Design of Mechanical Transmission Systems

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Week – 08

Lecture – 24

Lecture 24_Brake: Problem Solving and Friction Materials

Good morning to all. So welcome back to today's lecture. We will continue where we stopped on yesterday lectures right. Yesterday, we have covered various aspects particularly we have discussed about the braking efficiency, braking distance, brake factor. So based on that we will do a one problem to understand how the torque developed by the vehicle and the torque developed by the brake system are interconnected right by selecting the suitable friction lining that that problem we are going to do that and also we will have a short discussion about friction materials. Yeah these are the two things you are going to learn from today's lecture and I am sure you would know the equation right the minimum distance are total braking distance are total stopping distance both are same right.

That equation I just wanted to write

$$S_{min} = \frac{W}{2gC_{ae}} \ln\left(1 + \frac{C_{ae}{U_1}^2}{\eta_b \mu_s W + \mu_R W \cos\theta + W \sin\theta}\right)$$

So this is the equation. Tell me you know this is the weight of the vehicle fine and the velocity right the one which going to drive and what else is there the μ_s is right this is the road adhesion factor is there. So what do you understand from this equation do you think your stopping distance or total braking distance depends upon the vehicle depends upon the brake system nothing right.

It is purely depends upon your road adhesion factor you can see that. So road adhesion coefficient μ_s and the rolling resistance and your velocity and the vehicle weight. So it does not depends on the type of the brake, size of the brake, nothing to do with that it is a purely depends upon the the tyre road friction μ_s, I am talking about that part then the vehicle balance, right which is including W the load and skill of the driver the maneuvering skill that is very important, the maneuvering skill of driver is very critical for your total braking distance aspect on top of that the reaction time right. So the reaction when do you want to apply a brake right, that reaction time along with the distance that is also very critical. In

fact if you look at this is the one is given for a one standard vehicle you can see that how does this braking distance or stopping distance vary with respect to different kilometers, you can see that that is depends on the velocity right you can see that this depends on the velocity and then and again the reaction time this is what I was explaining earlier.

So this is the the brake reaction time, but it is given in the distance aspect and this is for the level road that is ok, but we will focus, this is your designed value then what exactly you are getting the value. So when you design you have to make sure that so whatever you are getting the distance should be achievable within that distance you cannot go beyond that ok. So again this is entire thing is depends on the velocity right, the μ_s factor and finally, the skill of the driver. So those are the things are critical to define the total stopping distance and also I have just wanted to reemphasize the discuss about the selection of friction lining depends on the your μ_l value right. So the code is clearly given so as increasing your μ_l value coefficient of friction of lining right, the code will change you can see that C, within the range D E F G H and this is the ungraded ok.

So this is what you wanted to see that. In fact, we will do a problem here right. So, please take down the problem. So, you have a a multi shift car weighing 12.4 kN is provided with the cast iron, brake drum with the diameter of 250 mm and wide 50 mm for the front wheels with one leading and one trailing shoe arrangements.

So this is a drum brake system yeah. The shoes are actuated by twin piston 30 mm diameter wheel cylinders the ratio of braking efforts in the front and the rear is given 1.7:1, the pedal ratio is 1.8:1, and the servo assistant is 4.86:1, the diameter of the master cylinder is clearly given 25 mm, the maximum pedal force is given 350 N and the coefficient of road adhesion is 0.8 ok. From the brake analysis find out suitable brake lining for the application as per SAE standards ok. Of course, the tyre diameter is given as a 650 mm ok. Then we are I am going to draw the brake arrangement in the next slides ok. So, what do you understand this problem? This is summarizing entire your design brake system right. It is design brake system.

So, the weight of the vehicle is given, size of the drum is clearly given and the the drum also the arrangement it is a shoe leading shoe and trailing shoe, I will give other information also. And look at how you operate a brake you have to use your pedal force which is 350 N clearly given the pedal force 350 N is given from there you have lever mechanism. So, the lever mechanism will enhance 1.8 times right from there we have vacuum booster that will again further enhance your braking effort 4.86 times that is clearly given ok.

So, that is the way happening from pedal to lever, a lever to vacuum booster vacuum booster weight goes master cylinder right. From master cylinder it should reach to finally, wheel cylinder. So, all the master cylinder pressure is given in terms of diameter similarly

wheel cylinder pressure is given in terms of diameter. So, that is also given right. So, that is one aspect and within that the braking proportion whatever the vehicle is coming those information not given the proportion is given your K_b front axle and K_b rear axle proportion is given you could see that the 1.7:1. So, 1.7 times is going to your front axle, one part will be the rear axle ok. So, the total will be 2.7 K_b right that that is that is a I am the with the respect to ratio aspect. So, that is clearly given ok.

Yeah I think we will we will do the problem now. So, how are you going to approach? The first step would be you need to understand that the torque developed by the vehicle when moves with the proportion that one thing we need to do that the other side the torque developed by the drum brake system. So, both has to be equated through brake factor and finally, find out the corresponding friction lining using SAE standard right this is the way you are going to approach. Data given W is equal to 12.4 kN ok yeah. The drum diameter is given brake drum diameter also given 250 mm right. Load transfer we can talk about load transfer right to front wheel yeah,

$$load\ transfer\ to\ front\ wheels = \frac{W \times (K_b)_{FA}}{(K_b)_{FA} + (K_b)_{RA}}$$

$$load\ transfer\ to\ front\ wheels = \frac{12.4 \times 1.7}{(1.7 + 1)}$$

$$N_{FA} = 7.8074kN$$

So, your N_{FA} right this is N_{FA}. The load transfer to the front axle 7.8074 so much kN. So, this much the load is not transferred is coming from the front axle the reaction load right this is coming ok. So, ultimately from this what is the braking torque right what will be the maximum braking torque at the front wheel that is what we are going to find out.

The maximum braking torque on the front wheels right. So, what will be the maximum braking torque at the front wheels

$$(T_b)_{FA} = ((P_b)_{FA}) \times R_w$$

$$(T_b)_{FA} = N_{FA} \times \mu_s \times R_w$$

T_b is a brake torque ok at the FA right that is depends upon what $F_{b\,FA}$ right into radius of the tire yeah R_w. So, in fact, P_b instead of P_b what we can do N_{FA} right, we can have N_{FA} into μ_s right into R_w ok.

$$(T_b)_{FA} = 7.8074 \times 10^3 \times 0.8 \times \frac{650 \times 10^{-3}}{2}$$

$$(T_b)_{FA} = 2.03\ kNm$$

$$(T_b)_{FA}\ per\ wheel = 1.015\ kNm \quad (1)$$

the diameter is 250 mm, but we want as a radius ok 250 by 2. I am sorry is it 250 or 650? 650. 250 for the drum diameter this is the wheel diameter. So, is a w will indicate the wheel diameter this should be as a 650 ok. So, what is the torque you are getting a T_b front alone right you should expect 2.03 so much kNm, this is the torque at the front wheels when I talk about it is a wheel per wheel in the front axle right. Obviously, it will be 1.015 so much kNm this will take it as equation number 1. Thus I will draw the arrangement leading and trailing arrangement yeah this is arrangement.

So, there is a pivot here right the pivot arrangement is as shown here just for understanding ok. And the activation distance is given right, from the tip of the pivot to tip, this is the tip where this force going to act here at P the distance clearly given here is 85 and from here to here is 95 ok. Then there is one more distance we need to have a so as rotating in this direction ok your F_n will be in this way and F_f of nothing please recollect what we derived yesterday yeah. So, the distance between the tip to the end of the drum right that is also given 96. So, this is the arrangement ok this is the arrangement we made simplified I just wanted to emphasize this is a very simple leading and trailing ok.

The moment you go for a leading and leading or SDO or DO servo or S-CAM then again the arrangement will change. So, accordingly you have to find out the friction lining based on the geometry right based on the geometry just giving information. From here the shoe factor for leading

$$(S.F)_{leading} = \frac{F_f}{P} = \frac{\mu_l . C}{n - m\mu_l}$$

right is your friction force by the activation force which already we have mentioned that where which is m which is m which is n which is m right. Then S F trailing will be again

$$(S.F)_{trailing} = \frac{F_f}{P} = \frac{\mu_l . C}{n + m\mu_l}$$

same F_f only thing is the sign will change yeah μ_l C n plus m μ_l ok. So, these are the two equation we need to find out. So, from here we know that C

$$C = 95 + 85 = 180\ mm$$

So, what is the m? m is 96 mm right and n would be 95 mm that ok fine. Now, we got it. So, this is the arrangement geometric arrangement of leading and trailing shoe arrangement ok. The question is now I need to find out the activation force right I need to find out the activation force and also I need to find out the torque developed by the drum brake right.

So, what is the activation force? The activation force how do I do that, how do I find out P? So, the first is your pedal force right you will have a pedal force F_P that is one thing is there. Then what is that you want to have a from pedal force to your lever that is how much 1.8 times it is a magnified 1.8 times ok elevated. Then after that what happened your vacuum booster it is a 4.86 fine. What else we have? From there the moment vacuum booster then pressure is developed then from the master cylinder the pressurized brake fluid will go to wheel cylinder ok. Whereas, the master cylinder has the diameter what? 25 right the master cylinder has a 25. So, the pressure will be very high the pressure will be very high, but the moment it reached the wheel cylinder the diameter is 30 mm. So, the pressure will be reduced. So, we have to do the proportionate right.

$$The\ activation\ force\ P = F_p \times 1.8 \times 4.86 \times \left(\frac{30}{25}\right)^2$$

$$The\ activation\ force\ P = 350 \times 1.8 \times 4.86 \times \left(\frac{30}{25}\right)^2$$

$$The\ activation\ force\ P = 4410\ N$$

So, that is the area thing right. So, obviously if you do that and I know my F_P equal to how much it is a F_P equal to 350 N. So, if you substitute can you give me the value 350 into 1.8 into 4.86 how does it matter because the ratio. So, I will straight away substitute in millimeter square is going to be cancel out. So, can I have the what is the value you are getting activation force? 4410 N. So, that is the value you should expect 4410 N this is the the activation force you are expecting ok that is fine yeah. So, earlier we found out the brake torque from the vehicle that already given 1.015 kNm. Now, we want to equate it from the brake drum torque right this is your activation force right. Then we need to find out the brake factor thing. So, the frictional torque of the drum. So, what are we talk about earlier the road adhesion torque now we talk about frictional torque developed on the drum right. So, your activation force, then radius of your drum ok this is the way the brake factor will come into the picture ok this is the way the brake factor come into the picture brake factor the BF ok it is a BF.

$$\text{Frictional torque developed on the drum} = \text{P} \times R_D \times BF$$

$$\text{Frictional torque developed on the drum} = 4410 \times 0.125 \times BF\ (2)$$

So, what is the for activation force 4410 what is the radius of the drum brake it is a 0.125. Do you know the braking value are we knowing the brake factor value we do not know right we have to find out. So, that is the equation number 2, but the concept would be we know that whatever the brake developed by the drum must be equal to the brake developed by the vehicle that has to be equated that has to be matched. So, if we do

$$(1) = (2)$$

$$1.015 \times 10^3 = 4410 \times 0.125 \times BF$$

$$BF = 1.842$$

So, I will get the BF ok. So, my braking factor it should be right 1.842. So, already BF we got it. So, braking factor. So, this is depends on what, this braking factor depends upon μ_l and dimension of drum system or drum brake ok right. So, but we know that what is the leading shoe factor and the trailing shoe factor ok, but we do not have the values of μ_l. So, we have to substitute the μ_l value by varying 1, 2 right 0.1, 0.2, 0.3, 0.4 like that until you meet the braking factor the values. So, when it meets that is a corresponding μ_l value you should provide based on the SAE standard right. So, we are going to use the trial and error method right. So, I am just going to have μ_l here, I need to find out the $S_{leading}$, $S_{trailing}$ right then my braking factor BF equal to $S_{leading}$ plus $S_{trailing}$.

$$BF = S_{leading} + S_{trailing}$$

So, we are going to have a table forming.

μ_l	$S_{leading}$	$S_{trailing}$	$BF=S_{leading}+S_{trailing}$
0.1	0.211	0.172	0.383
0.2	0.475	0.315	0.7902
0.3	0.816	0.432	1.252
0.4	1.272	0.540	1.812
0.5	1.915	0.629	2.544

So, what we are going to do we will change the value first we will try with the 0.1 right. So, already we derived what is the $S_{leading}$ right you substitute μ_l equal to 0.1 find out what is the value you are getting. So, you would expect leading will be always higher value to 0.211 and this will be 0.172. So, together when you add 0.383 right. So, similarly if you do change the μ_l 0.2 right. So, 0.475, 0.315 and 0.7902 similar I keep increasing what is the brake factor you are getting already we achieved the brake factor should be 1.842 right and till then you will keep increasing your μ_l value until then keep increasing your μ_l value. So, 0.816, 0.43 to 1.252 then I will go for 0.4, 1.272, 0.540, 1.812, but ours is 1.842 still it is not correct 0.5. So, that will be give 1.915, 0.629 and 2.544 right.

So, what is the brake factor we have? Brake factor we have 1.842. So, if we do this between these two value interpolation you will expect μ_l based on interpolation right the expect μ_l equal to 0.404. Now, if you refer your SAE standard. So, what is the code you are expecting right. So, μ_l is given 0.04. So, it is in the range right. So, what is the value you are expecting? As per SAE standard what is the code? The code friction lining code will be F value is it clear now? Yeah.

So, now you know how to select a friction lining right. So, you have to check the based on the type of brake system is it drum brake or disc brake. What happen if a disc brake straight away your b f will be 1.2 right, that is the 1.2 it is a fixed one. Whereas as you move on to the drum brake within the leading and trailing, leading leading or else servo DO or S-CAM these things we keep changing ok.

So, by doing a trial and error method finally, you can expect your friction lining right based on the SAE standard code F ok. So, let me ask few questions ok before proceeding to the friction materials. So, far we have discussed the entire vehicle move in a one surface right or μ_s that keep changing you can have a thar road which is a bituminous road or asphalt that we can do that or else you can have a concrete roads or else you can go for skiddy one, ice one, a gritty all those things we have discussed. That is as entire vehicle, my question is when you travel in a narrow road one side of vehicle will have a on the mud, the other side will be on the road. So, what do you expect? Let us have my question right the same axle one will have a different road adhesion factor another will have a different road adhesion factor.

So, how it is going to be changed? It will be even more quite challenging right that is one thing you need to understand that. So, another question, so far we have not discussed anything about the wheel drive whether it is a front wheel drive or all wheel drive. So, what happened when you have a these drives? How is going to be affect the braking performance? Those topics I am going to give as a homework study ok.

In fact, yeah I will give some textbook also you can refer it right. I will ask in fact, a few a couple of question in the assignments based on that ok. So, now I will move on to the friction material aspect right. So, we will talk about to only few minutes above the friction material. Understand the purpose of the friction material to develop the friction right it is a develop the friction. When you develop the friction in the sense, the friction is not only developed, but should be sustainable. It is not sustained you cannot hold the vehicle. So, it should be sustainable and not only that it should have a high friction and stable friction, it should have a high wear resistance, you should not expect the brake wearing out quickly ok that is third property. A fourth property what do you expect? High thermal conductivity ok. If it is a then only the heat dissipation can be easily carried away otherwise the heat is in contained in the brake lining that is going to affect the performance ok. Now we heard about brake fading what do you mean by brake fading? What do you understand brake fading? It is just fades away right what do you what do you think of it? So, when you apply the brake right when you apply the brake. So, heat generated and certain points due to stress concentration, they will have localized the heating they will have localized heating.

So, because of that you cannot the hardness of microstructure will change you cannot hold it you cannot hold it ok. Maybe I will give you some lighter example. Have you ever made

chapati right you have made chapati right. So, when you rolling on the skillet or tawa you will see the block spots, why the block spots coming? The heat supposed to be uniform you use you know you rotate. So, that the uniform it will come, then flip it another second you will get puffed chapati supposed to be, but instead of that you will have dark spots why this is coming that is because of localized heat.

So, just called hot spot same phenomena would occur in the brake pads also ok yeah. So, again so, the brake pads what happen as such this size of the vehicle change the material also will change. For aircraft application you expect the temperature even 1000°C that means, that means, friction need to be developed and not only that then the thermal conductivity accordingly should be increased the wear is also increased. So, there are you cannot have a single material for a manufacturing brake it will have a combination of many material that is why it is brake material generally comes under composite material ok. One more question I would like to ask, the question is you need to have a friction you need to have less wear and you should have very high thermal conductivity right that is correct.

At the same time it should not have any corrosive behavior because of any exposed to open right the brake pads generally opens they should the corrosive resistance will be very high that is also very important thing. And more when the when braking happening what you expect the high noise right, it is called squeal do you think is it comfortable for a passenger. So, for passenger car you have to think about the comfort also you do not want to have a very noisy brake. So, if you want that means, you should be have well less noise. So, if you want have less noise what are the things we need to change in the brake pad material combination right.

Then of course, noise can be affordable for the offload vehicle by tractor right or in the gun where I am talking army tank there is fine high noise is fine ok whereas, as a human traveling there you need to have a very comfort noise level. So, depends on the how you want to. So, based on that the elements in the brake pad will keep changing ok I think I will stop I will give this also as a homework because of this a complete material aspect not as much the design aspect ok. Thank you.