Design of Farm Machinery

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Lecture 53 : Design of an electric-vertical conveyor reaper (E-VCR)

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. In this lecture, I will discuss the design of an electric vertical conveyor reaper. The concepts covered here include: components of an electric vertical conveyor reaper and the design of its components.

The figure I am showing now relates to the vertical conveyor reaper, which is powered by a battery. That is why it is called an electric vertical conveyor reaper. The purpose remains the same, it will be utilized for harvesting paddy or wheat crops. The major components include a feeding unit (which consists of a star wheel and crop divider), a cutting unit (with a reciprocating knife and a ledger plate with a standard cutter bar). It also has a conveyor for cut crops and a power transmission unit to supply power to different components. There are pneumatic wheels for propulsion, batteries (which power the header and propulsion units), and a motor controller. These are the key components included in the electric vertical conveyor reaper developed at IIT Kharagpur. The major component is the feeding unit, which directs the crop toward the cutter bar. There must be a mechanism to push the crop forward. This mechanism consists of the star wheel and the divider. The divider separates the crop and distributes it along the knife, while the star wheel pushes the stems toward the knife.

So, as usual, we maintain the same triangular piece of metal as a divider, which is provided in the conventional vertical conveyor reaper. We follow the same crop divider with an angle on the side where the star wheel is present. We provide a slightly higher angle so that more crops can be handled by the star wheel. On the other side, the angle is 12 degrees, and on the star wheel side, the angle is 16 degrees. Then, β is kept greater than α. The reason is to have more handling by the star wheel. The number of star wheels is to be decided by the cutting width and the row-to-row width of the crop to be harvested. The condition is that the outer diameter of the star wheel should be greater than the spacing between the rows of the cultivated crop. If you look at the figure, the center of the star wheel is not aligned with the center of the triangular plate. It is offset from the center of the triangular plate by a distance of 50 millimeters. The star wheel is not a solid disk; it has curved fingers with the periphery of the disk open so that it can accommodate the stems of the crop to be pushed toward the knife. For deciding the number of star wheels, as I said, it depends on the cutter bar and the outer diameter of the star wheel. The width of the cutter bar divided by the outer diameter of the star wheel will give you the number of star wheels required. In our case, we have limited the cutting width to 60 centimeters. That is why two star wheels are selected, with an outer diameter of 30 centimeters. So, it can cover at least - if 20-centimeter row-to-row spacing is there, it can cover 3 rows; if 15 centimeters, then 4 rows can be covered. The outer diameter, as I said, should be greater than this spacing. So, 15 and 20 centimeters will be handled by these star wheels with an outer diameter of 30 centimeters.

Then there will be 3 crop dividers if you look at this figure there will be 3 crop dividers. So, the left hand side crop divider - left hand of the operator that does not have a star wheel. It will basically separate the uncut crop from the cut crops during the course of harvesting. The specification of the star wheel is: outside diameter is 300 millimeter, inside diameter is 140 millimeter, internal diameter of star wheel 15 - internal diameter of the star wheel bearing, I am talking about 15 millimetre, the number of fingers are 7 and material used is a plastic material.

Now, the condition is : the star wheel speed should be greater than the forward speed of the harvester. How much greater? It depends on the real speed index. Again reel speed index is a ratio of peripheral speed of the star wheel to the forward speed of the machine. So, if you consider the real speed index value which is varying from 1.25 to 1.5. So, now, if you take the maximum value of 1.5, then that way, $V_s = \lambda \times \frac{V_m}{cos\alpha}$. V_s can be calculated provided we know the angle α at which the crop dividers are fixed to the horizontal and the forward speed. It is a manual guided. So, forward speed cannot be more than 1 kilometer per hour. So, we fix the forward speed to 1 kilometer per hour and the α value again depends on how compact is the machine. If you want longer machine then you can reduce alpha, but the other condition is , the star wheel should touch the plant below the panicles. So, that it does not break - the stem should not break. So, with taking those two conditions into account, the constraints into account, so, the angle of inclination we have fixed at 70 degree and that way this speed of the star wheel comes to 1.18 meter per second.

Now design of conveyor chain: once you decide the crop divider and the star wheel then next comes the conveyor chain. That means, the chain which is used as a belt to transfer the material, material means the plant which are cut from one end to the other end and it will drop the cut material on the right side of the operator. So, what we are going to design here is the speed of the lugged chain and the diameter of the sprocket.

So, for calculating the speed of the lugged chain, if you look at the figure, there we can see that the star wheel is powered because of the contact between the lugs provided in the chain - conveyor chain and the fingers of the star wheel. If there is no contact then star wheel not to rotate. So, we want to rotate the star wheels at the same time there should be some contact, contact between the fingers and the conveyor belt. So, the speed of conveyor belt we have taken as 1.1 times the star wheel speed that means, considering losses there is no proper contact there may be some slippage depending on the quality of manufacturing. So, we have taken losses around 10 per cent. So, the speed of conveying belt we have kept as 10 per cent more than the speed of the star wheel. So, we have calculated speed of the star wheel as 1.18 meter per second. So, now, we multiplied with 1.1. So, that way we get this conveying speed of 1.3 meter per second. Now, taking a medium size sprocket with a diameter say 91 millimeter, then the speed of the lugged conveyor belt as you calculate as 1.3 meter per second. So, the rpm comes to 275, rpm of the pulley which will be fitted to - the rpm of the sprocket which will be fitted to the shaft of the conveyor. This shaft basically will get power from the motor which will be run by a set of battery. The crankshaft which is used for driving the conveyor shaft, it has a speed of 450 rpm and that speed has been calculated taking into consideration the knife speed. Knife speed means knife is reciprocating, so, you know the stroke length, stroke length because the cutter bar is a standard cutter bar. So, stroke length is 76 millimeter. So, we know the stroke length. To get that 1.8 meter to 2 meter per second, so, the rpm which comes to be 450. So, now, from that shaft, only power will be taken to the conveyor shaft. So, 450 rpm is to be reduced to 275. So, there will be a reduction in it, that means, a sprocket size will be bigger in the header unit to transmit power from the header unit to the conveying unit .

So, taking a sprocket of 13 teeth in the driving shaft, the number of teeth of the sprocket on the conveyor shaft was calculated that means, bigger teeth is on the conveyor shaft, a bigger size and smaller size is on the header shaft. So that we can get a reduction of 1.6:1. Then comes what should be the length of the lugged conveyor chain that is important. Since the cutting width is 600 millimeter or 60 centimeter. So, the center-to-center distance, center-to-center distance means the two shafts where the chains are supported or the sprockets are supported. So, that distance you have taken as $B = \frac{D_p}{2} + \text{length of cutterbar} + \frac{D_v}{2}$, where, D_p diameter of the driving sprocket and D_v diameter of the driven sprocket, that becomes the center-to-center distance. And then, by applying the number of teeth and pitches of the chain, we can calculate the length of the lugged conveyor belt, which is the lugged conveyor chain, as given by, $L = \frac{p(T_1+T_2)}{2} + 2B + \frac{p}{2B}\left[\mathrm{cosec}\frac{180°}{T_1} - \mathrm{cosec}\frac{180°}{T_2}\right]^2$. So, we need to know the value of the pitch of the chain, the number of teeth in the driving sprocket (T_2) and the driven sprocket (T_1), and the center-to-center distance (B). So, taking those values into account, we calculated the chain length to be 1.66 meters.

So, there will be two such chains, one on the top and the other at the bottom. Then comes the pitch of the lug. Because along the length of the chain, lugs are provided at a certain interval, which is nothing but the pitch. So, since I mentioned that the star wheel is operated because of the contact between the fingers of the star wheel and the lugs of the chain. The simple theory is: in one revolution, how many contacts are required - one revolution of the star wheel. So, in one revolution of the star wheel, the distance traveled will be πDs. During that time, the number of contacts - since I have decided the number of fingers is 7 - will be equal to $\pi D_s/N_s$, where N_s is the number of fingers. So, that way, we calculated the spacing between two adjacent lugs, which is nothing but the pitch, to be equal to 134.63 millimeters. So, roughly, we can take it as 135 millimeters. So, if that is the case, we have decided the length of the chain, and then we try to find out how many such lugs will be accommodated. So, we calculated that one, and that way, it is giving some fractional number. So, we have taken the rounded number as 13. So, if the number of lugs is increased to 13, the chain length has to be adjusted. So, initially it was 1.66 meters, now it has changed to 1.75 meters.

Then the lug length. So, the lug length should be such that the bunches of cut crops can be conveyed continuously without any blockage. We want that whatever material is cut has to be conveyed and dropped on the right side of the operator. So, for continuous conveying, the conveyor output per unit time should be greater than the plant stems cut by the cutter bar - that is the condition. So, how do you find that? If H is the lug length and V_c is the speed of the conveyor, then in that area the plant material which is cut will be calculated depending on how much width (W) it is covering, what the forward speed of the machine (V_m) is, and what the plant density (S_d) is? If you know, then you can find out this much area of crop stems should be accommodated in this area. But if you look at that area ($H \times V_c$) which is bounded by this lug length and the conveyor length, then in that area some area is lost - lost because of the lugs of the chains, because of the fingers of the star wheel, and because of the power losses. If you consider those losses into account, then you can find out what the total area available per unit time $H.V_c.(1 - P_1).(1 - P_2).(1 - P_3)$ is, and that should accommodate the number of plant stems cut -

that means the area of plant stems cut $(W \times V_m \times S_d)$. So, if you equate this i.e., $H.V_c.\ (1 - P_1).(1 - P_2).(1 - P_3) = W.V_m.S_d$, then that way you can calculate the value of H. Because we have already decided the value of V_c, which is the conveying speed, and we have decided the width of cut and the forward speed of the machine. The only unknown parameter on the right side is your plant density. Usually, the plant density is nothing but the number of hills present in one square-meter area and the number of stems it contains. If you know the exact number of stems and the diameter of the stem, then you can calculate the value of S_d.

Or roughly, you can say that the hill diameter is this much - it varies from 26 to 45 millimeters depending on the variety and the growth rate. So, that way, usually the value of S_d is taken as 0.15. If someone is very accurate, he can calculate the number of stems and then calculate the total area covered by the stems per unit area, then he can calculate the value of the right-hand equation. So, in our case, we have taken or assumed the S_d value as 0.15, and the losses which I told - losses due to the thickness of fingers of star wheels (P_1), we have considered as 20 per cent, that the area is lost. So, 20 per cent of the area is lost, and losses due to the thickness of lugs (P_2) we have taken as 2 per cent of the area, and slip losses - power transmission loss (P_3) is 10 per cent. So, in that way, if you equate this equation, then we will find out the value of H, which comes to a figure of 26.49 millimeters. So, this is very small compared to the contact between the finger and the chain lugs. So, what we have done is we have added some additional clearance, which is around 23.5. So that you can get a round figure of 50 millimeters. So, that will be the height or the length of the lug.

Then comes the design of the crop-supporting unit, because after cutting, when the crop material is pushed towards the chain, it is conveyed along the chain and has to be supported; otherwise, it will fall. So, for support, we have provided two springs. At the same time, we have adjusted the height of the platform behind the conveyor so that the crop can rest on the frame. So, we have decided on that height as 680 millimeters, taking into consideration the average paddy height of 750 millimeters. And the cutting height of the plant from the ground surface is 70 millimeters. So, the difference will give you 680. So, that way, we have set the height of the platform as 680 millimeters. And then, we provided two compression springs, one on the upper and one on the lower side. These are fitted below the star wheels. So that whatever crops are pushed towards the chain, these springs will try to hold the cut crop in a vertical position.

Then comes the power requirement for the conveying unit. Power is required for conveying, power is required for cutting, power is required for propelling. These are the three power requirements. So now, let us see how much power is required for carrying out the conveying of cut plants. So, for finding out the power requirement for conveying, we need to know the amount of crop, that means the weight of crop which is handled per unit time. So, to find that out that one, we need to know the yield rate, the straw-to-grain ratio, and then the conveying speed or the forward speed. Now, the yield for the IR 36 variety we have taken as 4500 kg per hectare, and the straw-to-grain ratio we have taken as 1.2:1. The forward speed we have already decided as 0.27 meters per second or 16.66 meters per minute. Now, the cutting width we have taken as 0.6 m, not this - 0.6 m. So now, the crop moved per unit time, that is kg per minute, we have to calculate by this equation: what is the cutting width, then the forward speed, then the total crop yield, which includes the weight of paddy and the weight of straw. So, taking that 1.2:1 ratio, the total paddy and straw weight comes to 9900 kg per hectare. Now, you know the cutting width, you know the forward speed, then divided by 10000 because it is in hectares, so that way you get a value of 9.89 kg per minute.

Now, next is the weight of crop for the entire cutting width at a particular instant of time, that means along the length of the belt, which is equal to the cutting width and in that cutting width, how much amount of crop is present at a particular instant. So, if you want to find that out, we need to know the weight of crop conveyed per unit time multiplied by the effective chain length, which is equal to your cutting width plus some clearance. So, that way, 0.69 meters. And then, what is the conveying speed? So, that way, we will find out how many kg will be available at the chain per unit time. This includes your weight of chain plus weight of crop - weight of paddy and weight of straw. Now, next is the chain has its own weight. So, there are 2 chains, so twice into weight of chain plus weight of crop that will give you the total weight. If you know the coefficient of friction between chain and crop material, then we find out what is the lateral force required to pull the entire weight towards one side. So, that way we will find out what is the lateral force, it is coming around 30.81 Newton and where you have considered the coefficient of friction between 0.13 to 0.19. Now, the power requirement, P_{co} = lateral force which is required × factor of safety× conveying speed. Conveying speed we have already decided 1.3 meter per second and pull we have just now calculated the lateral force and we have taken factor of safety as 2. So, that way we will find out. We got a value of 100.9 Watt. So, this is the power which is required for conveying.

Now, if you look at the figure this is the arrangement. So, the middle one is the header shaft which is receiving power from the electric motor and from the header shaft at the lower person the knife is connected with the help of a slider crank mechanism. And at the middle, power is transmitted to the conveying shaft. So, now, I am talking about this conveying shaft. So, this is the chain which is on the top, this is the chain which is provided in the bottom, these two chains are responsible for conveying.

Now, we want to design this conveyor shaft which is present. So, it is receiving power at the middle and it is transmitting power at the top as well as at the bottom. So, the torque will be acting at - if you denote these points where the torque is taken or where the torques are applied. So, I have taken this as A and this shaft is supported on bearing. So, this is the bearing support and this is the bearing support. Now, at point A, point B, point C, where we are taking power - we are receiving power at B and transmitting power at A and C. So, the torque acting at A and C, they are same. So that way because just now we calculated the force which is required to convey. So, that has to be multiplied with the 2 π n T. So, from there we know what is the power required for conveying then divided by 2 π n, n is the rpm of the conveyor shaft. So, that way you will find out what is the torque acting at point A. Similarly, at point B due to transmission of power to the conveyor shaft we calculated 150 Watt is the power transmitted divided by 2 π n that way we will find out this much is the torque which is acting at point B. So, you know the torque which is acting at point A, point C, point B and then we try to find out knowing the sprocket radius what are the forces acting and then knowing the distance between them we can find out the bending moment acting about the central axis. Now, we know the bending moment, we know the torque which is acting, then applying the maximum stress theory, we can find out utilizing this equation $\mathrm{T_{eh}} = \sqrt{(\mathrm{K_m} \times \mathrm{M_{fh}})^2 + (\mathrm{K_t} \times \mathrm{T_{fh}})^2}$ what is the equivalent torque, then assuming the shaft with circular in section and the design stress as 50 Mega Pascal, then the diameter of the header shaft will be will be calculated $\mathrm{T_{eh}} = \frac{\pi \times \tau \times \mathrm{d_h}^3}{16}$. And we have calculated taking all the factors. The T equivalent comes to 23.91 Newton meter and taking this design stress of 50 Mega Pascal, the diameter comes to 13.45 millimeter. So, we have taken a diameter of 15 millimeters.

So, these are some of the references which have been taken, and the conclusion is we discussed about the different components of the reaper. Then we discussed the power transmission system, the power requirement for the conveyor chain, and how to design the shaft which is transmitting or receiving the power to rotate this chain. That is all.

Thank you.