Design of Farm Machinery

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Lecture 13 : Rotavator

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 13, where I will try to cover different aspects of rotavator which will be helpful while designing the same implement. The concepts which will be covered are components of rotavator, types of blade which are used in a rotavator, then what are the different modes of operation, then how to find out tilling pitch, then angles associated with rotavator blade, then the soil resistance force acting on the blade.

We have so far been discussing about passive tillage implements. Now, we will switch over to the active tillage implements. As the name says active tillage implements that means, the working elements are powered. So, tillage carried out by implements, where the working elements are powered unlike the mode board plough, disk plough and cultivator are called active tillage implements. For example, rotavator and powered disk harrow. The most commonly used rotary tillage implements are your tractor drawn rotavator and power tiller drawn rota-tiller.

So, in my discussion, I will try to concentrate on tractor drawn rotavator. The total power requirement of the implement - this active implement includes power requirement for cutting the soil slices, in throwing the soil slices and power requirement for propelling. So, it has to cut the soil slice, it has to throw the soil slice then the implement has to be propelled forward. Then power requirement for propelling is reduced in case of active tillage implements depending on the modes of operation. If it is in the concurrent mode that means, along the direction of travel then we may get some negative draft that means, a pushing force will be generated. So, that will help in reducing the total draft requirement of the implement to move forward. So, this figure shows a tractor drawn rotavator. If you look at this figure what are the components let us try to identify. First thing is, there is a gear box and this gear box should be connected to the tractor PTO and then power is coming from the PTO to this gear box through this side to the central shaft. which is the main shaft. So, this gear box, we call as speed reduction unit, then there is a main shaft, it is a circular one. Over the shafts you can find gangs of disk are mounted. So, there will be 1, 2, 3, 4, 5, 6, 7, 8, 9. So, 9 disks are there and on those disks, there will be blades, a group of blades which will be arranged. Then this blade's shape may change depending on the soil condition. You may use L type, C type. So, all those things we will discuss. Then there is a shield at the back side. So, that it prevents the soil from throwing away and at the same time it will, it will level the ground after tilling. Then, there is a depth adjusting skid. These two are the depth adjusting skids. So, this is the main shaft over the shaft there are gangs of disk are present - the gangs of disk with blades are present. Then these are the gear boxes for reducing the rpm, then on the back side there is a shield. So, these are all different components - major components. So, this figure shows how a tractor is connected to a rotavator, so that it gives the powertrain. Powertrain means, how the power is transmitted from the tractor to the rotavator. So, if you look at this one, this first bigger dotted rectangle is nothing, but your tractor front wheels, rear wheels in between engine transmission and differential, then the PTO. And, then the other block, this is your rotavator. Rotavator has 2 gear boxes primary gear box, secondary gear box, then this gear box is to be connected to the tractor with the help of a cardan shaft to transmit power from the PTO to the rotavator axis or rotavator shaft. Now, the blades which are mounted in - I have said that the blades are mounted to a disk there will be several such disks and in each disk there will be two gangs of blades. One gang is oriented in one direction, the other gang is oriented in the other direction. So, the blades could be different shapes it could be L shaped, it could be C shaped, it could be J shaped and the blades are made up of high carbon steel or chilled cast iron. Let us now see the L shaped blade where you want to use - that is for wetland and trashy soil conditions, but it does not pulverize well. If you are utilizing L type blade then you may not get better pulverization. A ‘C’ shaped blade is for dry land and a J shaped blade is for grassy land. So, if the land is grassy then you can go for J type blade. So, beside these blades, a straight type of blade is also used on mulches and is design mainly for secondary tillage and to conserve the soil moisture. So, in brief we can say we have different types of blades like L, C and J and these blades are mounted to each disk present in the shaft.

The next main component is your main shaft, shaft on which the blades are mounted with the help of disk. The shaft is made up of carbon steel and to this shaft the blades are mounted in gangs. Then the primary speed reduction unit. The main function of this unit is to transmit tractor power to the second speed reduction unit. Why we require a speed reduction unit? that is the first question, because we need to transmit power from PTO to the shaft - rotary shaft. So, the PTO RPM is usually 540.

So, when 540 RPM is maintained, we do not require that much RPM of the shaft. From the literature what we found that the RPM requirement is 200 plus or minus 10 RPM. That means, shaft - rotor shafts rotate at an RPM either 210 or it rotates at 190. So, to meet that rpm requirement or the speed requirement, we need to reduce the rpm which we receive from the PTO. So, that is why we have to provide some gear boxes.

So, at one step you may not do that. So, what we do is, we require first a primary unit, then you further reduce on the sides of the rotavator. This speed reduction - again there is a bevel gear. The first primary unit is a bevel gear because PTO shaft and the shaft of the rotavator they are at 90 degree. So, we need to have a bevel gear to transmit it at 90 degree. Then, the secondary unit, it is provided at the one side of the tractor rotavator. Either it could be chain and sprocket type or it could be spur gear type both are acceptable.

Then there is a trailing board or skid. The main purpose of this skid is to level the ground and at the same time it will not allow the soil to be thrown to a larger distance. Because, when these working elements are powered then it will try to cut the soil and throw it backward if it is in concurrent mode. So, to prevent that we need to have some kind of protecting unit. So, that is nothing, but your skid. And at the same time, the skid also helps in maintaining the level of the ground and it is made up of mild steel plate.

Then the the other component is your - the depth controlling unit which I showed in the diagram, depth adjusting skids, these are provided at the end. So, there are provisions, they are mounted to this rotavator with help of nut and bolt. So, if you lower it or raise it that is going to control the depth of operation of these blades.

Then let us see if you are considering a L type blade which is very common, how it is going to cut a soil slice and how the soil slice will look like that is important. So, if you look at this diagram, you can see the blades are mounted. There are holes provided which will be used for mounting the blade to the disk.

And there is an extension part. This part is going to cut the soil surface. So, you have to provide some angles here and it has a radius - rotor radius. So, L shaped blade - C is the chord - chord of the blade, then L is the vertical section height, this is a vertical section height and S is the horizontal section height or width you can say and b_t is the thickness, this is your thickness, R is the radius of the rotor. Now, when it strikes the soil surface, so there will be repeated striking. So, you will get a soil slice of this shape.

So, there will be 5 faces. Top face you can forget. The face will be A B E F - A B E F the front one, then face A B C A - A B C A side one cut by the vertical part of the blade and the face A B E F is cut by the span of the preceding blade. then face A C D F - A C D F, the back side that is cut by the horizontal part of the blade and then F E D F - F E D F, this is the soil surface sheared from the uncut soil body. So, depth is given. Width is W and this you call tilling pitch. So, roughly you can say this soil slice volume can be equal to V. if I say volume of soil slice V can roughly approximated as l into W into D, this is this can be approximated with a slight error.

The blades can be rotated in two directions, one is concurrent to the direction of travel - forward direction of travel which is called concurrent revolution mode. The other one is reverse mode which is opposite to the forward motion. So, when a blade is operated at a velocity - forward velocity V with a peripheral speed u. So, what we get is the shape of the slices which are given here in this figure in case of reverse revolution, in case of concurrent revolution. So, if you look at this, the shapes are not same. If you match the concurrent mode with reverse mode even if you keep u and V same for both the cases. So, you are not getting the same shape of soil slice, same is the case, when u/V is 5. u/V means u is the peripheral speed and V is the forward speed. So, when it is 2.5 you are not getting same shape, when it is 5 you are also not getting same shape, when it is 10 you are getting more or less same. So, this indicates that whether you operate in concurrent mode or reverse mode, they are the soil slices, the tilling pitch or the shape of the soil slice, they all depend on what is the ratio you are maintaining - ratio of u and V. So, now if you look at 2.5 and 10 that means, with increase in u by V ratio, the soil slice or tilling pitch is reduced. Why because, if you look at u/V, u is the peripheral speed when I said u/V is increased, what does it mean? So, u has to be increased V remains same, ok.

So, u increased means rpm of the rotor is increased, forward speed is remaining say around 3 kilometer per hour. If you rotate at higher rpm, then there will be more number of bites. So, there will be reduction in tilling pitch. So, when there is reduction in tilling pitch so, there will be more pulverization. So, it all depends what we need? whether you need more pulverization or whether you need lesser pulverization?

So, this will be controlled by u and V, these are the two parameters which will influence whether you want more pulverization or whether you want lesser pulverization. And then the tilling pitch is also dependent or the shape of the furrow slice is also dependent on the mode as I said. So, there are three factors now u, V and the mode of operation.

Then let us see the kinematics of blade soil interaction. The path traced by the rigid blade is a cycloid. The reason is the rotor is rotating at the same time it is moving forward. So, if you look at this figure, so, at time t, suppose you take a time t during that time the blade has rotated by an angle say alpha 0 and at the same time the machine has moved forward. So, the x coordinate will be $Vt + Rcos(\omega t)$. So, where ω is your angular speed of the rotor and **α** is the angle which the blade has moved during time t and V is the forward velocity. So, that way you are getting a value $X = Vt + Rcos(\omega t)$. Now, the vertical component will be $Y = Rsin(\omega t)$, where R is the rotor radius or radius of the working set.

For a rotary cultivator with rigid teeth as I said, the path traced will be a cycloid. So, you can see here path traced by the blade and the shape of the soil slice. The blade starts cutting the soil at an angle 20 degree. When α_0 reaches 20 degree in case of a concurrent mode, the blade starts cutting soil and it will continue up to 100 degree that means, the blade will remain inside the soil for a span of 80 degree. Then for rotary cultivator with rigid teeth and vertical axis, this is horizontal axis of rotation what I have discussed.

Now, if you go for vertical axis of rotation, then in that case, the blade will be in touch with the soil at minus 100 degree and then it will continue up to plus 100 degree, that is the duration. Now, in case of a horizontal axis there will be two modes of operation, one is concurrent mode the other one is reverse mode. The specification which I have given just now - for concurrent revolution. Now, for reverse revolution, it starts from 260 degree. The blade in case of reverse mode of operation comes in contact the soil at an angle of 260 degree, then it continues up to 340 degree. So, the duration is same whether it is concurrent mode, reverse mode, duration is 80 degree.

Now, the most important parameter is the tilling pitch, which will control what will be the degree of pulverization. Tilling pitch is less means more pulverization, tilling pitch is more means more lesser pulverization. So, tilling pitch is, how to define it - is the length of soil slice which is cut by the blade is called tilling pitch. And how do you express - that will be equal to $\frac{60 \times V}{n \times z}$. So, V is forward speed in meter per second and n is the rpm of the rotor. So, that is why, we want to convert it into second. So, we have divided by 60. So, that is why 60 is multiplied in the numerator just to convert rpm to rps, because V is in meter per second. Now, z is an important parameter, z decides how many bites will be there in one revolution in one direction. So, in the beginning, I said there will be two groups of blades, which will be attached to the disk. So, these two groups that means, one group is in this direction, if it is L shaped blade the other group is in this direction. How many blades are in this orientation? How many blades are in this orientation? So, that has to be taken as z. Usually we take z is equal to 2 to 4, but 2 and 3 are very common. 3 is the most common. So, that means, 3 blades will strike the soil surface on this direction, 3 blades will strike on this direction, left side right side for each disk. Now if you want to express - bring because we said peripheral speed has role.

So, in this expression peripheral speed is not coming, only the rpm - this rotor speed is coming. If you want to find out - the peripheral speed has some role in tilling pitch, then we have converted this equation just by multiplying 2 π R in the numerator and similarly n is there. So, when you multiply 2 π R that becomes your peripheral speed 2 π R n by 60 that gives you your peripheral speed u - peripheral speed of the blade. So, this expression is little more influencing in the sense it takes into consideration the rotor radius, it takes into consideration the forward speed, it takes into consideration the rotor speed that means, blade speed - blade speed means total unit speed and then z is the number of blades working in one plane. So, all factors are included here.

So, that is why this is a very important expression. Now, let us see, what are the angles associated with the blade, when the axis of rotation is perpendicular to the direction of travel. So, what I have done basically is - there is a circle here. So, this is the circle - rotor circumference you can say. When the blade is only rotating, then this is the path traced by the blade.

When the blade is rotating at the same time moving forward the path will be this one. These are called the trajectories. So, I have drawn two tangents here. So, this is the point, where the blade tip is located, suppose at a particular instant. Now, at that point, this is the blade - the black one is your blade, outer surface is sharpened Then I have drawn two tangents: one is tangent to the trajectory, this is called trajectory. This is called rotor circumference, this is called trajectory.

So, two tangents are drawn. Tangent to the rotary circumference - the outer one and tangent to the cutting trajectory the inner one. And there are a few angles which are indicated here. One is $\boldsymbol{\gamma_0}$. So, let us see now what is this $\boldsymbol{\gamma_0}$? and γ is the cutting angle, angle between the plane of the blade and the tangent drawn to the cutting trajectory - this one - this is gamma and the angle should be minimum 15 degree. Then setting angle $\boldsymbol{\gamma_0}$, this is little more than the cutting angle that means, γ + $\Delta\boldsymbol{\delta}$ that becomes $\boldsymbol{\gamma_0}$. $\Delta\boldsymbol{\delta}$ means the angle between two tangents. So, γ + $\Delta\boldsymbol{\delta}$ that will give you the angle between the plane of the blade and the tangent drawn to the rotary circumference.

So, one angle I have defined with respect to rotary - the trajectory, the other angle I have defined with respect to the rotor circumference. Then upper-end clearance angle which is denoted as delta, the angle between back surface of the sharpened edge and the tangent to the rotary circumference, this one, this is back surface. So, this is the line and the rotary tangent is this one. So, this angle is delta this is called upper-end clearance angle. Now, effective clearance angle - delta dash - this is the angle between the back surface of the sharpened edge and tangent to the cutting trajectory. So, delta dash this one.

Then path intersection angle - $\Delta\boldsymbol{\delta}$ - there is a difference between the angle between the tangent to the cutting trajectory and the tangent to the rotor circumference. Then the important angle is your β - angle of knife sharpening. So, angle of knife sharpening means face of the blade and the back side of the blade that is called beta. So, when I said cutting angle means $\beta + \delta'$. So, total becomes cutting angle which will be equal to γ and minimum cutting angle should be around 15 degree I said γ is 15 degree. So, $\boldsymbol{\gamma_0} = \boldsymbol{\gamma_{min}} + \Delta\boldsymbol{\delta_{max}}$. So, now, from this if I go to this point say tip of this blade or the working element - since the blade is moving forward because blade is attached to the implement, implement is moving forward, so, it has a velocity V - forward velocity V, which is equal to the velocity of the tractor. Then since it is rotating - the blade is rotating, so, it has a peripheral speed u. So, V and u these are the two speeds. So, the resultant speed is your u_s that is the cutting speed.

Now, $\Delta\boldsymbol{\delta}$ will be the angle between this tangent or the resultant of this V and u and the peripheral speed if you denote it as the $\Delta\boldsymbol{\delta}$. So, tan $\Delta\boldsymbol{\delta}$ will be equal to - if you look at the diagram - so, this is A, this is B, this is C. Say A B C is the - A C B is the right angle triangle. In the triangle tan $\Delta\boldsymbol{\delta}$ will be equal to BC/AC. So, BC is nothing, but V$\cos\boldsymbol{\alpha}$. The angle here is 360 $-$ $\boldsymbol{\alpha}$ because this angle is not $\boldsymbol{\alpha}$. I have taken this angle as $\boldsymbol{\alpha}$ after rotating $\boldsymbol{\alpha}$ I have taken this point.

So, this angle becomes 360 $-$ $\boldsymbol{\alpha}$. So, that is why it becomes V$\cos\boldsymbol{\alpha}$ that means this component divided by u $-$ V$\sin\boldsymbol{\alpha}$, because this this component is negative V$\sin\boldsymbol{\alpha}$. So, u $-$ V$\sin\boldsymbol{\alpha}$. So, in this expression refers to tan $\Delta\boldsymbol{\delta}$. So, here what you can see is $\Delta\boldsymbol{\delta}$ is a function of angle of rotation of the blade, is a function of u/V ratio, is a function of forward speed. Then to find out expression for cutting speed u_s which is nothing but the resultant of speed of the rotor and forward speed, then this will be the expression $u_s = \frac{u - V\sin\alpha}{\cos\Delta\delta}$.

So, again you take that right angle triangle A C B from there, $u_s \cos\Delta\delta$- u s cos del delta will be equal to u minus. That means, this AC is $u_s \cos\Delta\delta$ and this AC is we have taken from the peripheral speed side $u - V\sin\alpha$. So, u_s will be equal to - cutting speed =

$\frac{\left(\frac{u}{V}\right)-\sin\alpha}{\frac{\cos\Delta\delta}{V}}$. That means, the cutting speed is a function of again u/V ratio, it is a function of angle of rotation of the blade and then forward speed. So, if you further simplify this one, so this is the expression. Now, how $\Delta\delta$ is changing with **α** that we are going to discuss now.

So, with angle of rotation, how this del delta values are varying? If you look at this one this has been plotted for both concurrent mode and the reverse mode. Concurrent mode is this side, reverse mode is this side. So, cutting starts I said in concurrent mode at 20 degree. So, this is the place where the cutting starts and it continues up to 100 degree. So, this is the place.

So, how the del delta value is changing? It is changing with both - with u/V ratio and the angle of rotation. This x axis is your angle of rotation. So, what you observe here is - with increase in u/V ratio the $\Delta\delta$ value is decreasing, when it was 2.5 the maximum was say around 23 degree. So, when it is - say u/V ratio 10 or 20, so you are somewhere here. That means, from 23 degree we have come down to say 5 degree and when u/V ratio is 20, it is around say 2.5 like that.

This is for concurrent mode of operation. Same is the case with reverse mode. This reverse mode cutting starts at 260 degree. So, this is the place and it continues up to 300 - up to this. So, during this time again the del delta value - it is highest for u/V ratio 2.5 and as you increase u/V ratio then it is decreasing- decreasing. So, what you can say is : $\Delta\delta$ value if you want to reduce that means, you want to reduce the fluctuation, then fluctuation in cutting speed, then we should have higher u/V ratio.

Then how cutting speed is varying with angle alpha, angle of rotation for concurrent mode and for reverse mode. The left side shows the reverse mode, the right side shows the concurrent mode for different u/V ratios starting from 2.5 to 20. So, what we observe here is when the cutting starts, the cutting speed is maximum as we go towards the end that means, around 100 degree and the cutting speed is slowly reduced, ok. And this cutting speed increases with increase in u/V and in the reverse mode, the cutting speed is more than the concurrent mode. The reason is this **α**. sin**α** is negative in case of reverse mode that is why cutting speed is more.

So, whether it is in concurrent mode or whether it is in reverse mode, cutting speed is a function of u/V and the angle of rotation. So, because of the variation in cutting speed and there will be a change in the torque, torque which is acting at the shaft. So, details of this and what are the forces acting on the tip of the tool those will be discussed in the coming class. These are the references and in brief I can say we have discussed about the components of rotavator, then what is the mode of operation of the rotavator, angles associated the blades of the rotavator and then how the cutting speed is varying with different modes whether it is in concurrent mode. reverse mode - in brief we have discussed, that is all.

Thank you.