Design of Farm Machinery

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Lecture 31 : Designs of feed roll shaft, furrow openers and frame

Hi everyone, this is Professor H. Raheman from Agricultural and Food Engineering Department. I welcome you all to this Swayam NPTEL course on Design of Farm Machinery. This is lecture 31, where I will try to cover design of feed roll shaft, furrow openers and frames related to seed drill or planter. The concept - the concept which will be covered are design of feed roll shaft, then design of furrow opener, design of frame. So, this is the seed drill which is used for sowing wheat seeds. This is a 9-row seed drill and is a tractor drawn one.

So, what you have to do is taking some of this data, then we will try to find out what will be the dimensions later on, but how to design a feed roll shaft that means, the shaft where the metering mechanisms are mounted. So, this is the shaft which is inside this hopper and in the bottom there you can see the pipes - are there. So, through this pipes it should be dropping to the furrow. Width of coverage will be the distance between the center of the ground wheels, center of the ground wheel that will be your width, but shaft length will be equal to width minus clearance between center of the wheel and the wall of the hopper. So, that distance is kept t_o by 2 that if t_o is spacing, spacing between two adjacent furrows then that can be taken as $t_o/2$ or it can be taken as 150 to 200 millimeter.

To design the feed roll shaft which where the metering mechanisms are mounted first we have to find out what are the forces acting? The shaft is supported at two bearings. So, the support reaction R_A and R_B are to be found out and the weight - it is subjected to weight, weight of grain or the seeds and weight of the shaft. And on one side there will be transmission of power from the ground wheel to the feeding shaft. Forces acting in the feed shaft of the seed drill I have indicated as $(W_h + W_s)/2$ which is nothing, but the weight of seed plus weight of shaft itself divided by 2 and total weight is $W_h + W_s$ and half of that is acting which I have indicated here and the total weight is uniformly distributed. Now, R_A is equal to R_B is equal to $(W_h + W_s)/2$, where W_s is the weight of shaft and W_h is the weight of hopper.

So, weight of hopper and weight of seed uniformly distributed over the length of the shaft, then we try to find out the bending moment and bending moment about the central axis which is denoted in black colour. Now, the support reaction we calculated from this equation, then for finding out the bending moment, we use bending moment will be equal to R_A into this distance. So, distance between the two supports that is L_b. So, $L_b/2$. So, R_A into $L_b/2$ and this is acting upward and the force which is acting downward will be W_h + W_s that is total weight of hopper and seed divided by 2 × $L_b/4$. So, this is $L_b/2$, this the other one is $L_b/4$. So, I can simplify that one and then that will give you the bending moment.

Now, torque is acting because from the ground wheel you are taking power to the feeding shaft or the feed roll shaft. So, that means, torque is acting. So, what is the torque? How to find out the torque? Torque will be equal to rolling resistance × r, rolling radius $\times N_g/N_f$, N_g is the speed of that - its rpm of the ground wheel and N_f is the rpm of the feed roll shaft.

So, to find out the rolling resistance you have to assume like in all our cases we have assumed that rolling - total rolling resistance of the implement and tractor you can take as 8 per cent of the total weight. Now, if you want to find out rolling resistance of equipment that is seed drill, then what is the weight of seed drill? It is 8 per cent weight divided by 2 because there are 2 ground wheels, but power is only taken from 1. So, that is why, I have divided by 2. Now once you know that then we will find out what will be the torque acting.

So, that is responsible for creating torsional moment. Now the shape of the shaft could be a square shaft or it could be a circular shaft. So, square shaft if you take because it will be easier for - it will be easier for mounting the metering unit to the square shaft. That is why we prefer a square shaft of dimension of each side equal to b. Then for a square solid shaft the stress due to bending $\sigma_b = \frac{M_s \times b/2}{b^4/12}$. So, that way we are getting stress due to bending.

Similarly, you have to find out stress due to torsion. So, $\tau = \frac{T_s \times b/2}{b^4/6}$. So, that is - these are the two stresses induced. Now, utilizing the maximum shear stress theory, $\tau_{max} = \frac{1}{2}\sqrt{(\sigma_b)^2 + 4(\tau)^2}$. So, I have replaced σ_b with $\frac{M_s \times b/2}{b^4/12}$. Now, this one I have replaced then for shear stress, τ, I have replaced with $\frac{T_s \times b/2}{b^4/6}$ and then finally, it will be reduced to $\frac{1}{2}\sqrt{\left(\frac{M_s}{b^3/6}\right)^2 + 4\left(\frac{T_s}{b^3/3}\right)^2}$. So, that way we will get $\frac{1}{b^3/3}\sqrt{{M_s}^2 + {T_s}^2}$. Then again we assume the fatigue and shock factor and for both bending and as well as torsional moment which you can take as 1.5 to 2. And the design stress if you consider as 50 Mega Pascal, then substituting this we can find out the value of $b = \left[\frac{3}{\tau_{max}}\sqrt{{M_s}^2 + {T_s}^2}\right]^{1/3}$ So, this is the procedure which has to be followed for finding out the dimensions of the shaft. The two things you have to find out : what are the forces acting and then once you find out the forces acting, you find out whether the forces are causing bending or torsion, and then find out the corresponding bending moment and torsional moment. And from there, utilizing the maximum shear stress theory, we have to find out the dimensions of the shaft - the feed roll shaft.

Next is the furrow opener. In fact, the furrow openers for a seed drill are similar to a cultivator. If you divide the seed drill from the center line - the center line in a lateral direction, then you can see that the lower portion is nothing but a cultivator. And the upper portion is nothing but a metering unit. So, I will follow the same procedure that means, for designing the furrow opener, first you have to find out what are the parameters which are going to affect. Number one is the type of soil; the second one is the speed of operation; the third one is the depth of operation; then, the type and size of the working element. So, the type of soil will give you the values of unit draft; the speed of operation - the more the speed, the more will be the draft and the depth of operation will indirectly give you what is the draft acting on the working element?

Because that is the cross-sectional area which will be opened depending on the depth and the width of the working - the working width of the working element and the depth at which the working element is operated. So, both will contribute towards the draft value. Then, the type and size of the working element: the working element could be a shoe type, it could be a shovel type, or it could be a disk type. But the design which we have made is for a shovel-type furrow opener - the design of a shovel-type furrow opener. When you try to design the furrow opener, it is obvious that, in a seedbed, the soil condition is nearly soft. So, you have to take the unit drought value between 12 to 15 kilo Newton per meter square, which is the unit draft value or the specific soil resistance. Then, the design soil resistance will be 3 to 5 times more than the actual average soil resistance. And knowing the working width and the depth of operation, we can find out how much draft is acting on the soil element. So, assuming a rectangular cross-section made by the furrow opener, the draft acting on the working element will be - if you look at this figure, draft is K_{obl}. So, K_{obl} will be equal to $D_u \times a \times b$. So, this 3 is: you have taken the factor of safety 3 to 5 times. I have taken 3 times.

So, I have also written this as K_H, which means the horizontal component of soil resistance. Now, to find out the vertical component of soil resistance, you need to know the angle at which the working element is fixed to the shank. The shank - the angle at which it is fixed to the shank is nothing but the load angle, and we will follow the same load angle as what is followed for the cultivator. Now, taking that, we can find out the vertical soil reaction force, which is K_V, will be equal to $K_H \tan(90° - \alpha)$, and that will be equal to $K_H \cot 25°$, where, α is the load angle, and the maximum we can take is 25 degrees. Now, after deciding the forces, the next thing is how to find out the bending moment or the torsional moment, which are acting on the frame as well as on the shank.

Now, if you consider the design of the shank for the shovel type, the shank is a symmetrical tool shovel. So, it is only subjected to bending; there is no torsion. And the bending is due to the horizontal component of soil reaction or soil resistance. So, K_{obl} or K_H can be taken as the force which is acting at the tip. So that we are designing for a higher moment.

So, the height of the shank has to be found. So, the height of the shank means H is the height of the shank, out of which delta H will be entering into the frame. So, this has no role in finding out the bending moment; only this H_1 + a, where a is the depth of operation and H_1 depends on the diameter of the wheel, the diameter of the ground wheel. So, H is written as $a_{max} + H_1 + \Delta H$. Now, H_1 depends on the diameter of the ground wheel. So, the maximum I can take, the minimum value is $D_g/2$, which is the clearance, plus 100 millimeters, meaning the depth - if you are, because we do not put seeds more than 100 millimeters depth. So, I have taken the maximum depth as 10 centimeters. So, a + $D_g/2$ is the minimum clearance, we have to provide. Then, the bending moment will be equal to $K_H \times (H_1 + a)$. So, K_H we have already derived, then H_1 depends on the diameter of the cage wheel, the ground wheel, and a is the depth of operation. So, by utilizing this, we can find out what the bending moment is. Once you find out the bending moment, then you find out the stress due to bending, which will be equal to $\sigma = \frac{M_b}{Z}$. z is the section modulus = I/y. I is the moment of inertia - this is a rectangular cross-section shank. We can take a rectangular cross-section with thickness b and width h. So, the moment of inertia will be $\frac{bh^3}{12}$.

Then, the design stress for mild steel - the maximum allowable stress is 150 Mega Pascals. By taking a factor of safety, it can be taken as 3, so that way you will get 50 Mega Pascals. And then, putting this value, b and h are two unknowns. Now you have to make a ratio between them, so the b:h ratio is to be taken. So, it is taken as 1:3. So, h/b =

3. So, then putting this into the formula, the section modulus becomes 1.5 b^3, and if you put it here, you will get an expression for b.

You can also assume the cross-section of the shank to be a square one, which is also possible, but usually, we prefer a rectangular one. So, that is why I have taken $bh^3/12$. The moment of inertia. Now, forces acting on the frame - frame means the frame to which the shanks are attached, that means the furrow openers are attached. So, let us now see which row has the maximum number of furrow openers. So, that we have to take, and the same dimension we have to follow in the front because, in the front, there are 4 furrow openers, and in the back row, there are 5 furrow openers.

So, we have taken the back one where I have indicated the furrow openers in the shape of shovels with shanks, and the vertical soil resistance forces K_v, which are acting downward, and the frame has its own weight. So, if the total weight of the machine is W, then this has to be distributed among 9 tines or 9 furrow openers. And out of which, 5 furrow openers are to be taken. So, W × 5/9 will give you the weight of the rear gang. So, the support reaction will be $R_1 = R_2$, which will be equal to the vertical forces acting, which is 5 tines means $5 \times K_v$, and then the weight of the machine, W, sorry, the weight of the wheel W_w, because there are 2 ground wheels. So, $2W_w + W_1 \times 5/9$. In the figure, I have indicated W_g. So, that is equal to $W_1 \times 5/9$. Half of that is acting here. So, that will be the total vertical force acting - all are acting downward. So, I have taken summation. So, divided by 2, that will give you the values of support reactions R_1 and R_2. Now, to find out the bending moment - bending moment about the central line, which is this.

Now R_1 is acting upwards. So, it is clockwise so positive So, $R_1 \times \left(4t_o + \frac{t_o}{4}\right) - (W_w \times 4.5\, t_o)$. Because half of 9 t_o. So, half of that full is 9 t_o. So, half is taken as 4.5 t_o. t_o is the spacing between two adjacent furrow openers. Then K_V, the first one with 4 t_o, second one with $2t_o$ and weight, weight is acting downward. So, that is, these 3 are acting downwards, so minus. So, weight is $(W_g/2) \times 2.25\, t_o$. So, this will give you expression for bending moment.

We have already defined for K_V after the after finding out the horizontal component taking the load angle as 25 degree there you have calculated K_V. So, those K_V value can be utilized here. Now, because of this horizontal force this will have a tendency to twist the frame because a torsional moment will act and assuming that the soil resistance is acting at the tip of the working element - soil resistance. So, that way if you know K_H we have already calculated taking from the unit draft and the cross-section of the furrow, which is opened by the furrow opener, then H_1 + a that will be the moment arm. H_1 is the clearance and a is the depth. So, stress due to torsion can be calculated by this, then where b is the thickness of the shank, h is the width of the shank, this is not shank actually this is frame, shank we have already designed.

And now applying the stress due to bending we have already calculated, then we have to find out since the frame is subjected to both bending as well as torsion. So, we have to follow the maximum shear stress theory from there assuming a ratio between h : b as 3 : 1, then we will find out dimensions of b utilizing the maximum stress theory, provided we need to know the design stress which is nothing, but 50 Mega Pascal assuming a factor of safety as 3 that means, maximum is 150, factor of safety 3. So, we have taken 50 Mega Pascal and then we try to find out simplify this expression by substituting with the shear stress value and the stress due to bending values with this expressions and then finally, we can calculate the values of the frame. And whatever values will come that means, b value then multiply 3 to find out the value of h.

Next important thing is : we have already discussed the design of feed roll shaft. Now, we will try to calculate with some data, what will be the design value of feed roll shaft. Now assuming this W - weight of shaft and weight of hopper to be 100 kg, now you can find out R_A is equal to R_B is equal to $(W_s + W_h)/2$ that means, 50 kg which is equal to 490.5 Newton, this is the weight acting, the support reaction is calculated. Now find out the bending moment. And, the span that is L_b, L_b - length of the shaft which is equal to total width of coverage is 1.8 meter and then I have deducted 150 millimeter on either side. So, that way L_b value is coming to be 1.5 meter, then bending moment acting on the shaft $Ms = \frac{R_A L_b}{2} - \left(\frac{W_h + W_s}{2}\right)\frac{L_b}{4}$. So, if you simplify this one, this is nothing, but $\frac{(W_h + W_s)L_b}{8}$. So, that way you are getting a bending moment of 92 Newton meter. Now torque transmitted to the feed roll shaft that has to be found out. For this, we need to know the rolling resistance and the radius of the ground wheel and the transmission ratio between the ground wheel and the feed shaft or the feed roll shaft.

Now, assuming 8 per cent of the total weight so, that way 250 + 80 kg of grains if you are carrying then total weight becomes 330 kg. 8 per cent of the total weight that one divided by 2 that would be the rolling resistance for a single wheel or single ground wheel. Now, 13.2 kg into 9.81 and then we have to assume a rolling radius of the ground wheel. Usually the diameter varies from 30 centimeter to 80 centimeter. The smaller the wheel, skid problem is there. So, on an average we are taking 60 centimeter as diameter. So, this is the rolling resistance. So, considering a transmission ratio of 1 that means, there is no speed reduction or so, that way we are getting 0.3 m is the radius.

So, we are getting a torsional moment of 38.85 Newton meter. Now again assuming the cross-section of the shaft to be solid square, we follow the stress due to bending, we try to calculate stress due to torsion. So, then we put it in the maximum shear stress theory, then this will be the final expression $\tau_{\max} = \frac{1}{2}\sqrt{\left(\frac{M_s \times b/2}{b^4/12}\right)^2 + 4\left(\frac{T_s \times b/2}{b^4/6}\right)^2} = \frac{1}{b^3/3}\sqrt{{M_s}^2 + {T_s}^2}$ Now, M s is the moment due to bending, T s is the torsional moment due to shear.

So, that value I have already calculated in terms of b. And then we take a factor of safety of 1.5 for both the cases and allowable stress 50 into 10^6 Pascal. So, that way we will get a value of b is equal to 2.8 centimeter. That means, a shaft - square shaft of 2.8 centimeter. We can take 3 also does not matter, 3 centimeter by 3 centimeter that will be the dimensions of the shaft. So, these are some of the references and finally, I can conclude that we discussed about the design components such as feed roll shaft, then furrow opener and frame of a tractor drawn seed drill and also we tried to solve the design calculation for the feed roll shaft.

Thank you.