Design of Farm Machinery

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Lecture 22 : Computation on design of active-passive tillage implement

Hi everyone, this is Professor H. Raheman. I welcome you all to the SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 22, where I will try to compute some design aspects related to active-passive tillage implements. The concepts which will be covered are computation and design of tractor-drawn active-passive tillage implements, where I will try to compute the design of the gang bolt, the frame, and how to find out the power requirement. So, when you are planning to design an active-passive tillage implement, the active-passive tillage implement considered in our design is an offset disk harrow, where the front gang is powered and the rear gang is not powered. So, that is called a combined offset disk harrow.

So, the first thing in designing an offset disk harrow is how to decide the size of the disk. So, the size of the disk and the number of disks have to be fixed. So, the number of disks should be such that the width of the cut should at least cover the track width of the tractor. So, in that way, we have decided that there will be 6 disks in the front gang and 6 disks in the rear gang. The front gang is powered, the rear gang is not powered, but the size of the disk will remain the same. Now, the number of disks we have decided is 6, and what is the depth? Depth, obviously, it is a secondary tillage operation. So, we limit it to 12 centimeters. Now, the disk diameter will be equal to k a by cos beta. This is a generalized equation whether it is a plough or harrow, you can utilize this equation where 'a' is the depth and 'beta' is the tilt angle. Since it is a disk harrow, so the tilt angle is 0, and the value of 'k' is between 3 to 5. 3 to 6. So, now assuming the value to be, say, 4, then the diameter comes to 48 centimeters with the depth as 12 centimeters. If you assume 'k' as 5, then the diameter comes to 60 centimeters, but in the market, the diameter of a disk available is 51 centimeters. So, we took 51 centimeters as the diameter.

Now, the next thing is what should be the spacing between two adjacent disks. So, again, that formula is $S = 2\{\sqrt{(a \times D - a)}\} \times \tan\theta_0$, where 'a' is the depth, 'D' is the diameter, and θ_0 is the setting angle or the gang angle. Now, if you substitute those values and assume a gang angle of 20 degrees, which is fair enough, we get a value of 15.74 centimeters, which is roughly 16 centimeters as the spacing. After deciding the spacing between two adjacent disks and the number of disks, the next thing is what will be the cutting width. So, for the cutting width, you can either utilize the ASABE equation or the BIS equation. So, I have taken the ASABE equation - the formula is cutting width = $\{0.95 \times (N - 2) \times S + 0.6 \times D\}/100$, where 'N' is the number of disks in a gang. And 'S' is the spacing in centimeters, and 'D' is the diameter in centimeters. So, in our case, 'D' is 51 centimeters, 'S' is 16 centimeters, and the number of disks we have taken is 6. So, that way, the cutting width comes to 0.914 meters. And the length of the shaft will be, there will be 6 disks, so 5 spacings, and extra on either side to accommodate - to mount the frame at the gang bolt on the frame. So, that way, you have taken the length of the gang bolt or the gang shaft as 96 centimeters.

Then comes the draft, an important parameter, because draft is the main parameter which will control. So, if you know the draft, then you can find out what the soil resistance is, which is acting parallel to the disk of the blade. So, as we discussed in my previous class where I gave the design of active-passive tillage implement, there I discussed how to find out the specific draft of an offset disk harrow - powered offset disk harrow. Because the equations which are available with ASABE, these equations are for the unpowered ones. For the powered one, the draft requirement will be different. So, you cannot utilize the ASABE equation. So, that is why the relationship which we developed at IIT Kharagpur, there is a specific draft model for the power disk gang that is utilized. So, the equation is in terms of alpha, that means, disk angle in terms of cone index value, in terms of depth and in terms of u/V ratio. So $C_0 + C_1 \times \alpha + C_2 \times \alpha^2 + C_3 \times CI + C_4 \times d + C_5 \times e^{\left(-\frac{u}{V}\right)}$. CI is the cone index, that is the resistance to push a cone-shaped probe into the soil. So, that is expressed as force per unit area. That means - but here the unit is in Mega Pascal, we can express in kilo Pascal, Pascal, but this is an empirical equation the unit of CI is in Mega Pascal and alpha is in degree and depth is in millimeter. That is it. So, the coefficients C_0, C_1, C_2, C_3, C_4, and C_5 - the values are available and I have kept this in this table. If you look at this table, the values are given. Now, utilizing this value and the alpha value you have taken here as the gang angle which is 20 degrees and CI value since this is going to work in undisturbed soil, we have taken as 800 kilo Pascal. So, that means 800 by 1000 will be the Mega Pascal. Now, the rpm at which the disk has to be operated is taken as 180, and knowing the radius - the radius is known. So, we can find out the peripheral speed of the disk. So, we calculated that the peripheral speed is 4.81 meters per second, and the forward speed is 3.6 kilometers per hour. So, that way, you can find out the u/V ratio by making the units the same.

So, in this equation, if you substitute those values, what I found is the specific draft model, that means, draft per unit cross-sectional area, which comes to 11.7777 kilo Newton per meter square. So, if you know the cross-sectional area of the disturbed soil, then you can find out what the total draft will be. Now, the draft of the front gang, which is powered, is the specific draft multiplied by the cross-sectional area of the disturbed soil. So, the width is 0.914 meters, and the depth is 0.12 meters. So, if you multiply by the specific draft, that will give you the total draft of the front gang, which comes to 1292 Newton.

Now, this is the horizontal force; we are also interested in finding out the vertical force. So, for the vertical force, if you take the ratio between horizontal force to vertical force as 1 is to 1.1, then the vertical force can be calculated. So, 1292 divided by 1.1, that way, we are getting a vertical force of 1175 Newton. So, the only thing is you have to fix the ratio; that way, once you calculate the draft, you can easily calculate what is the total vertical force?. Now, since there are 6 disks, I just divided by 6 to find out the vertical force acting on each disk.

Now, the weight of the implement is important. The weight of the implement for an offset disk harrow varies from 390 to 650 kg. It is not grams; it is kg per meter of cutting width. So, cutting width is 0.914 meter. So, we have taken the total weight of the implement as 550 kg. So, that way we are getting a total of 502.7 kg. So, it comes to 4931.48 Newton. This is for the total implement. So, assuming that the weight is uniformly distributed in the front gang as well as the rear gang. So, each gang will experience a weight of half of this one. The next thing is whether W is greater than V_T - the total vertical force or not, because usually in the case of a disk harrow. The vertical force is always acting upward. So, if the vertical force is more than the weight, then there is a tendency that the disk may not penetrate into the soil. So, we have to have a weight which is more than the vertical force. So, what we experience is the weight is 4931, and the vertical force, if you take half of that one, is greater than the total vertical force. So, that way, this condition is satisfied, which means penetration is not a problem. Now, after deciding the horizontal force and the vertical force, the next thing is how to design the shaft.

We have already decided the length of the shaft by multiplying the number of disks with the spacing between two adjacent disks, and we are getting 0.96 meters. Then, assuming the weight of each gang to be W_g, which is equal to 4931.48 divided by 2, and it is uniformly distributed along the shaft. So, we have to find out now what the forces acting are. So, this is the shaft, and the 6 disk positions are indicated here, and at each point, I have indicated the vertical force acting upward. So, now, the weight is acting downward, the vertical force is acting upward, then we try to find out the support reactions, $\mathrm{R_A} = \mathrm{R_B} = \frac{\mathrm{W_g - V_T}}{2}$. So that way, we are getting 644.87 Newton, and this is acting upward. Now, taking the moment about the central line, which is denoted by the red dotted line. So, R_A is acting at a distance of, say, if the spacing is S/2, S, S, S/2, that means 3 S. So, if I take a moment, the shaft is subjected to bending due to the vertical force which is acting and is subjected to torsion due to the force acting parallel to the face of the disk. Now, first, we try to calculate the bending moment, which is denoted as $M_S = \mathrm{R_A 3S} + 4.5\mathrm{VS} - \frac{\mathrm{W_g}}{2} \times 1.5\mathrm{S}$. So that way, we calculate the total bending moment. It comes to 154.76 Newton meters.

Now, the next thing is what is the force which is acting parallel to the face of the disk, that will be the draft divided by cos 20 degrees. So, that way, $\frac{D_i}{cos\alpha} \times$ N1, that will give you the force which is acting parallel to the face of the disk - the total force acting parallel to the face of the disk. And, assuming that the soil resistance is acting at a height of a/3, a is the depth. So, the moment arm will be $r - \frac{a}{3}$. So, r is the radius of the disk. So, if I take those values, the radius as 0.51 by 2, that means 51 centimeters was taken as the diameter. So, 51/2, that way gives you the radius. So, $N1 \times (\frac{D_i}{cos\alpha}) \times \left(r - \frac{a}{3}\right)$. So, that way we are getting a torsional moment of 295.61 Newton meters.

Next is assuming the gang shaft to be a square cross-section - solid square cross-section. So, it will be subjected to bending, it will be subjected to torsion. So, stress due to bending and stress due to torsion can be calculated utilizing this formula. So, and then utilizing the maximum stress theory - shear stress theory, we calculate to find out what will be the dimensions. So, I have just simply replaced σ_b with $\frac{M_s}{b^3/_6}$ and τ as $\frac{T_s}{b^3/_3}$, and then putting in this we got a relationship $b^3 = \frac{3}{\tau_{max}}\sqrt{\mathrm{M_s^2 + T_s^2}}$. Ms is the bending moment Ts is the torsional moment. And then taking a shock and fatigue factor of around 1.5. And design stress we have taken as 50 Mega Pascal. So, now, substituting in this we will find out. So that way, we find out b will be equal to 3.108 centimeters. This is with respect to the front gang.

Let us now see, with respect to the rear gang, what dimensions are coming. For calculating the dimensions of the rear gang, again, the first thing is we have to calculate the draft value. So, since it is unpowered, we can utilize the ASABE equation. So, that way, the ASABE equation is draft per unit meter of cutting width $D_{rm} = F_i$ [A + B(V_a) +

$C(V_a^2)]T_d$, where T_d is the depth. Now, the forward speed we have already assumed as 3.6 kilometers per hour.

Now, the Fi value I can take as 2 for medium soil. So, it will be 0.88, and then A, B, and C values are 254, 13.2, and the C value is 0. So, the C component will be 0. So, if I substitute here, then we will get a value of D_{rm}, that is draft per meter of cutting width, as 3184.05 Newton per meter. Now, the total draft will be just multiplied by the cutting width. So, that way, we are getting 2910.22 Newton. So, assuming a draft by vertical force ratio as 1.2, not 1.2. So, this is 1.2. V_T, the total vertical force, will be 2425.18 Newton. So, assuming that 2425 Newton is the total vertical force.

So, the total draft force is 2910.22 Newton. The total vertical force is 2425 Newton. So, then we try to find out the vertical force acting on each disk. So, that way it comes to 2425/6, which is 404.19 Newton. Then, for designing the shaft, the length of the shaft will remain the same because the number of disks is 6, and the spacing between them is the same. So, that way it comes to 0.96 meters.

Again, W_g will be half of the weight of the machine, assuming that it is uniformly distributed. So, we again calculate the total reaction - the total supporting force R_A and R_B, which will be equal to the total vertical force minus the total upward force acting, i.e., the downward force and upward force divided by 2. So, that way, it is coming to 20.3 Newton. Now, if you look at this again. So, there will be 6 disks. R_A and R_B will be acting at the end, and $W_g/2$ will be acting at the center of the half of the gang. Then, taking the moment about the center line, which is denoted as the red dotted line, we will get - $M_S = R_A 3S + 4.5VS - \frac{W_g}{2} \times 1.5S$. So, now, you substitute for those R_A, V, and W_g. So, that way, you are getting a bending moment of 7.766 Newton meter. Now, the torsional moment = $N1 \times (\frac{D_i}{cos\alpha}) \times \left(r - \frac{a}{3}\right)$, which means the soil resistance parallel to the face of the disk, which is equal to draft/cosα. So, N1 into Di will give you the total draft divided by cos 20, and then the moment arm is $r - \frac{a}{3}$. So, that way, you are getting 665.85 Newton meter. Here, the bending moment is less, whereas the torsional moment is much higher. Now, again assuming the cross-section of the gang shaft to be a solid square with a dimension b. So, we try to find out the stress due to bending, stress due to torsion, then utilizing the maximum stress theory, we come to an expression - b is equal b= $[\frac{3}{\tau_{max}}\sqrt{M_S^2 + T_S^2}]^{1/3}$. Now, assuming the shock and fatigue factor to be 1.5 for both bending as well as torsional moment and the design stress value as 50 Mega Pascal, so, b comes to 3.91 centimeters.

Now, I will go to the design of the frame. So, the frame is subjected to both bending as well as torsion. Bending is due to the vertical force on the shaft, that is R_A and W_g, and torsion is due to the draft. So, again, we will utilize the maximum stress theory: $\tau_{max} = \frac{1}{2}\sqrt{(\sigma_b)^2 + 4 \times (\tau)^2}$. So, where, σ_b is the stress due to bending and τ is the stress due to the torsional moment, then look at the arrangement of this kind of frame and what are the forces acting, how it is causing bending. So, the total bending moment will be: the support is at the two ends. So, bending moment, $M_F = 3R_AS - \frac{W_g}{2} \times 1.5S$. Since the disk is not directly in contact with the frame, it is supported. So, there will be a clearance. This clearance is there.

So, to find out the torsional moment, we need to know the draft into - draft into this distance plus this distance, and this is written as diameter minus a by 3. So, that will give you, suppose, so, this distance and this clearance. So, that way, that gives the moment arm, and $D_i/cos\alpha$ ×N1 will give you the total soil resistance acting parallel to the face of the disk. So, the stress due to bending, again, we calculated. So, $\left(\frac{M_F \times b/2}{b^4/12}\right)$. So that way, you get an expression for stress due to bending, then stress due to torsion $\frac{T_F \times b/2}{b^4/6}$. So, now you substitute in this formula - the maximum shear stress theory formula. So, b is equal to this. Again, we are taking a shock and fatigue factor of 1.5 and a factor of safety as 3. So that the design stress is 50 Mega Pascal. So, 50 into 10 to the power of 6.

So, this will be the expression. Now, we have to find out the bending moment. So, we calculated what the R_A value is, then this is the spacing. W_g, we have already assumed, and then putting in that formula, so, the bending moment comes to 67.44 Newton meter and the torsional moment comes to 783.7 Newton meter. Now, you substitute here. So, you will get a dimension of 4.13, which means, the frame assuming it to be a square one, and then it comes to 4.13 centimeters.

This calculation I have done based on the draft value of the front gang. Now, similarly, we will try to calculate the dimension based on the rear gang, because the rear gang experiences a higher draft, that is why I calculated. So, the bending moment which comes to minus 286.144, then the torsional moment again comes to 1765.28 and putting in this maximum shear stress theory formula. So, b comes to 5.44 centimeters. So, dimensions of the gang shaft for the front gang, when you consider the draft of the front gang, we got a dimension of 3.108 centimeters.

Now, when we consider the draft of the rear gang, the dimensions come to 3.9 centimeters. And similarly, for the front frame, you get a dimension of 4.13 centimeters, and if you consider the rear gang draft value, the dimension comes to be 5.44 centimeters. So, the dimensions of the front gang are 3.108, sorry, 4.13 centimeters, and the gang bolt is 3.108 centimeters. So, what we can do is either take the highest value and maintain the same value in the front as well as the rear gang. So, this higher value which you experience here may be because of the cone index value which you have taken because the ASABE equation, we have taken some values which are for secondary tillage.

So, that may be the reason why the draft value is coming higher, and since the draft value is higher. So, obviously, the dimensions should be higher for the rear gangs, but anyway, I have given you the procedure and how to find out the dimensions. So, the higher the dimensions, you can keep the dimension for both the gangs.

The next thing is how to calculate the power requirement. So, the power requirement, as we know, since the front gang is powered, that means we require some PTO power and we require some drawbar power. Some drawbar power means drawbar power to move the implement to take care of the draft values and drawbar power to move the tractor and implement. We will calculate each one of these components. So, the first component is the PTO power requirement; we know the draft value, the horizontal soil reaction parallel to the face of the disc for the front gang, then we know the rpm, which is 180, and putting this in this equation, we find out the power requirement at the gang shaft. Then, when you divide it by the transmission efficiency, we will find out that value, which will give you the power requirement at the PTO, the PTO power. So, the PTO power comes to rotating the disk, only the front gang disks.

So, 6.19 kilo Watt, you have taken a transmission efficiency as 0.9. Now, the drawbar power required for overcoming draft will be the draft of the front gang plus the draft of the rear gang multiplied by the forward speed. So, the draft of the front gang we have calculated is 2445 Newton, and the draft of the rear gang we have calculated is 2910.22 Newton. So, that way you are getting a total of 5355.22 Watt, which means 5.36 kilo Watt. This is to take care of the draft part.

Now, the drawbar power required to overcome motion resistance. So, assuming that 8 per cent of the total weight of the implement and tractor is the motion resistance, then the weight of the tractor is 2200 kg, and the weight of the implement we have already taken is 4931.48 Newton. So, the summation of this will give you the total force. Now, 8 per cent of that multiplied by the forward speed. So, that will give you the total power required for overcoming rolling resistance.

This is the drawbar power required to overcome motion resistance, which is 8 per cent of the total weight of the implement and tractor multiplied by the forward speed of travel. So, that way, we have multiplied here. So, then we got a value of 2.12 kilo Watt. Now, the total drawbar power required will be the drawbar power to overcome draft and the drawbar power to overcome the rolling resistance. So, 5.36 kilowatt is for draft, and 2.12 kilo Watt is for rolling resistance.

So, that way we are getting 7.48 kilo Watt. Now, the equivalent PTO power to total drawbar power. So, whatever drawbar power we got, that has to be converted to PTO power. So, if you know the transmission efficiency - if you look at this diagram. So, it requires 0.86 to 0.89. So, that way we will find out the PTO power. So, 7.48 kilo Watt was the drawbar power we divided by 0.86. So, that way we are getting 8.697 kilo Watt as the PTO power equivalent to drawbar power. Now, the total PTO power requirement will be in the PTO power required to rotate the gang. So, that way we are getting 6.19 kilo Watt and power required equivalent to the drawbar power which is 8.697. So, summation of this gives you 14.887 kilo Watt. Now, taking a 20 per cent power reserve, and assuming a transmission ratio between engine to PTO as 0.87. So, total PTO power required into 1.2 divided by transmission efficiency, so that way we are requiring a power of - engine power of 20.53 kilo Watt. So, this is how we have to calculate the engine power and the draft requirement, and from draft requirement, we can find out the bending moment and torsional moment, and then we will decide the dimensions. These are some of the references, and finally, I can say we discussed how to compute the design of different components of an active-passive tillage implement.

Thank you.