DESIGN OPTIMIZATION OF DISK BRAKESUBJECTED TO THERMAL LOADS USING ANSYS

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Abstract:The design of disk brake has a significant role in its heat dissipation capacity. The current research investigates the application of optimal space filling 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 secs 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.

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 shoe or pad temperature rises, they can generate gas. So, in order to eliminate the gas and avoid brake fading the friction material must have high heat dissipation characteristics.

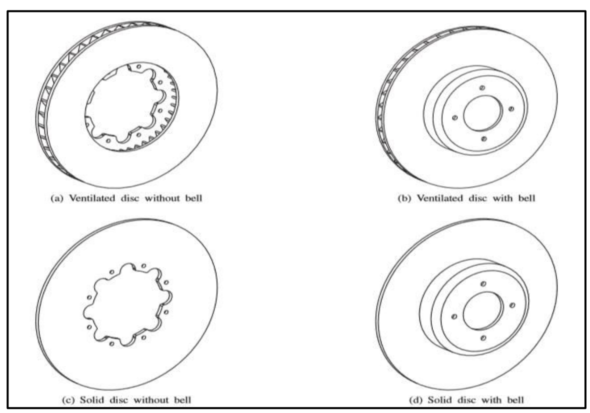

Figure 1: Types of disk brakes

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 the thermal gradients, since heat will be removed faster from hotter parts of the 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/CAEsoftware 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-axisymmetric load. The loading conditions, thermophysical 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 pad/disc interface during emergency braking indisputably evokes non-uniform temperature distributions in the domain of the rotor, whereas the pad element is constantly heated during mutual sliding.

2. 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.

3. 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].

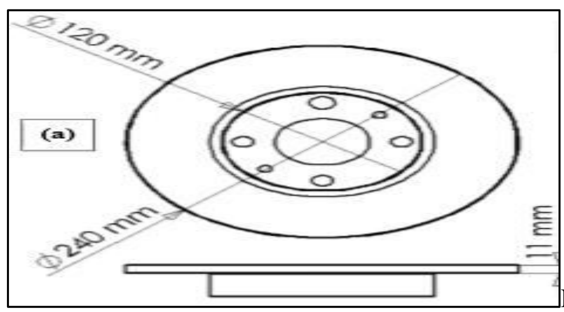

Figure 1: Schematic of disk brake [9]

The cross section of disk brake is sketched and revolved about central axis as shown in figure 2 below. The cross section is revolved to give final CAD model of disk brake as shown in figure 2 below.

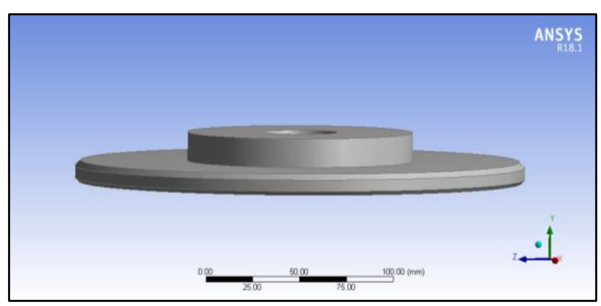

Figure 2: CAD model of disk brake

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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 3 below.

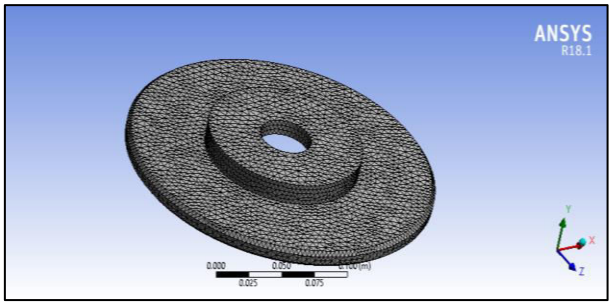

Figure 3: Meshed model of disk brake

The heat flux and convection is applied on disk brake as shown in figure 4 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].

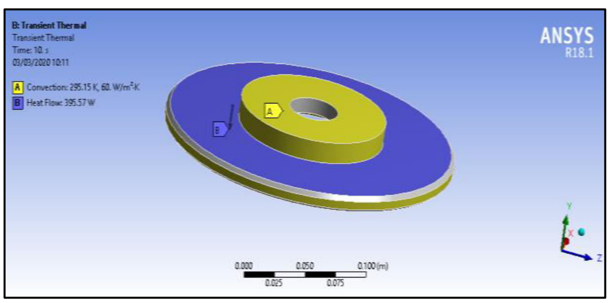

Figure 4: Loads and boundary conditions

The transient state analysis is run for 350 counter secs.

4. 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 5 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.

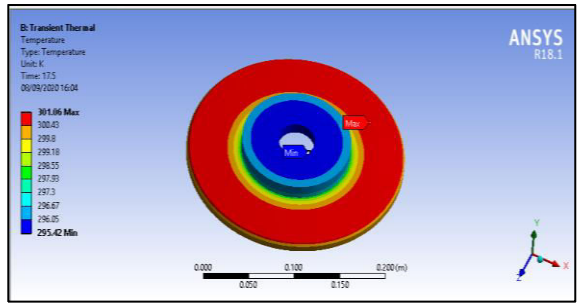

Figure 5: Temp. at 17.5secs

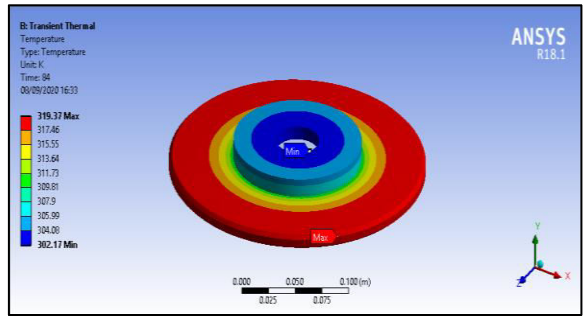

Figure 6: Temp. at 84secs

The temperature plot shows higher temperature magnitude on disk rotor as shown by red coloredregion in figure 6 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 secs is 301.06K and at 84 secs is 319.37K. The corner region between hub and rotor has nearly 310K temperature at 84 secs as shown by light green color.

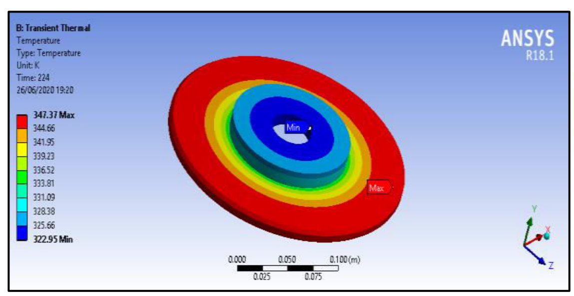

Figure 7: Temp. at 224secs

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

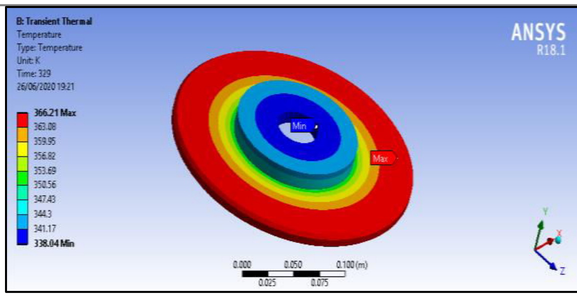

Figure 8: Temp. at 329secs

At 329 secs, the corner region between hub and rotor has nearly 353K temperature by light green color in figure 8 above.

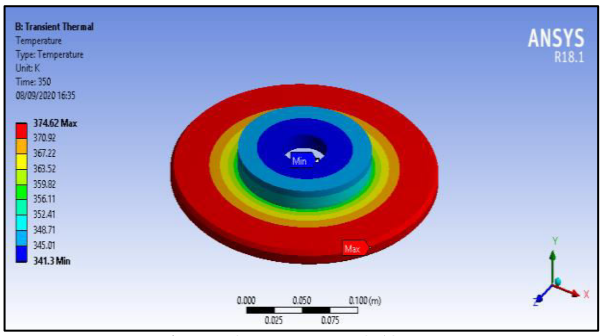

Figure 9: Temp. at 350secs

The maximum temperature at 350 secs is 374.62K and the corner region between hub and rotor has nearly 353K temperature at 350 secs as shown by light green color in figure 9 above. The design points are generated using Taguchi design of experiments as shown in figure 10 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 Schematic C2: Design of Experiments (Optimal Space-Filling Design : Max-Min Distance : Maximum Number Of Cycles = 10 : CCD Samples : Random Generator Seed

	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	11.489	56	295.15	341.98	62091
3	2	11.978	58.667	295.15	341.49	59174
4	3	10.511	62.667	295.15	341	59179
5	4	11.244	61.333	295.15	341.14	57271
6	5	10.267	54.667	295.15	342.2	55424
7	6	10.756	57.333	295.15	341.71	59259
8	7	11	65.333	295.15	340.8	55910
9	8	11.733	64	295.15	340.86	58510
10	9	10.022	60	295.15	341.28	58642

Figure 10: 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 7 having hub height of 11mm and hub radius of 65.33mm.

Table of Schematic C3: Response Surface: Tolerances

	A	B	C
1	Name	Calculated Minimum	Calculated Maximum
2	P1 - Temperature Minimum Minimum Value Over Time (K)	295.15	295.15
3	P2 - Temperature Maximum Minimum Value Over Time (K)	340.68	342.42
4	P3 - Directional Heat Flux Maximum (W m^-2)	55424	62091

Figure 11: 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 340.68K while minimum heat flux is 55424W/m^2 and maximum is observed to be 62091W/m^2.

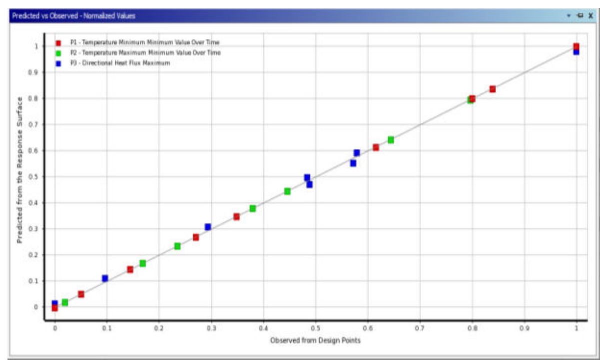

Figure 12: Sensitivity plot

The goodness of fit curve is generated as shown in figure 12 above. 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 colour box for temperature and blue colour boxes for directional heat flux.

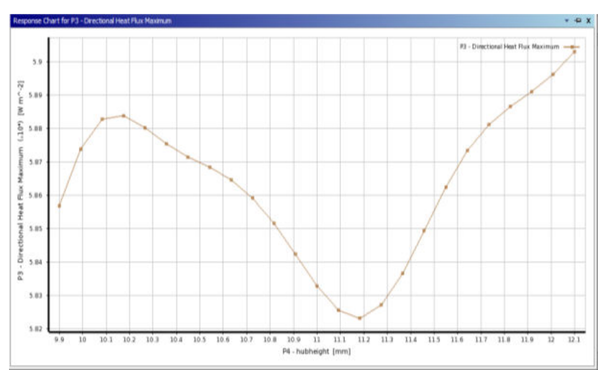

Figure 13: Directional heat flux vs hub height

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The heat flux plot shows linear increases in heat flux value upto hub height of 10.42mm and then decreases upto 11.27mm and then further increases. The maximum directional heat flux obtained from response surface optimization method shows maximum value of directional heat flux at hub height of 12.1mm. The minimum heat flux is observed for hub height of 11.27mm.

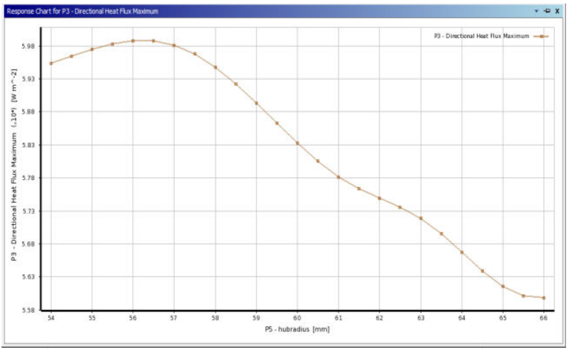

Figure 14: Directional heat flux vs hub radius

The maximum directional heat flux obtained from response surface optimization method shows maximum value of directional heat flux at hub radius of 56.5mm. The minimum heat flux is observed for hub radius of 66mm. The heat flux decreases with increase in hub radius after 56.5mm.

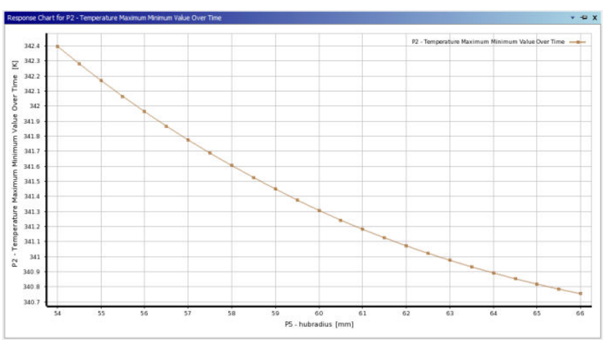

Figure 15: Temperature maximum vs hub radius

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.

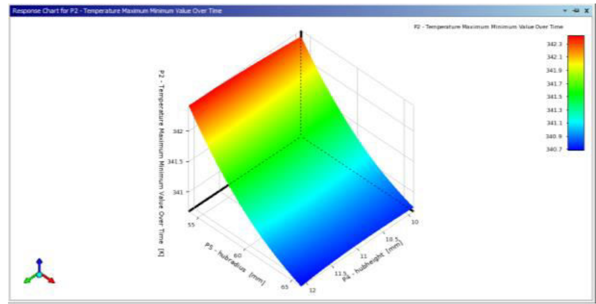

Figure 16: 3D response surface plot of temperature minimum

The 3D response surface plot obtained for temperature shows higher magnitude for 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 colour has lower temperature magnitude for remaining values of hub radius and hub width.

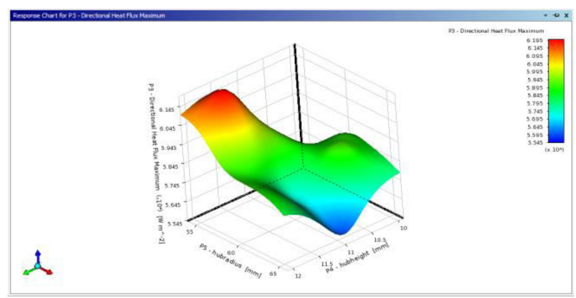

Figure 17: 3D response surface plot of directional heat flux

The maximum directional heat flux is obtained for hub radius ranging from 54mm to 57mm 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 10.5mm to 11.5mm as shown by dark blue color.

5. 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. For minimum temperature the hubheight shows 38.369(positive) sensitivity while hubradius shows 72.68 (negative) sensitivity, therefore hub radius has higher effect on minimum temperature of disk brake. For maximum temperature, the hubheight shows 2.0962(positive) sensitivity while hubradius shows 94.47 (negative) sensitivity, therefore hub radius has higher effect on maximum temperature of disk brake. For directional heat flux, the hubheight shows 11.83(positive) sensitivity while hubradius shows 58.148 (negative) sensitivity, therefore hub radius has higher effect on directional heat flux of disk brake.

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