Course Name: Engine System and Performance
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Lec 31: Measurement of torque: Power output from engine, Numerical problem

I welcome you all to the session on engine system and performance. In today's class, we shall discuss the measurement of torque, which is again an important quantity to be measured to predict engine performance. So, we have studied in our undergraduate internal combustion engine course. In fact, we have seen in the context of IC engine tests that to measure the power output, typically we use a particular device, and that is known as a dynamometer. So, today we shall discuss this particular device, and we shall see how using this device we can measure the torque produced by the engine and thereby the output energy for the operating range of speed and load of the engine.

So, dynamometer. This is a mechanical device, which is used to measure torque and speed and thereby power output for the operating range of speed and load of an engine. And this dynamometer can be classified into two different categories. So, if I write here, this dynamometer can be categorized into two groups. One is basically known as the transmission type dynamometer, and another category is the absorption type.

So, as I said, dynamometers are used to measure torque and speed of an engine over the operating ranges of speed and load. So, we can measure the torque. If we can measure torque, certainly we can measure the output power from the engine. Now, this transmission type, from the name itself, you can understand that essentially, we need to use a particular device to measure torque, and that should be the transmission type. In the transmission type, this utilizes the device.

So, a device is used to measure torque in terms of elastic twist or the device can be such that it can be inserted between two sections of the shaft and thereafter we can measure the torque. Special torque meter or a special torque meter is inserted between sections of a shaft to measure torque. So, this is all about transmission type. What about absorption type? So, from the name again, you can understand the output power or the power that is produced by the engine will be absorbed by some component of the dynamometer. Now, depending on the component again this particular dynamometer can be classified into subcategories.

So, absorption type dynamometer uses methods. So, utilizes methods to absorb energy output of the engine. So, now this is what we can see and since this particular dynamometer uses some means to absorb energy essentially that energy will be converted into heat. So, that heat must be dissipated. So, this is the main classification of this particular device which is used to measure torque and speed.

But that example of this absorption type dynamometer, which we will discuss in this particular course, are mechanical. Number two is eddy current dynamometer, electrical dynamometers. So, all these typically, in today's class we shall be discussing about this special mechanical type dynamometer which is or mechanical type dynamometers which are used to measure engine speed and torque over the operating ranges. this particular mechanical type again, there are many.

So, this mechanical dynamometer could be one. So, it can be further subclassified into two different categories. As such, two different mechanical dynamometers will be discussed today. One is the rope brake dynamometer. That is what is used in undergraduate internal combustion engine lab tests or lab testing facilities. Another is the hydraulic dynamometer. So, these two we shall discuss in today's class. So, if we go to the next slide, again this absorption type that we have discussed so far, further classified into further subcategories. So, absorption type dynamometer.

So, this particular type again can be further subclassified depending on the fact that whether or not they have the capability to motor the engine or spin the engine when the engine is not producing any work output. So, this particular type can be further subclassified into categories depending on the fact that, depending on the criterion, whether or not this particular type of dynamometer is able to motor the engine or spin the engine when the engine is not producing any output power. So, that way we can divide. This is equivalent to spinning the engine. Motor the engine or spin the engine when the engine is not producing power. So, based on this, this hydraulic type cannot motor the engine while the electrical type can motor the engine.

So, now, let us discuss these two different types as I have mentioned here: one is the rope brake dynamometer that you have already studied, and the second one is the hydraulic dynamometer. So, if you go to the next one, that is essentially the schematic depiction of the rope brake type dynamometer. It is very easy to understand what you can see from the schematic depiction is that, in this particular dynamometer, this is the engine shaft, which is essentially rotating when the engine is producing power and a circular disc or drum is mounted on this shaft. So, this is essentially, you can see, this is a drum which is mounted on the shaft. So, as the shaft is rotating, the drum will also rotate, and a few numbers of rope turns on the drum. So, the drum which is mounted on the engine shaft will rotate, and on the outside of the drum, a few numbers of rope turn on the drum, and the energy will be absorbed due to the friction of the rope and the drum.

So, as for the rope, there are two ends of the rope. One end is connected to the spring balance, and the other end of the rope is now holding this load. So, when the shaft is rotating, the drum will rotate. Now, if we try to apply some load on one end of the rope, that will create some resistance or frictional resistance between the rope and the drum, on the outside of the drum. The outer periphery of the drum will absorb energy due to that frictional effect, and that is why it is an absorption type.

Now, depending on the load from the spring balance, we can measure—using a calibrated spring—what the power output of the engine is. So, this is the simplest one, but the limitation is that this particular dynamometer though very simple, is not as accurate or flexible at higher energy levels. So, these are the simplest type of dynamometers, but they are not as flexible or accurate as other types at high energy levels. So, basically, if we talk about electrical or hydraulic types, they are more flexible as well as more accurate. So, compared to these types—electrical, eddy current, and hydraulic—the rope brake dynamometer is not as flexible or accurate. So, this is the limitation. So, just for the sake of completeness, the limitation is that this type is the simplest type, but it is not as flexible or accurate.

As others at high energy levels. So, that means if we need to use this particular dynamometer for measuring high work output or high-power output. This dynamometer may not be accurate as others. So, now let us go to discuss about this mechanical dynamometer which is hydraulic type 1. So, as I said you that all these dynamometers are essentially absorption type.

So, they absorb energy produced by the shaft and that in absorption of energy will be an indication of the measurement of the power output of the engine. So, what we seen in the context of rope brake dynamometer is that energy is absorbed by the friction between rope and the drum. So that energy as I said whenever any component is absorbing energy, so earlier case we have seen that is basically friction, so that frictional effect will give rise to heating, so heat has to be dissipated. Otherwise life of the components like rope and the material of the drum will reduce with time.

So, in this particular type from the name itself you can understand though it is mechanical type, absorption type, but it is hydraulic type. So essentially hydraulic, the word hydraulic is used to indicate that there is a working fluid and the working fluid is water. So, like you have studied hydraulic machines. Hydraulic machines are machines, are those machines whose working fluid is water. So, here only hydraulic type.

So, if we try to describe the constructional feature of this particular type. So, this is engine swap and that is rotating continuously. So, what you can see this hydraulic dynamometer whether it is type 1 and type 2 are used for measuring power of internal combustion engine or IC engine when power output and speed are very high.

So, rope brake dynamometer cannot be used for this type of application. So, this is number 1 and we are discussing type 1. So, this type 1 and type 2, this is again based on the classification. So, hydraulic type can be classified into two categories. That is number a) is, friction type. Number b) is, agitator type. So, this is the first one that we are talking or discussing is friction type. Hydraulic type, but again hydraulic type can be classified into two different categories. Type one, that is friction type.

So, this is the friction type—in this type, what is happening? The difference between friction type and agitator type. So, if you go to the next slide, then I'll come back again to this slide. So, friction type, this hydraulic, the water is used as the working fluid, that water is used as the medium of momentum exchange, or that water is used to absorb energy. Certainly, absorbing energy, water temperature will increase, but we need to have or we need to control the amount of water as well as its temperature using a servo-electrical control system. So, friction type—in this type, what is happening? That coupling force—what is this coupling force? So, if you try to recall the rope brake type, we had seen the force that is coupling—so basically, the rope and the drum. So, the outer periphery of the drum and the rope—so that there is a coupling force. So here also, so one is the stator; another one is the rotor. So, the rope is trying to retain or restrict the movement of the drum, and the drum will be rotating because of the shaft, which is rotating and which is integrated to the engine. So, the coupling force between the rotor and stator—arises from the viscous shearing of the fluid. While in agitator type, the coupling force, so as if something is trying to couple—so the rotation should be restricted/prevented. So that part—if we need to prevent the rotation of the strap, we need to have some forcing externally. So that force will try to couple.

So that is called coupling force. So, the coupling force arises for this particular type, which is the agitator type. From the change in momentum, of the fluid (water), because this is a hydraulic type, as it is transported from the rotor vane to the stator vane and back again.

So, this is what the agitator type is. So, based on this arrangement of momentum transfer, from one component to another, that is, from the rotor to the stator. In the earlier case, we used a rope. But in this case, the medium is water, which is a fluid used to absorb momentum. In the friction type, only viscous shearing effects are used, but here we use the change in momentum. However, while we are talking about the change in momentum, viscous shearing effects will still be present. So here, we also have viscous shearing effects that will try to transport or transfer momentum from the rotating component to the stator component. So, let us go back to the previous slide and let me discuss the operational method by which the output power of the engine can be measured.

So, this is the engine shaft, which will rotate, and in the engine shaft, you can see there are two stationary plates of the casing. This is the casing, and inside the casing, we have water, as you can see from the schematic depiction. Now, this is the rotating plate that you can see, which is also mounted on the shaft. So, these rotating plates are mounted on the shaft, and as the shaft rotates, these rotating plates will also rotate in tune with the engine shaft.

Now try to see this rotating plate is now immersed in this water or fluid. Now this casing is a stationary part which is connected to the shaft using trunion bearing. So, this is basically anti friction bearing. That means as the shaft is rotating, normal tendency of this casing, which is stationary will be to rotate in tune with the shaft as well but try to understand the water is now creating or acting as a mediator playing a role rather water is playing a role or playing a mediator role, so this rotating plate will rotate in tune with engine shaft which in turn will allow thus stationary plate also to rotate. But this is anti friction wearing, so there is no frictional effect, so as if the that momentum will be transported from the rotating plate via this water to the stationary plate and stationary plate also will try to rotate. We can prevent the rotation of stationary plate by having some breaking action that is called breaking of the engine and if we place some load cell from there we can say what is the power output of the engine.

So, this is how this mechanical type works. So, then if we go back to the next one that is type 2 mechanical dynamometer, hydraulic type 2. So, coupling force arises from the change in momentum of the fluid as it passes through rotor to stator and again back. The procedure by which this particular device is used to or can be used to measure power output. So, what will happen that you can see this is water in port through which water will come in. Now, when water is coming in, so this is the group in this rotor. So, it will strike the rotor and then from the water will take or water direction will change. So, rotor will direct the water jet towards the stator and again inside the while it is striking the stator, it will again be coming back to rotor and that way toroidal vortex will form that you can see from this schematic depiction. Now this rotor is having grouped, so water also will try to go to another side and again we have a stator. So, this part is stator that is shown here using sky color, and the stator is connected to the shaft using anti-friction bearing that we have discussed in the context of type 1. So as the engine is rotating, rotor is mounted on the shaft, it will rotate, but as the water is coming in, that water jet will strike the rotor blade, rotor vane again it will direct water, to go to stator vane from stator vane, again it will come to rotor vane.

So, momentum exchange will occur, and the tendency of that momentum which strikes the stator will be to rotate the stator. But if we can somehow arrest the motion of the stator using a torque meter and if we have a load cell, then using that load cell, we can see exactly what amount is needed to prevent the motion of the stator. From there, we can measure the power output. For the sake of completeness, number one is water flows through the vanes in a toroidal vortex pattern.

So, this is a special shape of the vortex that is formed because of the shape of the rotor and stator vanes. So, number two is the water flow creates torque. The water jet striking the rotor vanes, and this rotor vane directs water outward toward the stator vane. So, the water jet or water, directs water to strike the rotor vanes, and then the rotor vanes direct the water outward toward the stator vanes, which redirect water back into the rotor. That is the process I was discussing. Now, in the course of this phenomenon, if you go to the next slide, we can see there will be a change in momentum. So, the change in momentum experienced by the water as it changes direction is manifested as a reaction force on the stator housing. And so, over and above this momentum change that will be experienced by the water as it changes direction is manifested as a reaction force on the stator housing. So, momentum will be transported Also, momentum will be transported to some extent by the viscous shearing effect.

Because the tendency of the stator housing or stator would be to rotate as there is a change in momentum because that is reflected or manifested as a reaction force. The rotor will rotate. That momentum will be transported through the water jet onto the stator. The stator will also try to rotate, but the stator is placed on the shaft using anti-friction bearings, so there will be no consumption of power. So, there is no friction. Anti-friction bearings now, the normal tendency of the stator will be to rotate in tune with the rotor, but here you can see the stator. The tendency of the stator to rotate would be prevented by using some brake arm. So, that brake arm has a load cell. So, from there we can measure what is the torque produced by this engine shaft, and from there we can measure the work output. So, for the dynamometer resist the torque reaction. (Load cell on the dynamometer measure the torque).

So, the load cell signal, needs to be amplified again to get accurate information of the torque that is developed. And, the water temperature will increase in both cases, so also the amount of water will reduce with time. So, we need to replenish the water quantity, together with maintaining the temperature of the water intact. So, some arrangement should be there, and that is done by an electro-hydraulic servo system to maintain water temperature within a specified limit and also to maintain the amount of water inside that stationary plate or casing for the first one. Also, the amount of water should be used to absorb momentum from the rotor, and that would be transported to the stator for type 2. So, we have discussed this. Now, let me tell you one important thing: in this particular case, if we talk about the hydraulic type, the hydraulic type, whether it is type 1 or type 2, the absorption capacity or horsepower absorption capacity—that is, the absorption of energy or horsepower—is approximately a function of the cube of the rotor speed, and therefore, it is suitable for testing high-speed engines. So, this is the conclusion. And if we, say a few words about this—if we go to the previous slide—so this is, as compared to the mechanical type, it is, economical. And also, since this particular type can be used for testing high-speed engines, this hydraulic type has or is used widely for the measurement of engine power through the measurement of torque and speed.

So, let us now solve one numerical problem to illustrate the concept that we have learned today. So, if we go here, this is the problem statement. Let me read the problem statement first, then we will solve.

Problem 1: The speed of an engine is 450 rpm; load on the hydraulic dynamometer is calculated as 790 N. The dynamometer constant is 11,200. Calculate brake power of the engine.

So, the problem here is to calculate the brake power—essentially, we need to brake the engine. The engine will be running; the shaft will be running or the shaft will be rotating. So, the energy that will be produced by the engine should be, we need to brake the engine. So, we need to break the power rather. So, we need to absorb the power. We have discussed three different types: rope break, hydraulic type 1, and type 2. Our objective is to prevent the motion of the stator in the latter two cases, while in the former case, we tried to restrict the motion of the drum itself.

So, essentially, we are trying to break the power, and that is why we need to know the brake power. So, if we solve this problem, that is the brake power—the power available at the shaft—and that power should be measured using this hydraulic dynamometer. So, nothing is mentioned about whether type 1 or type 2 is used, but let us solve this problem.

Solution: So, while calculating brake horsepower using the method we discussed today—we have discussed three different dynamometers. This BHP is calculated using this formula:

$$BHP = \frac{W \times N}{K}$$

What is *K*? *K* is dynamometer constant. So, this is typically provided by the manufacturer of the dynamometer. So, I am writing here, *W* is load on the dynamometer and *N* is certainly speed. So, what we can see from the straight plane that speed of the engine is given 450 rpm. Load on the hydraulic diameter is calculated at 790 N that I told that in the stator itself load cells will be there and load cells essentially, that you need to have some brake arm to prevent or to stop the motion of the stator which will have a tendency to rotate in tune with the rotor's motion. So, from the load cell if the signal will be there sometimes or many times we need to amplify the signal. Depending on the requirement. If the power produced by the engine is very small and then perhaps we need to amplify the signal to get the accurate data. So, now, from there we can calculate the load on the dynamometer and that is 790 Newton that is given in this problem.

The dynamometer constant is 11200 that is the value of *K* as I said this is provided by the manufacturer. So, straight away we can calculate the BHP. So, if we calculate BHP, brake horsepower using this formula is

$$BHP = \frac{790 \times 450}{11200}$$

So, that is the brake horsepower. So, it is very simple and very straightforward. So, essentially, what you can see is that this brake horsepower can be calculated quite easily using the dynamometer, as the dynamometer constant is provided by the manufacturer. What we need to know is the engine speed, which we will measure using a tachometer, as we have discussed in one of the previous classes. The load on the dynamometer can be measured using load cell data. So, with this particular problem, we have seen that using a dynamometer, the brake horsepower can be calculated.

So, if we try to summarize today's discussion, we have talked about a special device called a dynamometer, which is used for measuring engine power or engine output power—an important quantity. Essentially, by knowing the engine output power, we can certify or predict the engine performance. So, we have solved one numerical problem, though it is very easy, just to illustrate that the conceptual part—or rather, the mechanical part—that we have discussed today, and this particular problem will help you understand how we can really calculate the brake horsepower. So, if we now discuss what we have solved and what we have covered in a few previous classes in the context of engine performance.

we have discussed the measurement of a few important quantities like speed, air flow rate, fuel flow rate, indicated work, and today we have discussed brake horsepower. So, indicated power—that is, the power available inside the cylinder—certainly, that power is not available at the engine shaft. So, today we have discussed brake horsepower measurement, which is the power that is really obtained from the engine. So, these important quantities—have been discussed in a few lectures. So, with this, I will stop here today, and we shall continue our discussion in the next class.

Thank you.