Design of Farm Machinery

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Lecture 55 : Onion topper cum digger

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is Lecture 55, where I will cover the onion topper cum digger. The concepts which will be covered include components of an onion topper cum digger, the design of different components, its development, and the performance of the developed onion topper cum digger.

Usually, in India, onions are harvested manually, and mechanization is very low. Onion harvesting comprises two steps: first, the onion bulbs are uprooted from the ground, and then the leaves are chopped off. These are the essential steps required for harvesting onions. Currently, we do not have machines that can both chop the leaves and dig the onion bulbs simultaneously. That is the limitation. At IIT Kharagpur, we tried to develop such a machine. The power source is the power tiller.

This harvesting of onions will be carried out so that chopping the leaves and digging the bulbs can be done simultaneously. With that goal in mind, we have developed this machine. The developed machine is shown here, where I have clearly indicated the different components. The front yellow square is the unit mounted to the front of the power tiller or hand tractor, which is the chopping or topping unit. It will top off the leaves of the onions to be harvested. The middle square I have indicated is the hand tractor, which is the power tiller.

Then we have fitted data acquisition system to collect some data related to force requirement etcetera which is of not much use to this class, but for our research activities we collected. Then there is a digging unit which is attached to the power tiller at the back side. So, the limitation here is: we cannot utilize the rota-tiller which is provided at the power tiller and the digger at the same time. So, we have to remove the rota-tiller and in place of rota-tiller we have to put the digger, digger cum conveyor, we can say. So, digger and conveyor both and this has to be attached and power is to be taken from the shaft, where the power is taken for the rota-tiller.

So, basically we have three units one is the topper, the second one is the digger which is nothing, but a blade and the third one is the conveyor. And the digger and the conveyor they are mounted to the power tiller in place of the rota-tiller and the topper is fixed at the front of the power tiller, but the power supply is from the same engine that is the concept. So, now if you look at these two figures where I have indicated the components of the topper and the conveyor and digger. Number 1 is your wire cutter. So, the wire cutter means it has to have cutting element as the wire - simple plastic wire, but stiffed enough to give impact force to the onion leaf, so that it can be cut by impact. So, then this has to be supported. So, the supporting shaft is your telescopic shaft which is indicated as number 2. So, the shaft is telescopic, so that we can adjust the height of cut. And then there is a bevel gear. So, you are taking power from the flywheel - flywheel of the power tiller. So, that has to be converted to vertical axis. So, we tried to put a bevel gear, and the speed also needed to be reduced. So, we wanted to increase the speed. So, that is why we have to have a gearbox. Then we transmit power with the help of a belt and pulley. Number 6 is the engine, and a linear actuator is mounted to support this topper. So, during transportation, we can raise it, and when it is not used, we can lower it. The linear actuator is indicated by number 7. So, that is only for raising or lowering the telescopic shaft. Then we take power from the flywheel to the topping unit, and on the rear side, there is a V-shaped digging blade. There is a rotary disk that will give a clean cut width. There are two such rotary disks. Then there is an agitator, a kind of vibration it will give to the conveyor.

Then, this digging as well as the conveying unit needs to be supported. So, handles are provided so that, with the help of these bars or linkages, they can be connected to the handle to support the rear side. And there are support wheels, you can say gauge wheels. So, you can increase or decrease the depth. Then there is a cover. Since there is a chain drive, we try to cover it, and finally, this entire unit is operated by a hand tractor. So, I have given number 16 for the hand tractor.

Now as I said the main component is a chopping unit or the topping unit for the chopping of matured onion leaves, a rotary wire type cutting equipment was used to cut the onion leaves by impact. The action is because the leaves are not that strong. So, we require lesser power. So, we go for cutting with the help of a wire. So, the circular cross section wire of diameter 3 millimeter was used for cutting as it is easily available in the market.

And the length of the wire that means, radius of cutting area, we have kept as 0.3 meter, so that it can cover the track width of the power tiller of the hand tractor. The radius is 300 millimeter and the angular speed we try to maintain that is the rotational speed is 1800 rpm. So, we can find out. So, this is rpm not angular speed revolution. So, we can calculate $2\pi n/60$. This 1800 we have taken from the literature and we have also tried in the laboratory. So, we found that 1800 rpm is the best to carry out this dropping operation for onion leaves. The diameter is known then mass of the nylon wire is 3.6 gram for 15 meters of air weighing 90 gram. From there we calculated what will be the (weight) grams for that 600 mm - 60 centimeter. Then the centrifugal force we try to calculate is m ω^2 r. So, that we find out this must be the centrifugal force which is acting. Taking a factor of safety 2, the total force requirement is 77 Newton.

Now, torque acting on the shaft will be force into distance, distance is here the radius. So, force is 77 Newton distance is 0.3 m. So that way we find out what is the torque acting and the shaft is subjected to only torsion not the bending. So, we try to find out applying this failure theory. So, allowable stress is equal to (torsional moment × d/2)/$\pi d^4/32$, assuming that the section of the shaft is circular and is solid. So, that way we try to find out. We have taken the allowable stress as 42 Mega Pascal and we find out the value of diameter of the shaft - comes to 14.09 mm. But 16 mm is the diameter available in the market. So, we try to select the 16 mm diameter. Then the wire cutter was attached to a telescopic shaft, so that the shaft can be raised or lowered depending on the height of the cut. Then the telescopic shaft was supplied power from the flywheel of the hand tractor through a bevel gear box with the help of V-belt and pulley. So, a nut and bolt arrangement was made in the telescopic shaft to increase or decrease the length, so that it can control the height of cut. Then we utilize a linear actuator of stroke length 300 millimeter to lift or lower the entire topping unit while taking a turn at the headland or during transportation also. So, the linear actuator was powered by 12 Volt battery and 7 ampere hour capacity. Then the digging unit, the function of digging unit is to loosen the soil around the onion bulbs and dig out the bulbs from the ground, so that it can easily be transported to the conveyor. So, the selection of material for the digging blade is a carbon steel and it is a multi V shaped, you can see, number of it can cover a width of 60 centimeter just the width of the - track width of the power tiller. A multiple V shaped digging blade. And this is a rigid blade, this is not powered, neither oscillated. So, this has to be only simply dragged. So, its depth has to be controlled. So, as I said in the beginning, there are two gauge wheels provided by which you can raise or lower the depth of the operation. So, usually the onion bulbs are mostly within 70 millimetres of depth. So, we kept that depth as 70 millimetres, and we can increase or decrease from there by raising or lowering the gauge wheel provided at the conveyor.

So, the digging blade has three 8-millimetre rods which are welded at the back side so that whatever material is riding over the blade will fall through these openings. So, these are gaps basically. So, through these gaps, the bigger clods will drop because we also want that the soil clod should not accumulate; it should not be carried along with the onions. And the main thing is the rake angle - the angle of this with the horizontal, the total blade with the horizontal, that angle. The rake angle is kept as 21 degrees. This also you have taken from the literature as well as from our practical experience in the field, from which we tried to finalize this value.

Now, there should be a vibrating unit and a conveyor. That means the entire conveying unit has to be vibrated. So, the vibrating conveying unit, this was designed to separate the soil mass, the stones, etc., while digging out the onion bulbs from the soil. This is possible by giving some kind of jerks or vibrations. The conveyor was vibrated with the help of an oval-type agitator provided at the rolling shaft, where we try to power this rod-type conveyor. Then, the chain and sprocket arrangement was made to transfer power from the driver shaft of the hand tractor to the conveyor.

So, we transmit power from the rotor shaft, where the rotor was initially present because we removed it during operation. So, we took power from there and transmitted it to the conveyor. So, what should be the conveyor speed? That is an important component. So, how do you determine the conveyor speed? So, we try to calculate the mass of the soil and onion mixture handled per unit time by the conveyor. So, that depends on the density of the soil and onion mixture, the width of the digging blade, the thickness of the material, and the speed of the conveyor. So, the multiplication of these factors should equal the mass of the soil and onion mixture dug out by the blade. Since the width of the digging blade is already fixed, and assuming the thickness of the material flowing along the conveyor to be 50 millimeters, with a density of 1450 kg per cubic meter, we determine: this is the mass of the soil and onion mixture handled per unit time, and from there, we determine the required conveyor speed. The forward speed during operation is less than 1 kilometer per hour, which is around 0.27 meters per second. So, the conveyor speed is greater than the forward speed. This ensures the design is safe, meaning there will be no accumulation of the onion and soil mixture on the conveyor. So, we must keep that value higher than the forward speed to ensure proper conveying. Otherwise, accumulation will occur, increasing drag force and draft. These are different views of the digger-cum-conveying unit. It comprises multiple V-shaped digging blades (labeled as number 2), a pair of rotary disks (number 5), a set of gauge wheels (number 6), and rod-type chains. Rod-type chains are provided so that soil material can drop back into the field during transport, while preventing onions from falling. So, that is why the spacing of - spacing between two adjacent rods they are kept in such a way that they do not allow the onion bulb to drop in during the course of conveying. So, our aim is the free bbulbs should be available at the end of the conveyor and then from there it will be dropping on the ground. So, the collection of bulbs will be made manually. As you obtained the speed of the conveyor to be 36 per cent higher than the forward speed of the travel, therefore, this speed of the conveyor was sufficient to move all the materials to the rear end of the harvester without any accumulation. Then the length of the conveyor was selected as 650 millimeters. So, this is decided because after removing the rotor unit hardly 1 meter was left because the operator has to work behind the hand tractor. So, we limited - the limited the length to 650 millimeter so that a person can easily control this during operation control the handles during the operation. Then the minimum polar or equilateral diameter of onion bulbs was taken into consideration while deciding the space between two adjacent rods in the conveyor. So, that was kept as 30 millimeter and those materials for the rods were mild steel and the diameter was taken as 8 millimeter. These are basically to support the total mass of mixture that means, mixture of onion bulbs and the soil.

Then the conveyor rods are fixed at an angle of 25 degree lesser than the angle of repose. That means, we keep it so that the onion should not slide down that was the aim. So, during conveying onion should not slide down to the front, it should go along with the conveyor. So, with that concept we have kept an angle which is 25 degree lesser than the angle of repose of the onion bulbs. Then looking at the power transmission system to the conveyor you can see power is taken from the rotor shaft which was originally used to drive the rota-tiller. So, that shaft is used from there we try to transmit power to the front roller of the rod type conveyor using a chain and sprocket. The rotor shaft revolves in the direction of travel of the hand tractor. So, in order to reverse the direction, we have put some idlers, because the direction of movement of the hand tractor and the direction of movement of the conveyor they are opposite. So, to do that we have incorporated some idlers. A separate chain and sprocket arrangement was also made to power the back roller. So, there are two shafts. So, one is the front, the other one is the rear. So, both are powered, this one and this one. So, this is finally, the power transmission system which is followed for the onion topper cum digger. You can see at the centre this is the hand tractor and from the flywheel we are taking power to a gearbox with the help of belt and pulley. The gear ratio was 1:1.71 here, we are increasing the rpm. So, 1 : 1.71. Now, from the gearbox we are taking power to the cutting unit where there is a reduction of 1 : 0.56. Now, from the engine power goes to the wheel and this is in built one. So, we did not disturb anything only thing we have taken power for the conveyor.

So, to make the conveyor operational, we took power from the rotary shaft with a gear ratio of 1:2.15 by using a chain and sprocket. So, for the topping unit, we have taken power with the help of a belt and pulley, and for the conveying unit, we take power with the help of a chain and sprocket. And in front of the conveyor, the blade, the blade which is used for digging the onion bulb - digging out the onion bulb is present. So, that is non-powered; it is a passive tillage blade.

So, this is the developed hand-tractor-operated onion harvester, and these are the specifications. Specifications, in the sense, the total dimensions come to 2637 millimeter, 850 millimeter is the width, and 1223 millimeter is the height. These are in millimeters. Then, the topping unit separately has dimensions of 360 by 507 by 700 millimeters, that means length, width, and height. Then, the weight is 265 Newtons. The cutting is by impact with the help of a nylon wire. Then, the length of the wire we have taken is 600 millimeters. That means the total width of cover is 600 millimeters, and the diameter of the wire is 3 millimeters. The shaft to which these cutting wires are attached is a telescopic shaft. The length is 620 millimeters, the diameter is 25 millimeters, and the gearbox, etcetera - the specifications are given. Then, the lifting mechanism, as I said, is a linear actuator. So, the stroke length is 300 millimeters, and it is powered by a 12-Volt 7 ampere-hour battery.

Then, coming to the digging-cum-vibratory conveying unit, the total weight was 961 Newtons, that means roughly around 100 kg. Then, the size of the digging blade is 600 × 150 × 8. So, 600 is the width, 150 is the length, and 8 millimeters is the thickness. So, the shape of the blade is multiple V-shaped, and the blade material is high-carbon steel. The rake angle we keep is 21 degrees. Then, the type of conveyor is a rod-type conveyor, and the length is 650 millimeters. The number of rods, spacing between rods, and diameter of rods - all those things are given here. So, finally, this is tested in the field.

So, you can see the power is transmitted. Now the power tiller has been started, and the chopper is in operation. So, the unit which you are seeing is a torque transducer, just mounted to measure the torque requirement. So, now here he has just operated the telescopic shaft. Now he is operating the entire unit. So, the front portion is trying to chop the onion leaves. On the rear side, you can see the blade is digging up the onion bulbs, then the onion bulbs are moving through the conveyor, a rod-type conveyor, and they are falling along with the soil clods. So, this is the field operation. Now you can see during transportation, you can see the telescopic unit has been raised - it has been raised. So, that it does not hit during transportation or during turning at the bunds, which are provided at the end of the field. So, this is possible by utilizing the linear actuator. And then these are the onion bulbs, which are dug out from the soil surface, and after chopping, they are falling on the ground.

So, then I will give you the performance parameters which were observed during the field test. We tried with a field size of 0.6 meters $\times$ 10 meters. We have carried out several replications, and then the moisture content of the soil was 11.84 ± 1.05 per cent. The bulk density of the soil was 1522 kg per cubic meter. The operating width was 600 millimeters, and the depth of digging we carried out was 70 millimeters. The height of cut above the neck - this is above the onion bulbs - the vertices left, that is, this value, 43 millimeters. So, what we observed is a topping efficiency of 82 per cent and a digging efficiency of 92 per cent, with a damage of 10 per cent. So, the actual field capacity varies from 0.042, if you are operating in first gear, then it is 0.042; if you are operating in second gear, it is 0.040. That means roughly the field capacity is 0.04 hectares per hour with a field efficiency of 65 per cent, 50 per cent - roughly around 55 to 60 per cent is the field efficiency. This field efficiency is low in the sense we have to operate the telescopic shaft and during turning we have to raise it. So, that takes some time. So, more is the time lost due to raising or lowering of the telescopic shaft. So, we are reduced, the field efficiency is reduced. And forward speed was only 0.83 kilometer per hour and wheel slippage was 21 per cent to 26 per cent.

Now, the fuel consumption was 0.993 liter per hour to 1.116 liter per hour. So, these are some of the observations like what is the total torque and power requirement for cutting. So, what we observed is torque requirement is 2.64 Newton meter and power requirement is 495 Watt. The value of draft, actual speed and power required for propelling while carrying out digging at a rake angle of 21 degree and at a depth of 70 millimeter they are found to be 703 Newton, 0.257 meter per second and 181.2 Watt is required for propelling. The absolute torque and total maximum torque required for conveying in first gear, it was 10.3 Newton meter, 11.76 Newton meter at a rotational speed of 112.66 rpm of the conveyor roller shaft. Similar values for second gear were found to be 19 Newton meter and 21 Newton meter at a rotational speed of 165.51 rpm. The higher torque and power requirement in second gear was due to higher rotational speed of the conveyor roller shaft. Hence, frequency of oscillation was more due to the agitators provided in the conveyor roller. So, that resulted in higher torque requirement. So, higher power requirements at higher frequencies were observed because greater torque inputs were required to overcome the inertia forces, which increased with the operating frequency. So, this figure will give you an overall idea of how much power is consumed for topping, propelling with digging, digging without conveying, and digging with conveying in first gear and second gear, as well as the total power requirement in first gear and the total power requirement in second gear. So, the total power, if you look at it, is 0.8 kilo Watt in first gear and 1.1 kilo Watt in second gear, which is quite acceptable in the sense that the power tiller can easily handle this kind of equipment for carrying out the harvesting of onion crops. The power requirement for topping, propelling with digging, and conveying in the fast gear of the rotor shaft of the hand tractor was found to be 25.5 per cent, 9.34 per cent, and 16.07 per cent of the total power available from the hand tractor, respectively. The same figures for the second gear are 25.53 per cent, 9.34 per cent, and 29.12 per cent. So, the total power required by the conveying unit in first and second gear is 807 Watts and 1060 Watts, respectively. So, it is the conveying unit that basically requires more power compared to the chopping unit.

These are some of the references, and finally, I can say we discussed an onion crop digger unit that has been developed at IIT Kharagpur. We discussed what are the different components available or required to carry out this onion topping and digging. Then, we discussed how it is fixed to the power tiller, and its field performance was also discussed. And the total power requirement was discussed.

Thank you.