Dynamics of Machines

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Module - 3 Lecture - 3
Balancing Machines and Field Balancing of Rotating Discs

We have seen earlier how to design a rotating system, so that it is completely free from unbalanced forces and moments, resulting in a perfectly smooth operation. Now we should discuss, given a rotor or a rotating system, how to balance it. This balancing of existing rotors or rotating objects can be done in two ways. When the objects or the rotors concerned are small in dimension, they can be placed on some machines that you call as balancing machines. On the other hand, if the rotor and the rotating system are very large, like an alternator or some huge turbine rotor, in such cases it is not possible to put this rotating object on any machine for balancing purpose. We have to devise a technique for balancing those big rotors and big rotating objects in their original position.

First, we will take up the case of balancing machines. We will take up two types of machines: one, a very simple and rather crude version which is called the pivoted-carriage balancing machine, the other is slightly more sophisticated and provides better accuracy called Gisholt balancing machine. The basic principles are very similar.

First, we will take up the simpler machine and explain the fundamental underlying principle that is used in all balancing machines. If you have a rotor, say our rotor is like this, which we would like to balance. It has been told before, that we need two balancing masses to be placed at suitable angular positions at some two suitably chosen balancing planes. Then if everything is okay, the whole system will be absolutely free from unbalanced forces and moments. Now the choice of balancing planes that depend on the construction of the actual rotor. For example, in the case, it may be more convenient to select these planes as the balancing planes.

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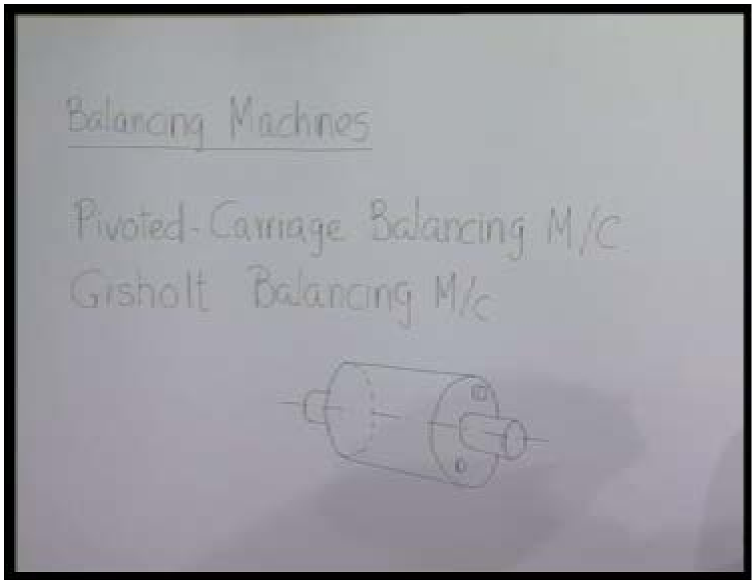

It is easier to add a mass here or the same result can be achieved if some mass is cooked out or removed from a diametrically opposite position. The effect will be same as adding a mass here. Therefore, these faces of the rotors may be chosen as the balancing planes. Anyhow, this is just one particular case, so it will depend on the situation.

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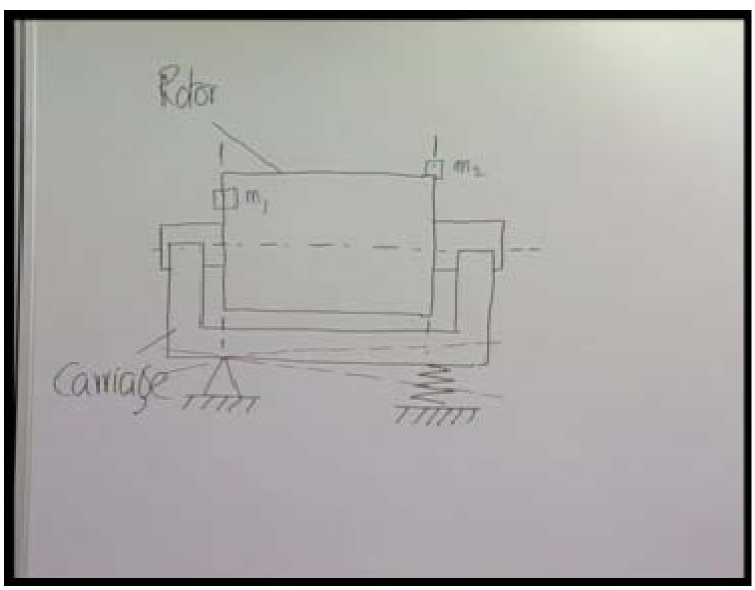

If you have a rotor like this, rotor is placed on a carriage, the carriage has two half bearings. Now, we take a pivot to support one end of this carriage and the other end is supported on a spring. Now once this rotor starts rotating, then the centrifugal force or unbalanced inertia forces will start appearing depending on the speed of the rotor.

Now here we may assume that the complete unbalance of this rotor represented by two masses, one in this plane and the other in this plane. It is our choice now. If that be the case, then if we say, that this is some mass m_1 and say some mass here m_2, these two masses make complete representation of the total unbalance situation of the rotor. If we put the pivot on plane one or just under plane one and support the carriage by a spring at the other end, then this m_2 which represents the unbalance of the rotor and this mass m_1 which represents the unbalance of the rotor on this plane, the effect of the unbalanced force produced by this will be nullified because this point is hinge. So, the rocking motion which will be generated, the carriage will rock like this with this as the pivot. The effect of this unbalance will be completely gone. We then attach one trial mass on plane two and rotate its location gradually, until that time when the amplitude of oscillation at a particular speed becomes minimum.

In this situation, we may consider that this trial mass is approximately opposite to the m_2. You can explain this way, if m_2 is this, then the location where mt_2 will have minimum vibration produced will have to be here, diametrically opposite. At any other position, the amount of m_2 inertia force which this will neutralise will be lesser, here it will be maximum effect. Therefore, amplitude of oscillation will be minimum due to the unbalance created by m_2.

Next, we have to gradually adjust mt_2 magnitude or its radial position, because what actually matters is the eccentricity and the mass product. You can change the magnitude of the mass or vary its radial position, whatever may be the case, when you change this product gradually until and unless this vibration almost stops. We completely neutralised the effect of m_2 by putting a suitable balancing mass which has been adjusted to become the balancing mass, the original trial mass has been converted, so that this effect of m_2 in creating unbalance is neutralised.

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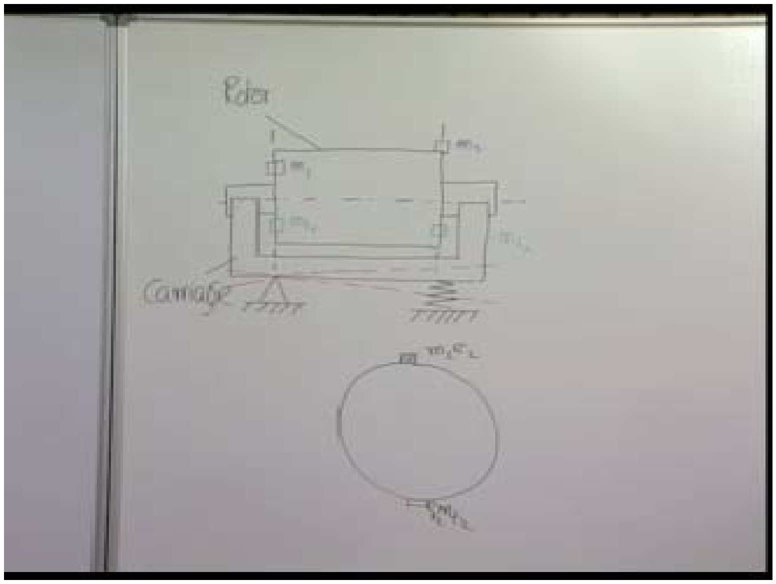

Next, we just shift this pivot to the other balancing plane two. What will happen? The oscillation and spring is shifted here. When it is rotated, the unbalance which is created by m_2 will be having no effect and unbalance created by m_1 is going to have the effect. We follow the same procedure in placing one balancing mass on this plane. We start with balancing or trial mass mt_1. We first see that which angular position this produces minimum oscillation and then we adjust the product mt_1 and e_1, so that the vibration almost vanishes.

Of course, you may say that this is purely a very crude arrangement because we are doing everything based on our visual senses and tactile senses, but it gives reasonably good performance or good results. Though the result what we get here may not be perfect or balancing may not be absolutely accurate.

Now, the same principle can be applied in the Gisholt type machine, only it is more sophisticated. We will explain the fundamental principle. Here the disadvantage was some inertia of this carriage, so that itself makes the whole operation somewhat inaccurate and less sensitive to the unbalance present in the rotor. If the unbalance present is very small, may be it will completely offset by the effect of the large inertia of the carriage etc.

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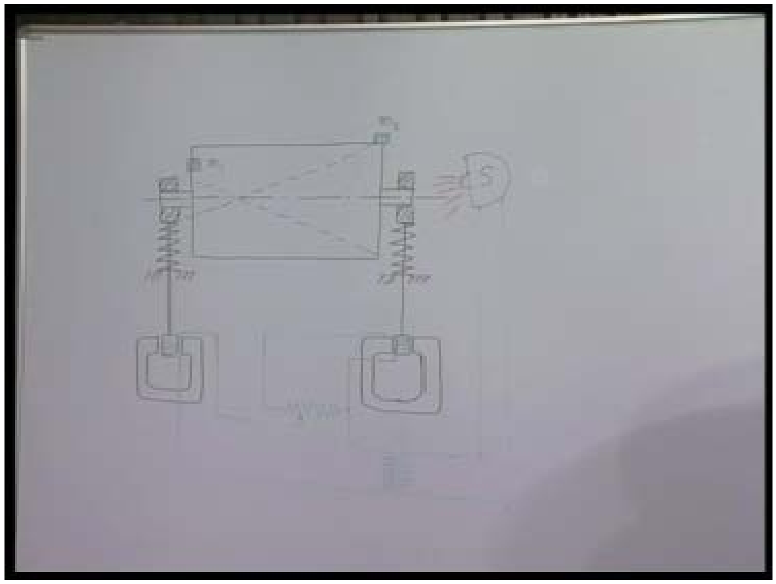

In Gisholt type machine, no carriage is used. It is mounted on two bearings and the bearings are supported by springs. We do not use any carriage but we just place the whole rotor on just two light bearings which are supported by springs. The motion of this bearing is picked up by a solenoid or rather it is connected to a solenoid, which can then move along with the bearings. There is some kind of an electromagnet or permanent magnet. This we are using green for the electrical circuit.

First, let us understand the whole setup. As we were mentioning, these bearings which can move up and down supported by springs, either up and down or to and fro. It may be that whole thing is actually is in horizontal plane or maybe vertical plane. Then these solenoids also move up and down here. These are the electromagnets or rather permanent magnets. The coils here, they will generate some motion depending on this voltage.

The amplitude of this voltage, which is an alternating one will depend on the amplitude of this for a particular given frequency. Again, if you now keep the same principle in mind, that the whole system’s unbalance can be represented by or can be imagined to be represented by two unbalance masses. We know that the effect of this mass, if we ignore this, to produce an unbalanced force here will make this end oscillate at a larger amplitude.

If somehow, we ignore this, then the oscillation of this rotor axis will move like this. The voltage generated here will be more then the voltage generated here. The ratio of the two voltages, because of this m_2 only, here and here it is something fixed depending on the rotor's construction etc. If we now adjust, that means this voltage here, which is generated, if we apply it here so that we adjust this in such a manner, that this fraction of the voltage generated here is exactly equal to the fraction of the voltage generated here. Here what you will get is 0, because this voltage generated here is suitably compensated by this voltage generated here.

The ratio of the two voltages is taken care of by this potentiometre arrangement. Effectively this circuit will now be insensitive to any unbalanced produced at this end. Whatever this circuit looks, depending on the location of this potentiometre arrangement, it will now give whatever effect or voltage here comes is due to this same one, which is present. Though, temporarily we imagine it to be absent, but it is present. Now, whenever this moves up and down and this voltage changes its direction, this stroboscope will flash for 1 microsecond, as soon as the direction of the voltage or the sign of the voltage changes. It is arranged in such a way, that when this is at the top position in its vibration, then it flashes.

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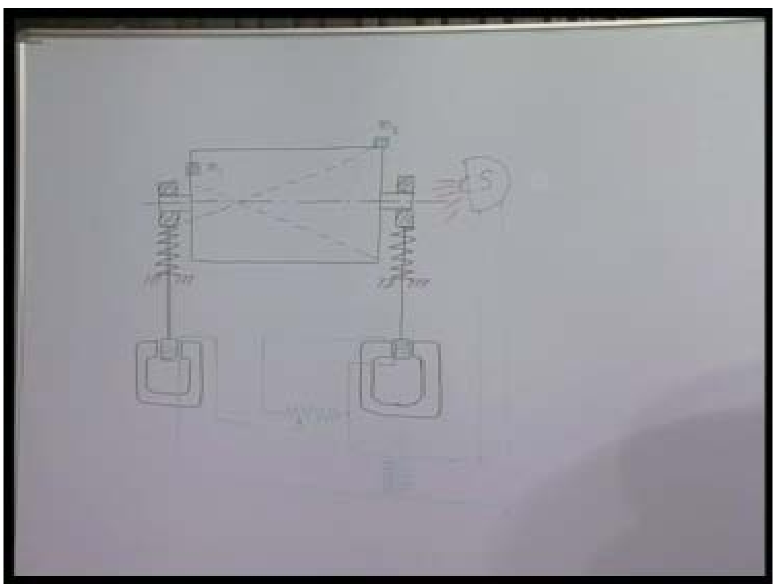

You can see the angular position, if it rotates at a reasonably high speed then flashing will also be reasonably high speed. You can see the marking, there will generally be a protected kind of arrangement, which will show you the angular position when this is at the highest or where m_1 is the lowest. If the damping in the system is less or very little, then the motion will be in phase with the disturbing force. If the natural frequency is not above the normal frequency or the natural frequency is not above of that.

Similarly, if we have another circuit, where we have compensated the voltage generated here due to this suitably, so that the voltage generated by this due to this effect, that circuit will produce the flashing, only when this particular mass's effect is concerned. Thus, depending on which circuit we are using we can find out the angular position of this and angular position of this using the stroboscope. This can also tell us about the magnitude of the two unbalances present by suitable calibration. The basic principle will be that you will slowly adjust the magnitude of the mass or the magnitude of the product of the mass and its eccentricity, in such a way that the result is minimized to 0. These are the principles of balancing machines, which are used for balancing of actual rotors when they are not very large.

Let us consider the case where the rotors are very large and you cannot bring them to your lab to put on balancing machines, say like a turbine rotor or a huge industrial fan and so on.

Such cases have to be tackled and balanced in their original position or in the field itself that is why this technique which we represent is called field balancing. It is very important, particularly for engineers who are working in the industry. First, we will discuss the case of balancing a disc. It is not only that the basic principle of this technique will be clearer with the help of this two dimensional object, but in many circumstances the real thing may be approximated as a disc like a huge industrial fan or blower, which is in the form of thin blades. Therefore, let us take the case of a disc balancing.

We will take up two cases, one is slightly advanced and sophisticated, which requires some instrumentation, the other case which requires minimum instrumentation and can be done by almost anybody. The setup will be something like this. This is a disc on the shaft. The shaft is mounted on bearings. This is an oscilloscope which can measure two signals, double beam oscilloscope. The whole disc is shown here. This is the view from this side, where you have taken this pickup. This is a vibration pickup, which picks up the vibration of this disk through some kind of a sensing. You can put this pickup on bearings or anywhere suitable position. Its main job is to measure the vibration signal. This shaft is also connected to a device which you call - sine-wave generator. Now, this signal and this signal when they are taken to a double beam oscilloscope, this will produce a simple sine wave and this sine-wave generator and disc are physically locked to it because they are rigidly connected. The sine wave generated will depend on the rotation of this or it is representing a rotation of this, its angular position whereas this will show the vibration of the disc, because of the unbalance present and when it rotates at some suitable large speed.

Now what will happen? The sine-wave generator generates a sine-wave continuously and this pickup, say for example gives a vibration, remember since in steady state situation the frequency of this vibration also will be same as the speed of rotation because the vibration force or the exciting force is nothing but the centrifugal force generated by the rotation. They will have the same frequency, but they need not be at the same phase.

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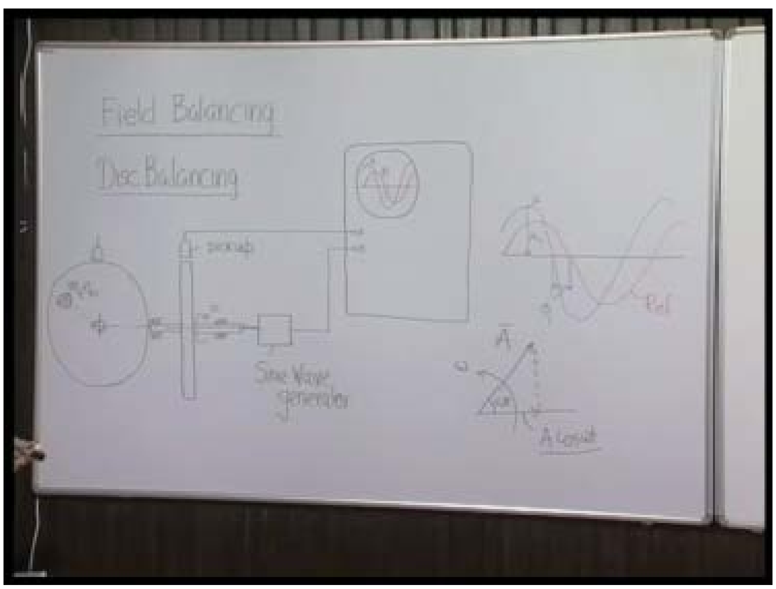

This will be pickup A and this will be pickup B. We will draw it in a slightly bigger. This is the sine-wave generator.

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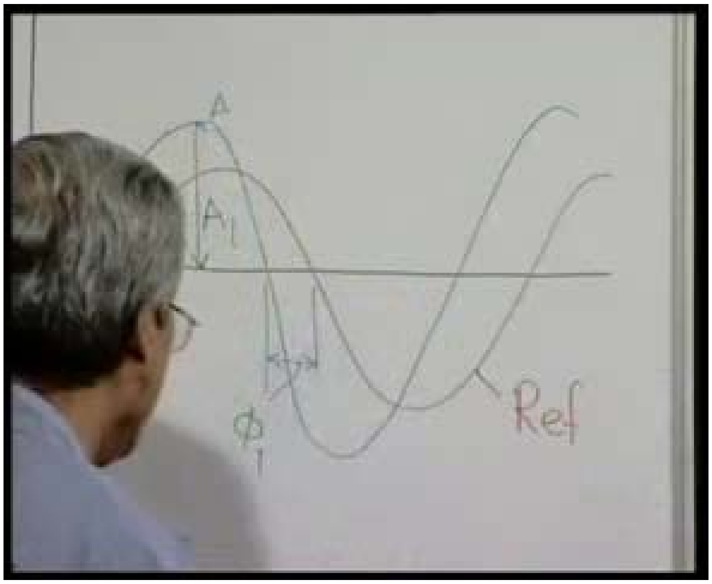

The signal, which we are getting from the vibration pickup is given by this and so on. Therefore, this is nothing but the angle by which the vibration or signal of this is leading the sine-wave generator. We have taken the rotor in its own position, rotated it at a suitable speed omega to generate enough vibration which can be picked up. Then the signal which you have picked up is given by a sine wave whose magnitude is A and which is at an angle phi subscript 1 from our reference, this is the reference. We can draw it with the help of a rotating vector.

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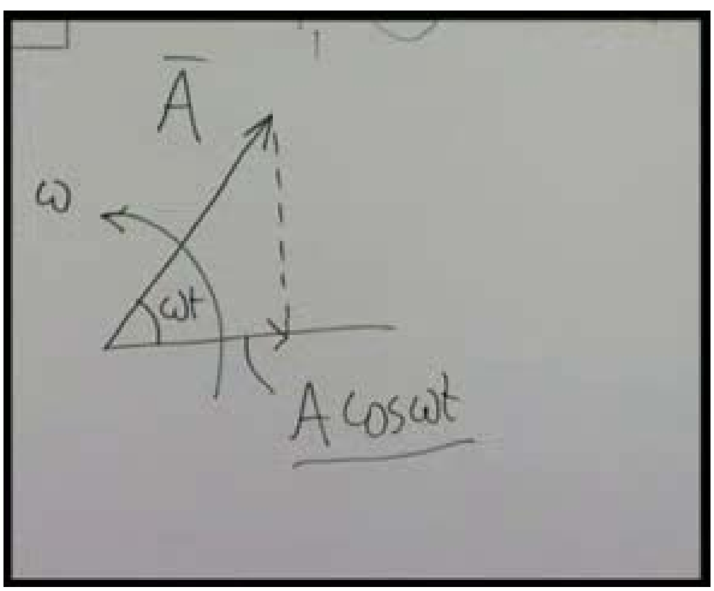

A rotating vector can represent any harmonic function of time when we consider only the component of that rotating vector as the real quantity. If this is a vector A rotating with a speed omega, then at any instant this is omega t and its magnitude is simply A cosine omega t, a harmonic function of time. We will just represent the vibration when it is rotated at speed omega by A_1. A_1 magnitude is this and its location from this reference is this, where this angle is phi subscript 1.

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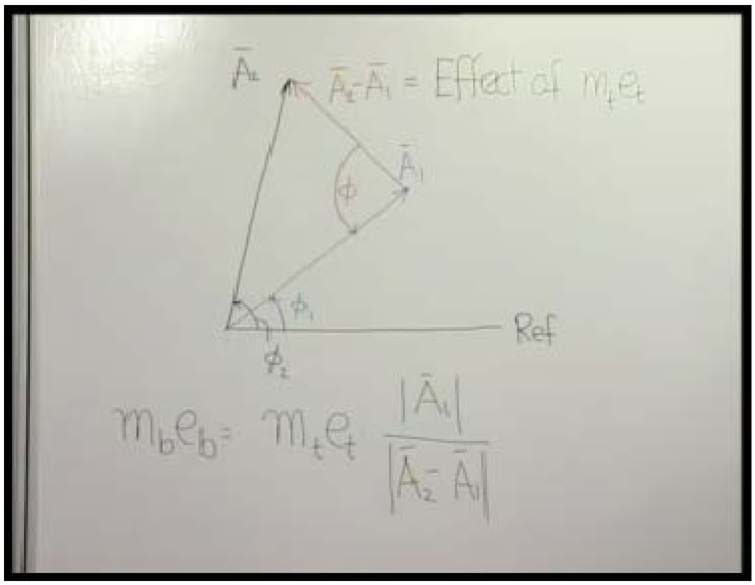

Next, we attach at some suitable location, a trial mass at an eccentricity e_t. Again we rotate the whole system at the same speed omega and we get another signal which you call A_2, whose magnitude is this much and it has a phase lead with our same reference, because this attachment we have not changed, so whatever this generates is actually physically connected to the whole physical system. Now we get another signal, which is also a harmonic function of time and therefore can be represented by another rotating vector A_2, where this angle is phi subscript 2. We have rotated the rotor or the disc at suitable speed to produce measurable vibration and the vibration what you get is represented by a rotating vector of magnitude A_1. Then we attach a trial mass m_t e_t and rotate the system at the same speed omega and we get again a vibration as A_2 which is at a different angle from the reference phi subscript 2. What is this quantity? We are representing this bar over the number to indicate that they are vector quantities.

This A_2 minus A_1, originally without any trial mass we had this vibration with trial mass we have this vibration so, the original vibration plus this, becomes the final. This is nothing but the effect of the trial mass. Where do we put our balancing mass so that the vibration, which is produced by its original unbalance is completely gone? If we rotate this effect of m_t e_t in this direction by this angle phi, so that it matches with the original vibrations direction. Its magnitude is increased or changed in such a manner, that this length and this length equal, then what will happen if we rotate this by an angle phi and put our balancing mass m_b e_b here.

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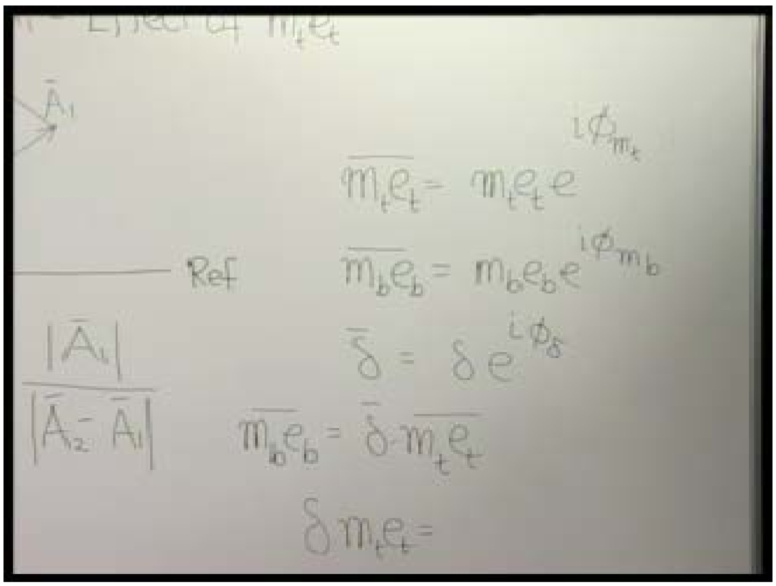

m_b e_b is such, the magnitude of A_1 vector by the magnitude of A_2 vector minus magnitude of A_1 vector. This m_b e_b, its effect will completely neutralise the effect of the original unbalance. The vibration produced in the system will be 0. This is the technique, which we can use for balancing disc like objects. Now here of course, we can also treat the whole thing as a vector 1. If we take m_t e_t as a vector quantity, in this way, m_t e_t vector is equal to m_t e_t e to the power of i phi subscript m_t and $m_b e_b$ vector, always this product is important, is equal to m_b e_b e to the power of i phi subscript m_b (by another complex quantity), delta vector is equal to delta e to the power of i phi subscript delta (another vector or complex quantity), then m_b e_b vector we can say is delta multiplied by m_t e_t vector. The delta we are using as an operator which will be later a very useful concept when we go for rotor balancing. You can see that operating one vector by another vector, what it does is it changes its magnitude by taking the product of the two magnitudes, that means, the magnitude of m_b e_b, will be magnitude of delta into magnitude of m_t e_t.

Similarly, the phase or the angular position will be added: phi m_b will be phi m_t plus phi delta. Magnitude of delta and value of phi, this can be found out just as we mentioned here. We will discuss this at later stage when we take up rotor balancing in the next class. Here we do not need that complex notation as much, because this is quite simple and clear. Sometimes one may find a situation, where you do not have a sine-wave generator and a double beam oscilloscope. What you may have in industry is simply a vibrometre, which can measure the amplitude of vibration, nothing else. Even with that kind of a simple instrumentation, we can do field balancing which we will tell now.

We will take up the case where we have a simple vibration pickup, where you can get the amplitude of vibration that is all, nothing else. We do not need the sine-wave generator or any kind of complicated instrumentation like a double beam oscilloscope.

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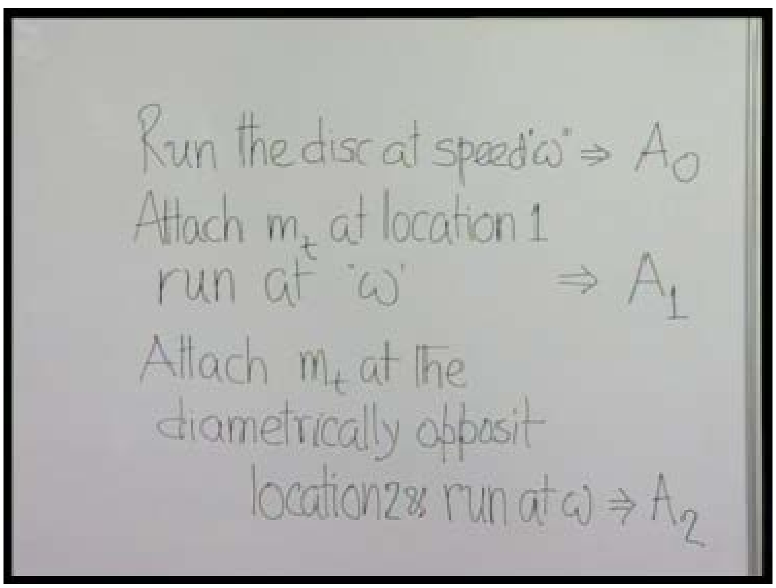

We take the disc, rotate it at a suitable rpm or suitable speed omega and measure the vibration amplitude A. We call it A_0. Therefore run the disc at speed omega that gives vibration A_1 amplitude, we cannot have any phase or anything like that. We attach a trial mass at any suitable location 1 and run the system at the same speed omega, this will give vibration amplitude A_2.

Attach m_t at the diametrically opposite location 2 and run at speed omega, this will A_3. A better way of whole thing may be, if we try to match this 1 and this. It is possible to do like this. If we want to have that it is possible to call it 0 and since it is 1, we call it 1, opposite location 2 so we call it A_2 (Refer Slide Time: 40:15). So this is location1, this is location 2.

Now you see a very interesting thing. A_0 is the amplitude of vibration without any attached mass. A_1 is the amplitude of vibration when a mass m_t is attached at location 1. Similarly, A_2 is the amplitude of vibration when the same attached mass is shifted to a diametrically opposite position. From these three quantities, we get lot of information. Let us see.

If the vibration is due to the original unbalance is say A_0 and say the effect of m_t in location 1 is this. Then A_1 will be this, when you place it in the diametrically opposite position, then obviously the effect of trial mass will have to be opposite to this and A_2 will be this.

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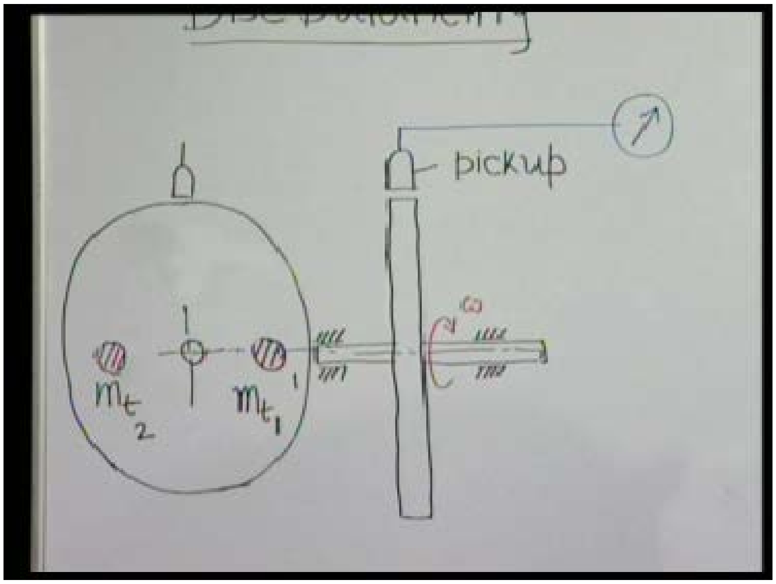

Just getting these three quantities it is possible to have this diagram. How we do it? We draw a triangle with one side is $2A_0$, one side is A_1 and other side is A_2. This triangle we can always draw. As you can see that, this is equal to this, this is equal to this, this A_2 is equal to this A_2. If we draw this triangle $2A_0$ A_1 A_2, then we know this is the effect of the trial mass in its position one. So we know how much it has to be rotated and in which direction.

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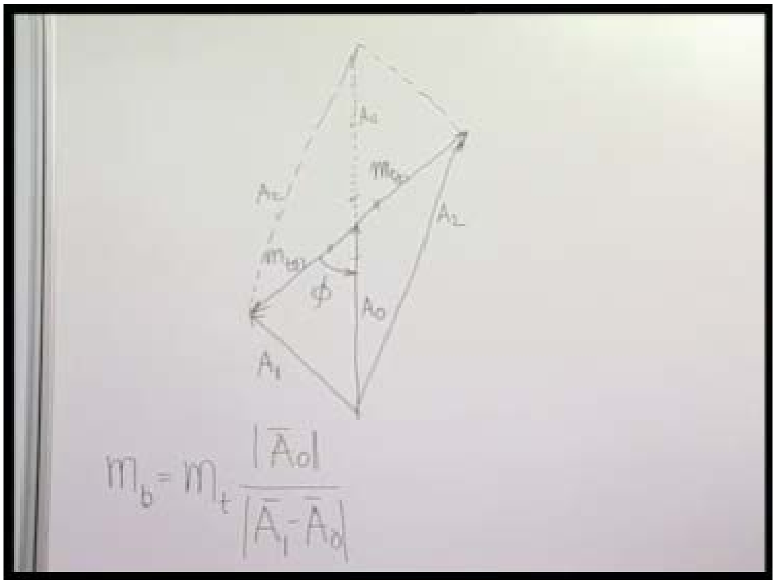

Therefore, the actual position of this trial mass will have to be somewhere here, balancing mass. We have to rotate in the same sense by a same angle phi, to nullify the effect of the original unbalanced. You have to of course change the magnitude also m_b will be equal to m_t into magnitude of A_0 by magnitude of A_1 minus A_0. Since A_1, A_0 are known and phi is drawn through this diagram, we draw a triangle $2A_0$ A_1 and A_2. The moment you do that the midpoint if you join, this becomes phi. So, phi is known from this diagram and magnitude of the balancing mass required to nullify or neutralise the effect of the original unbalanced. This is okay, but there is only one (Refer Slide Time: 45.00), that when we draw a triangle this, then we can draw the triangle like this also. The same angle phi, which we will get here indicates that the location of the balancing mass will be at an angle phi, but in the clockwise direction.

There are two possibilities, which is the correct one? To do that, what we propose to do is, we locate the trial mass, we make a third attempt, the same trial mass we locate at a position which is at right angles to the position one and position two like this, that means rotated by 90 degrees in the clockwise direction. Then attach m_t at location 3 at 90 degrees and run at omega. Now you get A_3, the amplitude of vibration. Here you will find that it is possible with this data to distinguish between the two. If this is the situation, this is the effect of the trial mass in position one, then what will be the effect of the trial mass at 90 degrees?

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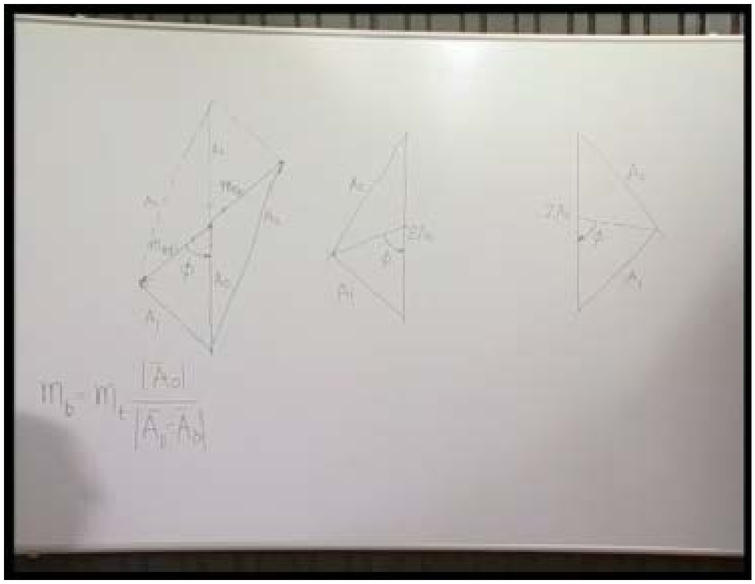

When rotated by 90 degrees in the clockwise direction or anticlockwise direction, as you have done it here, so the effect will also be shifted by 90 degrees this way and resultant effect will be finally A_3. On the other hand, if this is the situation, this is the original A_0 and this is the effect of m_t at location 1, then if you rotate this by 90 degrees, the effect of m_t in the anticlockwise direction, this would have been the effect of the trial mass in position three. Your A_3 would have been. Therefore, considering whether your A_3 is large or A_3 is a small quantity, you can find out whether the configuration will be this or configuration will be this. This third trial will be essential to identify the two or identify the correct configuration.

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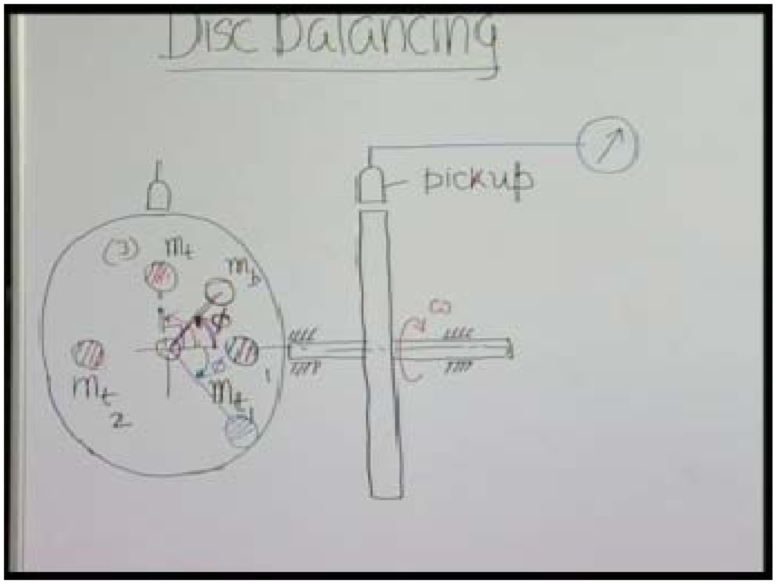

You can see here, that we do not need any sophisticated instrumentation. We only need a vibration pickup to give you only the amplitude of vibration. Then run the system at some suitable speed, so that you get measurable vibration and the amplitude is A_0. Then at some suitable location, you attach a trial mass m_t and run at the same speed, get amplitude of vibration A_1. Rotate this by 180 degree that means, take it to the diametrically opposite position, run at speed omega, you get amplitude of vibration A_2. Before that you can also rotate it by 90 degrees and a third location you can choose to put your m_t and run the system at same speed omega, will give you amplitude of vibration A_3.

With that, you can draw the figure. It will be either this or that, depending on what is the magnitude of A_3. If it is large, that is the configuration and then you have to rotate your trial mass in the clockwise direction by an angle phi, magnitude will remain or it will be given by the same relationship, but at least the position will be different. It will be here. This is the second case, you have to place it here and its magnitude will be suitably scaled, according to that equation.

If A_3 is small, then your location will be this and this will be your phi. This is the way we handle the field balancing problems of disc like objects. Disc like object means most of the matter is considered to be confined to a plane, which is perpendicular to the axis of rotation.

In the next session, we will extend this technique of disc-like objects for finding out the balancing mass required, by some experiments in the field, in its own position for rotors. That is a major problem. A large number of systems are actually extremely critical from this point of view of balancing like alternators, turbines and so on, where they are very heavy and they have to balance in their original position.