Design of Farm Machinery

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Lecture 21 : Design of an active-passive combination tillage implement

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 21, where I will try to discuss the design of an active-passive combination tillage implement. Now, the concept which will be covered is the design of an active-passive combination tillage implement, then a numerical will be solved to compute the power requirement of an active-passive combination tillage implement. The figure which I am showing here is a combined offset disk harrow. So, a combined offset disk harrow means it is an offset disk harrow, but the front gang - the front gang is powered - this gang is powered by taking power from the PTO, but the rear gang is not powered. If you compare this one with an offset disk harrow, both the gangs in an offset disk harrow are not powered. In a combined offset disk harrow, only the front gang is powered, which means the front gang is active, and the rear gang is passive. So, that is why I am calling it an active-passive combination tillage implement.

Now, the design of a combined offset disk harrow, what exactly we will do is: we try to design the front set - that is the powered set, the front gang, and we will try to maintain the same dimensions for the rear gang. Why? Because the front gang is subjected to torque since you are powering it, and so, as compared to the rear gang, it is subjected to more torque. So, we are designing for the front. So, now the first thing in the case of the design of a disk harrow, an offset disk harrow, is to find out the diameter, and we know that the $D = K\frac{a}{\cos\beta}$, where, β is the tilt angle. In the case of a disk harrow, the tilt angle is 0, and a is the depth of operation, and the value of k varies from 3 to 5. So, by putting those values, we can calculate what the diameter of the disk to be fitted will be. Then, disk spacing is important because disk spacing will decide how many disks are to be accommodated, and at the same time, it will decide the cutting width of the disk harrow.

So, this is the formula which will be utilized and is given by Bernacki, and we have derived how to find out this expression. So, spacing, $S = \left[2\sqrt{c(D-c)}\right] tan\alpha,$ where, α is the gang angle, c is the ridge height, and D is the diameter; these are in centimeters. So, c is equal to a for a harrow. So, you can calculate the value of spacing between two adjacent disks.

Then we try to find out the cutting width of a disk harrow. The cutting width of an offset disk harrow can be calculated by utilizing two equations given like - this BIS equation or ASABE equation - both are the same. So, you can utilize this equation or you can utilize this ASABE equation. So, the only difference is: here we are - in the case of BIS, we are taking this number of spacings - number of spacings here, and in the case of the ASABE equation, we are only taking the number of disks, not spacing. So, S we have calculated, D we have calculated; just put and fix the number of disks. So, that at least the cutting width should cover the track width; that is the constraint. So, you can find out the cutting width.

Next is how to find out the draft requirement, the draft requirement of a powered disk because the ASABE equation does not take care of a powered disk; it only gives you the disks, meaning either it is a single-acting disk harrow, double-acting disk harrow, or an offset disk harrow, but it does not give the draft requirement of a powered disk harrow. At IIT, Kharagpur, we developed an equation based on our experimental data to find out what will be the value of the specific draft of a powered disk. So, if you look at these equations, the specific draft of a powered disk , $SD_{CODH} = C_0 + C_1 \times \alpha + C_2 \times \alpha^2 + C_3 \times CI + C_4 \times d + C_5 \times e^{\left(-\frac{u}{V}\right)}$. CI is the cone index. That means, this equation is a function of α, which is the gang angle. You can see α and α^2 both are there. Then, it is a function of the cone index value. What was the cone index value before the operation? That means, what is the strength of the soil? Then, it also depends on the depth, and it also depends on the u/V ratio, which is the peripheral speed of the disk to the forward speed of the tractor. So, to utilize this equation, you need to know the values of these coefficients C0 to C5. So, I have listed those coefficients, and you can look at this.

Regression coefficients - the values are given. So, it will - by taking the values of these coefficients C0 to C5 and putting the value of this α, CI, d, and u/v ratio, we can calculate how much is the specific draft. Specific draft means draft per unit cross-sectional area. Now, assuming the cross-sectional area to be rectangular, that means width into depth, width of cut into depth, that will give you the area, and multiply with this Sd value, that is the specific draft value, we will find out what will be the value of the draft. Because draft is the important component which will be required for designing the disk harrow, designing the disk harrow means designing the gang shaft and the frame.

Now, the values which are given, like α, should be in degrees, and the cone index value should be in Mega Pascal, and because this is an empirical equation, you have to be very careful in handling this. If you change the units, then the applicability of this equation is not known, and u/V is the ratio, so it is a dimensionless thing, and then speed is in kilometers per hour, and d is the depth in cm. So, now utilizing this equation, we will try to find out what will be the draft required by the powered disk, that means the power gang. Then, for finding out the unpowered gang, we can take the help of the ASABE equation, okay. So, what we have done here is the draft for the powered disk gang, we calculated utilizing the equation which we discussed just now. Then, if you want to find out the draft at each disk of the powered disk gang, just divide it by the number of disks, and that will give you the draft value acting on each disk.

Now, for the unpowered gang, we take the help of the ASABE equation, and here, the ASABE equation, the values of A, B, and C are to be taken for tilled soil, the secondary tillage. So, now, taking the values of A, B, and C as 254, 13.2, and the contribution of C is 0, and F, again, if you are designing for sandy clay loam soil, the value you can take is 2, or if you are designing for coarse soil, you can take the value of 3; accordingly, the value of F will change. So, speed is in kilometers per hour, and T_d is the depth in centimeters. So, we can find out D_p - this is the draft required per meter of cutting width. So, now, we know the width of cut; just multiply it, and that will give the total draft of the rear gang. Now, the front gang we have also calculated; the summation will give you the total draft of the offset - the combined offset disk harrow, that is D_C. So, just the draft of the front powered gang, the draft of the rear unpowered gang, so that will give you the total draft.

Now, the question is how to find out the power requirement; that is important. In the case of a passive tillage implement, the drawbar power is used for carrying out tillage, while in the case of a combination tillage implement, that is active-passive, both PTO power is required as well as drawbar power is required. PTO power is required to rotate the gang, that is the front gang, and drawbar power is required to pull the implement and to overcome the draft part, then also to overcome the rolling resistance. Rolling resistance due to tractor weight, due to implement weight. So, the total power required for carrying out tillage with a combination tillage implement, that is active-passive, can be expressed either in terms of drawbar power or in terms of PTO power, as it comprises two components. So, you can convert it into one component; if you know the transmission efficiency, either you can convert it to drawbar power or you can convert it to PTO power, knowing the transmission efficiency. Now, the total power requirement is expressed as equivalent PTO power in kilowatts, that is the summation of drawbar power required for pulling the implement, converted to PTO power. Drawbar power required for moving the tractor is converted to PTO power, and the power required to rotate the gang is PTO power. So, now all three components are converted to PTO power. So, you can take the summation of those. So, the power requirement I have given the expression: three components, first component, second component, third component. The first component refers to the draft part D_C into V_a divided by the constant, then transmission efficiency I have divided to convert it from drawbar power to PTO power.

Now, rolling resistance into forward speed divided by a constant 3.6, then we have again divided the transmission efficiency from drawbar power to PTO power. These are two drawbar powers which are converted to equivalent PTO power. Then, for finding out the power requirement for rotating the disk, if you know the torque which is acting on the gang, where the disks are to be rotated, and the RPM of that gang, then 2 π NT by 60. So, that will give you the power requirement at the gang shaft. Now, that transmission efficiency, that means, the ratio of gears which are used because the PTO power and the RPM of the PTO and the RPM of the shaft are not the same. The RPM is at 540 - PTO RPM is 540, and the RPM of the gang is 200, 210, like that. So, again, transmission losses are there. So, that has to be taken care of to find out what is the PTO power required. So, equivalent PTO power you can calculate for these two, then PTO power available from the tractor if you know the engine power multiplying with transmission efficiency that will give you the PTO power available. Now, if that is denoted as P, ~~so~~ and summation of these two draft drawbar power converted to equivalent PTO power. So, that difference will give you this much is the power available at the PTO to rotate.

And now again from here, you can find out what will be the maximum torque available for rotating. So, we are not interested in this maximum torque, but we should know it. So, the torque acting on the shaft should always be less than this; only then can the tractor pull or rotate it. Otherwise, the tractor will not be able to rotate it. N_{fg} is the speed of rotation of the front gang shaft, and T_{fg} is the maximum torque available at the front gang. So, next is the length of the shaft. We have already calculated the spacing between two adjacent disks, and we have also decided the number of disks. So, you can find out what the length of the shaft will be; the shaft means the gang shaft. So, that is how we calculate it.

Next is the spacing between two adjacent disks and the width of cut, which is computed using these equations. These equations have been discussed again and again. So, now you can know what are the different values we have, which are to be used. Now, this is not a/ 2; this is a.

Now, the draft of the front power gang can be obtained by multiplying this specific draft with the soil disturbed area. That means, width ×depth× the specific draft will give you the draft. Then, by taking a ratio between the draft and the vertical soil reaction, we can find out what the value of V_v will be from here. And this vertical soil reaction we have already taken the ratio from the table, which we discussed earlier. The range varies from 0.5 to 1.5, and that again depends on the size of the disk as well as on the gang angle. Next, after calculating the vertical force acting on the disk, we find out what is the vertical force acting on each disk. So, just divide by the number of disks. So, that will give you the vertical force which is acting on each disk. So, now, we have the data for the draft which is acting on each disk, the vertical force which is acting on each disk, and the next thing is the weight acting on the shaft. So, it will be equal to half the weight of the implement, okay? So, if the total weight is W_t, then W_g, which is acting on the front gang or the rear gang, we have taken equally.

So, $W_t/2$. So, usually, the total weight varies from 390 to 650 kg per meter width. So, if you know the cutting width, you can find out what will be the weight. Then, we try to find out how these forces are going to create bending moment or bending and torsion both. Now, if you only consider the vertical forces which are acting, in the case of a disk harrow, the vertical forces are acting upward.

So, I have indicated the shaft here and the supporting forces. The shaft is supported at the two ends, and there are four disks. Suppose there are four disks. So, V_1, V_1, V_1, V_1, and the weight is W_g. So, half of the weight is acting here. Now, taking the bending moment about the central axis. So, this will be the expression: R_A is equal to R_B is equal to the sum of the forces. The vertical forces Wg are acting downward, and V_1 is acting upward. So, $(W_g - 4V_1)/2$, that will give you the support reaction.

Now, taking a moment, this will be the expression R_A into - if the distance between two adjacent disks is S, then $R_A \times 2S$ will be positive, this one and $V_1 \times 1.5$ S, this is positive, and $V_1 \times 0.5$ S. So, these three are positive, and the weight is acting downwards. So, this is anti-clockwise. So, minus $(W_g/2)\times$ S (S/2, S/2, and S)by two. So, that way, this is the expression for the bending moment of the gang shaft due to the vertical force.

Now, due to the horizontal force which is acting parallel to the face of the blade. So, that is nothing but if you take a - so I will show you that in the diagram. So, if this is the disk, so this is your draft, so this is your soil resistance which is going to create torsion in the shaft. So, to find out this, we need to know the gang angle. Sorry, this is the component, this is the component, this is the horizontal component, this is the sideways component, this is the soil resistance. So, you know the gang angle as α. So, the soil resistance force which is creating torsion will be equal to $\frac{D_x}{cos\alpha}$. So, that into the moment arm, which is equal to your $r - \frac{a}{3}$. So, that will give the torsional moment. So, bending moment we calculated, torsional moment we calculated, then the stress due to bending, stress due to torsion. Then applying the maximum stress theory, $\tau_{max} = \frac{1}{2}\sqrt{(\sigma_b^2+4\tau^2)}$. So, that way, we are getting b = $[\frac{3}{\tau_{max}}\sqrt{M_s^2 + T_s^2}]^{1/3}$

Now, considering the shock and fatigue factors for both bending and torsional moments and taking K m and K t as 1.5, you can calculate the value of b assuming a design stress of 50 Mega Pascal. So, this is how you have to calculate. So, these calculations are made for the bending moment and stress due to bending, assuming the cross-section of the shaft to be a square one. So, if you take a rectangular one, that is also possible, but a gang shaft is never taken as a circular one. Because if you take a circular one, there is a possibility of slippage of the disk. So, either you take a square one or a rectangular one and then try to follow this maximum stress theory to find out the dimension.

I will give you an example - a numerical problem. The numerical will try to explain how to find out the power requirement. Try to solve this, and it will give you how to calculate the power requirement. A combined offset disk harrow with 4 disks of diameter 51 centimeters in each gang, with a disk spacing of 26 centimeters, is operated by a 2-wheel drive tractor with a BHP of 45 in sandy clay loam soil at an average moisture content of 9.5 percent dry basis. The actual forward speed and average operating depth are 3 kilometers per hour and 12 centimeters, respectively. The front gang of this offset disk harrow has a gang angle of 25 degrees and is powered by the tractor PTO and is rotated at 200 rpm.

The draft required to pull the implement is measured to be 1.6 kilo Newton. The rolling resistance of the tractor with the offset disk harrow is 0.65 kilo Newton. The horizontal soil reaction force acting on each disk parallel to its face is 350 Newtons and is acting at a height of one-third of the depth of operation from the bottom of the soil surface disturbed. So, these are the information given.

What is asked is to find out the maximum torque available on the front gang and the total power utilized for operating the combined offset disk harrow. Assume the transmission efficiency from the engine to the tractor PTO as 87 per cent, from the PTO to the drawbar as 86 per cent, and from the PTO to the gang shaft as 95 per cent, with a power reserve of 20 percent. So, these are some additional pieces of information given.

So, to start with, the available PTO power is to be first calculated. To calculate the PTO power, we know the tractor engine BHP power. So, BHP multiplied by the transmission efficiency. This is for converting it into kilo Watts. So, we will get 45 HP as the BHP and the transmission efficiency of the tractor gearbox is 0.87, with a coefficient of power reserve of 0.8. So, that way, you are getting 45 multiplied by 0.87 multiplied by 0.8 multiplied by 0.746, which is the power available at the PTO. Now, the PTO power equivalent to the drawbar power - what is the power consumed? Let us see.

So, the draft value is given. The rolling resistance value is given, the operating speed is given, and the transmission efficiency is given. So, you just put it in this equation to find out the equivalent PTO power - the equivalent PTO power from the drawbar power. So, the draft is given, the forward speed is given, and the rolling resistance value is given. So, putting these values here, you can find out that this is the total power - the drawbar power - the equivalent PTO power to the drawbar power. This comes to around 2.18 kilo Watts.

Now, PTO power available was 23.36 killo Watt, and now, if you deduct it, this is the power available at the PTO. Torque available at the gang shaft will be equal to - because the rpm are different, 540 to 200. So, that is why I have divided this. So, this is the torque available at the gangshaft.

The torque acting due to soil resistance is given. So, given means soil resistance force is given as 350. This is your r, radius, and this is the depth, which is 12. So, a/3, it is acting at a/3. So, 12/3. So, that way, you are getting for one disk; this is the value. Now, there are 4 disks. So, you just multiply with 4 to find out the total torque acting due to soil resistance. So, if you look - compare this one with this one, yes, the tractor will be able to rotate the disk because it is 1011, it is 301 Newton. So, torque available is higher than the torque required. So, the tractor can easily rotate the gang. Power required to rotate the front gang will be this much.

That means, we know the torque, we know the rpm, so 2πnt. So, that way you are getting 6.30 kilo Watt. Now, PTO power is required to rotate the front gang. Because you are calculating the power requirement at the gang shaft. So, PTO power will be the multiplied with transmission efficiency. So, again 0.9 if you take, so that way it will give you 7 kilo Watt. Now, the total power utilized is drawbar power equivalent PTO power for drawbar power P_1, which comes to 2.18, and the power required to rotate. So, that we are getting 7 kilo Watt. So, the total power consumed is 9.18 kilo Watt. So, the question is asked to find out the total power utilized. So, the total power utilized will be - Out of this PTO power 23.36 kilo Watt, you are utilizing only 9.18 kilo Watt. So, power utilization efficiency, if you try to calculate, power utilization efficiency will be total power utilized is 9.18 kilo Watt and power available is 23.36 kilo Watt - 23.36 kilowatt. So, this into 100, if you express in terms of percentage. So, that will be the total power utilization efficiency. So, this will help you how to calculate the power requirement of an active-passive tillage implement, where part of the power is used in the form of drawbar power and part of the power is used in the form of PTO power. So, it is not simply just adding one power with another power. So, you can add it only when the two powers are the same, that means, when either you express the two powers as PTO power or you can express them as drawbar power, then only you can add it.

So, this will give you a fair idea of how to calculate the power requirement, the power requirement of an active-passive tillage implement. So, these are some of the references, and in brief, we can say we discussed how to design an active-passive tillage implement, and then we took the help of a numerical problem to discuss how to compute the power requirement of an active-passive tillage implement.

Thank you.