

Mechanical Measurements and Metrology

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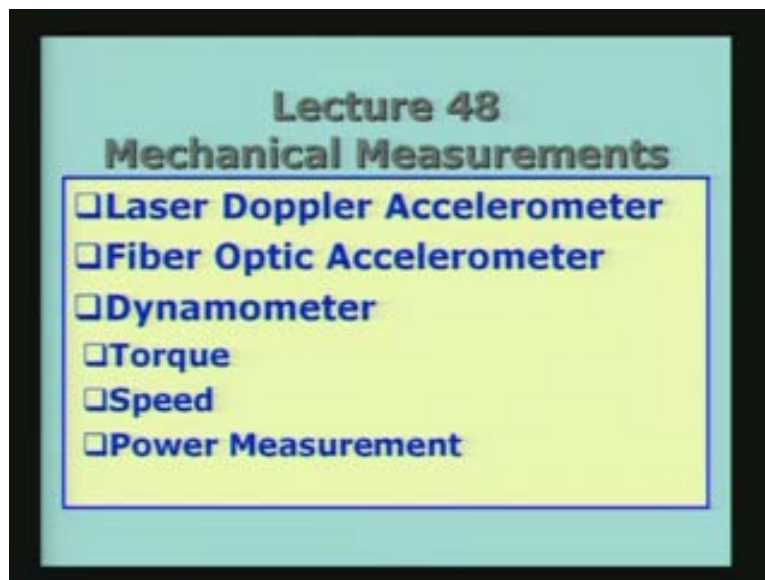
Module - 4

Lecture - 48

Laser Doppler Accelerometer, Speed, Torque and Power Measurements

This is lecture 48 on our ongoing series on Mechanical Measurements. Towards the end of the last lecture we were actually talking about vibration measurement and in particular we were talking about the laser Doppler accelerometer. We will resume from there, and in the current lecture we would like to cover the following topics. We will discuss about the laser Doppler accelerometer then we will also look at a new instrument called fiber optic accelerometer then we will switch over to the measurement of torque, speed and power which are relevant for characterizing engines, power sources and so on. So, that will be the final topic for today.

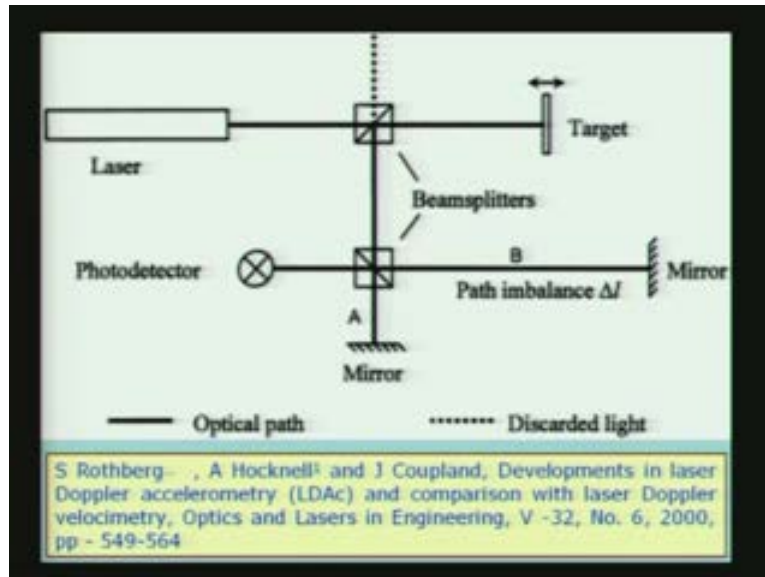
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So we will revert back to the laser Doppler accelerometer which is shown here, in the schematic. As we were explaining in the last lecture, we have a source of radiation in the form of laser, the beam is allowed to be incident on the target which is the vibrating member whose vibration we would like to study. That means the target is moving in and out as it is shown here by

these arrows and the light is reflected from this..... If one wants one can attach a small reflecting tape on to the target so that the light will be reflected back.

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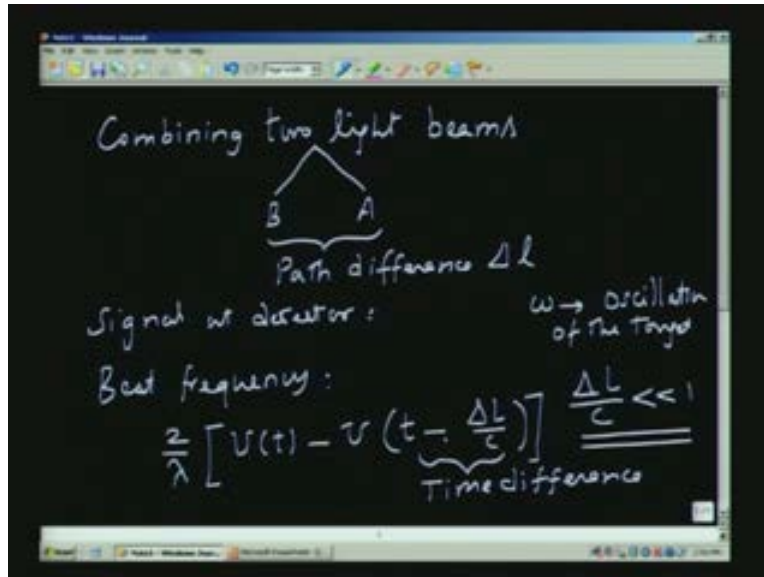
And we have a beam splitter which makes the beam take a 90 degrees turn, and it is incident on a second beam splitter, and this beam splitter will split into two parts where one goes towards this mirror, and the other one goes to this mirror. Hence this length is much larger or much different from this length so there is a path difference between path b and path a.

This path imbalance inserted or introduced wanderly, and that is given by ΔL . Again, the reflected light from this mirror as well as this mirror combine together and are incident on the photo detector. So what happens in this particular instrument is that the laser light which is reflected from the target which is oscillating is combined together after splitting it into two parts one which travels a longer path, and the other one which travels a shorter path, and the path difference being ΔL . Because of this path difference a certain phase difference is introduced, and that is the one which will help us to find out the vibration of the target. So let us look at that in more detail by looking at the following expression.

So now we are combining two light beams, and we are using a laser light because, it gives you a highly coherent beam with a fixed frequency or

wavelength. These two light beams one if I call it the B, and, A there is a path difference which has been introduced intentionally the ΔL . So the signal at the detector, if I am thinking of the frequency, or the circular frequency to be ω this is the oscillation of the target. So the target is oscillating or vibrating. Right now we can assume it is the constant ω .

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Of course, if it consists of different waves put together we can take the Fourier component and work on that. So I am looking at one such component oscillation at a target at ω and now what we get at the signal is a combination of the two beams, B and A and there will be a beat frequency, because when we combine two beams with a phase difference we will get a beat frequency.

So it can be shown that, it is proportional to $(2 \text{ by } \lambda)$ multiplied by the first beam or the second beam $U(t) - U(t - \Delta L/c)$. Because of the path difference, there is a time difference here. This is the time difference. Of course, remember that the velocity of the beam of light is same as the speed of the light and it is a very high value. Therefore $\Delta L/c$ will usually be a small quantity. It is not a large number we are talking about. So it is like combining two beams or two quantities here with a small time difference, and we know from our ideas of differentiation that the difference between two signals is taken with a small time difference. If the quantity we are talking about is the velocity, the difference will be

acceleration, because with a small time difference if you take the two signals it will be proportional to the acceleration. Here, we can assume that U is a sinusoidal given by $A \sin(\omega t)$ and $U(t - \Delta L/c)$ will be $A \sin\{\omega[t - (\Delta L/c)]\}$. So we are now taking the difference between these two sinusoidal functions, and I can use trigonometric relations, so it is something like this; $(\sin A - \sin B)$ is equal to $2 \cos[(A + B)/2] \sin[(A - B)/2]$.

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Best frequency:

$$\frac{2}{\lambda} \left[U(t) - U\left(t - \underbrace{\frac{\Delta L}{c}}_{\text{Time difference}}\right) \right] \quad \frac{\Delta L}{c} \ll 1$$

$$U(t) = A \sin(\omega t)$$

$$U\left(t - \frac{\Delta L}{c}\right) = A \sin\left(\omega\left(t - \frac{\Delta L}{c}\right)\right)$$

$$\sin A - \sin B = 2 \cos\left(\frac{A+B}{2}\right) \sin\left(\frac{A-B}{2}\right)$$

$\approx \omega t$ $\approx \omega t$

So I can combine these two. The difference between these two quantities is nothing but there is a component $(A + B)/2$ and the other one is $(A - B)/2$, this $(A + B)/2$ will be, $(\omega t) + \omega[t - (\Delta L/c)]$ because this is very small and this is simply (ωt) itself. And this is the one which contains the difference in the two quantities, A and B . Therefore, this will be proportional to this $\Delta L/c$. Because this is sine of a small quantity, we can also use sine theta is equal to theta formula and this will simply become ω into $\Delta L/c$. This $(A - B)/2$ becomes ω into $\Delta L/c$. Therefore the signal at the detector will vary according to this form, ω into $\Delta L/c$ into $\cos(\omega t)$. And this $\omega \cos(\omega t)$ if you see here is nothing but dU/dt and dU/dt is $A \omega$ but the factor A is not very important, it is just the amplitude, so you see that this is proportional to acceleration so $(\Delta L/c)$ into acceleration.

In this particular case, the signal in the laser Doppler instrument is proportional to the acceleration, and the acceleration is the output of the instrument. So that is one type of instrument which we can think of where we are using the vibration to generate the acceleration signal through the optical mixing of two beams by introducing a certain ΔL path difference.

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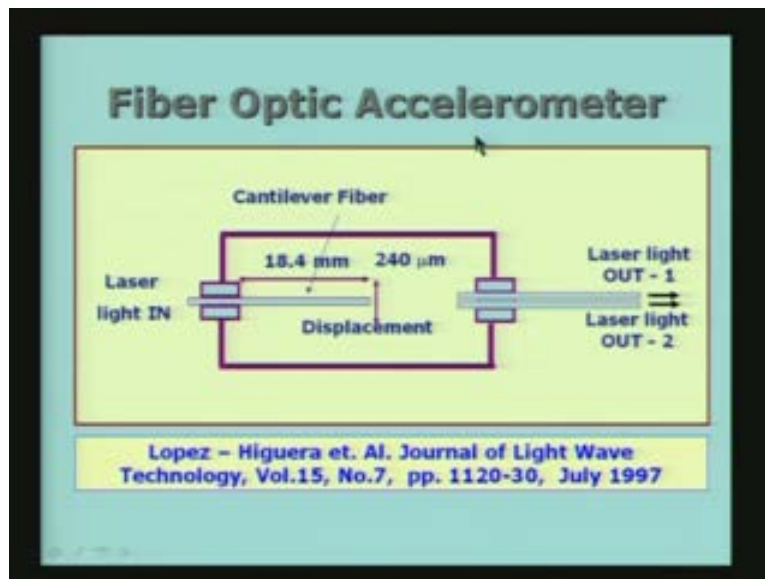
The image shows a blackboard with handwritten mathematical derivations. At the top left, there is a label ΔL . To the right, it says "Time difference". The main derivation starts with two sine wave functions: $V(t) = A \sin(\omega t)$ and $V(t - \frac{\Delta L}{c}) = A \sin(\omega(t - \frac{\Delta L}{c}))$. Below these, the trigonometric identity $\sin A - \sin B = 2 \cos(\frac{A+B}{2}) \sin(\frac{A-B}{2})$ is used. The terms are substituted as $A = \omega t$ and $B = \omega(t - \frac{\Delta L}{c})$. This leads to $\sin \theta = \theta$ where $\theta = \frac{\omega \Delta L}{c}$. The final result is $\text{Signal at detector} = \frac{\omega \Delta L}{c} \cos(\omega t) \propto \frac{\Delta L}{c} \cdot \text{accl.}$

This path difference can be introduced in a simple way. Now-a-days a simple way of doing is to take a coil of optic fiber, and the length can be suitably adjusted so that you get a sizable factor ΔL by c , the light passes through the optical fiber goes to the other end gets reflected from the mirror, and comes back to the same fiber, and then it is mixed with the other beams. The two beams can be mixed together with a large path length required ΔL can be got, because c is a very large quantity. So that is one way of measuring the vibration or the vibration acceleration.

And the second one I am going to look at is a very simple idea. This is called a fiber optic accelerometer. Here we have a cantilever fiber. It is a very small diameter fiber. In this case we can see it is 18.4 mm long, and 240 micrometers diameter, it is a very small fiber. Why do I use a fiber because, I send light beam through the fiber. So, from the laser light on the left side it goes through the fiber and exits from this side.

So if the cantilever beam is perfectly stationary, that is if there is no movement, the beam which enters here will come straight down on this side. So it comes axially out of the cantilever fiber. At the downward side, I have got two optical fibers to collect the light which is coming from the left. These two fibers are kept spatially at different positions. So what will happen is, if the laser beam is coming through this a part of the laser light will enter through the one and the other part will enter through the two and if it is symmetrically arranged with respect to the fiber then one half will come, and the other half will come here therefore the intensity of laser light coming through this, and this will be exactly equal.

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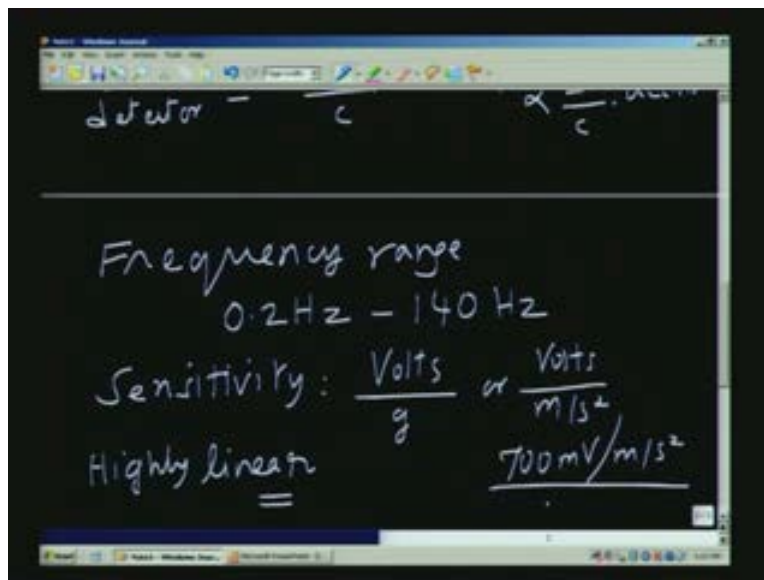
To start with, when the fiber cantilever fiber is perfectly stationary, then these two will give you the same output; the signal will be the same. Now imagine a certain vibration being imparted to this fiber. This fiber is now going to sense the vibration which we want to measure. So what will happen is, if I subject it to vibration the free end will start going up and down. So if the free end moves down it will communicate more to the lower fiber, and less to the top fiber. Therefore, if you take the output from these two, and look at them they will oscillate, they will also change in time. So the displacement of this will create a difference between these two signals through this, and therefore whatever information I have here in terms of the frequency of vibration will also be the vibrational frequency at which this

signal will oscillate. That is the basis for this particular method, and it is a very simple instrument.

This whole thing can be very small enclosure with the cantilever fiber being attached here, and two fibers are going out they can be attached to the suitable attachment here, and these two fibers can be very long so that you can make the measurement far away from this particular accelerometer. The accelerometer is very small. The point is, if the frequency of vibration impressed on the cantilever fiber is much smaller than the natural frequency of the fiber itself, then it responds very well to the input signal. So displacement will be proportional to the input if the natural frequency of the cantilever fiber is much larger than the frequency at which the vibration is taking place.

Therefore, it will respond to the acceleration signal, and what you get here will be proportional to the acceleration, and that is what we would like to measure in this case. Here are some figures which discuss the specifications for this particular instrument. The frequency range for this instrument is about 0.2 Hz, in this particular example, and the one which I have constructed is 140 Hz, and sensitivity as usual is given in terms of the output voltage for a given acceleration therefore v by g or v by m by s square, either one can be given.

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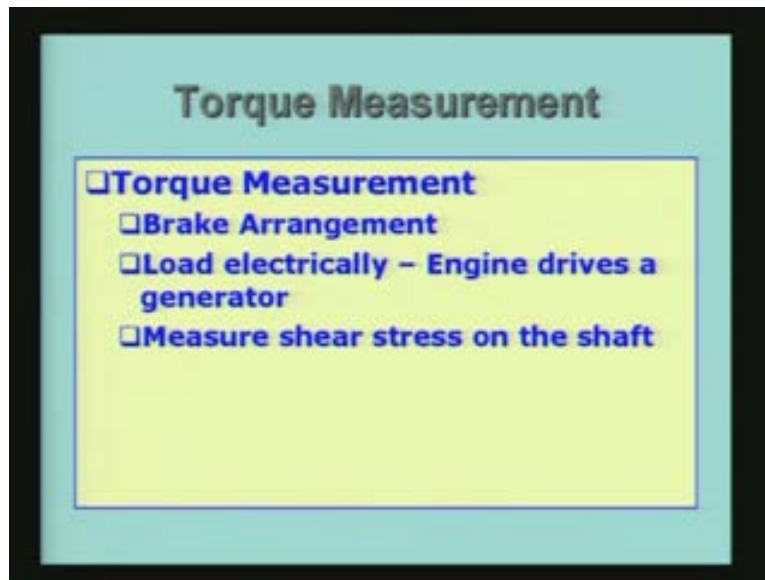


In this particular case, the value quoted is about 700mV by m by s square is the sensitivity of the instrument. It is highly linear, so that is also another important feature of this particular instrument To just to recapitulate what we have done in the last two lectures we have tried to cover as many ways of measuring the vibration related quantities like vibration frequency, vibrational amplitude and the acceleration because of vibration. These are the quantities we have highlighted. That completes in one sense one area of measurement which we encounter in mechanical engineering.

We will now move on to another interesting area known as measurement of torque which is the last area I am going to consider in this course of lectures. Why do we measure torque? Torque is measured because we want to measure the mechanical output of an engine or a power source as to whatever we are interested in. For example, we may want to know the rating of a motor so in all these cases we need to measure the torque. The torque itself can be measured by various ways. For example, you can use a brake arrangement.

And if you remember from your thermodynamics, and applied thermodynamics courses, we usually talk about the brake horse power or brake power output. We can also measure the torque by allowing the engine to run a generator or drive a generator and the generator is generating electrical current with certain voltage, now I can load the engine load the generator by connecting it to a set of resistances which will dissipate the energy in the form of heat.

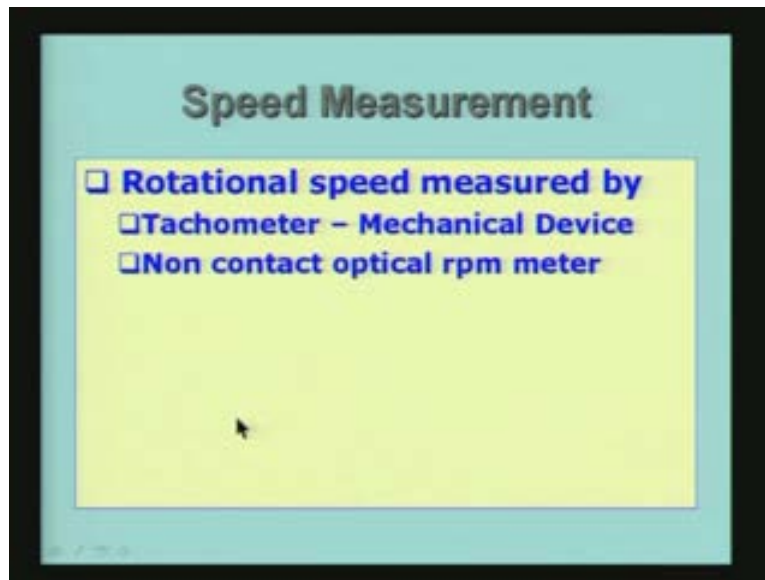
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So I convert the mechanical power to electrical power and the electrical power is dissipated. And the more I dissipate the electrical power the more load it will bring on the engine therefore the engine load can be changed. And as the engine load changes we would like to find out what is the power developed and what are the characteristics. For example, I may be interested in finding out how much fuel it is consuming for a certain output.

So I have to measure the fuel input, the amount of fuel which is consumed and find out what is the power and then I will be able to relate these two quantities. So one method is to load electrically, an engine which drives the generator, and the generator is loaded electrically to a given node. In the case of brake arrangement, it is the mechanical loading, and in the case of a generator which is being run it is the electrical loading which is done. We can measure the torque directly by using a brake arrangement, or we can measure the shear stress on the shaft as it rotates, and from the shear stress I can find out what is the corresponding torque which is possible.

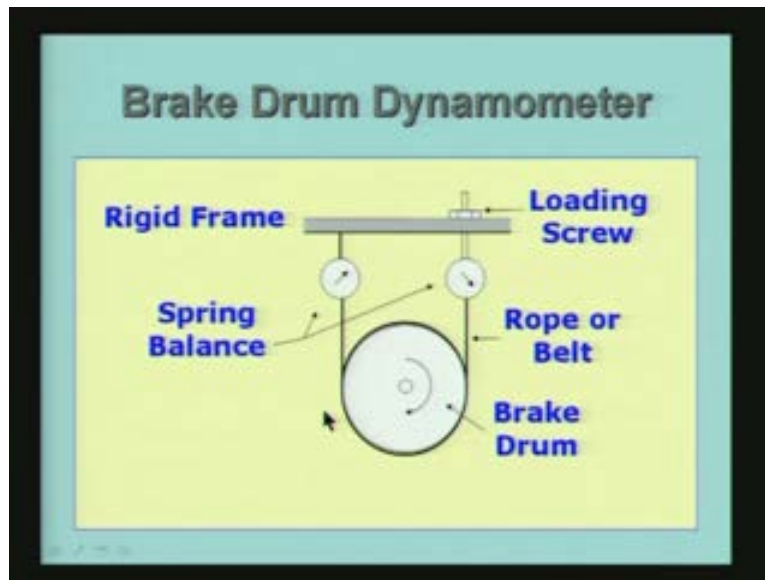
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And if I want to measure the speed in most cases, I will be interested in the rotation speed. It can be either measured by a mechanical device either the tachometer or a speedometer, or I can use a non contact optical rpm meter.

For example, we have a brake drum dynamometer which is a very simple instrument. What we have done is that we have a rigid frame and this is the brake drum which is driven by the shaft, and the shaft is driven by the engine, which I want to test. So, on the brake drum, I have got either a belt or a rope which can go around several times, it is not necessary to have just going once it can go around several times, and it is attached firmly to the rigid frame on the left side here, and with a spring balance and on the right side I have a loading screw so that I can increase or decrease the tension by turning the screw so you can load the beam. So what will happen in the case of brake drum dynamometer is that, because of the friction between the brake drum, and that is why it is called the brake, in a brake it is the friction which is going to come into play. So the friction between the drum and the rope or the belt is going to make the tension here different from this.

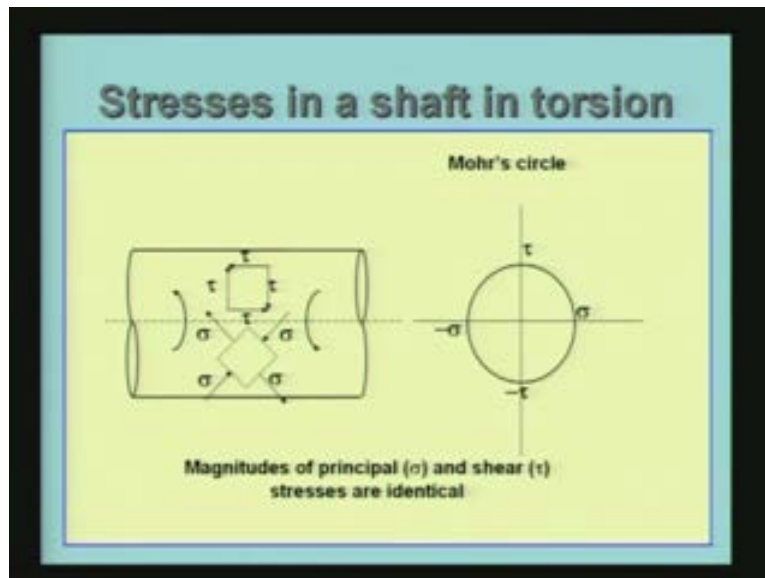
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This will be higher than this, it is rotating like this and here this is the higher tension and this is the lower tension, therefore, there is a difference in force, this force is different from this force and that multiplied by this radius of the brake drum actually gives you the torque which is being applied on the engine. So the engine torque is measured by the difference between these two spring balance readings multiplied by the radius of the drum. This is one way of doing it.

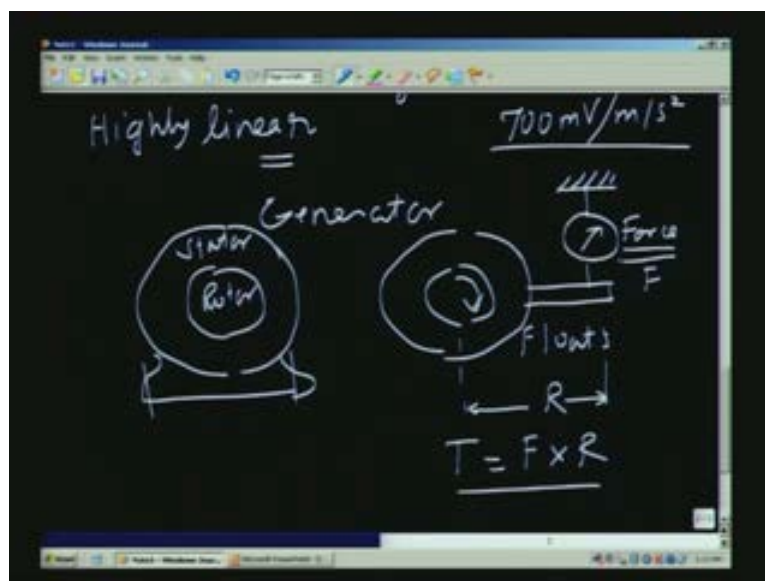
Another way of doing is to actually to use what is called a pony brake in which instead of using an arrangement like this and two spring balances we can actually have a brake riding on the brake drum, and it will be resting against a platform balance, and it will press on it, The reaction from the balance will be measured directly, from the balance reading. Therefore the platform balance measures the force, and that force multiplied by the lever arm will directly give you the torque.

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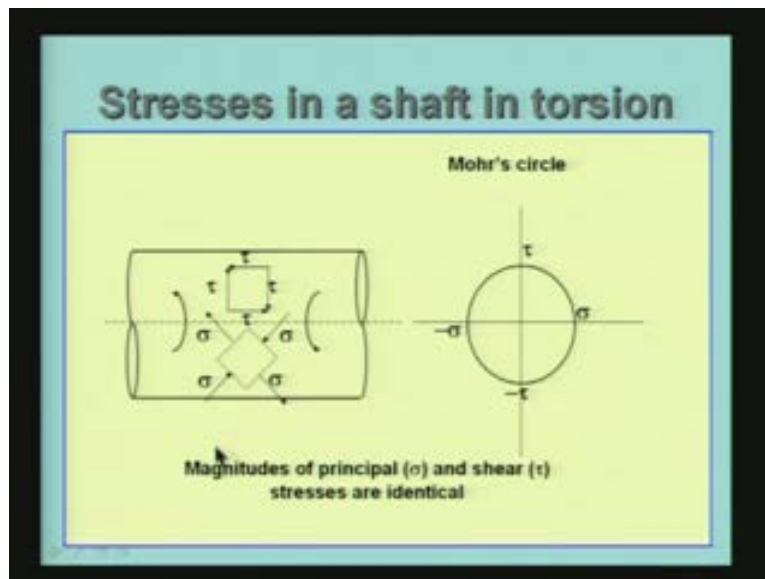
So the other ways of measuring the thing is to measure the stress is in a shaft in torsion. For example, if this is a generator, and this is the rotor, this is the stator generally of course, the stator will be fixed to the ground. But in this arrangement what we will do is, we will allow the stator also to float. So this is the rotor, this is the stator, it is floating because it is mounted onto bearings at the two ends so if the rotor rotates this is also free to rotate.

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But what we will do is we will attach some kind of an arm to it, and then put it against, or I can put a force measuring force balance here. So if this rotates, this will also tend to rotate, and therefore there will be a force and the tendency to rotate is balanced by the force which is acting here and therefore this is a floating design. So the generator in which the stator floats, and it transmits the force or the torque onto this arm, and this force which you measure here is multiplied by this distance, so we will call it R, this is F, torque is F into R. This is one way of measuring it. These are purely mechanical way of measuring the torque, directly by measuring the force and the corresponding momentum, and then the product of these two is going to give you the torque. The other method which we will discuss is the one which uses the following arrangement.

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We know that if you have a shaft which is in torsion there is a shear stress. If you draw the shear stress diagram it is like this on the surface of the shaft, and if you draw the corresponding principle stresses they are at 45 degrees. You can see here that this is at 45 degrees to the axis, and this is also at 45 degrees, and you also will notice that these two principle stresses are tensile while these two are compressive. There are two compressive stresses in this direction, and the tensile is in this direction, and all these are equal in pure shear when you have a shaft in shear.

In fact you can draw the Mohr's circle which is familiar to you. If you apply mechanics you can see that the tau and the sigma and minus sigma are the Mohr's circle and these are the two principle stresses, and you can immediately see what we can do. Suppose, we are able to place two load cells in this direction, and in this direction, this will respond to the tensile strain and this will respond to the compressive strain. Therefore this will be reducing the length of the load cell, and this will be increasing the length of the load cell, and therefore a difference between these two will be able to give you a large enough signal. And also you notice that, these two sigma values are similar, and has the same value as the tau value. The tau and sigma have the same magnitude in this particular case of pure shear. So imagine the shaft to be the shaft of the engine which is driving either the generator or it is connected to a brake.

You need not measure anything towards the brake side, but now I am measuring everything on the shaft itself. The advantage of this is, this can be permanently attached to the shaft and we can do the measurement without any problem. It does not involve too much of manipulation as in the other case where you need external measuring device, a force balance and things like that.

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Stresses in a shaft in torsion

- The magnitude of the shear stress or the principal stress on the surface is given by
- T = Applied Torque
- R = Shaft radius
- J = Moment of Inertia about the shaft axis

$$\tau = \sigma = \frac{TR}{J}$$

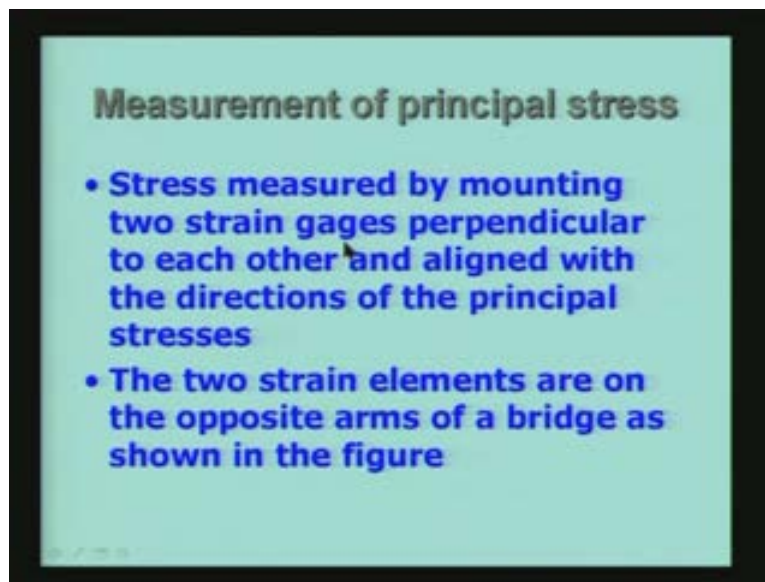
Note: $J = \frac{\pi R^4}{2}$

Torque is being estimated

So the magnitude of the shear stress, or the principle stress on the surface is given by this formula tau is equal to sigma is equal to TR by J, where T is the torque applied, R is the radius of the shaft, J is the moment of inertia of

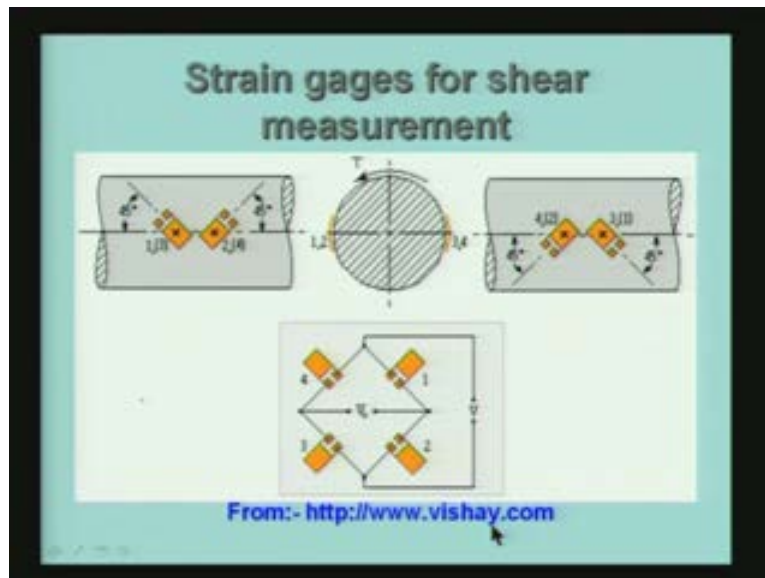
the shaft, and J is actually given by $\pi R^4/2$. So all I have to do is substitute it here so if I know the value of R , if I measure σ or τ , because this is proportional to the load cell reading which I am going to get because, I am going to use a load cell to measure that, I can actually get T is equal to $\sigma J/R$ and that is how you measure the torque. Therefore for measuring the σ or the τ indirectly what we can do is, we can measure by mounting two strain gages perpendicular to each other and align with the directions of the principal stresses.

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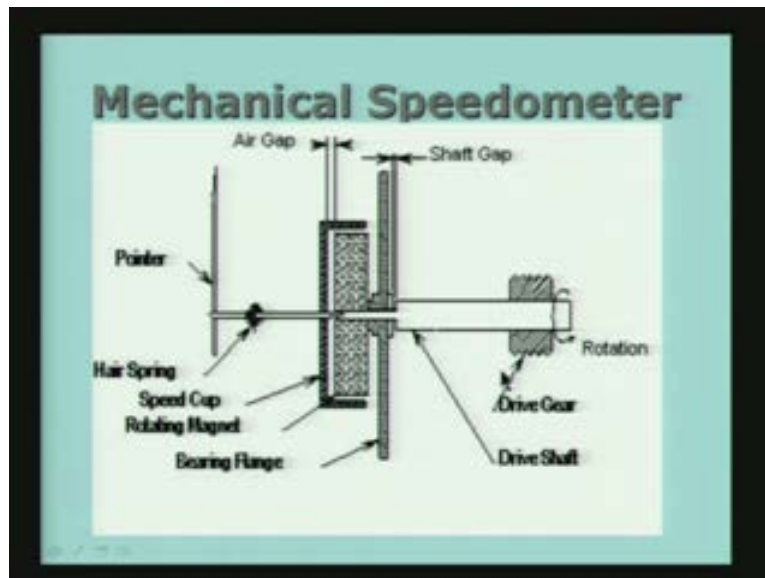
That means if you remember that the principal stresses are now 45 degrees to the shaft axis. Therefore these two strain gages must be aligned at 45 degrees with respect to the axis, and the two strain elements can be placed on opposite arms of a bridge, because one of them is in tension, and the other one is in compression. So the change of the resistance on both the arms will help in enhancing the signal. Now you can see how it is going to happen.

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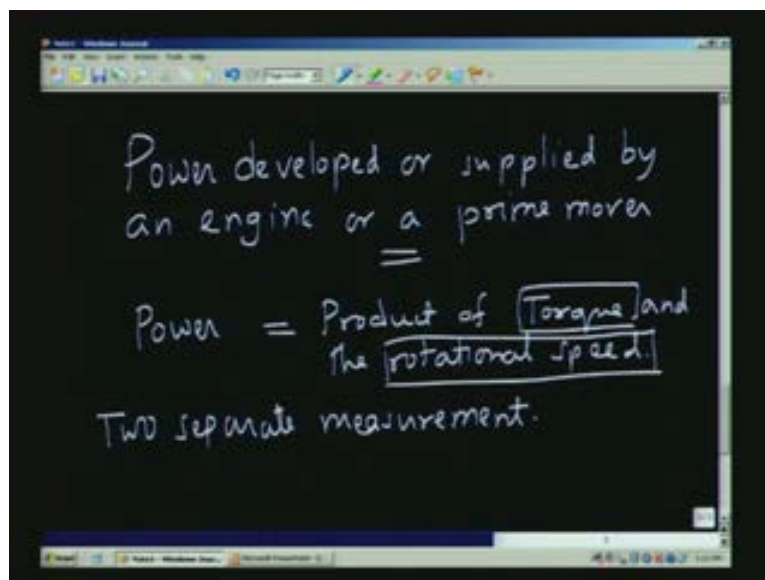
If I look at the strain gages attached here, this is the shaft I have got, 1 and 3 and 2 and 4, there are two and you can see here 4 and 2, 3 and 1 they are on the opposite sides. I have arranged 1 and 2 this side and 3 and 4 on this side. So two strain gages are attached on this side and the other two strain gages are attached on the other side, and this is how they are connected. So 1 and 3 are on the opposite arms of the bridge and 2 and 4 are in the other arms of the bridge. Therefore the signal here is bigger than if I have only one of them for example, because in principle I can measure the sigma by just attaching one of them at 45 degrees. The idea of putting them in this particular arrangement is to get a larger signal, and in this case I have got two, 4 and 2, 1 and 3 are on the opposite sides of the bridge, and when we discussed about pressure transducers and so on we have already seen how we analyze such a system, and we know that the signal is in fact proportional to two times the signal because they are going to magnify them and this will be another two times so this will be proportional to four times the signal so you get a large advantage.

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So having discussed the measurement of torque let us look at the measurement of speed. When I am talking about speed I am talking about the rotational speed of a shaft or rotational speed of an engine. Let us know why it is important, why we require this.

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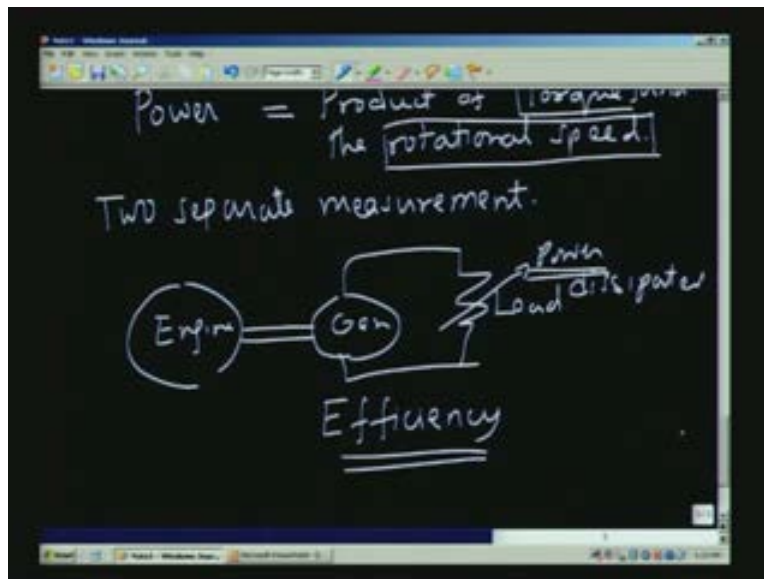


If I am interested in determining the power developed, or supplied by the engine or a prime mover, which is under a test then how we do that. The

basic idea is to measure the power as the product of torque and the rotational speed. So we are now thinking in terms of measuring the torque separately and the rotational speed separately. So these are two separate measurements. Of course, it is also possible that one may be able to measure the power directly.

For example, we have already talked about a generator being connected to the engine. We will just look at how it can be done. We have the engine or the power is connected to the generator, and it is supplying a load and power is dissipated here. So in fact it is perfectly logical to find out what is power dissipated and directly relate it to the engine power. Of course, the problem is that there may be some efficiency involved. To the extent that the efficiency of the generator and the coupling and so on is not known, or has uncertainty that will be affecting the power measurement in this direct measurement. So in the case of direct measurement even though it is possible the power dissipated through the load can be directly related to the power generated from the engine if we know the efficiency of the intervening items.

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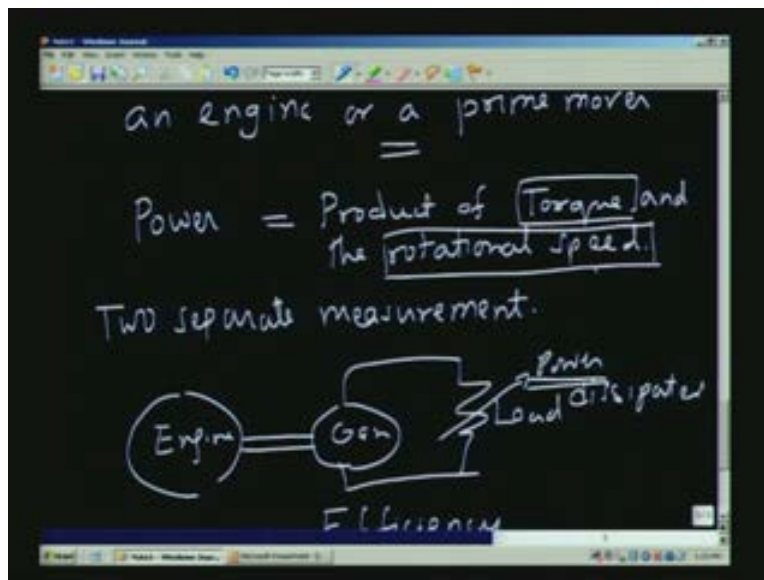


Hence, in this case, it is the generator efficiency, and then the coupling efficiency, there may be friction and other losses and so on. Those are the problems which make it difficult to use this method. Even though for rough measurement it is perfectly logical to make the measurement in this

particular form. Or, for example, if an engine is running the water pump for example, and if you can measure the output of the pump in terms of the flow rate or the mass flow rate of the water, and we know the head through which it is being pumped that is another way of finding what is the power output. This also gives you the power output. Of course, there again the same problem will come.

Problems like what the pump efficiency is or what is the intervening lubricate losses due to friction and so on will come into picture. But for a rough estimate, it is possible to do that, and in the many cases that will be sufficient. But what we are now talking about is when you want do a very accurate work, and when you want to measure it looks like the only possibility is to measure the torque and the rotational speed separately.

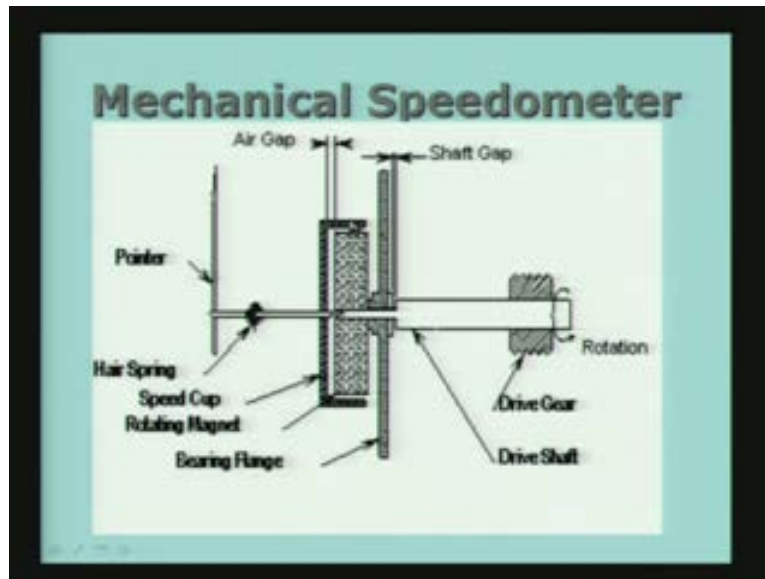
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So we have already seen how to measure torque and the different methods available in measuring the torque. Now let us look at the rotational speed. We will take a look at one or two different ways of doing it. So we have two types of arrangements. We can have a mechanical speedometer and that is schematically shown here. This is again an electrical setup, so the rotation of the drive shaft through gear mechanism will rotate the shaft here. This is what I want to measure the rotational speed this is now connected to whatever engine or source whose rotational speed I want to measure.

Now this is going to relate to that one. It may be either directly equal to that or it may be a fraction of that, because you can have a gear time doing that. Let us see what the components are in that. This is the heart of the speedometer, we have a magnet, this is the magnet which is surrounded by a speed cup or this can be the rotating magnet and this could be the flange.

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So what happens is when you rotate a magnet by connecting it to the shaft here, this flange will tend to follow the magnet, because it is going to be facing or experiencing a varying magnetic field, and because of that this will tend to rotate and the rotation is actually prevented by connecting it to a spring. It will react to the changes in the magnetic field but restrained by the spring. Therefore it will take up a certain position of equilibrium where the torque applied by the spring is equal to the torque which is generated by the varying magnetic field, because of the magnetic cup which is rotating over that.

How does it come about?

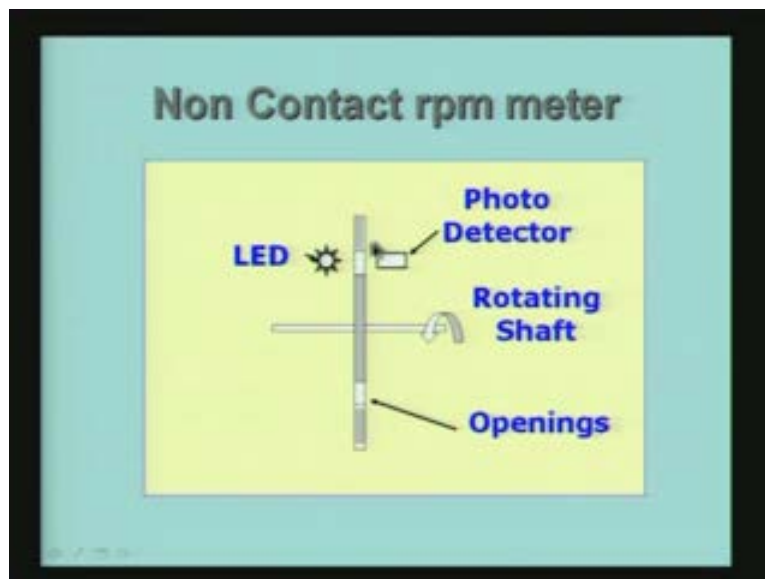
It comes about because of this flange the eddy currents will be generated and the eddy currents will be dissipated through that in the form of heat, and therefore it is going to experience a torque. So actually we are converting a rotation which is what we want to measure through a torque, and this torque is balanced by a spring, and the pointer here will indicate the speed direction. This is the mechanical speedometer which is found in most

automobiles and other two wheelers and so on. This is a simple instrument and it contains a permanent magnet and the flange which is rotating inside is going to generate the torque which is restrained by the spring, and you are going to have a pointer which indicates the speed directly.

So the second method which is going to be discussed, is slightly different. This is a non contact rpm meter. In fact there are many variations of this. The one which I have shown here is only one such thing, and I will describe one or two more on the board. So what does it contain?

It contains the rotating shaft which is connected to the engine or whatever whose rotational speed I want to measure, and there is a wheel, this is the wheel with holes in it. In this case, I have shown two holes at 180 degrees apart, but there can be more holes or there can be one hole depending on the particular design. I have a light emitting diode which is shown here, and opposite this is the photo detector which is shown here.

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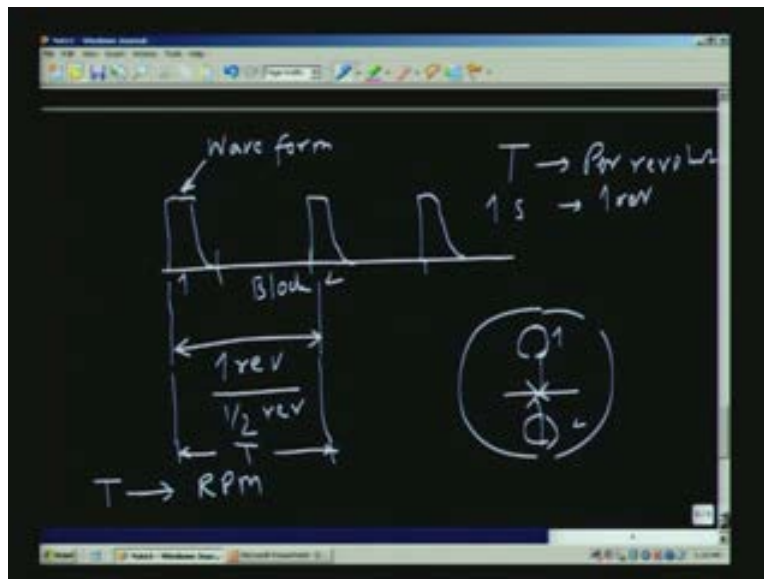


Therefore a light emitting diode or a source of light, and a photo detector is an important thing which will respond to the light which is falling on it. And you can immediately see what is happening. When the shaft rotates, sometimes the hole will be in front of the detector or in between the LED and the detector, and sometimes the hole will be away in which case there will be no communication between these two. So essentially what we are doing is the communication between the light leaving the light emitting

diode and the photo detector is blocked when the hole is not in front of it, and it is open or it is communicated when the hole comes in front of that.

Suppose, I look at the signal from the photo detector the photo detector will show a signal as something like this. The photo detector gives electrical output. This is a simple diagram of a photo detector. This is the output and this is the block, and again when the hole comes in front of the detector you get that signal, and you again see a block and so on. This is the waveform showing how it is going to change. So you see that the period of this is, if there is only one hole this will be one revolution, if there is only one hole at three 360° , that is you have an arrangement like this you have only one hole. So whenever it comes in between the photo diode and LED, it will give you a signal. Suppose I have two of them, this is one and two so this will correspond to one, this will correspond to two and this will correspond to half revolution.

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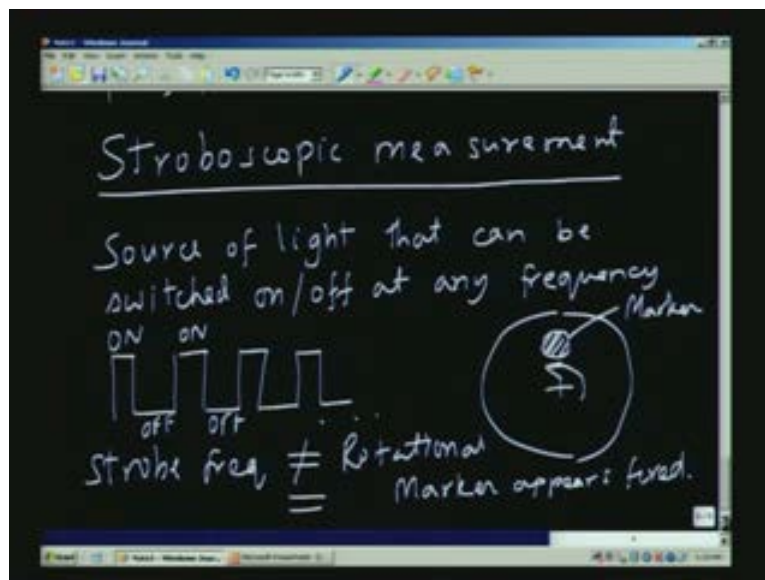
Therefore, if you measure the time taken from here to here we will call it as T , then this T will be either equal to one revolution, time taken for one revolution or it could be a half a revolution, or if I have four of them you can see that you can now get a signal, every time a hole comes in front of it you are going to get a small blip, or an output and the rest of the time it is going to be 0. Therefore, it is like actually the number of times the hole is coming in between the light emitting diode and the photo detector. So the time here

can be either related to one revolution or half a revolution or a quarter revolution and so on.

Therefore we can see that, the time here is per revolution, T is related to per revolution, so suppose you get one second in one revolution you can immediately see what the rpm is, because one minute will correspond to sixty seconds therefore there will be sixty revolutions. This just gives you a direct relationship between the period or T or the period between the two of these and the revolution. So T is directly related to rpm.

Of course, the factor will depend on whether we are going to have one hole or two holes and so on and so forth. So there is a conversion factor which depends on the amount of time T here, so T by rpm, so T corresponds to some revolution per minute because in the case of the single hole every time we are measuring 2π or one revolution correspond to that time and if it is two holes it will correspond to half a revolution, because every half revolution will come in front of that. This is one way of measuring the rpm.

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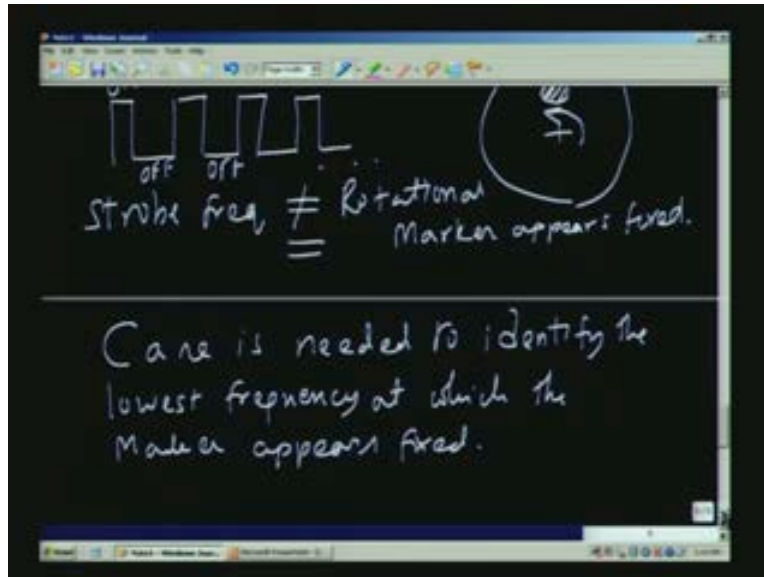
Let us look at another method which is also very interesting called stroboscopic measurement. Stroboscope is nothing but a source of light that can be switched on and off at any frequency. So, it is on for a small period and it is off and again on. So, in this case the source of light comes like this. This is on, off, on, off and so on.

Suppose I do the following; Suppose I have a wheel on which I have put a small marker this is the marker, you have a wheel which is rotating and you have a marker, suppose I have the stroboscopic light incident on the place where the marker is present suppose, I illuminate it with the stroboscope, and suppose the stroboscope frequency is different from the frequency with which this marker is rotating, sometimes you will see the marker and sometimes you will not see the marker. So, if the strobe frequency is not equal to rotational frequency,

So, if the strobe frequency and the rotational speed are not related to each other, the marker will be sometimes seen or sometimes you will not see the marker. In other words, it will appear as though the marker is moving, sometimes you see the marker and sometimes you do not see. Suppose this frequency is the same as the rotational frequency so every time the light comes on the marker is in the same position. So what will happen is if the strobe frequency is equal to the rotational frequency exactly equal to it then marker appears stationary.

Of course, the observation is made by the operator. So you have the strobe in the hand and illuminate it and hold it against the marker and then keep on changing the frequency of the strobe. There is a dial and you change the dial so that you increase the frequency. You start from a low value and keep on increasing. At some particular value of the strobe frequency which of course, is calibrated in the dial will show you what the frequency is, and you will see that the marker appears fixed. That means that the strobe frequency and the frequency with which the marker is coming to that particular place are exactly the same. Therefore, you can immediately see that, this frequency and this frequency of the marker curve, if there is a single marker it will come once in every revolution just like the hole coming in between the LED and the photo detector here the marker is doing the same job. The marker is coming back to the same location and the marker's location if it appears to be fixed, then there is no shifting of the marker it looks stationary, then you know that the strobe frequency and the rotational frequency are the same, and therefore the rpm can be directly related to each other. But the problem is the following.

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Suppose, if the marker comes after every two revolutions to the same position, for example, if the strobe frequency is double the rotational frequency of the shaft, if it is doubled then also it will appear fixed, because every two times the strobe will go twice and, because our eye will not be able to follow that it is just because we are using eye as the device. So what will happen is, if the strobe frequency is multiple of the rotational frequency of the shaft also there will be appearance of the stationary marker so that is the problem.

Therefore one good way of doing that is to start from a lower frequency and go up so that the first time you will get a match so that is the correct speed. Or, if you do the following, if you vary the strobe frequency it will appear to be stationary at one particular value again at another value at another value, and so on you can look at the ratios of these so that will tell us something about whether it is fundamental or the higher speed or the higher speed and so on and so forth. Therefore the only thing is we have to be careful about care is required to identify the lowest frequency at which the match will come; the marker appears stationary or fixed. This is one way of measuring the rotational speed.

We actually discussed three methods; one was the speedometer which is based on the rotating magnet principle, the second one was the photo diode pick up, and the photo diode LED pick up is now commercially available in

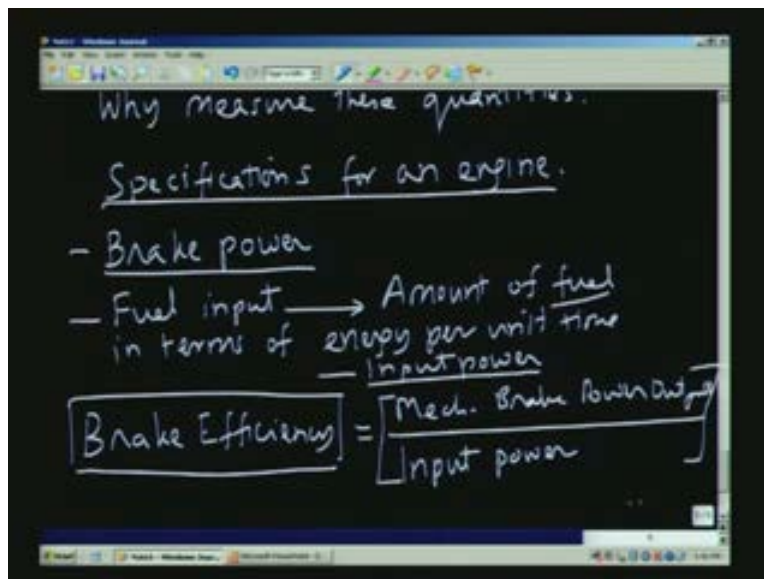
the form a unit along with it's electronics and it does not require too much of effort to set it up. You do not have to but each item separately and so on but it is available as a unit and you can buy it and set it up.

Of course, the advantage of this handheld speedometer is that, it is a mechanical instrument and there is nothing to go wrong in it and it is very easy to use it. But if you are going to use the handle speedometer it requires some arrangement on the shaft and therefore many times it is not desirable. Normally now-a-days what is the best method which is useful is the one which consists of the LED and the photo detector. Let us look at the reason why these measurements are important, this will be the last part of the discussion here.

Why measure these quantities?

Already we have mentioned a few reasons for it. One is, of course, in drawing specifications for an engine for example. So what are the things we have to do is we have to measure the brake power, next we have to measure the fuel input. So what does the fuel input say? It gives you the amount of fuel in terms of energy per unit time which is again an input power.

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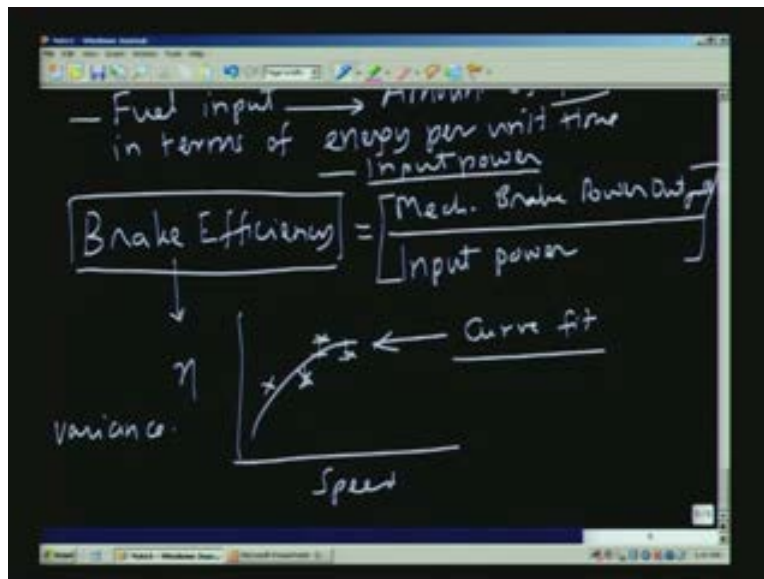


If you look at the engine as a transducer or a converter what it is doing is, it is taking the input power in the form of internal energy in the fuel or chemical energy or potential energy in the fuel, and it is converting into

brake power. Therefore normally what we do is we define an efficiency, or brake efficiency, or sometimes we also call it as, the brake thermal efficiency which is usually given in terms of mechanical brake power output, because the brake power output is a mechanical output, we are running the engine against a mechanical load, therefore it is a mechanical power output which we are talking about, divided by the input power in the form of the chemical energy in the fuel. So this will be the most important specification of our engine.

Of course, there are other things also. For example, we would like to know what is the range of speeds at which it can be operated, and also the characteristics of an engine. For example, I would like to do the following; the efficiency and its quantity versus speed, I should be able to draw curves which give the efficiency of the speed so that I will know how the engine is behaving. In this case, I have taken the example of an engine, it could be any prime mover so you will get some curve like this, some numbers like this. So you will immediately see that, this data can be analyzed by using the methods we have discussed earlier by curve fitting.

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Therefore in any activity which involves measurement including the characterization of an engine we can talk in terms of fitting the curve and then talking about the variations. For example, you can see these are the error bars, there are errors here, you can find out the variance of the eta or

the standard deviation of the eeta which we are measuring. Therefore it contains lot of wealth of information. This is only possible by making measurements. Thank you.