Topological Optimization of Disc Brake Rotor

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Abstract: The main purpose of this study is to analyze the thermo-mechanical behavior of the brake disc during the braking phase. Brakes must undergo through continuous use, so many issues surround their heating characteristics when it comes to their development, including contact region properties, material choice, and development of hot spots, associated physical geometry, and deformation. The coupled thermal-structural analysis is used to determine the deformation and the Von Misses stress established in the disc to enhance performance and life of the rotor disc. A comparison between analytical calculations and results obtained from Finite Element Analysis (ANSYS) is done and the values obtained from the analysis are in the range of allowable values. The experiment has been performed with different disc-geometries. Based on the experiment results we have performed ANSYS simulation for the disc-brake. Hence best suitable optimum design is suggested based on the performance, strength and rigidity criteria.

Keywords: ANSYS, Disc Brake, FEA, Thermo-Mechanical

I. INTRODUCTION

A brake is a device by means of which artificial frictional resistance is applied to moving machine member, in order to stop the motion of a machine. In the process of performing this function, the brakes absorb either kinetic energy of the moving member or the potential energy given up by objects. The energy absorbed by brakes is dissipated in the form of heat. This heat is dissipated in to the surrounding atmosphere.

II. TOPOLOGY OF ROTOR

Weight optimization of rotor is possible by creating hole on surface. According to study, size and number of hole play key role for optimization. Number of hole again depend the space between two holes. So space between two holes is classified based on circumference distance and radial distance as shown in figure 1.

III. PARAMETRIC OPTIMIZATION

Following possible value of hole diameter, circular distance and radial distance between two hole are selected based on geometry of gear.

Table 1 Gear Geometry

| Hole diameter (mm) | 4  | 6  | 8  | 10 |
|-------------------|----|----|----|----|
| Circular Distance between two hole | 3  | 5  | 7  | 9  |
| Radial distance between two hole (mm) | 3  | 5  | 7  | 9  |

Here we have total three parameters and four values of each parameter. So total $3^4 = 81$ solution is possible. So to reduce solution we need to go for parametric optimization by using Taguchi method in MINITAB software.

In this project 3 level and 4 factor uses in experiment and L16 orthogonal array is chosen due to its capability to check the interactions among factors. This possible array is generated by MINITAB.

Table 2 Parametric Set

| Set No | Hole diameter (mm) | DC (mm) | DR (mm) |
|--------|--------------------|---------|---------|
| 1      | 4                  | 3       | 3       |
| 2      | 4                  | 5       | 5       |
| 3      | 4                  | 7       | 7       |
| 4      | 4                  | 9       | 9       |
| 5      | 6                  | 3       | 3       |
| 6      | 6                  | 5       | 5       |
| 7      | 6                  | 7       | 7       |
| 8      | 6                  | 9       | 9       |
| 9      | 8                  | 3       | 3       |
| 10     | 8                  | 5       | 5       |
| 11     | 8                  | 7       | 7       |
| 12     | 8                  | 9       | 9       |
| 13     | 10                 | 3       | 3       |
| 14     | 10                 | 5       | 5       |
| 15     | 10                 | 7       | 7       |
| 16     | 10                 | 9       | 9       |
IV. THERMO-STATIC ANALYSIS

Apply temperature of 109°C at surface A and convection at all surfaces of rotor as shown in below figure for transient analysis. Then apply fixed support at four holes where rotor is fixed by means of bolt. Also apply 7152 N of force at both side of rotor surface and angular velocity of 123.65 r/s as boundary condition for FEA as per theoretical calculations.

Table 3 Result and Discussion of Thermo-Static Analysis

| Set No. | Hole Diameter (mm) | DC (mm) | DR (mm) | Stress (MPa) | Displacement (mm) | Weight (kg) | Weight Reduction |
|---------|--------------------|---------|---------|--------------|------------------|-------------|-----------------|
| 1       | 4                  | 3       | 3       | 43.03        | 0.136            | 2.678       | 11.6            |
| 2       | 4                  | 5       | 5       | 44.89        | 0.137            | 2.803       | 07.5            |
| 3       | 4                  | 7       | 7       | 43.65        | 0.136            | 2.847       | 06.0            |
| 4       | 4                  | 9       | 9       | 316.76       | 0.110            | 2.917       | 03.8            |
| 5       | 6                  | 3       | 3       | 41.25        | 0.137            | 2.640       | 12.9            |
| 6       | 6                  | 5       | 5       | 45.03        | 0.137            | 2.604       | 14.0            |
| 7       | 6                  | 7       | 7       | 43.42        | 0.136            | 2.775       | 08.5            |
| 8       | 6                  | 9       | 9       | 42.59        | 0.137            | 2.879       | 05.0            |
| 9       | 8                  | 3       | 3       | 38.86        | 0.136            | 2.673       | 11.07           |
| 10      | 8                  | 5       | 5       | 55.95        | 0.134            | 2.416       | 20.26           |
| 11      | 8                  | 7       | 7       | 44.24        | 0.137            | 2.760       | 08.91           |
| 12      | 8                  | 9       | 9       | 44.22        | 0.137            | 2.796       | 07.72           |
| 13      | 10                 | 3       | 3       | 322.35       | 0.110            | 2.573       | 15.08           |
| 14      | 10                 | 5       | 5       | 43.68        | 0.137            | 2.596       | 14.32           |
| 15      | 10                 | 7       | 7       | 44.86        | 0.136            | 2.658       | 12.27           |
| 16      | 10                 | 9       | 9       | 42.89        | 0.137            | 2.692       | 11.15           |

V. TAGUCHI ANALYSIS FOR STRESS

From below graph, mean is average value for reading taken for particular parameter. From figure 2, mean value is maximum for 10 mm of hole diameter and minimum for 6 mm of hole. Mean value is maximum for 9 mm of circular pitch and minimum for 7 mm of circular pitch. Mean value is maximum for 9 mm of radial pitch and minimum for 7 mm of circular pitch.

VI. TAGUCHI ANALYSIS FOR WEIGHT

From below graph, mean is average value for reading taken for particular parameter. From figure 4, mean value is maximum for 4 mm of hole diameter and minimum for 10 mm of hole diameter. Mean value is maximum for 9 mm of circular pitch and minimum for 5 mm of circular pitch. Mean value is maximum for 7 mm of radial pitch and minimum for 9 mm of circular pitch.
VII. THERMO-STATIC FEA OF OPTIMIZED SET

Below table represent optimized parameter based on response factor of Taguchi method.

| Set | Diameter of hole (mm) | Circular Pitch (mm) | Radial Pitch (mm) |
|-----|-----------------------|---------------------|-------------------|
| 1   | 6                     | 7                   | 7                 |
| 2   | 10                    | 5                   | 9                 |

Apply temperature of 109 C\(^0\) at surface for 5 second and convection at all surfaces of rotor as shown in below figure for transient analysis. Then Apply fixed support at four holes where rotor is fixed by means of bolt. Also apply 7152 N of force at both side of rotor surface and angular velocity of 123.65 r/s as boundary conditions for FEA same as previous.

VIII. RESULT AND DISCUSSION OF THERMO-STATIC ANALYSIS OF OPTIMIZED SET

From above result we can conclude that set 2 give best result among all previous set. Because stress and weight is minimum among all experimental set.

IX. CONCLUSION

The analysis of thermo mechanical behavior of break disc was carried out. The Coupled thermo Structural analysis determined Von misses stress and hence the performance of life of rotor disc was calculated. Experiment with different disc geometries and analysis through Ansys were compared. 18 different models are modeled by using Orthogonal Array in Taguchi method and their thermo-structural behaviors investigated. The FEA analysis is carried out and compared with Taguchi result. Among all set, 10 mm diameter of hole having 5 mm of circular pitch and 9 mm of radial pitch give best 20 % of weight reduction.

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Mit Patel, Assistant Professor at Silver Oak College of Engineering and Technology. He is currently pursuing his Ph. D. in Solar Thermal Systems. He has achieved the degree of Master of Technology in Thermal Engineering and Bachelor of Engineering in Mechanical Engineering. During his tenure as an Assistant Professor, he has guided many research projects at Graduation and Post Graduation level. He has published his research papers in various National and International journals. Not only this, he has presented his research theories in number of Conferences.

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