Design of Farm Machinery

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Lecture 24 : Performance parameters (Contd.)

Hi everyone, this is Professor Hifzur Raheman from IIT Kharagpur. I welcome you all to this NPTEL course on the Design of Farm Machinery. Today is Lecture 24, where I will discuss about a few other performance parameters. These parameters include power requirement, fuel consumption, fuel capacity, soil inversion, and soil pulverization.

We have already discussed power requirement in the last class, but that power requirement is related to the drawbar. Now, power is also required to rotate the active tillage implement, which means we have to consider the PTO power. So, when you try to measure the PTO power, we need to know the torque acting. So, to measure the torque, we will discuss how to measure the torque and then how to determine the power requirement. So, the power requirement for rotating the active tillage implement, which means any implement where the working elements are powered, will be computed by measuring the torque acting on the PTO shaft or the shaft to which the power is transmitted. Now, torque measurement can be done in different ways.

So, one of the ways is the slip ring torque sensor. The slip ring torque transducer or sensor is a contact-type transducer in which strain gauges are bonded to a suitably designed shaft. So, when a torsional moment is applied to the shaft, it causes the shaft to twist, thereby inducing shear stresses, which are measured by bonding strain gauges at a 45-degree angle to the horizontal axis. So, typically, there will be four strain gauges connected to a Wheatstone bridge configuration with temperature compensation components included within the bridge circuitry. Then, with an excitation voltage applied to the bridge, the torque induced in the shaft will result in an electric output linearly proportionate to it. So, what will happen is we have to calibrate this with a known torque, and then we can determine the actual torque acting on the shaft.

Now, there is another transducer available, a torque transducer, which has been used at IIT Kharagpur to measure the torque directly on the PTO shaft. So, we tried with a powered disk arrow. So, the arrangement is shown here. The torque transducer is this one, which is attached to the PTO shaft, which is connected to the PTO. Now, there is a bellow coupling here, and there is a bearing here to support the vibrations and misalignment, if any, and then the bellow coupling will take care of it, and then the power is connected to the implement.

The bellow coupling is mounted between the torque transducer and the telescopic shaft to protect the mechanism in it and to sustain an inline connection; if there is a little bit of misalignment, that bellow coupling will take care of it. And a pillow block bearing is also mounted between the coupling and the telescopic shaft to support the rotating shaft. The output of the torque transducer is connected to a Datum Universal Interface having a built-in display to display the torque, speed, and power. So, three factors are displayed so that you can directly take the readings. So, this is a contact type of transducer. The problem here - in fact, there is no problem - the cables are there, and since it is rotating, the cables are to be kept in such a way that they should not wind up with the shaft. Otherwise, you know that some problem will come; else, this is a very good arrangement and a very accurate arrangement. So, to overcome that, a wireless type PTO torque transducer has already been developed by Hens et al. to measure torque, and this is at a much lesser cost as compared to the previous one. Now, this basically consists of a transmitter with an encoder, and there will be a receiver with a decoder. Then the transmitter end and the transmitter and the encoder units are installed on the rotating shaft with a special fiber-reinforced tape and steel strip. So, then there is an antenna with a transmitter that will transmit the signal to the receiver in terms of frequency, and then the transmission part is powered by a battery. So, the transmission part has to be powered, and it is powered by a battery. Then, the receiving part has a receiver with a decoder and a receiving antenna with a cable. The receiver has an LED bar indicator for showing the actual level of the signal and successful auto-zero calibration. So, these are just developed and published in some journals. So, that is why I have taken and put it here. So that you can have an idea, okay. There are different torque transducers available, or you can directly put the strain gauge on the shaft and measure it.

So, since torque transducers are available, you can better utilize that one to measure the torque. Once you know the torque and the speed at which the shaft is rotating, then multiplying torque with angular speed - $2\pi nt$ - will give you the power consumed by the shaft or by the implement that is to be rotated. In the case of an active tillage implement, the gangs are to be rotated. So, you can mount it before the gang or directly on the gang; both are possible.

Now, the next performance parameter is your fuel consumption. So, how much fuel is consumed? If you can measure it during a tillage operation, that means, for carrying out a particular tillage operation, how much fuel is consumed has to be measured. So, there are different ways by which you can measure it. So, once you know the fuel consumption, that means this much fuel is consumed per hour, and then you know the calorific value. So, calorific value multiplied by the fuel consumption will give you the energy that is consumed, okay.

So, to measure the fuel consumption, there are two methods available. One consists of a capillary tube with an auxiliary fuel tank, measuring scale, valve, and pipelines. They together can be used to measure the quantity of fuel that the tractor is going to consume during the tillage operation. I will show you the schematic view; you can see it here. So, this is your capillary tube, and this is the main fuel tank. We can take it to the auxiliary fuel tank; this is your auxiliary fuel tank. Then, on the side, there is a capillary tube which is connected to this auxiliary tank, and behind the capillary tube, there is a scale, a measuring scale. So, you can know how much is the depth of fuel which is consumed, then you calibrate that depth with the quantity of fuel. So, that has to be done beforehand. So, the procedure is a two-way valve is to be used to control the flow of fuel from the auxiliary tank to the fuel pump, okay. So, if you do not want the two-way valve, then you just close it. And then, a measuring scale has to be fixed close to the capillary tube of the auxiliary fuel tank for measuring the fuel consumption. That means, how much fuel is consumed actually it will give the depth of fuel, but that has to be calibrated - this much depth is equal to this much volume; that has to be calibrated. So, during calibration, the tank is to be kept horizontal to the ground by keeping the tractor on a level surface. Otherwise, the depth may vary. So, to avoid that difficulty, the tractor has to be kept on a horizontal surface, not on an inclined surface. Then, for a known volume of diesel fuel added to the auxiliary tank, what is the corresponding rise in the fuel level in the capillary tube that is to be noted, and that is to be noted from the scale which is fixed closer to the capillary tube. The same procedure has to be repeated for several known quantities of fuel. So, you can get a good amount of data from which you can find out for this much depth if you measure what is the corresponding volume of fuel consumed. So, this is the actual setup where this capillary tube is mounted to the auxiliary tank, and this is the main tractor, and on the side, there is a scale. So, you can measure the amount of fuel consumed.

The other method is by fixing a fuel flow meter. So, the right side figure shows how the fuel consumption is measured using a fuel flow meter. There should be two fuel flow meters: one will be attached to the supply line, and the other one is attached to the return line. So, the supply line is indicated as 1, and the return line is indicated as 2, and the display board is there at 3. So, the 3-way gateway valve is 4, this one, and the fifth one is the auxiliary fuel tank. This fifth one is the auxiliary fuel tank. You may not use the auxiliary fuel tank, but the return fuel is allowed to go to the tank. We just measure it in the auxiliary fuel tank or keep it in the auxiliary fuel tank. So, the fuel flow meter will measure how much fuel is entering into the system and how much is coming out unused. That means, how much fuel is unused will be measured by the return line. So, the difference will give you the amount of fuel consumed. And, the output from both the fuel flow meters is recorded and shown on the display board, which is indicated here as number 3. So, directly you can see how much fuel is going to the engine and how much is returning from the engine. So, that is called a control DFM DC display board. This is a New Zealand company that is manufacturing this one. Then, a 12-volt DC battery is required to power the display board. So, in addition to this, we have to have a stopwatch. So, it is used to record the duration of the operation. So, by dividing the total amount of fuel used during the operation by the duration, we can determine the amount of fuel consumed.

This is a schematic diagram. You can see the same thing I have put in a schematic view. You can see this is the supply fuel flow meter, this is the return fuel flow meter, and here the fuel is taken from the auxiliary fuel tank and it is also returning to the auxiliary fuel tank. So, now, whatever is going is displayed on the display board, and whatever is returning is also displayed on the display board. So, we have to take the difference and also take the time interval for which you are measuring. So, then we will find out what will be the fuel consumption per unit time.

The other performance parameter is the field capacity. Field capacity means how much area is covered per unit time. So, there are two types of field capacity: one is the actual field capacity or the effective field capacity, and the other one is the theoretical field capacity. So, for the effective field capacity, the implement should be operated for at least 4 hours continuously in the field. And the area covered during that period is measured in hectares. So, the total area covered divided by time will give you the effective field capacity. It will include both productive as well as unproductive time. That means unproductive time includes some time lost while taking a turn or if there is some problem adjusting the implement; those times are included. So, that is why the area covered will be a little less than the theoretical speed and the theoretical area covered.

On the basis of the width of the implement and the speed of operation, because speed will change during operation when draft is more, there will be slippage. So, speed will change. So, when calculating the theoretical field capacity, we consider the speed without slip. So, width multiplied by forward speed. That will give you directly the area which is covered per unit time. Now, you know the effective field capacity, we know the theoretical field capacity, and then the ratio is expressed in percentage, which is called field efficiency. So, it is the ratio of effective field capacity to the theoretical field capacity, and the expression is given as, Field efficiency $= \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100$. It indicates basically the time which is lost in the field during turning, for machine adjustments, and the failure to utilize the working width of the implement. These are the factors which will be indicated by field efficiency. When I said 80 per cent, it means 80 per cent is a very good number. Usually, for all the tillage implements, efficiency should be more than 75 per cent, okay. So, field efficiency, as I indicated, will be calculated using this equation. So, before that, we need to know what is the actual forward speed, what is the theoretical forward speed, that means speed without slip, and then we should know the cutting width or width of the implement.

Then we discuss wheel slip, which we have already discussed in the last class, but again I am putting it here because to measure the actual speed, we need to know what is the slip. For measuring slip, we need to have some instrumentation like proximity sensors with a ring with spikes. So, that it can be attached to the front wheel as well as to the rear wheel. From there, we will get the signals to find out the angular speed, and then knowing the rolling radius, we can find out what is the actual speed and theoretical speed. Actual speed is related to the front wheel, and the theoretical speed is related to the rear wheel.

Now, the other performance parameters are like soil inversion. So, soil inversion means how much the weeds are removed. So, if you are operating a tillage implement, how many weeds are removed. So, how to measure it? So, the procedure is as given by BIS. So, you have to take a square ring of 30 centimeters × 30 centimeters. The rings you can take several rings and then those rings are to be distributed randomly. You just throw these rings randomly on the field and then wherever it falls you try to calculate the - you just uproot the weeds and take the weight. This has to be done before operation and a similar exercise has to be done after operation. Again, after operating the tillage implement, you have to throw these rings randomly. So, wherever it falls you try to collect the weeds just remove the weeds by hand and then take the weight. So, we have a group of weeds before operation, we have a group of weeds after operation. So, take the weight, the difference will give you the soil inversion. That means, $Soil\ inversion = \frac{100 \times (Number\ or\ weight\ of\ weeds\ before\ test - Number\ or\ weight\ of\ weeds\ after\ test)}{Number\ or\ weight\ of\ weeds\ before\ test}$. So, that will give you soil inversion in percentage.

Then another parameter is soil pulverization. Soil pulverization means what is the reduction in soil clod diameter. Basically, we operate tillage implements to reduce the soil clod diameter. So, as per BIS standard, soil pulverization is measured by using a penetrometer. So, you randomly select some places in the ploughed field, and the penetrometer is held vertically at that place, and a hammer is dropped onto it from a height of 1 meter. And then, you measure the corresponding depth. When you drop the hammer from a height of 1 meter, the corresponding depth to which the penetrometer has been pushed in has to be recorded for every 2 such drops. That means, for 2 drops, you have to take the depth to which the penetrometer has been pushed into the soil. It is a drop-type penetrometer. So, you can always take another cone penetrometer, which is available, like a pushing type, directly you can push it into the soil and see what the strength of the soil is.

The soil pulverization can also be evaluated by measuring the soil clod diameter. So, what you have to do is collect soil samples after the tillage operation, and then you try to pass it through a set of sieves of different sizes, and then try to collect the weight of soil samples which are retained in each sieve and the weight of soil which is passing through the sieve and the representative diameter. To do this exercise, you have to again take the soil samples by randomly throwing square rings of 15 × 15 centimeters or 50 × 50 centimeters or 100 × 100 centimeters. You just throw these rings randomly, and then wherever it falls, you collect the soil sample and then carry out the sieve analysis. I have given 3 dimensions here: 15 × 15, 50 × 50, and 100 × 100; these are all dependent on the clod size. If clod sizes are bigger, then you go for 100 × 100 centimeters; if clod sizes are medium, then you go for 50 × 50; if clod sizes are smaller, then you go for 15 × 15. So, it depends on the clod size. The size of the ring which has to be thrown depends on the clod diameter; the smaller the diameter, go for smaller sizes, and the bigger the diameter, go for bigger sizes.

The soil sample, which is collected from the sampling area, has to pass through a set of sieves. The weight of the soil retained on the largest aperture sieve, which is passed through a sieve and retained on the next sieve, and passed through the smallest aperture sieve, they are all to be taken. And I have given a table where you can see the set of sieves: 10, 20, just randomly I have given 10, 20, 30, 40, and 50. This is the size of the aperture of the sieve. And then the diameters of soil which pass the left sieve, that means, less than 10 millimeters, will pass through this. And greater than 10 centimeters will be retained. So, what I have to do is I have to put a 50-millimeter size aperture on the top, then 40, 30, 20, and 10, like that.

So, when I put the soil sample in this set of sieves, greater than 50 will be retained on the top. Then smaller than 50 will pass through. So, 40 to 50 size diameter will pass through. So, that representative diameter I have taken as 45, the average of this, and then what is the weight of soil retained in that sieve that I have taken as E. Similarly, in a 40-millimeter aperture size, the diameter of soil which passes will be between 30 to 40, and the representative diameter is the average that I have taken as 35, and the weight which is retained in that sieve is D.

A similar exercise I have done for 20 to 30, 10 to 20, and less than 10. So, that means I have a set of weights of soil which is retained and the representative diameter, and then I put in this equation to find out the mean weighted soil clod diameter. $\boldsymbol{dsc} = \frac{1}{\mathrm{W}}(\mathrm{A} \times \mathrm{RD1} + \mathrm{B} \times \mathrm{RD2} + \mathrm{C} \times \mathrm{RD3} + \mathrm{D} \times \mathrm{RD4} + \mathrm{E} \times \mathrm{RD5} + \mathrm{N} \times \mathrm{F})$. N is the largest size. So, we have to take the average diameter of the largest size; you may have different diameters. So, then you have to take the average size. So, that is represented as N, which is greater than 50 millimeters. So, after putting in this equation, this will be nothing but the weighted average divided by the total weight. $\frac{1}{\mathrm{W}}(\mathrm{A} \times \mathrm{RD1} + \mathrm{B} \times \mathrm{RD2} + \mathrm{C} \times \mathrm{RD3} + \mathrm{D} \times \mathrm{RD4} + \mathrm{E} \times \mathrm{RD5} + \mathrm{N} \times \mathrm{F})$. The total weight, W = A+B+C+D+E+F. So, that will give you the mean weighted diameter.

Some researchers express soil pulverization in terms of the difference in the cone index of the soil before and after the operation of the tillage implement. That means, before the operation, you try to find out the average cone index. So, for that, again, you can either take a drop-type cone penetrometer or you can take the directly pushing type continuously push-type penetrometer. So, you have to take measurements randomly at 4 or 5 places to find out what the strength of the soil is before carrying out the tillage operation. And the same exercise you have to do after the tillage operation; that means, randomly you have to again take the cone index value at 4 or 5 places. So, since the soil is tilled, that means, the topsoil will be reducing its strength. So, you will get a lesser value. So, the difference between the cone index - the average cone index before the operation and the average cone index after the operation - divided by the cone index - the average cone index before the operation - into 100, that will give you the reduction in cone index percentage. That will indirectly give you the soil pulverization because if the difference is more, that means, the soil is more pulverized.

What I said is the cone index before operation. This is an average because you have to take it at 4 or 5 random places, then similarly average the cone index after operation. So, the difference of this, if you denote it as ΔCI, divided by CI before operation (CI_b), can be expressed in percentage. So, that will give you an indirect way of measuring soil pulverization. So, when the soil is more pulverized, that means the delta CI value will increase. So, this number, which I am calculating that will increase. So, the higher the number, the higher the soil pulverization. So, these are some of the ways by which you can measure soil pulverization, soil inversion, then we discuss how to measure the torque, and then field capacity.

Thank you.