Design of Farm Machinery

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Lecture 49 : Components of harvesting equipment with shear cutting

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 49, where I will try to cover design aspects of components of harvesting equipment with shear cutting. The concepts which will be covered: components of harvesting equipment with shear cutting, then how to design or what are the design considerations we have to take for reel as well as cutting unit. Cutting unit means the knife.

Now if you look at the figure, these are two harvesting machines or equipment, which are used for harvesting cereal crops. So, as I said these are - these machines are used for cereal crops. So, we cannot go for impact cutting. So, regarding impact cutting we have been discussing in last two classes. So, today I will try to discuss about shear cutting, where cutting takes place because of the shearing action.

The major components are reel or the feeding unit, feeding unit for the crop to be cut, then cutting unit and conveying unit. So, if you look at the vertical conveyor reaper these reels or the star wheels, so, each one of the star wheels will be provided to accommodate one row. So, star wheels here will be for feeding the crop and then and below there will be the knife which will be reciprocating and the third one is conveying unit which will convey by this lugged belt. After cutting, the cut crops will be conveyed and it will be dropped on one side in windrow. In case of a combined harvester, the reel is this one, which is mounted in the front with axis perpendicular to the direction of travel and then below that there is cutter bar. So, the reel will feed the crop to the cutter bar. The knife will cut and then augers are there to feed the crop to the threshing unit. So, this is how cutting takes place in case of vertical conveyor reaper or combine harvester. If you look at the reels in case of a combine harvester, you can see the axis is perpendicular to the direction of travel whereas, in case of vertical conveyor reaper, they are horizontal. When you operate, they are at certain angle to the horizontal. So, that is the difference. It is rotated about an inclined axis whereas, it is rotated about a horizontal axis.

So, let us now discuss about the reel which is provided with a combine harvester. That means, a circular reel over which the bars are provided. So, the reels have to be rotated so that it can push the crop towards the cutter bar. So, when it is rotated that means, the machin, the reel is also attached to the machine so that means, it will not follow a circular path rather it will follow a cycloid. You can see these are the path - the dotted lines are the path which will be traced by different numbers here. Suppose this 1, 2, 3, 4, 5, 6, 7 - these are 8 - these are reel bars so they will follow this path. So, from the discussion what we conclude is that the reel has to move or push the crop towards the cutter bar, that means the speed of the reel should be greater than the speed of the harvesting equipment. We will come later how much higher than the forward speed of the harvesting equipment, but it should be higher than that.

Then reel shaft is usually kept 150 to 300 millimeter ahead of the cutter bar. So that it can easily push towards the cutter bar - the crops And the reel radius in practice varies from 500 to 800 millimeter with a number of bars varying from 5 to 6. Now, if you look at the dotted line which is given by a circle that means, the real is rotating about the center O. Now, during time t, O has occupied a position O_1 and if you look at the bar which was there at point A, now it has come to touch the crop. So, we want that when the bar touches the crop, at that point there should not be any horizontal component of that velocity.

So, that is our requirement. So, let us now see that during time t, the bar has moved from A to A_1, and at the same time, the machine is moving forward. So, the center of the reel has also moved from O to O_1. Now, if you come back to the other position O_2, then you can see that the bar is pushing the crop toward the cutter bar. The cutter bar is here, and this is the ground. So, now, you have to find out the coordinates of the point A_2. So, the x and y coordinates, the x will be equal to OO_2 plus the component of this one. So, $X = OO_2 + R\cos\omega t = V_m t + R\cos\omega t$, where, ω is the angular speed, and if V_m is the forward speed of the machine, then $V_m \times t$ will give you OO_2. That means, during time t, O has moved from O to O_2. So, this is the final expression for the x-coordinate. Now, the y-coordinate will be: if you look at this figure, capital H is the height from the cutting plane. This is the cutter bar. From here, the center of the reel is at a height H, and small h is the height of the cut. That means, from the ground, at what height the cutting is carried out—that is small h. So, H + h, that small h means the distance from the center to the ground, but actually, A has moved to A_2. So, this minus R sin omega t becomes $H = L - h + R\sin\omega t$.

Now, what is the velocity? Now, if you know x, dx/dt will give you the velocity, and the velocity will be equal to - if you differentiate this with respect to t, we will get $\frac{dx}{dt} = V_m -$

$R\omega\sin\omega t$. Similarly, for y, $\frac{dy}{dt} = -R\omega\cos\omega t$. Now, in order to push the crop toward the harvester, we want that this $V_m - R\omega\sin\omega t$ should be less than or equal to 0. If it is more than 0, we do not accept it. It should be at least equal to 0. So, that means $V_m = R\omega\sin\omega t$. So, we define a terminology called the reel speed index. So, it is the ratio of the peripheral speed of the reel to the forward speed of the harvester, and from the design point of view, this value should be between 1.25 to 1.5.

The main aim is to push the crop towards the cutter bar. So, now, if somebody says, I will keep it 1.5 or more than 1.5, yes, he can keep it. The only problem is there will be shattering loss because when you want to increase the peripheral speed, the bar will strike the crop at a higher speed. So, that may create some shattering losses. So, to avoid that, this is the range which has been given. Now, $V_m - R\omega\sin\omega t$, if I write in a different way, $V_m = R\omega\sin\omega t$.

So, for a given radius and given angular speed, you can say omega R is constant. So, I can write it as $\sin\omega t$. Now, to find out the height of reel positioning - why do you require the height of reel positioning? So, this one I can write as $\sin\omega t$ is equal to $V_m/R\omega$. This ωR is nothing but the peripheral speed, So, $\sin\omega t$, I can write as $1/\lambda$, where, λ is the reel speed index.

So, that way I have derived it. Now, we have to have a provision for varying the height of the center of the reel because the crops are not of the same height. It varies from variety to variety, the variety of crop. And the fields are not also at a level ground; they may have some undulation. To take care of this, we have to have some provisions to vary the height of the reel. So, that is why I am deriving now: the height of reel positioning will be equal to H. H is the distance from the cutter bar where you try to cut the crop. That will be equal to now I have converted it to in terms of length of the - the height of the crop which is denoted as $L - h + R\sin\omega t$. So, this will be the height. Now, what is the maximum height? So, if I want to express in terms of reel speed index, then I can write as $H = L - h + R\sin\omega t = L - h + \frac{R}{\lambda}$, because just now you derived $\sin\omega t = \frac{1}{\lambda}$. So, that means, height of reel is dependent on the length of the crop, it is dependent on the height at which you carry out cutting, it depends on the reel radius, it depends on the reel speed index. So, these are the parameters which will try to - which will try to influence the height of positioning the reel. Now, what will be the maximum position? $H_{max} = L_{max} - h_{min} + R/\lambda_{min}$. and what is minimum height? $H_{min} = L_{min} - h_{max} + R/\lambda_{max}$. So, this is the range we have to provide and while designing we should keep this in your mind that yes there should be provision to vary the reel height.

Next important component is the cutting unit actually, cutting unit as I said in case of a shear cutting we have to use the reciprocating knife, the knife has to reciprocate that means, to and fro motion. So, the knives are riveted to a bar which is called cutterbar. So, cutter bar consists of two basic components. A movable bar to which are riveted the knives, the knives are usually in trapezoidal shape. If you look at this one as I draw a dotted line here these are knives. ok and this has to reciprocate on a horizontal plane. And to protect the knife from external obstructions we have to provide a guard or the finger. So, a stationary bar to which are attached with screws what are called fingers that means, the fingers have opening. In that opening, the cutter bar will reciprocate - the knife will reciprocate. The knife reciprocation is possible by taking power from a slider-crank mechanism. That means, the rotational motion has to be converted to reciprocating motion. Now, I am showing you the cross section of a cutterbar, where you can see this black edged one is your knife, the lower one is the countershear or the ledger plate. And the front triangular portion is called the guard at the finger, then there is a knife clip.

The knife clips are provided at regular intervals along with the wearing plate. The purpose of providing knife clip is to maintain the gap between knife and the ledger plate. And the purpose of providing this wearing plate is to give support to the knife. So, let me give you some more information. The tapering fingers, which will separate the cut material into portions which are to be cut by individual moveable knives. That means, it will distribute the crop to different sections of the knife.

So that the knife will get more or less uniform crop material for cutting. Then the lateral sides of the fingers, they constitute the counter cutting edge of this for the shearing action. The ledger plate is that counter cutting edge. Ledger plate is riveted riveted to the fingers, but the ledger plate is not moving, it is stationary. Knife is only moving. The finger guards have cut outs in which the knives hide at instantaneous extreme positions or through which they pass. So, at each end of the stroke, the front portion of the knife will be hiding in that guard.

The knife clips are provided at regular intervals and are fixed with screws to the finger bar to maintain the tightness of the knives and the gap between the laser plate. The wear plates provide vertical support to the rear of the knife sections and also absorb the rearward thrust of the knife. Now, let us see what different cutter bars are available. Usually, cutter bars are of three types: the standard cutter bar or conventional cutter bar, the low-cut type cutter bar, and the medium-cut type cutter bar. These are the three cutter bars available.

Now, let us see what the difference is between these three. The first cutter bar, which I called the standard cutter bar, has a stroke length of 76.2 millimeters or 76 millimeters. That means, in one stroke, from this point to this point, the distance is 76 millimeters. So, when moving from this point to this point, the knife will align with the centerline of the knife and the center of the guard, which is called registration. The spacing between fingers and the stroke length are the same.

However, in the low-cut type cutter bar, the stroke length is the same (76.2 millimeters), but instead of two guards, there is an additional guard. That means, between these two guards, there will be one more guard. So, the stroke will again be divided into two parts: 76.2/2. This means there will be more or less uniform feeding to the knife. So, the crops will not accumulate. So, knife will have sufficient space to cut.

Then the last one which is the medium cut type cutter bar, there the spacing is higher than the low-cut type cutter bar, spacing I am talking about between two adjacent fingers. This is higher than this a low-cut type cutter bar, but it is lesser than the standard cutter bar that is why I have indicated here as t is equal to 50.8 millimeter. So, these are some of the information which are available and depending on the crop density we can - we can have to choose what type of cutter bar is to be fitted. Then there are two adjustments I just said one adjustment, related to mower - two adjustments: registration and alignment, but alignment is not a valid adjustment for a vertical reaper or a combined harvester. The reason is the cutter bar is supported at both the ends at both the sides the cutter bar is supported. So, we do not require alignment only we require registration. Alignment is required only in case of a mower where the drive is taken from the PTO through a pitman. So, registration is nothing, but a knife is in proper register when midpoint of the stroke is centered between adjacent guards. If the stroke is the same length as the guard spacing, the knife sections are centered in the guards at each end of the stroke. That means, in one revolution of the crankshaft from where the power is given to the cutter bar, there will be one forward movement and then bringing back it to the origin. So, while moving forward or moving backward the center of the knife section should match with the center of the guard then only you can say it is registered or registration. Then alignment as I said alignment if you take a top view then the point at which it is connected to the pitman and the point at which the other extreme end - they are not in one line. So, the free end is little ahead of the point, where it is connected to the pitman. So, the reason is during movement, the outer end is not supported. So, there will be some deflection. So, during operation it will come to the same line as that of pitman side. So, that is why we have to keep a lead that lead is around

20 millimeter per meter of bar length. Now what should be the knife speed, whether the knife speed is constant or it is varying. So, if you look at the figure here I have indicated that knife speed is varying sinusoidally. I said it is 0, where it is just matching with the center of the guard there the knife velocity is 0, then it reaches to a peak and then again when it reaches to the next guard then the velocity is again 0. So, first stroke, second stroke. So, it is a sinusoidal type, but this is the case when the knife is reciprocating, but the machine is stationary, but in the field or during operation both knife is reciprocating and the machine is moving forward. So, what will happen, the path which is traced will be this path - is a curvilinear path not exactly a straight path. And the knife velocity if you know the peripheral speed of the crank which is denoted as V_0 at the point - this this point, then I can find out what is the knife speed when the machine is stationary only the knife is reciprocating. That in time t, this point has reached to this point that means, it is covering an angle an angle ωt. Now, the knife speed will be equal to V_{nz} will be equal to $V_0 \cos(90 - \omega t)$ that means, sinωt. Here, r is the - this is the crank radius and during movement - so, when it is moving, the machine is also moving forward during one stroke which is denoted here as h, the point has moved from this to this.

V_{km} that is - that will vary, vary during the cutting stroke. Hence, the coordinate system which will rotate about the z axis and the direction of V_{kg} varies. So, during the motion of the knife, now we will consider there are three conditions, one condition is when the knife is only moving - machine is stationary. So, the motion of the knife is alone relative to the field is stationary. When the machine is relative to the field is stationary.

So, in that case the velocity of sliding cut, V_t will be equal to $V_{nz} \sin\alpha$. V_{nz}, the knife speed and V_t is the component which will be acting in this direction. So, V_t will have - V_t is the velocity of sliding cut along the face of the blade. So, we are considering a point A here and there try to find out the knife velocity. Knife speed is V_{nz}. and this is considered as a function of path of X. If you look at this you can calculate V_{nz} from V_0, V_0 is the peripheral speed. Peripheral speed can be computed by knowing the radius and angular speed, ω, ωr. So, at a particular instant you can find out the V_{nz} value knowing the value of V_0. So, V_0 you know then from V_{nz}, V_{nz} you can calculate.

So, V_{nz} will be $V_0 \cos(90 - \omega t)$. So, that will be $V_0 \sin\omega t$. Now, V_0 is ωr. So, total will be $\omega r \sin\omega t$. V_{nz}, average velocity, average velocity of the knife can be calculated if you know the stroke length and the rpm of the crank which is causing the movement of the knife. So, if n is rpm, s is the stroke then 2 s n/60 that will give you the average speed. Now, if you look at this equation $\omega r \sin\omega t$. This V_{nz} is this one, now if I substitute in this equation for

V_{nz}. So, that becomes V_t, velocity of sliding cut along the face of the knife V_t will be equal to ωr sinωt sinα.

Now, this ωr sinα, this is constant - constant for a given blade and a given inclination of the knife face. So, V_t will be now equal to a constant A sin omega t here A, I can write as amplitude, amplitude of the harmonic motion because this is A sin omega t is nothing, but the sinusoidal motion. So, A is the amplitude.

Now the second case is the knife is stationary, now the velocity - the harvester is moving forward So, in that case V_m is the velocity. Now, if you want to find out the velocity of sliding cut along the face of the blade, then V_m will have two components: V_t' and V_n'. One is the tangential component V_t', and the other one is the normal component V_n', which is perpendicular to the face of the blade.

Now, when both - the third condition is: when both the knife as well as the machine are moving, that means the harvester is moving forward and the knife is reciprocating, then the resultant of V_{nz}, and the total normal components now becomes - because V_{nz} was having two components: the normal component V_n and the tangential component V_t. So, V_t and V_n. Now both V_n'and V_n are in the same direction. So, the normal component will be V_n'', which is equal to $V_{nz} \cos \alpha + V_n \sin \alpha$.

Now, the tangential component, if you look at which are parallel to the face of the blade, the V_t is acting downward and V_t' is acting upward. So, V_t ''double dash will be equal to $V_{nz} \sin\alpha - V_n \cos\alpha$. So, these are the components of the resultant velocity, which is denoted here. So, you can see V_t'' and then V_n'', and the resultant is V, which is making an angle τ with the normal component. Now, tan τ , which is nothing but the coefficient of sliding cut, will be equal to the tangential component by normal component, which is the ratio of these two.

So, when I divide the numerator and denominator by $V_{nz} \cos\alpha$, then I will get an expression: coefficient of sliding cut is equal to $\frac{\tan\alpha - V_m/V_{nz}}{1+\frac{V_m}{V_{nz}}\tan\alpha}$. That means the coefficient of sliding cut is a function of α, is a function of the forward speed of the machine, and is a function of the knife speed. So, three factors will decide what will be the coefficient of sliding cut? Our aim during cutting with a harvester is that this resultant sliding velocity V_t'' should always act towards the rear end - the rear end of the knife. So, to satisfy that one, the V_t should always be greater than V_t'.

So, the V_t is nothing, but V_{nz} sinα this should be greater than Vt' which is equal to V_m cosα. or tanα is greater than V_m/V_{nz}. So, α will be equal to, $\tan^{-1}\alpha$ should be greater than $\tan^{-1}(\frac{V_m}{V_{nz}})$. So, if you want that the crop should be fed towards the bottom rear end of the knife, then this condition has to be satisfied. So, this has to be taken into consideration while designing. So, from here you can find out what should be the slope of the face of the knife, so that the velocity of sliding cut is always directed downwards. Now, I will show you the cutting path, cutting path traced while carrying out the shear cutting.

Now, this is the cutter bar, this is the counter edge. Now, look at the point midpoint of the knife, cutting starts when this point matches with this point. If you look at this one now, the knife has moved so that this point is matching with the counter edge. So, the cutting starts here and it will continue along this line. How long? When this midpoint is again coming to this point which is the centre that means, this edge. So, the cutting takes place along this path E F. So, what it indicates that the crop which is present in this shaded area, they are all pushed towards the side of the counter edge and cutting takes place at this line. So, crops present here, here, here, here, here they are all pushed to this side. And the guard is also that is the ledger plate is also pushing the crop. So, this side - this side the right side crops are pushed by the ledger plate, the left side crops are pushed by the knife and cutting takes place along this line. So, if more crops are there then there is a possibility of slippage. So, in order to prevent slippage we have to have different types of cutter bar that we discussed in the beginning.

So, this is how cutting takes place and the different components of cutting. What angle has to be maintained? and what speed has to be maintained? So, that the reels can sufficiently and efficiently feed the crop for cutting. That is all.

Thank you.