Design of Farm Machinery

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Lecture 57 : Power requirement of threshing equipment and design information

Hello everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 57, where I will try to find out the basic governing equation for carrying out threshing operations, then we try to discuss some design information. The concepts will be power requirement for carrying out threshing and then design information for major components of a threshing equipment.

Power requirement of a thresher: power is required for detaching the grains which is called as useful resistance, what is the power required to detach only the grains. Then you have to drag the crop inside this cylinder and concave system. So, there will be some frictional force and we have to rotate the cylinder there will be some bearing frictions and there will be resistance due to air because the cylinder is rotating. So, there will be some air resistance. So, basically you can call the power requirement comprises of two major components one is the idle power which will take care of the frictional part and the other one is the useful component which is the useful power requirement which will take care of the impact force as well as dragging the crop inside the cylinder and concave system.

Now power required to overcome idle resistance, if I denote it as N_i, then this is primarily dependent on the peripheral speed. Now the relationship is given by Goryachkin and it can be written as idle resistance, $N_i = Au + Bu^3$. A and B are coefficients, the values are given. u is peripheral speed of drum or cylinder in meter per second. A is the moment from the frictional forces and bearings, value lies between 5 to 5.5 Newton for spike tooth and between 0.8 to 0.9 Newton for rasp bar for 100 kg of drum in both the cases.

So, that means the value of A is different for the rasp bar type and different for the spike tooth type. These are the two common threshers used for carrying out threshing, which is why these values are given for these two threshers. Then, B is a factor characterizing the

frictional forces in the bearing and the drum. B is the factor that will characterize the drum ventilating effect, meaning air resistance, and it depends on the geometry of the rotating parts of the drum, their size, and the density and other properties of air. Its value per meter length of the drum of 550 millimeter diameter is 0.045 Newton second square per meter square for the spike tooth cylinder and 0.065 Newton second square per meter square for the rasp bar type cylinder.

Then comes the power required to overcome useful resistance, meaning the useful power requirement for carrying out threshing, which is given by Goryachkin's drum theory. So, before we jump into Goryachkin's drum theory, there are some assumptions to be made. The assumptions are: the stroke of the rasp bar against the grain layer is inelastic. Hence, the impulse of the force is equal to the momentum of the crop mass, meaning impulse is nothing but the duration for which the force is acting, and momentum is nothing but the change in velocity. So, m ΔV will be the momentum. If P_1 is the force applied for a duration of, say, Δt, during which the velocity has changed from, say, V_1 to V_2, and that is indicated by ΔV. So, as per the assumption, $P_1 \Delta t = m \Delta V$, or you can rearrange this as $P_1 = (m/\Delta t) \times \Delta V$, and m upon delta t is nothing but the feed rate ($\dot{m}$), meaning kg of crop, which is fed into the system - mass of crop fed per unit time. During that time, what is the gain in velocity, if that is indicated as ΔV,. So, the mass of the crop material struck by the rasp bar or the feed rate of the crop is in kg per second. Now, ΔV,is the velocity gained by the mass of crop, which is m. Now, $P_1 = \dot{m} \Delta V$, where, $\dot{m}$ is the mass feed rate. Now, if you assume that the initial velocity is 0 and the final velocity is V, then $P_1 = \dot{m}V$. You can directly write ΔV as V. Now, what is the power requirement? So, before calculating the power requirement, we have to calculate - because power is required for giving impact and, at the same time, it has to drag the crop inside the cylinder and concave. The resistance offered by the concave has to be calculated. So, for doing that Goryachkin's drum theory says if you denote that as P_2 that resistance that is equal to a coefficient $f \times P$. If P is the total resistance out of this total resistance, f is a coefficient that means, this much percentage of resistance will be equal to P_2 and that value of f is 0.65 to 0.7 for rasp bar type and 0.7 to 0.8 for spike tooth type thresher. Now if you write this equation total resistance, $P = P_1 + P_2$ and then substituting for P_1 as $\dot{m}V$ and P_2 as $f \times P$. So, then total resistance, $P = \dot{m}V + f \times P$. Now, I rearrange this one. So, $P - f \times P = \dot{m}V$. Now, P I took common. So, $P(1 - f) = \dot{m}V$. Now, $P = \dot{m}V/((1 - f))$. Now, to find out the power required, this is the resistance, this resistance is to be multiplied with a velocity. If V is the velocity or peripheral velocity, then this will be the power requirement, $N_u = \dfrac{\dot{m}V^2}{1-f}$. Here, we assume that the peripheral speed of the drum is equal to the speed which the grain has attained during the time t. So, if that is the case then only you will get this equation, otherwise you will get an equation like this V will be replaced by u, peripheral speed and the relationship between u and V is u cannot be equal to V. In actual case, because V is the velocity gained by the grain which

is always lesser than u. So, you can get, get a coefficient 0.7 to 0.8 times u is equal to V. That means, velocity of grain is lesser than the peripheral speed that is the actual case. But ideal case, we assume that this u and the V which is attained by the grains they are same that is why you can write directly the power requirement, useful power requirement, $N_u = \frac{\dot{m}V^2}{1-f}$.

Then the total power requirement will be the power required for overcoming the idle resistance, then the power required for overcoming the useful resistance. So, $Au + Bu^3$ that will be the power required for overcoming the idle resistance and $\frac{\dot{m}V^2}{1-f}$ that will the power required to overcome actual resistance for carrying out threshing. Now if N is the power which is supplied that means, either it could be engine, it could be tractor PTO or it could be a DC motor then $N - N_r$, N is the power supplied, N_r is the power required. So, if it is positive, the difference is positive then the speed of drum will increase and if it is negative then the speed of the drum will decrease. So, that is the concept. Now, $N - N_r$, I can write as : which is nothing, but the power which is equal to T×ω. Instead of T, I can write I_r ω × α, α is the angular acceleration. So, I_r ω dω/dt, rate of angular acceleration. So, in other words if I rearrange this one then d omega by d t is nothing, but $\frac{d\omega}{dt} = (N - N_r) / I_r \omega$. So, ω is the angular speed and I_r is the reduced moment of inertia of threshing drum and $\frac{d\omega}{dt}$ is the angular acceleration of the drum. Now, if I put the values, actual values of N_r, so, it becomes $\frac{d\omega}{dt} = (N - (Au + Bu^3 + \frac{\dot{m}V^2}{1-f})) / I_r \omega$. This is the governing equation for carrying out threshing. So, it takes into account three things. It establishes, establishes the relationship between the three constituents of the technological process. What are those three constituents? Plant mass or the crop mass which is represented by $\dot{m}$ and f, friction, coefficient which you have taken as 0.7 to, for rasp bar it is 0.65 to 0.7 and for spike tooth we have taken as 0.7 to 0.8. So, the other parameters will be the drum, drum the I_r it is moment of inertia and ω is the angular speed and it also have a relation with power source N. So, all these three components which are required for carrying out threshing are related by this angular acceleration d omega by d t, angular acceleration of the drum.

Now, I am showing you a graph where the variation of $\frac{d\omega}{dt}$ is plotted against the feed rate which is q. Now, this has been plotted for three different cylinder and concave arrangements.

The three cylinder and concave arrangements are 1, 2 and 3. 1, moment of inertia is I_1, velocity is u_1. The second one has moment of inertia is I_2, velocity u_1. That means I2 is greater than I_1, but u_1 remains the same. The third one has I_3 is equal to I_1, but the speed is higher, u_2 is greater than u_1. Now, if you look at this graph, we can say that for an unit

change in the feed rate, dq, what is the corresponding change in the angular acceleration or rate of angular acceleration? This has been indicated by $d\omega_1/dt$ is for curve number 1, $d\omega_2/dt$ is for curve number 2, and $d\omega_3/dt$ is for curve number 3, which represent the rate of increase in angular acceleration. Now, if you look at the figure, $d\omega 1/dt$ is greater than $d\omega_2/dt$ for the same change in feed rate. A bigger drum (since 2 has a higher moment of inertia) means the drum diameter is bigger. So, a bigger drum with lesser angular speed is preferred over a smaller drum with higher angular speed. Otherwise, sharp changes in speed impose greater stress on the working parts and the drive mechanism. Thus, it is advisable to have thresher drums with a larger moment of inertia. This is a very good finding. Now, comparing $d\omega/dt$ between 1 and 3, the difference is that the moment of inertia is the same, but the peripheral speed is different. The peripheral speed u_2 of thresher number 3 is greater than u_1. In that case, $d\omega_1/dt < d\omega_3/dt$, meaning the rate of change of angular acceleration is lower for thresher 1 compared to thresher 3. Thresher 1 has a lower rate of angular acceleration compared to thresher 3. So, for the same change in feed rate, $d\omega_1/dt$ is less than $d\omega_3/dt$. So, for steady state condition, what will happen? That means, $d\omega/dt$ is 0. If that is so, we are getting higher output either with 1 or 2. Now, if you take into consideration this factor and this factor, then we can conclude that we should have a higher drum diameter and lesser speed, which will give you better output.

Then there are some design considerations like what should be the length and what should be the capacity of different threshers. So, I have given some relationships. So, for a rasp bar type, you can take the output, thresher output, or throughput of the thresher as equal to the permissible feed rate or allowable feed rate per ras bar multiplied by the length of the drum multiplied by the number of bars. So, that will give you the total output, and the permissible feed rate is 0.35 to 0.4 kg per second per meter length of ras bar at a moisture content of 14 to 18 per cent. Now, a similar expression is available for spike tooth type, where the threshing capacity is equal to the permissible feed rate per tooth per second multiplied by the number of teeth. So, to find out the number of teeth, this is the equation $Z = m_p(\frac{L_p}{a} + 1)$, where, m_p is the pitch, L_p is the length of the drum, a is the distance between two adjacent rows of teeth or the paths in which the teeth are provided. So, if I give this figure, that will be more clear on how to find out Z. That means, the number of teeth which lie in the same plane of rotation is equal to half the number of cross bars, and the values could be 3, 4, or 5, and a is the distance between two adjacent paths. So, if you look at this figure, this is the distance. These are the paths. The dotted lines are the paths traced by the working elements. So, the distance between two adjacent paths is denoted as a and the values could be 25 to 29 millimeters.

Then, the length of the drum, L_p, should be the working length of the drum. So, if you know the number of teeth, the distance, and the pitch - then you can find out from here what will be the length of the drum. Then, d is the drum diameter, and $t_p = $ a×M. So, teeth on the concave. So, if teeth are provided, then the teeth on the concave are placed between the adjacent planes of rotation - that means, in between these two rows, we have to provide the teeth of the concave. So, the teeth of the concave and the teeth of the cylinder should not strike each other.

Now, I will give you a 3D figure here. So, where the x-axis is the concave length, the drum's peripheral speed (y-axis) versus shifting capacity. Concave length has been increased from, say, 170 to 680 millimeters. For a given peripheral speed, with an increase in concave length, the threshing efficiency increases - you can see the slope. The same is the case here, the same is the case here, the same is the case here. Now, if we increase the peripheral speed while keeping the length the same, that also increases, but the rate of rise is higher in the case of concave length than in the case of peripheral speed.

Now, just the opposite of that one - this is the threshing efficiency, you can say, and this is the loss. So, now, length is increased in this way, and peripheral speed is increased in this way, and then you can see, at higher concave length and higher peripheral speed, you get the minimum loss. Now, if you have a longer length of concave, but the peripheral speed is only 20, then you can see the loss is greater. So, to get this benefit by increasing the concave length, we have to increase the peripheral speed; then only the better output will be obtained in terms of efficiency. So, these are some of the factors we discussed in the last class, and I am giving some more information so that, while deciding the length of the drum, we should take these factors into consideration, along with the RPM.

Now, the diameter and length of the cylinder, some design information are available. So, the diameter varies from 445 to 610 millimeters for the spike tooth cylinder, and it varies from 425 to 610 millimeters for the rasp bar third cylinder, and the number of rasp bars is 6 to 8. Similarly, for the length of the cylinder, the length varies from 1100 to 1750 millimeters in the case of the rasp bar type, and in the case of the spike tooth type, it varies from 650 to 1200 millimeters. So, the length of the concave - just now, we discussed the length of the concave. Now, the dimensions of the concave significantly affect the threshing of the crop, grain spillage, and the breakup of the straw. So, when the length of the concave is increased, the undermilling decreases because the crop will be retained inside the system for a longer period of time. So, it will be exposed to more strikes, hence

more separation. So, you have to take these factors into account and then decide what the length of the concave should be, corresponding to the peripheral speed.

The cylinder-concave gap at the inlet should be about 4 times greater than that at the exit. For wheat, rye, and oats, a gap of 16 to 18 millimeters is provided at the inlet, and 4 to 6 millimeters is provided at the outlet. These are considered optimal, and these are the gaps between the tips of the blades or spikes. So, while designing a thresher, we should keep these factors in mind. Nevertheless, the gap provided at the inlet is always higher than the gap provided at the outlet. Now, the peripheral speed - you cannot keep it constant. Suppose you are designing a multi-crop thresher; then, you should have a provision to vary the cylinder speed. If you look at the peripheral speed requirement for different crops I have listed here. So, our interest is rice, which is paddy, and soybean, then wheat, then corn. Now, if you look at this, rice has 23 to 28 meters per second, and wheat has 25 to 30 meters per second. That means, to some extent, wheat requires a slightly higher peripheral speed compared to rice. The reason is very obvious because wheat straw is more resistant, so we require more impact force. So, the peripheral force has to be increased, but the difference is not that much. Now, if you look at corn, the peripheral speed is only 13 to 22 meters per second, whereas, in the case of soybean, it is 15 to 20 meters per second. So, if you are designing a multi-crop thresher, then our design should be such that we can vary the cylinder speed, that means the peripheral speed of the cylinder, by changing the rpm of the cylinder. Because we are not going to change the diameter of the cylinder, nor are we going to change the working element of the cylinder. The simplest way is to change the rpm, which is possible by changing the pulley.

Now, these are some of the references, and what we discussed is the basic governing equation for calculating the power requirement and then angular acceleration, which is responsible for giving you the fluctuations in the speed of the drum that we have discussed with respect to the feed or the mass handled by the thresher. And then we tried to - I tried to give some design information that is very useful while designing a thresher. So, that is all.

Thank you.