"Optimization of Disk Brake using Taguchi Design of Experiments"

Lovelesh[1], Somvir Arya[2]

[1]*Lovelesh, M.Tech., Research scholar, Department of Mechanical Engineering, Vardey Devi Institute of Engineering and Technology, Jind, Haryana, India.*

[2]*Somvir Arya, Professor, Department of Mechanical Engineering, Vardey Devi Institute of Engineering and Technology, Jind, Haryana, India.*

---***---

Abstract- *The design of disk brake has a significant role in its heat dissipation capacity. The current research investigates the application of box Behnken design scheme of Taguchi response surface method in existing design of disk brake. The optimization parameters considered for analysis are hub height and hub radius. The thermal analysis is conducted using ANSYS FEA software for 350 seconds to determine heat flux and temperature plot at different time intervals. The response of each optimization variable is evaluated using 3D response surface plots and effect of each variable is studied using sensitivity plots. The critical values of optimization variables is determined for which optimization parameters has minimum and maximum values.*

Key Words: **Disk Brake, FEA, Response Surface Method.**

1. INTRODUCTION

The disk brake is used in almost all 2 wheelers and 4 wheelers. The disk brakes are subjected high thermal loads due to extreme braking which can cause brake fade. For designing a disk brake, the heat dissipation capacity is the most important parameter to be taken into consideration. The excessive heat generated during continuous or hard braking tends to brake fading. As brake shoe or brake pad temperature hikes and they can generate hot gases. So, in order to annihilate the hot gases and avoid brake shoe or brake pad fading the friction material of the brake must have high heat dissipation characteristics.

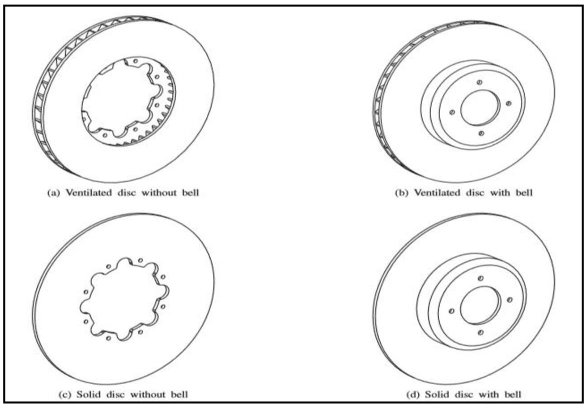

Figure 1: Types of disk brakes

There are basically two different types of disk brakes. The first is solid disk brake and second is ventilated disk brake. The solid disk brake can be without bell and with bell as shown in figure 1. Similarly, the ventilated disk brake is also without bell or with bell. The unexpected increase in temperature causes thermal shock and thermal stress within the disk [10]. Usually brake system contains a cast iron disc bolted to wheel hub and calliper [11].

2. LITERATURE REVIEW

Masahiro Kubota et al. [1] conducted CFD analysis on lightweight brake disc rotor to achieve an optimal balance of thermal, vibration characteristics. The airflow is made at inlet of ventilated disk brake and heat dissipation rate is studied at holes

Choi and Lee [2] conducted FEA analysis on disk brake to determine thermo elastic behaviour for contact problem and frictional heat generation. The material investigated is carbon composite and results obtained are better than conventional steel materials.

Jiang Lanet al. [3] conducted CFD analysis of disk brake using Sci/6061 alloy material during emergency braking. The cooling behaviour of disk brake is investigated and suggested that the higher convection coefficients achieved with airflow cooling will not only reduce the maximum temperature in the braking but also reduce or decrease the thermal gradients, since heat will be removed faster from hotter parts of the brake shoe/disk.

Oder G. et al. [4] conducted FEA analysis of disk brake under braking to a standstill condition and braking on a hill and maintaining a constant speed condition. The thermal load conditions are applied i.e. heat flux and results are validated with experimental findings for graphite material.

Talati and Jalalifar [5] conducted analysis of disk brake subjected to variations such as material, vehicle velocity and geometries. The analytical calculation is made using green function approach and the heat generated due to friction between the disk and the pad should be ideally dissipated to the environment.

Zaid, et al [6] conducted Finite Element Analysis of using ABAQUS/CAE software on ventilated disc brake rotor of normal passenger vehicle with full load of capacity. The thermal and structural behaviour of disk brake are studied under transient state conditions for grey cast iron. The results obtained would enable designers to optimize design of disk brake.

Piotr Grzes & Adam Adamowicz [7] conducted 2D and 3D Finite Element Analysis of disk brake subjected to non-axis symmetric load. The loading conditions, thermo physical properties of materials are taken from real representation of the braking process of the passenger vehicle. The results have shown that the large amount of heat generated at the brake pad/disc interface during emergency braking indisputably evokes non-uniform temperature or heat distributions in the domain of the rotor, whereas the pad element is constantly heated during mutual sliding.

3. OBJECTIVE

The current research investigates the application of response surface optimization in optimizing design of disk brake subjected to thermal loads. The optimization scheme used for analysis is optimal space filling and optimization variables selected for analysis are hub height and hub radius. The FEA analysis is conducted using ANSYS software.

4. METHODOLOGY

The CAD model of disk brake is developed in ANSYS design modeler using revolve, fillet and chamfer tool. The dimensions of disk brake is shown in figure 2 below. The dimensions are taken from literature [9].

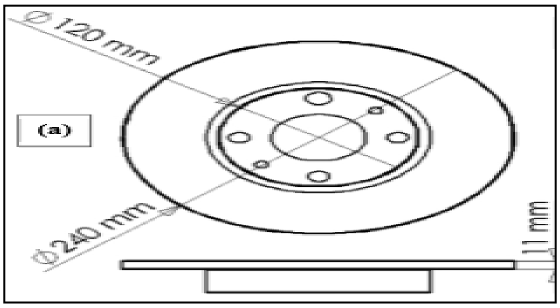

Figure 2: Schematic of disk brake [9]

The cross section of disk brake is sketched and revolved about central axis as shown in figure 3 below. The cross section is revolved to give final CAD model of disk brake as shown in figure 3 below.

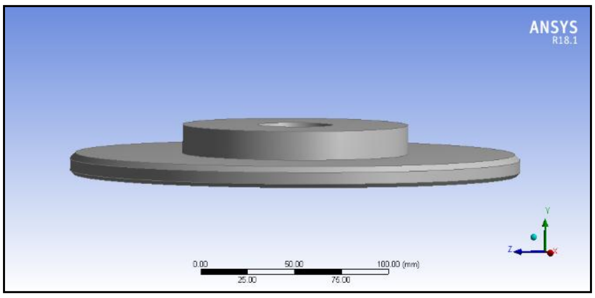

Figure 3: CAD model of disk brake

The CAD model of disk brake is meshed using tetrahedral elements. The size function is set to adaptive and fine. The meshed model of disk brake is shown in figure 4 below.

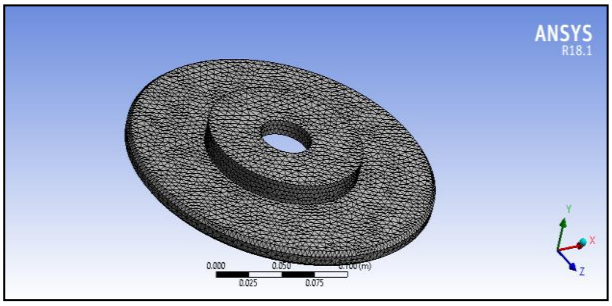

Figure 4: Meshed model of disk brake

The heat flux and convection is applied on disk brake as shown in figure 5 below. The heat flux value applied is 395.57J which is calculated from power torque formula as discussed below. The heat flux is applied on top and bottom face of disk brake while convection is applied on remaining faces of disk brake. To simulate the effects of real-world working environments in FEA, various load types can be applied to the FE model, including, Nodal: forces, moments, displacements, velocities, accelerations, temperature and heat flux [8].

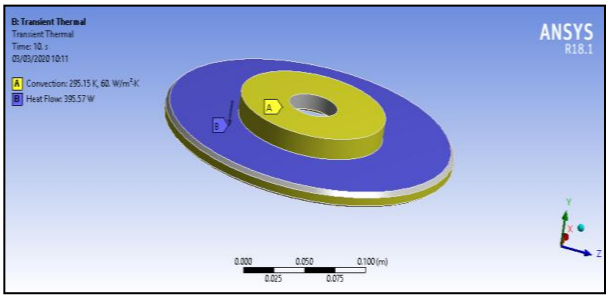

Figure 5: Loads and boundary conditions

The transient state analysis is run for 350 counter seconds.

5. RESULTS AND DISCUSSION

The transient analysis is run for 350 counter seconds and results are obtained for each counter seconds. The temperature plot is obtained at different time intervals as shown in figure 6 below. The maximum temperature is observed at region of heat flow as shown by red contour and reduces as we move towards region of convection as shown by light green and blue color contour.

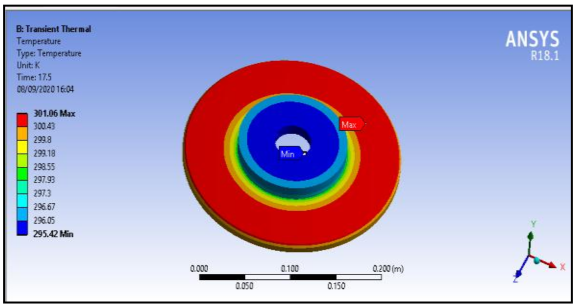

Figure 6: Temp. at 17.5secs

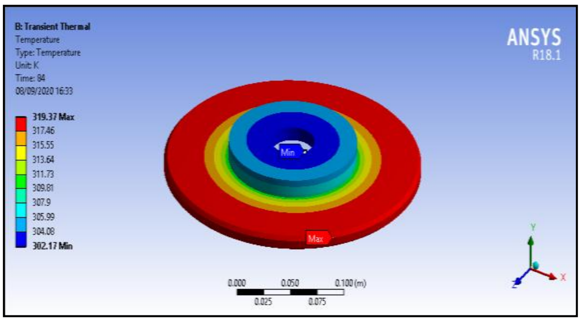

Figure 7: Temp. at 84secs

The temperature plot shows higher temperature magnitude on disk rotor as shown by red colored region in figure 7 above which is in immediate contact with brake pad. The hub region has lowest magnitude of temperature as shown by dark blue colored region. The maximum temperature at 17.5 seconds is 301.06K and at 84 seconds is 319.37K. The corner region between hub and rotor has nearly 310K temperature at 84 seconds as shown by light green color.

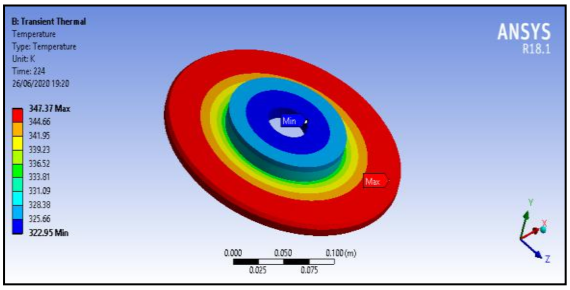

Figure 8: Temp. at 224secs

The maximum temperature at 224 seconds is 347.37K and at 329 seconds is 366.21K. The corner region between hub and rotor has nearly 336K temperature at 224 seconds as shown by light green color.

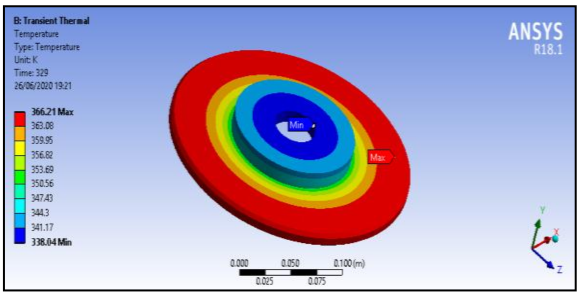

Figure 9: Temp. at 329secs

At 329 seconds, the corner region between hub and rotor has nearly 353K temperature by light green color in figure 9 above.

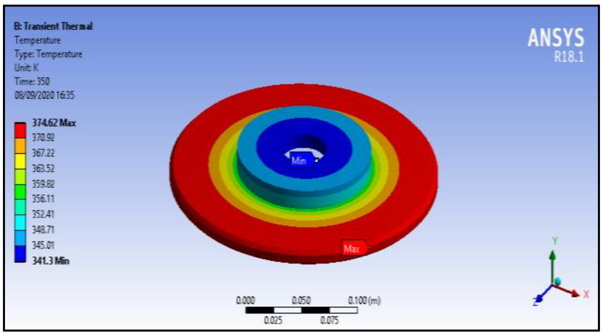

Figure 10: Temp. at 350secs

The maximum temperature at 350 seconds is 374.62K and the corner region between hub and rotor has nearly 353K temperature at 350 seconds as shown by light green color in figure 10 above. The design points are generated using Taguchi design of experiments as shown in figure 11 below. The values show marginal changes in maximum and minimum temperature of disk brake but major changes in directional heat flux. The optimization is performed using optimal space filling design.

Table of Outline A2: Design Points of Design of Experiments

	A	B	C	D	E	F
1	Name	P4 - hubheight (mm)	P5 - hubradius (mm)	P1 - Temperature Minimum Minimum Value Over Time (K)	P2 - Temperature Maximum Minimum Value Over Time (K)	P3 - Directional Heat Flux Maximum (W m^-2)
2	1 DP 0	11	60	295.15	340.92	63745
3	2	9.9	54	295.15	341.96	55967
4	3	12.1	54	295.15	341.93	59081
5	4	9.9	66	295.15	340.45	57137
6	5	12.1	66	295.15	340.26	55656

Figure 11: Design points generated

The maximum directional heat flux is obtained for original dimensions of disc brake i.e. hub height of 11mm and hub radius of 60mm. The minimum heat flux is observed for design point number 5 having hub height of 12.1mm and hub radius of 66mm.

1	Name	Calculated Minimum	Calculated Maximum	Maximum Predicted Error
2	P1 - Temperature Minimum Minimum Value Over Time (K)	295.15	295.15	0.00010134
3	P2 - Temperature Maximum Minimum Value Over Time (K)	340.26	341.96	0.26392
4	P3 - Directional Heat Flux Maximum (W m^-2)	55652	63751	5319.6

Figure 12: Maximum and minimum values of temperature and directional heat flux

From the response surface optimization, the minimum temperature over time is observed to be 295.15 and maximum is observed to be 341.96K while minimum heat flux is 55652W/m^2 and maximum is observed to be 63751W/m^2.

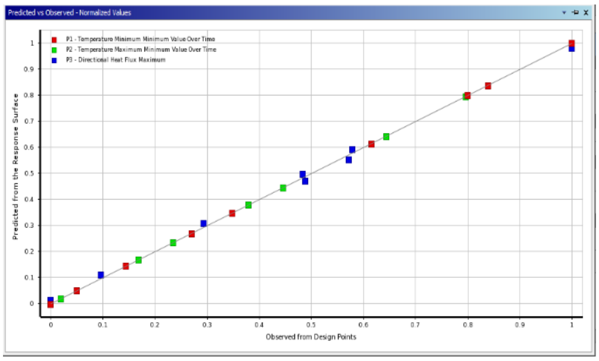

Figure 13: Sensitivity plot

Goodness of fit curve shows deviation of observed values from expected values. In this case except for certain design points both temperature and directional heat flux doesn't show much deviation from expected values as shown by red color box for temperature and blue color boxes for directional heat flux.

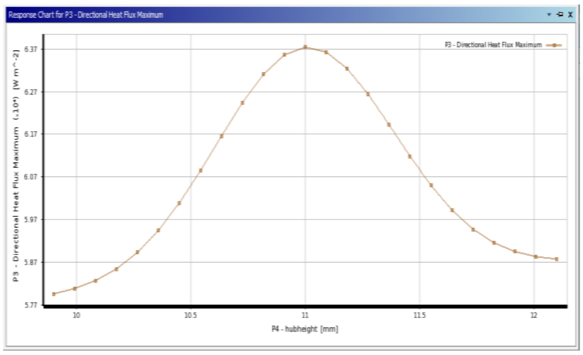

Figure 14: Directional heat flux vs hub height

The heat flux plot shows linear increases in heat flux value up to hub height of 11mm and then decreases up to 12.2mm. The maximum directional heat flux obtained from response surface optimization method shows maximum value of directional heat flux at hub height of 11mm with magnitude of 63745W/m². The minimum heat flux is observed for hub height of 9.9mm with magnitude of 57958W/m².

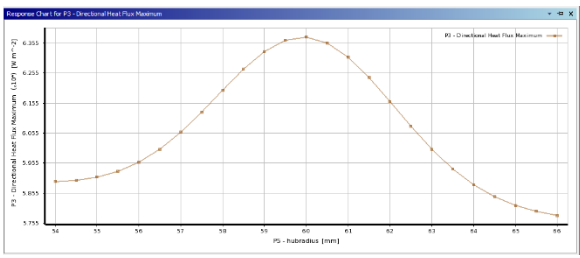

Figure 15: Directional heat flux vs hub radius

The maximum directional heat flux obtained from response surface optimization method shows maximum value of directional heat flux at hub radius of 60mm with magnitude of 63745W/m². The minimum heat flux is observed for hub radius of 66mm with magnitude of 57802 W/m². The heat flux decreases with increase in hub radius after 60mm.

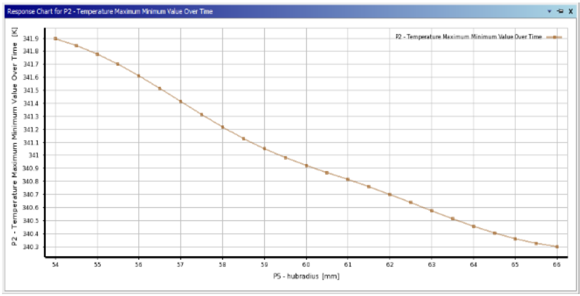

Figure 16: Temperature maximum vs hub radius

The temperature curve obtained from Taguchi optimization method shows linear decrease of temperature with increase in hub radius. The maximum temperature is observed for hub radius of 54mm and minimum temperature is observed for hub radius of 66mm.

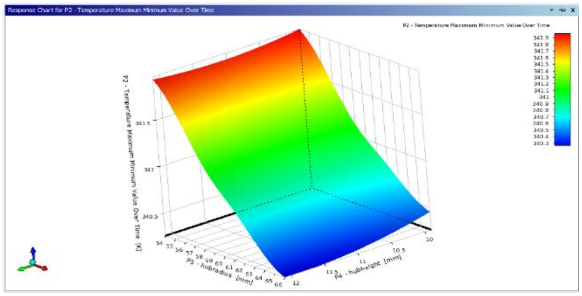

Figure 17: 3D response surface plot of temperature minimum

The 3D response surface plot obtained for temperature shows higher magnitude for hub radius ranging from 54mm to 56mm and hub height ranging from 10mm to 12mm as shown by dark red region. The remaining region as shown by green color has lower temperature magnitude for remaining values of hub radius and hub width.

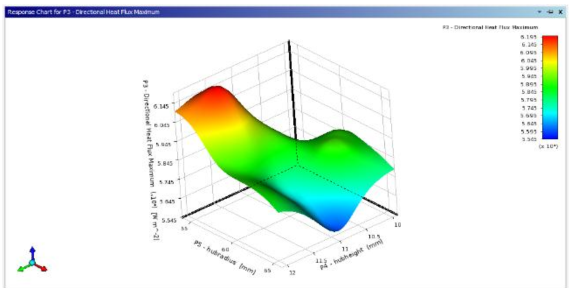

Figure 18: 3D response surface plot of directional heat flux

The maximum directional heat flux is obtained for hub radius ranging from 58mm to 61mm and hub height ranging from 10.5mm to 11.5mm as shown by dark red contour plot while minimum directional heat flux is obtained for hub radius ranging from 64mm to 66mm and hub height ranging from 11.5mm to 12mm as shown by dark blue color.

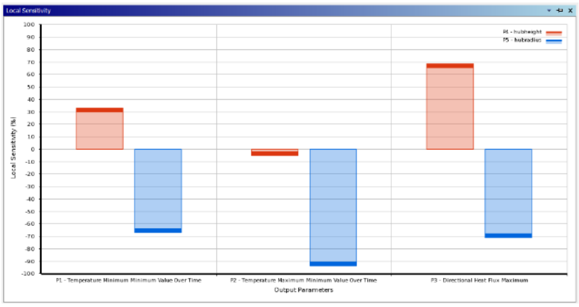

Figure 19: Sensitivity plot of different variables

The sensitivity plot is obtained for optimization variables i.e. hub radius and hub height. For minimum temperature the hub height shows 33.07 (positive) sensitivity while hub radius shows 66.92 (negative) sensitivity, therefore hub radius has higher effect on minimum temperature of disk brake. For maximum temperature, the hub height shows 5.03 (negative) sensitivity while hub radius shows 93.74 (negative) sensitivity, therefore hub radius has higher effect on maximum temperature of disk brake. For directional heat flux, the hub height shows 68.78 (positive) sensitivity while hub radius shows 70.91 (negative) sensitivity, therefore hub radius has higher effect on directional heat flux of disk brake.

6. CONCLUSION

The transient thermal analysis is conducted on disk brake using ANSYS software. The simulation results thus obtained enabled to determine critical areas of high thermal gradient and flux. The design optimization conducted using Taguchi response surface optimization method led to determine optimized dimensions and effect of each optimization variable on the thermal output received. The maximum directional heat flux is obtained for hub radius ranging from 58mm to 61mm and hub height ranging from 10.5mm to 11.5mm. The minimum directional heat flux is obtained for hub radius ranging from 64mm to 66mm and hub height ranging from 11.5mm to 12mm as shown by dark blue color.

ACKNOWLEDGEMENT

The contentment and the exhilaration I feel in completion of **"Optimization of Disk Brake Using Taguchi Design of Experiments"** Would be curtailed if the names of those people whose indispensable guidance and encouragement crowned my efforts with success.

I take this opportunity to thank my supervisor Er. Somvir Arya, Professor of Mechanical Engineering department, Vardey Devi Institute of Engg. & Tech., Jind, Haryana for his guidance, supervision and encouragement without whom it would not have been possible to complete this project.

Last but not least my sincere thanks to all the faculty members, staff and friends for their support and co-operation.

REFERENCES

[1]. Masahiro Kubota., 2000. "Development of lightweight brake disc rotor: A design approach for achieving an optimum thermal, vibration and weight balance." JASE review 21 (2000) 349-355.

[2]. Ji-Hoon Chio, 2003. "Finite element Analysis of transient thermo elastic-behaviors in disk brakes", Wear, 257 (2004) 47-58.

[3]. JIANG Lan, 2011, "Thermal analysis for brake disk of Sci/6061 Al. Alloy co-continuous composite for CRH3 during emergency braking considering air flow cooling", Trans. Nonferrous Met. Soc. China 22(2012) 2783-2791.

[4]. Oder G., "Thermal and stress analysis of brake discs in railway vehicles", Advance Engineering 3(2009) ,ISSN: 1846-5900.

[5]. Faramarz talati, 2009. "Analysis of heat conduction in a disk brake system", Spinger-Velag2009.

[6]. Ziad, 2009. "An investigation of disc brake rotor by FEA."ISSN: 1985-3157, Vol.3, No. 2, July Dec 2009.

[7]. Adam Adamowicz, 2011. "Analysis of disc brake temperature distribution during single braking under non-axis-symmetric load", Applied thermal engineering 31(2011) 1003-1012.

[8]. Vanam B. C. L, Rajyalakshmi M. and Inala R, (2012). Static Analysis of an Isotropic Rectangular Plate Using Finite Element Analysis (FEA). Journal of Mechanical Engineering Research, V.4 (4), pp. 148-16.

[9]. A. Alnaqi, Abdulwahab, "Reduced scale thermal characterization of automotive disc brake" Applied Thermal Engineering (2014)

[10]. Aziz A, "Simulation of Thermal Stresses in A Disc" thesis work (2012)

[11]. Sowjanya, K Suresh "Structural Analysis of Disk Brake Rotor" International Journal of Computer Trends and Technology (2013)

BIOGRAPHIES

Lovelesh was born in India in 1995. He is a M.Tech.(ME) Schoolar in VDIET, Jind (Affiliated to KUK University), Haryana, India. He was completed his B.Tech.(ME) from IIET, Jind (Affiliated to KUK University), Haryana in 2018. His research interest in Brakes.