DESIGN OF FARM MACHINERY

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Lecture 14 : Soil resistance and specific work of the rotavator

Hi everyone, this is Professor H. Raheman. I welcome you all to this NPTEL course on Design of Farm Machinery. Today is lecture 14, where I will try to discuss about the soil resistance and specific work related to rotavator. The concepts which will be covered is soil resistance force due to cutting - cutting of the soil with the blades, then what is the specific work for a rotavator, then how to compute tilling pitch and how the tilling pitch varies with u/V ratio. As I said soil resistance force then let us see what is that soil resistance force.

When the blade is striking the soil surface it will experience a force. So, that force is related - is called soil resistance force. So, here I have indicated soil resistance force as K. So it is inclined, inclined to the vertical as well as the horizontal. So what is its importance? If you look at - the soil resistance is nothing, but offered by the soil during cutting and it can be computed as M upon R'. M means the moment, which is acting on the shaft because of the soil resistance - there will be moment and then if you know that moment or the torque then $M/R' = K$.

Now, the question is: what is that R'? Because the radius of rotation in case of a blade - rotavator blade is not constant. So, that radius changes. So, $R' = R \cos(\boldsymbol{\psi} - \Delta\delta)$. So, if you look at the torque versus alpha, alpha means angle of rotation. So then, I said the blade will be coming in contact with soil at an angle 20 degree and it will remain in the soil for an angle 100 degree. That means, between 20 to 100 degree, there will be torque after that there will be no torque, that is why we are getting a peak here and then slowly that peak reduces as it passes the soil. So, this will be a cyclic kind of thing.

So, the torque acting because of single blade I have indicated here. So, torque is changing. The simple reason is R' is changing and R' is a function of R, which is rotor radius that means, blade radius. And, that can be expressed as $R \cos(\boldsymbol{\psi} - \Delta\delta)$, where, $\boldsymbol{\psi}$ is - if you look at this figure, then $\boldsymbol{\psi}$ is nothing, but the angle between the soil resistance and the tangent to the cutting trajectory, this one. So, that is the angle $\boldsymbol{\psi}$. So, that $\boldsymbol{\psi}$, the minimum value you can take is 10 to 15 degree. This is the range, the $\boldsymbol{\psi}$ is varying.

So, if you know $\boldsymbol{\psi}$, if you know $\Delta\delta$ - $\Delta\delta$ is the angle between two tangents - tangent to the rotor circumference the lower one and tangent to the cutting trajectory as the blade is moving along with the tractor. So, there will be a difference. That angle is $\Delta\delta$ and last time we discussed about what is the role of $\Delta\delta$? So, R is a function of $\boldsymbol{\psi}$ and $\Delta\delta$ and K, which is the soil resistance, this is equal to M/R'. So, R' is changing because $\boldsymbol{\psi}$ is changing $\Delta\delta$ is changing. So, M is not constant, M is also not constant.

So, K is varying. So, if I resolve into two components, K as K_x, horizontal component and K_y as the vertical component. So, $K_x = K \sin(\alpha + \psi - \Delta\delta)$, this is the horizontal component which is going to affect the blade design. This is also going to affect the rotor shaft design. Similarly, the vertical force, which is Ky and $K_y = K \cos(\alpha + \psi - \Delta\delta)$. So, these two forces are to be determined, so that we can simply design the blade.

The vertical component is responsible for bending, bending of the shaft. Now, let us see how this peripheral force is varying because I said K, K is not constant. So, Soil resistance is not constant. Assuming that the blade is only rotating on the circumference then what will happen, the resistance force which is denoted as $K_0 = M/R$. M is the torque acting on the shaft because of the rotation of the blade then R is the rotor radius. So, M is a torque or rotor radius then this is how the K_0 is varying, varying with peripheral speed, u. K_0 is in the y axis. Peripheral speed in the x axis. So, what you can observe is: there is a peak value.

The moment it strikes the soil that becomes your peak value after that soil is disturbed. So, slowly lesser resistance will be offered by the blade. So, it rises to a peak then goes down. So, from this figure what you can conclude is K_0 is a function of u. More this speed, speed of rotation more will be the peripheral force. So, in design calculations what happens if you take K, which is equal to M/R', so, there all the variables are changing.

So, in this case R is fixed. So, either you can say K_0 is fixed that means, you can take the peak value that will be helpful for design. And they have extended actually this curve if you touch the peak points and then extend it to y axis, it will touch the y axis at a point that will give you a value, where peripheral force is computed for 0 forward 0 peripheral speed. Peripheral force with 0 peripheral speed that means, when it is not rotated, what is the force required that becomes your static component. So, we divide K_0 into two components. The peripheral force will be divided into two components, one is the static component which refers to this K_0 value at 0 peripheral speed and K_d is the dynamic component, dynamic peripheral force for cutting the furrow slice.

How to arrange these working elements so that the the fluctuation of K is minimized. The figures which I showed is for a single blade. Now, to minimize that fluctuation, whether it is a torque, whether it is K_0, we have to arrange the blades in a certain fashion. So, let us now discuss some of the requirements by which you can reduce or minimize this fluctuation. The first requirement is the angular interval between individual working elements. The angular interval between individual working elements should be even to make the elements penetrate the soil individually in the same time interval. Ok.

Then, second requirement is the interval between adjacent blades should be as large as possible to prevent clogging with soil thus which will produce additional forces. Because if clogging is there it will produce additional force, which will increase the soil resistance. So, to maintain this uniformity or minimizing the fluctuation of this peripheral force or the torque, we have to arrange in such a way that the angle between two adjacent blades that means, angular intervals between two blades should be equal to 360 degree by i into z_t. I into z_t means i is the number of sets or disks on which the blades are mounted and z_t is the total number of blades present in the disk or the set. At a particular time not more than one fourth of the total blade should be in contact with the soil, that is another requirement, ok. So, if you follow this then only these fluctuations of torque or fluctuation of peripheral force is minimized.

Let us now see the other important parameter which is specific work. The definition is work done by a rotavator during one revolution of working set and it is expressed per unit volume of soil. That means, kg meter per meter cube of soil. How much torque is required to handle unit volume of soil in one rotation that is called specific work. So, specific work can be expressed as $\frac{2\times \pi \times M}{z\times l \times a\times b_m}$. So, M is nothing, but your torque, z is the number of blades which are working in the same plane in a working set that means, in a disk there will be either 2 or 3 they are working in one plane. So, if total number of blades are 6, then 3 will be working in one plane. If total number of blades are 4, then 2 will be working - working in the same plane. So, z is that value either 2 or 3, then l is the tilling pitch and a is the depth and bm is the width of cut or width of the machine or equipment. Now for concurrent revolution, there will be another force which is coming. This is - this A_x is nothing, but the pushing force. When a blade is biting the soil in concurrent mode, it will try to push the equipment or the rotavator forward. So, that part is taken as A_x. So, A_x is nothing, but it is associated with the pushing force parallel to the direction of travel.

So, I have taken minus, that is because, in concurrent mode it is giving a forward pushing force that is why, the total force has to be deducted. So, we have taken the minus sign. So, in concurrent revolution mode, we can neglect this sign because this is going to reduce it, but since you are designing for a higher value. So, you can neglect this x component. So, x component can be neglected. So, directly you can say that specific work is equal to $\frac{2\times\pi\times M}{z\times l\times a\times b_m}$.

But, for reverse mode we cannot neglect. We have to take that component. So, the plus component will come. Same value, but it has a plus. So, we cannot neglect. In designing we have to take the total So, specific work has now divided into two components : one is your static specific work which is denoted as A_0, the other one is the dynamic specific work which is denoted as A_B. So, A will be equal to A_0 plus A_B. So, let us now see what is this A_0 and how to compute A_0. A_0 is dependent on the soil specific resistance.

Specific work A_0, that is static specific work is equal to C_0 into k_0. C_0 is a coefficient whose value varies from 2.5 to 3.5 and I will give you the details of those values and k_0 is nothing, but your specific draft that is unit draft. And again unit draft varies with type of soil. So, the values of k_0 which has to be taken is again dependent on type of soil, lighter light soil, medium soil, heavy soil 0.2 to 0.3, 0.3 to 0.5 and 0.5 to 0.7 kg/cm^2. So, once you know the unit draft, considering the value of C_0 you can straight away calculate what is the static specific work.

Then, for dynamic specific work we need to know this certain values that means, dynamic specific work A_B. If the length of soil slice is constant, then you can express A_B as $\alpha_v V^2$ or $\alpha_u u^2$. Either you take this part or you take this part. If you are taking the first part that is related to the forward speed, if you are taking the second part that is related to the peripheral speed. So, what is that coefficient α_v and α_u? These are dynamic specific resistance whose values are available. I will give you in a table for different types of blades like rotary cultivator with L knife, bent knife at different working depths, what is the length of soil slice, then what is the soil, whether it is a tilled soil or meadow soil, grass, then what will be the value of C_0 and what will be the value of α_u.

α_u unit is kg-s^2/m^4 and its value ranges from say 400 to 600. So, if you if you take the value of alpha u and we know the peripheral speed at which the blade is rotated then we can immediately calculate the dynamics specific work. So, if you take this equation then alpha u u square, then you can immediately calculate what is the dynamic specific resistance.

And this α_u or α_v they can be related with each other that means, $\alpha_v = \alpha_u (u/V)^2$. So, once you know the value of A_0 and A_B, we can take the summation and find out what is the value of A and then you equate with that specific work equation to find out how much is the torque acting for a given rotavator.

So, we have been discussing about peripheral force where I said is K_0 is divided into 2 components. One is the static component, other one is the dynamic component. The static component $K_s + K_d$. So, $K_s = A_0 \left(\frac{V}{u}\right) ab_m$ and $K_d = A_B \left(\frac{V}{u}\right) ab_m$. This can be derived by taking those equations K = M/R and M is related to specific work. From there, these equations have been derived. So, part of the dynamic force, which is K_d is used for cutting, part is used for throwing the soil and the part which is used for throwing the soil that will be responsible for throwing the soil to one side or to the back side depending on the orientation of the blade. So, the energy which is required to throw the soil slice, we can write as $E = \left(\frac{mc^2}{2}\right)$. Basically, the kinetic energy which is imparted to soil mass. m is the mass of soil, c is the speed at which the soil is thrown and $\left(\frac{mc^2}{2}\right)$. So, that way we will find out the energy required. But the c at which the soil masses are thrown is not the speed at equal to the peripheral speed. So, what we have to do is, we have to take a coefficient, whose coefficient is Єu. That coefficient value varies from 0.4 to 0.7. So, the speed of the soil mass which is thrown is lesser than the speed of the rotor blade - rotary blade. Now, considering the losses, because it is rotating. The soil masses are thrown. So, there will be some losses due to ventilation effect that means, air resistance due to some frictional losses.

So, if you consider that then the total energy requirement will be equal to $\frac{mc^2}{2}$. So, $\frac{mc^2}{2}$. I have substituted c with this Єu and then the efficiency to take care of this soil friction and ventilation. So, that way the energy required for throwing the soil slice will be $E = \frac{m(Єu)^2}{2η}$. So, dividing energy with volume of soil slices, how much volume it is handling. So, that will give you energy - specific work for throwing the soil slice, specific work for throwing the soil slices.

So, energy whatever you are getting here, just divide by volume. Volume is the entire width $b_m \times a \times l$, a is the depth, l is the tilling pitch. So, this will give you - whatever we have discussed that will give an idea, how much will be the force which is acting and how to utilize that force. Next thing to do - to do that utilization part. Before that we should know how to calculate the tilling pitch, which is very important parameter. Tilling pitch in fact, is the length of soil slice which is cut. So, how to calculate it, that we will do with some exercise.

Now, a problem is given like a tractor drawn rotary cultivator in concurrent revolution mode when operated at 210 rpm at a depth of 120 millimeter and at a forward speed of 3.6 kilometer per hour experiences a mean torque of 440 Newton meter at the rotor shaft. The radius of the working set is 300 millimeter and the number of blades which would cut identical path is 3. The working width of the cultivator is 1.8 meter. Calculate the tilling pitch and specific work done in one complete revolution. So, there are two parts one is tilling pitch the other one is specific work done.

So, for calculating the tilling pitch, we need to know the formula. Tilling pitch is nothing, but , $l = \frac{60 \times V}{n \times z}$. where Vis the forward speed n is the rpm of the rotor z is the number of blades working in one plane. The values are clearly given in this problem. The forward speed is given as 3.6 km/h rpm of the rotor is given as 210 and z is 3. So, you just substitute there and then find out the value of l which comes to around 9.52 centimeter. The next part is what is the specific work done? We have the expression: specific work is equal to, A = $\frac{2\pi M}{\mathrm{z\,l\,a}b_m}$.

Now, in this equation M is the torque which is acting, it is given as 440 Newton meter, z is the number of teeth or blades which are striking which are working in the same plane, which is given as 3. and l is the tilling pitch which we have just now calculated, a is the depth which is given as 120 millimeter and b_m is the width of the machine which is given as 1.8 meter. So, in this equation everything is given, except tilling pitch which we have calculated and then substitute in this equation to find out what will be the value of A. So, it comes around 44814.71 J/m^3 or 4.48 kJ/m^3.

Let us see one more problem. A tractor drawn rotary cultivator is operated in concurrent revolution mode at a depth of 130 millimeter and forward speed of 3.6 km/h. The radius of the working set is 280 millimeter and the number of blades which would cut identical path is 3. The working width of the cultivator is 1.8 meter. The cultivator is to be powered from the tractor PTO running at 540 rpm through a suitable gearbox. What should be the gear ratio for getting a tilling pitch of 74.1 millimeter? Find out the cutting speed of the blade, when the blade will just start cutting.

So, again there are 2 bits, first bit is what should be the gear ratio? Because the rotavator shaft is not rotated at the same speed at which the PTO is operated.

Usually, the standard PTO speed is 540 rpm, it could be 1000 rpm, but we have taken as 540 rpm that is mentioned here. Then, what should be the gear ratio so that you can get a tilling pitch that means, if you remember that tilling pitch formula, here the n has to be found out. So, l is given 74.1 millimeter V forward speed is given 3.6 km/h, z is the number of blades which are working in the same plane that is also given as 3. So, just put in this equation then find out the value of n. So, n will be equal to 270 rpm. This is small n capital N. So, that we were getting 269.91. So, roughly around 270 rpm that means, the rotor has to be rotated at 270 rpm. So, the gear ratio will be 2 is to 1, 540 is to be reduced to 270. So, first part is over. Second part is cutting speed. So, if you remember the cutting speed equation $u_s = \frac{V\,[\left(\frac{u}{V}\right) - sin\,\alpha]}{\cos \varDelta\delta}$.

So, the important thing here is you have to first calculate u/V and u/V will decide what is the value of $\cos \varDelta\delta$. So, for calculating u/V, we have to calculate peripheral speed which comes to 7.92 m/s. So, what is given is : R is given 280 millimeter , n just now we calculated as 270. Now, if you substitute here, this would be 270 and 280 is the rotor radius. So that, we are getting 7.92 m/s.

Now, V is 3.6 km/h. So, the ratio comes to be 7.92. Now, corresponding to this ratio, what is the value of $\varDelta\delta$? So, we have already given a figure - last class, how the $\varDelta\delta$ values are changing. So, from that figure, we can find out the value of $\varDelta\delta$ which comes around 7 degree. Higher the u/V ratio lesser will be the value. So, it comes around 7 degree. So, if you substitute here then - and the question which is asked is the blade speed when the blade is just started cutting. So, it is a concurrent mode the blade starts cutting at 20 degree. So, the alpha value is to be taken as 20 degree. So, if you substitute in this equation, then it comes around 7.63 m/s.

So, as you move forward, your this alpha value will change. So, this is not a constant speed. It will change. It will vary throughout the cutting zone at the cutting time.

Next thing is another question - a tractor drawn rotavator of radius 30 centimeter rotating at 210 rpm with 3 blade working in same plane for each set of blades is operated at a forward speed of 3.5 km/h. If the forward speed is increased by 10 per cent and rotor speed is decreased by 10 per cent, what will be the change in peripheral to forward speed ratio and the tilling pitch as compared to the initial operating conditions.

So, what we have done is, we have changed the speed : forward speed as well as the rotor speed that means, rpm. So, let us first find out what was the initial tilling pitch when the condition was 200 rpm and rotor radius is give, forward speed is 3.5 km/h. So, if I substitute in this equation, the tilling pitch comes to 0.0926 meter. Now, corresponding to this what is the u/V ratio? u/V ratio is : peripheral speed is given rotor radius is given. So, we just put it there $2\times \pi \times R \times \frac{n}{60}$ /V. It is in m/s.

So that is why, multiply with 10 by 36. So, we are getting a u/V ratio for initial condition is 6.786 corresponding to that the tilling pitch was this. Now, the question asked is, the forward speed is increased by 10 per cent that means, V has been increased to 1.1 V and the rotor speed is decreased by 10 per cent that means, the RPM is reduced to 0.9 n, n is the RPM. So, if that is the case, again I substitute in that tilling pitch equation to find out what will be the tilling pitch value. So that way you are getting a tilling pitch of 0.1132 meter.

Now corresponding to this condition: increase in forward speed and decrease in peripheral speed, what is the u/V ratio? This comes to 5.55. So, now the percentage change in tilling pitch. It was 0.1132 after changing and before it was 0.926. So, that way we are getting 22.25 per cent increase in tilling pitch. And how about u/V? It was 6.786, when we change the forward speed and the rotor speed it has come down to 5.55. So, the change in - percentage change in u/V is 18.21 per cent. So, from this what we can conclude is with reduction in u/V ratio, the tilling pitch is increased. It is obvious. When reduction in u/V means, u/V reduction will happen only when u is decreased. So, when u is decreased means there will be lesser number of bytes, so tilling pitch will increase.

So, that is the concept. So, concept related to tilling pitch is given here and it will be clear. So, these are the some of the references. And in brief I can say, soil resistance which is acting on the blade while cutting and specific work for a rotavator are discussed. Numericals are solved for computing tilling pitch and by varying the u/V ratio, how it is affecting the tilling pitch.

That is all. Thank you.