Design of Farm Machinery

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Lecture – 19 : Draft and power requirement of combination tillage implements

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 19, where I will try to cover some of the active-passive combination tillage implements - how they operate, and then we will cover important parameters like draft and power requirements of combination tillage implements. The concepts to be covered are the performance of active-passive combination tillage implements, then we will discuss the draft of combination tillage implements, followed by an important parameter called draft utilization ratio, then specific work of combination tillage implements, and finally, the power requirement of combination tillage implements. In the last class, we discussed the passive-passive tillage implement and the passive-active tillage implement.

This is an implement that I am showing here - it is an active-passive tillage implement. That means the front - this is an offset disk harrow. The front gang has been powered by taking power from the PTO, and the rear gang is unpowered. This has been developed at IIT, Kharagpur. I will show you the operation. The front gang is powered by taking power from the PTO through a cardan shaft. You can see that it is rotating, and this is how it is operated in the field. Now, the same implement is being operated in a grassy land. You can see the height of the grass.

So, the offset disk harrow is simply cutting those grasses and mixing them with the soil. And the front gang, you can see the degree of pulverization. The soils are just thrown after tilling. So, the field condition, if you look at it - this was the first one where the land is harvested, and the stalks are available. And during one pass of CODH, CODH means combined offset disk harrow, you can see the soil condition. The right side is with only offset disk harrow, which means it is not powered, an ordinary disk harrow, one pass. Now, if you operate twice in the same soil, you can see the soil condition - two passes with CODH and two passes of ODH, offset disk harrow.

So, you can see the difference. Visually, you can very well mark that. A CODH gives better tillage, which means soil clod sizes are smaller than those of your offset disk harrow, which is a non-powered, free-rolling offset disk harrow. Now, performance-wise, again, we try to compare; only visualization will not help. So, we measured different parameters like the volume of soil handled, fuel energy, then cone index before and after, then Δ CI by CI_b. So, Δ CI by CI_b, then soil inversion, and fuel energy. And then you combine like tillage performance index is proportional to the volume of soil handled, it is proportional to the reduction in the cone index value, it is proportional to the soil inversion, and these are directly proportional, and it is inversely proportional to the fuel consumption or the fuel energy consumed.

Now, this will be equal to K into - a constant into all these factors - and that constant, when you try to compare your tillage implements by operating in the same field condition and operating conditions, then that constant can be taken as 1, and it becomes easier for us to compare. Now, if you look at this - this has been operated at 3.46 km/h forward speed, CODH, and here the PTO RPM is changed. We did not change the forward speed; rather, the PTO RPM is changed. So that you are getting different u/V ratios. The bracketed term indicates the u by V ratios, starting from 4.59 to 2.91. So, these are the volumes of soil handled, and what you observed is TPI is maximum 90.18 in 133 RPM.

So, that means when the u/V ratio is 4.06, then you are getting the maximum TPI. Now, if you operate the offset disc free-rolling, which is not powered, at the same forward speed, you are getting a TPI value of 30.87. So, look at 90 and look at 30.87. So, that means there is a gain - a gain in terms of overall performance. So, that is possible because of the soil pulverization and inversion.

If you look at the inversion values, you can see 56% is the inversion with CODH, whereas, in the case of free rolling, it is only 28%. So, this is almost half. The same is the case in the reduction in cone index value: 0.66, whereas, in the case of free rolling, it is 0.36. So, that indicates that yes, CODH is giving you better benefits - overall benefits, more than what we are getting with free rolling ODH. Similarly, we carried out the field operation of CODH at 4.55 km/h and 6.82 km/h, then we compared. Everywhere you can see, if you compare these values with this value, you can say 92.85 is the maximum TPI you are getting. Whereas, in the case of a free rolling disk, you are only getting 44.10, that means there is a gain. The gain is just double, you can say, and the same is the case here: 78, 79, 63, but the increase you are getting is only 59.

So, from this, we can conclude that an active-passive tillage implement is better than a passive tillage implement. The only thing is, when you are operating the active-passive tillage implement, you have to maintain a u /V ratio, where you are getting the maximum benefit. Even if you are running at 3.46, 4.55, 6.82, you can see there is one u/V ratio corresponding to this 3.46, where you are getting the maximum, which is 4.06. Similarly, at 4.55, 3.09 is the u/V ratio, that means the u/V ratio of 3 to 4 will give you the maximum TPI. What is the percentage reduction as compared to - when you compare CODH when you are operating this at the same forward speed at an rpm of 133 in the case of CODH at a depth of 12 centimeters, you can see the reduction in slip value.

So, at a forward speed of 3.46, the reduction in slip value is 79.55, that means the draft value has been reduced. So, there is no slip. So, the slip value is reduced. Reduction in draft is 51.63%, reduction in CI value is 46.9%, reduction in mean wet diameter, that means you are getting a lesser clod size. The CRBE - increase in CRBE, that means crop residual burial efficiency. Crop residual burial efficiency means what is the inversion, indirectly it gives.

So, the increase in fuel consumption is the only factor. There is an increase in fuel consumption, but corresponding to the increase in fuel consumption, the gain which you are getting for all these parameters is quite substantial. The same is the case here. When you are operating at 4.55 km/h with a u/V ratio of 3.09, then when you are operating at 6.82 km/h with a u/V ratio of 2.06. Everywhere we can see the reduction, which means we are getting a better output with a lesser power requirement. So, in summary, you can say the use of a combination tillage implement, active and passive, gives you better performance as compared to your normal or conventional tillage implements. Then, two parameters which are very important in the case of tillage implements are the draft and the power requirement.

Draft - if you look at this figure which I am showing, there are two independent units I have shown, one is the disk harrow, the other one is a cultivator, two tines of the cultivator. When I simply pull it on undisturbed soil, I will experience a draft which is denoted as D_{fi}. I am only operating independently, only a single disk harrow. When I operate the cultivator, similarly, we are experiencing a draft which is denoted as D_{ri}. Now, when I combine this.

D_{fi} is the draft of the front passive set, D_{ri} is the draft of the rear passive set. So, when I combine this and try to pull it, then the total draft will be D_c. D_c can be written as,

$D_c = D_{fc} + D_{rc}$ where, D_{fc} is the draft of the front passive set when operated in combination tillage. And D_{rc} is the draft of the rear passive set when operated in combination tillage, but D_{rc} and D_{ri}, they are not the same. The reason is D_{ri} is the draft of the passive set when it is operated in undisturbed soil, but when you are combining two tillage implements and try to pull it, what happens is the draft of the rear passive set is operated in disturbed soil, initially it was undisturbed.

Now, when you are operating in a combination that is operated in disturbed soil. So, D_{rc} is not equal to D_{ri}. So, we have to write it in a different way. Different way means the draft of combination tillage implements is equal to the draft of the front passive set when operated independently and individually, plus we are multiplying a coefficient here into D_{ri}. That means, D_{rc} is replaced with a factor λ into Dri. So, the λ will take care of the disturbance of soil. So, we can say that the draft of a combination tillage implement will be equal to the draft of the front passive tillage implement when it is operated independently and the draft of the rear passive implement when it is operated independently, multiplied with a fraction or a coefficient which is denoted as lambda, and lambda is called the draft utilization ratio. $D_c = D_{fi} + \lambda D_{ri}$

Now, specific draft, which is nothing but draft for unit cross-sectional area of soil disturbed for a passive-passive tillage implement. In the case of a combination tillage implement, I can write this specific draft of Ac, $A_c = A_{fc} + A_{rc}$. This is I am talking about two tillage implements combined together, and the two tillage implements are passive tillage implements. So, that way I am getting an expression: $A_c = A_{fc} + A_{rc}$. A_{fc} is the specific draft of the front passive set of the combination tillage implement, and A_{rc} is the specific draft of the rear passive set of the combination tillage implement. Now I can write the specific draft of the combination tillage implement in a different way, as I said in the draft expression.

So, $A_c = A_{fi} + \lambda A_{ri}$. So, A_{fi} is nothing but the specific draft when it is operated individually, that means in undisturbed soil. Whether it is operated in combination, it will also operate in undisturbed soil; whether it is operated independently, it will also operate in undisturbed soil. That is why I can write A_{fc} as A_{fi}, and when I try to replace A_{rc} with A_{ri}, that means A_{ri} refers to undisturbed soil. So, I cannot write that because in a combination, always the second set of implement will be operating in disturbed soil. So, I cannot write in place of A_{rc} as A_{ri}. So, I have to multiply with a coefficient that is denoted as λ.

And the λ is the fraction of draft of the rear passive set operating as an individual implement and is named as the draft utilization ratio for the rear passive set. For various passive-passive combination tillage implements, the maximum value of lambda can be taken as 1. So, the value of λ is - it cannot be 0. It has to offer some draft. So, it cannot be 1 also. So, that means it is lying between 0 and 1 and depends on many factors like the type of soil, the width of the implement, the type of rear passive implements, the bulk density, speed, cone index of soil, and depth of operation. The total specific draft of the combination tillage implement can be expressed as $A_c = A_{fc} + A_{rc} = A_{fi} + \lambda A_{ri}$ Now, the draft utilization ratio for the rear passive set can be expressed as:

So, the draft utilization ratio, lambda, will be equal to - if you look at this expression, if you compare these two expressions, now A_{rc} will be equal to - now if you compare these two, you can see because $A_{fc} = A_{fi}$, now $A_{rc} = \lambda \times A_{ri}$ or $\lambda = A_{rc}/A_{ri}$. So, that is what I have written here. And A_{rc} I am replacing it with draft per unit cross-sectional area. So, A_{rc} will be D_{rc}/a_{rc}. So, that will represent A_{rc}, which is the specific work. Then A_{ri}, I can replace as D_{ri}/a_{ri}. Now, if you rearrange this, assuming Drc, the draft of the rear combination tillage implement, $D_{rc} = D_c - D_{fc}$, which means the total draft is $D_{fc} + D_{rc}$.

Now, if I replace D_{rc} with $D - D_{fc}$, that is what I have done here, and D_{fc} is equal to D_{fi} when it is operated in combination or independently, then I can write $D_{fc} = D_{fi}$, and a_{rc} depth in combination is equal to depth in independent, individually when it is operated, then the equation will be reduced to $\lambda = (D_c - D_{fi})/D_{ri}$. Now, the depth factor is lost. So, it is basically the change in draft divided by the draft of the second set of implement when it is operated independently. So, in other words, we can say Dc, the draft of the combination tillage implement, is equal to the draft of the front set when it is operated independently plus lambda into D_{ri}, ($D_c = D_{fi} + \lambda D_{ri}$). This I have explained at the beginning, and that I have proven it. Now, what will be the power requirement then?

Once you know the draft of a combination tillage implement, that means knowing the draft of individual tillage implements and knowing the value of λ, you can find out what the total draft of the combination tillage implement. Then, multiplying by the forward speed - the forward speed of the tractor - will give you the power requirement. Let us now see. So, these are explanations and then the draft of a combination tillage implement. Let us solve a problem that will further clarify the measurement of draft and how to utilize this combination draft of a combination tillage implement and then what the power requirement is.

The draft of a combination tillage implement comprising a moldboard plough in the front gang and a disk harrow in the rear gang, when operated at a forward speed of 3.5 km/h and a depth of 15 centimeters in sandy clay loam soil, the draft value is given as 4 kilo Newtons. For the same operating conditions, the draft of the moldboard plough when operated alone is 3.3 kilo Newtons, and the draft utilization ratio is given as 0.6. What is asked is to compute the power requirement of the disk harrow without the moldboard plough for the same operating conditions. Compute the power requirement of the disk harrow. So, what is given? The total draft D_c is given as 4 kilo Newtons, and the draft of the front gang is given as 3.3 kilo Newtons. So, we know that the draft of the combination tillage implement, $D_C = D_{fi} + \lambda D_{ri}$

So, D_{fi} is given, λ is given, which is the draft utilization ratio. So, from here, you can find out the draft of the harrow, which is in the second gang when it is operated independently. That means (4 - 3.3)/0.6. So, that will give you the draft of the disk harrow. Now, what is asked is to calculate the power requirement of the disk harrow without the moldboard plough. So, that means the power requirement will be D_{ri} multiplied by the forward speed. So, this is how we have to find out the power requirement.

Now, these are the solutions you can see. So, we are getting a draft of 1.167 kN, then when you multiply it with the forward speed of 3.5 kilometers per hour. So, the power requirement of the second gang is 1.16 kilowatts. If you want to find out the total power requirement, just simply multiply the total draft, which is given as 4 kilo Newtons, with the forward speed of 3.5 kilometers per hour. So, you can replace this one with 4 into 3.5 into 1000 by 3600, that will give you the value of power requirement for the combination tillage implement.

Now, let us see the draft of the passive-active combination tillage implement. Whether it is passive or active or active-passive. So, this is the schematic diagram. Here, we have taken specific work, that is, the work done by the combination tillage implement during one revolution. In one revolution of the active shape, what is the work done?

So, the work done is the sum of the specific work done by the passive set and the active set, which can be expressed $A_C = \lambda_P A_P + \lambda_A A_A$. Here, A_C is the specific work of the combination tillage implement, A_p is the specific work of the passive set operating as an individual implement. and A_a, A suffix a, is the specific work of the active set operating as an individual implement. Here, the active implement is on the back side, that means, the rear side, and the coefficients λ_P and λ_A, the fractions of specific draft of passive and active tillage implements acting as individual implements. The values of this λ_P and λ_A, are less than or equal to 1. Why I said less than or equal to 1 means λ_p, since it is in the front side it will be equal to 1 whereas, λ_A is not equal to 1 it is always less than 1. So, that is why I said less than or equal to 1. Then A_C can also be written as that means, specific work of the combination tillage implement can be expressed as summation of specific work of combination tillage resulting from pulling resistance and specific work of combination tillage implement resulting from torque. So, one is because of pulling the implement the other one is because of the torque requirement for rotating the blades.

So, that I have denoted as A_R and A_T. So, A_C can be written as A_R plus A_T and comparing the two equations what you can - two equations - we can write $A_C = \lambda_P.A_P + \lambda_A.A_A$. Now, if you compare these two equations, so we can write that $\lambda_P.A_P = A_R$ and $\lambda_A.A_A = A_T$. Draft of combination tillage implement will be equal to - combination means this is active-passive combination or passive-active combination. This will be equal to draft for pulling the implement D_p and this D_x is nothing, but the horizontal component of soil resistance which is acting on the tip of the blade when the rotavator is rotating. So, that becomes D_x. So, D_p plus D_x Now, D_p is the draft of passive implement in combination tillage implement and D_x is the horizontal component of peripheral force acting at the shaft of the active implement.

Then specific work of individual implement using combination tillage can be calculated according to the formula given below.

$$A_P = \frac{D_P}{a_P b_P}$$

D_P is the draft corresponding to the soil resistance of passive implement - pulling resistance and a_P is the depth, b_P is the width -width of passive tillage implement.

$$A_R = \frac{D_C}{a_C b_C}$$

D_C is the combination - draft of combination implement, a_C is the depth of combination, b_C is the width of combination tillage implement.

$$A_A = \frac{2\pi T_A}{a_A b_A l_g}$$

Then A_A because of the rotation that means, the powered unit which is rotavator.

So, that specific work, we can write as $2\pi T_A/a_A b_A l_g$. a_A is the depth, b_A is the width, and l_g is the distance traveled in one revolution of the rotavator.

Similarly, $$A_T = \frac{2\pi T_C}{a_C b_C l_g}$$

$$l_g = \frac{2\pi V}{\omega}$$.

That means, if the rotavator is operating at, say, n rpm, so in 1 second, it is covering n by 60. So, if the forward velocity is V, then in 1 second, the forward velocity will be V into n by 60. 60 by N, sorry.

If the RPM of the rotor is N, that means, in 1 minute, there will be N revolutions, ok. So, in 1 second, how many revolutions is it making? What we are finding out is, in 1 revolution, what is the distance? That means, how much time is required to cover 1 revolution? That will be 60 by N, okay. So, 60 by N into V will give you the distance covered. If I multiply with 2π in the numerator and denominator, that becomes 2πV, 2πV by 2πN by 60. So, this 2πN by 60 is nothing but ω. So, that way, lg will be equal to $2\pi V/\omega$. Now, some of the explanations related to AP, where suffix P, A, and C indicate the passive, active, and combinational tillage implements, then a is the depth of operation, b is the width of the implement, D is the draft of the implement, T is the torque acting on the implement, then the travel length covered by the combinational tillage implement in one full revolution of the shaft, V is the forward speed, and ω is the angular speed. Now, if you substitute λP, λP will be equal to aAr by Ap because we know that λ just $\lambda_p.A_p$ is equal to A_r. So, $\lambda_p = A_r/A_p$, and $\lambda_a = A_t/A_a$. So, now, you substitute this here in this equation. So, A_r/A_p I substitute with the values which we just now derived,

$$\lambda_P = \frac{A_R}{A_P} = \left(\frac{D_C}{a_C b_c}\right) / \left(\frac{D_P}{a_P b_P}\right) = \left(\frac{D_C}{a_C b_c}\right)\left(\frac{a_P b_P}{D_P}\right)$$

Similarly,

$$\lambda_A = \frac{A_T}{A_A} = \left(\frac{T_C}{a_C b_C l_g}\right) / \left(\frac{T_A}{\alpha_A b_A l_g}\right) = \left(\frac{T_C}{a_C b_C}\right)\left(\frac{\alpha_A b_A}{T_A}\right)$$

So, these are expressions for λ_P and λ_A. Assuming that both the - considering the width of operation of individual implements to be the same as that of the combination tillage implement. That is, width b_C will be equal b_A, and the depth of operation of the passive tillage implement to be the same as the depth of operation of the combination tillage implement, that means a_P is equal to a_C. So, the above two equations will be further simplified to:

$$\lambda_P = \left(\frac{D_C}{D_P}\right)$$

$$\lambda_A = \left(\frac{T_C}{T_A}\right)\left(\frac{a_A}{a_C}\right)$$

.

So, this is the simplified version of this coefficient λ_P and λ_A. Now, the next thing is what will be the power requirement, the power requirement for operating the combination tillage implements.

The total power requirement for operating an active-passive combination tillage implement, if you denote it as P_C, that will be equal to the sum of the power required to pull the combination tillage implement. If you denote it as P_P, then it will be the drawbar power. Now, the other component is the power required to rotate the active tillage implement, which is denoted as P_A. So, there will be a summation of drawbar power and the PTO power. So, I can write $P_C = P_P + P_A$, the power required to pull the combination tillage implement and the power required to rotate the active tillage implement. So, I can write P_C is equal to specific work into the volume per unit time. So, $A_C \times a_C b_C V$. So, that will give you the total power requirement of the combination tillage implement.

So, A_C, I can replace with $A_R + A_T$, and again $A_R + A_T$ can be replaced by $(D_C / a_C b_C) \times a_C b_C V + A_T$. In place of A_T, I am writing $2\pi T_C$ by A_C B C into l_g into a_C b_C into V. So, that way, if you simplify, this will cancel out. So, D_C into V, which is your drawbar power, and here $2\pi T_C/l_g$, lg we have already expressed in a different way. So, $a_C b_C$ will cancel out. So, here what we will get is we will get $2\pi T_C/l_g$ into V. So, l_g we have in the previous slide - we have $2\pi V/\omega$. So, if I replace this l_g with $2\pi V/\omega$.

So, V will cancel out, 2π will cancel out. So, what we get is $T_C \times \omega$.. That means, finally, you come to an expression for the total power requirement of a combination tillage implement. D_C, draft of the combination tillage implement into forward speed, this will take care of the drawbar power requirement, and T_C, the torque of the combination tillage implement, the power required to rotate the rotavator $T_C\, \omega$. So, the summation of this will give you the power requirement for passive-active tillage - combination tillage - combination tillage implement.

This is all about the power requirement and draft requirement, and in summary, you can say these are the references. And in summary, we can say the performance of active-passive combination tillage implement and the draft and power requirement of combination tillage implements, both passive and active, are discussed, and we derived an expression for the power requirement for active-passive tillage implement as well as passive-passive tillage implement. That is all. Thank you.