Design of Farm Machinery

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Lecture 59 : Design of a spike tooth thresher

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture fifty-nine, where I will try to cover the design of a spike-tooth thresher. The concepts which will be covered are the power requirement for carrying out threshing of wheat, then the design of components of a spike-tooth thresher for threshing wheat crop.

Threshing means the detachment of grains from the harvested crop. So, this is accomplished by different threshing equipment available, but the basic concept is either you have to give impact force, or you have to give rubbing action, or you have to give both impact and rubbing and then, to some extent, vibrations.

So, this part - how separation takes place, we have been discussing; we have discussed it in the last two classes, and there I have given some design information. Now, I will try to utilize those information and design a thresher exclusively for threshing wheat crop. So, the first thing when you try to design a wheat thresher is: what is the capacity? What capacity are you going to design? So, that is the main thing. How much crop it can handle? So, let us decide that the handling capacity is 3600 kg per hour that is the crop quantity the thresher is going to handle. So, to carry out threshing for this quantity of crop, what will be the power requirement? So, the equations which are available are based on Goryachkin's drum theory. So, there we derived that the total power, (N) will be equal to idle power (N_i) plus useful power (N_u), and they have given coefficients for calculating the idle power. For example, N_i, N_i here is the idle power, which comprises two components: Au and Bu^3 . Basically, this component will be utilized for overcoming the frictional resistance, resistance of air, and all those things. So, to utilize this equation then we need to know the values of A, B and u, where u is the peripheral speed. For carrying out threshing - for threshing of wheat, the peripheral speed of the cylinder is kept as 28 to 30 meter per second. So, we fix the peripheral speed and then we take the values of A and B which are given for different types of thresher. Now, this is a spike tooth thresher. So, the values of A and B are 5 Newton and 0.045 Newton second square per meter square per meter length, respectively. So, once you decide this next thing is since the value of B is given for meter length. So, what should be the length, length of the cylinder which you are going to design. So, if you fix the length of the cylinder as 1200 millimetre and diameter as 450 millimetre, then utilizing the equation you can easily calculate, what will be the value for the idle resistance, power required to overcome idle resistance. That comes to 1.325 as we have fixed the value of peripheral speed as 28 meter per second. Next thing is how to calculate the useful power.

For calculating the useful power, we need to know the values of quantity of crop to be fed per unit time, then V is the velocity of grain that means, velocity of grain will be 80 per cent of the peripheral speed of the drum. So, we have taken u was 28 meter per second. So, V will be equal to 22.4 meter per second. Now, mass flow rate that means, amount of crop which is fed that is 1 kg per second. If you take 3600 kg per hour then it comes to 1 kg per second. Now, the value of f is a coefficient whose value is taken as 0.65 to 0.75. So, I have taken a value of 0.7. So that way, we will find out the value of useful power. So, that comes to 2090.66 Watts, which is 2.09 kilo Watts. So, useful power and idle power together come to 3.416 kilo Watts. This much power will be required to carry out threshing - only detaching the grains.

Now, let us see what are the other components? We have simply calculated the power requirement, but that is not the design of a thresher. We should know how many spikes are to be provided, at what distance they are to be provided, and the design of spikes - all those things we have to calculate.

So, the first step is: we decided a few parameters like the length of the cylinder, then we decided the peripheral speed for a given feed rate. So, based on that, we have found that this much is the power requirement. After deciding the power requirement, the next thing is how threshing takes place. Based on that, we will decide the number of spikes. Those things I will discuss. Now, if you look at this figure, this is the cylinder. The cylinder will be rotating and dragging the crop from the inlet side. This is your inlet side, and this is your outlet side. So, the crop will be dragged. At the same time, you can see the spacing between the cylinder and concave at the inlet and the spacing between the cylinder and concave at the outlet, they are not the same. This spacing is gradually decreased, meaning we want to compress the crop dragged into the system, thereby increasing friction and improving separation - that is the concept.

Now, what will be the RPM, and how much crop are we feeding into the system? Based on that, we have to find out what will be the number of teeth, okay. So, now, while dragging the crop inside, there will be a group of teeth that will be attacking or giving an impact force to the crop. We have to find out how many teeth are impacting the crop, and then we will decide the size of the teeth.

So, if you look at this figure, you can see the force - the impact force, which is applied to the crop. It is not fixed; it is changing its orientation. So, at this point, this is the force which has been resolved into two components. This is the point where it is at 90 degrees to the horizontal. So, where there is no component, it is directly a horizontal force. Now, at this point, you can see this is the resultant force. It will have two components: vertical and horizontal. So, the maximum force will be acting at this point. You have to take this into account and then find out what will be the size of the tooth.

Now, for deciding the dimensions of the cylinder, the length of the cylinder should lie in the range of 1100 to 1750 millimeters, and the diameter of the cylinder should lie in the range of 445 to 610 millimeters for spike tooth and 425 to 610 millimeters for rasp bar. Since we are designing a spike tooth type thresher, our diameter can be taken between 445 to 610 millimeters. We have taken it as 450 millimeters, and the length we have already decided as 1200 millimeters. Now, if you look at this equation, the handling rate, q_s is equal to the permissible feed rate per tooth (q_a') multiplied by the number of teeth. So, q_i'× Z. So, q_a' for a spike-tooth type thresher varies from 0.025 to 0.04 kg per second per tooth. Now, what you have to do is assume a value of permissible feed rate, then we have to find out how many teeth are to be provided on the cylinder. So, that is the next step.

So, to find out the number of teeth, Z = $m_p(\frac{L_p}{a}+1)$. So, taking L_p as the length of the cylinder, a as the distance between two adjacent paths - this is the distance a - and m_p as the pitch. So, in this equation, to handle - our handling capacity was 3600 kg per hour. So, that way, if you are taking 0.025, then the number of teeth required is 40. So, from this equation, we have found the number of teeth required is 40. Now, what we have to found out, the value of a. So, for that we have to fix the pitch of the helix. So, pitch of the helix, we have taken as 3. So, number of bars will be 6 that means, there will be 6 rows of teeth and pitch of the helix is 3 and if you substitute in this equation the value of a comes to 97.31 millimeter.

Now, next thing is what is the peripheral speed that means, what is the rpm of the cylinder? Now, cylinder diameter I have assumed and the speed of the drum that is peripheral speed required for carrying out threshing of wheat is 28 meter per second. So, the rpm the cylinder from there you can find out. Because the drum diameter is 45, then the spike length you have to take into consideration. So, spike I have taken as 6 centimeter that means, 60 millimeter. So, that way the total diameter comes to 450 plus 120 and so, rpm of the drum should be around 938.17. So, roughly around 938, so that we can get a peripheral speed of 28 meter per second.

Now, next thing is what should be the dimension and how they will be arranged in the drum. Arrangements mean arrangement of teeth. Assuming a circular section of spike that is solid circular section, then we have to find out what will be the value of impact force ok. So, if you follow the Goryachkin's drum theory, there we have calculated that total resistance, resistance due to impact, P = $\frac{\dot{m}V}{1-f}$.. $\dot{m}$ means feed rate V is the speed of the crop and $1 - f$, f is a coefficient., whose value is 0.7. V value is not the peripheral speed, a coefficient into peripheral speed. So that way we have calculated the value of V and $\dot{m}$ is 1 kg per second. Then substituting in this equation $\frac{\dot{m}V}{1-f}$, we find out the value. The total impact force is around 74.67 Newton. Now, taking a factor of safety as 3, so now the total force for which you are going to design the spikes will be 224 Newton. So, now question arises how many rows of teeth are engaged at a time. So, there are 40 teeth. So, 40 teeth means if you are taking a pitch as 3, then there will be 6 rows. 6 rows and the arrangement will be 7 teeth in one row 6 teeth in another row. So, likewise 6, 7, 6, 7 like that. So, altogether there will be 39 teeth. Now, what is the angle at which the concave is subtending at the center? So, if you are taking - usually the angle varies from - usually the concave subtends an angle around 120 degree to 150 degree that means, 1 third to 5 twelfth. So, that way if you are taking one third that means, 120 degree is subtended by the concave.

Now, 120 degree is subtended by the concave and there will be 6 rows. So, at a time there will be 2 rows of teeth which will be striking the crop material. So, that way we have taken. Considering the 2 rows, so, there will be 13 number of teeth which will be striking the crop at a time. So, the force which you calculated - the resistance 224 Newton that has to be shared by 13 teeth. So, each of these teeth, each tooth will be experiencing a force of 224 by 13. So, that way 17.23 Newton. So, this is what I am saying. This is sustaining an angle of 120 degrees, and in that 120 degrees, these are the 2 rows which will be - 2 rows of teeth that will be striking the crop material. So, 1, 2, 3, 4, 5, 6. Out of this, only 2 rows will be striking the curve at a time. So, the force now, what we have taken is this: This is the maximum force. So, I have taken this force for designing. So, this force is 17.23 Newton, which is what we calculated: total resistance by the number of teeth.

Now, each spike or tooth is subjected to what? Bending or twisting? That we have to decide. Since it is a circular spike, what you can say is - this is only subjected to bending. Now, assuming a length or height of the spike as 6 centimeters. So, the bending moment which will be acting will be equal to 17.23 Newton, which is the force acting on each tooth, multiplied by the length. The length is this one: 6 centimeters we have taken, so 0.06 meters. So, that way, we are getting 1.03 Newton meter. That will be the bending moment.

Now, taking the allowable stress, that is, design stress as 50 Mega Pascal, then the design stress, $f_s = \frac{MC}{I}$. C is the distance from the neutral axis to the extreme fiber, which is equal to d/2, diameter by 2, and I, the moment of inertia for a solid circular section is $\pi d^4/64$. The bending moment we have calculated as 1.03 Newton meter. Now, substituting these values in this equation. So, we found out the diameter to be around 5.94 millimeters. So, roughly we can say 6 millimeters is the diameter, okay.

So, the next thing is the design of the concave. So, for designing the concave, what is the portion of the drum or the cylinder that a concave is going to subtend? So, what you have taken is - the literature says it should subtend an angle, a portion starting from 1/3 to 5/12 of the drum periphery. So, if you take that into consideration, the periphery of the drum is πD, which is 1790.7 millimeters. So, that way, this will be the peripheral width of the concave

Now, the concave has to be provided with clearance, clearance at the inlet. Usually, the clearance is given as 16 to 18 millimeters at the inlet and 4 to 6 millimeters at the outlet. So, that way, we can provide this clearance. Now, the concave is to be perforated. That means it acts as a sieve. So, how much perforation do we have to provide? So, you have to provide 40 per cent of the total area of the concave.

And the next question is, what should be the size of those openings? Whether you put circular holes or small bars with spacings, it depends on the grain size and the area you are covering. So, the area has to be determined. So, if you know the angle which is subtended, then you can find out the peripheral distance, which is r theta, where r is the radius. Then, the length of the concave, which is nothing but perpendicular to the screen that is equal to the length of the cylinder, L_p. So, r theta multiplied by L_p. L_p we have already considered as 1200 millimeters. So, knowing the angle, we can find out the area, and from there, we can determine the perforation percentage.

The next thing is the design of a centrifugal blower. This blower or aspirator will be utilized to suck the chaff and throw it away, so that only clean grains will fall on the tray. That is the concept, and the blower is mounted on the same shaft - the shaft of the cylinder. That means we are rotating at 938 rpm. So, the same rpm is to be maintained, and for that rpm, you are going to design the blower. Now, from the literature, what you have collected is the quantity of air required for 1 kg of chaff. Chaff consists of smaller pieces of straw. So, now, that has been given as 5 to 8 kg per kg of chaff. The next thing is how much chaff will be present, which depends on the straw-to-grain ratio. What is the straw-to-grain ratio? Usually, it is 60:40, but it depends. So, we have considered 60:40, which means 60 per cent is straw and 40 per cent is grain. So, our feed rate is 1 kg per second. So, that way per second we are going to handle 0.6 kg of straw. So, to handle this much of straw, the amount of air which is required is : if you consider 5 kg of air is the desired flow rate - mass flow rate, then it comes to 3 kg per second. Now, if I divide with the density so, that will give you the volume of air which is required to be given by the blower to blow out the chaff which are present. So, now, the terminal velocity of the chaff is 10 meter per second. So, we have to maintain a speed of 10 meter per second so, that the chaffs will be thrown away. So, to maintain that, the velocity of the air will be equal to a coefficient into, sorry divided by a coefficient that will give you the peripheral speed of the blade. That means, if u_a is the peripheral speed of the blade which are present in the blower, then it is has to be multiplied with a coefficient to get the velocity of air which is required. So, in our case 10 meters per second is the velocity which is required, now the coefficient is 0.55. So, that way we are getting - we require that the blade speed should be around 18.18 meter per second. Now, what will be the size of the or the dimensions of the blade?

It is a circular section no doubt. So, for finding out the quantity of air which is handled by a circular section having inner diameter r_i, outer diameter r_0. If you take a small strip then integrate it over the limit r_i to r_0. So, then we will find out this will be the area $2\ \pi r \times dr \times w_b$. $2\ \pi r\ dr$ that will give you the area multiply with the length that is width width of the blade. So, that will give you volume and then multiply with rpm. 2 pi r dr will give you the area multiplied with w b that will give the volume multiplied with the rpm, at what rpm it is rotating. So, that will give you this much of volume of air is produced by the blower per minute.

So, now, what will be the outer diameter because here everythings are open. We do not know r_0, we do not know r_i, we do not know w_b and only one thing we know is what is the rpm at which it has to be rotated and what is the quantity of air we want. So, you have to either fix r_i or you have to fix r_0 and then find out what will be the value of width of the blade that means, this distance. So, we fix the outer diameter of the blade to around 700 millimeter because the range is from 470 to 720 millimeter. So, we fix that as 700 then the average diameter we calculated knowing the peripheral speed because peripheral speed is 18.18 and rpm is 938 from there we found out that this is the average diameter. Average diameter is known, outer diameter is fixed. So, from there we try to find out what will be the inner diameter. So, this is inner radius and multiplied with 2 that will give the inner diameter. Now, if when I put these values in this equation. So, I have to use Q t already you have calculated Q t as 2.5 meter cube per second. So, 2.5 meter cube per second r 0 is you have calculated r i is calculated N_a is known. So, from here we will find out what will be the value of w_b that is width. So, from here we find out w_b is equal to 417 millimeter.

So, next question is what will be the power requirement, power requirement for blowing air. So, for calculating power requirement you need to know the pressure, pressure which is required and which is built up and the volume. Volume we have already calculated. Pressure it comprises of two components static pressure and velocity pressure. Static pressure roughly varies from 500 to 1000 Pascal. So, we have considered 1000 Pascal and then velocity pressure is nothing, but $\frac{1}{2}\rho v_a^2$. So, from there we calculated the value to be 201.61 Pascal. Now, the total pressure will be sum of static pressure plus velocity pressure. So, that way it comes to 1201.6 Pascal. Now, considering the efficiency of the blower as 70 per cent. So, power requirement of the blower will be equal to $P_t \times \frac{V_a}{\eta_b}$, this V_a is the volume not velocity, this is volume (Q_t). So, $P_t \times \frac{V_a}{\eta_b}$ and η_b we have taken 70 per cent. So, that way you get a value of 4.29 kilo Watt. So, now question is what will be the total power requirement as I said in the beginning. So, total power requirement is nothing, but sum of the power which is required for carrying out threshing and power requirement for blowing.

And the other component is your shaker part, which I have not covered in this class. The shaker part, we assume that it consumes 5 to 10 per cent of the total power, so that we can calculate what will be the total power requirement for carrying out threshing.

So, these are some of the things, like how to utilize the design information given in previous classes and how to use those information to design that I have discussed in this class. So, these are some of the references, and in brief, I can say we discussed how to utilize Goryachkin's drum theory, how to find out the total power requirement, and then we tried to discuss how to decide the number of spikes and their location, then what the length of the concave and the size of the spikes - all those things we discussed. And then we tried to find out how much air will be required to blow the chaff obtained, and then what is the power requirement for removing chaff and how to calculate the total power requirement.

Thank you.