Design of Mechanical Transmission Systems

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Week – 10

Lecture – 28

Lecture 28_Brake: Thermal Analysis Problem Solving

Good morning. So, we will continue in brake system design aspects. We have been covered so many topics within the brake system and currently we are doing with the thermal analysis and we have covered for a brake energy and braking power and also how the braking power is observed by brake lining and drum and also, we discussed about the single stop braking, repeated braking as well as drag braking. I think we in last lecture we have done a couple of problem and we will continue to do couple of problems today's lecture also by solving the problem we will understand the difference between single stop braking, continued braking as well as repeated braking. I think in the last problem we have done with the repeated braking right. We understood that within the small number of cycles the maximum temperature is attained that is what we have understood.

Now we will go for today's problem yes please check down. Compute the average brake temperature of a tractor semi-trailer descending a 7% grade at a constant speed of 32.2 kmph. Necklet and engine retardation compute the brake temperature after 1.6, 3.2 and 8 km of operation. Use the data that follow vehicle weight 355.84 kN, tire rolling resistance coefficient 0.01, brake drum volume 0.0079 m^3, cooling area 0.37 m^2, convective heat transfer coefficient 73.83 $W/m^2/K$ and relative braking power per one tractor near break 0.11 and initial ambient temperatures are 338 K and 283 K respectively. So what type of problem is it? It is a drag braking right it is a slope braking clearly given once again.

So clearly given 7 % grade is given so the gradient aspect okay and also we need to find out what would be the right temperature after 1.6 is a km but is equivalent to 1 mile, 3.2 km which is again 2 miles and for 8 km equivalent to 5 miles. So when you travel when the vehicle operate in the slope for different distance covered right when the distance different covered what happen to the temperature okay. You may ask question so as I said earlier why 3 different testing right understand about temperature we talk about single stop braking then again repeated braking and drag braking okay while solving the problem you understand why we need to give importance all 3 aspects okay.

The data is clearly given right, so it is a clear problem, it is a drag braking okay yeah. Then move on to the data given so what are the data is given right so the vehicle weight is given

W = 355.84 kN

Speed = 32.2 kmph = $V_1 = \frac{32.2\times10^3}{3600} = 8.94\ m/s$

Gradient = 7% = 0.07

μ_R =0.01 , 11% brake power absorbed

355.84 kN that is a weight of the vehicle okay. So anything else is given yeah speed is given vehicle speed is given 32.2 kmph and if you want as a velocity V_1 okay 32.2 10 power 3 for converting km to m and since it is an hour we need to have in seconds divided by 3600 okay. So that gives the speed okay. So what else we have yeah it is given gradient g normally we say that g gradient in terms of percentage 7 % the gradient is given or maybe I will write gradient 7 % equal to 0.07 that is clearly given. What else we have the rolling resistance mu r is given equal to 0.01 rolling resistance okay rolling resistance is given any other data 11 % is observed that is what given right the 11% in the front brake 11 % energy brake energy I would say brake power absorbed clearly given. So what is the velocity are you getting 8.94 yeah 8.94 m/s.

So before solving the problem finding out the temperature we need to know how much brake power is observed in the during the drag braking okay. So what is the equation the drag the average brake power remember what is the equation

$$BP = WV_1 \sin \propto = WV_1 G$$

WV_1 sinα right this is the equation we use or else we can say WV_1 sinα can be written as a gradient I am sure you would know that okay written as a gradient G, you can have a gradient also and when the vehicle move down right this is a slope assuming this is θ okay and the vehicle is here, so it is it is moving down right when it is moving down it has to move against rolling resistance also right yeah it has to move against rolling resistance. So I think this is the equation already I have written in in the previous lecture okay that we got it, this is fine anything other any other data is missing now I think that is all and percentage how much is going to be observed for front brake system right yeah the percentage is 0.11 okay.

$$BP = WV_1 \sin \propto = WV_1(G - \mu_R) \times 0.11$$

$$BP = 355.84 \times 10^3 \times 8.94 \times (0.07 - 0.01) \times 0.11$$

$$BP = 21kW$$

So can you substitute please and in that 11% this is the total energy right this is your total brake power within that 11% is absorbed by the front yeah that is given. So can you tell me what is the value you are getting okay are you getting 21 kW right you should be expert the power absorbed 20 kW okay and remember and we need to have the values also right because we are going to use the thermal equation please note down the density of the drum or disc 7228 kg/m^3 where specific heat 419 J/ kg/K and if you need I am not sure we will see that thermal conductivity 48.5 W/mK that is also you should note down. Now the scenario we can say this is the Q_R that is heat absorbed or brake is absorbed from the calculation we got it

$Q_R = 21\times10^3$ W

so much W it is okay. Now what is the equation we should use is for drag braking for continued or drag braking okay so we need to find out the temperature right the temperature.

$$T_{(t)} = \left[T_i - T_\infty - \frac{Q_R}{h_R A_R}\right] \times e^{\frac{(-h_R A_R t_c)}{(\rho_R C_R V_R)}} + T_\infty + \frac{Q_R}{h_R A_R}$$

Ti = 338 K

h = 73.83 W/m^2K

A_R = 0.372 m^2

V_R = 0.0079 m^3

ρ_R = 7228 kg/m^3

C_R = 419 J/kg/K

So what is the initial temperature, we know Q_R, Q_R is already known to us yes what is the T_i is given, your T_i is 338 K, your ambient temperature 283 K respectively okay fine this is okay and what is the t_b what is the braking time t_b what is the braking time, we have to find out right we need to find out case by case we will we will wait for that second aspect is heat transfer coefficient h is given 73.83 W/m^2K h is given and A_R 0.372 m^2 meter square V_R 0.0079 m^3 meter cube this is the swept volume then ρ_R I am rewrite again 7228 kg/m^3 okay and conductive heat specific heat 419 J/kg/ okay any other data right. So we have heat transfer coefficient, the area is given, ρ_R also, C_R also we know that and V_R except t_b is not there okay t_b it depends on the how much distance you are travelling velocity is given but we need to know the distance the problem clearly given three distance 1.6 km, 3.2 km, and 8 km three distance we are going to do that the first case okay I will go for it in detail for the case one the distance travelled 1.6 km. So, corresponding braking time what do you expect corresponding braking time your V_1 velocity right yeah sorry the braking time we know that the distance and the velocity will give you distance travelled velocity is 1600 m I am just converting into everything SI units okay and what is the velocity 8.94 m/s yeah

$$t_b = \frac{1600}{8.94} = 179s$$

you should expect 179 seconds. So, that is the braking time 179 second is the braking time okay. So, I need to find out this the maximum temperature T_{max} I have to find out

$$T_{(t)max} = \left[T_i - T_\infty - \frac{Q_R}{h_R A_R}\right] \times e^{\frac{(-h_R A_R t_c)}{(\rho_R C_R V_R)}} + T_\infty + \frac{Q_R}{h_R A_R}$$

okay can you substitute the value please tell me what is the answer you are getting. So, I am just simplifying that.

$$T_{(t)max} = -577.82 + 283 + 764.62$$

$$T_{(t)max} = 469.8 \cong 470\ K$$

I am just after substituting these are the value you are getting. So, you should expect 469.8 K approximately T_{max} temperature after 1.6 km okay 470 K this is your answer okay for case 1 okay 470 K.

So, similarly you have to substitute and find out for the case 2 for 3.2 km and case 3 for 8 km. The question is which variable will change here in this general equation I have given the general equation right in this equation, which is the variable change your braking time the other things are remain constant okay the braking time will change other things are remain constants. So, we have to find out the braking time for the other cases okay.

So, the case 2 the distance 3.2 km. So, obviously what happened your braking time yeah the t_b braking time

$$t_b = \frac{3200}{8.94} = 358s$$

okay that should give me the braking time 358 s. So, I am giving you straight away answer the temperature

$$T_{(t)max} = 576\ K$$

$T_{(t)}$ for 3.2 km that is give me 576 K. Similarly, if you go for case 3 the distance travelled 8 km okay. So, your braking time

$$t_b = \frac{8000}{8.94} = 894s$$

So, second would be the braking time would be more 894 s okay this is your braking time.

$$T_{(t)max} = 792\ K$$

So, finally the $T_{(t)}$ at 8 km the reached okay 792 K yeah. So, I will write one more answer T(t) for 1.6 km that answer what you got we have 469 K okay. So, I am showing all 3 answers look at when the vehicle is moving down for 1.6 km, vehicle able to reach its temperature 469 K. The moment distance doubled 3.2 km the temperature shoot up to 576 K okay. And again if you increasing the distance further in the slope, the temperature reach to 790 K maybe even if you removing a 300 okay that means 500 °C right very high temperature. So, what is your observation what you understand? Remember in the drag braking or continued braking you are applying a brake to control the velocity okay you do not want to topple the vehicle okay. Your purpose is, you do not want to stop the vehicle, but you want to control in a constant speed such a way that you have moved down safely on the slope that is what is happened okay. But interestingly the more the slope what happened to your temperature in the brake is high.

So, now do you know why we have to do the repeated braking sorry continued braking or drag braking because a temperature is the limiting factor. You may ask question why temperature is a limiting factor because you have to understand how much temperature can absorbed by the brake lining on the drum or disc. If it is goes beyond then you will have fading right then you cannot expect to lock up. So, that leads to catastrophic failure. So, now you know that why importance given for 3 different breaking aspects right.

So, now you know that for the drag braking aspect now we will go for the single braking okay. Now we will do the one more problem for single breaking. Any doubt in this problem aspect? Fine yeah. So, now we will do the another problem okay.

So, take this problem compute the maximum front disc brake temperature of a passenger car decelerating at point G from a speed of 128 kmph without brake lock up okay. The vehicle weight is given 20 kN, 70% of brake is absorbed on the front disc or front brakes. The heat dissipation onto rotor is 90 %, the tyre slip is 80 % and the swept area of one rotor side is $323 \times 10^{-4}\ m^2$ and initial brake temperature is 311 K okay. So, now we are talking about single stop braking. You know what do you understand about single stop braking? In single stop braking okay you are allowing the vehicle to move at a maximum speed and apply the brake okay. In continued braking, but you have the cooling system. In spite of cooling system temperature rises as the more distance travel on the slope okay. Whereas in repeated braking which we did it okay for 5^{th}, 10^{th} and 200 that is a there is also cooling time okay. In single stop braking, there is no cooling time, because you are allowing the vehicle to maximum speed and apply the brake right. So, the braking time is so small you do not have enough time for heat dissipated right or cooling that is what happening. So, that is those things already we have discussed.

Now, we will solve the problem okay I will solve the problem. So, data is clearly given right. This is the vehicle speed 128 kmph is clearly given and deceleration rate is given this may be I will write down here. The deceleration rate is given 0.8 g okay. The speed is clearly given as a 128 kmph.

a = 0.8 g

$$speed V_1 = 128\ kmph = \frac{128\times 10^3}{3600} = 35.56\ m/s$$

W = 20×10^3 N

Slip = 8%

Heat dissipation = 90%

$A_R = 323 \times 10^{-4}\ m^2$

So, which formula I will be using first we need to understand how much power is absorbed by the brake that is the first step right for single stopping. So, what is I using okay the average brake power okay, what is the equation, we are going to use it remember K_m right

$$Q = \frac{K_m(1-s)WV_1 a}{2g}$$

$$Q = \frac{1\times(1-0.08)\times 20\times 10^3\times 35.56\times 0.8\times 9.81}{2\times 9.81}$$

$$Q = 261.72\ \times 10^3\ W$$

So, it can tell me how much energy is coming right the average brake energy of the vehicle that should give me 261.72 power of so much what this is the average brake power the when the vehicle stop from 124 km right on a plane stop okay. So, now, this over we have to find out the braking time or the brake time or stopping distance time t_b okay.

$$t_b = \frac{V_1}{a} = \frac{35.56}{0.8\times 9.81} = 4.54s$$

Now, I just want to point out remember what are the braking time when we vehicle is move on the slope 1.6, 3.2, and 8km they are in minutes right they were in minutes so many seconds, but look at the there the vehicle is moving at 32.2 kmph very slow speed okay whereas the vehicle moves here very high speed 124 kmph okay, but what happen your braking time much smaller right. So, obviously, you do not have any cooling aspect because of by time it reaches to the mid portion of your drum thickness right that time it will even very smaller okay. So, now, we need to find out the brake power right for this aspect okay. So, the average braking power absorbed for front brake right and it is you are taking about the entire vehicle then you take consider only the front brake within the front brake you consider one side of front brake okay.

$$\text{average braking power absorbed for front brake and one side}$$
$$= 261.72 \times 10^3 \times \frac{1}{2} \times \frac{1}{2} \times 0.72 \times 0.9$$

So, we know that this is 261.72×10^3W. So, this is entire thing is right within that we will take it for a front then for one side that is what clearly given okay. So, normally entire brake energy 72 % absorbed very front so, 0.72 within that how much is absorbed by the disc at run it is a 90 % Q_R remember, Q_R is given 90 % okay 0.9. So, I am talking about the Q_R you should expect

$$Q_R = 42.4 \times 10^3 W$$

So, this much energy is absorbed okay. So, now, we need to understand about the temperature calculation okay. So, temperature calculation yeah for temperature calculation, it requires because we always talk about surface area requires the heat flux into swept area, swept area already we have okay

$$\frac{Q_R}{area} = \frac{42.4 \times 10^3}{323 \times 10^{-4}} = 1.313 \times 10^6 W/m^2$$

this much energy is given okay. Now, we got it so, earlier we try to find out the total brake power energy within that how much energy is absorbed by one side of the front brake okay. Now, ultimately we need to find out what would be the maximum temperature right. So, it is a single stop braking okay to find the maximum temperature for a single stop braking

$$T_{max,L} - T_i = \left(\frac{5}{18}\right)^{\frac{1}{2}} \times \frac{Q(t_b)^{\frac{1}{2}}}{(\rho C k)^{\frac{1}{2}}}$$

k = 48.45 W/mK

ρ_R = 7228 kg/m^3

C_R = 419 J/kg/K

T_i = 311 K

So, it is all ρ_R , C_R all the others and and half okay. So, we know Q_R and t_b also known to us right 4.54 yeah the braking time known to us density known what is the density we know that from the table 7288 kg/m^3so okay. What about specific heat capacity 419 J/kg/K, I think joule per kilogram Kelvin sorry not kilo joule Kelvin yeah yeah yeah does not matter both are drum and disc are interrelated I was telling from the beginning onwards yes drum or disc they are same that is what I said from the beginning onwards okay. So, the thermal connectivity k is given 48.45 W/mK okay. So, can you substitute please tell me what is that value you are getting

$$T_{max,L} - T_i = 121.65$$

$$T_{max,L} = 121.65 + 311 = 432\ K$$

T_{max} I just want to know your value okay the value what you are getting I got some value, but there is a small thing T_i is clearly given as a 311 K. So, what is the value you are getting yes value please do you want me to show the equation again it is fine right yes what is the what is the value I am getting 121.65, but not sure is it correct or not. So, that is why I wanted to know it from you is it correct value 121.65 okay fine okay. So, 121.65 okay then T_{max} the okay 121.65 plus 311 okay. So, that is give me my maximum temperature with respect to single stop 432 okay no need to do Kelvin yeah this is the maximum temperature attained right this is maximum temperature, remember this is our rotor or drum brake does not matter. So, okay. So, this is what we take it as a length right half of the length only we are take as a length of the thing okay we know this braking time is 4.54 second okay.

$$\frac{t_b}{2} = \frac{4.54}{2} \cong 2.25s$$

So, in the half of that if you take the half of by 2 right what is that you are getting this 2.25 second right you need a 2.25 second to reach the heat to the middle of the your drum or middle of the disc okay. So, one more clearly given no lockup what do you mean by no lockup. It is not able to hold right that is what is no lockup okay.

The moment you reach beyond this temperature right the brake fading going to happen the moment you reach beyond anything greater than 432 K the vehicle have a fading effect that is why you are not able to stop the vehicle that is what is for no lock okay yeah. I think there is one more problem I have this is very big problem okay. So, we will discuss both aspect it discuss about the single stop braking okay consider the van is braked 90 km in 6 second, determine the peak and bulk temperature that is one thing. Then same thing if the vehicle is braked repeatedly from 80 km to 30 km with the interval of which is a repeated braking okay. In both aspect we need to understand okay we will solve it in tomorrow lectures I will stop now okay.