Design of Farm Machinery

Prof. Hifjur Raheman
Agricultural and Food Engineering Department
Indian Institute of Technology Kharagpur

Week - 01

Lecture - 05

Hi everyone, this is Professor H. Raheman.

I welcome you all to this Swayam NPTEL course on Design of Farm Machinery.

This is lecture 5, where I will try to discuss in details about disk harrow.

The concepts which will be covered under this are : functions of a harrow and its classification. Then types of disk harrow; force representation for a disk blade; then forces acting upon a disk harrow; then few numerical problems and then what are the couples acting on the disc harrow gangs; then vertical forces acting on a pull type offset disk harrow.

These are the things which will be covered.

So, the purpose of using harrow is to level the land surface, to pulverize the soil and to prepare the soil structure ready for sowing by destroying weeds, roots and mixing fertilizers soil.

So, so many activities are to be performed by a disk harrow or spike tooth harrow.

I said disk harrow, spike tooth harrow is because, disk harrow is most commonly used and the classification of harrows depends on different soil conditions for which and different operating conditions which are to be satisfied by not a single type of disk harrow or not a single type of harrow.

So, that is why you have to have different types of harrows and we basically classify harrows into two types : disk harrow and tooth harrow.

This is a disk harrow, tandem disk arrow in fact, tractor drawn. This is a spike tooth harrow.

The difference is the working elements. Here they are made of disks which are rotating, whereas, working elements here is : in case of spike tooth arrow are spikes.

So, that is why it is called tooth harrow.

So, I will cover in details about this.

So, types of disk harrow - it could be a single acting disk arrow, it could be a double acting disk arrow or it could be an offset disk arrow.

So, this is a single acting disk arrow, where it has 2 gangs of disks. One gang is this one, the other gang is this one.

So, there are 2 gangs of disk.

This one, this one and they will throw soil in 2 directions that means, throwing soil outward.

Then this is a double acting disk arrow or tandem disk harrow. It has 4 gangs: front 2 gangs rear 2 gangs. It is basically combination of 4 gangs and the front gangs will throw soil outward and the rear gangs will throw soil inward.

And this one is offset disk harrow.

As the name says offset that means, the line of pull and the center of the disturbed area that means, they do not lie in one line.

So, that is why it is called offset and again this has got 2 gangs of this.

But the 2 gangs are placed one behind the other not like the single acting disk arrow, where the 2 gangs are side by side. Here the 2 gangs are one after the another.

So, in this figure I have shown how the soil is thrown in one direction. The left gang will throw soil in left towards the left side, the right gang will throw soil towards right side and this is the direction of travel.

Similarly, in case of a double acting disk harrow, the front gang if you look at, the left gang will throw soil to the left, right gang will throw soil to the right.

The two rear gangs they will bring soil inward that means, the right rear gang will bring soil from outward to inward and the left gang will bring soil from left side to inward.

So, the arrow: you can see the difference in arrow.

And an offset disk harrow, the front gang will throw soil to one side, towards the outer side and the rear gang will throw soil inwards.

And if you look at, the gangs are making an angle which are denoted as α_f, α_f, They are same. These are called gang angle which is equivalent to your disk angle in case of a disk plough.

Then, the rear gang is also making an angle which is α_r, which is called rear gang angle and here also same thing. The two rear gangs will make the same gang angle.

Similarly, in offset disk harrow you can see the front gang is making an angle α_f, which is front gang angle and the rear gang is making an angle α_r, which is rear gang angle.

Here, the alpha f is lesser than alpha r, the reason is that means, the front gang angle is kept lower than the or lesser than the rear gang angle.

The reason is the front gang is operated in a more or less different soil conditions whereas, the rear gang, they work in a disturbed soil.

So, that is why rear gang can go to a deeper depth and can handle more volume of soil, that is why the rear gang angle is kept a little higher than the front gang.

So, these are all discussed.

Then if you look at those figures, you can see each gang comprises of certain components, which are very common, common to all these three types.

That means, it has a frame, it has a gang, it has a disk, it has a set of disks, then a spool, gang axle, gang angle mechanism, then scraper.

These are common elements, which are available in either in single acting disk harrow or double acting disk harrow or tandem disk harrow and the offset disk harrow.

The frame is there, is a rigid structure on which the gangs are fitted.

So, it will support the gangs, that the gang is nothing, but a set of disks which is mounted on a common shaft and the disks are separated by a spool.

Spool is nothing, but the flange tube which is mounted on a gang axle between every two disks.

The reason is it will prevent the lateral movement of the disk on the shaft.

Then disk. This is concave disk. The concave disk is circular concave steel plate which is used for cutting and inverting the soil. Partial inversion is there.

Then gang axle. This a shaft which is of rectangular or square cross section, to which the set of concave disks are fitted.

So, a single acting disk arrow will have 2 gangs. A double acting disk arrow will have 4 gangs, gang axle and an offset disk arrow will have 2 gang axles.

Then, gang angle mechanism, the mechanism by means of which the gang angles are adjusted.

So, I will discuss in detail later on about this.

Then scraper. Scraper is required for removing the sticky soils, the soils which are sticking to the disk, those are to be removed otherwise draft requirement will increase and there will be no inversion or pulverization.

So, these are the common elements available in all types of disk arrow whether it is a single acting disk harrow, double acting disk harrow or offset disk harrow.

Then the typical sizes and masses of disk harrows. If you look at the table, I have given in the table the diameter, what is the spacing between two adjacent disks, then what is available width and then what is the mass per unit of width that means, kg per meter.

So, if it is a tandem type mounted one, then the blade could be 41 to 56 centimeter. 41, 46, 51, 56 cm, these are diameter of the blade, disk blade.

Then the spacing is between 18 to 23 cm and the available width is from 1.5 meter to 4 meter. These are all dependent on the size of the tractor.

Then mass per unit width is 150 to 270 kg per meter.

If it is a light duty tandem wheel type disk harrow, then again the diameter is 46, 51 and 56 centimeter and the spacing is again 18 to 24 centimeter and available width is from 2.4 to 6.4 meter and the weight is 270 to 370 kg per meter.

Then, similarly there are other types like tandem wheel type medium duty. Then heavy duty tandem wheel type. Then offset pull type when there is no wheel.

So, these are all given here.

So, while designing, these information will be required. So, that is why, I have summarized in this table.

If you look at the offset pull type with wheels, the diameter varies from 56 to 71 centimeter, and the spacing is 23 to 28 centimeter. Bigger the diameter more spacing is given.

So, spool size is bigger and blade spacing is 23 to 28 centimeter then width you can say, available width is from 2.1 to 7.3 meter and mass per unit width is 400 to 750 kg.

If you look at the mass the mass is very high in the sense because the disk harrow, the vertical force, when we will talk about what are the forces acting the vertical force is always acting upward.

So, in order to have the vertical force downward, we have to add extra mass or we have to increase the weight.

So, that 'V' is acting downward and then the disk harrow can properly penetrate into the soil.

Some information which are relevant while designing a disk harrow, I am giving you.

The wider units of disk harrow have hinged outer sections that provide flexibility during operation in uneven fields and they can be folded upward hydraulically to reduce the width of transport.

So, if you are going for bigger sections, then they are to be made in sub section.

So, that portion of the disk harrow can be lifted during transportation.

When a disk harrow has wheels, the hitch between the frame and the tractor driver must be rigid or semi rigid in the vertical direction to provide uniform depth control for front and rear gangs.

Then, the bearings on disk harrow gangs are subjected to both radial and thrust loads and they operate in dirt condition. Since it is engaged with soil most of the disk harrow gangs have sealed ball bearings.

Tapered roller bearings are provided with wheels.

The larger sizes and wider spacings are preferable for cutting of heavy cover crops and they permit greater operating depth than the smaller blade.

The maximum operating depth for a disk harrow is usually about one fourth of the disk diameter.

It is only the lower portion of the disk is engaged with the soil.

So, if you want more depth, you have to have more diameter.

Smaller diameter disk penetrates more easily than do larger disk. So, that is because they require less vertical force to hold them to a given depth.

Reducing the concavity that means, larger radius of curvature and sharpening the disk from the concave side rather than the convex side that helps in increasing the penetration.

Some disk harrows are equipped with cut out or notched disks.

The reason is : cut out disk will penetrate a little better than plane blade because of reduced peripheral contact area and it also helps to cut the grasses or weeds in the field.

Usually one cut per each 2.5 centimeter of radius is provided.

So, let us now see what are, what are the forces acting and how these forces are represented, whether it is a disk blade of a harrow or disk blade of a plough, what are the forces acting and how they are represented?

In fact, there are two ways of representation. The first way is : if you look at this figure, there will be a radial force which is the resultant of radial force is denoted as U with the resultant of M and V_v. V_v is the vertical soil reaction and M is the soil reaction parallel to the face of the disk.

So, resultant of M and V_v is denote as U which is called radial force and this radial force always acts little behind the center line of the disk to create a torque. So, that it can overcome bearing friction and at the same time it will help in rotating the disk.

So, this is one important soil reaction force. Then the other force is T, which is denoted here, thrust force, is coming from the soil side.

So, it is always acting below the center line of the disk. This is the center line of the disk.

So, T is always acting below the center line of the disk.

So, you can represent U and T. And this kind of presentation is important while calculating the load coming on the bearings.

The other type is the normal one, the soil reaction result into three components. The longitudinal component L, lateral component S_s and the vertical component V_v. And the resultant of L and S_s is denoted as Rh. So, we generally represent R_h and V_v because these two forces are non-intersecting.

So, they will create a torque, which will cause the disk to rotate. Rotate about an axis parallel - axis along the direction of travel.

So, these are two different ways by which you can represent the forces, which are acting on a disk blade, whether it belongs to a harrow or it belongs to a disk plough.

So, after knowing the forces and how they are acting, so, I am giving you a problem, a tandem type disk harrow has 11 disks of diameter 50 centimeter in each gang and each gang axle is supported by 2 tapered roller bearings.

While working at a gang angle of 20 degree, the resultant effect of soil reactions to the to produce a radial force of 60 kg at an angle of 45 degree and an axial thrust of 100 kg acting at a distance of 20 centimeter below the canter of the disk.

The total weight of the rotating assembly per gang is 300 kg and the coefficient of rolling resistance is 0.45.

Assuming that the radial force passes through the center of the disk, we have to calculate what is the radial load on each bearing, then the thrust load on each bearing and total power required to pull the harrow at a speed of 4.5 km/h.

So, this is a double acting disk harrow or a tandem disk harrow that means, there are 4 gangs of disk.

Now, we only concentrate for one gang, then we just multiply or divide depending on whether you require total draft or not.

So, what exactly we will do is, we will try to indicate the radial force, which is acting which is denoted here as R_f. So, in a gang there will be 11 disks.

So, that means, total radial force acting will be 11×60. So, that way it will give you 660 kg.

So, this will be acting, the angle has been denoted as 45 degree ok.

Now, the weight for each gang which is denoted as 300 kg.

So, 300 kg weight and the radial force is acting.

So, I am representing this R_f, R_f will be acting along the center of the central disk that is 6th disk from the either end.

So, there are 11 disks. So, if you count from either left side right side does not matter. It will fall on the 6th disk from either of the ends.

So, the weight of the gang is 300 kg and it will be acting vertically downward.

So, the resultant will be - resultant radial load will be equal to

$R = \sqrt{660^2 + 300^2 + (2 \times 660 \times 300 \times \cos 45°)}$ that will give you the value of R. And I say in the question is given is R : is passing through the center of the disk.

So, the first part, radial load on each bearing will be equal to this radial load divided by 2, because each gang is supported on 2 bearings.

So, that is why. So, the total radial will be - radial force will be divided by 2.

So, that will be the radial load on each bearing.

Now, the second part is total thrust load on each bearing.

So, thrust acting on each disk is 100 kg that is given in the question.

So, there are 11 disks. So, total thrust load will be 1100 kg, ok.

So, then, since this is a tandem disk arrow this thrust load will be balanced. Because the 2 gangs will oppose each other.

So, that is why the thrust load will be balanced.

Then the last question which was asked is total draft.

Total draft, total drawbar power.

So, for calculating drawbar power, we have to know what is the total draft required for pulling the implement.

So, then if you know the draft, you know the forward speed is given. So, we can find out what is the drawbar power which is required.

Now, total draft is nothing but some of horizontal components of the forces acting on each gang.

What are the forces acting?

Your radial force 660 kg. That radial force is acting and it is acting parallel to the face of the blade.

So, I have indicated this is acting at an angle 45 degree.

So, the horizontal component which is parallel to the face of the blade will be 660 cos 45°.

Then draft will be along the direction of travel.

So, this will be your draft and the gang angle is given as 20 degree.

So, now, this has to be converted to this component that means, 660 cos 45°, its component along the direction of travel will be again cos 20°.

So, that is why, it is written 660 cos 45° × cos 20° that gives you 438.5 kg.

This is only from the radial load. The other part is rolling resistance.

Rolling resistance, the coefficient of rolling resistance value is given. Coefficient of rolling resistance is defined as rolling resistance divided by weight.

So, total weight coming on each gang is 300 kg.

So, that is why, I have multiplied coefficient of rolling resistance 0.45 × 300. So, that becomes 135 kg.

So, the total resistance will be sum of this component and this component.

So, total resistance will be - which will be equal to your draft is 573.5 kg.

Now, to find out power requirement for 4 gangs, so this draft has to be multiplied with 4.

So, that becomes - because there are 4 gangs, so, 573.5 kg × 4 that gives you 2294 kg and if you convert into kilo Newton, it will be 22.50 kN.

Now, you know the forward speed. Draft × forward speed, that will give you in kilowatt, the power requirement in kilowatt.

So, 22.5 × 4.5, is the speed which is given at which the disk harrow has to be operated and this 10 by 36 is nothing, but the conversion factor to make it kilo Newton meter per second.

So, that becomes kilowatt. So, that way we are getting a value of 28.125.

Next we will see how the soil reactions L, V and S, they are varying with disk angle. Disk angle means your gang angle.

So, the x axis is your disk angle, which is varying from 10 degree to 35 degree and then the y axis it is a force L V and S. If you look at this L, V and S they have been measured for a single disk in sandy soil at 8.4 per cent moisture content.

And, it is operated at 4 kilometer per hour at a 0 tilt angle.

So, what you observe here is, all these 3 forces they try to reduce, that means, they will reduce with increase in disk angle up to 23 degree. After that the reduction is very minimal.

So, up to 23, 25 degree what happens exactly is, the contact area between the convex that means the back side of the disk and the furrow wall is decreased.

So, that is why, the force requirement is decreased.

The total vertical force for a pull type disk harrow without wheel is approximately equal to the gravitational force on the implement and any added masses, ok.

So, for a pull type disk harrow, what is the total vertical force - that is equal to the gravitational force.

That means, what is the weight of the implement and if there is some weight added, then weight of the implement plus that weight that will give you the value of V.

If a disk harrow has wheel or it is tractor mounted, the mass of the implement merely establishes the maximum vertical force for the condition when the wheels or tractors are carrying no vertical load from the implement.

Some typical values of this L/V ratio that means, draft by vertical soil force ratio and side draft by vertical soil force ratio have been given for different disk angles starting from 15 to 23 degree and the disk sizes 46 centimeter to 56 centimeter.

Then what you can observe here is, for 46 centimeter, it varies from 0.5 to 1.2 L/V and the 46 centimeter S/V ratio varies from 0.6 to 1.55.

Whereas, L/V ratio for 56 centimeter disk is varying from 0.7 to 1.5 and it increases with increase in disk angle.

Similarly, S/V ratio also varies from 0.15 to 1.4.

So, if you compare these two disks 46 and 56 cm, you can see the L/V ratio is higher in 56 centimeter disk as compared to 46 centimeter disk. Whereas, the S/V ratio is lesser, lesser than the 46 centimeter disk.

Then forces acting upon a disk harrow.

What we have discussed so far is the forces acting on a single disk.

Now, we will see the what are the forces acting on a disk harrow as a complete gang.

So, what we do is the combined soil reactions for a group or a gang of disk, it is considered to be acting upon a single disk, a blade in the average position of all blades, that is, at the center of the gang.

The forces acting on the disk harrow are the resultant soil reaction on each gang, then the force of gravity acting upon the implement and any extra mass added, then supporting soil forces provided by wheels or as a result of being mounted on a tractor, then the pull of the power source. These are the forces acting.

For uniform motion, these forces must be in equilibrium.

If there is to be no side draft, the sum of side components of all soil reactions must be equal to 0.

Let us now see what are the horizontal forces acting on a disk harrow - offset disk harrow.

So, if you look at this figure there are 3 hitch points given F 1, F 0, F 2 and the 2 gangs, front gang and the rear gang.

The soil reactions are given and the resultant soil reaction is this one and this is R_{hf}, this is R_h.

So, if you extend it, they will meet at a point, this point is called horizontal center of resistance.

So, when there is no side draft that means, the horizontal center of resistance point. H and the hitching point F0, they are in one line that means, F 0 is ahead of H.

So, there will be no side draft.

So, if you resolve R_{hf} and R_{hr} into components like L_f longitudinal component, S_f side component, S_r L_r, this S_f will be equal to S_r and there will be no side draft.

So, the draft will be equal to P_x which is summation of L_f plus L_r.

Now, we will see another condition, where the hitch point has been moved from F 0 to F 2 that means, the disk harrow has been moved towards the left side.

So, what happens, the line of pull will change. The point - hitching point F 2 is no more in front of H. So, there will be an inclination that is denoted as Ph.

And because of that what will happen, the equilibrium is just disturbed. Equilibrium between the forces acting on the disk harrow is disturbed.

So, what will happen, the front gang will try to increase the disk gang angle, the rear gang will try to reduce the gang angle.

So that the S_f minus S_r will take care of the horizontal component of pull which is denoted as P_y.

Another condition is the offset condition extreme right that means, the hitch point has now been moved from F 2 to F 1.

So, the line of pull is this one.

So, it will have a component - horizontal component P_y that means, the pull will have two component P_y and P_x. So, what will happen?

Then again the equilibrium is disturbed and the front gang will reduce its gang angle, the rear gang will increase its gang angle.

So that the difference of S_f and S_r will take care of this P_y, Ok.

So, total included angle in these two extreme conditions will remain same only the front and the rear will re-adjust.

So that the horizontal component of pull will try to take care of the difference in side forces and the draft will be again summation of L_f and $L_{r,}$ that is the longitudinal component of resultant soil reaction.

Then coming to the vertical forces, which are acting on a pull type offset or tandem disk arrow, these are 2 gangs you can see the line of pull is this, this is the line of pull.

So, intersection of line of pull and the weight which is acting, they will meet at a point G. So, G and the resultant soil reaction - in the front gang R_{vf} and R_{vr}, they will adjust themselves to pass through G.

So, if you increase this line of pull to say from F 0 to this point.

So, what will happen, the G will move towards the front gang that means, the front gang will have more depth of operation rather than the rear gang.

So, this is all about the different forces which are acting.

Now this problem will take up little later.

And this is the couple which is acting. There are two couples acting. One is because of the thrust force that will be a T' which will be acting at the center of the gang.

Then for vertical force V, there will be a weight acting W. So that two torques which are acting will be equal to W’ into H and T into F, they will balance each other.

$$W'h = Tf$$

In case of single acting and tandem disk harrow to obtain uniform penetration by having the couples of the laterally opposite gangs counteract each other.

So, that is the plus point for single acting and double acting disk arrows.

A couple of the front gang in an offset disk arrow is usually larger than that of the rear gang. This is because of the operation of the front gang in hard soil as compared to the operation of the rear gang.

So, in conclusion I can say I had briefly discussed the types of disk harrow, then force representation for a disk blade, force acting on disk gang, disk harrow, horizontal forces, vertical forces. Then some numerical problems we carried out, then what are the couples acting.

Then, couples acting on a disk harrow. These are all discussed in this lecture.

Thank you.