Design of Farm Machinery

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Lecture 23 : Performance parameters

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 23, where I will try to cover performance parameters of tillage implements. The concepts which will be covered in this lecture will be wheel slip and power requirement. The performance parameter is not limited to wheel slip and power requirement, but we will first discuss these two parameters and then we will subsequently discuss the other parameters in later classes.

Now, coming to wheel slip, the concept of wheel slip is important in the sense that if you know its role, then only you can understand its effect and why it should be measured. Because wheel slip will decide the forward speed. So, when you are calculating the field capacity, the wheel slip will decide how much time it will take to cover a particular area. Otherwise, what we will do is we simply multiply the theoretical speed with cutting width and find out this much is the area which is covered, but actually, this is not the area which is covered; it involves many more things. So, wheel slip is important, and similarly, the draft value, because of the draft, there will be wheel slip.

So, I will give you the concept of what wheel slip is. This tractor wheel is running without a pull applied, that means it is simply rolling. Now, when a pull is applied, which is denoted by an arrow as a pull. So, then what will happen is its speed will reduce. So, if you count 10 revolutions or 5 revolutions when there is no load and when there is a load, the distance traveled will be different. And to find out that, we have to use the traditional method, which is to count the number of revolutions, measure the distance covered, and, knowing the time, we can determine the forward speed. And with load and without load, we have to repeat it. So, first, you take the tractor to the field, then you rotate it without engaging the implement, move the tractor forward, count the number of revolutions of the rear wheel, suppose 5 revolutions, and then measure the distance it covered. Similarly, we engage the implement, rotate for 5 revolutions, and then measure the distance. So, if there is a slip, then the distance covered will not be the same, and we measure the distance as well as the time to find out the theoretical speed, which is when there is no implement, and the actual forward speed when the implement is used. So, then we try to find out the actual forward speed, which is distance divided by time. So, distance per revolution can be calculated, which will be better with load and without load. So, from there, we can calculate the wheel slip. This is the traditional method, or manual method we can say, but nowadays, there are techniques available by which you can measure the wheel slip values. Wheel slip value is calculated from the differential rpm of the front and rear wheels of a 2-wheel drive tractor.

The actual speed of the tractor is obtained from the front wheel, assuming that the front wheel is not a powered wheel. So, the two-wheel drive tractor I am talking about has front wheels that are towed wheels and rear wheels that are powered wheels. So, the front wheel speed will give you the actual speed, and the rear wheel speed will give you the theoretical speed. So, what exactly you want to measure there is the rpm of both the wheels. To measure the rpm of both the wheels, there are several techniques available nowadays, one of which is the Hall effect sensor.

So, a metallic disk with small circular magnets on the periphery of the disk will be attached to the front and rear wheels of the tractor. So, here if you look at these, they are the magnets which are attached to a disk, and the wheel rpm can be counted by using a Hall effect sensor. The Hall effect sensor will be placed close to this metallic disk. So, there will be a variation in the magnetic field when it senses the magnet, which will be caused by the wheel rpm. So, it will detect the magnetic pulses, or you can say the magnets. When you detect the magnets, there will be a voltage signal pulse generated. When the sensor comes close - not exactly in contact but closer to the magnet, the total number of pulses generated in a single revolution will be equal to the number of mounted magnets on the material. So, you have to count the number of such signals, which are voltage pulses, and then from there, we will try to find out the rpm of the wheel. So, obviously, the more the number of magnets, the higher will be the accuracy. The signal pulse output from the sensor can be recorded by a microcontroller, where an IDE algorithm calculates the actual and theoretical speeds of the tractor. This has to be mounted on the front wheel as well as on the rear wheels. So, we will have two different rpms.

Now, similarly, we will also calculate the rpm of the wheels utilizing an inductive proximity sensor. If you do not have a Hall effect sensor, then you can go for utilizing an inductive proximity sensor - it is a very simple one. So, instead of a magnet, we are putting a disk with spikes. A ring with spikes, and then you put the proximity sensor very close to this ring. So, whenever the spikes cross this proximity sensor, the proximity sensor will sense it and give a pulse. Here it is a non-contact type sensor which will detect the presence of a metallic object when the object interrupts the electromagnetic field around the sensor's surface. So, thereby you will get a pulse. Each pass of a metallic object results in an electric pulse, and the number of such pulses per unit of time is counted to calculate the angular speed of the front wheel and the rear wheel axle. Now, once you know the angular speed, knowing the rolling radius, you can find out the forward speed, the actual speed, and the theoretical speed. So, what exactly we have done here is there are spikes, around 8 spikes, present in that ring which is fitted close to the front and rear wheels, and the proximity sensor is kept here. So, the moment it crosses the spike, the proximity sensor will get a signal.

Now, to measure the angular velocity of the front and rear wheels, a circular ring, as I said, with 8 spikes is to be attached to one of the front rims as well as both of the rear wheel rims, and proximity sensors are to be mounted on the rigid frame and the tractor chassis. Then, for every 8 pulses, since we have 8 spikes, so obviously, for 8 pulses generated, the number of wheel revolutions is taken as 1. So, the actual speed of the wheel is computed using the equation $V = \frac{2\pi RN}{60}$, and

$N = \frac{1}{corresponding\ time\ for\ every\ 8\ pulses\ (in\ second)} \times 60$. So, I have multiplied by 60. So, that way, that will give you N in rpm, revolution per minute, and knowing the rolling radius, the peripheral speed of the wheel can be calculated in meters per second.

Then, another important parameter is the power requirement. A power requirement, as you know, is nothing but draft in - power requirement means drawbar power requirement; we measure draft. So, draft into forward speed will give you the drawbar power requirement. So, for measuring actual speed, just now we discussed, and then for measuring draft, we have to employ certain techniques. So, the manual method - the manual method means we can utilize a load cell. That load cell has to be mounted between tractors. Between tractors means there has to be a dummy tractor. So, the dummy tractor and the actual tractor in between you have to mount - you have to fix, in the sense you have to put a cable, and closer to the cable you have to put a load cell or a mechanical dynamometer - the spring dynamometer, and then we try to measure - we try to pull the tractor with the implement with the dummy tractor, and then we remove the implement and just pull it - pull only the tractor. So, the difference will give you the draft of that implement. So, you have to take this kind of measurement many times in the field and then take the average. So that it will give you the average draft requirement. Because the soil conditions may not be uniform, so you have to take a good amount of data for each run so that you will get a good average. Then for a mounted tractor implement, a drumming tractor is used as I discussed. Then the first one is the dummy tractor, the second one is the actual tractor, which is fitted with the implement, and in between there is a cable, and closer to the dummy tractor or closer to the actual tractor you have to put the load cell or the dynamometer and then take the readings. Either you can acquire the readings in a data acquisition system if it is a load cell, or if it is a spring dynamometer then you have to take readings manually.

Once you know the draft, then you know the speed; the draft into speed will give you the drawbar power requirement. Now, there are other arrangements available like drawbar pins. So, instead of a spring dynamometer, because the spring dynamometer has the problem that the draft is not constant, it is varying. So, because of the variation, it is difficult to get the exact value. So, you have to be very accurate in taking and noting down the readings. So, if you want to get rid of this, then there are certain other arrangements available, one is your drawbar pins. The usual procedure to measure the drawbar power is to insert the drawbar pin in the implement hitch point. Then the pin transducer has two rings, one inner ring and the other one is the outer ring. The outer ring protects the inner ring, which is fitted with the strain gauges to sense the force. During drawbar operation, the outer ring is compressed against the inner ring by the implement and the tractor hitch. Thus, compressive and tensile stresses are developed on the outer surface of the inner ring in the plane parallel to and perpendicular to the direction of the load which is applied. So, this instrument is limited only to the free linkage system; we cannot utilize it in a three-point linkage. So, for utilizing a three-point linkage, we have to have a ring transducer, an extended octagonal ring transducer, or a double extended octagonal ring transducer. So, what we can see is that the ring transducer, due to friction in bushes and drawbar pins, causes substantial errors in measuring the draft value. So, we go for an extended ring transducer or an extended octagonal ring transducer, which gives better stability. And let us see the figure; this is an extended octagonal ring transducer, okay. So, the strain gauges are to be mounted on this at different positions; these positions are called nodes. So that we can measure both horizontal, vertical, and the moment which are acting.

So, this is a double extended octagonal ring transducer, and the arrangement you can see allows you to directly put a hitch for a trailed implement at this point instead of a spring dynamometer, and you can take the readings. So, this will give both horizontal as well as vertical force. So, that is an advantage. So, these extended octagonal ring transducers can measure both horizontal force, vertical force, and the moments. Then, extended octagonal ring transducers are easier to fabricate than the circular ones, and during operation, if it is a circular one, the stability during operation is a problem.

So, we prefer the extended octagonal ring transducer. Now, ring transducers have a machined block made up of steel or aluminum. There are some specific positions, as I said in the ring transducer, called nodes, where the strain from the other force component has no contribution, okay. So, that means it can measure the forces independently - horizontal and vertical. Strain gauges are mounted at these nodes for monitoring the horizontal and vertical force components and the resulting moment. The diametrical forces and tangential forces are zero at an angle of 39.5 degrees and 90 degrees, respectively, on the surface of the ring transducer. So, this angle is important, where we can mount the strain gauges.

Then, the draft of the mounted implement can be measured by strain gauges attached to the lower links. That is a new achievement in the sense - directly, instead of putting some external load cell - directly, you can put strain gauges on the links of the three-point linkage of the tractor, that is, the two lower links and the top link. By a three-point hitch dynamometer, you can measure the draft force. So, we can either utilize the strain gauges attached to the links or utilize the three-point hitch dynamometer. So, in the case of strain gauges fitted to the links, we can see that - the thing is, we have to measure the forces as well as the angle at which these forces are acting. That is important because the lower links and the upper links are not horizontal or perfectly vertical. So, it has angles in the horizontal plane and angles in the vertical plane.

So, you have to measure not only the forces acting but also the angles. Then, by which you can convert it to draft utilizing a suitable equation, which I will give you later. So, these are the linkages you can see: the top link, which is split into two, and in between, you have put a ring dynamometer. Then, the lower links - two lower links where the strain gauges are mounted. This is the actual scenario when it is fitted to the tractor three-point linkage. That means there are potentiometers attached. So that it will give the angle at which - the angle to the vertical plane and to the horizontal plane of the lower links as well as the top link. So, angles are measured by putting potentiometers. So, the draft of the tillage implement is measured using a system which comprises an instrumented three-point linkage of the tractor, as shown above. We can see it in the figure.

It consists of strain gauges which are configured as a Wheatstone bridge circuit to measure the draft in the field. In order to measure the tensile and bending forces, electrical strain gauges must be installed on the lower side of the lower links. For measuring the forces, because the two lower links are subjected to tensile force and the upper link is subjected to compressive force. For measuring the compressive force acting on the top link during tillage, a proving ring made of mild steel is installed. The angles of the lower links, as I said, in the horizontal and vertical planes, and the top link in the vertical planes are to be measured. So, these are measured with respect to a potentiometer. So, in accordance with vector geometry, if the amount of forces acting at the bottom and top links, as well as the angles created by these links in the horizontal and vertical planes are known, then the draft of the implement can be calculated using the equation given as. $D_{fi} = T_f \cos\theta \cos\varnothing + B_f \cos\theta \sin\varnothing - C_f \cos\gamma$

Where D_{fi} is the draft force, T_f is the tensile force in the lower link, D_f is the bending force in the lower link, and C_f is the compressive force in the top link. Theta is the angle of the lower link in the horizontal plane, phi is the angle of the lower link in the vertical plane, and gamma is the angle of the top link in the vertical plane. So, the angles are to be measured with the help of a potentiometer. And these forces, T_f, B_f, and C_f, will be measured from the Wheatstone bridge made by positioning different strain gauges at different positions of the links.

Then, if you do not want to use these three-point linkages, there will be other arrangements like a three-point hitch dynamometer. It can be a chassis type or linkage type. The chassis type dynamometer has a specially constructed frame, and transducers are mounted on this frame. This frame is inserted between the tractor and the implement. This is the frame you can see. The chassis is made of an adjustable telescopic shaft to accommodate various implements of different dimensions, okay. So, this can be extended or retracted both sidewise and topwise also. Then the force sensing elements are 3 load cells. You can put any load cells at these 3 points. These are the points where the load cells have to be put. Then usually the load cells in a 3-point hitch dynamometer are arranged in such a way that the 2 lower links are subjected to tensile forces, and the top link load cell experiences a compressive force. So, we have to have 3 load cells to measure the forces acting on the 3 links. And then, knowing the forces, we can directly calculate the draft of the implement by utilizing this equation: $D = F_{tlR} + F_{tlL} - F_{cT}$,

Horizontal tensile force at the right lower link, which is Ft_{1R}, and F_{t1L} is the horizontal tensile force at the left lower link, and F_{CT} is the horizontal compressive force at the top link. So, you can directly find out because this is sensing the horizontal forces. So, you do not have to convert by utilizing the angles. So, directly you take the summation; two are positive, one is negative, that is, the compressive force is taken as negative, so, you can directly find out how much will be the draft.

The only difficulty which will come here is because of the frame. The implement is attached to the tractor at a greater distance. That means, the position of the implement relative to the tractor is changed. So, that may create some problems during operation due to the sudden application of forces. To solve this problem, at IIT Kharagpur, we have developed a special type of sensor - draft sensing units. You can say there are three draft sensing units which will be mounted to the three links: one on the top link and two on the two lower links, in such a way that it only allows the resultant horizontal forces to act on the load cell. So, if you look at the single unit, you can see there is a frame to be attached to the tractor's hitch side.

There is a frame which will be attached to the implement hitch side, and in between, there is a load cell. The load cell is connected to these two frames with the help of a curved plate. This type of arrangement reduces the magnitude of the imposed force and the vibration to the load cell, thereby increasing the life of the load cell and the accuracy while measuring the draft. So, this is the load cell. It is fitted closely with some curved plates, and the curved plate is connected to these two frames. When there is a tensile force, the force experienced on the load cell will be a compressive force, just opposite of what is experienced by the frames. So, the load cell is mounted laterally to the direction of travel. The nature of the force acting on the load cell will change accordingly. When the linkage is under tension, the two curved plates will be compressed, and a compressive force will be imposed. Similarly, this is the arrangement we can see, okay. So, when there is compression or tension, these are the forces acting. So, these forces will be transmitted to this load cell, which is an S-type load cell, by which you can measure the draft force. Now, if you look at the arrangement, the top link has one sensing unit, and the lower links also have one sensing unit each.

So, once you know the forces, you simply take the addition of this - the algebraic sum of these forces acting, as these are horizontal forces. So, then we do not have to take the components. So, the right lower link, left lower link, and the top link force. So, summation, since the top link is compressive, I have taken it as negative. So, that way, you will get the total draft.

The only problem is the manufacturing of these curved units; that is the only problem. Otherwise, these sensing units are very powerful and very reliable during operation in the field. To overcome this difficulty, we also tried to develop a different set. The mechanism is the same; only we replace these curved plates with 2 frames. This load cell is connected in such a way that if you look at this. So, if there is tension, it directly goes to that load cell, okay. And unlike the previous case, where it goes through the curved plate. So, we remove the curved plates directly; you have put it by making 2 U-frames, you can say U-shaped frames. One will be attached to the implement side, and the other one will be attached to the tractor side. And these 3 sensing units are to be attached to the 3-point linkage, okay. The 3-point linkage, and since the load acting is directly horizontal, you do not have to resolve it into components. So, you can see the arrangement of the load cell with the detachable frames and the mounting of force sensing units between the tractor and the implement, which allows the force imposed on the tractor's 3-point linkage to be transferred longitudinally to the load cells and made it insensitive to vertical and side forces acting on the linkage during the tillage operation. However, the direction of forces imposed on the load cell will be opposite to the forces acting on the linkages. So, if there is a tensile force, the load cell will experience a compressive force, and if there is a compressive force, the load cell will experience a tensile force.

So, after knowing this draft, we have instrumentation for measuring actual speed. Then, actual speed is measured by the front wheel, and theoretical speed is made from the rear wheels by putting those either Hall sensors, Hall effect sensors, or proximity sensors, and knowing the draft and the actual speed, we can calculate how much is the drawbar power requirement. So, this is, in brief, about draft and power requirement and also the wheel slip. These are some of the references.

And in summary, I can say I have discussed the instrumentation techniques used to measure wheel slip, used to measure draft, and then how to measure the power requirement knowing the draft and the actual speed. And by which, these are the parameters by which you can measure the performance of a tillage implement or when you try to compare the performance of tillage implements, these parameters will be helpful.

Thank you.