Fundamentals of Automotive Systems
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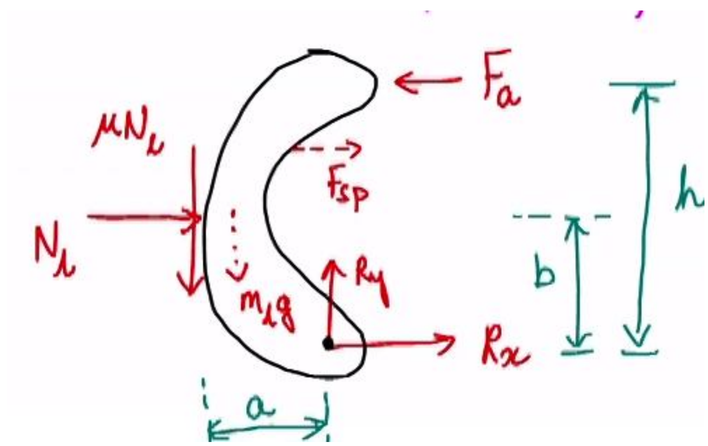
Lecture 44
Components of a Brake System and Drum Brake - Part 2



So let us draw the free body diagram of this, so-called leading shoe. So now, let us say if I draw this, so once again I am going to do a lumped analysis. So let us say this is my leading shoe. Let us identify all the forces that act on it right. Let us say through the either the cam or the wheel cylinder I have an actuation force right. So F_a is nothing but the actuation force that acts on the brake shoe right. So now imagine a scenario where the brake shoe has rotated about its pivot, the friction lining has gone and contacted the inner surface of the brake drum.

So the brake shoe has been pushed against the brake drum. So what is going to happen? The brake shoe is going to apply a normal load on the surface of the brake drum and the brake drum is going to apply a reaction right on the brake shoe. Of course the reaction force, reaction load is going to be normal to the surface of the entire brake shoe, but for the sake of simple analysis, simplicity what we are going to do is, like let us lump all those normal loads into one load right.

So we are going to do a lumped analysis right and let us say the lumped normal load L am saying that it acts somewhere here and let us consider that to be some N subscript L okay. I hope it is clear what N subscript L is. The subscript l stands for leading shoe, N is the lumped normal load on the brake shoe right. So if once I have done this, I can once now represent a lumped friction force on the brake shoe.

As we know the friction force is going to be perpendicular to the direction of the normal. So now if I draw the perpendicular line to the direction of the normal load, that is going to be this. So this mu times N_L where now this mu is the friction lining coefficient, or okay we will say brake lining friction coefficient, let us call it that way brake lining friction coefficient is the brake force that acts on the shoe. Now should this be pointing upward or downward, this mu N_L?

So let us reason it out by looking at this figure right. So now we see that the drum is rotating counterclockwise. So let us say just to understand what is going on, I am at this point right. So now on the drum the braking process will generate a torque wise clock, sorry, sorry clockwise torque right. So essentially since the brake drum is rotating counterclockwise, we are going to apply a clockwise torque on the drum.

So if a clockwise torque is applied on the drum the deceleration torque, if you lump the tangential force at this point, you will immediately see that at this point the friction force on the drum is going to be upwards right. Only then, you will get a clockwise deceleration torque, do you agree? So that is the direction of the lumped friction force at that point on the drum. Now what would reaction be on the shoe?

It will be downwards right. So this mu N_L would consequently be pointing downwards correct? So in addition to this let us say we have the reaction forces. Let us say we label them as R_x R_y. Let us say I am drawing it as a dashed line, because we are going to neglect that effect. Let us say this is M_{Lg} right and another force due to the spring, let us say F spring right, the restoring force from the spring, but we will neglect these effects okay.

So now what we are going to do is that like let me draw some dimension. So let us say we call this height with a distance between the pivot and the place where the actuation forces applied is some h, the place where we are lumping the normal load on the pivot to be some let us say “b” and the place from the pivot and in this direction to where the lump friction force is acting to be some “a” distance here okay. So this is the free body diagram okay.

Now please recall the scenario that we are looking at right. So we essentially have applied the brake. This brake shoe has gone and contacted the brake drum, alright and the friction torque is being generated. So of course the brake shoe is going to vibrate a bit due to the motion and so on, but then like we can safely assume that you know like we can neglect the inertia I alpha, when we compare to the other torques, because the motion to overcome the clearance has been completed right.

So we will make that assumption and then like we will write down the equation, so taking moments above the pivot. So pretty much we are going to deal with this as a statics problem, an equivalent quasi static problem right. So that is what we are going to do. So taking moments about the pivot, assuming that the inertial term is negligible okay, what do we get? So if I take moment about the pivot, so one counterclockwise torque which I am going to get is $F_a h$, then we are going to get mu N_L times “a” right.

$\mu \rightarrow Brake\ lining\ friction\ coefficient.(Actuation\ force)$

$$\underbrace{F_a h + \mu N_l a} - N_L b = 0$$

The torque due to the friction force augments that due to the actuation force.
This is termed as “self-energization”.

So that is due to the friction force, that is another counter clockwise torque and then a clockwise torque is going to be N_L times “b” and this we take it to be zero right. So we are neglecting the other terms. So we have got a very simple equation and this is something which is very interesting, why, because if you look at these two terms $F_a h$ is the, what to say is the torque due to the actuation force mu N_L times “a” is the torque due to the friction force.

See by and large, we associate friction with a negative connotation right, which essentially is working against a process right, but in this case you can see that the torque due to the friction force is adding on or augmenting the torque due to the actuation force right, which is something which is quite positive about this particular shoe in a drum brake and even if you want to look at overall associate this equation with what happens?

So since the drum is rotating counterclockwise you see that moment the leading shoe contacts the drum, it is going to be pulled in right due to friction, that is the physics behind it and the consequent physical action. So imagine that this drum essentially goes and contacts, the brake sorry the brake shoe goes and contacts the drum due to the rotation of the drum in the counterclockwise direction. The brake shoe is going to be even more pulled in.

That is the physics behind this is due to this term top right mu N_L times "a". So the torque due to the friction force augments that due to the actuation force okay. This is specific to the leading shoe in a drum brake okay. We will see shortly why it is called leading all right. So this is specific to a leading shoe in a drum brake and this what to say concept or phenomena is what is called as self energization okay. So this happens only in the leading shoe of a drum brake okay.

So self the so called within quote self energization okay is a very positive attribute of a drum brake okay. We will see how it helps us okay. So once again to repeat self energization is a phenomena or the concept of the torque due to the friction force aiding the torque due to the actuation force in brake application and that happens in the leading shoe offer drum brake. So if you process this equation, what do we get?

We get N_L that is from the above equation, we get N_L equals F_ah divided by b minus mu a right. So that is the normal load. So this implies that the friction force from the leading shoe is going to be equal to mu times N_L , that is going to be mu F_ah and divided by b minus mu a okay.

$$\Rightarrow\ N_l = \frac{F_a h}{b - \mu_a}$$

$$\Rightarrow Friction\ Force\ from\ the\ leading\ shoe = \mu N_l = \frac{\mu F_a h}{b - \mu_a}$$

$$Brake\ Factor\ of\ the\ leading\ shoe, (BF)_l = \frac{\mu N_l}{F_a} = \boxed{\frac{\mu h}{b - \mu_a}}$$

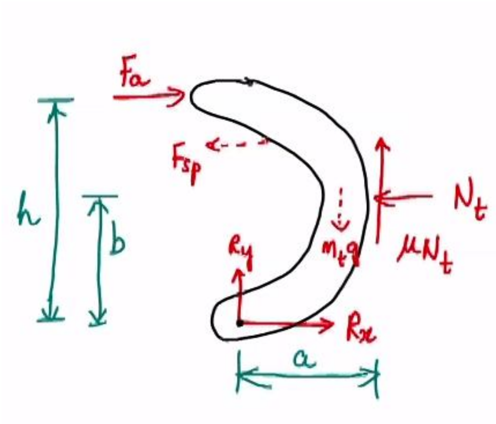
Now there is something called as a brake factor. Brake factor of the leading shoe, let us define what that is, so the term brake factor is the following. So the brake factor of the leading shoe which we are going to indicate as BF subscript l is going to be nothing but the ratio of the output friction force to the input actuation force. So this is like output by input. So if we substitute mu N_L , what is going to happen, F_a is going to cancel off right and then we will essentially get mu h divided by b minus mu a okay.

So that is what we are doing. So this is a an important advantage because you can observe that looking at a mathematical term right, if you look at the denominator you are going to get b minus mu a right. So what is going to happen is it for typical dimensions and typical brake friction coefficient, lining friction coefficient values. This b minus mu a is going to drive up this brake factor a lot right, so is not it?

The denominator is going to be made smaller right, because we are subtracting mu a from b and as a result the ratio is going to become larger. So would a larger brake factor be desirable? Of course, yes right, because brake factor as we have seen is essentially the friction force output to the actuation force input. So if I have a larger brake factor for the same input, I get more braking force right or to obtain the same braking force, I need to give a smaller actuation force right.

So I have an advantage from that perspective. So of course, this discussion would be completed once we do the same analysis for the trailing shoe, which we will do now, right. Then, we will be able to up appreciate what I mean by larger and smaller. See, when I say larger or smaller, we need to compare it with something else right. So we are going to do that. So let us draw the free body diagram of the trailing shoe now okay, considering the same dimensions, under similar set of assumptions.

So this is my trailing shoe and if you mark all the forces F_a is my actuation force. Once again you know we lump all the normal loads and then call it as N_t. Now mu N_t is going to be perpendicular, of course to the normal load okay. The question is which will be the direction? So now let us go and reason it out.



So now we are going to look at this point right. When I stand at this point right, if I want to generate a clockwise braking torque on the drum, the tangential force on the drum at that point should be downwards right, for the rotation that we are considered correct.

So what will be the corresponding reaction force on the shoe? It would be upwards right. I hope everyone got this correct. So mu N_t would now be pointing upwards right and then let me use the same approximations. Let us say this is my M_tg and then this is some F spring right and let us say there is some there are reactions at the pivot okay and then let us use the same dimensions. So this is going to be H and this distance is what we call as b and this distance was a.

Take moments about the pivot,

$$F_a h - \mu N_t a - N_t b = 0$$

$$\Rightarrow \; N_t = \frac{F_a h}{b+\mu_a}$$

So once again, we assume the same scenario where the brake shoe has contacted and then we are drawing this free body diagram. So once again we take moments about the pivot neglecting the inertial term. So what do we obtain? So about the pilot and now let us say I have F_ah, that is going to be a clockwise torque, you can put a negative sign or you can now just take in this fashion right. So let us say we put F_ah as a clockwise talk, which is positive.

Then what are we going to get? We are going to get minus mu N_t times a minus N_t times B right equals zero. Now we can immediately observe that the torque due to the friction force is no longer augmenting the torque due to the actuation force. So this is also something, which we can what to say relate in practice by looking at this diagram. So note that the drum is rotating counterclockwise, I am pushing this brake shoe against the drum.

So the drum is due to its rotation and due to the friction, it is going to push the brake shoe away from that drum right. So that is going that is what is reflected in this equation okay. The friction force will create a tendency for the brake shoe to be pushed away from the drum okay. So that is what is happening here. So there is no self energization right. So consequently what is going to happen? We are going to have changes in the equations.

But of course, please note that we are doing a very, very first cut rudimentary analysis with lot of assumptions. So we need to take these, what to say expressions also from that sense right. So they may provide an initial first cut qualitative comparison right. So N_t is going to be F_ah divided by b plus mu “a” alright okay. This implies the friction force from the trailing shoe is going to be equal to mu N_t , which is going to be mu F_ah divided by “b” plus mu “a” and the brake factor of the trailing shoe is going to be equal to mu N_t okay.

$$Brake\ Factor\ of\ the\ trailing\ shoe\ (BF)_t = \frac{\mu N_t}{F_a} = \boxed{\frac{\mu h}{b + \mu_a}}$$

Let us denote it by BF subscript “t” that is going to be equal to be mu N_t divided by F_a, which is going to be equal to mu h divided by “b” plus mu “a” okay. So that is the form alright okay. So now we can compare right for the same values of a, b, h, mu. Now I hope it is clear what I meant by larger and smaller right. If you compare the expressions for the brake factor of the leading and the trailing shoe, which one would be larger?

Obviously, the leading shoe right, the reason being the presence of that “b” minus mu “a” term in the denominator. What is the physics behind the “b” minus mu “a” term in the denominator, due to this concept of self energization right, because friction force is aiding the actuation force in terms of the torque generation right. So that is the difference. So you can see that the leading shoe leads the trailing shoe in the brake force generation.

So one can see that the terms come about from that perspective. So two points this concept of self energization happens in the leading shoe, not in the trailing shoe. Consequently, the output from the leading shoe for the same input force would be more. The brake force output would be more in the leading shoe than the trailing shoe. So those are two important conclusions that we can draw. So we can immediately observe that if I reverse the direction of motion, what I have labeled as leading shoe and trailing shoe they will get swapped.

See with everything remaining the same right, so if I just change the direction of motion of the drum from counterclockwise to clockwise, what we are calling as leading shoe would change to trailing and vice versa. So as an exercise, I want you to draw the free body diagram and convince yourself right okay. That is one thing. Suppose, we want a two leading shoe drum brake, by the way this is what is called as a leading-trailing shoe drum brake okay.

That means that it has one leading shoe, one trailing shoe okay. This is what is called as a leading-trailing shoe drum brake okay. So now if I want a two leading shoe drum brake, what should I do? So suppose just for the sake of discussion, if I want a two leading shoe drum brake, what will I do? I will just push this pivot to this point and have an actuation force at the bottom for this shoe, then you will see that for this particular configuration, schematic that we are considering, both shoes will become leading shoes right, is it not?

But however what is the, of course the advantage is that we get more brake force output for the same input because the brake factors increase right and essentially from performance viewpoint, it is good. But however, what is the trade-off? We see that to generate an actuation force at the bottom, we need to have a similar actuation mechanism at the bottom. We need to duplicate it at the bottom right.

So for example, in a hydraulic brake system, we will encountered this component called wheel cylinder. So if I want to generate this actuation force here, I need to put a similar wheel cylinder here and I need to put a fluid line which will actuate the particular brake shoe. So the cost complexity everything goes up, you know, that the unit becomes complex in that regard alright. So that is what is called as a two leading shoe brake.

So today in most applications, we have what is called as a duo servo brake okay, that is the most common configuration used in automotive drum brakes today. So what is the duo servo brake? Duo servo brake is just a modification of this leading-trailing shoe brake okay. So typically what happens is that like in today most drum brakes, there is an adjustment mechanism, which connects the two shoes. What is in self adjusting mechanism?

If there is wear and tear of the brake shoe, it just adjusts the initial positions of the shoes themselves, so that like the travel of the shoes are not increased tremendously right. So that is the concept behind self adjustment. So due to that what happens is that, these pivots are no longer rigidly fixed, but then I am just exaggerating to just convey the concept. They can be moved in some slots right. So because we want to push the brake pads closer to the drum if the brake wear is more.

So when this happens and the two brake shoes are now connected through a link, which is adjustment mechanism in the duo servo brake, what happens is that when the brake is applied, the drum brake anyway is pulled in right due to this self energization. Now the drum brake also tries to apply a force, sorry this shoe sorry not that drum brake, the leading shoe is pulled into the drum brake.

So due to self energization and when the leading shoe is pulled in this pivot essentially travels a little bit in that slot and tries to apply a force through this link on the trailing shoe. So the trailing shoe is pushed from the top. It is pushed from the bottom. So imagine this, you know like previously, we are having the trailing shoe only pushed from the top and there was a tendency for it to come out due to the friction force right, direction of the friction torque right.

Now what we are doing, we are pushing the trailing shoe much more effectively against the drum from both ends right, to some extent okay. So that way we are improving the brake force output from the trailing shoe right. So that is the concept of a duo servo brake. So for the same set of components right, you get a higher brake force output from a duo servo brake, when you compare it to this leading trailing shoe brake.

So if you look at the brake factor output, brake factor of leading trading shoe will be the lowest followed by duo servo brake followed by the two leading shoe brake. Two leading shoe brake will give you a highest output for the same design same dimensions everything remaining the same alright. So that is the, what to say, concept of all these brakes.

$$(BF)_{Drum} = (BF)_l + (BF)_t = \frac{\mu h}{b-\mu_a} + \frac{\mu h}{b+\mu_a}$$

So finally to just conclude, so the brake factor of the drum brake is going to be equal to the brake factor of the leading shoe plus the brake factor of the trailing shoe, which is going to be mu h divided by "b" minus mu "a" plus mu h divided by "b" plus mu "a" okay. So this will be the total brake factor of the drum brake, okay. So I will stop here and in the next lecture, we will look at the disc brake and then like we will compare the disc brake and the drum brake and then like learn some critical attributes of them okay. Thank you.