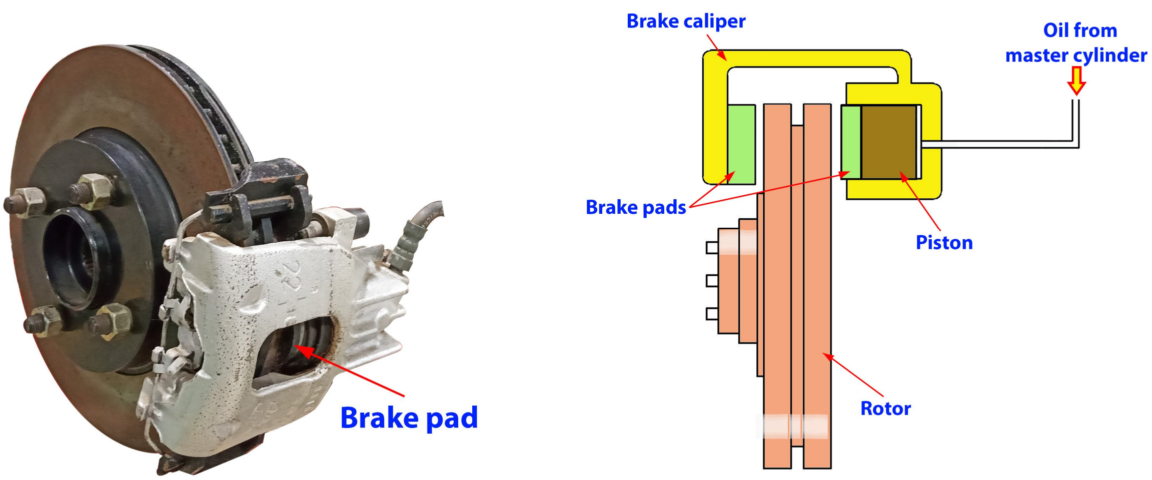
Fundamentals of Automotive Systems
Prof. C. S. Shankar Ram
Department of Engineering Design
Indian Institute of Technology – Madras

Lecture - 45
Disc Brake and Introduction to Hydraulic Brake - Part 1

Okay greetings. So welcome to this lecture. So a quick recap of where we stopped previously. So history we are looking at the drum brake right. So we looked at the typical operation of a drum brake and we just stated a very simple analysis. We saw what was the concept of self energization in drum brake, so wherein the torque due to the friction force essentially adds on to the torque due to the actuation force right. So that is self energization. So the consequence of that is that like the output from the drum brake, particularly what is called as a leading shoe of the drum brake would be a more for a given actuation force right.

So that is something, which we saw and that was quantified by means of what is called as a brake factor and we did a similar analysis for the trailing shoe and then we saw that this so-called self energization is absent in the trailing shoe and so consequently the brake factor is comparatively lower right. So then we looked at what is called as a two leading shoe brake and then duo servo brake. So that is where we stopped yesterday.



DISC BRAKE

So today let us start by looking at the disc brake so, and then like we will do a comparison of both drums and disc, you know to gain some understanding. So in a typical drum brake is an internal expanding brake alright and in a disc brake what happens is it like a rotor connected to the wheel assembly is clasped on either sides by brake pads. So the brake pads essentially go and touch against the rotor and then like generate friction.

So the displacement of the braking element in a disc brake is along the axis of rotation of the rotor alright. So we have this rotor and we have what is called as a caliper assembly. So the brake pads are inside okay. So when the brake is applied, so the brake pads are essentially pressed against the rotor okay. So that is how the disc brake works. So the simple schematic is this. So we can see that this is the rotor.

And what happens is that like this hosing is what is called as a caliper hosing. We will shortly come to what is called as a floating caliper hosing right. We will see what it means. So when the driver presses the brake pedal, let us say we consider a hydraulic brake system used in passenger cars. So the brake fluid enters and then like what is going to happen is that like it is going to act on the piston and it will press this brake pad against this rotor.

So the pressurized fluid will also act on this face and then move this so-called floating caliper, okay towards the right, so that this brake pad is also pressed against the rotor okay. So that is the reason why it is called as a floating caliper okay. So the term floating caliper is because the caliper has some freedom to move along the axis of the rotor right, so to enable this braking action right.

So we can immediately see that you know, this is simpler than what is called as a fixed caliper design. So wherein, in a fixed caliper disc brake, by the way this is a floating caliper disc brake with the schematic that has been drawn corresponds to a floating caliper disc brake. So in a fixed caliper disc brake you know, as we can understand we are going to have the same assembly or set of components that we see on this side or on the other side also.

So the caliper will be fixed, but the brake fluid will also enter from the other side and then like press the corresponding brake pad against the rotor. So obviously the number of components will increase and we also need to provide brake fluid to both sides right. So because now we will need a brake fluid and corresponding components like hoses and other elements on this side also right. We will have a similar assembly on the other side right.

So what will happen is that not only the number of components and complexity increase, but in a disc brake you know like it is packaged in the wheel hub. So there is a space constraint also right. So we are also constrained by the space that is available for packaging the brake in the wheel hub right. So in that way you know the floating caliper is a better choice okay. So that is the difference between a floating caliper versus a fixed caliper disc brake.

Today, we are using floating caliper disc brakes, you know. Now what about this analysis that is similar to what we did yesterday right. So let us look at a very simple first cut analysis of the disc brake. So if we are looking from this side right, so let us say this is my rotor correct and let us say without loss of generality the rotor is rotating in the counterclockwise direction. Now what will happen is that we will have the brake pad.

Let us say you know I am just drawing a rough diagram on one side. So that is going to be pushed, what to say, against the rotor. So let us say in this schematic the brake pad is moving into the plane right. So let us say the brake pad is pushed with an actuation force that is lump actuation force F_a. At steady state what would be the normal reaction?

The normal reaction on the brake pad will be equal to F_a right. So because we are pushing with F_a that is going to be a force that is going to come back. We are once again neglecting inertia and other effects, because we are only looking at what happens once the brake has been sufficiently pushed against the rotor right. Now if this is rotating counterclockwise you know like if I draw the free body diagram of the brake pad, we can immediately see that the friction force on the brake pad will be acting in this direction.

Because the friction force on the rotor will be acting towards the other side, so that to generate a clockwise brake torque, on the pad it is going to act in this way. So consequently, the friction force from the brake pad, once again this is a very simple lumped analysis just to understand the concept right. So from the brake pad is going to be equal to mu times "n", which is going to be equal to mu times F_a.

Disc Brake Analysis

$At\ steady\ state, N = F_a.$

$Friction\ force\ from\ the\ brake\ pad = \mu N = \mu F_a$

$$Brake\ factor\ of\ one\ brake\ pad = \frac{\mu N}{F_a} = \mu$$

$$\underset{(BF)_{Disc}}{Brake\ factor\ of\ the\ disc\ brake} \approx 2\mu$$

$(BF)_{Drum} > (BF)_{Disc}\ for\ the\ same\ value\ of\ \mu.$

So we can immediately see that the brake factor of one brake pad in the disc brake okay. So that is one side right. So we can see that there are in general two, what to say, the rotor is clasped from both ends right, from one side right. It is going to be equal to mu times "n", that is the output divided by the input as F_a right. This is the definition of brake factor. The friction force output to the actuation force input right. So once we have this, what will we get?

This is going to be approximately equal to mu. So we can immediately observe that the brake factor of the disc brake, we can essentially say that that is going to be almost equal to two mu, because the reason I am putting almost is because this is a simplified first cut analysis right. So the main thing is that like, but the main point to observe is that like the brake factor of the disc brake depends on the, what is mu by the way?

It is the brake friction lining coefficient right. So we can see that it is almost directly proportional to mu, however, the brake factor of the drum brake was a nonlinear function of mu please remember this right. So the brake factor of the disc brake is going to be almost like two mu based on a simple first cut analysis. So typically you know like if you look at a typical disc and drum brakes right, given the same lining right, brake lining, you will see that the brake factor of the drum brake would be more than that of the disc brake for typical designs.

So that means that drum brakes are better right, is not it? Because for the same actuation force, we are going to get more braking force from the drum brake. Conversely for the same braking force output, we need to provide a lesser actuation force. Lesser actuation force means we can go for smaller actuators given the same brake pressure. We are going to discuss that later on. So essentially the brake becomes more much smaller in size, the actuator sizes right.

So it just becomes more compact, cost is lower and so on right. So then from all those perspectives, you know like drum brakes seem to be better right, is not it?

$$\Rightarrow More\ brake\ force\ output\ from\ the\ drum\ brake\ for\ the\ same\ actuation\ force.$$

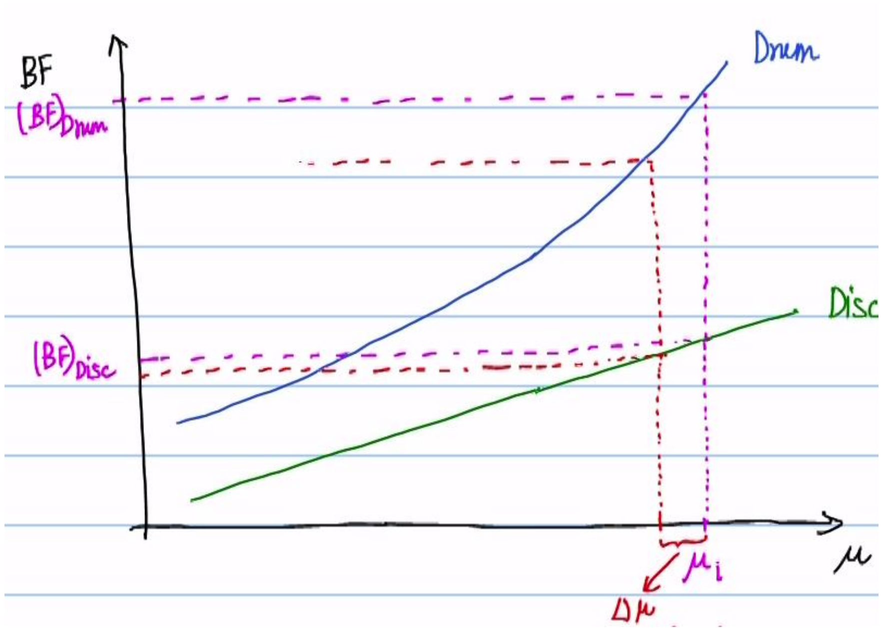
$$\Rightarrow For\ obtaining\ the\ same\ brake\ force, a\ smaller\ actuation\ force\ is\ required\ in\ a\ drum\ brake,$$

So we can observe that by and large, the brake factor of the drum is going to be greater than the brake factor of the disc for the same value of mu right, so typically okay. So this implies that more brake force output from the drum brake for the same actuation force. Conversely for obtaining the same brake force a smaller actuation force is sufficient, is required in a drum brake okay. So it appears as if like the drum brake is much more advantageous.

Of course, it is advantageous from this perspective right, because we have the so-called self energization, which pushes up the brake factor, but of course also kindly recall that yesterday as we discussed, the brake factor of the duo servo brake is going to be in between the brake factor of the two leading shoe configuration and the brake factor of the leading-trailing configuration right. So the arrangement of the brake factor will be leading-trailing shoe followed by duo server followed by two leading shoe right.

So that is the what to say sequence of increasing brake factors for drum brake right. However, you know like, irrespective of the configuration for a typical drum brake and disc brake the brake factor of the drum is going to be greater than this. So we have these advantages, but then we see that today there is an increasing shift towards disc bricks right. So if you look at an entry level compact passenger car where economy is important people use drum brakes because disc brakes are a bit expensive than drum right.

However, if we want performance and we are looking at you know like high-end vehicles right, you will see that all four brakes would be disc bricks and in the middle segment, you will see that there is a trade-off right. We have disc in the front and drum in the rear. So we are going to answer, at least we are going to discuss right, we are going to figure out at least why this is the case from this analysis okay.



So to do that, let me once again do a qualitative plot of the brake factor of both brakes versus the brake friction lining coefficient okay. So this is a just a qualitative plot of, so let us say at the drum brake, which is non linear. Let us say the brake factor goes something like this right and let us say the disc brake, which is linear the brake factor goes something like this okay. So let us say you know like we start with some initial value of mu.

Let us say we put in the same, what to say, friction lining in both the brakes, so mu I being the initial friction lining coefficient. Now if we go up, we can immediately observe, once again this is a qualitative diagram, please take it in that spirit right. So we can immediately see that the brake factor of the disc brake somewhere here and the brake factor of the drum brake is somewhere here. So obviously till now, it appears that the drum is better right.

Okay sorry, this should have been, I should have labeled the blue curve as drum, the green one as disc, yeah sorry about that, right okay. So now as we have already seen, you know like I already discussed right, so the value of mu keeps on decreasing with usage right. So essentially you put a fresh lining, it will have the best value of mu, but with use what is going to happen due to heat the friction lining coefficient is going to drop right. That is what we discussed as brake fade right.

So if you recall the term brake fade, so it is the reduction in mu with the increase in temperature. So that essentially broadly, it means that it is a phenomena associated with reduction in the friction characteristics of the lining with increase in temperature right. So the increase in temperature. Further there is going to be wear and tear of the brake, so consequently the value of mu may further reduce right.

So if this happens and let us say for the sake of argument, you know in both the disc brake and the drum brake, I am exaggerating this just to convey the concept. Let us say, we have the same delta mu right, after some time. Now let us see what happens right. So I projected once again to get the brake factors. Once again these are qualitative curves. So please take it in good spirit right and now let us look at the new brake factors.

So what is it that we can observe? We can immediately observe that the change in the brake factor, let us say we call it as delta bf disc is much lower than the change in the brake factor for the drum brake right, as we can observe right okay and is this a big advantage of disc brakes? Yes, it is. Why? Because with usage, what does it mean, what does change in brake factor mean?

You keep on pressing the brake pedal in the same way in a car, that means we are giving the same actuation force, the change in the brake force output is smaller in disc brake when compared with drum brakes. So that is an advantage right, is not it? Because let us say we take two vehicles you know like vehicle one has all drum brakes and vehicle two has all disc brakes okay, just for the sake of comparison.

And let us say we want a hundred Newton of brake force from either brakes. So the brakes have been designed for that specification. I am just taking the number of hundred Newton as a round number, just as an argument. Now let us say the brake's characteristics, friction characteristics keep on changing. Due to this, let us say that disc brake's brake factor drops by let us say five percentage. So hundred Newton would have become ninety five Newton, when the driver presses the brake pedal completely.

Is not it? So when the driver presses the brake pedal completely, he or she is expecting hundred Newton, that is our expectation right, but with change in this mu that hundred would have decreased to ninety five and okay I think that may be acceptable to us. On the other hand, in the drum brake, that hundred Newton may decrease to eighty Newton right because of a larger decrease in the brake factor with mu and that may create problems right as time progresses okay. So that is where.

That is one of the biggest advantages of disc brakes. So this is what is called as this term used by a few is what is called as mu sensitivity. So what is mu sensitivity? You know like it is indicative of the change in the brake's performance with change in mu right. So that is what is called as mu sensitivity. So we can immediately see that disc brakes have a lower mu new sensitivity than drum brakes.

So essentially, what it means is that with use, we get more reliable brake force output from a disc brake right. So essentially, this implies more reliable brake force output, which matches the design expectations or design specifications, as we keep on operating the brake right, in the vehicle. Of course disc brakes are also going to deteriorate okay. At some point of time, we may need to replace the brake pads. No question about it, but it is just a question of comparison.

You know, which is more sensitive and which is less sensitive to changes in mu. So that is a big advantage of disc brakes, point number one. In this discussion, we assume the same delta mu, but the question is, if I have the same usage pattern. See, let us say, I have once again vehicle one with all drum brakes and vehicle two with all disc brakes and let us say I am coming downhill from a hill station and I keep on using the brakes repeatedly.

So what is going to happen? The brakes are going to get hot right, would they not? The question is would the value of mu decrease by the same amount in both drum and disc? Certainly not. Why? That is where the better heat dissipation characteristics of a disc brake come into play. So you can see that in a drum brake, if we go up, what happens is that there is a drum, which is enclosing this entire contraption right.

So when the brake shoe contacts the drum, the heat energy has to be dissipated first by conduction through the drum, then the drum gets hot and then like it is transferred to the air, which is flowing over the drum okay. So the drum brake is also a very compact unit okay, if you look at one in practice right. So the air circulation in the drum brake and the mechanism of heat dissipation essentially results in the fact that you know the heat dissipation characteristics of a drum brake or relatively what to say I would not say poor.

But relatively you know like less desirable than in a disc brake. On the other hand, in a disc brake, the way it is built, you can see that the rotor, only a part of the rotor is engaged the brake pad, the other parts are open to the atmosphere and you can also see that the rotor has a hollow cavity. So there are paths, which are essentially built into this cavity through which air can flow and that is going to enable better heat dissipation.

So by the design itself, the disc brake rotor is exposed to you know better air flow and air flow is also enhanced by these paths for or channels within the rotor. So those are all like pretty positive aspects of disc brakes okay. So second point is disc brakes also have better heat dissipation characteristics. So we can immediately see that disc brakes are less sensitive. You know like to essentially potential increases in temperature, because not only due to lower mu sensitivity, but also they can dissipate the heat better.

So consequently, if we are going to use the drum brake and the disc brake in the same braking maneuver right, so we subjected to the same braking cycle right, the temperature increase in the disc brake would be lower right, because of better heat dissipation right, everything being the same. That is an advantage. So even brake fade would be lower in magnitude right, so in disc brake.

That is a positive advantage. So the effective reduction in brake factor also will be lower right when subject to the same brake cycle. So this essentially ensures that you know like the disc brakes can also be used at higher temperatures. So just like, what to say, another perspective of this thing is that, since they have lower mu sensitivity you can use disc brakes in braking maneuvers and braking cycles, where the heat energy that is dissipated is also higher.

So that would result in a higher delta T or a temperature change right, because we can still expect some reasonable performance right, under a more what to say demanding brake cycle. So to summarize, you know like disc brakes are popular primarily due to these reasons right. One is lower mu sensitivity, so lower reduction in the brake force output, which changes in the value of the friction lining coefficient. That is point number one.

Second point is better heat dissipation characteristics, so lower brake fade when subjected to the same brake cycle right, when compared to a drum brake, right.