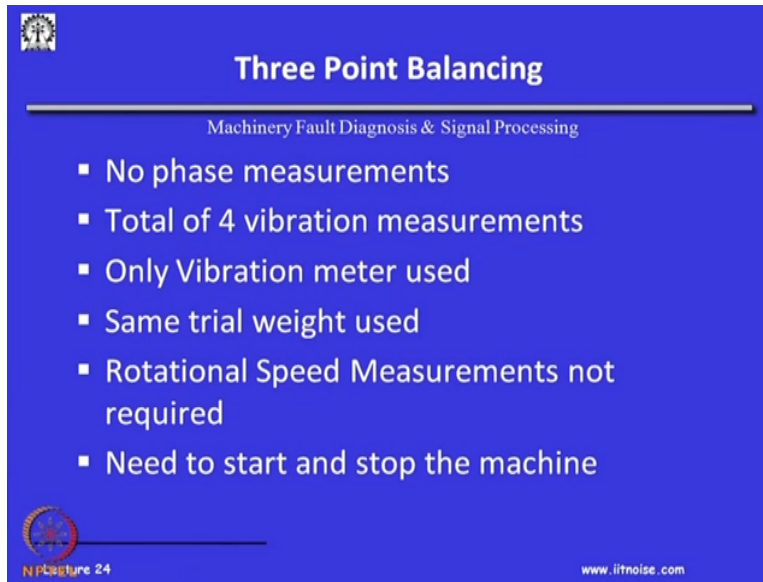
So to summarize this single plane balancing with single phase measurement phase the frequency measure phase and acceleration measurement.

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We have to see that we have to the rotational speed measurements and a phase measurement and then we have a vibration measurement okay. So in this example we use an accelerometer for this phase we measure FFT analyzer and then it is tachometer okay. This is very expensive in terms of the equipment we have used it require three equipment to do this.

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A blue presentation slide titled "Three Point Balancing" with a horizontal line below the title. The subtitle "Machinery Fault Diagnosis & Signal Processing" is centered below the line. A bulleted list of six items is on the left. In the bottom left corner is a small circular logo with "NPTEL" and "Lecture 24" text. In the bottom right corner is the website "www.litnoise.com".

Three Point Balancing

Machinery Fault Diagnosis & Signal Processing

- No phase measurements
- Total of 4 vibration measurements
- Only Vibration meter used
- Same trial weight used
- Rotational Speed Measurements not required
- Need to start and stop the machine

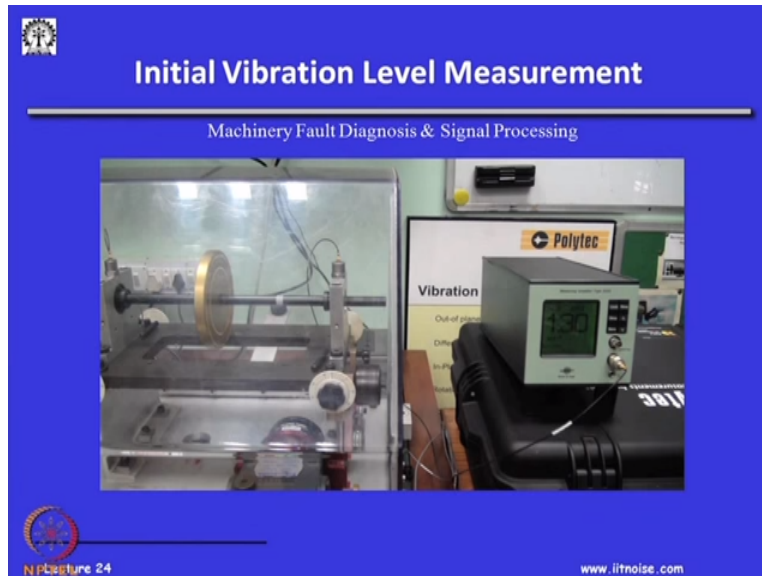
NPTEL Lecture 24

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But another very easy way to do the vibration balancing of shaft is what is known as the three point balancing. As it says this requires no phase measurements so we do not require attack of FFT analyzer. But of course if requires four sets of vibration measurements it require four sets of vibration measurements but to measure vibration only on vibration can be used rotational speed measurement is not required but we need to frequently stop and start the machine because four measurements have to be done.

And this three point vibration measurement basically what we do is we do not know where this unbalance mass is okay I will okay all have to do initially measure the vibration okay

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And through that earlier example I showed you this screen shot of FFT analyzer I showed you the tacho probe and then accelerometer okay in this example in that we can see here this same rotor where there are two bearings and then I have attach the accelerometer here in the previous class unbalance detection I am talking about the phase measurement it was phase between this transducer and this transducer.

So phase would be closed 0 degree and we got something around 13 degrees but here in this previous example I had used this accelerometer and used tacho probe somewhere here and this is the rotor in this three point measurement what we have done is we have just put an accelerometer and just got an vibration meter to see the initial level of vibration level measurements and which comes to about 1.3 meters per second square.

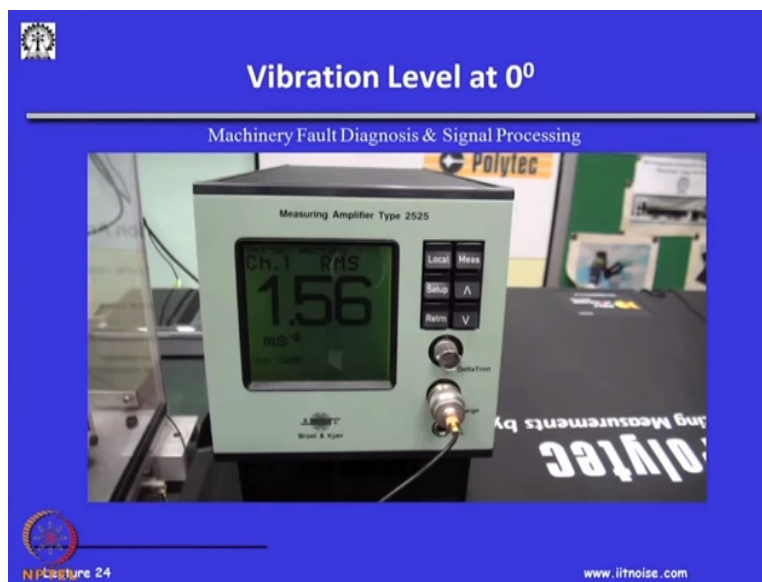
So to being with I have an initial unbalance of 1.3 meters per second square okay and this gives the overall level and this vibration meter is set from 3 hertz to 1000 hertz okay. This is giving the overall I am not specifying the rotational speed I do not care about the speed rotating as long as rotating at constant speed some speed it is rotating I will just put and accelerometer measure it initial is 1.3 meter per second square that is my V_{naught} okay.

And the next instance what I do is switch off the machine and at location 1 some location okay which is 0 degrees. 0 degrees I means V_{naught} was in this direction okay I put this has reference access because reference access is very important because once I come up with some angle it has

to be always measure with relative to some axis. So initially I decided that wherever I have put my axis and with this am measuring V_{naught} and I will put V_1 here okay.

This becomes by V_1 this is V_{naught} am measuring V_1 is lines with this and 0 degrees to measure with so henceforth any angle calculation value as state this as 0 degree at this point of 0 degree and then move along the rotation of the direction. If I move opposite the direction of the rotation the angle will be negative so this is by 0 degree going clock wise in this direction will be deposited axis.

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Handwritten calculations on a blue background:

$$\bar{V}_1 = 1.56 \text{ m/s}^2$$

$$\bar{V}_2 = 2.03 \text{ m/s}^2$$

$$\bar{V}_3 = 0.735 \text{ m/s}^2$$

$$V_D = 1.3 \text{ m/s}^2$$

$$M_T = 6.18 \text{ gm}$$

$$\bar{V}_1 = \bar{V}_2 = \bar{V}_3 \quad \times$$

$$\bar{V}_T = \bar{V}_1 + \bar{V}_2 + \bar{V}_3$$

$$= 1.56 \angle 0^\circ + 2.03 \angle 120^\circ + 0.735 \angle 240^\circ$$

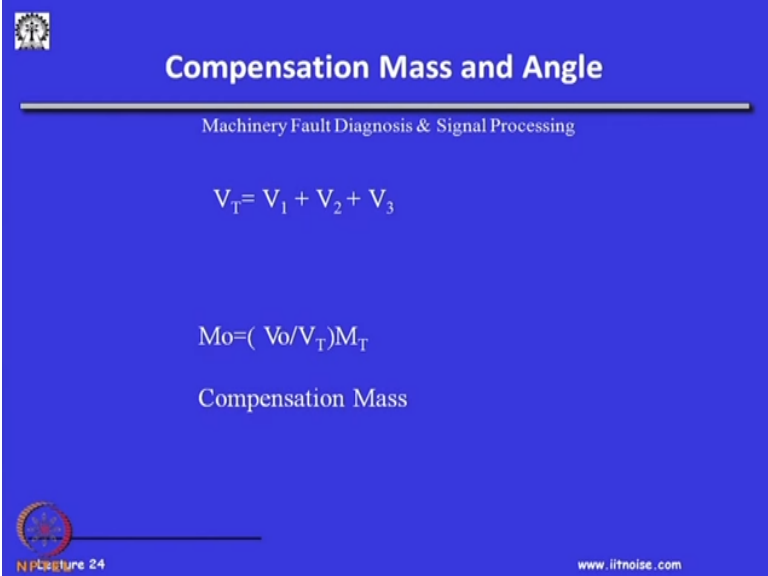
$$= \bar{V}_T \angle \theta_T$$

And then what we did is at 0 degree I got my V_1 as 1.56 meter per second square at first round and of course V naught was 1.3 meters per second square okay and mind this are all vectors am writing it as magnitude but they are at particular angle okay. These are all vibration vectors so 1.56 meters per second square next is I removed the mass from V_1 switch off the machine remove the mass from location V_1 move to the location V_2 mounted and then rotate at the system.

So vibration level at 120 degree that means I have put a mass at 120 degrees this is the vibration level and that comes to 2.03 meters per second square okay. Now imagine this was perfectly balanced machine out of got all this as same okay. And then the next case I moved it to 240 locations am getting V_3 as 0.735 meters per second square how did I say this one this is .735 meter per second square.

You all will appreciate that if this was a perfectly balanced rotor V_1 should have been = V_2 should have been = V_3 and which is not in the case of in our case. Because we have put some unbalance mass at some location and now what we have to do is very simple thing we have to find out vector V_T which is nothing but the of course I will denote it as vector V_T is nothing but $V_1 + V_2 + V_3$.

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Compensation Mass and Angle

Machinery Fault Diagnosis & Signal Processing

$$V_T = V_1 + V_2 + V_3$$

$$M_o = (V_o / V_T) M_T$$

Compensation Mass

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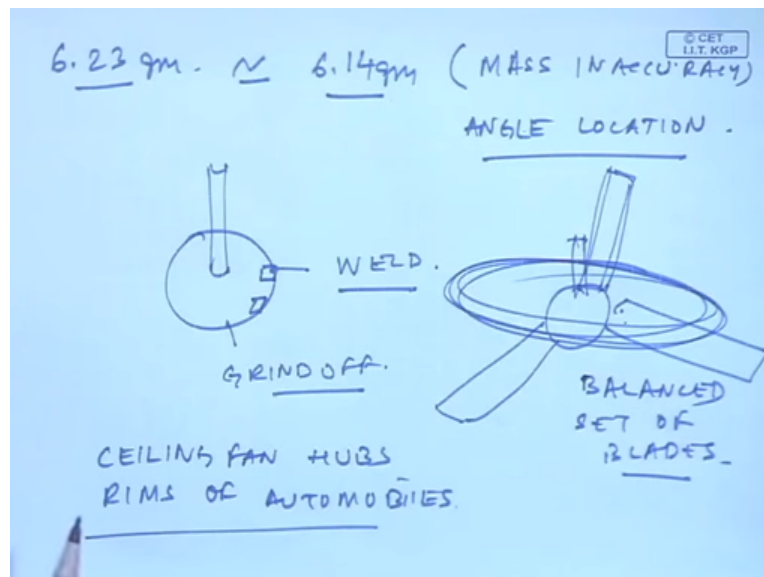
So this will give me the effective residual unbalance and which happens to be in our case $V_T = V_1 + V_2 + V_3$ and this you can measure it this this if you have one of those calculators you can

find out the VT magnitude and VT phase okay. And once we have done that you take this equation and $M_{\text{naught}} = V_{\text{naught}} / VT \text{ times } MT$ and V_{naught} was this and we had given a mass to being with I think in this case we had given a mass of $MT = 6.18 \text{ gram}$.

So using this equation $M_{\text{naught}} = V_{\text{Naught}} / VT \text{ times } MT$ I will get the mass M_{naught} and then once I know the angle I have to just put it $VT + 180 \text{ degrees}$ okay from this location this is my starting point so I will get a VT angle I will place it on this and add so I will know the location of the VT angle that is my unbalance mass direction and then 280 degree that I put that unbalance compensation mass whatever am M_{naught} calculate.

And I finally learn up with .629 meter per second square to start with I started with 1.3 meter per second square and then I learn up with 6.629 meter per second square again in this example you would see that we have not quite reduced it because of again the same reason that the mass which you measure may be always a problem sorry.

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The mass which you measure 6.14 grams is quite not what it was expected by if it say 6.23 grams I may not be having very close manufacturing trial weight so i took the close available to me was 6.14 gram so this is the mass and a accuracy other is angle location okay.

So in practice how do we overcome this again in practice there are lots of trial weight have different size and shapes but usually in many of this rotors you will see many times they weld

either weld masses the final mass or grid off okay this you will notice in the ceiling fan hubs in the rims of automobiles you will see people well in masses or fans or remove them and sure all of you must have in a ceiling fan is a very good example.

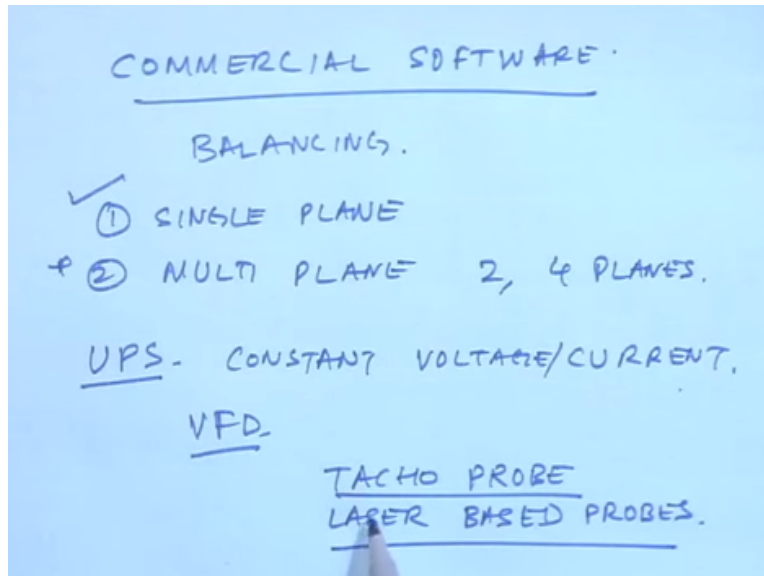
Many of the ceiling fans the high end ceiling they come with the set of blades which are many times balance to particular fan okay and if you if you change the blade orientation say of one versus the other or they will you have seen the effect of how unbalance there could be warbling okay. So balanced set of blades even by changing the orientation of one blade angle is going to create a raise to an unbalanced okay this as to be taken care off.

So in practically you can choose many method there are other methods also but the one advantage over the other is one you are accurate in the sense you are accurate in both the cases here accuracy depends and on mass location a mass trial mass and the angle location but in one we need to do more it measurements and we need to frequently start and stop like in the three point balancing but the measurement is very simple all we require is a portable hand held vibration meter.

And you do not require any phase in measurement okay and this very simple experiments which people do in this students do in the lab as well just we have the rotor mark 120 degrees sectors of 3 vectors 120 degree to each other put a trial mass measure the unbalance again put it at three difference locations 0 degree, 120 degree, 240 degree by the vibration level I will calculate that find out VT and calculate the compensation mass and put it at whatever angle $VT + 180$ degrees.

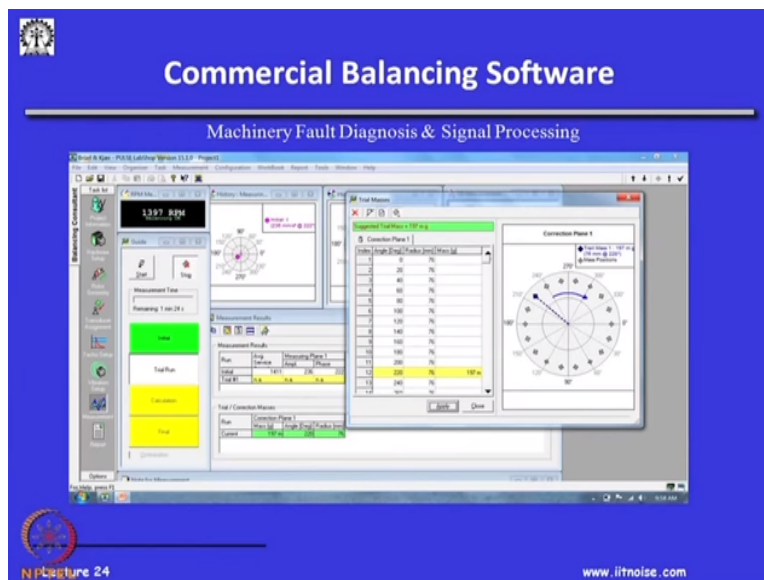
And that is the most simplest way of doing single plane balancing but another one suppose not allowed to switch off the machine may be one just to put trial mass. You can do the phase single channel phase and single channel vibration.

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But there are many commercial software available for balancing I will just show you the screen shot of one such balancing software which we have in our laboratory.

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And this is how it looks like okay and there are in this balancing software there are many options you can do single plane you can do multi plane you can go as 2, 4 planes okay. But in this class we discuss about the single plane balancing and then this are I will tell you do it initial do the trial runs do the calculations do the final mass and you can select the trial mass at different angles.

What is radius at says that what is the trial mass values and then vector in a graph it going to show you the rotor and show you where the mass is to put and this basically what we did in the previous calculations are the same things which are there in the software and very simple balancing is the most easiest thing to do in a machinery trouble shooting balancing only thing it should have the perfect instrument to measure the vibration and the phase or the phase.

And then of course you have to measure the RPM also many times what happen this is while you are doing the balancing if it is a maybe this balancing operation takes place about couple of hours to do the you know large plan it takes couple of hours to switch of the system and while you are doing the measurements for what did the speed as changed and that is very well important speed changes all your vector diagrams as no meaning because the they would have changed as well.

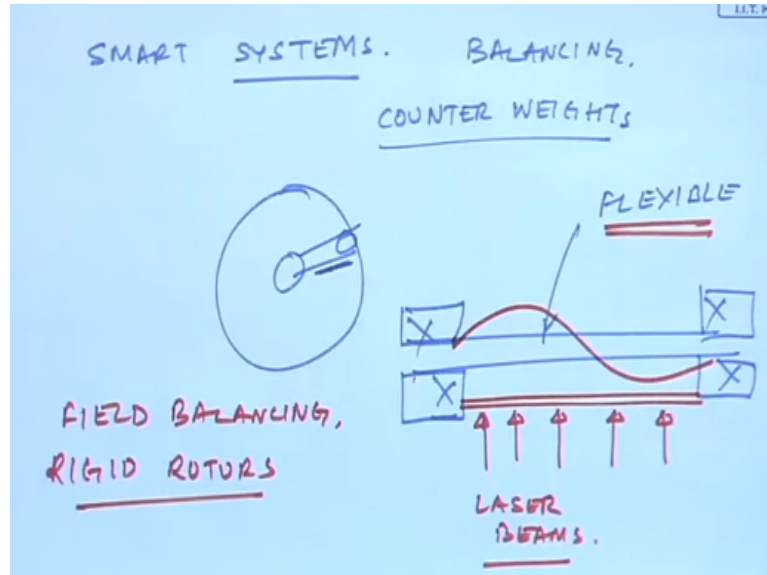
The magnitude would have changed so we have to have ensure that always the speed is the same okay in the laboratory it is okay we can make sure the trans and constants speed in fact while we do measurement in the laboratory we actually have in our systems on UPS and constants voltage and current supply okay. But it is in many of the industries we have this VFD drives okay with close look compensation so that the speed in variable does not change okay.

Once the speed is does not change and the speed you have measured correctly and what are the ways by which we measure the speed from an industrial rolling system is usually tacho probe or laser based probes. Because we cannot measure this with having a contact type of probe okay and we may not be allowed to probe very close to the rolls or rolls rotating at high speeds high temperature think of the steel plants and cold rolling mills CRM, HRM whether rolls are rotating at very high speed.

We cannot even go close to them because of safety issues because of temperature issues in those cases we can shoot the laser beam get the reflected beam back and measure the angle of speed or some of them are pre-installed digital RPM indicator wherein they have a reluctant start pickup which are used to measure the rotational speed. Once we have a good feel of the rotational speed only requirement imbalancing is obviously we have to balance we have to add gate or remove gate so we need to stop and start the machine to do the field balance.

Nowhere you do the balancing without switching off the machine okay we have to put weights and remove it and so on okay.

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Of course now a day many smart systems are available where balancing using counter weights okay wherein you are monitoring the vibration level and then at a particular phase if you see that unbalance is occurring they will be systems which will move the counter its other inwards or outward okay they will guides by which this can be moved. So you that you take care of unbalances okay.

There are smart systems there are many ways but we are not talking about this is innovation yet okay but in this class in the previous class we just introduced you to the case of unbalance okay how we did the unbalance and in this class I just told you two simple measurement techniques to do field balancing one case it was the single plane measurement by the phase measurement and the acceleration measurement vibration measurement.

Wherein we not switch off so often and the second example I told about the three point balancing wherein we have to just have a vibration meter which is very cheap and handy and we do not require to measure the rotational speed or the phase say it is cheap that way now only disadvantage is that it have to stop it about 4 times 3 to 4 times to add on the masses okay. And then commercial software's are there where we can do balancing and many planes.

Of course there we require software a long cannot do the balancing we have to do the measurements since it at the bearing locations okay. Sometimes the problem happens that how do I do the equations measurements along the rotor suppose I am talking about last systems so far we discussed about rigid rotors and suppose this is the flexible rotors last steam turbines from gas turbines in this case what happens there may be because of more shapes.

So what we can do is I need to a measure a long length of the shaft so I can shoot laser beams on to the shaft and then find out the points where large portions are and then again use the software I can find out the how to we take care unbalance and how do we reduce it okay by this something which we are going to discuss in this class and then we are not discussed this the flexible rotor balancing.

So as long as we know how to balance rigid rotors field balancing we are doing good okay. I think with this I will stop class okay thank you