Design of Farm Machinery

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Week - 02

Lecture 09 : Design of spike tooth harrow

Hello everyone, this is Professor H. Rahman. I welcome you all to this Swayam NPTEL course on Design of Farm Machinery. Today I will cover the design of the spike tooth harrow. The concepts which will be covered are how to classify different tooth harrows and then how to design different components of a spike tooth harrow. The purpose of harrowing is leveling out the land surface, then pulverizing the soil, preparing the soil structure for sowing, destroying weed roots, and mixing fertilizer with the soil.

These are the activities which will be performed by a harrow. Whether it is a tooth harrow or a disk harrow, these are the activities which are to be done. So, to do these activities, different types of models of harrows are available. Because the conditions are different, to accommodate all those conditions, a single model may not be suitable. So, we have to have different models of harrows. So, let us see now how a spike tooth harrow looks like, and then if you look at the spike tooth harrow which I have shown here. And there will be spikes at regular intervals, and there will be number of spikes arranged in different rows, and this has to be pulled by a power source. It could be a power tiller, it could be a tractor, or it could be an animal.

So, we classify a tooth harrow based on the tooth structure. So, spike tooth harrows are divided as rigid and spring types based on the tooth structure, then according to weight, they can be divided as light, medium, and heavy, then according to the purpose for which they are used, such as tiller and weeder. So, the basic components, as I said, it comprises spikes and a frame. Usually, harrows with rigid tines are very common, and the frames of these harrows could be a zigzag type or an 'S' shaped type.

I am showing you the zigzag type, then I have shown you the 'S' shaped type. The frame is looking like an 'S'. So, that is why it is called the 'S' type. But here it is zigzag, so that is why it is called the zigzag type. The thing is, you can have several such sections, and they can be joined together by hinges or by chains to increase the width.

Then the spikes which are to be fixed to the frame are of different types, okay. So, the rigid tines or spikes can be bent oval tines, can be tines of heavy-duty harrows, or could be medium harrow tines, light harrow tines, oval tines, or knives of Laacki's harrow. So, that means (a) refers to bent oval tine, (b) refers to this one, (b) refers to (b), and (c) both refer to tines of heavy-duty harrows, (d) and (e) refer to medium harrow tines, and (g) and (f) refer to light harrow tines. This is light harrow tines, (g) is shovel tine, and (h) is the knife of Laaki's harrow. So, these are of different shapes. If you look at these tines, on the top of the tines, a square thread is provided with a nut. So, this square thread has to be entered into the frame, and on the top of the frame, after inserting these tines, they have to be bolted. So that during operation, because of the soil reaction forces, it will not turn; it will remain fixed. So, for that reason, a thread with a nut has been provided.

Harrow tines are normally made up of spring steel, forged steel, carbon steel, or carbon manganese steel with carbon content varying from 0.7 to 0.9 per cent. The working part of the tine is hardened up to a hardness of 450 to 550 Brinell hardness number. The working part means the lower portion, that portion which enters into the soil. And the depth of harrowing is not more than 15 cm. 15 cm is the maximum. So, we limit it to 12 cm, 14 cm, like that. As I said, these tines are bolted to the beams, and the square part of the tine enters the square opening in the beam, just preventing them from turning around due to the action of the soil. So, what exactly does it do during operation? So, when you try to pull a spike or tine, it will try to hit the soil clods.

So, by hitting what happens? There will be an impact force, and because of that impact, the clod will reduce its size. So, maybe a single impact is not sufficient. You have to have a series of impacts. To do that, you have to provide a good number of tines. So, that is why you have to take a section, and the spikes or tines are to be fixed to that section in different positions. So that, a single clod will be hit by a number of tines. So that, the soil clods will be reduced, and the soil clod size will be reduced.

So, to do that, we have to have a series of spikes in rows, in different rows. So, during harrowing, individual harrow times do not meet a uniform resistance. So, what will happen because of that is there will be a sinus motion of the harrow. So, to reduce that, we have to provide more number of tines or spikes. If you provide less number of tines or teeth and the shallower the implement sinks into the soil, the sinus motion will be more. So, to prevent that, you have to have a good number of teeth, tines, or spikes, whatever you call it.

Tines of light and medium harrows with rigid beams are set perpendicular to the plane of the frame. That means the angle between the frame and these spikes is 90 degrees. But the setting angle of the two thin harrows, where the beams are adjustable, can be changed from 70 to 110 degrees. I will show you the picture. Here you can see, where **α** is the setting angle. The setting angle is less than 90 degrees, the second one is equal to 90 degrees, and the third one is greater than 90 degrees, which is an obtuse angle. So, what is the advantage of providing this at different angles or at an angle of 90 degrees?

This is the direction of travel. Suppose I want to pull this one forward. So, where the setting angle is kept less than 90 degrees, let us now see what are the forces acting when you try to pull it. So, there will be a soil reaction, which is denoted as K, and K will have two components. One is the horizontal component K_x, and the other one is the vertical component K_y. So, the vertical component direction, if you look at it, is acting downward. That means this kind of orientation will help in better penetration. That means the teeth or the spikes will be entering the soil without any problem. Now, let K_x be the horizontal component. Because of the horizontal component, it will have thrust on the spikes, and we will later on discuss how this is going to affect the size of the spike.

The next orientation is: the setting angle is at 90 degrees. So, when it is at 90 degrees, what are the forces acting? The soil reaction will be perfectly horizontal. So, the direction of travel is indicated here; there will be no vertical component. So, whatever penetration we have provided, taking the help from the tractor hydraulics, the same depth will be maintained depending on the soil resistance.

Then the third orientation is: where alpha, that is the setting angle, is more than 90 degrees. So, the direction of travel is this one, and when you pull it, the soil reaction K will be acting in this angular form, at an angular distance from the horizontal. So, it will have again two components. The horizontal component is K_x, and the vertical component is K_z or K_v or K_y, whatever you call it, but here I have indicated it as K_z. So, the direction, if you look at this, is acting upward. That means it will have a tendency not to penetrate into the soil. So, depending on our soil condition, whether you want to operate at a lighter depth or at a deeper depth, we have to select which kind of orientation the spikes have to be connected to or fixed to the beam.

Then comes, what is the operating zone of harrow tines. When you try to pull a single spike, then it will affect the soil, both in the lateral direction as well as in the longitudinal direction. So, that is called the working zone or the operating zone of a single tooth or spike. So, the width of the zone affecting the front and side parts of the tine in the field depends on the angle of internal friction of the soil. It depends on the angle of internal friction of the soil, and the second component is the depth of harrowing.

Now, t_s, which is the width of coverage by a single spike or tine or tooth. So, $t_s = 2a \tan\delta + d$. So, a here is the depth of operation. $\tan\delta$, δ is the angle of internal soil friction, and d is the thickness of the tine. So, if you look at this figure, this is the depth. So, a $\tan\delta$ means this distance from here to this centerline, again from this to this. So, this is your angle of internal soil friction, which is δ.

So, now, this becomes a $\tan\delta$. This becomes a $\tan\delta$, sorry, this one, not this one, a $\tan\delta$, and this is a $\tan\delta$ plus this is the thickness of the tine. So, altogether, if you add it, that becomes your t_s. Now, if you provide two tines together, so there will be another working zone from this tine. It may happen that if the spacing is not sufficient, these two working zones may overlap. So, we have to see that there is - the overlap should be as minimal as possible; otherwise, there will be an accumulation of soil.

Now, this is what I am talking about: lateral spacing between two tines, which is about t_0, denoted here as t_0, and t_0 should always be greater than t_s. ts is the individual width, and t_0 is the distance between two adjacent tines. So, t_0 should be greater than t_s so that there is no overlap. If it is less than t_s, there is a possibility of overlap, and hence, there will be an accumulation of soil. Consequently, the force required to pull will also increase. So, the transversal spacing t_0 can be written as $2a_{max} + d + \Delta \boldsymbol{t}$. That means amax, I have taken as the maximum depth, assuming that δ, the angle of soil internal friction, is 45 degrees. $a\tan\delta$ becomes a. So, that a, I have taken as a_{max}, and this is nothing but your t_s, and this is the spacing between two working zones, which is denoted as $\Delta \boldsymbol{t}$, and $\Delta \boldsymbol{t}$ I have taken as 2 to 5 cm. So, that way, you can find out what the spacing is between two adjacent tines. This is what I am talking about: transversal spacing.

Now, the longitudinal spacing of tines between rows should be considerably greater than the zone of forward action of the tines on soil in order to minimize blocking of the furrow with grasses, couch grass, and other weeds. So, because it is operated in grassy land, what will happen is the grass will accumulate. If you do not provide sufficient spacing between two adjacent rows, then this is going to create a blockage. So, to avoid that, ts should be greater than the t_0 value. So, once you understand the importance of spacing and how much spacing you have to provide, then the question arises: how to place these tines in different rows. So, I have shown you one example.

So, I have drawn some lines and parallel lines here, and the crossing points will be the positions where the tines or spikes are to be fixed after providing the desired spacing. Now, essentially, when you try to construct the section of a tooth harrow, it can be based upon the method of development of the multi-coil helix.

So, I have indicated here how the helix will be shown. Then, as I said in the beginning, the frame should be a zigzag type or S type. So, when placing the tines in a harrow section, maximum spacing should be provided to avoid overlapping of the traces of the tines. Traces of tines mean these lines I am talking about. Suppose there is a tine here; this will be the trace - the path traced by the tine - that is called traces of tines.

So, no two traces should overlap each other. The arrangement should be such that no two traces should overlap each other. So, the method to be followed to achieve this is: What should be the number of spacings? First, we have to decide, and what should be the number of rows? Suppose I decide the number of spacings as 3. Spacing means 1, this is 1 spacing, this is another spacing, and this is another spacing. That means, if there are 4 times or 4 spikes, then there will be 3 spacings.

That is denoted as K. So, K is the number of spacings, and M is the number of rows. How many rows of teeth do we want to provide? So, after knowing this, then t_0, the working zone of a single tine, will be equal to MS_z. M is the number of rows of teeth, S_z is the spacing between two adjacent traces of tines. So, that is denoted as $t_0 = t/K$., t is this one total. So, this is t. So, t/K will be equal to t_0, and t will be from here. $t = t_0 \times K$, and substituting for t_0 that will be equal to substituting for t as M S_z. So, you can write t as M K S_z. That means, the lateral cutting width t will be equal to the number of rows, the spacings, and the spacing between two adjacent traces. The longitudinal spacing between tines, that means the distance between 2 rows which is denoted as h, will be equal to $C_z \times S_z$. Cz is a coefficient, and the value of the coefficient depends on what is the type of harrow: light, medium, or heavy. Depending on that, we have to find out the value of C_z. Now, the constraint here is: K should always be greater than 1. That means we have to have a minimum of 2, 2 numbers of tines in a row.

So, K should always be greater than 1, and M should always be greater than K +1. So, and there should be no common divisor between K and M. Suppose I have taken K as 3, then M will be greater than 3 + 1, 4. That means I can take 5, I can take 6, but I cannot take 6 because 3 and 6 have a common divisor. So, that is why I cannot take 3 and 6. I can take 3 and 5 or 3 and 7. So, there will be several adaptable pairs of numbers K and

M, such as M is equal to 5, for K is equal to 2 or 3. M is equal to 7, for K is equal to 2, 3, 4, or 5. So, these are some of the combinations.

Now, spacing of teeth in harrow. So, for a zigzag harrow, when K is equal to 3 and M is equal to 5, that means K is equal to 3. There will be 1, 2, 3, 4, 4 teeth: 1 row, second row, third row, fourth row, and fifth row. This is your fifth row. So, if you want to make a zigzag shape or if you want to make an S shape, then you have to make it like this. I will give you the procedure. So, to draw this net, first you need to know the value of α_1, the orientation of these lines. So, tanα_1 will be equal to: if you look at this triangle, this is h. So, tan$\alpha_1 = \frac{h}{KS_z}$.

And tan α_2, this orientation, $\frac{h}{(M-K)S_z}$. So, the longitudinal spacing of tines, as I said, h = $C_z K_z$, and the value of C_z, which is the coefficient, depends on whether it is a light harrow, a medium harrow, or a heavy harrow. So, accordingly, the value changes from 6 to 7, 5 to 6, and 4 to 5. So, the minimum is 4. The heavier the harrow, the lesser the value of C_z. The lighter the harrow, the greater the value of C_z. So, once you decide the value of C_z and you decide the K and M value, then immediately you can calculate α_1 and α_2. By knowing the α_1 and α_2 value, we can easily construct this net. $t_o = MS_z = \frac{t}{k}$, t = t_0 K = M K S_z. So, you know the t_0 value, we know the t value, and we know the angle α_1 value and the value of α_2.

So, what I have to do is, first, I draw this line, then at these points - any point you can take - draw an angle α_1, draw this line, then at a distance t_0, you get the point B, then you draw this line. So, likewise, at different points, C, D, I have to draw these lines. This angle is α_1; this is α_2, α_1, α_2. So, like that, I have to draw these lines, parallel lines. So, they will meet at this point. So, at a distance h, they will meet.

So, I will draw these horizontal lines. Now, I get these junctions, where these three lines intersect each other. So, the next thing is, I draw a line like this. So, this one, then I move like this. Then I move like this.

So, that becomes your zigzag path. So, this next row also like this, this like that, like that I have to do for the entire frame. Then it becomes, at each junction, we have to provide the spikes. So, that will be your zigzag type. Now, the frame, instead of making it zigzag, we can, if you want to make an 'S' shape, then I will make a curve like this, curve like this at the end - these two end rows.

So, that becomes. So, this will be your 'S'-shaped harrow. So, I have given you the description of how to draw the nets and then how to make the frame. So, now, I will solve a problem that will give more clarity on what we have discussed so far. Determine the number, numbers, size of spikes, location of spikes on the frame on which the spikes are to be fixed for a mounted-type heavy-duty 'S'-shaped spike tooth harrow with a setting angle of spikes as 70 degrees for the following conditions. What are the conditions given?

Depth of operation is given. Number of spacings in a row is given. Maximum angle of soil internal friction is given as 45 degrees. Specific resistance of soil is given as 0.2 to 0.3 kg/cm^2, then height or distance h is given as 30 cm, coefficient C_z is given as 5, and maximum shear stress value for the material is given as 1250 kg/cm^2. So, the first thing we want to do is, we have to find out the t_0 value and the t value, and then for that, you need to know how many spikes or tines are to be fixed in a row. So, the number of spacings is given as 3. So, the K value is given. So, then the M value will be the number of rows of spikes, that is, M will be greater than K+1.

So, then it becomes 5. You can take 7 also, that is possible. You can also take 9, that is possible. So, we have taken the minimum one, 5. Now, the next thing is to find out the number of spikes in a row. So, the spacings are 3. So, 3 + 1, 4 number of spikes will be present in a row. Then the distance between rows, h is given as 30 centimeters. So, and the C_z value is given as 5.

So, from here, we will find out the S_z value, that means, the distance between two adjacent traces of tines. So, t_0. So, now, we find out alpha 1. $tan\alpha_1 = \frac{h}{KS_z}$. So, from there $\boldsymbol{\alpha}_1$ comes to 59.03 degrees, then $tan\alpha_2 = \frac{h}{(M-K)S_z}$ that way we got $\boldsymbol{\alpha}_2$ is equal to 68.20 degrees. Then t_0 is nothing but M $\times S_z$. So, from there, we will find out what is the distance between two adjacent times, then t, the total cutting width will be equal to $t_0 \times$ K. So, that way, we will get the value of 90 cm. Now, t, t is given. So, you draw a line t, then at point A, you draw an angle $\boldsymbol{\alpha}_1$, draw this line. Then at point B. So, point B is established by taking a distance t_0, then at B, you draw a line at an angle $\boldsymbol{\alpha}_2$ in this orientation.

So, you just extend those lines. Then, at a distance h, we draw this line. So, at a distance h, you draw this line. So, automatically, these junction points will appear. So, we will get the data from there, and again, we will draw this line. So, that becomes your zigzag set.

So, the next thing is how to find out the size of the spike. The size of the spike basically means what should be the diameter and what should be the length? So, for doing that, we need to find out what is the unit draft for which you are going to design. Since the range is given as 0.2 to 0.3. So, you will always take the highest value, which means 0.3 kg/cm^2. Now, t_0 value is cutting width, the area covered by one tine, and 'a' is the depth.

So, that way, we are getting a value of 117 kg. Each tine will experience a draft of 117 kg. Now, if you consider a factor of 2, then the total design draft value will be 234 kg. And this draft value is going to create bending. It is a case of simple bending.

So, bending, stress due to bending will be equal to the bending moment into d by 2 because the cross-section of the spike is circular. So, we follow this formula: $\sigma_b = \frac{BM \times d/2}{\pi d^4/64}$, which will be equal to the allowable stress. So, here, to calculate the bending moment, we need to know what is the clearance between the tip of the spike and the frame — the lower portion of the frame. So, this distance is to be decided. So, since the depth is given as 13 cm. So, we provide another 10 cm clearance. So, that becomes 23. So, I have taken 23. 117 into 2, which means this is the design draft value, and I multiplied it with the clearance. So, that will give you the bending moment, and then, by putting it in the formula, I got it. And I have taken the allowable stress as 625, half of that, taking the factor of safety as 2. So, that way the diameter has come down to 4.44 cm.

This is how you are going to design the diameter of the spike. Now, these spikes are attached to the frame. So, the frame will be subjected to torsion and bending again. So, we will discuss this. Similar kinds of things we have already discussed for the disk harrow, and the same thing you have to follow here. The beam may be a square hollow section or it may be a rectangular hollow section. But preferably, it is a square hollow section.

And this cross-section I am indicating, and this. At different places, tines will be there. So, because of the draft force, it will try to give a torsional moment. And because of the self-weight, it will have a bending effect. So, you have to consider both bending and torsion and then find out, using the maximum stress theory, what is the stress developed, and the dimension should be selected in such a way that the stress induced should be less than the allowable stress.

This is all about the spike tooth harrow: how to design different components. Component means how to design the teeth and how to design the frame. These are the references. So, in brief, we can say that the design of the spike tooth harrow has been discussed along with a numerical to explain the design in a clearer way.

Thank you.