Design of Mechanical Transmission Systems

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Lecture - 17

Lecture 17_Brake: Torque Requirement for Drum Brake Systems

We will continue where we stopped in the last lecture about brakes aspect. So learning outcomes for today lectures, we are going to understand the drum brake system. Already working method is covered and types also covered even then I will give a brief information about the types aspect, then we move on to brake torque requirement okay. Particularly we are focusing about internal shoe expanding brake aspect and I am sure you know this is the typical schematic diagram about the internal shoe expanding brake hard drum brake. When you say internal expanding shoe brake so the shoes are arranged inside the drum right. You can have outside also depends on the application. In automobile usually the shoes are arranged inside the drum and the moment you have a force activated through wheel cylinder right the shoes will try to move to make a contact on the drum. So that is why it is called internal expanding shoe. Based on this arrangement again you can have various classification and you can see this is a very nice internal expanding shoe brake. In fact this is actually you can see only one wheel cylinder then you have the adjusting thing it is leading and trailing shoe brake okay.

This is the leading and trailing. We will discuss what does it mean leading, what does it mean trailing aspect and this is again the complete assembly of a drum brake system where you could see this is a brake drum cover and this is a hold down spring to holding the entire the brake shoe arrangement and on top of it will be sitting onto the brake adjuster and this is your wheel cylinder. Hope you remember yesterday in the one of the sample demonstration I have explained about the bleeder valve aspect where when any leakage is there, any trap air trap that has to be removed right. That is the purpose of having a bleeder valve and this is the brake line where the brake fluid goes inside to activate the cylinder for the activation foot on the tip of the shoes okay. And based on the arrangement so drum brake can be classified into four different aspect leading, trailing shoe brake, two leading shoe brake, S cam, Geo servo shoe brake.

I am sure you would have seen the videos, nevertheless we will explain about the first two arrangement leading, trailing shoe brake as well as two leading shoe brake aspect and you can see that this is a leading, trailing shoe brake okay. This is the type of brake is equally effective for forward as well as reverse braking offers a stable braking force. In general it is used most often as a rear brake in passenger vehicle that is that is true. Always the drum brake are preferred to fix at the rear rather than the front axle. The front usually the disc brakes are arranged.

In fact if we see why this is called a leading and trailing shoe right we will explain about. So this is the leading shoe okay. This you could see this is a drum rotation right. So what is the friction aspect? The friction on the drum direction would be opposite to the rotation. So this is your friction right.

This is the drag or friction something like that we can say that this is drag on the drum. This is on the drum okay. So this is moving right. This is how happened. Now what do you expect the friction force on the shoe? Should be opposite of that because that is the one is going to make and we have to balance the forces okay. Now this is the way the wheel center will come and will give this is your activation force. This is activation force. Let me ask a simple question. If your drag force and active force activation force are the same in the direction what is the effort of braking? Would be easier or tough? So maybe I will give another two example.

You are moving on the road. So your friend also moving on the road on the same direction which is easier. If he moving on the same direction pull him off or if he is opposite direction. Opposite direction where you need to have more force to stop him right whereas the same direction then the effort will be very less right very less. So in fact this is moment okay so the moment of friction drag force along the shoe input okay which is happening so thus the increase in input load increase the friction drag force and finally this is called self-servo effect.

It is called self-servo effect or self-energizing effect. This is the arrangement if you have a leading shoe. The friction force and the activation force are in the same direction the braking effort will be very I mean braking effort will be good with the less effort. That is the difference okay. That is why this is called a leading shoe. Then when you go for this excellent for a braking effect, true and this is the trailing shoe. So the drum is rotating obviously the drag force will be in this direction for the drum. This is drag on the drum okay and obviously this will have to balance the force the friction force acting on the shoe will be opposite direction. This is you can see that and this is the activation force and take the moment what happened that would be opposing the things. That would be oppose the shoe input load.

So what happened if you have opposes the shoe input load okay so thus increase the input load decrease the drag force obviously further reduce the braking effect. This is what happening when you have a trailing shoe okay. You may ask another question what happened if you have reverse direction. How do you expect in the reverse direction? The leading shoe will be a trailing shoe and the trailing shoe will be leading shoe okay. So it will change okay. So to avoid that you can have another wheel cylinder at the bottom.

So the two wheel cylinder so any given time both leading and leading you can do the arrangement. By doing that the braking effort would be much better right and maybe you can see here this is the in fact and this is the shoe arrangement. So the trailing shoe you can see this is your friction material and for leading shoe the area wise right the friction material is less compared to a trailing shoe. Obvious because your braking effort already better if you have a leading shoe then you do not need to have a more friction material to create the braking effect. So in fact by looking this arrangement you can easily identify which would be the leading shoe and the trailing shoe also. But this is this is based on the leading and trailing. How about if you have two leading? Then the size of the brake lining would be equal. You cannot able to find out the differentiation. This is difference can be able to find out only if the brake arrangement is the leading and trailing aspect okay. Now we are talking about two leading or two leading brake system.

You could see that the two wheel cylinders right two wheel cylinder. So when one force is acting from one wheel cylinder right the same wheel cylinder acting another way. So what do you expect? You would expect two leading aspect. During the forward movement the vehicles both shoe act as a leading shoes and providing a superior braking force. This type of use where such a strong force required mainly in truck and other commercial vehicles. Wherever you have a large vehicles where you need a more braking effort there you could have twin or two leading shoe arrangement. In fact in the demonstration, yesterday demonstration I have shown the two leading right. Do you have seen the two leading I mean instead of two leading two cylinder drum brake you would have seen that the bigger one and smaller one. So both are used for trucks and every commercial vehicle. You can see that so by looking at if you have this is the wheel cylinder one and this is another wheel cylinder. So there is no adjustment group. At any given time right both shoes would be a leading shoe so that you would have a better the braking effort right.

The brake torque analysis. Now we will understand about how the force activated, how the torque applied and when it said torque it is a frictional torque and for drum brake analysis right. So these are the following assumption we have used. Exclusively used for automotive application drum brake I am talking about a drum brake aspect. Compact and economical, brake shoe one end pivoted another end is subjected to actuating force that is true okay. Then assumption before deriving the equation this is the following assumption we need to consider. The intensity of normal pressure distributed between the friction lining and the brake drum at any point is proportional to vertical distance. This is the assumption we have to have. That is one assumption. The second one is the brake drum and shoe are rigid. The centrifugal force acting on the shoe is negligible. More importantly the coefficient of friction is constant. Obviously friction is variable due to temperature right. Variable due to temperature. So what I am going to do, so I will just show schematic diagram okay. I draw the circle. This is for the drum aspect. The drum is pivoted at the middle right. So drum is pivoted at the middle okay and assuming that it is rotating so in this direction. So when it is rotated right R is the radius of the drum okay and the lining where it starts that position to till there we can say as a θ then right. So you would expect two things. One is your normal force right. We will take this small dN and that is since it is against doing with the friction is the frictional force. These two things are operating. This is on the drum okay. So let us see for the shoe also right. On the shoe arrangement just I wanted to show the shoe alone. Yeah. So the radius is R that already you know that. This is the radius is R.

Usually shoe will have a pivots right. This will have a pivots then moves like this okay. Then I am just showing only one aspect. Then the activation force will be in this direction. P is the activation force and then we will have friction material. Friction material this is your friction material right. The angle right where it starts to end is the θ okay. This is the theta. We will discuss in detail and the distance from the pivot to where the activation force starts us normally we say as a C. Then from the center of drum to okay the center of the pivot okay this distance called taken as h. This is just giving a description about the shoe arrangement in the drum brake okay and this is shoe right okay. Let me ask what is the forces act on the shoes now. What are the forces acting on the drum? Same force will be in opposite direction right. It will have a in this direction μ dN and in this you will have a normal force dN. In fact I will go in detail maybe you could see the free body diagram. You can see the complete information right. So the complete information you could see here from the pivot to where activation force start the distance we already have mentioned. Then from the center of the drum to and the pivot the horizontal distance h is mentioned okay and this is your the radius of your drum R is given. Then where the friction line starts right from the pivot to where friction line starts is the θ_1.

Then where the friction linings ends right from the pivot to θ_2. Then the $\theta = \theta_2 - \theta_1$. So that is your arc length of the brake lining right. You could see that is the arc length of the brake lining. In fact to further understand what we do we will take a small strip. This strip alone we will take it right. This strip alone take $d\theta$ is assuming that yeah $d\theta$ then try to do the the force balances. This force balances already said. There are two forces. One is normal force another one is frictional force. These two forces are going to act on the shoe okay. Since rotation is there obviously you are talking about we are talking about the friction. You can see that this is your friction in this direction will come right. Then the normal would be in this direction right normal would be in this direction. So this is the free body diagram.

Hope you will understand that. So what I am going to do? I am not due to time constraint I am not going to detail. You can refer any text book where complete information is given. It take another two lectures to complete derive the equation to understand. So instead that what I am going to do I will straight away give the equation and proceed further okay.

So what happen? Let me check. So always we will take the moment. When they take the moment with respect to pivot acting on the tip that is normal right that is one thing. The another one is frictional moment which is the responsible for torque friction right frictional torque. So these two things we are going to right straight away get the equations. The total brake torque equation

$$M_f = \int \mu \, dNR$$

$$M_f = \frac{\mu W R^2 p_{max}}{Sin\theta_{max}} \int_{\theta_1}^{\theta_2} Sin\theta \, d\theta$$

$$M_f = \frac{\mu W R^2 p_{max}}{Sin\theta_{max}} (Cos\theta_1 - Cos\theta_1)$$

So where the W is the width of friction lining width of friction. So this is about the total brake torque equation aspect. Now we will find out for the moment of normal pressure

$$M_n = \int dNhSin\theta$$

$$M_n = \frac{WRhp_{max}}{Sin\theta} \int_{\theta_1}^{\theta_2} Sin^2\theta d\theta$$

$$M_n = \frac{WRhp_{max}[(\theta_2 - \theta_1) - (Sin2\theta_2 - Sin\theta_1)]}{4Sin\theta_{max}}$$

$$\theta_{max} = 90°, \;\; when \; \theta_2 > 90°$$

$$\theta_{max} = \theta_2, \;\; when \; \theta_2 < 90°$$

So these are two condition we always use for solving the torque equation of brake torque. Now we will go for the actual aspect. So we derived the equation okay we derived for the moment of normal pressure and also the moment of frictional torque as well both we have done that right. Now we will take it as a activation force remember this is a drum right and this is your shoe arrangement okay. So from here to here this is the P and this is a distance C okay you take the pivot with respect pivot moment whe an applied force here right. So what do you expect the equation right I think I might have it here yeah then I think let me check yeah we would expect

$$P \times C + M_f - M_n = 0$$

$$P \times C = M_n - M_f$$

$$P = \frac{M_n - M_f}{C} \quad \rightarrow leading\ shoe$$

$$P = \frac{M_n + M_f}{C} \rightarrow trailing\ shoe$$

I am trying to balance it right. So the P into C act as a couple then in clockwise direction that is what we assumed. So when you make it will simplistic way P into C equal to m n minus m f finally if you want to understand to find what would be the activation force m n m f by C this is the equation you are expecting okay. This is equation is for leading shoe or trailing shoe what we have done is for leading shoe aspect for a leading shoe right the breaking effort will be very less. Suppose for trailing shoe what you are expecting the activation force would be more or less see the friction force change the direction right the friction force will changing direction.

So obviously P equal to (M_n + M_f)/ C. So you can see that this is adding m f is adding to your trailing shoe that means the breaking effort will be very less you have to have a more effort. So this is for the trailing shoe aspect. This is for trailing shoe aspect. Okay let me ask question what happen when you do the reverse direction. What do you expect reverse direction? Yeah what do you expect in the reverse direction? Yes it will reverse okay it will be reverse and I will I have to talk about there is a concept called self locking right. So this is reverse okay I will ask one more question what do you expect if my M_n equal to M_f what happen then? There is a chance right there is a chance where the normal right force right the moment of normal force the moment of friction force are equal what happen to the vehicle? It will be self locking.

What do you mean by self locking? The brake won't be effective the wheels will rotate freely and vehicle cannot move right that is what happen it is a instability right. So self locking is nothing but instability so that is not advisable we always try to have a difference of a difference in between the magnitude difference between M_n and M_f ,never ever design the brake such a that both are equal okay that has to be taken into consideration. Yeah you can see this so in fact clockwise rotation of the brake drum

$$P = \frac{M_n - M_f}{C}$$

(M_n - M_f)/ C self-energising effect when the activation force P is zero then you will have self locking, if the anticlockwise rotation the brake drum then M_f direction change which already I have discussed okay.

Now we will do a problem okay we will do a problem you want to write the equations okay yeah, when we do the problem we will write the equation in detail again can you take down the problem please this is very generic problem. Yeah Maruti 800 car weighing 1100 kg along with the passenger is moving on a level road at a speed of 65 kmph when the brakes are applied the car stops in 4 seconds the brakes are applied in all 4 wheels the radius of tyre is given 220 mm if the weight of each brake drum assembly is 12 kg and specific heat capacity is 460J/kg°C.

a)determine braking distance

b)total energy absorbed by each brake if kinetic energy absorbed by each brake if kinetic energy of rotating parts is 10% of kinetic energy of moving parts and

c)torque capacity of each brake and D temperature rise of brake drum assembly.

This is normal physics based problem okay even though the application is related to brake it to understand for you what exactly happening due to the physics aspect. So the data is given the weight is given 1100 kg along with the passengers the speed is given 65 kmph and the car stops 4 seconds that means that is your braking time (t_b) braking time is given 4 seconds the brakes are applied in 4 wheels so the radius of tyre is given 220 mm and each brake drum weight also given 12 kg then specific heat capacity 460 J/kg°C. So we have to find out the braking distance total energy right torque capacity of each brake and temperature rise these are the thing we need to find out this is our first problem. So we will find out the car velocity right this is the first problem right car velocity is given car velocity given how much 65 kmph right

$$V = \frac{65000}{3600} = 18.06\ m/s$$

so that is a velocity the braking time what is the braking time 4 second right t_b surface for braking time 4 second is given okay. So this is the car is moving right car is moving so when car is moving initial velocity is 65 kmph what is the final velocity 0, V_2 equal to 0 so that is your final velocity yeah so final velocity is given so we need to find out the distance travelled right, braking distance we need to find out so distance travelled yeah S_1 we will take the we have to take the average velocity right 0 velocity and then 18.06 by 2 into your braking time.

$$S_1 = \left(\frac{0 + 18.06}{2}\right) \times t_b = 36.12\ m$$

So what is the answer you are getting you should expect 36.12 meter that is your braking distance. This is your braking distance okay then we have to find out the the the the the the

the the total kinetic energy because we need to find out the ultimately the energy absorbed each brake right energy absorbed each brake we need to find out, so this car weight is given W right 1100 kilogram okay so change in kinetic energy what will be the change in kinetic energy I am talking about change in kinetic energy of the vehicle

$$\Delta K.E = \frac{1}{2}m\left({V_1}^2 - {V_2}^2\right)$$

$$\Delta K.E = \frac{1}{2} \times 1100 \times (18.06^2) = 179.39\ kNm$$

this should be the change in kinetic energy of the vehicle okay just I wanted to inform you right when this car is moving the car is moving in straight direction the car is moving in straight direction what happened the other parts inside the car, when the car is moving it is a translation motion right is in a translation but there are components we have a rotational movements also they have rotational movements what are they your flywheel is a rotation movements, your clutch is a rotational movement okay not only flywheel clutch your entire gearbox the gears are rotating movement okay so then wheels your brake wheels your tires also rotation motion so in fact, they are also carry the energy right so that you have to consider so that is the precise reason they said kinetic energy of moving part you can usually take it in the percentage wise, maximum 20% it varies depends on the size so 10% of the vehicle you can assume as for the moving aspects in fact, when we do a problem we have to find out precisely how the moving parts kinetic energy would affect the brake performance as we move on to the lectures we will understand that aspect as well so the kinetic energy of the vehicle kinetic energy of moving or rotating parts both are same moving parts both are same moving parts should be 10% of right vehicle is given right when percent of the vehicle is given so that should be 17.939 kNm, then the total kinetic energy

$$total\ K.E = 179.39 + 17.939 = 197.239 kNm$$

I should expect that the total kinetic energy of the vehicle plus kinetic energy of moving parts 197.329 so much kNm this is the total kinetic energy of the entire vehicle right so what was the question asked what was the question asked they asked energy absorbed by each brake system right, so energy absorbed by each brake system so when you want to have energy absorbed by each brake so what do you do? So what you do? How many wheels are there? How many brake system? 4 so divided by 4

$$total\ K.E(E_b)\ per\ wheel = \frac{197.239}{4} = 49.32\ kNm$$

so that should give 49.32 so much kilo Newton meter this is the for each brake system energy E_b per brake this is the answer you should have it right yeah now we need to find out what is the next question torque, yeah what is the next point we need to find out torque capacity yeah so how are we going to do find out the torque capacity the basic physics equation so you have energy is given, so what else we need to find out the M_t right but we know E_b is given already we know the energy also so how can we do the how can we able to find out M_t torque into angular right can we say angular rotation or angle acceleration what is that? Angular rotation, if you do that can we able to find out the torque right so in fact your

$$E_b = M_t \times \theta$$

$$E_b = M_t \times \theta$$

E_b equal to M_t into theta radians angular rotation is given so we need to find out the angular velocity so we need to find out the angular velocity so we need to find out the theta value what is the value right and we know

$$V = R_w \times \omega$$

$$\omega = \frac{V}{R_w} = \frac{18.06}{0.22} = 82.09 rad/s$$

$$\theta = \frac{S_1}{R_w} = \frac{36.12}{0.22} = 164.18\, radians$$

V equal to what r omega r omega so r is the radius of the wheel or tire either way you can say that the speed we need to know that yeah so can you find out what will be the theta please yeah this we have to use the equation theta is nothing but your the sliding distance yes what we found out from there your radius of the wheel so you have to use these two equation to find out the V and θ okay can you find out please what is the value you are getting what is the ω value first your ω value V equal to 18.06 right R equal to 0.22 that is the meters okay that should give me 82.09 radian per second so this is the value of theta so this is the radian per second omega I have then another thing is I need to find out the radian theta which is nothing but S_1 equal to what 36.12 right and this is R equal to 0.22 that should give me 164.18 radians I have all those things

$$M_t = \frac{49.332 \times 10^3}{164.18} = 300 Nm$$

then M_t equal to 49.332 so much 10 power 3 will make it as the Nm divided by your 164.18. The torque capacity would give me 300 Nm. This is the value you should expect. This value you should expect. Now, the another one temperature rise. So, energy equal to cooling law

$$E = m \times C_p \times \Delta T$$

$$\Delta T = \frac{E}{mC_p} = \frac{49332}{12 \times 460} = 8.94\text{°C}$$

So, this will be 49332. What is m here? Brake weight of the brake 12. Then specific heat capacity given 460. So, when you do that, so the temperature rise due to the braking thing is 8.94 °C. This is the thing. So, that is fine.

We will move on to the one more problem just for you to understand. This is another problem. This is a four wheel automobile as a total mass of 1000 kg. The moment of inertia each wheel about a traverse axis through its center of gravity is given as a 0.5 kgm^2. The rolling radius of the wheel is given as 0.35 meter. The rotating and the reciprocating parts of the engine and the transmission system are equivalent to moment of inertia of 2.5 kgm^2 which rotates at five times the road wheel speed. The car is travelling at the speed of 100 kilometer on a plain road. When the brakes are applied, the car decelerates at the rate 0.5 g. There are brakes on four wheels. So, you need to find out the energy absorbed by each brake and also the torque capacity of each brake. So, how does this problem is different from the previous one? What data do you have here? The mass is given as 1000 kg.

Mass is given. Then center of gravity is given as 0.5kgm^2. Then radius of the wheel is given as 0.35 m. Then moment of inertia of the rotating and reciprocating parts of the engine and the transmission system are equivalent to moment of inertia of the rotating and reciprocating parts. It is given as 2.5kgm^2. One more information is given. These parts will rotate five times on the road wheel speed aspect. That is clearly given. The speed is also given. Instead of velocity, it is given gravity is given 0.5 g. So, how are we going to solve this problem? I think similar way right. Whatever you did, we did it in the previous problem.

Same way you can do that. The only difference is you have deceleration. I think I will stop now. I will stop here. So, you do the problem. We will discuss it on tomorrow lecture.