Project 2. Design Optimization of a Brake Disk

Zirui Zhai

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Problem definition

The objective of this project is to optimize the design of an automobile brake disk. The design variables of this brake disk are three geometric dimension parameters, i.e., inner radius, outer radius, and thickness. The performances of the design include maximum stress under static loading, frequency of free vibration, and maximum temperature. The design constrains mainly come from the geometry, since the dimensions cannot be either too large or too small. The objective of the design is to have less strain value, higher vibration frequency, and low temperature. The software ANSYS is used to perform the analysis and optimization.

Model setup

A brake disk part model is obtained from A. Durgude, A. Vipradas, S. Kishore, and S. Nimse. It is first input to the ANSYS workbench, and it is shared by different modules. Three modules are used for different analysis purposes, including static mechanical analysis, modal analysis, and transient thermal analysis. The topology of the model setup is shown in Figure 1. The geometry of the part is generated from the input parameters. The part geometry and materials properties are shared by the three modules. Structural steel is assigned to the pad, and grey casting iron is assigned to the main body.

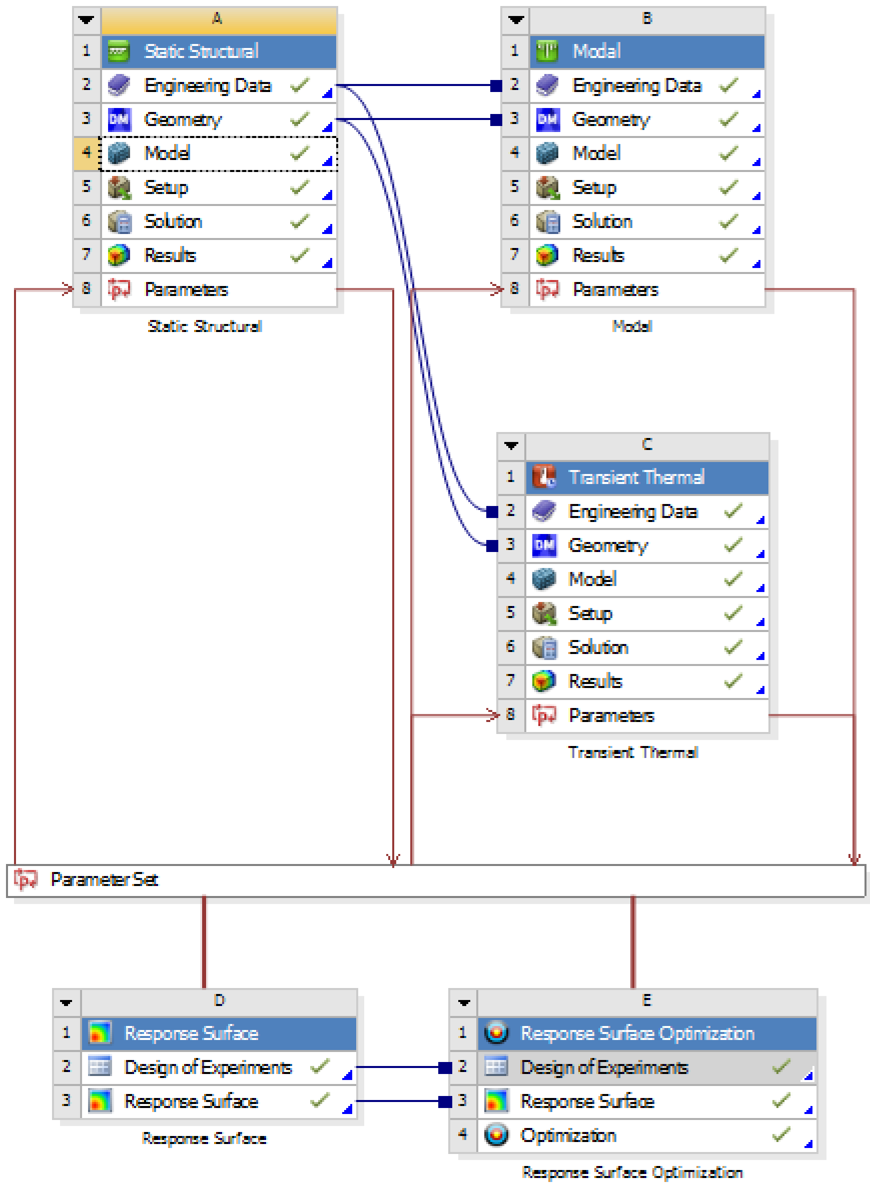

Figure 1: The setup of the design optimization process

Static mechanical analysis

Static structural module is used for the analysis. The main body of the brake disk is assigned to rotate along the y axis with a speed of 250 rad/s. Frictional contact is applied between the main body and the two pads. The pads are constrained in the x and z direction, and pressures of 10.5 MPa are applied on the outer faces of the pads. The setup of the mechanical model is shown in Figure 2. The maximum Von Mises stress and the volume of the main body are calculated and used as the output values.

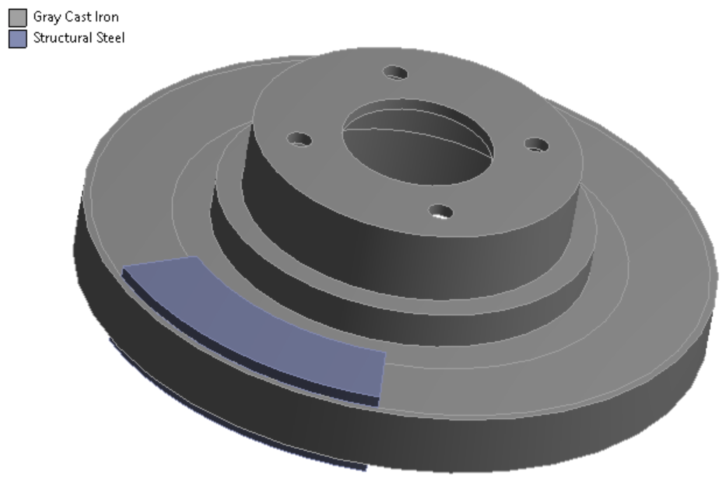

Figure 2: Setup of the brake disk assembly model

Modal analysis

The modal module is used for this analysis. The same geometry and materials assignment is adopted from the static structural analysis, while the two brake pads are removed from the simulation. No boundary conditions are applied to the part since we are solving the free vibration response. The 7th vibration mode is selected since the first six modes are rigid-body vibration modes. The frequency of the mode is used as the output for modal analysis.

Thermal analysis

The transient thermal module is used for this analysis. The same geometry and materials assignment is adopted from the static structural analysis, while the two brake pads are removed from the simulation. Convection boundary conditions are applied to all the faces of the geometry, with factor set as 5 W/m^2. Heat flux of1500 kW/m^2 is applied to the surface of main body contacting with the pads. The maximum temperature is extracted for output value.

Initial design performance

The input parameters of the initial design are set as: Inner diameter = 75 mm, outer diameter = 125 mm, and thickness = 25mm. The volume of the initial design is After performing static structural analysis, the Von Mises stress distribution is shown in Figure 3. The maximum Von Mises stress of the initial design is 12.4 MPa.

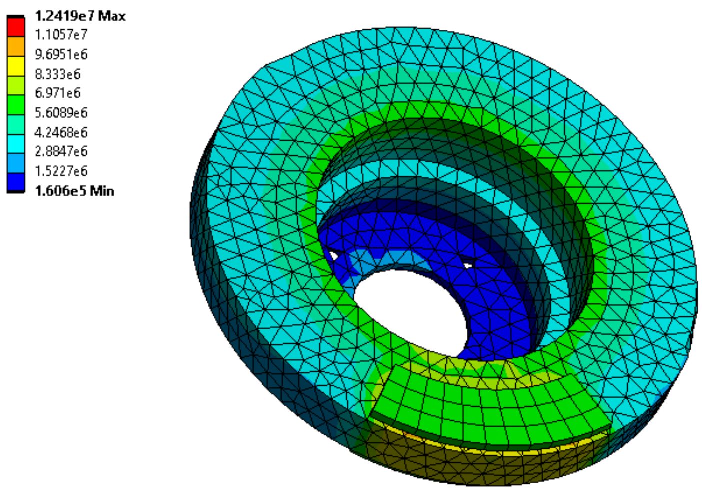

Figure 3: Distribution of the Von Mises stress

After performing vibration modal analysis, the deformation mode of the 7th mode of the initial design is shown in Figure 4. The corresponded frequency is 1615.6 Hz.

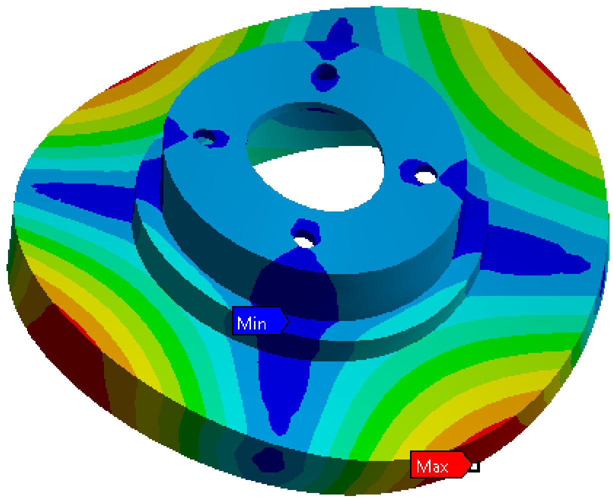

Figure 4. Deformation of the 7th vibration mode

After performing transient thermal analysis, the temperature distribution of the initial design is shown in Figure 5. The maximum temperature is 340.45 °C, and it is located at the contacting surface with the pads.

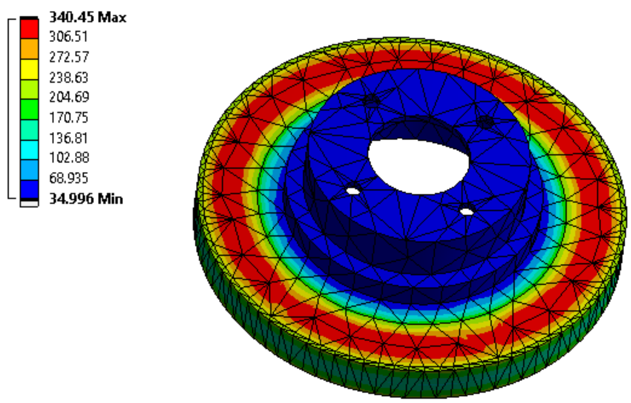

Figure 5. Temperature distribution of the initial design

Response surface

Since the design variables are all dimensional parameters, they are all continuous. The input parameters are constrained by the following range:

Name	Lower Bound	Upper Bound
P1 - rotor_thickness (mm)	22.5	27.5
P2 - rotor_OD (mm)	125	137.5
P3 - rotor_ID (mm)	67.5	82.5

Figure 6. Design parameter lower and upper bounds

For the sake of computing time, 20 design points are generated using the LHS method. And the three analysis are performed for the design points. Neural networks are used to fit the relationship between the input parameters and the responses. Selected response surfaces are shown in Figures 7, 8, and 9. From Figure 7, increase outer diameter will increase stress, while stress is not sensitive to thickness. From Figure 8, reducing the inner and outer diameter will both increase the vibration frequency. From Figure 9, increasing the thickness will reduce the temperature, while changing the inner diameter is not so effective.

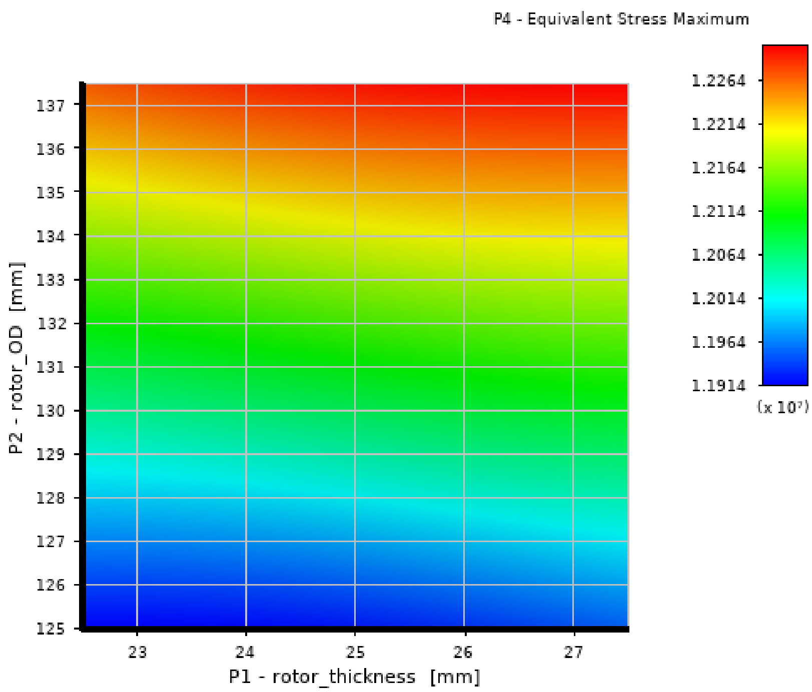

Figure 7. Responses surface with thickness and outer diameter as viarables and stress as objective.

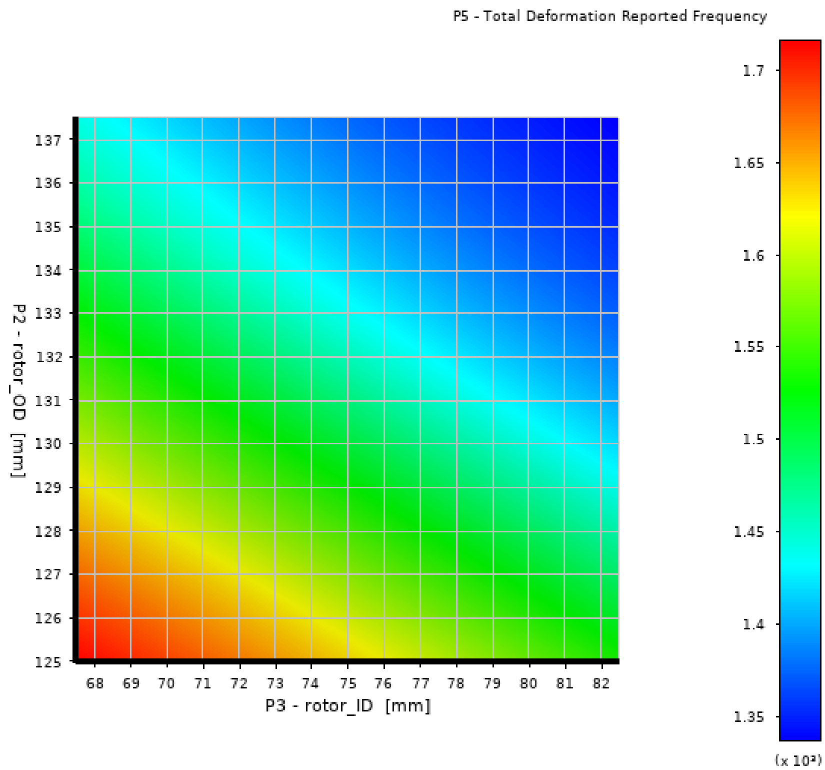

Figure 8. Responses surface with inner diameter and outer diameter as viarables and frequency as objective.

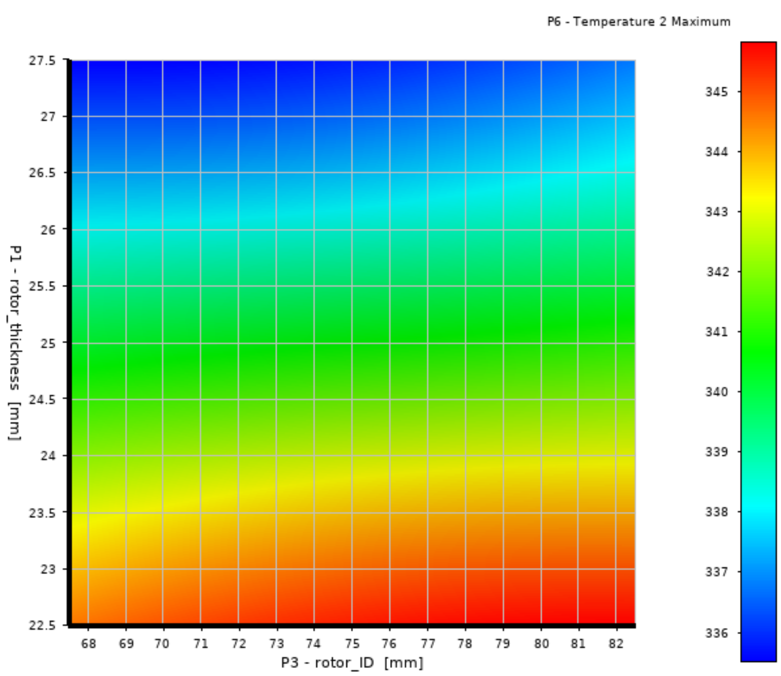

Figure 9. Responses surface with inner diameter and thickness as viarables and temperature as objective.

Sensitivity

The sensitivity between design variables and responses can be calculated by the ANSYS and it is plotted in Figure 10. From the sensitivity results, inner diameter has the largest positive effect on the maximum stress, and increasing the inner and outer diameters will both increase the stress value. Temperature is most sensitive to the thickness of the disk, and it can be reduced by increasing the thickness. Reducing thickness and outer diameter will reduce the volume of the disk, and increasing the inner diameter will reduce the volume of the disk. The stress is not sensitive to thickness, and the temperature is not sensitive to inner and outer diameters.

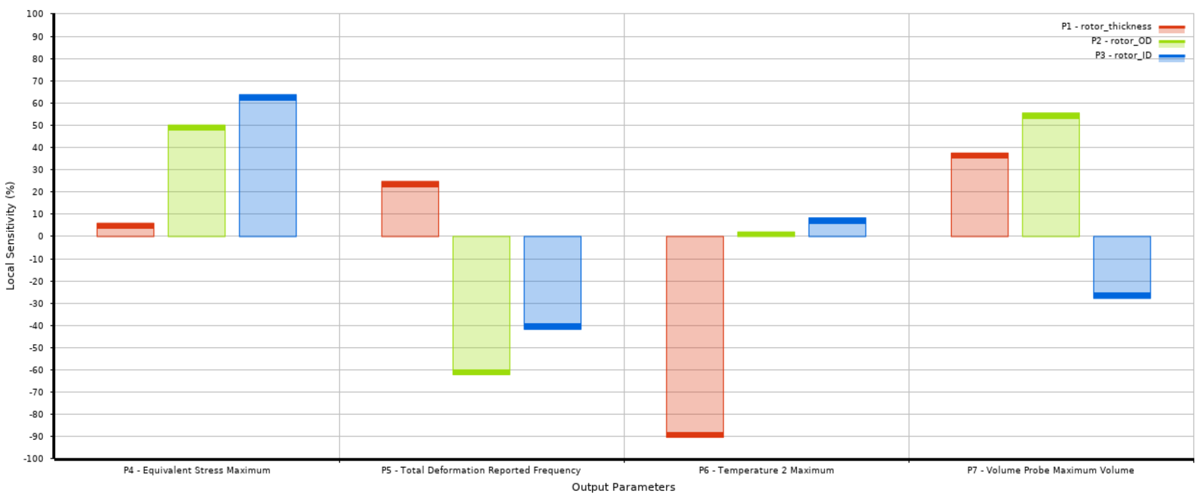

Figure 10. Sensitivity between different design parameters and objectives

Optimization and final design performance

Because there are multiple objectives in this design, the Multiobjective Genetic Algorithm (MOGA) is used to find the best design candidates. The objective of the optimization is to minimize volume, stress, and temperature, and maximize frequency. Default importance is applied to each responses. The best design candidates are shown in Figure 11. Compared with the initial designs, the best design candidates have better performance on stress relief, higher frequency, and temperature relief, while the reduction of volume is not obvious. For the design parameters, the best design candidate has larger thickness, similar outer diameter, and smaller inner diameters. Based on engineering knowledge and the response surfaces, the final design can be explained. Increasing thickness will increase reduce temperature and increase frequency, so it is increased in the final design. Reducing outer parameter will reduce stress and volume and increase frequency, so it is reduced to the lower bound in the final design. Reducing inner parameter will reduce stress and increase frequency and volume, so it is reduced but not to the lower bound.

	Candidate Point 1	Candidate Point 2	Candidate Point 3
P1 - rotor_thickness (mm)	25.381	26.491	27.201
P2 - rotor_OD (mm)	125.15	125.06	125.09
P3 - rotor_ID (mm)	67.722	68.765	70.2
P4 - Equivalent Stress Maximum (Pa)	★★★ 1.1753E+07	★★★ 1.1783E+07	★★ 1.1824E+07
P5 - Total Deformation Reported Frequency (Hz)	★★★ 1713.9	★★★ 1694.6	★★ 1669.5
P6 - Temperature 2 Maximum (C)	★ 339.43	★★ 337.93	★★ 336.8
P7 - Volume Probe Maximum Volume (m^3)	★ 0.0010617	- 0.0010993	- 0.0011168

Figure 11. Best design candidates and their performances