Design of Farm Machinery

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Lecture 51 : Design of a self-propelled vertical conveyor reaper

Hi everyone, this is Professor H. Raheman. I welcome you all to this NPTEL course on Design of Form Machinery. Today's lecture 51, where I will try to cover the design aspects of a self propelled vertical conveyor reaper. The concepts which will be covered are components of a self-propelled vertical conveyor reaper or in short you can say VCR, then design of components of VCR.

The figure which is shown is a top view, where I have indicated the components of a vertical conveyor reaper. The major components are the feeding unit, the cutting unit, conveying unit, power transmission unit and propelling unit. Feeding unit comprises of reel and crop divider. Cutting unit is the cutter bar which is used for cutting crop, then conveying is for conveying the cut crop to one side. In case of a vertical conveyor reaper as the name says vertical conveyor reaper that means, it will convey the cut material vertically and it will throw it on the on one side in a windrow. So, you have to have a conveying unit, then power transmission unit, how power will be transmitted from the source to power these different units, feeding unit, cutting unit, then a propelling unit, then lastly the propelling unit, basically, the devices which are used to move the machine forward for transportation etcetera. The frontal part of a VCR is the feeding unit which comprises the crop dividers with star wheels which will feed the crop stems to be cut by the knife.

So, some components should be there when the machine moves forward, that component will try to push the crop stems towards the cutter bar or the knife, so that cutter bar can easily cut it. The header unit which comprises of cutting and conveying units, the cutting unit consists of serrated standard cutter bar, then ledger guards with slider crank arrangement. That means, the reciprocating motion from the source has to be converted to the circular motion from the source has to be converted to reciprocating motion, so that knife can move to and fro. Then the conveying unit consists of lugged conveyor chains for moving the reaped stem to one side of the VCR and the propelling unit comprises the pneumatic wheels and the gear box and the powering unit comprises the power source and the power transmission system.

Then coming to the feeding unit. It is a crop divider which will divide the crop and feed it smoothly into the header unit with the help of a star wheel. The crop divider is basically a triangular plate which will divide the crop so that the star wheel can move this crop towards the knife. If you look at the figure, I have indicated the crop divider. This is your crop divider, and this is not horizontal; it is kept at a certain angle. And the top - if you take a top view, the crop divider is a triangular piece; it has a front angle, you can see. It is not symmetrical; you can see 12 degrees, 16 degrees. That means one side has more angle where the star wheels are present, so that more crops can be handled - the crops can be diverted towards the star wheel. So, a star wheel will help to push those crops towards the cutter bar. So, it is advisable to have beta - beta means this angle -greater than alpha. So that the star wheel will help to feed the crop towards the cutter bar. Now, if you look from the side view, this will be your crop divider, and below that is present the star wheel or the wheel which is used to feed the crop towards the cutter bar. And the center of the star wheel and the center of the crop divider are not aligned. So, it is a little away so that it can easily handle more crops. And the star wheel is not a solid disk; it has curved fingers with the periphery of the disk opened, so that it can easily accommodate the crop to be pushed. Crop means crop stems to be pushed towards the cutter bar. The number of star wheels depends on the type of crop to be harvested, it depends on the row-to-row width, and it depends on the outer diameter of the star wheel. So, usually, the outer diameter of the star wheel should be greater than the spacing between the rows of cultivated crops. That means, the crop which has to be harvested - if you know the row-to-row spacing, then the star wheel diameter should be higher than this.

The number of star wheels to be used in the conveying unit is decided based on the star wheel outer diameter and the cutting width. So, the width of the cutter bar divided by the outer diameter of the star wheel will give you the number of star wheels to be included. Usually, one star wheel will at least accommodate one row of crops. The inclination of the star wheel depends on the length of the crop divider. The inclination of the star wheel should be such that its finger, the finger of the star wheel should touch the plant below the center of gravity. So, the plant should not break during pushing. The horizontal component of the star wheel velocity should be greater than the forward speed of the machine for proper cutting and guiding the crop to fall behind the cutting unit. So, this is one important aspect in designing the star wheel. The horizontal component of the star wheel should be greater than the forward velocity of the machine. Usually, if you denote the forward velocity as V_m and the star wheel speed as V_s, then $V_s\cos\alpha$ should be greater than V_m. Now, where angle α is the angle of inclination of the star wheel from the horizontal. This is the same as the angle of inclination of the crop divider with the horizontal.

For a harvesting equipment, we know that the reel index (λ), a terminology we defined as the ratio of the peripheral speed of the star wheel to the forward speed of the reaper or the harvester varies from 1.25 to 1.5. So, if you try to incorporate λ into this, then the velocity of the star wheel, $V_s = \lambda \times V_m/\cos\alpha$. Then, the design of the cutting unit: the decision on the cutting width has to be made on the basis of power availability, field capacity, and the number of rows to be covered with minimum power consumption. How much area do you want to cover? And what is the power available? The power source - what is its capacity? All that will decide what will be the cutting width. Usually, a vertical conveyor reaper is a manually guided one and self-propelled. The engine provided could be a diesel engine or a petrol engine.

So, since a manual operator is there who has to walk behind the machine to guide it, the forward speed is usually taken as 1 to 1.2 kilometers per hour, not more than that. So, the selection of the knife and knife back is made according to the IS standard, which is available. And a reciprocating-type cutter bar with a stroke of 76.2 millimeters is usually selected. So, that means in one revolution of the crankshaft, which is used for powering the knife, it should move 76.2 millimeters in one direction and then come back 76.2 millimeters in the other direction. The knife section is trapezoidal, and these are serrated. The edges are serrated to avoid slipping of the stalks, and knives with 1 to 1.25 millimeters pitch of serration, which is 2 to 3 times smaller than the diameter for paddy and wheat stems, are selected to prevent choking and reduce power requirements. The knives with smaller rake angles and sharp cutting edges have greater cutting ability, but they become blunt more rapidly. So, what we have to do is, for harvesting cereal crops, a rake angle of knives in the range of 20 to 30 degrees is selected. Therefore, the knives with a sharp cutting edge and a rake angle of 20 degrees are to be selected for greater durability and efficient cutting. Now, the ledger guards, or the fingers - in other words, we can call them fingers are to be selected according to IS 6024. The standard-size twin ledger guards with lips are to be used in the cutting unit for preparing cereal crops for reaping cereal crops.

Then, the ledger guards are to be fastened to an MS flat and fixed below the cutting knife. Then, there are knife clips, which are bolted to the MS flat over the cutter bar to hold the cutter bar in place and maintain a clearance of 0.5 to 1 millimeter between the cutter bar and the counter shear of the ledger plate for efficient cutting of stems. If you increase this gap, then you may not get proper cutting. Then, at the end, a slider-crank arrangement is to be provided to convert the rotary motion of the header shaft to the reciprocating motion of the cutter bar, so that a stroke of 76 millimeters is obtained. So, in this figure, you can see there are two chains - three chains, in fact. The middle one is for transmitting power from the central shaft to the conveying shaft, and the upper chain and the lower chain are for conveying the cut crop.

These chains are provided with lugs at regular interval. - these lugs. The height of the lugs - we will calculate how to find out the height or length of the lugs. And from the middle power is taken from the shaft to the conveyor shaft and at the bottom of the shaft there is a slider crank mechanism, the crank has to be connected there. So, this is the main shaft which takes care of the power transmission, power transmission to the cutter bar, power transmission to the conveying shaft, and for receiving power from the source. Now design of the conveyor chain: the crop which is to be cut by the cutting unit needs to be conveyed, conveyed in a vertical orientation to the right side of the VCR. For this purpose two lugged conveyor chains are used in vertical platform.

The speed of the lugged conveyor chain is given as V - if you denote it as V_c, $V_c = \frac{\pi \times D_p \times N_p}{60}$. D_p is the diameter of the pulley or the sprocket, where the chains are mounted and then N_p is the rpm. So, knowing the rpm and diameter, we can find out the peripheral speed of the lugged chain. In fact, the reels which are present below the crop divider they get powered by this conveying unit. The lugs which are provided, these logs are in contact with the fingers of the star wheel. So, whenever the conveying chain rotates the reel will also rotate because of the contact between finger and the lugs. So in that way, we can take that conveying speed is equal to star wheel speed with a loss of 10 per cent. So, if you know the star wheel speed, you can find out the conveying speed or if you know the conveying speed you can find out the star wheel speed either way.

Then the next important component is your length of the chain: length of the chain which are there are - two chains. In fact, we want that the cut crop should be vertically adjusted in the platform and it will be conveyed from one end to the other end. So, for that the height of the platform should be sufficient to hold the crop vertically and the chain will then move this cut crop. So, the length of the chain can be calculated by simple physics you can apply. If you know the pitch, pitch of the chain and then number of teeth in the sprocket, then length of the chain $L = \frac{p(T1+T2)}{2} + 2B + \frac{p}{2B}$, where, B is nothing, but the length of the cutter bar + $D_p/2$ + $D_v/2$. D_p is the diameter of the driving sprocket on the conveying unit, D_v is the driven sprocket. This is the driving sprocket, this is the driven sprocket and then the other thing is one should decide the length of the chain that means, length of the chain is a function of mostly the cutting width. We have to have a chain which has a little longer length than the cutting width. So, that way we calculated. Then pitch of the lugs because you want to provide lugs on the chain. So, what will be the pitch of lugs, which are to be provided in the conveyor chain that is decided by knowing the diameter of the star wheel. The number of fingers present in the star wheel, if you denote it as N_s and pitch of the lugs if you take as P_i, so, $P_i \times N_s = \pi \times D_s$. Where, D_s is the outer diameter - outer diameter of the star wheel.

To calculate the lug length that means, this distance, where the crop after cutting will be accommodated. So, the lug length should be calculated based on the fact that the bunches of cut crops can be conveyed continuously without any blockage. There should not be any blockage, whatever material is cut that should be immediately conveyed. With that concept, we have to decide the height or length of the lug. For continuous conveying of the crop, the conveyor output per unit time should be greater than the plant stem cut by the cutter bar. So, now question arises what will be the plant area which is cut by the cutter bar. So, if you know the forward speed of the machine or the harvester and the width of cut, if you know that, it means you know per unit time how much area it is covering and how many plants are present in that unit area. So, then you can calculate what will be the stem area. So, what you have done is W is the width, V_m is the forward speed multiplied by a factor called S_d, which is the plant density. Plant density usually depends on - for example, in paddy crops - it depends on hill-to-hill spacing and row-to-row spacing. If you know that, you can find out how many hills are present per unit area. And per hill, on average, there will be some stems per hill, the number of stems varies again depending on the variety of the crop. So, usually we take 45 stems, 40 stems, like that. Or you can take the average diameter of the hill. So, once you know the average diameter of the hill, which is usually around 26 millimeters to 30 millimeters, like that. So, then you can know how many hills are present.

So, you can find out $\pi d^2/4$, which will give you the area of each hill - the stem area of each hill and then multiply by the number of hills, which will give you the total stem area per unit area covered by the machine. So, the right-hand side equation is related to the stem area, and this much stem is to be accommodated in which place - in this space. So, if H is the lug length, this length is denoted as H and the velocity of conveying is V_c, then this much stem should be accommodated in this area - this much area. But some area is lost because of these lugs, some area is lost because of the slippage, and some area is lost because of the thickness of the spikes of the star wheel. So, if you take those losses into account, then $H \times V_c \times (1-P_1) \times (1-P_2) \times (1-P_3) \geq W \times V_m \times S_d$, where P_1 is the losses due to the thickness of spikes of the star wheel, which we usually take as 20 per cent. Then P_2 is the losses due to the thickness of lugs, these lugs, and P_3 is the slip losses. So, these three factor if you take into consideration then this much when you multiply that will give you the area where this plant or the stem is to be accommodated $(W \times V_m \times S_d)$. If you equate this i.e., $H \times V_c \times (1-P_1) \times (1-P_2) \times (1-P_3) = W \times V_m \times S_d$, then you can find out what will be the value of H, because we know the value of V_c that the velocity at which it is conveyed. Then you know the forward speed at which you are moving, the width you know and plant density is known. So, you can find out the value of H.

Then design of crop supporting unit, supporting unit means after cut the plant materials are pushed towards the the platform - the vertical platform. So, the machine should convey the cut crop on a vertical platform continuously and without any blockage. The height of the vertical platform is decided based on the plant height of paddy crop or you can take the average height. Because you cannot change or go on changing the height of the platform. So, you have to take the average height of paddy and wheat then accordingly you have to design. Cutting height of plant from the ground surface. So, we usually left 10 centimeter from the ground surface. So, total height of the crop average height minus 10 centimeter that should be available in the platform to accommodate the cut crop.

Then in addition to conveyor chain there are compression springs which are present that are fitted below the star wheel in between the two locked conveyor chains to keep the cut crop in upright position while the crops are being conveyed out of the VCR. So, in addition to lugs you have to provide two springs and so that the spring will press the cut crops towards the platform. The nearer the spring is to the vertical platform, the better is the conveying that means, the crops are more compressed. Now, comes the power transmission unit.

If you look at the diagram which is presented here, there is an engine which is a power source, then from the engine power goes to the propelling unit. So, you have a speed reduction unit - gear box depending on what size of ground speed we are fixing. Then power is also taken from the engine through the speed reduction to the driving shaft, driving shaft for running the cutter bar. So, that is called cutting unit. Then from cutting unit again we are taking power to the lugged belt that is conveyor belt and then to the star wheel. So, power has to be provided to the propelling unit, power has to be provided to the cutting unit, power has to be provided to the conveying and feeding unit. That means, the moment the machine is started and you start moving forward all the three are active - propelling, cutting and conveying. Let us now see how to calculate the power required for cutting paddy crop. The speed of the knife is to be kept 1.5 times greater than the forward speed of the VCR to reduce the number of uncut stalks. Even some laboratory experiments have been conducted for paddy and wheat crops in our department - Agriculture and Food Engineering Department, IIT Kharagpur, where we found that this velocity varies - cutting speed varies from 1.8 to 2.6 meter per second. This much speed has to be maintained. Of course, higher the speed better is the cutting, but again power consumption will be more and if the grain is matured then if you go for higher speed, there will be shattering loss, the grains will be falling on the ground. So, you have to maintain a speed around 2 meter per second for better output. So, the total power required by the cutting unit of a VCR is the sum of power required for overcoming friction, friction due to maybe bearing friction, friction due to moving parts, then absolute power required for cutting the paddy crop. So, summation of these two will give you the total power required for cutting.

In addition to this, there will be conveying - power requirement for conveying. So, P_C plus the power requirement for conveying will give you the total power requirement for cutting and conveying. So, the model which we developed at IIT Kharagpur to find out the frictional power - so, frictional power, $P_f = (60.71 \times V_k) - 41.38$, where V_k is the knife speed in meter per second. So, this has been developed for a cutting width of 600 millimeters. By putting the knife speed, you can immediately find out what will be the value of frictional power.

Then, the power requirement for cutting paddy crop could be estimated by utilizing an equation $P_c = 0.998 \times E_{sps} \times A_s \times V_f \times W_c$, where, A_s, the stem area per unit area covered by the harvesting machine, V_f is the forward speed of the machine or the harvester, and W c is the width of cut. So, this specific cutting energy, E_{sps} is in joules per millimeter square, joules per millimeter square means the stem area. So, we have to find out the stem area. So, for finding out the stem area, A_s again, as I said in the beginning, the number of hills present per unit area must be found out, and knowing the average diameter of the hill, you can find out A_s.

Then, the forward speed is 1 kilometer per hour, usually with a self-propelled, manually controlled vertical conveyor reaper with the cutting width as 1.2 meters. So, if you put in this equation, you can find out what will be the power requirement for cutting. So, the total power requirement will be like this: the summation of idle power, which will take care of the friction part, and the second component, which will take care of the cutting part. So, we will find out the cutting power. Now, the specific cutting energy, the value of which varies from 0.061 to 0.075 joules per millimeter square. This is for a particular variety of paddy and it has been also reported by few other researchers the values are - the maximum value is 0.09 joule per millimeter square. So, roughly it can give you an idea, this much will be the power required for carrying out cutting. Then power requirement for conveying unit : power requirement for conveying unit is an essential part in the design of the header unit - we need to know how much crop - quantity of crop to be moved per unit time. Then if you know the weight of crop then you can find out how much weight is resting on the chain and knowing the coefficient of friction we can find out what is the force required to pull the chain.

So, basically what we have done is we have first found out what is the mass of crop which is conveyed or which has to be moved per unit time. We know the cutting width, we know the forward speed, then the total crop yield if you know, then crop yield including paddy and straw if you know, then we can find out what is the weight of crop for the entire cutting - weight of crop to be conveyed per unit time. Then weight of crop for the entire cutting width will be equal to the mass which will be conveyed per unit time multiplied by the length of the chain divided by the belt speed. So, that will give you the weight of crop which is supported on the chain. Now, the total pull on the chain in Newton = $9.81 \times \mu_c \left[\left(2 \times \text{Length of chain} \times W_{chain}\right) + W_{crop}\right]$. So, this bracketed term will basically give you weight of the chain and the weight of crop this has to be multiplied with the coefficient of friction, μ_c then that will give you the total pull required for moving - moving the chain or conveying. So, total power requirement for conveying, P_{co} = Total pull on the chain × Factor of safety × conveying speed. Some thumb rules have been followed: a few researchers have reported that the conveying power is equal to 50 per cent of the cutting power. So, I have mentioned this one. So, either you can follow this one or you can directly for simplicity of calculation you can just take whatever cutting power is obtained just take 50 per cent of that. So, that becomes your conveying power.

Then power requirement for propelling can be computed knowing the rolling resistance and the forward speed at which the harvesting is to be carried out. Since the VCR is a manually operated machine - manually guided machine hence, the average forward speed can be taken as 1 kilometer per hour. and the rolling resistance can be calculated using Brixius equation. Since pneumatic wheels are used, so, we can use Brixius equation. For utilizing Brixius equation we need to know the B_n value. The B_n value depends on what is the cone index, what is the tyre size - section width, the diameter of the tyre and what is the deflection. Usually the deflection for agriculture tyre, we take 20 per cent. So, in this case we can take 15 per cent also does not matter and what is the weight coming on the wheel? So, if you know, then you can find out B_n and once you know the B_n then you can put in this equation to find out the rolling resistance of one wheel. So, there are usually two wheels provided. So, 2 into R_1 that will give you the total resistance and here W_g is the weight coming on each wheel not the total. So, once you calculate the rolling resistance we know the forward speed we can calculate the power requirement for propelling. So, this is all about.

This is the reference from which I have discussed about the design of vertical conveyor reaper. And finally, I can say we discussed about the different components of a VCR and then how to design those components, how the power is to be transmitted and how to estimate the power requirement for a vertical conveyor reaper.

Thank you.