Design of Farm Machinery

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Week - 02
Lecture10: Cultivator

Hi everyone, this is Professor H. Raheman. I welcome you all to this Swayam NPTEL course on Design of Farm Machinery. This is lecture 10, where I will discuss about the cultivator. The concepts that will be covered are: the work to be done by a cultivator, the different components of a cultivator, and design information on the cultivator. This will help you understand how to design a cultivator. As you know, the function of a cultivator is: it is a secondary tillage implement used for pulverizing soil and partly crushing the tilled soil beds.

So, the cultivator is used to accomplish the following objectives. Objective 1: to control weeds so that they do not compete with crops for water and nutrients. To maintain the seedbed in good tilth during the growth of the crop. To achieve rapid infiltration of rainfall and adequate aeration. It can also be utilized for mixing fertilizer with the soil and other work connected with the preparation of soil for sowing and to prevent surface evaporation losses. So, these are the functions to be accomplished by the cultivator.

Now, if you look at the cultivator, it could be a mounted type cultivator, which means the entire weight is supported by the tractor, or it could be a semi-mounted type. Semi-mounted type means it is provided with transport wheels. Usually, the mounted cultivators are lighter than the semi-mounted ones. The main components of a cultivator, whether it is a tractor-drawn cultivator, a power tiller drawn cultivator, or an animal-drawn cultivator, are the tines, the frame, and the hitching arrangement.

So, the figure I have shown here is a tractor-drawn cultivator. That is why, I have indicated here a 3-point hitch. Then, there will be a frame to which these tines are attached. The tines: the top portion is called the shank, and over the shank at the bottom, there will be a working element attached by bolting. So, there will be a minimum of two rows of tines arranged with certain spacing to prevent overlapping.

The components, as I said, are the cultivator's teeth, which is nothing but - it is called a tine, comprising shanks and working elements, then there is a frame and a 3-point hitch. The types of working elements could be shovel type, sweep type, or half sweep type. So, shovel type means it is mostly used for tilling, sweep type means it is used for tilling as well as cutting the grasses or weeds, then half sweep also - it is used for tilling and cutting grasses or weeds. The cultivator teeth may be divided into three types: one is the flexible type or the spring type, then the semi-rigid type, and the rigid type. The figure which I am showing here is a spring tine or a flexible tooth.

If you look at it, this is similar to your harrow type, but it is provided with one more spring. So, at one end, it will be connected to the frame by a yoke, and at the other end, the working element, which is denoted here, is shown here. This is the working element, which is connected to this tooth with a bolt, a countersunk bolt, and this end is connected to the frame. This is S-shaped, circular. This is a two-sided shovel. This is a one-sided shovel. Two-sided shovel means both sides are pointed. One-sided shovel means only one side. Two-sided shovel has an advantage: once one side is worn out, you can just rotate it and then tighten it again, so that you can utilize that shovel. If it is one-sided, then you have to throw it. So, you can utilize that shovel. If it is one-sided, then you have to throw it.

So, in the case of a spring tine, what happens is, this is the original position. Now, when you try to pull it, there will be soil force acting. Because of the soil force, this will be displaced backward. Because of the displacement, the spring will camber, and the angle which the tip of the working element makes with the horizontal is changing. So, the spring should be sufficiently rigid to counteract that force, the soil reaction force, the soil force acting on the working element. So, I have denoted $K_x = C \times f$. K_x means the horizontal component of soil reaction, which is nothing but your draft, then C is the spring constant, and the value I have given is less than or equal to 6 kg/cm^2, that is spring stiffness, and f is the deflection due to draft.

And the maximum tooth deflection should not exceed 10 cm; it should be less than or equal to 10 cm. So, the angle which I have indicated here is called the load angle, and the load angle should not exceed, in the case of sweep or shovel, by 30 degrees that means, it should not go beyond 30 degrees. When there is no force, $\boldsymbol{\alpha}$ lies between 15 to 20 degrees, then by the action of the force or the draft, it is shifted backward, and the load angle is changed. And when it is changing, the value of $\boldsymbol{\alpha}$ should not exceed 30 degrees.

The advantage of using the spring tines is that it removes the roots of the grass or the roots of the weeds. Instead of only cutting, what it will do is remove the roots from the soil surface; that is the advantage. But it cannot be applied to all soil conditions because, due to the spring action having deflection, what happens is that the teeth will try to pull the wet soil out onto the surface, thereby causing the soil to dry. So, if you want to maintain moisture, then this type of tine or tooth is not suitable. The disadvantage is that it is difficult to maintain a uniform depth. Since it is a spring tine, it deflects. The moment the draft force increases, it will try to be lifted backward. So, thereby, it is difficult to maintain the working depth. And the other difficulty, as I said, is that the clods which are pulled upward will dry very easily. So, these are the two big drawbacks.

Then, coming to the semi-rigid one, as I said, semi-rigid means it is partly spring and partly rigid. The top portion is spring-type, and the bottom portion is rigid. So, these are the teeth which are used for sweeps only; the working element is a sweep, not a shovel. The constant of the spring here is: since it is a semi-rigid tooth, the constant of the spring, that means, the value of C is less than or equal to 15 kg/cm^2, whereas, in the case of a spring-type tooth, it is less than 6 kg/cm^2. So, that is the difference.

So, when there is a force acting, this rigid structure will not deflect that much because the spring constant is higher. So, and it is connected to the frame; one side is connected to the frame, and the other side, where the working elements are attached, is connected to the frame with a yoke. Then, the third one is the rigid tooth. There is no spring action here. The tooth is rigid, and at the end, one end is free, which will be attached to the frame; the other end is where the working elements will be provided.

The working elements could be sweep type or shovel type. And these working elements are connected to the tine or tooth by screws, indicated here by this counter-sunk screw.. So that there is no projection. If there is a projection, the soil may stick to it, or the soil's free flow will be blocked.

Now, I am giving you a question - a problem that will give you some more idea about how this deflection is affecting the soil reaction. The shank of a spring tine tractor-drawn cultivator, when operated at a forward speed of 3 km/h, was displaced horizontally by 5 cm, and the load angle was changed from 25 to 30 degrees. If the spring constant of the tine is 5 kg/cm, find the change in soil reaction force acting on each tine.

So, if you recall this diagram which I showed before, this will be your spring tine initial condition. There will be a draft force acting K_x. Because of the draft force, there will be a displacement f, and the load angle here is changed. Initially, it was 25 degrees; now it has changed to 30 degrees. Now, what is asked is to find out the change in soil reaction. So, how to do this?

The thing is, initially, it is not operated and simply it is resting on the soil. So, the soil reaction, I can take as 0, which means the draft is 0; there is no draft acting. So, when there will be a draft, it is shifted backward. So, how much is it shifting? By a distance of 5 cm. So, 5 × 5. The spring stiffness is 5 kg/cm^2.

So, the displacement is 5 cm. So, that way, you will get the draft force equal to 25 kg. So, I have indicated the forces here. This will be your soil reaction, and this is your K_x, and this is the vertical component of the soil reaction. So, K_x I have indicated as 25 kg. Now, this angle is 30 degrees.

So, this is 90. Soil reaction to the tip is 90 degrees, and this angle is 60 degrees. So, now, what is asked is, what is the soil reaction at the new condition - the new position? So, that means the draft is 25 kg. So, $\frac{25}{\text{Soil reaction}}$ = cos60. So, the soil reaction $= \frac{25}{\cos 60}$. That will be your soil reaction. Since initially there was no soil reaction, this will be your final soil reaction. So, the change in soil reaction is nothing but $= \frac{25}{\cos 60}$.

Next is, what is the working zone of the cultivator's tooth? As I discussed for the spike tooth harrow, there will be a longitudinal displacement of soil and a lateral disturbance of soil. So, both are represented here. You can see this is your longitudinal area disturbed by or `width disturbed by each working element. Now, the width of the working element is B0. Now, if I draw a line here, the depth is 'a'. Now, this is your angle of internal soil friction, which you denoted as φ or δ before. Now, for maximum, δ is 45 degrees, which means this distance is a_{max}, this distance is a_{max}, and this distance is your B_0.

So, the total working width by each tooth = $B_0 + 2\ a_{max}$. Now, the spacing between two adjacent tines is not exactly harrow. Because if you look at the figure, for a cultivator, the tines are arranged in two rows. I am talking about two adjacent rows, the distance between two adjacent tines. It could be one tine in the front, the other tine in the rear row. So, that distance is denoted as t_0, and t_0 should be such that this should be greater than the value which you are getting now, $B_0 + 2a_{max}$. So, t_0 should be greater than this value; then only there will be no overlapping.

Otherwise, there is a possibility of overlapping, as I said in the beginning, the beginning, in the last class. When there is overlapping, there will be an accumulation of soil, which may increase the resistance acting on the tillage implement. And this is t_s. t_s will be equal t_o - t_s means this distance. This is t_s. 2a tanφ + d, d means B_0 here. The transversal spacing, I have denoted just now 2amax plus B0 plus delta t, and these are the values of delta t: given as 2 to 5 cm for shovels and 0 to 5 cm for sweeps. Sweeps, you may not provide this space. Then the mean value of the angle of internal friction is 45 degrees.

So, that way, you are getting a_{max}. a tanφ is nothing but a_{max}. So, t_s becomes a tanφ and L. Now, coming to the longitudinal distance between two adjacent rows L. So, L will be equal to a $_{max}$ + l. Small l is the distance from the tip of the working element to the frame. This distance is l. So, L Type equation here.should be greater than a_{max} + l. I will give some design information related to sweeps or shovels. The overlap, the spacing between 2 adjacent tines, when you try to calculate, then the C value should be 2 to 3 cm. Sweeps of the second row are wider than those of the first row.

The working width of the cultivator with sweep amounts to $B_k = B_0 n - C(n-1)$. Working width means: suppose there is an overlap, then that is why, if you take 9 into 11, that means, sorry, 9 × 30 cm. So, 9 × 30 centimeters means the working width, generally we take as 9 × 30, 270 centimeters. But there is some overlap.

So, that overlap we have deducted here, C(n-1). So, the actual width covered will be B_0n, and B_0 is the width of each working element, n is the number of working elements, C is the overlap, which is taken as 2, and the number of overlaps will be n-1. So, that way, this will be the actual working width B_k. Now, the number of sweeps these are some. n is the number of sweeps, B_θ is the width of the sweep, C is the overlap I have already discussed. Then some design information related to shovel: the load angle of a shovel is contained within the limits of 20 to 45 degrees; it should not exceed.

Narrow shovels with load angles greater than 30 degrees are used with rigid teeth. Then the apex angle: this angle is called apex angle, 2θ. The apex angle should be between 70 to 90 degrees. The width of shovels ranges from 45 mm to 100 mm, and their thickness is around 7 mm - between 7 to 10 mm. Shovels are made of carbon steel. The blade of the shovel is hardened on a width of about 40 mm up to a hardness of 500 Brinell hardness number, and the hardness of the remaining part of the shovel is below 300 Brinell hardness number.

So, only the working area is hardened more. Then the soil reaction, which acts when you try to pull a shovel or a sweep in the soil, is shown here, demonstrating how the soil resistance is dependent. So, the working elements are pulled at a depth, and the soil reaction is indicated here as K. K will have a component K_s, and the point where K acts is at a distance 0.2a from the tip of the tool - tip of the working element. If ‘a’ is the depth, 0.2a. So, this distance is 0.2a. Now, here, in case of a sweep, what we observe is, there will be a soil reaction similar to this one and the same thing. It is at certain height, which we can take as 0.2 a and the load angle is indicated here. Now, what is the soil resistance K_x?

How it varies with depth is given for a shovel. This is only kg, which means it directly gives the draft force, whereas, in the case of sweep type, it gives specific resistance. That means, kg per meter of width. What is the force experienced, and how it varies with 'a' is plotted, and more or less, you can say it is linear. Initially, there is some - the rate of rise is little low, after which the rate of rise increases. The same thing here. So, what we can say is, the soil resistance increases with an increase in depth, whether it is a swivel type or a sweep type.

The reason is it handles more volume of soil; more volume of soil means more draft. Then, the distribution of forces during cutting of weed roots by the sweep. When the sweep is attached, as I said, it not only pulverizes the soil but also cuts the weeds. So, when it cuts the weeds, there are some forces involved. So, which I am going to discuss.

Now, when this is a half sweep, when we try to move it forward, what happens? The weeds present here or the grasses present here, so, the blade will try to exert pressure on these weeds or grasses. So, because of that, there will be a reaction force, which I have indicated as Q. Q will have two components: one is the normal component N and the other one is the tangential component S. And Q is at angle θ_0 because the blade, the sweep, is at an angle θ_0. θ_0 is the setting angle. So, Q will be oriented with this face of the blade by an angle θ_0, which means, S will be equal to how much? S will be equal to, $S/Q = \cos\theta_0$. Now, to counteract this thing N, there will be a frictional force because of the normal force. There will be a sliding action between the crop and the face of the blade. So, that is given as T.

So, T will be equal to, the coefficient of friction, which is equal to $\tan\varphi$. So, suppose φ is the angle of internal friction between the grass and the face of the blade, then T can be calculated as, T is equal to N $\tan\varphi$. So, the weeds will only be cut when S is greater than T. When S is greater than T, then only the weed will be cut; otherwise, the weeds or grasses will not be cut. So, from here, what you can say is, N $\tan\varphi$, which is nothing but your value T, should be less than Q $\cos\theta_0$, S, that means, T should be less than S; then only cutting will take place; otherwise, there will be no cutting.

So, from this condition, we will now try to find out what the value of θ_0 will be. So, N will be equal to Q $\sin\theta_0$. If you take this triangle, N will be equal to Q $\sin\theta_0$. Now, you substitute for Q. So, then you get a relationship: tan φ will be equal to, less than equal to, less than $\cot\theta_0$. $\cot\theta_0$ you can take as tan $(90 - \theta_0)$. So, φ will be equal to 90 minus, less than $90 - \theta_0$, but we are not interested in φ; we are interested in theta 0, what should be the setting angle so that the weeds will be cut. So, if you reverse this one, so, θ_0 will be less than equal to $(90 - \varphi)$. φ is the angle of friction, the angle of friction between grass and the face of the blade, which is: the maximum value it can take is 45 degrees. If that is 45, so, the value of θ_0 will be less than equal to 45. So, $2\theta_0$ will be equal to, less than equal to 90 degrees. So, from this relationship, we can find out what the setting angle here should be for the sweep, so that it can easily cut the grasses as well as pulverize the soil.

In addition to θ_0, there is one angle indicated here - $\boldsymbol{\alpha}$, which is the load angle. And that will decide what will be the orientation of soil reaction and another angle is given as gamma, which is the cutting angle and the cutting angle depends on which orientation the blade is sharpened. The blade, meaning this front portion, can be sharpened from the top side or it can be sharpened from the bottom side. So, the cross-section I have indicated here. If it is sharpened from the bottom side, you can see there is a gap. So, that gap is denoted as angle ϵ, which is the relief or rake angle, and i is the angle of sharpness. So, $i + \epsilon = \gamma$

If it is sharpened from the top, then the relief angle has no value. So, you can directly take that. So, usually the better one is if it is sharpened from the front side. So that, it can easily cut the grass. There is some more information I will give you related to sweep. The apex angle, that means, if this is your apex angle, this is your sweep, then this is the apex angle. The range is between 60 to 90 degrees, and most frequently it should be 70 degrees. The load angle should be between 12 to 20 degrees.

Smaller angles are taken for sweeps or spring teeth, while larger angles are taken for rigid teeth tines. The cutting angle, γ should be in the range of 18 to 30 degrees. Then, because of the durability of the blade, the angle of sharpness should be contained within 12 to 15 degrees. The sharpening of sweeps or swivels of a cultivator can vary, but sharpening from above is considered as the best one. Then, sweeps are pressed from a steel plate with a carbon content of 0.7 per cent, and the thickness of the steel sheet depends on the working width. If the working width is less than 200 mm, then the thickness is between 3 to 4 mm. If it is between 200 to 300 mm, the thickness is 5 mm. If it is between 300 mm, then the thickness is 6 mm.

So, the higher the width, the greater the thickness, as it is going to handle a larger volume of soil. The blade of the sweep is hardened again, just like your spikes, up to a width of 25 to 40 mm, to a hardness of about 500 Brinell hardness number. The remaining part of the sweep's hardness should not exceed 350 Brinell hardness number. Now, the shape of the shank, let us see how much the clearance will be, because we are putting a working element at the bottom end. Then, how much the shank should be - what should the height of the shank be, so that sufficient clearance is provided, there is no accumulation of weeds or soil, and there will be a free flow of this material. The shape of the shank here is denoted by the slope ‘l’ and by the radius of curvature R, which is dependent on the load angle.

So, the load angle indicated here is $\boldsymbol{\alpha}$, and h_0 is the distance from the center of the curvature to the tip of the working element. That distance is denoted as h_0, and $h_0 = R \cos\boldsymbol{\alpha} + l_1 \sin\boldsymbol{\alpha}$. R $\cos\boldsymbol{\alpha}$, this distance and h_0 sin , $l_1\sin \boldsymbol{\alpha}$. This is $\boldsymbol{\alpha}$, so, $l_1\sin\boldsymbol{\alpha}$. So, the summation of this will give you R. So, if you rearrange this one, you will get the expression for the radius of curvature. Then, l_1 is the length of the breast of the sweep. The slope of the shank is most frequently adapted in the range of 200 to 250 mm, and the radius of curvature is less than or equal to 120 mm. Now, there will be a portion indicated as ΔH, which is provided to fix the shank to the frame.

And the height H, from the tip of the working element to below the frame, is denoted as H. H is equal to: if you look at this figure, H = ‘a’, which is the depth of operation + H_1 + ΔH. So, how you are going to fasten it to the frame will decide, what will be the value of H? The minimum clearance H_1 between the surface of the lower edge of the frame should amount to greater than 200 millimeters. H_1 should be greater than 200 mm. Usually, we take 300; 200 to 300 is allowable for this distance. So, this is your depth after the working element has entered into the soil; this much clearance has to be provided. So that there is no blockage. So, the final expression for H, the height, = $a_{max} + H_1 + \Delta H$. The question is, if somebody provides a higher height, what will happen? We will discuss this in the coming class.

These are the references, and in brief, we can say the components of the cultivator, along with information for the design of the cultivator working elements, are briefly discussed.

Thank you.