Design of Farm Machinery

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Lecture 06 : Design of Disk Harrow

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 6, where I will try to cover the design of a disk harrow. The concepts which will be covered are how to compute the offset for a disk harrow, then how to design disk implements, design of the diameter of the disk, how to decide the diameter of a disk, the spacing between two adjacent disks, what will be the cutting width, how to design a gang bolt, that means how to decide the dimensions of the gang bolt, and then the frame. Now, if you look at it, first I will give you a problem that will help you understand how to calculate the draft requirement of a single-acting trailed disk harrow.

So, this is a problem where a tractor-operated single-acting trailed disk harrow which has 7 disks in each gang. The gang angle for both gangs is given as 35 degrees, and the horizontal component of the resultant soil reaction force on each disk is given as 600 Newton, and the horizontal soil reaction is making an angle of 30 degrees with the gang axis. If the speed of operation is 6 kilometers per hour, then the required drawbar power in kilowatt has been asked to be found out. So, the value of the draft which is given, not the draft actually, is the horizontal component of the resultant soil reaction. So, in the previous class, we have resolved the forces acting, the horizontal forces acting on a disk blade into two components: what is the lateral component and the longitudinal component. So, the longitudinal component will be your draft. And the resultant soil reaction is indicated here as F_R for the right gang - this is and F_L for the left gang, and the total soil reaction force will be the summation of all the soil reaction forces acting on each disk.

The value of each disk is given as 600 Newton. So, that is why there are 7 disks in each gang. So, we multiply 7 with 600 to find out the total resultant soil reaction force acting, and this is acting at an angle of 30 degrees to the gang axis. Now, to find out the draft, the F_R has to be converted along this direction. So, if you look at it, I have extended this one. So, this is making an angle α, and what you have to find out is this angle. This orientation.

So, that becomes your 90 minus 65. Because, it has a gang angle of - the original component is making an angle of 30 degrees and the gang angle is 35 degrees. So, together it will be 65. So, 90 − 65 will be 25 degrees. So, $F_R \cos\boldsymbol{\alpha}$ will be for this, $\boldsymbol{\alpha}$ is 25 degrees.

So, $F_R \cos\boldsymbol{\alpha}$ is for this side draft for this side, and $F_L \cos\boldsymbol{\alpha}$ will be draft for the left side. So, the summation of this will give you the total draft force. Now, speed is given. Draft × velocity or forward speed will give you the total drawbar power. So, that becomes 12.68 kilowatt.

Then, for designing the disk harrow, the first thing you have to find out is what should be the diameter of the disk? So, if you know the depth of operation, then we can find out the diameter of the disk, $\mathrm{D} = \mathrm{k}\frac{\mathrm{a}}{\cos\beta}$. k is a coefficient whose value is given as 3 to 6 for tillage harrows, and β is the tilt angle. In the case of a disk harrow, the tilt angle is not there. This is a very generalized equation. It can be applied to both disk plough and disk harrow, which is why β is given. But in the case of a disk harrow, this β angle is 0. So, that means, this D will be equal to – for harrow, D = k × a, where a is the depth of operation in centimeters and k is the coefficient varying from 3 to 6. So, if you know the depth - the maximum depth of operation, deciding the value of k, we can find out what should be the diameter required. What you observed before is, the higher the diameter, the better the penetration.

So, that way, there is a limitation given while discussing the disk harrow, that maximum we can go one fourth of the diameter for the depth of operation, okay. That way we can find out what will be the diameter of the disk.

Now, a problem is given like the maximum depth of operation is 14 centimeters, the size of the disk is to be calculated for carrying out tillage operation. So, the formula is $\mathrm{k}\frac{\mathrm{a}}{\cos\beta}$. So, you can - here β will be - for harrow it will be 0 and for the disk plough, it is 15 degrees and k value decide suppose 3 or 4, then D = 4 × depth is 14 centimeters is given divided by cos 0, 1. So 56 centimeters, okay. So, this way you can calculate.

Now, the next design parameter will be, what will be the spacing between two adjacent disks in a disk harrow? This figure shows here on the left side, the front view and the bottom figure is the top view, where we can find out the relationship between the spacing S and the disk angle and the depth of operation and the diameter. If you look at this diagram, ABC. So, this diameter D_c refers to the diameter of the disk, when the disk is operating at a height - at a depth c, that is the height of the ridge.

So, the diameter corresponding to the ridge height is D_c, and the total diameter is D. Now, if you look at the triangle ABC, and θ_0 is your setting angle or the gang angle, then this will be angle BAC will be θ_0. So, from there, you can find out the expression for BC. So, BC will be equal to how much? AB $\tan\theta_0$. Similarly, in the triangle CDE, CD will be equal to DE $\tan\theta_0$. Now, if you sum these two, then BC + CD = AB $\tan\theta_0$. If you take common (AB plus DE) $\tan\theta_0$. AB+DE is nothing, but AB + DE, that is nothing but DC. So, AB + DE = DC, and BC + CD is nothing but BC+ CD, which is nothing but S. So, S = DC $\tan\theta_0$, okay.

So, now, to find out the spacing, you need to know the value of θ_0. θ_0 is the disk angle that you know, and you have to find out the diameter of the disk. So, the diameter of the disk $= 2\sqrt{c(D-c)}$, which we have already derived before. So, knowing this, you can find out the total expression will be, $S = 2\sqrt{c(D-c)}$ $\tan\theta_0$. So, I have given the values of θ_0, c, and the tillage depth a.

Then, what should be the cutting width of this harrow? So, there are two equations available: one is available from the Bureau of Indian Standards, and the other one is available from the American Society of Agricultural and Biological Engineers for three different disk harrows - one is the single-acting disk harrow, the other one is the double-acting disk harrow, and the third one is the offset disk harrow. If you look at these equations, then what you can see is, basically, these two equations are the same. $W = (0.95 \times N \times S + 0.3 \times D)/100$. This division is for converting the expression to meters. For N is the number of spacings, S is the spacing between two adjacent disks. So, this is for the single-acting disk harrow.

If you compare with the ASABE equation, you can see 0.95 is there. Instead of N, there is $N1 - 2$, and S is there in both the equations, and the other thing 0.3 D is there for both the standards. So, this N1 is nothing but the number of disks. So, in the case of the BIS standard, it is given the number of spacings, whereas, in the case of ASABE, it is given the number of disks. So, $N1 - 2$. Similarly, for the double-acting disk harrow, the same thing. The expression is more or less the same. Instead of N, they are using $N1 - 2$, and in the case of the offset disk harrow, instead of N, again they are changing to $N1 - 1$. Okay. But the rest of the coefficients, if you look at, 0.6, 0.6 there, 1.2, 1.2. So, here N is the number of spacings, N1 is the number of disks, and S is the spacing between two adjacent disks in the case of a single-acting disk harrow, and S for a double-acting disk harrow is the spacing between two adjacent disks in the rear gang.

Similarly, in the case of an offset disk harrow, S is the spacing between two adjacent disks in the rear gang. These are S in centimeters, D is the diameter of the disk in centimeters. So, here I have written D1, D, D1. So, both are the same. So, that's why. But these equations have been developed for a disk angle or gang angle of 18 degrees, but it has been written that these equations can be applied starting from 14 degrees to 22 degrees with minimum error. So, let us now see how to utilize these equations to find out the cutting width and then subsequently how it is affecting the volume of soil.

The first question which is given is: a single-acting disk harrow with 7 disks of 51-centimeter diameter. They are put in each gang with a gang angle of 20 degrees, when it is operated at a depth of 12 centimeters and at a forward speed of 3 km/h. Find the area covered by the disk harrow and the volume of soil handled per unit time.

So, the first thing we have to calculate is the spacing. If you want to utilize the, if you want to find out the area covered, you need to know what is the width of cut and then what is the forward speed?

So, if you know the width of cut. For finding out the width of cut, we have to find out what should be the spacing between two adjacent disks. So, $\mathrm{S} = 2\sqrt{c(D-c)}\ tan\theta_0$. So, the c value here is 12 centimeters, the depth. So, substituting here, you can find out the spacing required is 15.75 centimeters. Now, once you know the spacing, then next is either you use the BIS standard or use the ASABE standard to find out the cutting width. Both will give you the same value. If you look at the equations, N for 2 gangs there will be 7 plus 7, 14 disks. So, the number of spacings if you count in 1 gang there will be 6 spacings. So, that is why I have taken here 12, 12 means 6 into 2. So, that will be 12 number of spacings and the spacing value is 15.75 centimeters. So, that way, you are getting 1.95 meters. Whereas, in the case of ASABE, instead of 12, I have taken 14 minus 2, which means the total number of this is 14 minus 2. So, that way, it will give 12. So, again, we will get the same cutting width. So, once you decide the cutting width, multiply it with the forward speed. So, that will give you the total area covered. Then, multiply it with the depth of operation, which will give you the volume of soil handled. So, that way, it comes to around 702 cubic meters per hour.

Similarly, for a double-acting disk harrow with 7 disks of 51-centimeter diameter in each gang, with a gang angle of 20 degrees in the front and rear, it is operated at a depth of 12 centimeters and at a forward speed of 3 kilometers per hour. So, the volume of soil handled per unit time. The same equation I have used for BIS, ASABE. But here, the coefficients are different because it is a tandem disk harrow or a double-acting disk harrow. So, that way, we get a value of 2.408. But here, the number of disks is not 7 into 4. You have to take the number of disks in the rear gang. So, the rear gang left side and right side together will be 14. So, 14 minus 2, which means the number of spacings will be 12. So, that is why I have taken 12 here. So, the same is the case with ASABE: 14 minus 2, and the rest of the things are the same. This is a plus. So, we will get a cutting width of 2.408 meters. Now, the width is known. The speed is known. We can calculate the area covered and then multiply it with the depth, which will give the volume of soil handled per unit time.

The next problem is an offset disk harrow with 7 disks of 51-centimeter diameter in each gang and with a gang angle of 20 degrees in the front and the rear. Both gang angles are the same, and the rear is operated at a depth of 12 centimeters and at a forward speed of 3 kilometers per hour. So, the same procedure you will follow. But here, the problem will be how many disks you are going to take? So, the number of disks will be 7, that is, on the rear gang, okay. So, 7 minus 1 will give you 6. So, 6 will be the spacing for BIS, and N1 will be 7. Utilizing the formula given by BIS or ASABE, you can easily calculate what the cutting width will be. So, 1.204 meters is the cutting width. Now, knowing the cutting width and forward speed, we calculate the area covered. But these are the theoretical area, not the actual area. So, I have not considered the actual area. So, we have only considered the theoretical area, and the volume of soil handled will be again area into depth, which will give you this much volume of soil that is handled. So, if you compare these three, the single-acting disk harrow, double-acting disk harrow, and offset disk harrow, obviously, the offset disk harrow will give you the minimum volume of soil handled. Because it has only two gangs, one after the other. So, that is why the volume of soil handled will be less, as the cutting width is less.

Now, the next thing is how to find out the shaft dimensions, that means, what should be the length of the shaft? The shaft means the gang bolt on which the disks are mounted. Usually, what we do is we only design for one shaft, and the same dimensions have been kept for the other gang. If it is an offset disk harrow, obviously, the rear gang is handling more volume of soil. If it is a double-acting disk harrow, the rear gangs are handling more volume of soil, hence the forces, where the forces are more, that gang we can take and find out the dimensions of that gang. So, for designing the gang shaft, we need to know what should be the length of the shaft. Because we know this disk spacing. So, the number of disk spacings into the spacing between two adjacent disks, if you multiply, that will give you the length of the shaft. Usually, you can express it in terms of centimeters or meters; it does not matter, but you have to have some extra length for fitting purposes.

Then, what is the cross-section of the bolt? That is important. Usually, the gang bolt means the bolt is usually circular, but in the case of a disk harrow, the gang bolt is never a circular cross-section; it is a square or rectangular cross-section. So, that is the difference. So, to design the bolt, first, we have to find out what are the forces acting and how these forces are going to decide the dimensions. So, we need to know the spacing. This W is nothing but the spacing between two adjacent disks. Then, once you know the depth at which the disk harrow is to be operated and the diameter and the gang angle, then you can find out what is the spacing between two adjacent disks.

Then, the cross-sectional area of the soil tilled by one disk, which is nothing but S into a, the area depth. So, W into a or you can write S into a. So, that will give you this much area, which is disturbed by each disk. Then, to find out, because draft is the important component which is going to have some influence on the gang bolt. So, we have to find out what is the draft required per disk? So, if you know the cross-sectional area, we have calculated here, and if you know the unit draft, then you can multiply and find out what is the draft acting on each disk. Then, the number of disks, if you multiply, will give you the total draft acting on each gang.

And, we know the draft to vertical soil reaction ratio, which is given in this table for different disk angles and for 46 and 56 centimeter diameter disks. So, once you know the draft acting, then you can find out what is the vertical force acting, assuming a ratio. Then, suppose you are designing a single-acting disk harrow. So, the weight of the disk gang assembly has to be decided. So, in the previous lecture, I have given you the value of disk harrow per meter of cutting width - 150 to 270 kg. So, that way you can. Once you know - once you calculate the cutting width, you can find out what will be the weight of the implement.

So, if it is a single-acting disk harrow, there will be 2 gangs. And the weight will be divided by 2, that means, if the total weight is W_t, the weight acting on each gang will be $W_t/2$, and that will be the weight of each gang. Now, look, let us look at this diagram that will give you more idea about what are the forces acting and how these forces are causing moments about this gang bolt. So, I have calculated the draft, which is denoted - this one draft, and I have represented it as acting at the center of the total draft, which is represented as acting at the center of the gang bolt, which is denoted by this line. And then there is an important component that is the soil reaction, which is parallel to the face of the blade, which I denoted as this one.

The angle between this horizontal soil reaction - resultant soil reaction parallel to the face of the blade, which is denoted as M. So, the relationship between M and D_f is, M is equal to $\frac{D_f}{cos\alpha}$, where **α** is the gang angle, ok. So, we have - how M is going to affect the design. So, we will discuss it a little later. So, now, I have indicated the gang axle here and what are the forces acting at each disk where the disk is attached to the gang. There will be a vertical force, and there will be a horizontal force. The vertical force is denoted as V. So, there will be 7 Vs, sorry, there will be 6 Vs because I have, I am just giving an example that 6 disks are present in the gang.

So, the support at the two ends will be equal to the total vertical force acting downward divided by 2. So, the total vertical force acting downward will be $W_g/2$ acting downward, and the vertical force acting at each of the disks is upward. The summation of this will be equal to $\frac{W_g-6V}{2}$, which will give you the value of R_A and R_B. These are the two support reactions. Then, this vertical force is going to create bending, bending of the gang bolt. So, the maximum bending moment I try to calculate. So, that will be equal to M_s, will be equal to V × 2.5S (If you look at this diagram, V ×(S + S + S/2), this is 2.5S) + V ×1.5S + V × 0.5S + R_A × 3S (S, S, S by 2, S by 2). So, that way this is your vertical force and reaction force, a support reaction force. Then W_g by 2, 1.5S. W_g, half of the weight, is acting on this side. So, that will be − (W_g/2)×1.5×S. So, that way you are getting an expression for M_s. Now, this M, which is the resultant soil reaction acting parallel to the face of the blade, will try to create torsion, torsion on the gang bolt. So, the torsional moment will be the horizontal force into the moment arm into the number of disks. So, if you are calculating for each disk, the number of disks into the horizontal force will give you the total value of M, M × the moment arm. The moment arm will be equal to either the radius of the disk or $r-\frac{a}{3}$, assuming that the horizontal soil action is acting at a height of a/3, that means, depth by 3.

So, $\frac{D_i}{cos\alpha}$, D_i is nothing but the draft, individual draft of the individual disk, $(D_i/cos\alpha)\times(r-\frac{a}{3})\times N1.$ So, N 1 into this component will give you the total M acting, and this will be your moment arm. Then, since it is subjected to both bending as well as torsion. So, you have to take the maximum shear stress theory as it is a ductile material. So, we have to first calculate what is the stress due to bending and what is the stress due to shear, and then try to find out $\tau_{max}=\frac{1}{2}\sqrt{(\sigma_b)^2+4(\tau)^2}$. So, the bending, since we have assumed that the gang bolt is a square cross section. So, of each side b, then the solid shaft, this will be the formula for calculating the bending shear stress due to bending, and this will be the formula for calculating the shear stress due to the torsional moment. So, that way, if I substitute, finally, we will get an expression $b=\left[\frac{3}{\tau_{max}}\sqrt{{M_s}^2+{T_s}^2}\right]^{1/3}$. So, this τ_{max} is the allowable stress of the material.

This is the problem I am giving you. A single-acting disk harrow with 5 disks of diameter 51 centimeters in each gang and at a gang angle of 18 degrees is operated at a depth of 12 centimeters and at a forward speed of 3 kilometers per hour, and the disk spacing in each gang is given as 21 centimeters. So, what is asked is to find out the soil reaction force causing torsion to the gang shaft and the drawbar power required to operate the harrow in sandy clay loam soil with a unit draft of 0.2 kg/cm^2.

So, first, you have to calculate the width, the cutting width. So, the values are given; the number of disks is given. So, the spacing is given, and it is a single-acting disk harrow. So, you utilize the formula of ASABE or BIS and then find out what the value is. So, it comes around 1.75 meters. Then, what is the cross-sectional area in which the soil is disturbed by the harrow? It will be width multiplied by depth. So, 1.75 multiplied by 0.12, which is the depth, will give you the area disturbed. The unit draft is given. So, you can find out what is the draft acting, okay.

So, since the draft is given as 0.2 kg/cm^2, that is why I have multiplied this by 10 to the power of 4. So, that way, you are getting a value of 4120 Newtons. Now, this is the draft. Then what is asked is to find out the soil reaction. So, if you know the disk angle, you can find out Di divided by cos(alpha), which will give you the soil reaction. So, 4120 divided by cos(alpha) will give you the soil reaction as 4332.02.

Then, the drawbar power required will be draft multiplied by speed. This is the draft, 4120 multiplied by 30 divided by 36, which will give you the drawbar power requirement. So, this value will change a little bit. So, this is the soil reaction force which is causing torsion to the implement. So, briefly, I have discussed the computation of offset for an offset disk harrow, along with how to design the different components of a disk harrow with suitable numericals. That is all.

Thank you.