Design of Farm Machinery

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Lecture 07 : Numericals related to design of tractor drawn 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 7, where I will try to discuss some numericals along with the design of a tractor-drawn disk harrow. The concept should be numericals related to the computation of offset, the design of a disk harrow, particularly the gang bolt. The slides which I am showing now, there we have to calculate the offset, the offset of an offset disk harrow.

How much offset? Offset means the distance between the hitch point to the center of cut, the center of the soil which is disturbed, ok. Here, it is denoted as this distance, this distance, e. So, to compute this one, we have to take moments, moments about the hitch point. So, R_{hf} is the horizontal soil reaction acting on the front gang, the resultant horizontal soil reaction, and R_{hr} is the resultant soil reaction acting on the rear gang. So, when I extend these two lines, they will meet at a point H. So, that is called the horizontal center of resistance.

And now, R_{hf} has two components, one is the longitudinal component denoted as L_f and the lateral component S_f. And similarly, the resultant soil reaction on the rear gang is resolved into two components, L_r, which is the longitudinal component, and S_r, which is the lateral component. So, if you now take moments about the hitch point F_1, so. $eL_f + eL_r + bS_f - (b + d) S_r = 0$. So, here the value of b and d, let me explain. b is the distance between the hitch point and the center of the front gang. Similarly, d is the distance between the center of the front gang and the center of the rear gang.

So, now, if you want to measure the distance from the hitch point to the rear, the center of the rear gang, then it becomes b + d. Now, if you rearrange this one, then the expression for $e = \frac{b(S_r - S_f) + dS_r}{L_f + L_r}$. So, if you further simplify this one, then S_r minus S_f divided by L_f plus L_r is nothing but your tan alpha, that means, this P_y component divided by this P_x component. So, that becomes your tan$\boldsymbol{\alpha}$, $\boldsymbol{\alpha}$ is the angle between the horizontal line of pull and the direction of travel. So, P_h is the horizontal component of pull and P_x is the draft.

So, if you substitute here, then $e = btan\alpha + \frac{dS_r}{L_f+L_r}$. So, that means, offset is a function of the line of pull, how much angle it is making with the direction of travel.

And it is a function of the distance between the two gangs - the center of the gangs is a function of the lateral force acting on the rear gang and the longitudinal forces acting on the front and rear gangs. So, in the case of no side draft, that means S_f will be equal to S_r, which is equal to S. Then in that case, $\boldsymbol{\alpha}$ will be equal to 0. P_h will lie along P_x, and then the expression will be $e_0 = \frac{dS}{L_f+L_r}$. So, I will solve a problem where it will be more clear how to compute the offset for an offset disk harrow. So, the problem is a right-hand offset disk harrow operating with gang angles of 15 degrees and 21 degrees, respectively, for the front and rear gangs. The centers of the two gangs are 2.5 m and 4.25 m behind a transverse line through the hitch point of the tractor drawbar.

The horizontal soil force components are given, such as L_f and L_r. S_f and S_r side components are given, then how to calculate the offset of the center of the cut with respect to the hitch point and the horizontal component of pull. There are two things which we are going to compute here. The first thing is the offset. We know the expression for the offset. Then we try to find out all the values, which are given. Only the d value, the d value is also, the d value will be equal to the difference between 4.25 and 2.5. So, that way, you are getting a value of 1.75 m. So, L_f, L_r, S_r, S_f, and d. b, all those values are given. Then by substituting in this equation, you can find out the value of e, which is equal to the offset.

Now, for finding out the horizontal component, that means P_h, the horizontal component of pull, P_h, we have to calculate the angle alpha and then the P_x value and P_y value. So, $P_x = L_f + L_r$, and $P_y = S_r - S_f$. So, tan$\boldsymbol{\alpha}$ = P_y/P_x. So, that way, you can calculate L_f + L_r. So, that way, you can calculate tan$\boldsymbol{\alpha}$. Now, to calculate P_h, $P_h = \sqrt{P_x^2 + P_y^2}$. So, P_x is calculated, P_y is calculated, then by substituting here, we can find out the value of P_h, which is the horizontal component of pull.

Let me give one more problem, which is related to the right-hand offset disk harrow again. Each gang of a right-hand offset disk harrow without wheels has seven 61-centimeter blades, and 24 centimeters apart. The total mass is 700 kg. During operation, the vertical force experienced at the front and rear gang is 6.7 and 4.3 kilo Newton, with a disk angle of 16 degrees and 20 degrees, respectively. The total longitudinal to vertical force and lateral to vertical force ratio are 0.9 and 0.7 for the front gang and the rear gang, respectively. The longitudinal force to vertical force and the lateral force to vertical force ratio are 0.9 and 0.7 for the front gang, respectively, as compared to 1.2 and 1.1 for the rear gang.

Calculate the total draft and draft per unit mass of the offset disk harrow. This is the first component. The second component is: if the centers of the two gangs are located 2.5 meters and 4.25 meters behind a transverse line passing through the tractor drawbar's hitch point, then calculate the amount of offset of the center of the cut with respect to the hitch point and the horizontal component of the pull. So, first we have to find out. This is the diagram, where it is indicated that the front gang and the rear gang are indicated, and the forces which are acting have been indicated and have resolved the forces—the resultant forces into components. And then, we try to locate or we try to write down the values which are given in the problem.

The disk angle of the front gang is given as 16 degrees, the vertical force is given as 6.7 kilo Newton, and the total longitudinal force to vertical force ratio is also given. So, the next thing is, we have to calculate. The total lateral force to vertical force ratio is also given. So, what you have to calculate is the longitudinal force and the side force or the lateral force. So, since the vertical force is given, just multiply it with this ratio. So, that will give you a longitudinal force of 6.03 kilo Newton and a lateral force of 4.69 kilo Newton.

Similarly, we have to find out what are the data given for the rear gang. So, let us now see, the disk angle or the gang angle is given as 22 degrees. The vertical force is given as 4.3 kilo Newton. The total longitudinal force to vertical force ratio is given as 1.2. Then, since the vertical force is given and the ratio is given, to find out the longitudinal force, we just multiply. So, that will give you 5.16 kilo Newton as the longitudinal force. Now, the total lateral force ratio with vertical force is 1.1.

So, again multiplying with the vertical force, we will find out the lateral force. So, now, we got the values of L_f, L_r, S_f, and S_r independently. So, the question which is asked is: what is the total draft? That means, the total draft will be equal to your total longitudinal force, since they are acting in the same direction. So, it is the summation of those two, L_f plus L_r, which gives 11.19 kilo Newton.

Now, side draft is the difference between S_r and S_f. Since S_r is - S_r means the side force which is acting in the rear gang, and the rear gang has a higher gang angle, so it is obvious that it will handle more volume of soil. Hence, your side draft will be more in the rear gang as compared to the front gang. So, S_r minus S_f will be equal to the difference if you take it; it is coming that means 4.73 kilo Newton in the rear gang and 4.69 kilo Newton in the front gang. So, the difference will be equal to 0.04 kilo Newton. Now, the other question which is asked is to find out the draft per unit mass of the offset disk harrow.

So, the mass of the offset disk harrow is given as 700 kg, and the total draft is coming as 11.19 kilo Newton. So, if you take the ratio, I have converted this into Newton: 11.19 into 1000, then this was in kg force. So, I multiplied it with 9.81. So, that way, the units are the same, and the ratio comes to 1.63. This is the first part of that problem.

The second part was again how to find out the offset, and the other thing is the horizontal component of pull. So, the values which are given are b as 2.5 meters and d as the difference, that is 4.25 minus 2.5; that way, the d value has been computed. Then, if you look at the offset equation, here b value you know, d value you have computed, S_r value you have computed just now, and the longitudinal force also you have computed. So, putting all those values in this equation, that way it becomes total draft, that is L_f plus L_r becomes P_x, which will be equal to 11.19 kilo Newton. And P_y, which is nothing but the difference between lateral forces, that is side draft, that will be equal to 4.73 minus 4.69. So that way, you are getting 0.04 kilo Newton.

Now, the horizontal component will be the square root of P_x squared plus P_y squared. So, I have taken 11.19 as P_x and 0.04 as P_y. So, taking the square of these two terms and taking the square root, adding and then taking the square root, the horizontal component of pull comes to 11.19 kilo Newton. So, these two examples will help you find out the draft, find out the inclination of the pull in the horizontal direction, and then find out the offset in an offset disk harrow. This offset is required to utilize the offset disk harrow in orchards because beneath the tree, we cannot go; we cannot take a tractor with an implement. So, the tractor has to be a little away from the tree, and then the implement should come beneath the tree.

So, that is why this example will help you in finding out what the offset will be or what the maximum distance the implement can be moved is. So that you can accordingly plan to prepare the soil beneath the tree.

The next problem is related to your design of a gang bolt. A gang bolt is nothing but the shaft on which the disks are mounted. So, I am going to design that for a particular case, like the problem given is: the draft of an offset disk harrow with 6 disks of 51 cm diameter in each gang with a front gang angle of 15 degrees and a rear gang angle of 20 degrees, when operated at a depth of 10 cm and 12 cm, respectively at a forward speed of 3 km/h. The draft comes to be 4750 Newton, and the total weight of the implement is given as 300 kg. If the draft of the rear gang is 20 per cent more than the draft of the front gang, then decide the dimensions of the gang bolt for each gang of the disk harrow.

The question is a little tricky in the sense that we need to know how to design the gang bolt of an offset disk harrow. Usually, in the offset disk harrow, the front gang operates at a lesser depth, and the rear gang operates at a higher depth. The reason is that the front gang comes in contact with soil that is a little harder than the rear gang. Because, once the front gang interacts with the soil, the soil is disturbed, and the rear gang comes in contact with that disturbed soil. So, that is why the gang angle is made larger so that the rear gang can operate at a greater depth compared to the front gang and thereby it handles more volume of soil. So, that is the concept. So, now the thing is, which gang bolts should we design? Should we design for the front gang or should we design for the rear gang?

The obvious answer is, since the rear gang is handling more volume of soil, it will experience more draft. So, we have to design for the rear gang, and the same dimensions can be kept for the front gang. So, to find out what is the draft acting and what are the forces acting, which are trying to affect the gang bolt. So, that you have to first locate. So, if you look at the figure here, this offset disk harrow, I have indicated the $\boldsymbol{\alpha}_f$, $\boldsymbol{\alpha}_f$ will be equal to 15 degrees, and $\boldsymbol{\alpha}_r$ will be equal to 20 degrees, as given in the problem.

Then, the rear gang is operated at a depth of 12 cm, and the front gang is operated at a depth of 10 cm. Both are operated at a forward speed of 3 km/h. So, now the force which is causing or which has to be considered for designing the gang bolt is: What is the draft force? And what is the soil reaction force? That means, the force which is acting parallel to the plane of the disk, if you know, then we can go for designing. So, for finding out the draft, we need to know the values of the draft. So, the values of the draft are given as 4750 Newton, but that is given for the total implement. Another clue given is that the draft of the rear gang is 20 per cent more than the draft of the front gang. That means, if the front gang draft is x, then the rear gang draft will be 1.2x. So, the summation of this is given as 4750 Newton.

So, now, to find out x, this will be equal to 4750 divided by 2.2. So, that way, we will get the draft for the front gang. But we are going to design the draft for the rear gang. So, we have multiplied it by 1.2 to find out the total draft acting on the rear gang. And if you want to find out the draft acting on a single disk, then you just divide it by 6, because 6 is the number of disks provided in the gang. So, if you divide by 6, then that will give you the draft acting on each disk.

Now, once you know the draft, then we can find out the vertical soil reaction, that is V or V_t, the same thing. So, the L by V ratio, because we have discussed in the previous classes, what is the L by V ratio - the draft to vertical force ratio for different disks at different angles, starting from 15 to 23 degrees. So, these are the values given for different diameters of the disk. Since our diameter is 51 cm. So, I would rather prefer to, and the gang angle is 20 degrees since we are designing for the rear gang. So, we are somewhere here. L by V ratio. So, I have taken the L by V ratio as 0.95, and then once I know the value of the draft which is coming to this value per disk, you can just utilize this one. That means, D_r divided by 0.95 will give you the vertical force acting.

Now, let us see how this vertical force is going to affect the design of a gang bolt. So, I have shown the number of disks. This is the gang bolt. So, the vertical force is basically going to create a bending of the gang bolt.

So, at each disk, the vertical force acting is denoted as V, and there will be weight acting on the gang. So, assuming that the weight is uniformly distributed on the front and the rear gang, that means the total weight was given as 300 kg. So, 150 kg will come on one gang. Now, if you look at this one, the gang weight will be equal to the total weight divided by 2. So, now, if you put it here.

So, the gang bolt is supported at the two ends. So, the support reactions, R_A and R_B, will be equal to W_g, which is the weight coming on the gang bolt, minus the summation of vertical forces. Because weight is acting downward, and V is acting upward. So, that is why, W_g minus 6 V by 2. So, that way, you can calculate R_A and R_B. Then, because of this, let us now take the moment about - the bending moment about the central line, which is denoted here as red color.

So, the bending moment due to vertical forces will be equal to M_s, if you denote it as M_s. So, M_s will be equal to V into (1, 2, half S, So,) 2.5S, then V into 1.5S, V into 0.5S, plus R_A into 3S (S, S, S by 2, S by 2). So, that is why I have written R_A into 3S. And W_g is acting downward. So, $W_g/2$, minus I have taken, $-W_g/2$, because half of the weight is here. So, $W_g/2 \times 1.5S$. So, that way, if you simplify, this is the expression for the bending moment due to vertical force.

Now, the vertical force you have computed. So, the weight of the implement is this much, 300 kg. So, in one gang, it will come half. Spacing between two adjacent disks. So, before going for further calculation, then we have to find out what is the spacing between two adjacent disks, which is important. So that, we can find out what will be the length of the shaft.

So, the length of the shaft - if you find out the spacing, spacing into the number of spacings into spacing, that will give you the length of the shaft. So, for finding out the spacing between two adjacent disks, that is denoted as S. S = $2\sqrt{a(D-a)}\tan\theta_0$, where a is the depth of operation and θ_0 is the disk angle or the gang angle, both are the same. So, the depth for the rear gang is 12 cm. So, I have taken 12, and the diameter is given as 51 cm, and the gang angle is 20 degrees. Now, substituting this in this equation, we find out that the spacing between two adjacent disks is 15.75 cm.

Now, the length of the shaft will be equal to N1 into the spacing between two adjacent disks. So, that way, you are getting a diameter roughly around 0.8 - the length roughly around 0.8 meters. Now, the W_g is uniformly distributed along the shaft. So, R_A and R_B, I have already done this exercise. So, the downward force is this much, and the vertical force is this much. So, that way, you can get a value of 107.865. The shaft is subjected to bending due to vertical forces. So, now, you put all those values. So, these values, when I put them, the bending moment comes to 371.386 Newton meter. So, this is the bending moment.

So, but the shaft is not only subjected to bending, it is also subjected to a torsional moment. So, the torsional moment, T_s will be equal to your - the soil reaction force, which is acting parallel to the face of the blade into the distance between the point where the soil reaction is acting and the center of the disk. So, that way, N1 × $D_i/\cos\boldsymbol{\alpha}$. This will give you the total soil reaction force, which is acting on the gang. $D_i/\cos\boldsymbol{\alpha}$ is nothing, but the soil reaction force which is acting at each disk. So, if N1 is the number of disks, if I multiply this one, that will give you the total soil reaction force acting parallel to the face of the blade.

Now, the distance which I am talking about is - assuming that the soil reaction force is acting at a height of a/3 from the furrow sole, a is the depth. So, then the distance will be r − a/3. The distance from the center of the disk will be equal to r − a/3. So, r is the radius of the disk. So, now, if you substitute here, the torsional moment acting comes to 592.795 Newton meter.

Now, what is the cross-section? The cross-section of the gang bolt cannot be a circular one, the reason is, the disk may slip. So, we have to have a rectangular section or we have to have a square section. So, I have taken as a square section of each side b. Then, the shaft is subjected to both bending as well as torsion. So, because of the bending, a stress will be induced. So, bending, the stress due to bending, $\sigma_b = \frac{M_s \times b/2}{b^4/12}$. The moment of inertia is nothing, but for a square section - a solid square section.

Now, we have to take a solid section because we need the vertical force to act downward. So, we want the implement to be heavy. So, that is why we have taken a solid section. So, the moment of inertia for a solid square section is $b^4/12$ and b/2 is nothing, but the extreme fiber from the neutral axis - the distance of the extreme fiber from the neutral axis. So, that way, if you take this one, this becomes b/2.

So, this is the expression for stress due to bending moment and similarly, the shear stress induced will be equal to $\tau = \frac{T_s \times b/2}{b^4/6}$. So, the polar moment of inertia for a square section is $b^4/12 + b^4/12$ that means $b^4/6$. Now, applying maximum shear stress theory, since it is a ductile material, so the expression - the stress developed $= \frac{1}{2}\sqrt{(\sigma_b)^2 + 4(\tau)^2}$. So, I have substituted for sigma b and tau here. And when I simplify this one, the final expression is this one, τ is equal to this.

Now, when I rearrange this, then $b^3 = \frac{3}{\tau_{max}}\sqrt{{M_s}^2 + {T_s}^2}$, and then if you take the shock and fatigue factor for both bending and torsional moment, K_m and K_t, as 1.5. Then the gang axle - as the gang axle is made of mild steel and where the allowable stress for mild steel is 150 Mega Pascal, and taking a factor of safety of 3, we can take the design stress as 50 Mega Pascal. So, the tau value - the τ_{max} value - is taken as 50 Mega Pascal, and then substituting this K_m value, M_s value, that means, the bending moment value, this shock and fatigue factor for torsional moment, and then the torsional moment value, we come to a value of 0.0398 meter, that means, 3.98 centimeters. So, roughly 4 cm, you can say. So, a square of 4 cm solid shaft can be utilized to put the rear disks.

Since we cannot go for different designs, it is unnecessary. So, what we have to do is, we follow the same dimension, that means, the same size of shaft is put on the front gang as well as on the rear gang. So, this is how you have to design.

These are the references. So, in brief, we can say, we did the computation of offset and how the offset is varying with or dependent on longitudinal force, that means, the draft and the side force.

And then we designed the gang bolt—how to find out the forces acting, which forces are responsible for causing bending and for causing torsion. So, that will give you a brief idea of how to design a gang bolt or a gang shaft for a disk harrow.

Thank you.