

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

THERMAL ANALYSIS OF DISC ROTOR

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ABSTRACT

The road vehicle braking has become broad and complicated field over years. The braking of commercial vehicle is more complicated and conversion of kinetic energy into heat is immense as it subjected to heavy loads as compared to cars, two wheelers and passenger cars. The purpose of study is to analyze forces and bulk temperature rise analytically for steady state heat dissipation. The temperature rise for different materials is calculated analytically and numerical simulation using ANSYS for constant braking rate of 0.5. The results are compared for different materials. The study is carried out on simple ventilated disc brake.

Keywords: *Heat dissipation, Numerical simulation.*

I. INTRODUCTION

Braking system is one of the significant cardinal safety components of vehicle. It is used to decelerate the vehicle from an initial speed to a given speed. Friction braking system is most widely and commonly used braking system. Disc brakes are friction brake system used in modern vehicle due to their reliability, high braking capacity and efficiency. In disc brake friction material called friction pad are pressed or forced against disc to stop vehicles by hydraulically or pneumatically. This converts large amount of kinetic energy into heat. Repetitive braking of vehicles generates large amount of heat. This heat has to be dissipated for better performance of brake. Braking performance largely affected by the temperature rise in the brake components. High temperature may cause thermal cracks, brake fade, wear and reduction in coefficient of friction. The heat dissipation and temperature rise in disc brake has been studied in past by numerical simulation using ANSYS. Andrew Day studied different types of brakes in addition he also presented force analysis, different types of friction materials. He also presented formulae and relations for heat dissipation in disc rotors. Commercial vehicles such as trucks and trailers combination the bulk temperature rise of disc rotor is important as they subjected to heavy loads and inadequate supply of air for convection cooling. Nowadays the convective cooling analysis is carried out by using CFD (Computational Fluid Dynamics). The purpose of this study is to present simple analytical method for calculating forces, heat and bulk temperature rise. The disc brake used is simple ventilated disc having rectangular fins. The study is carried out for different materials such as aluminium alloys, stainless steel, structural steel and gray cast iron. Analytical results are compared with the ANSYS results and variation in results is shown as percentage of errors.

Nomenclature:

M	Mass of the vehicle (kg).
P	Vehicle weight (N); this differs from the UN Regulation 13 and 13H, where P is specified as the 'mass of the vehicle'. In this book the mass of vehicle is denoted as 'M' (Kg).
P_i	Normal reaction at the road surface of axle ' i ' under static condition (N). Note that subscript ' i ' refer to the axle, so for the vehicle illustrated here ' $i=1$ ' indicates the front axle and ' $i=2$ ' the rear axle.
N_i	Dynamic normal reaction at the road surface of axle ' i ' under braking condition on the road (N).
T_i	Braking force exerted by the brakes on axle ' i ' under normal braking conditions on the road (N).
Z	J/g = Rate of braking of the vehicle. In road vehicle braking parlance 'z' is usually quoted as a decimal, e.g.

'0.5', or as a percentage. Thus, the statement 'z=0.5' and 'z=50%' both mean that the deceleration of the vehicle is $0.5 \cdot 9.81 \text{ m/s}^2$.

- H Height of centre of gravity of the vehicle above the road surface (m)
- E Wheelbase (m)= L_1+L_2
- L_1 Horizontal distance from the front axle to the vehicle's centre of gravity (m)
- L_2 Horizontal distance from the rear axle to the vehicle's centre of gravity (m)
- X_i Proportion of the total vehicle braking force generated at the axle ' i '
- M_t Mass of the trailer (kg).
- P_t Trailer weight (N).
- h_2 Height of the centre of gravity of the trailer above the road surface (m).
- h_3 Height of the tow hitch (car and trailer) above the road surface (m).
- E_2 Horizontal distance from the trailer hitch to the trailer axle centre line (m).
- a_2 Horizontal distance of the trailer centre of gravity behind the trailer tow hitch (m).
- C Horizontal distance from the car rear axle to the car tow hitch (m).

II. METHOD

The articulated lorry or tractor and semi-trailer combination represents the largest group of heavy vehicles on modern roads. The tractor and trailer are connected through the coupling which transmits horizontal and vertical forces between two parts of vehicle. The tractor is designed to carry a substantial portion of weight of trailer via the coupling and retardation forces provided by its brakes must be capable of decelerating both the tractor mass and portion of tractor mass. The analysis of forces acting on tractor the tractor and semi-trailer combination. The force system for tractor and semi-trailer combination is shown in figure. The best approach might be to do the analysis of optimum braking distribution i.e. when braking on each axle is proportional to normal load carried by the axle. The braking efficiency is considered as one.

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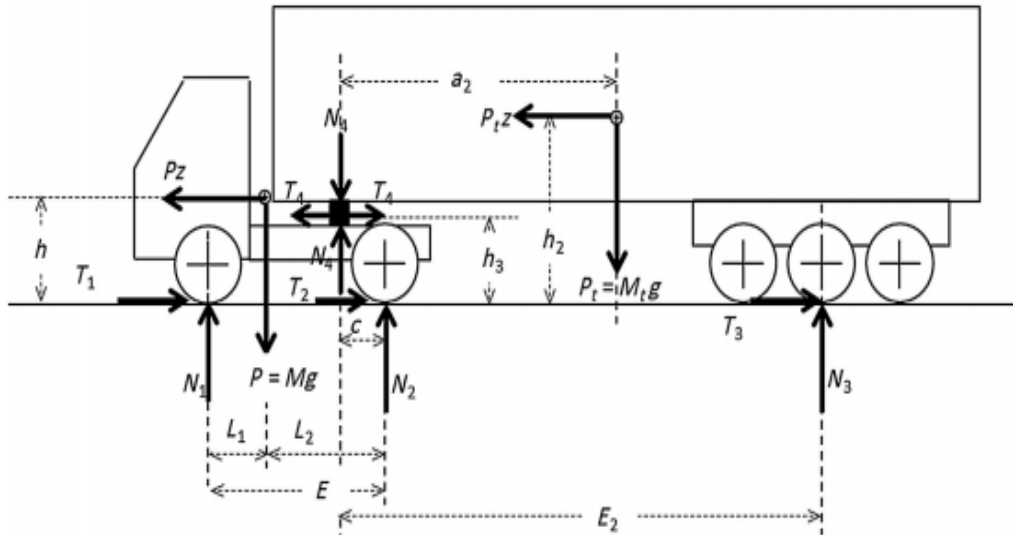


Figure: Tractor and semi-trailer combination force system.

For tractor:

Resolving forces vertically: $N_1 - P + N_2 - N_4 = 0 \dots (1)$

Resolving forces horizontally: $T_1 + T_2 - P - T_4 = 0 \dots (2)$

Taking moments about the points of contact between the front wheels and the road surface:

$N_4 (E + c) + P L_1 - N_2 E - P z h - T_4 h_3 = 0 \dots (3)$

For semi-trailer:

Resolving forces vertically: $N_4 + N_3 - Pt = 00 \dots (4)$

Resolving forces horizontally: $T_4 = T_3 - Ptz = 00 \dots (5)$

Taking moments about the coupling (fifth wheel):

$Pta_2 - N_3E_2 - T_3h_3 - Ptz (h_2 - h_3) = 00 \dots (6)$

Maximum brake torque requires at each wheel.

Knowing the values of T_1, T_2, T_3 .

The braking torque at each wheel is calculated by relation

$\tau_{wi} = T_{wirr} = T_{irr}/2$

The maximum heat produced due to absorption kinetic energy at each axle.

$Q_i = \frac{1}{2} * M (v)^2$

Bulk temperature:

The temperature rise in disc due to conversion of kinetic energy into heat is given at each axle by

$\Delta\theta_i = Q_i/mC_p$

ANSYS Results:

Temperature Distribution

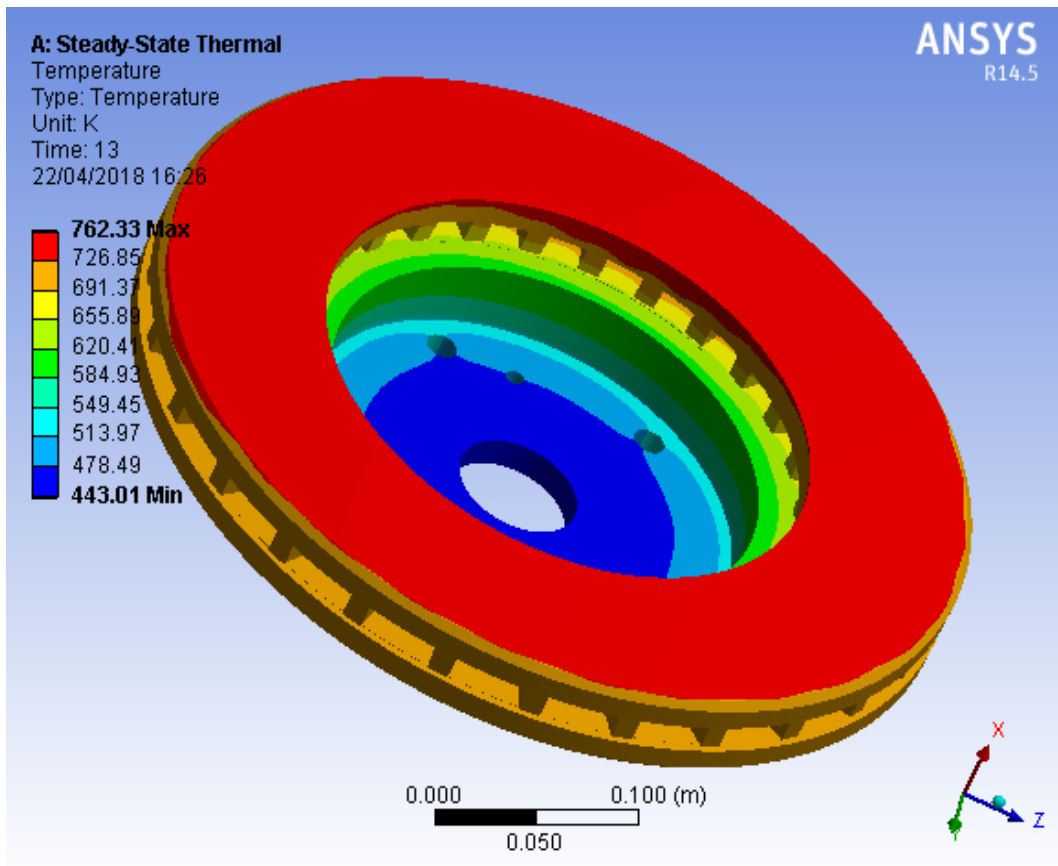


Figure: Temperature Distribution of Cast Iron Disc.

Figure shows steady state thermal analysis of Cast Iron disc rotor. From analysis it is clear that the maximum temperature rise is 762.33 K. And the minimum temperature rise is 443.01 K. The overall temperature distribution

is shown with different colors on the disc and each color represents the criticality of temperature induced in the disc rotor.

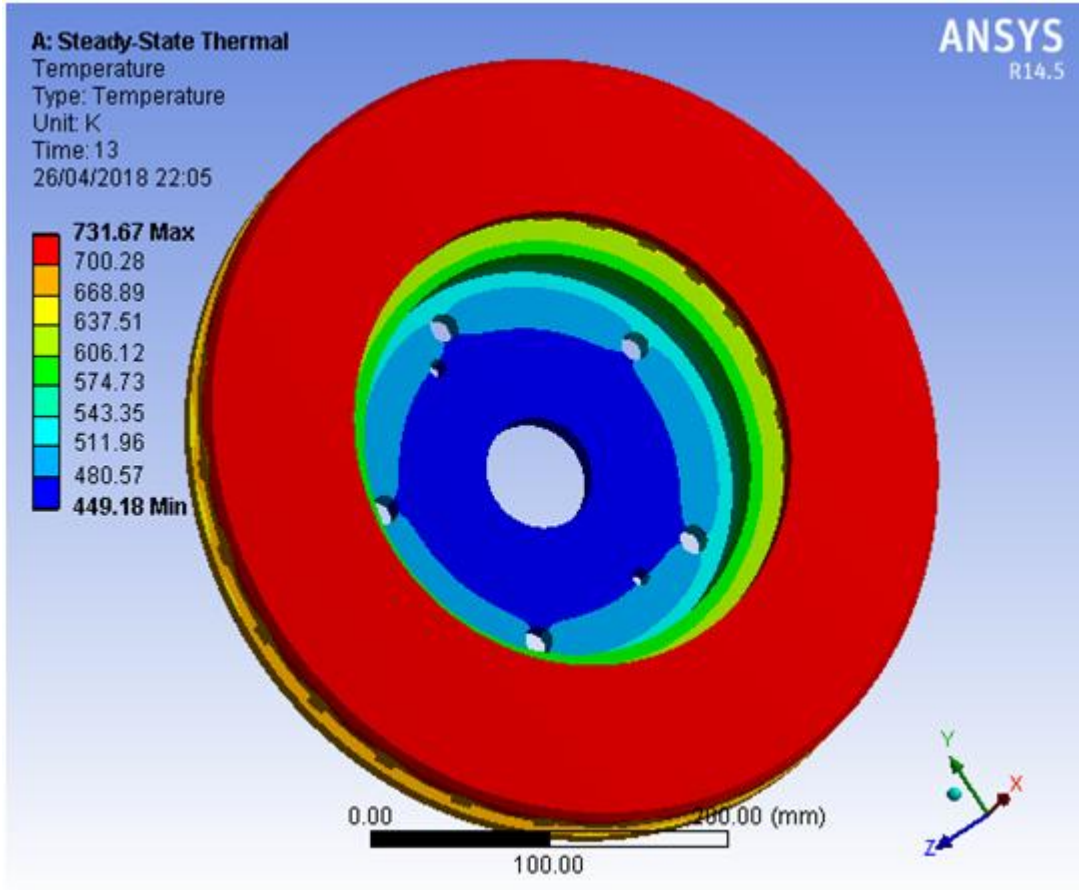


Figure: Temperature Distribution of Structural Steel Disc

Figure shows steady state thermal analysis of Structural Steel disc rotor. From analysis it is clear that the maximum temperature rise is 731.67 K. And the minimum temperature rise is 449.18 K. The overall temperature distribution is shown with different colors on the disc and each color represents the criticality of temperature induced in the disc rotor.

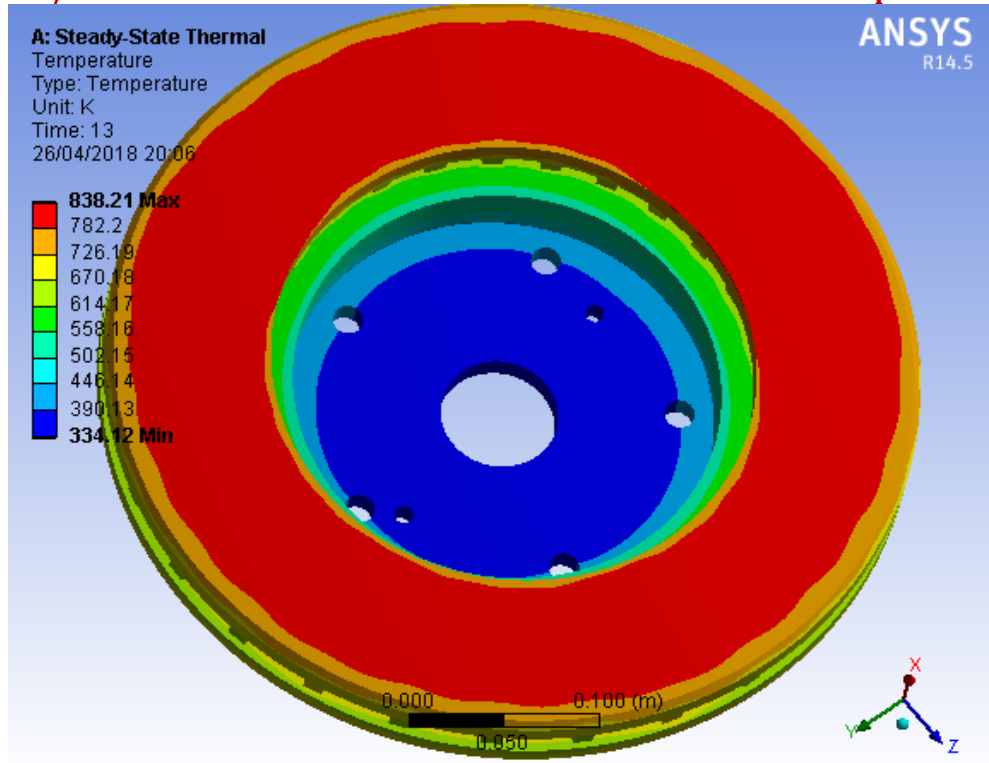


Figure: Temperature Distribution of Stainless Steel Disc

Figure shows steady state thermal analysis of stainless steel disc rotor. From analysis it is clear that the maximum temperature rise is 838.21 K. And the minimum temperature rise is 334.21 K. The overall temperature distribution is shown with different colors on the disc and each color represents the criticality of temperature induced in the disc rotor.

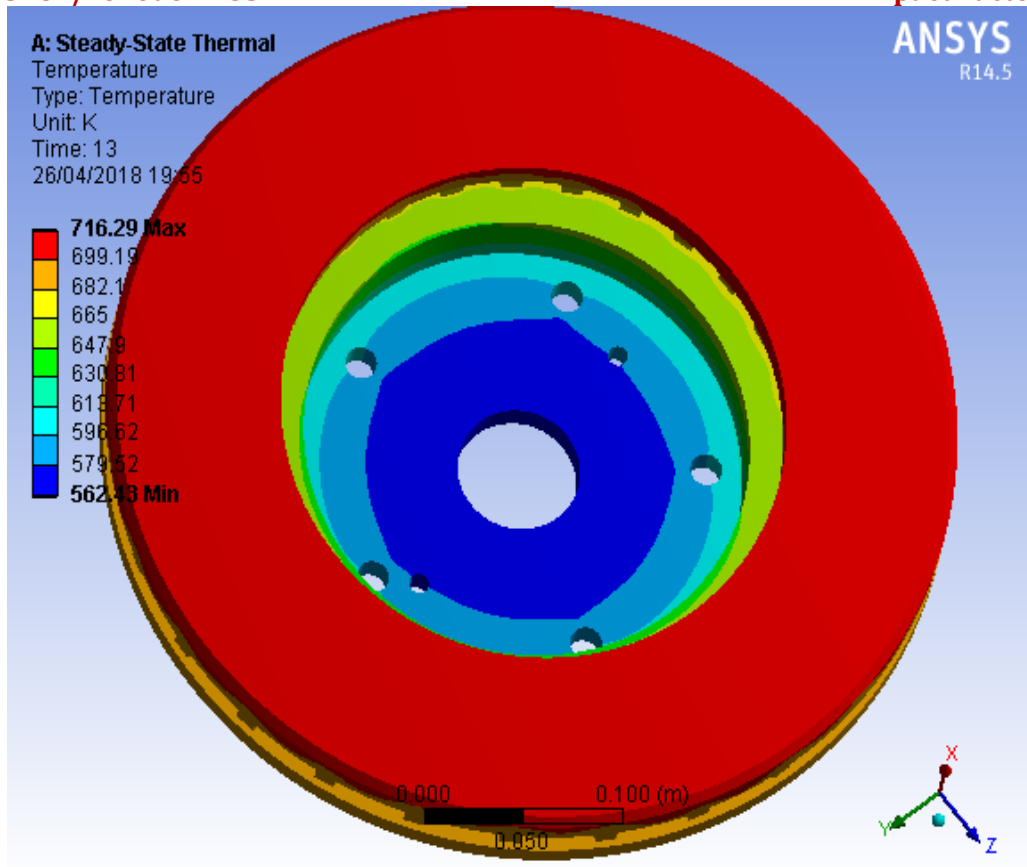


Figure: Temperature Distribution of Aluminium Alloy Disc

Figure shows steady state thermal analysis of Aluminium Alloy disc rotor. From analysis it is clear that the maximum temperature rise is 716.29 K. And the minimum temperature rise is 562.43 K. The overall temperature distribution is shown with different colors on the disc and each color represents the criticality of temperature induced in the disc rotor.

III. RESULTS & DISCUSSION

Table no: Comparison of ANSYS and analytical calculations.

Sr. No	Results	ANSYS calculations Temperature (K)	Analytical Calculations Temperature (K)	Percentage error (%)
		T _{max}	T _{max}	
1	Gray Cast Iron	762.33	787.2	3.26
2	Aluminum Alloy	716.29	764	6.66
3	Stainless Steel	838.21	782.41	7.13
4	Structural steel	731.67	811	10.84

IV. CONCLUSION

In this study we, presented an analytical and numerical simulation of thermal behavior of full ventilated disc brake in steady state. We use ANSYS 14.0 software to study the temperature rise of different materials. From this study we came to know that the maximum temperature rise is for disc of structural steel is 801.93 K and that of

aluminium alloy is 548.57 K. This temperature rise in aluminium alloy is minimum as compared to other materials. In past twenty years MMCs had progressed from primarily laboratory enterprise with only narrow commercial significance to diverse a robust class of material with numerous important applications across a number of commercial markets. We conclude that aluminium alloys are better option as compared to other materials because of their properties such as; light in weight, high specific heat, etc. Due its high specific heat it helps to dissipate more amount of heat which reduces the temperature rise, which is required for commercial vehicles as they are subjected to heavy loads. The life of aluminium alloys disc rotors is more than that of other materials.

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