# Design of Farm Machinery

**Prof. Hifjur Raheman**
**Agricultural and Food Engineering Department**
**Indian Institute of Technology Kharagpur**
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## Lecture 54 : Power requirement and field performance of an electric vertical conveyor reaper

Hi everyone, this is Professor H. Raheman. I welcome you on to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 54, where I will try to cover the power requirement, how to compute power requirement for an electric vertical conveyor reaper and we will also discuss the field performance of the developed electric vertical conveyor reaper. So, the concepts will be where the power will be consumed that we will try to calculate and then how much is the power that is consumed that has to be calculated then how this power is to be met. So, since this is an electric vertical conveyor reaper, so, we try to find out what will be the size of the DC motors, what will be the size of battery which will be supplying power to this DC motors because the source is DC motor. And then the developed one will be displayed, displayed in the sense the video will be shown and then we will discuss about its performance.

So, in the last class we discussed about power requirement for conveying and here I will try to discuss about power requirement for cutting and propelling. So, if you look at the figure which is shown in this slide - the left side, power is transmitted from this source to the main shaft. So, it is receiving power at the top, then at the bottom power is taken for reciprocation of the knife. So, at point A, the header shaft is receiving power from a DC motor and at B, power is taken to the conveyor shaft and at C, power is taken for driving the cutter bar. So, the header shaft is supported on the chassis of the harvester at point D and E. So, these are the support points. Now, diameter of the sprocket at A sprocket at B and sprocket at C are fixed depending on the rpm. So, for deciding the rpm of the header shaft that depends on the stroke length - stroke length of the knife. So, knife has a stroke length : For a standard cutter bar, the stroke length is 76 millimetre and cutting knife speed is 2 meter per second. So, that way you have to find out how much will be the rpm and we know the source rpm that means, rpm of the motor then we find out what should be the reduction because motor rpm is always higher than this.

So, what should be the reduction? so, that we decide the sprocket size to be fixed at A. Now after deciding this sprocket size next thing is you have to calculate the torque acting acting at point B due to transmission of power to the conveyor shaft, then torque acting at C due to transmission of power to the crank of the slider crank mechanism, then at A which is receiving the power from DC motor. So, torque required for cutting we calculated around - we measured in fact, measured around 5 Newton meter. And torque acting at B is equal to : because we know the rpm at which the shaft is running, then from there we try to transmit power to the conveyor shaft. So, there the torque acting is equal to 3.18 Newton meter. So, you know the torque. Then, total torque which is acting if you know and knowing the forces, we know the diameter of the sprockets, so, we can find out force which is acting at each point A, B and C and then the at the support reaction at D and E, then we try to find out what is the bending moment, total bending moment acting. So, knowing the bending moment and the torque which are acting, we can find out the dimensions of the shaft taking into consideration that the shaft is of solid circular section. And applying the maximum stress theory, we try to find out the values of T equivalent, $T_{eh} = \sqrt{(K_m \times M_{fh})^2 + (K_t \times T_{fh})^2}$ and then utilizing this equation, $T_{eh} = \frac{\pi \times \tau \times {d_h}^3}{16}$ with a design stress as 50 Mega Pascal, the diameter comes to 27.82 millimeter and we have taken a diameter as 30 millimeter. So, basically the torque which is acting that is to be found out at different points, then we have to find out knowing the diameter of the sprocket or radius you can say, you can find out the forces and then from forces knowing the distance at which it is acting, then we will try to find out the bending moments. So, torque and bending moment together I will give you the equivalent torque. And, then from there we calculate using the maximum stress theory - we calculate the dimensions of the shaft.

Next thing comes the power requirement for propelling. So, the entire unit is to be propelled. So, we require at least two wheels for propelling. So, we provided two wheels and these are pneumatic wheels. So, naturally when we use a pneumatic wheel then we have to find out what is the rolling resistance. So, for finding out rolling resistance there are some equations available like Wismur and Luth, Brixius equation, but Wismur and Luth equation is very old. So, it does not take into consideration the deflection part. So, we try to concentrate on Brixius equation and based on Brixius equation, we try to find out how much is the rolling resistance. So, that equation is : rolling resistance, $R_1 = [\frac{1}{B_n} + 0.04 + \frac{0.5\, s}{\sqrt{B_n}}] \times W_g]$, $W_g$ is the weight coming on each wheel.

If the total weight is say 150 kg for the vertical conveyor reaper then half of that is acting on each wheel. So, we have to first decide the size of the wheel and then we will try to find out what will be the rolling resistance. So, while deciding the size of the wheel, the two things are to be taken into consideration one is it should have load carrying ability and at the same time the dimensions should be such that you have sufficient clearance. And it should be durable with a normal pressure it can handle this much of weight with a deflection not more than 20 per cent. So, that is the constraint.

So, looking at that we have selected 4.00-8 tyre that means, it is giving an overall diameter of 41 centimeter. So, once you know the diameter then the next unknown parameter is your CI, CI means cone index. Usually the cone index of the paddy field is not that hard, it is medium you can say. So, we have taken 800 kilo Pascal and then section width, diameter and the total weight we have taken as 150 kg. So, 75 kg is coming on each wheel. Taking that into account, we have calculated the $B_n = \frac{CIbd}{W_g}\left[\frac{1+5\ \delta/h}{1+3\ b/d}\right]$ as 37.67. Now, rolling resistance of the wheel will be equal to this multiplied with 75 kg. So, I have converted into Newton. So, that way you are getting 57.53 Newton. So, this is for one wheel and for two wheels it will be 115.06 Newton and knowing the forward speed we have to consider as 0.27 meter per second, we can find out what is the power requirement for propelling.

Now the power transmission system is shown in this figure you can see we have transmitted power from a DC motor to a gearbox and at a reduction of 2 is to 1 with the help of belt and pulley and the ratio is 7.5 is to 1 in the worm gear. This is the worm gear with a total speed reduction of 7.5 is to 1. There are two gears in fact, one is the fast reduction with the help of a belt and pulley, the other one is through the worm gear. So, worm gear is mounted here because we want to transmit power at 90 degree to the motor shaft. So, that is why we are providing a worm gear here and the shaft passing through the gear box you can have two wheels ok. So, the total reduction from motor to the wheel axle is around 15 is to 1 this is the total reduction. Now, we need a speed, minimum speed of 0.8 kilometer per hour that is why we require this much of reduction because the motor rpm is high. So, we require to reduce this amount. Then the total torque required by the wheel was calculated multiplying the motion resistance of the wheel to the static loader radius of the wheel. Torque required by each of the wheel was computed as this much 23.5 per Newton meter, then taking a transmission efficiency of 80 per cent and considering a factor of safety as 3 due to uneven soil conditions in the paddy field during harvesting, the torque required from the motor was found to be around 6 Newton meter. So, n is there. This much is the torque which is required at the motor, because torque required at the wheel shaft is this much. So, just I multiplied the transmission ratio and considering the losses that is transmission efficiency. So, that way we calculated this one because we are reducing the rpm. So, torque is multiplied. So, torque requirement at the wheel is 23.58 Newton meter and torque requirement at the motor is 6 Newton meter. Now the pneumatic wheels are attached to a shaft at a distance of 255 millimeter from the centre of the gearbox. That means, the total centre to centre distance between the two wheels is 510 millimeter.

And the weight coming on each of the wheels we have calculated. And the reactions at A and B. So, basically we are going to design the shaft or the axle on which the wheels are to be mounted. So, the axle is subjected to both bending as well as torsion. So, bending moment is calculated because we have calculated just now how much is the force acting. Half of this will be act at the centre. So, that way 736 into 255. So, $R_A$ into this distance minus, this is $R_A$ is acting upward and the half of the weight which is 735.75, we have rounded up to 736 ×255/2. So, this distance is 255, so half. So that way we are getting this much is the bending moment due to weight. Now the torque we have already calculated which is 47.16 - rolling resistance into the radius that comes to 47.16 Newton meter. Now considering the shaft to be solid and a combined shock and fatigue factor ($K_m$ and $K_t$) we have taken as 1.5 and that way we find out the T equivalent, $T_{eg} = \sqrt{\left(K_m \times M_{fg}\right)^2 + (K_t \times T_{fg})^2}$ = 157.535 Newton meter. And applying the maximum stress theory you can find out the diameter of the axle. So, T equivalent, $T_{eg} = \frac{\pi \times \tau \times {d_g}^3}{16}$, design stress we have taken as 50 Mega Pascal. So, now, the diameter comes to 25.22 millimeter. So, we have taken 25 millimeter as the axle diameter.

Now the total power requirement for cutting if you look at because we have already calculated power requirement for propelling, power requirement for conveying, now we are going to calculate the power requirement for cutting, $P_T = P_f + P_c$. So, power requirement for cutting comprises of two components one is idle power $P_f$, which will take after the friction, then there will be absolute cutting power Pc. So, there are some empirical equations available and we will try to utilize these equations to find out the total power requirement of the EVCR. Now, this one is the power requirement for cutting. In addition to that there will be a power requirement for conveying.

So, power requirement for cutting and conveying $P_{Th} = P_f + P_c + P_{co}$. Now, if you assume that $P_{co}$ is half of $P_c$, why we assume because we have already calculated the value of $P_{co}$ and what we found is around 50 per cent, 50 per cent of the power required for cutting. So, that is why I have taken is 0.5 $P_c$. and the total power requirement for cutting and conveying will be equal to $P_{Th} = P_f + P_c + 0.5\ P_c = P_f + 1.5\ P_c$. Now, $P_c$ has to be calculated and $P_f$ has to be calculated. So, for calculating $P_f$ , we have an empirical equation, $P_f = [(60.71 \times V_k) - 41.38]$. If you know the power loss per meter of width, then we can calculate this $P_f$ value, which is power loss - can be calculated by this equation. If you know the knife speed then $E_{hf}$ can be calculated that is the total. This value can be calculated - totally as by this equation $P_{Th} = (E_{hf} \times W_c) + 1.5\left(E_{sps} \times A_s \times V_f \times W_c\right)$. So, we calculated this, then $E_{sps}$ this is calculated by this value. So, this is nothing, but specific cutting energy multiplied with the stem area per meter square, then how much area we are covering per unit time. So, this value of $E_{sps}$ is in joule per millimeter square, this is in millimeter square by meter square and this is in meter per second, this is in meter. So, that way we are getting joule per second. So, this will become Watt. So, putting in this we can find out the total power requirement for cutting and conveying. Power requirement of the header unit is the sum of the total cutting power and conveying power. So, cutting power comes to 357.5 Watt and then conveying power we have already calculated as 147 Watt or you can take half of this one that is also possible. So, altogether you can get a value of 504.6 Watt that means, around half a kilo Watt is required for cutting and conveying.

Now consider a power reserve of 50 per cent to take care of the varying crop density and power losses due to transmission etcetera, the total power requirement by the header unit comes to 756 Watt. So, what we have done is we have selected a DC motor of 800 Watt capacity, which is operated by 48 volt and the torque availability is 15 Newton meter at 3000 rpm. So, that is the motor which is selected for cutting. We have separate motor for propelling. So, there are two motors selected one for the header unit that means, for cutting and conveying and the other motor is for only propelling.

So, for propelling, we require a torque of 6 Newton meters, and to match this torque requirement, the size of the DC motor available in the market is a 350-Watt, 24-Volt DC motor, which can provide a torque of 10 Newton meters. So, it is sufficient to propel it. So, after selecting the DC motors, I have provided a picture where you can see the power transmission system and how the power is transmitted. So, we have a set of batteries that will supply 48 Volts and 18 ampere-hours. I will explain how this value was determined. Then, the same group of batteries will supply power to the propelling unit as well as to the header unit with the help of a motor controller. So, you can increase or decrease the speed.

Power goes to the header shaft. So, this is the power available at the header shaft (800 Watts, 450 rpm, and 16.98 Newton meters). Now, from the header shaft, power goes to the slider-crank mechanism, which requires 357.51 Watts, the rpm is 450, the torque requirement is 5 Newton meters, and it goes to the cutter bar. Then, another portion of power is taken from the header shaft to the conveying shaft, where we require only this much power: 147.14 Watts, then 275 rpm, and 3.18 Newton meters. And this power, which is taken from the header shaft to the conveying shaft, is for operating the chains - lugged chains, both upper and lower. The upper chain will try to operate the star wheel due to the contact between the lugs of the chain and the fingers of the star wheel. This is one side.

Then, the other side is the propelling unit. The power goes from the battery to the motor controller and then to the DC motor. So, the DC motor selected is 350 Watts, 300 rpm, and 10 Newton meters. The power then goes to a worm gear, and from the worm gear, it goes to a dog clutch. Through the dog clutch, it goes to the wheel shaft. The dog clutch is used because we utilize it for turning by disconnecting the power supply when you want to take a turn. So, we have to provide a dog clutch.

So, we provided a dog clutch and finally, the power is available at the wheel shaft. So, this much is the power available at the wheel shaft. Now as I said the batteries are used, then question arises what should be the capacity of the battery that is important. So, we selected lead acid deep cycle batteries for operating the DC motors. The batteries are selected such that they produce required nominal voltage and current required by the DC motor of the header unit for carrying out harvesting operation as well as for carrying out the propelling of the harvester.

So, for deciding the battery capacity for header unit, Cutting speed, power requirement for cutting, conveying and propelling, motor size, battery size $\text{Battery Capacity} = \frac{\text{Energy consumption per day}}{\text{battery voltage} \times \text{depth of discharge}}$, what is the energy which is consumed per day divided by the battery voltage and the depth of discharge, how much you allow the battery to be discharged. So, if you know these, then you will calculate this one. So, the maximum power required by the header unit is 756.97 Watt and the nominal voltage is 48 Volt and the duration suppose you want to operate for 6 hours a day with a degree of autonomy 2 hours that means, every 2 hours interval you have to charge it. So, that way $\text{battery capacity} = \frac{756.97\ \text{W} \times \frac{6\ \text{hour}}{\text{day}} \times (\frac{2}{24})\text{day}}{48 \times 0.5} = 15.77$ Ah. So that way the current ampere hour requirement comes to 15.77. So, what we have done is: we have selected 4 batteries of 12 Volt and 18 ampere hour, they are connected in series and parallel. So that we can get a voltage of 48 Volt and that can produce a current of 18 ampere. Our requirement is 15.77, but it produces 18 ampere so that you can run it for a longer period of time. Now, I am summarizing the DC motor specifications which is used for header unit, which is used for propelling unit and what is the corresponding voltage, current, torque and speed. So, this is 848 Volt 16 ampere. Torque availability is 50 Newton meter and speed is 3000 rpm. And in the propelling side, the motor which is selected as specification like power is 350 Watt 24 volt 3.1 rated current with a torque availability is 10 Newton meter at a speed of 300 rpm. So, finally, this is the specification of the developed electric VCR which we developed at IIT Kharagpur. It has a cutting width of 600 millimeter and all the specifications like what are the different knife sections, the serrated blade with a trapezoidal section, length, height, pitch of the knife section, then clearance between knife and the ledger plate that is given as 0.5 to 1 millimeter. Then outer and inner diameter of the star wheels 300 millimeter, 140 millimeter, number of fingers, then conveyor chain length, pitch of the lugs, number of lugs in the chain all these things whatever we have discussed the same parameters we tried to maintain.

Then these are the specifications of the motors, then propelling unit DC motor, its controller, then the final dimensions come to : length is 1970 millimeter, width is 988 millimeter, height 50 millimeter and the total weight comes to 135 kg. So, these are the final specifications, then we try to operate in the field I will show you a video. So, this is the machine which we developed and it is cutting and throwing crop to the right side. So, these were the field performance parameters we tried to collect for different crop varieties. We tried in field where IR 36 is grown then Badshabhog. Performance of EVCR is this side and the performance with the conventional vertical conveyor is on that side, you can see the difference. So, forward speed was limited to 1 kilometer per hour whereas, in case of a conventional that is VST Shakti vertical conveyor reaper it was 1.4 even it can go up to 1.71. That means, the field capacity will be affected and what field capacity we are getting is only 0.06 hectare per hour. The field efficiency is high. So, because it is a smaller unit it can take easy turn. Since there is no fuel. So, fuel consumption is not given. So, cutting width was 600 millimeter and the stubble height that means, the portion of uncut crop which is left on the ground is around 60 to 70 millimetre in case of IR36 variety and in case of Badshabhog, it is 60 to 80 millimeter.

So, performance wise it is very good in the sense it is covering a good area and then the main thing is how much is the duration for which it was operated. So, the duration was : at a single charging, when the batteries are completely charged it can work up to 2 hours. And the turning radius is small so that way field efficiency is better. So, only thing is you have to have another set of batteries. So that if you want to continuously run the machine then we required two sets of batteries which depends on the farmer's ability. So, there he can spare 2 sets of batteries or he wants to give some time, so that the batteries can be charged. In 1.5 hour the batteries will be charged again he can bring those batteries. So, that is the only limitation otherwise the machine is effective and efficient in carrying out the harvesting operations.

These are some of the references. And in summary I can say I discussed about the power requirement of the vertical conveyor reaper, then power requirement I mean the power requirement for propelling, power requirement for cutting and then the total power requirement, how the DC motor sizes are fixed, then how to decide the battery capacity. And then finally, I tried to show the video where this developed machine - harvesting machine was operated and then the performance parameters.

Thank you.