Design of Farm Machinery

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Lecture 52 : Numericals related to cutting by impact and shear

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. I will cover some numerical problems related to cutting by impact. The concept is the design aspects we discussed are to be solved by taking some examples. So, that will give you some more clarity.

The forward speed - forward velocity V is 5 per cent of the peripheral velocity for a rotary mower. Determine the maximum oblique angle φ_{ob} and the blade angle theta at which it occurs. To maximize the oblique angle, φ_{ob}, you need to differentiate with respect to θ. Now, the expression for tan φ_{ob}, is: $\tan \varphi_{ob} = V\cos\theta/(V_p - V\sin\theta)$. So, this has to be differentiated with respect to θ. Now, I can write this as $[(V_p - V\sin\theta) \times d(V\cos\theta)/d\theta - V\cos\theta \times d(V_p - V\sin\theta)/d\theta]/(V_p - V\sin\theta)^2$. You have to maximize this, meaning after differentiation, this side should be equated to 0. Now, if I simplify this, it becomes $[(V_p - V\sin\theta)(-V\sin\theta) - V\cos\theta\,(-V\cos\theta)]/(V_p - V\sin\theta)^2$. So, now, this will be equal to $- V_pV\sin\theta + V^2\sin^2\theta + V^2\cos^2\theta$. So, this should be divided by $(V_p - V\sin\theta)^2$. So, this should be equated to 0. So, that means, so this $\sin^2\theta\ \cos^2\theta$, so, this becomes V^2. $V^2 - V_p \times V\sin\theta = 0$. V cannot be zero. So, the other component will be $(V - V_p\sin\theta)$ is 0 or $V = V_p\sin\theta$ or $\sin\theta = V/V_p$. So, this is nothing but is given as 5 per cent. Sign of this one is this. So, $\theta = \sin^{-1}(V/V_p)$. $\theta = \sin^{-1}(0.05)$. So that way we are getting 2.86 degree.

Then the second one is estimate the power requirement of a disk type rotary mower which has 6 disks with 4 blades in each disk and each has a cutting width of 0.4 meter with an overlap of 4 per cent between adjacent disks. The blades are sharp and the travel speed is 15 kilometer per hour assuming the specific power loss at 1.5 ah as 1.5 kilowatt per meter of disk and specific cutting energy as 1.7 kilo joule per meter square.

So, first we have to find out what is the cutting width. There is an overlap of 4 per cent. So, the cutting width - the actual cutting width will be equal to, if there is no overlap, then there will be 6 disks, 6 multiplied by 0.4, which will give you 2.4 meters. Since there is an overlap, I will deduct the overlap amount, which is nothing but 0.04, meaning 4 percent of 0.4, and there will be 5 such overlaps. So, that is how we calculate it. So, that comes to 2.32 meters. So, this will be the cutting width.

Now, to find out the power requirement of a rotary mower. So, the rotary mower's power requirement, is equal to the power loss - the specific power loss, if you denote it as P_s multiplied by W, the cutting width, plus the specific cutting energy multiplied by the forward speed and W, the width, i.e., $P_T = P_s \times W + E_{sc} \times V_f \times W$. So, if I take W outside, then it becomes $P_T = (P_s + E_{sc} \times V_f)W$, Now, P_s is given as 1.5 kilowatts per meter. So, 1.5, and the E_{sc} is given as 1.7 kilojoules per square meter. So, 1.7 multiplied by the forward speed, which is given as 15 kilometers per hour. So, I can convert it to 15,000 divided by 3,600. So, this multiplied by 2.32 will be - so that way, you will get 19.913 kilo Watts. So, basically, we need to find out the cutting width that is important -what is the effective cutting width? From there, we have to calculate the total power requirement. The equations are available. The specific cutting energy multiplied by the forward speed and the width of cut will be the actual cutting power, and this will be the idle power or the frictional power.

Consider a disk type rotary mower that has 6 disks, each cutting a width of 0.4 meter. The mower is travelling at 15 kilometer per hour. The specific power loss due to Air, stubble and gear train friction is 1.5 kilo Watt per meter of cutting width and specific cutting energy is 1.5 kilo Joule per meter square when the blade is sharp and 2.1 kilo Joule per meter square when the blade is worn out. Then estimate the PTO power requirement if the blades are sharp and also estimate the PTO power requirement for the same mower after the blades become - blades become worn. So, the total PTO power, P_{PTO}, I can write as $(P_{LS} + E_{SC} \times V_f)W$. W is the width.

So, here width is - since there is no overlap, so, width I can directly calculate, W_C is equal to 6 disks are there, 6 into 0.4. So, 2.4 meter and next is what is given? E_{SC} is given, forward speed is given and P_{LS} value is given. Specific cutting energy is given for sharp blade is given for worn out blades. And the loss, the specific power loss to overcome the air, stubble and gear train friction that is given as 1.5. So, PLS value is given as 1.5 kilo Watt per meter. Now, E_{SC} value for first case is it is a sharp blade. So, you have to take the E_{SC} value as 1.5. So, $(1.5 + 1.5 \times V_f)W_c$, V_f is 15 kilometer per hour. So, by 3600 into W_C is 2.4. So, this will be the power requirement when the blade is sharp. So, that way it gives 18.6 kilo Watt.

Now, for the second case, when the blades are worn out. So, P_{PTO} will again be this value, this 1.5 value - the specific cutting energy is to be changed. Friction - this friction power remains the same. So, I will take 1.5. Instead of 1.5 for specific energy; I will take 2.1. So, E_{SC} has $2.1 \times 15000/3600 \times 2.4$. So, that way we are getting 24.6 kilo Watt. So, that means, when the blade is worn out, you can see the difference, how much is the power difference? So, the equations which we developed have to be given for sharpened blade and for worn-out blade; then only you can see the difference, otherwise you cannot visualize the difference. So, this way you have to calculate the power requirement, PTO power requirement for carrying out mowing with a disk-type mower when the blade is sharpened and when the blade is worn out.

Then comes a self-propelled vertical conveyor reaper, which is to be used for cutting wheat at a working speed of 1 kilometer per hour. Assuming the inclination of the star wheel to be 30 degrees, outer and inner diameter to be 21 and 16 centimeters, respectively. The number of arms on the star wheel are 7, and 10 per cent is the slippage between the star wheel and lugs of the conveying belt, then determine the following. Following means you have to find out the velocity of the star wheel, then the pitch of the lugs on the vertical belt, then the rotary speed of the belt pulley for moving the belt, if the driving pulley of the belt is 0.12 meter.

So, as you know, in a vertical conveyor reaper, the velocity of the star wheel, that means V_s, is not horizontal or vertical; it is kept at a certain angle, and we know that the speed should be greater than the forward speed. So, $V_s\cos\alpha$, if the star wheel is inclined at an angle α. So, $(V_s\cos\alpha/V_m) > 1$. You can take it as 1.2, 1.1 does not matter, but it should be higher than that. So, the minimum velocity should be equal to. So, $V_s = V_m/\cos\alpha$ - that is the case minimum - this is minimum. So, V_m is given as 1 kilometer per hour, which will be roughly around 0.27 meters per second divided by cos30. So that way, you have to find out the speed of the star wheel, which comes to 1.75 meters per second.

The next question is the pitch of the lugs, the pitch of the lugs on the vertical belt. So, to find out the pitch of the lugs in one revolution of the star wheel, the number of fingers should touch the lugs, which are present on the conveyor belt. So, if the pitch of the lugs is $p_i \times N_s = \pi D_s$. So, D_s means the outer diameter, and the outer diameter is given as 21 cm. So, $\pi \times 21 = p_i \times N_s$, where, p i is the pitch; N_s is the number of fingers, which is given as 7. So, $p_i = \pi \times 21/7$. So, 3π, which is equal to 94.24 millimeters - that means 9.4 centimeters. This will be the pitch.

Now comes the rotary speed of the belt pulley for moving the belt. Rotary speed means the rpm. What is the rotational speed? So, to do that, we have to first find out what is the belt speed?. So, the belt speed should be - in ideal conditions, the same as the speed of the star wheel because the star wheel is in contact. So, the belt speed and star wheel speed should be the same, but since there is slippage, there is a point contact. So, there is a possibility of slippage. So, you can take the belt speed to be 10 per cent more than the speed of the star wheel. So, in that case, the speed of the star wheel you have calculated is 1.75 meters per second. So, the belt speed should be equal to 1.1 times 1.75 meters per second. So, that will be the belt speed. So, that comes to 1.925 meters per second. Now, the rotary speed - what is the pulley which is provided? So, π d N/ 60. So, that should be equal to 1.925 meters per second. So, d is given as 0.12 meters. So, N will be calculated as $1.925\times60/(\pi \times0.12)$. So, that way, it comes to 306.67. So, this will be the rpm of the belt.

So, here you have to make some justifications like what should be the forward speed and star wheel speed those are to be fixed first. So, that will give you the first answer. Next is how many number of fingers are present in the star wheel, because the number of fingers will decide what should be the pitch, pitch of the lugs which are provided in the conveyor belt and the outer diameter. These two - number of fingers and outer diameter will decide what should be the pitch of the lugs. Then third one is, it depends what is the nature of contact, contact is proper or not. So, that will decide what will be the loss. But in all practical purposes - for all practical purposes, we have taken this as 10 per cent. So, that we have calculated.

In a vertical conveyor reaper with a cutting width of 1.2 meter is used to carry out harvesting of paddy crop at a forward speed of 1.2 kilometer per hour. The hill to hill spacing of paddy crop is 20 by 20 centimeter and average hill diameter is 26 millimeter. If specific cutting energy is 0.065 joule per millimeter square, find the total power required for cutting paddy crop. Assume power required for conveying and frictional power lost in operating the cutting unit is 50 per cent and 10 per cent of the power required for cutting, respectively.

So, what we have to do is, first we have to calculate the power required for cutting. So, once you calculate that one, then 50 per cent of that is your conveying and 10 per cent of that is to overcome the idle power, which will take care of the fictional losses. So, power requirement for cutting - for that we have to use the specific cutting energy. So, specific cutting energy that means, power required for cutting, $P_{cutting} = E_{SC} \times A_s$ - area of stem per unit area covered by the harvester. So, unit area covered by the harvester is width of the harvester into forward speed of the harvester. So, this has to be multiplied with a coefficient 0.998. So, I am not taking 0.998. So, directly I am taking as 1. So, E_{SC} is given we have to calculate this A_S value, stem area. So, for calculating stem area, you have to first find out in 1 meter square how many hills are present. So, hill to hill spacing is given as 20 by 20 that means, each hill is covering this much of area. So, this is 400 centimeter square. So, I divided by 10,000. So, that becomes your meter square. So, in 1 meter square, how much is the number of hills? So, this 1 divided by this. So, it comes to 25. So, in 1 square meter area, the number of hills are 25. Now, we know the number of hills, then the stem area. For calculating the stem area, we need to know either the number of stems which are present in each hill or the average diameter of the hill. So, what is given is : the average diameter of the hill is given. So, the total stem area will be in 1 meter square - per meter square will be 25 $\times \pi/4 \times$ hill diameter^2 - the hill diameter is given as 26 mm. So, this will be the area - stem area per meter square. Now, this has to be multiplied by W and V_f. So, $P_{cutting} = 0.065\times25\times(\pi/4)\times26^2\times1.2\times1.2\times1000/3600$. So, this is in joule per millimeter square, this is in millimeter square. So, millimeter square, millimeter square will cancel out. So, joule, meter square, meter square will cancel out here. Here, this is per meter square, and here this is in meters, this is in meters. So, meter, meter square will cancel out. So, joule, joule per second. So, finally, we will get a value in joule per second. So, which comes to - if I multiply this coefficient 0.998 to be more accurate, I can take this, or else I can directly take 1. So that way if I multiply, it comes to 344.41 Watt So, this is how you have to calculate that means, basically we have to find out the stem area that is important. Stem area can be computed either if you know the hill spacing and the average hill diameter or hill spacing and the number of stems and diameter - average diameter of each stem is known, then you can find out total stems present. The total stem area per hill and then multiply with number of hills that will give you the total stem area or average hill diameter, if is known, so directly you can calculate the stem area per unit area - per meter square. And you know how much area is covered by the machine per unit time. So, that will give you this many stem area which has to be cut and the specific cutting energy is given. So, just multiply that will give you the power requirement.

Now, this is the power requirement for cutting. Now, this has to be added with power requirement for conveying and power requirement for overcoming friction This value which you are getting is 344.41 Watt. Now, 50 per cent of this is for conveying and 10 per cent of the power is required for overcoming the frictional power. So, 50 per cent, so

0.5 of this P_c and 0.1 of this P_c that will be for conveying and overcoming the frictional power plus P_c for cutting. So, 0.5 P_c + 0.1 P_c + P_c this will be your total power. So, that means, 1.6 times P_c. So, this value which you got is P_c and I multiply with 1.6. So, that way you are getting 5501.056. So, that way we are getting this in Watt. So, 0.550 kiloWatt is the final answer.

Next, during the cutting of a forage crop with a stem diameter of 15 millimeters by impact force, it is loaded horizontally at a height of 30 millimeters above the ground. The mass of the plant above the cut is 0.02 kg, and the knife speed is 4.2 meters per second. The CG height of the cut plant above the plane of cutting is 30 millimeters. Calculate the force applied by the knife causing failure if the ultimate tensile strength of the forage stem is 35 Newtons per square millimeter.

So, first, we have to calculate the bending resistance. So, bending resistance, if you find out, is nothing but the resistance offered by the plant when force is applied. So, for calculating that, we need to know the ultimate strength of the material. So, ultimate strength (stress) will be equal to bending moment multiplied by Y divided by I. So, bending moment will be - suppose F_x multiplied by the height above the ground. So, that will give you L, and L is 30 mm. So, 30. This will give you the bending moment, and Y is nothing but your diameter divided by 2. So, the diameter is 15 millimeters. So, 15 divided by 2, and the moment of inertia is assumed to be a solid circular section. So, $\pi d^4/64$. So, d is nothing but 15 mm. So, $F_x \times 30 \times 7.5/(\pi \times 15^4/64)$. 64. This would be equal to your SU - is given as 35 Newton per millimeter square. So, now, from here we will find out the value of F_x which is nothing, but F_b, this has to be supported - this much force has to be supported by the plant that means, this is the bending resistance. So, this way it comes to 386.56 Newton.

Now what is asked is to find out what is the cutting force applied when the blade is rotated at a knife speed of 4.2 meter per second. So, the knife is rotated at 4.2 meter per second. So, we know $V_k^2 = (F_x - F_b)Z_c \times \frac{d}{[(Z_c+Z_{cg})\times m_p \times 1000]}$. V_k, knife speed in meter per second, Z_c is the plane of cut from the ground which is given here as 30 millimeter. d, diameter of the stem this is in millimeter, Z_{cg} is the height of CG of the cut plant from the cutting plane in millimeter, m_p. mass of the crop which is cut. Now, in this equation, V_k is known. F_b we have just now calculated, Z_c is given, Z_{cg} is given and diameter is 15 mm given, mass of crop cut is given as 0.02 kg and utilizing this equation, we can find out $(F_x - F_b) = V_k^2 \times \frac{[(Z_c+Z_{cg})\times m_p \times 1000]}{Z_c \times 15}$. So, $F_x = F_b + V_k^2 \times \frac{[(Z_c+Z_{cg})\times m_p \times 1000]}{Z_c \times 15}$ So, that way we are getting this term as 47.04 Newtons, and F_b, just now you calculated, is 386.56. So, the summation of this will give you 433.6 Newtons. So, this much is the force which is applied to the plant to cause cutting by impact at a height of 30 millimeters from the ground.

So, we have solved a good number of problems. These are some of the references, and whatever I have discussed in the previous class, those equations are utilized, and that will give you a clear idea of how to find out different operating parameters while designing a vertical cutter reaper or a rotary mower.

Thank you.