

# MAE 598 Design Optimization Project 2

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This project is to find the optimum solutions through industrial software by using existing brake disc model. The content of the project is separated into three parts: model analysis, model optimization and conclusion.

## 1 Model Analysis

The flowchart for brake disc model optimization is shown in figure 1, which includes static structural, modal and transient thermal. The brake disc geometry is prepared in ANSYS as shown in figure 2. The design variable of brake disc optimization is rotor thickness (P1), rotor inner outer radius (P2) and rotor inner radius (P3). The initial value of these variable are set as 25 mm, 125 mm and 75 mm respectively.

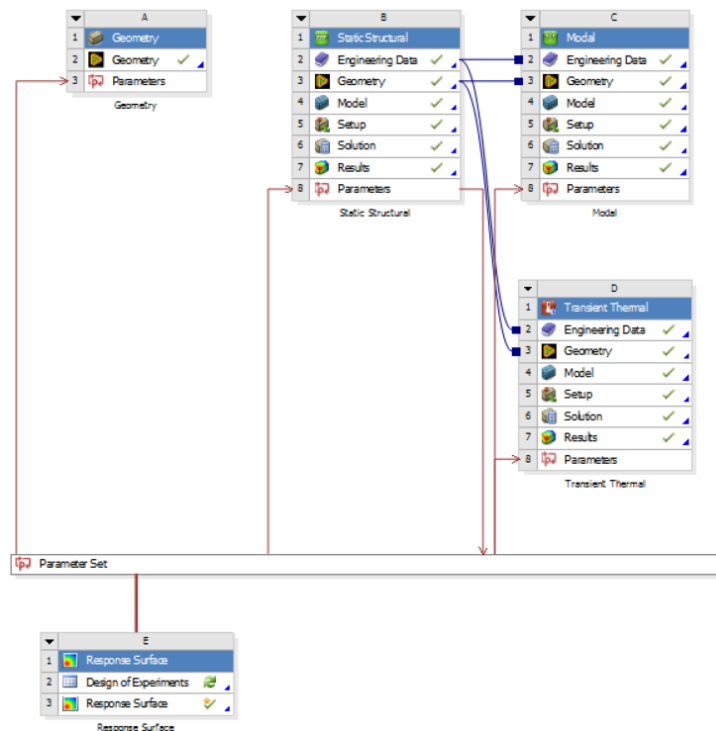


Figure 1: ANSYS optimization flowchart

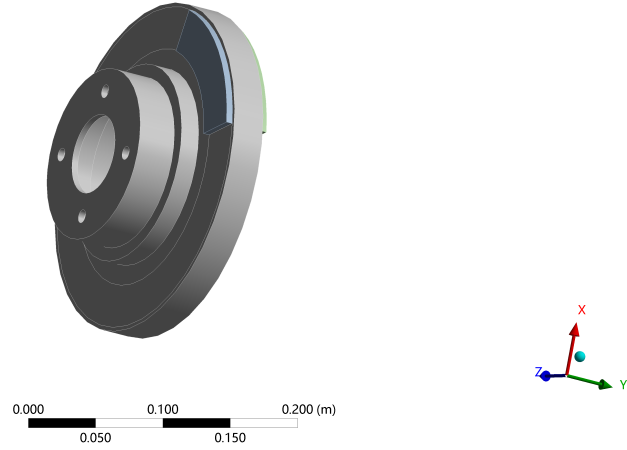


Figure 2: Disk brake CAD model

## 1.1 Structural Analysis

Static structural analysis is implemented after loading the constraint and stress for the brake disc. We set the rotational velocity of brake disc as 250 rad/s in the Y axis and constrain the brake pads on the X and Z axis. Besides, revolved joint is applied to the inner diameter of disc, which is in contact with the shaft. We consider the frictional contact between the brake pads and disc and apply 10.495 MPa stress on the brake pads face. Figure 3 shows the analysis result. The maximum stress is in the contact region between the brake disc and the brake pads, which is 13.07 MPa.

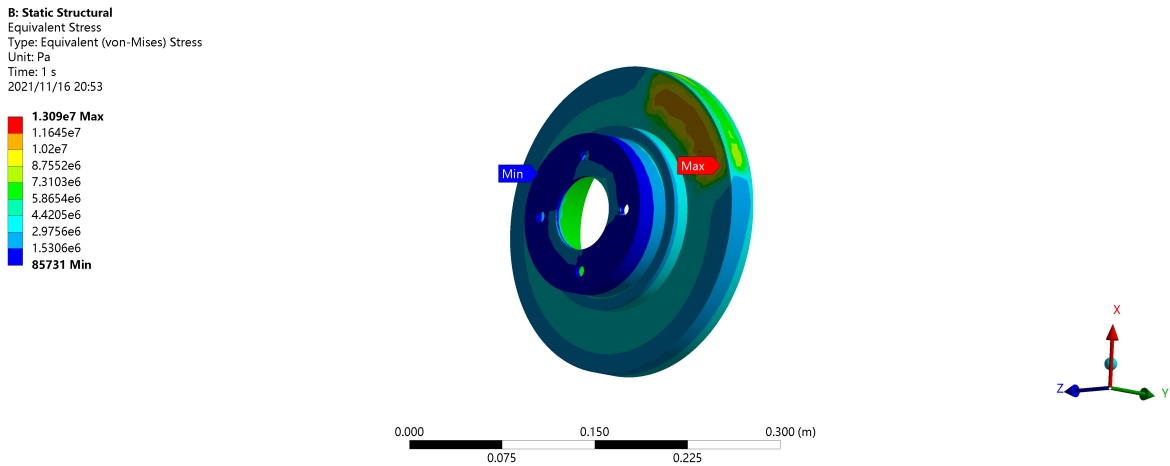


Figure 3: Static structural analysis for initial condition

## 1.2 Modal Analysis

Modal analysis is implemented to determine the disc nature frequency after having the total deformation. Figure 4 shows that the natural frequency of the brake disk is 1590.4 Hz and the maximum deformation is 0.80965 m.

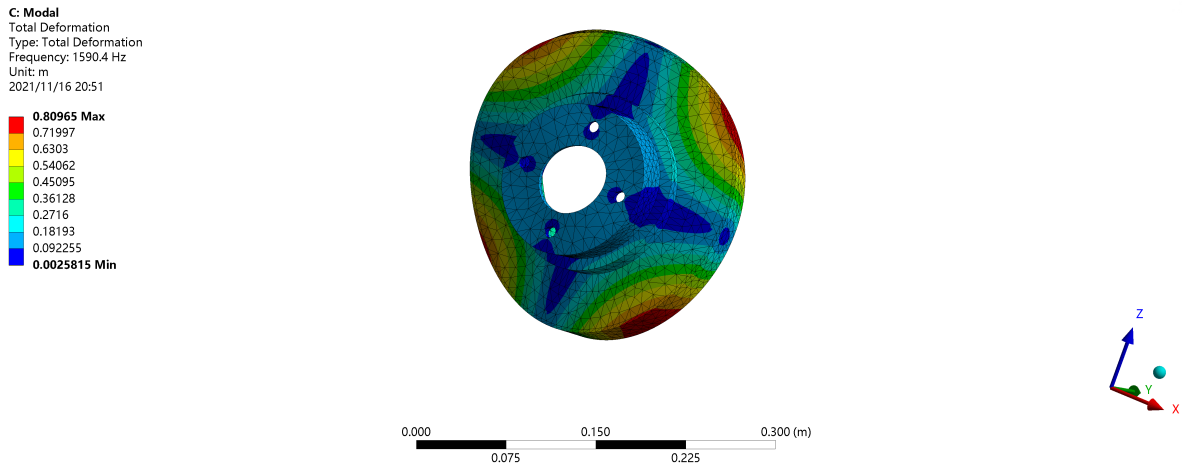


Figure 4: Modal analysis for initial condition

## 1.3 Thermal Analysis

Thermal analysis is implemented to observe the maximum temperature rise after the braking operation. The temperature of the disk is initialized as 35 °C. Convection is applied on all surfaces of the model surface with the film coefficient of 5  $W/m^2$  °C. Heat flux of  $1.5395 \times 10^6 W/m^2$  is applied on the two surfaces of the brake disk. Figure 5 shows the analysis result. The maximum temperature is 335.38 °C

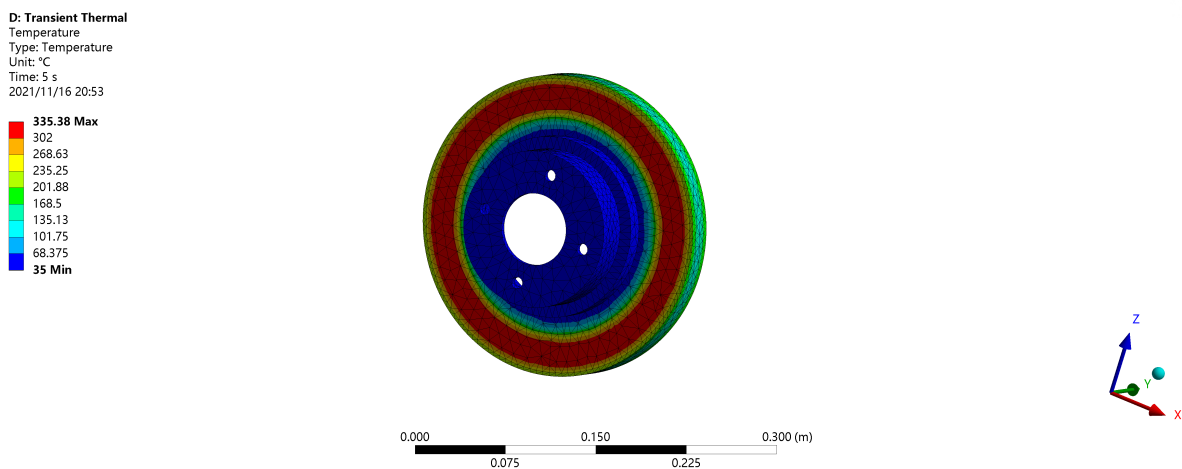


Figure 5: Thermal analysis for initial condition

## 2 Model Optimization

After we have the initial analysis for the structural, modal and thermal, the relationship between the design variables (P1, P2, P3) and output response is known. All of the design variables are continuous. In this section, we will implement DOE and ANSYS build-in optimized method to find the optimum solutions when the objective function is the stress and volume of the brake disc.

### 2.1 Design of Experiment

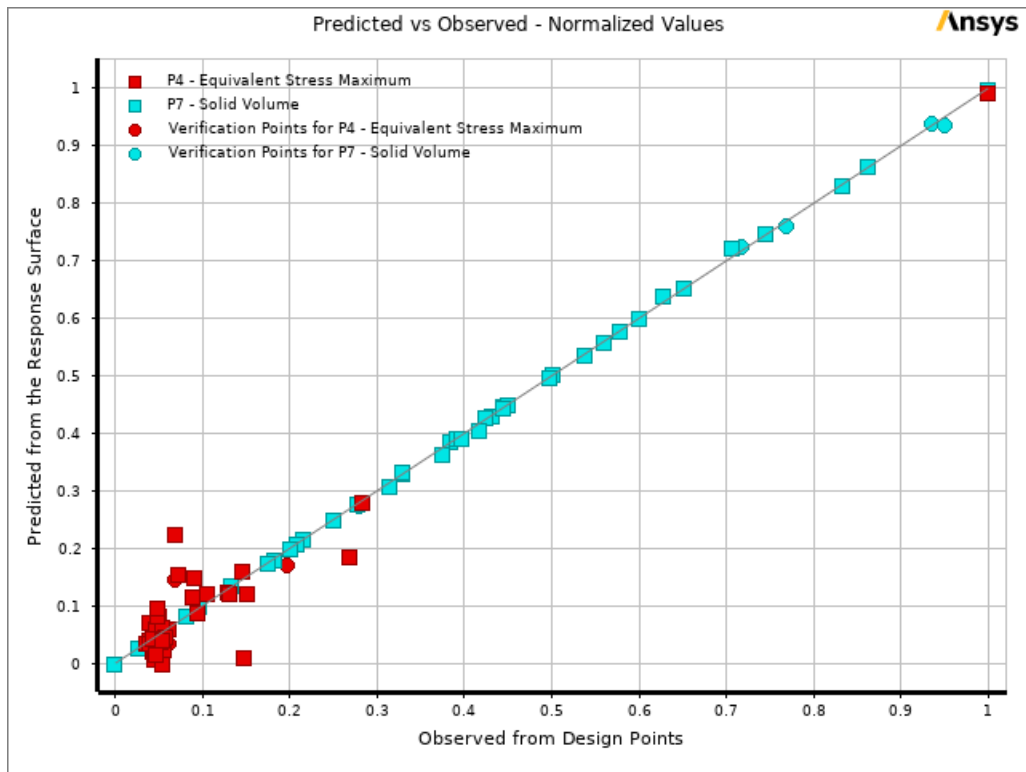
We use Latin Hypercube Sampling (LHS) to sample the data from the given data space and then create the output response. The bound of design variable is shown in the Table 1. After the design of experiments process, we obtain various combinations of design variables and the corresponding output response. 40 total DOE points are generated.

Table 1: Upper and lower bounds of design variables in DOE

<b>Design Variable</b>	<b>Lower Bound (mm)</b>	<b>Upper Bound (mm)</b>
Thickness (P1)	14	28
Outer Diameter (P2)	120	140
Inner Diameter (P3)	70	85

### 2.2 Response Surface

After DOE, a response surface is generated for all the design variables and the corresponding output response through neural network, which the number of cell is 3. Also, we set up 10 verification points. The goodness of fit plot for the structural analysis is shown below.



	A	B	C
1		P4 - Equivalent Stress Maximum	P7 - Solid Volume
2	Coefficient of Determination (Best Value = ...)		
3	Learning Points	= 0.91909	★★★ 0.99962
4	Root Mean Square Error (Best Value = ...)		
5	Learning Points	1.3331E+06	3.2649E-06
6	Verification Points	1.2108E+06	6.027E-06
7	Relative Maximum Absolute Error (Best Value = ...)		
8	Learning Points	✖✖✖ 101.43	= 6.224
9	Verification Points	✖✖✖ 53.71	= 5.3275
10	Relative Average Absolute Error (Best Value = ...)		
11	Learning Points	✖✖ 17.304	★★ 1.0547
12	Verification Points	✖✖ 20.655	★ 2.8343

Figure 6: Goodness of fit plot for structural analysis

Besides, we also show the sensitivity analysis as below. We can find the optimum solutions through ANSYS build-in optimization method after loading the stress and constraint for the brake disc.

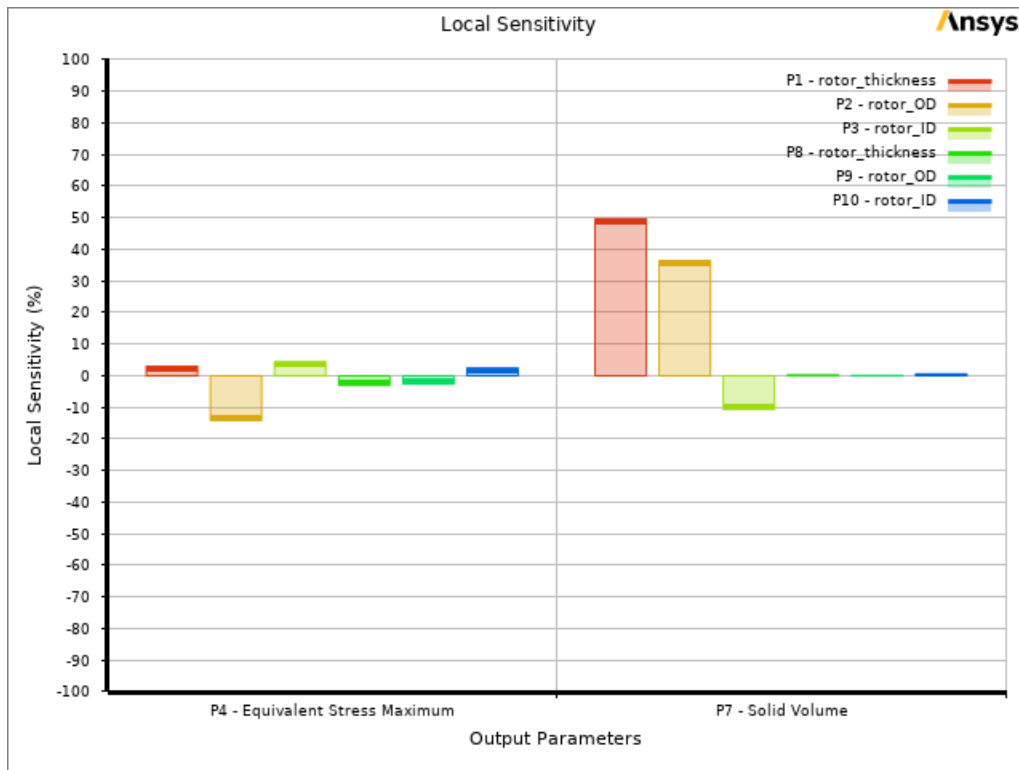


Figure 7: Local sensitivity analysis

Figure 9 shows the response curve of stress (y-axis) with respect to the design variables (P1, P2, P3, x-axis).

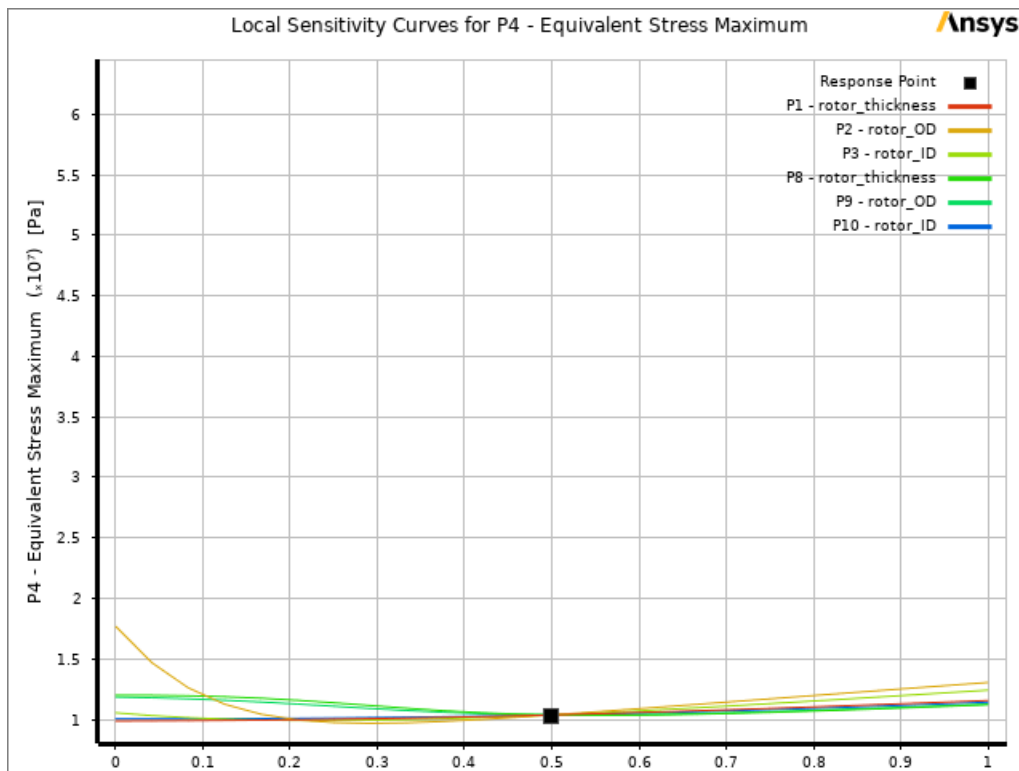


Figure 8: Stress sensitivity analysis

Figure 10 shows the response curve of volume (y-axis) with respect to the design variables (P1, P2, P3, x-axis).

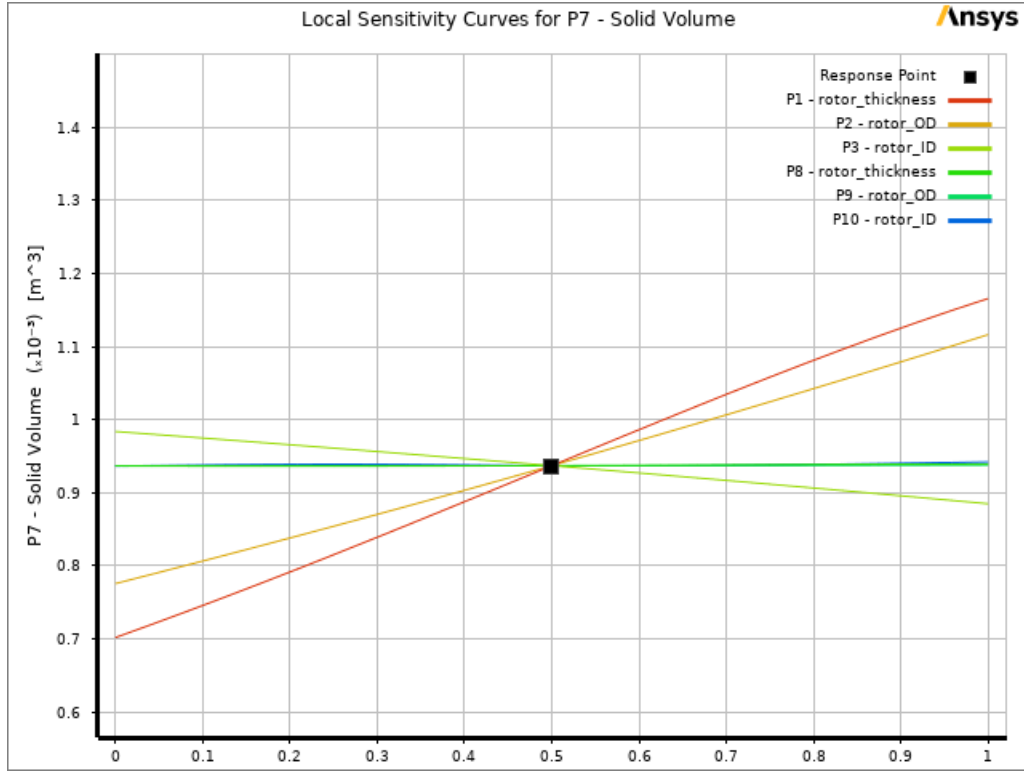


Figure 9: Volume sensitivity analysis

### 3 Conclusion

This project firstly completes three analysis for the brake disc including structural, modal and thermal and then implements DOE with neural network to obtain optimum solutions for the objective function, which is the stress and volume of the brake disc. Through the analysis, we can find that the volume of the brake disc is reduced from  $0.00099667 \text{ m}^3$  to  $0.00093011 \text{ m}^3$  after loading the stress and constraint, which volume reeducation is 5.98 %. The comparison between initial and final variables is shown in Table 2.

Table 2: Comparison between initial and final variables

	Thickness P1 (mm)	Outer Diameter P2 (mm)	Inner Diameter P3 (mm)	Maximum Stress (MPa)	Volume ( $\text{m}^3$ )
Initial	25	125	75	10.39	0.00099667
Final	21	130	77.5	10.369	0.00093706