Traction Engineering
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Lecture 30
Measurement of Tractive Efficiency

Hello everyone, this is Professor H Raheman from Agricultural and Food Engineering Department. I welcome you all to this NPTEL course on Traction Engineering. This is Lecture 30, where we will try to cover on measurement of Tractive Efficiency.

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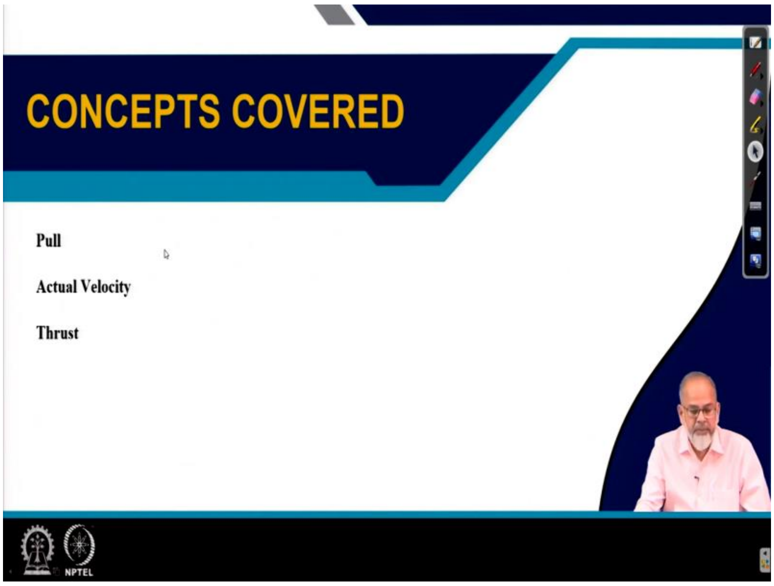

The concepts which I am going to cover is, what are the parameters which will be affecting tractive efficiency like pull, actual velocity and thrust and how to measure tractive efficiency when you get data related to these three parameters. So, the setup which will be used will be a single wheel tester and there we will try to vary pull, to vary the load, to vary the inflation pressure. In fact, tractive efficiency is a function of load, is a function of pull, is a function of soil condition, is a function of inflation pressure.

But for our purpose what I will do is, I will keep the load and soil condition same only, and inflation pressure also I will keep the same and I will only vary the pull so that what is the corresponding slip you are going to measure and then knowing the pull values, actual velocity values, slip value and the torque how much you have supplied and the rolling radius of the wheel. We can utilize those values to find out tractive efficiency.

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Now, I will show you how to evaluate the performance of a tractor tyre. So, the set of which is available here is a single wheel tester, only one will be tested at different operating conditions. When I said operating conditions, that means you have to vary the load, you have to vary the inflation pressure you have to vary the soil condition. Soil condition means the moisture content as well as the strength of soil that is cone index.

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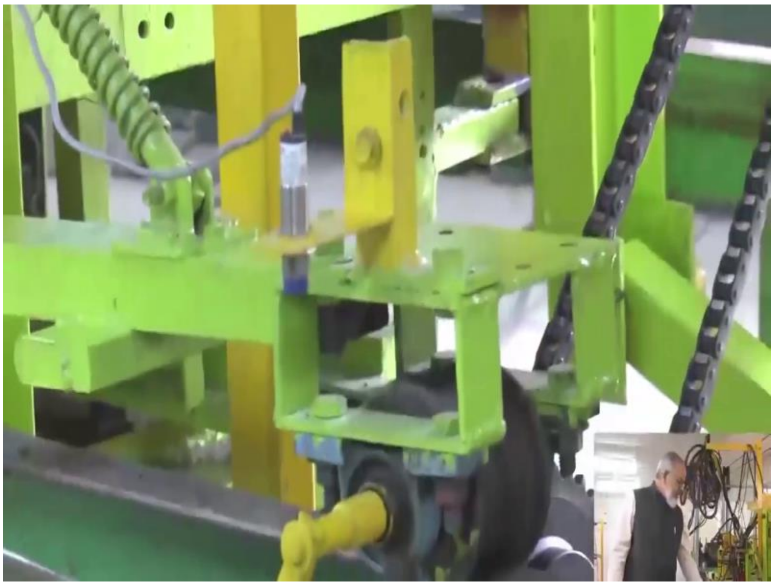

So, to vary the load, what we have done is we have added some external weights, it has its own, the setup has its own weight and suppose you want to test at 1400 kg then the extra weight which is required, we have to put it on this platform so that the entire weight comes on the wheel. Now, to vary the inflation pressure, we can put more here or you can remove air by which you can vary the inflation pressure of tire.

Then the power has to be supplied, that is the important thing. Power has to be supplied to the axle of the wheel. So, we have taken basically from an electric motor, three phase AC motor, so, 1450 RPM has to be converted into RPM which is corresponding to 2.5 or 3.5 km/h.

So, we have made some transmission arrangement, where the gears are, this sprocket chain and sprockets are provided which will give the positive drive, so there is absolutely no slip and then there is a gearbox. So, finally, we want more torque and low speed. So, that is possible with the help of this gearbox and the chain and sprocket drive. Then in addition to that, we need to measure the theoretical speed as well as actual speed.

So, for measuring actual speed, we have a proximity sensor here and there is a roller here with a metal bar. So, when the wheel moves forward, this is going to rotate and this bar which is provided here, when it comes in the closeness of this proximity switch, then there will be a signal sent to the output so that output will be stored in the computer.

So, you will basically measure the number of pulses and the corresponding time. So, number of pulses divided by time that will give you actual velocity. Then the most important thing is how much pull you are going to apply.

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So, we have to apply pull. For applying pull, we have a brake drum dynamometer, and a wire is wound over this and the end of the wire has to be connected to this frame with the help of a loadcell, so that loadcell will give you how much pull you are going to apply.

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So, we are connecting the wire which is wound around the back drum and then it is connected to the ring type loadcell. So, now we will apply load by using some external weight. So, this is a brake drum dynamometer. When I put some weight that means that will give tension to this wire. So, thereby it will try to exert pull on the total frame.

So, this frame is attached to the frame of the wheel. So, indirectly we are pulling the wheel from behind. So, that is going to give you how much pull you are applied and then corresponding to that pull how much will be the slip that we are going to measure.

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We have to apply a power to the axle of the wheel, to measure that power to the axle of the wheel, we need to know how much torque is coming. So, for measuring torque, we have installed a torque meter here and that will give you how much is the torque which is coming from this electric motor. Then knowing the transmission efficiency, we can find out how much torque is supplied to the wheel.

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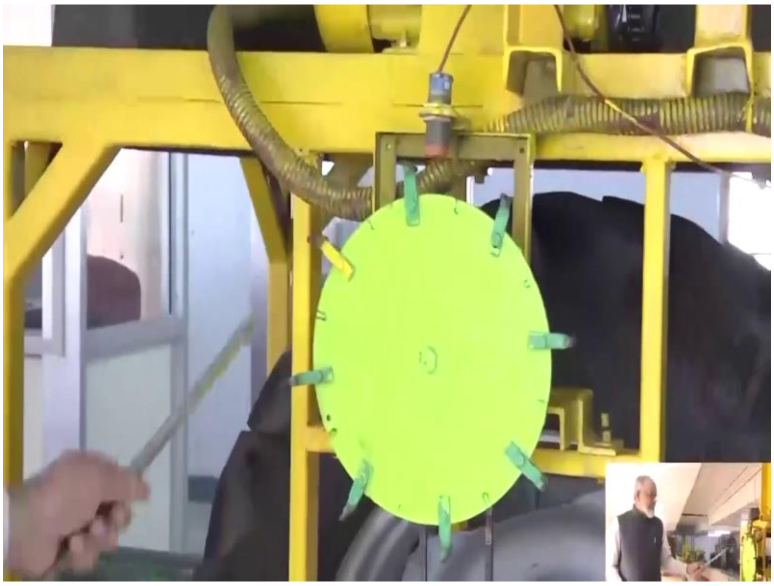

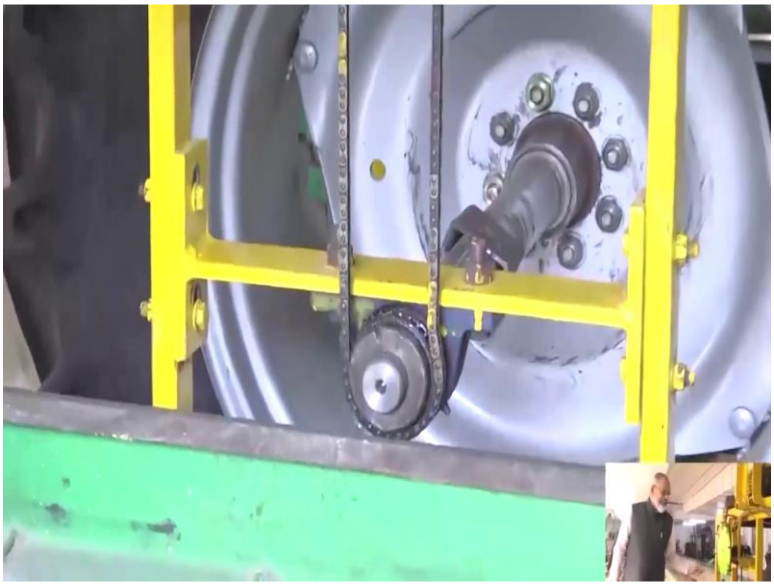

And next is the theoretical speed, the theoretical arrangement is again the proximity switch with eight spikes here which are provided. Each spike when it comes in closeness to the proximity switch then there will be a pulse generated and that pulses will be counted and that pulses will be recorded in the computer directly.

And knowing the time and the number of pulses we can find out how much is the theoretical speed of that wheel. So, we have a transmission here system, so you have maintained same gear ratio, so that whatever is the RPM of the wheel, same RPM is provided to the shaft, where this flat shaped plate is attached. So, there are eight spikes.

So, that means, in one complete revolution, we will get eight spikes. So, eight spikes means one revolution. If you know the time then you can find out what is the revolution per unit time. Now, I will show you what is the soil condition before starting the experiment on tractive performance of a tyre.

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So, you can see the soil bin, it is very labeled and we have already measured the cone index, the cone index value, our cone index value is coming around 630 kilo Pascal. So, we will start by switching on the power supply to the motor. Now, you have switch in power to the motor. So, power is transmitted, the wheel is moving, pull is applied and we will measure the actual speed, theoretical speed, pull and torque simultaneously.

Now, you can see the pull is perfectly horizontal. Now, you can see the pull is perfectly horizontal that means the line of action is perfectly horizontal. And we have already measured the different parameters like pull, actual speed, theoretical speed, torque, and then you can see the soil bin condition. After the operation you can get a clear print of the single wheel, you can see the footprint, footprint of the tyre.

So, if you are interested in finding out how much is the sinkage that also you can measure, because we know the level of the soil before and now how much it has inserted that means how much is the sinkage we can check the sinkage by using a pointer.

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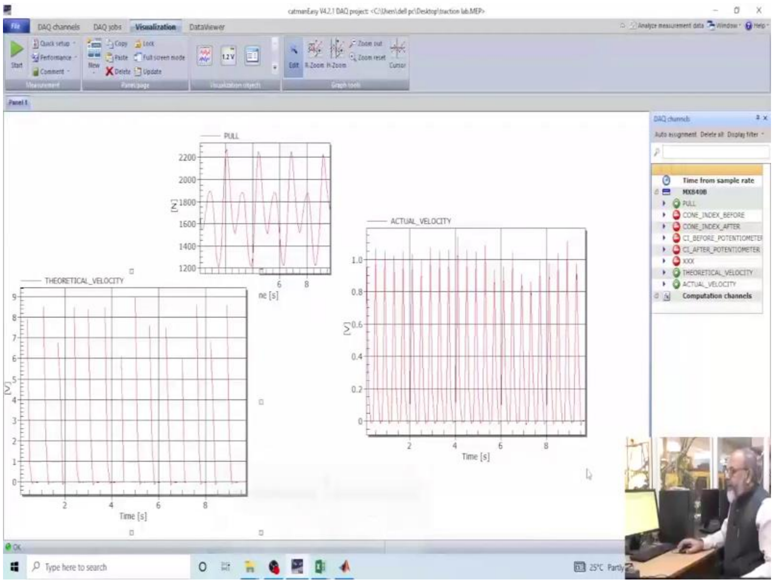

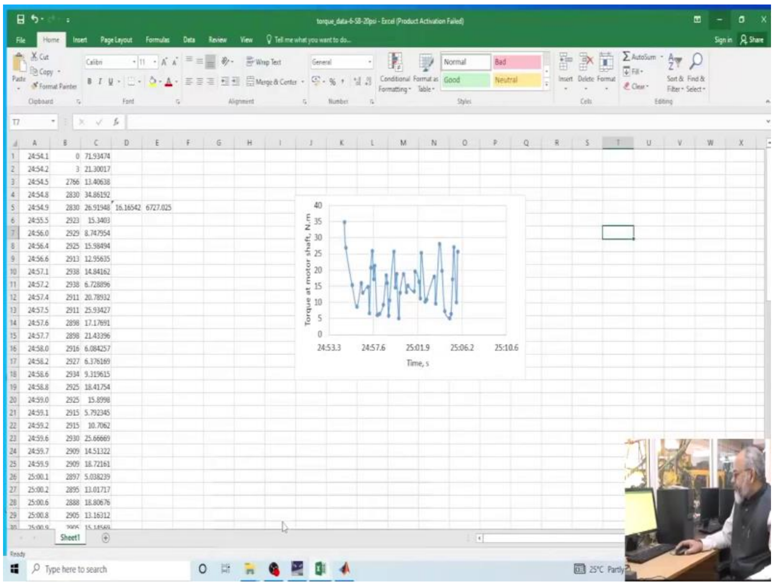

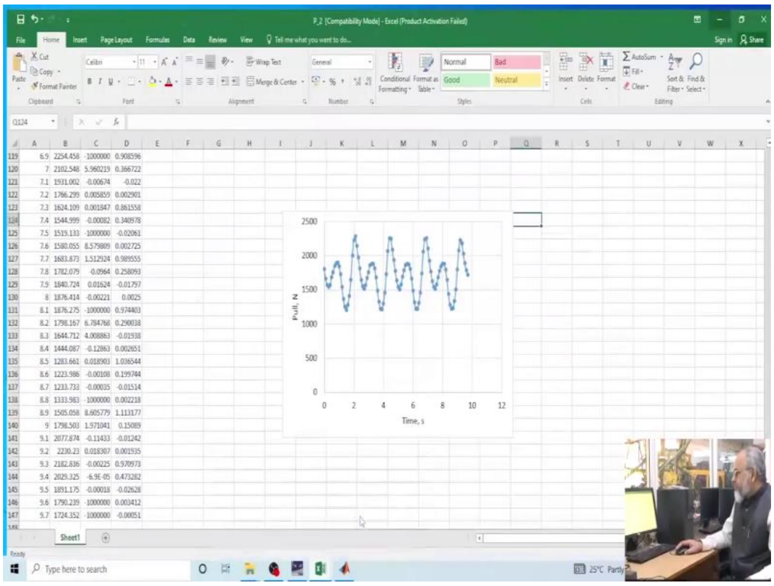

The data which you are acquired through a data acquisition system they are transferred to a computer and these are the direct plots. I can show you, plot of pull versus time, theoretical velocity that means number of pulses which are coming versus time, then what is the number of pulses coming for measuring actual velocity these three plots directly they are coming to the computer.

And in addition to that, we have plots of pull versus time, this is pull versus time. So, you can see how the pull is varying. So, you have to take the average pull, so you are getting a big pull here. So, and the minimum pull because this cyclic type of thing which is happening. So, either you have to take maximum pull all you have to take the other is pull, so it is better to take maximum pull because since you have exerted maximum pull, so corresponding to that there will be certain amount of slippage.

So, you are taking maximum pull here and then we measured torque. So, this is how torque is varying. So, you can take the average torque or you can take the maximum torque. So, we have the data related to pull, we have the data related to torque, we have done data related to the actual velocity which is coming around 0.703 m/s and we have data related to theoretical speed which is coming around 0.73 m/s.

So, now with these values, next thing is how to find out the coefficient of traction, then we have to find out what is the tractive efficiency. So, for finding out coefficient of traction we need to know the value of pull and the weight, weight total is coming on the wheel as 1400 kg. So, once we find out what is the maximum pull, then pull divided by weight will give you coefficient of traction.

Then to find out the tractive efficiency, we need to know the coefficient of traction value then we need to know the torque value because it is the ratio of drawbar power to axle power. So, axle power we can calculate by knowing the torque and the RPM, so Tω will give you the axle power and for drawbar power we know the pull we know the actual velocity, so $(P\times V_a)/T\omega$. So, that will give you the tractive efficiency.

When you will multiply with 100 so that will give you tractive efficiency in percentage. That means, we have measured coefficient of traction, we have measured slip, we have measured tractive efficiency, these are the parameters which are required to find out to the tractive performance of a wheel.

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Now, I will take the cone penetrometer reading after operation of the tire. Now, he has made it zero. So, this shows the zero level. Now, he has pushed the cone penetrometer into the soil. So, that will give you how much is the strength of soil after operation of the tire.

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We try to measure the sinkage level after the operation of the tire. So, initially I will take the depth of the soil surface which is not disturbed with respect to this rail and then again, I will take the depth with respect of that route which has been formed with respect to that. So, first I am getting 21.5, 21.5.

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Now, I will take the depth of that rod which is found at the center. What is the depth with respect to the rail? So, it is 19.5. They will also measure the cone index after the operation of the tyre. We measured the cone index value before the operation of the tyre and again, we will measure the cone index value after the operation of the tire. And the difference will give you what will be the compaction level after the operation of the tyre.

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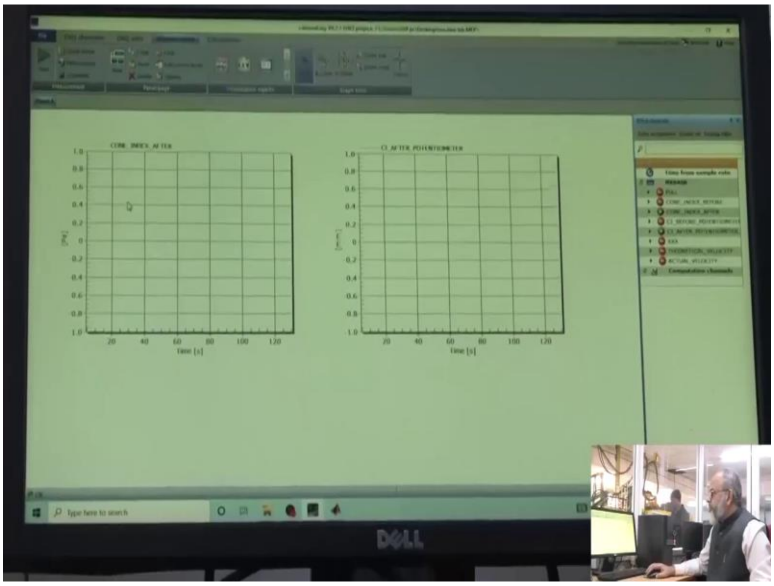

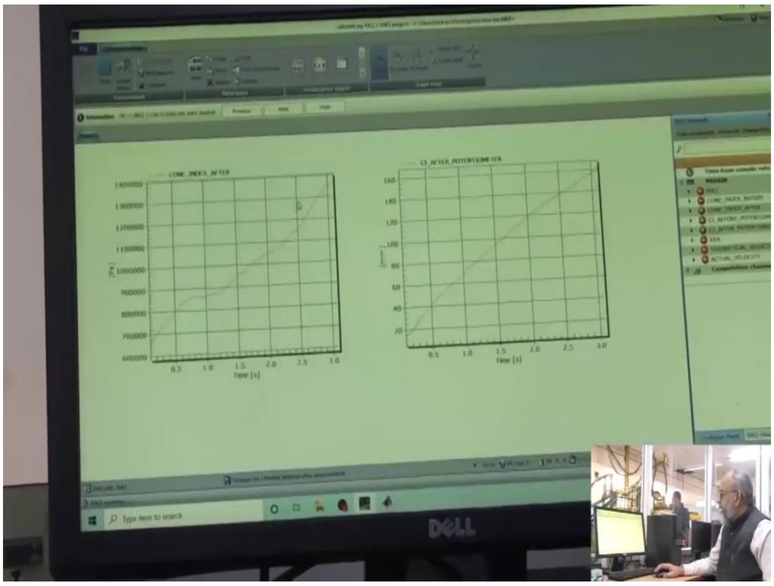

Now, I am going to show you how to measure the cone index after the operation of the tire. So, we will follow the same procedure what we have followed in case of cone index measurement before the operation. That means, initially we will see that the cone base should be flushed with the soil surface. So, that becomes the zero condition.

So, you can see there is no reading. Now, when I start this, we can see the cone index value is increasing as well as the depth is also increasing.

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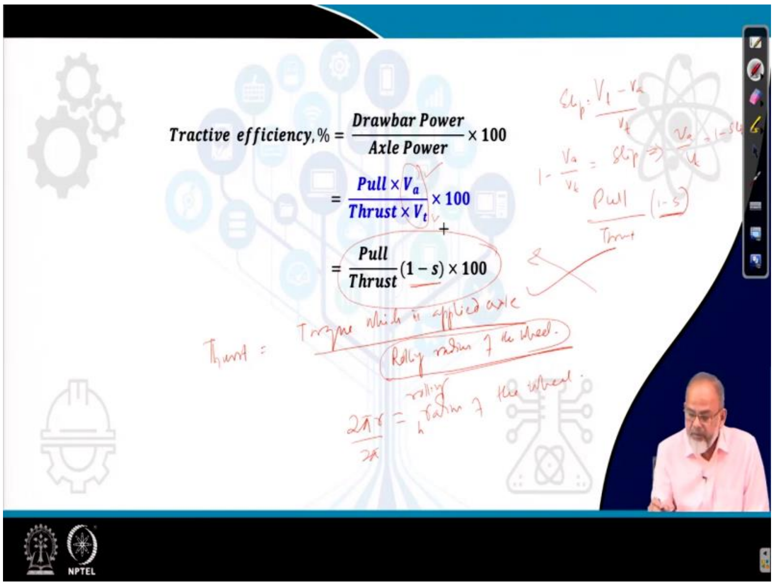

When I say tractive efficiency, it is basically how much power is obtained for a given input power that means it is the ratio of output power to input power. So, naturally efficiency will be always less than 100 percent. So, what is that input power? What is that output power? Output power usually call it as drawbar power, drawbar power is nothing but the product of pull into actual velocity, P × V_a.

And what is that input power? How much power is given to the axle? So, that we have measured using a torque transducer. So, torque transducer will indicate how much torque we are supplying. Knowing the theoretical speed, we can calculate what will be the value of input power or the axle power. So, if I put this in a different way, drawback power is equal to pull into velocity, actual velocity V_a.

And axle power has taken as thrust, thrust means the force which is developed because of the interaction of wheel with soil. When you are trying to give power to the axle of the wheel and the wheel will try to move forward, it will interact with soil. As a result, there will be thrust force which will be developed at the contact patch, contact patch of wheel and soil. And this is developed because of the interaction.

So, that thrust force is nothing but torque divided by the rolling radius of that wheel. So, if I want to calculate thrust, thrust is nothing but torque which you are applying to the axle, which is applied to the axle divided by the rolling radius of the wheel. So, for measuring the rolling radius of the wheel, we have to first find out how much distance the wheel is covering in one revolution.

So, if I measure that, then divided by 2π, that will give you rolling radius. This has to be carried out at zero slip. That means, we are not applying any pull. Simply we are rolling the wheel and then finding out how much distance it is covering in one revolution. Now, after knowing the distance covered in one revolution, so, this is nothing but 2πr.

Now, I am dividing it to 2π, so that gives you radius of the wheel or the rolling radius, rolling radius of the wheel. Now torque, I said we have utilized the torque transducer, so directly we will get the value of torque. So, torque divided by r will give you thrust. Now, if I substitute those values in this equation, pull we have measured utilizing a ring transducer, then thrust we have measured indirectly by utilizing a torque transducer and then dividing the torque data with rolling radius.

So, we will get the data of pull and thrust. Then the other parameter which is required is, 1-s, so this 1-s comes from here V_a/V_t. We have calculated slip = $(V_t – V_a)/V_t$. Now, for replacing V_a/V_t, what I have done is, $1-V_a/V_t$ = slip(s). So, this implies, V_a/V_t = 1-s. So, I have replaced V_a/V_t by 1-s. So, either you can utilize directly this V_a value or V_t value or you can utilize slip value both are possible.

Now, once you know the slip value, once you know the pull value, once you know the thrust value, then utilizing this equation, you can immediately find out what will be the tractive efficiency. So, the data which we acquired that is for a 13.6-28 tyre which is subjected to a load of 1000 kg and at inflation pressure of 14 psi.

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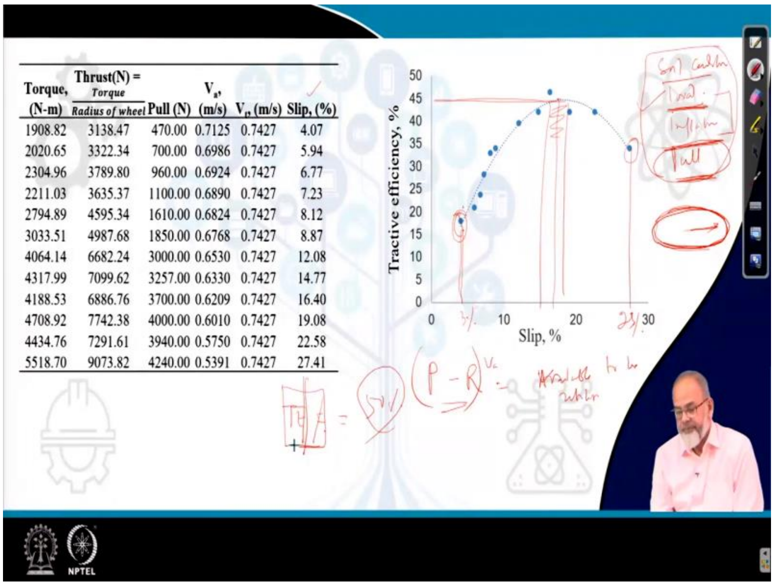

Torque, (N-m)	Thrust(N) = Torque / Radius of wheel	Pull (N)	V_a, (m/s)	V_t, (m/s)	Slip, (%)
1908.82	3138.47	470.00	0.7125	0.7427	4.07
2020.65	3322.34	700.00	0.6986	0.7427	5.94
2304.96	3789.80	960.00	0.6924	0.7427	6.77
2211.03	3635.37	1100.00	0.6890	0.7427	7.23
2794.89	4595.34	1610.00	0.6824	0.7427	8.12
3033.51	4987.68	1850.00	0.6768	0.7427	8.87
4064.14	6682.24	3000.00	0.6530	0.7427	12.08
4317.99	7099.62	3257.00	0.6330	0.7427	14.77
4188.53	6886.76	3700.00	0.6209	0.7427	16.40
4708.92	7742.38	4000.00	0.6010	0.7427	19.08
4434.76	7291.61	3940.00	0.5750	0.7427	22.58
5518.70	9073.82	4240.00	0.5391	0.7427	27.41

Now, these are the data which I got, torque data, then pull data, V_a actual velocity, V_t theoretical velocity and slip is computed from V_a and V_t and thrust is obtained by knowing the radius of the wheel and torque, torque data you got, torque divided by the radius of the wheel that will give you the thrust value. Now, utilizing that equation, we tried to find out the tractive efficiency at each of these points.

So, those data I have plotted here on the right side. We can see slip, that is on the x axis and tractive efficiency data on the y axis. So, what I obtained here is, the tractive efficiency is increasing at a very faster rate reaching to a peak, then with further increase in slip, the tractive efficiency is going down.

That means, there is a particular value of slip or a range of slip, very narrow range we can say where we are getting the maximum tractive efficiency which is in this case is around 45 percent. So, what happens at this point and what happens at this point, why the tractive efficiency is very low at this point, which is corresponding a slip of say 3 percent and here this 25 percent.

So, on the lower side of slip, whatever pull is developed, that is being utilized for overcoming the rolling resistance. So, that is not a useful power, that is a power which is lost. So, rolling resistance, the power which is pull, which is developed minus rolling that is the power which is available to be utilized. I said power because I multiplied V_a.

So, that means, there is an optimum slip value where you are getting maximum. Beyond that if you increase, the tractive efficiency value decreases because the power is lost because of the wheel. The soil is no more offering any resistance, so that is why we are not that, wheel is not able to develop that much pull. So, whether it is a low slip, whether it is a higher slip, both are not suitable for developing maximum tractive efficiency.

So, tractive efficiency is such a parameter, it varies with so many operating, it is varying with so many parameters like soil condition, then what is the load coming on the wheel, then what is the inflation pressure and then pull. If soil condition is hard, for the same pull will develop more tractive efficiency or more power. If load is more, wheel will develop more power.

If inflation pressure is more, wheel will develop less power because inflation pressure, wheel will decide along with the load how much will be the contact area, contact area of the tyre. If contact area is more, wheel will develop more force or more tractive force. If contact area is less, wheel will develop less tractive force. So, if the load and inflation pressure together will control what will be the contact area and accordingly the power which is developed will be decided.

Then the fourth parameter is your pull. So, these are the parameters which will control how much power you are going to develop, useful power. So, we are therefore combining these all parameters and expressing tractive efficiency and this is expressed for a given soil conditions for a given slip. So, if I say tractive efficiency 50 percent, it has no meaning you have to mention at what slip you are getting this 50 percent, that is important.

So, basically, this is the parameter which will give you how much will be the useful power we are getting from a tractor or from a single wheel for a given input power. So, it is always preferable that one should mention at what soil condition at what moisture content you have carried out the test that is important for a tractive efficiency.

You have to mention what is the soil type, what is the soil condition, means strength of soil, cone index value, then what is the moisture content, then you have to mention Okay, under these conditions, I have developed a tractive efficiency of this for a given wheel.