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 brake disc thickness (P1), brake disc outer diameter (P2) and brake disc inner diameter (P3). The initial value of these variable are set as 25 mm, 125 mm and 75 mm respectively.

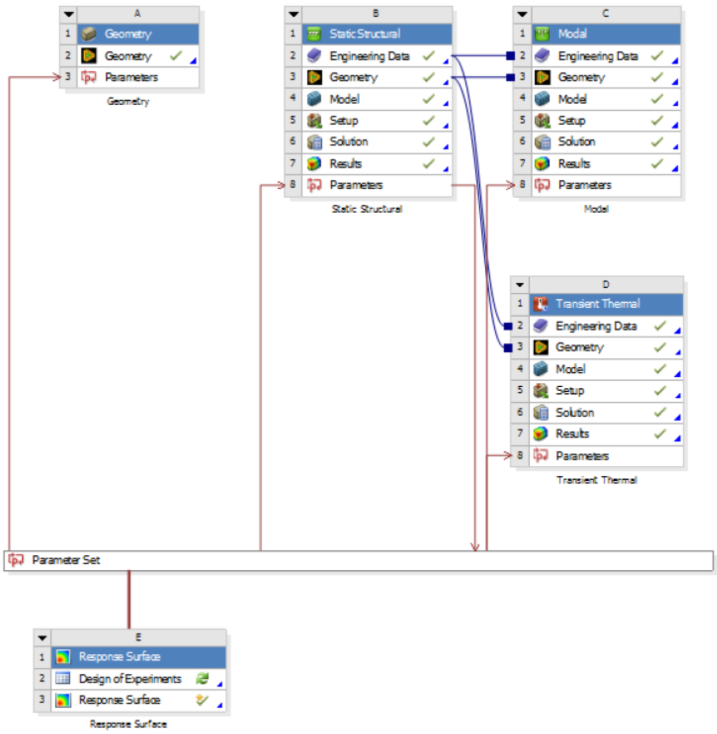


Figure 1: ANSYS optimization flowchart

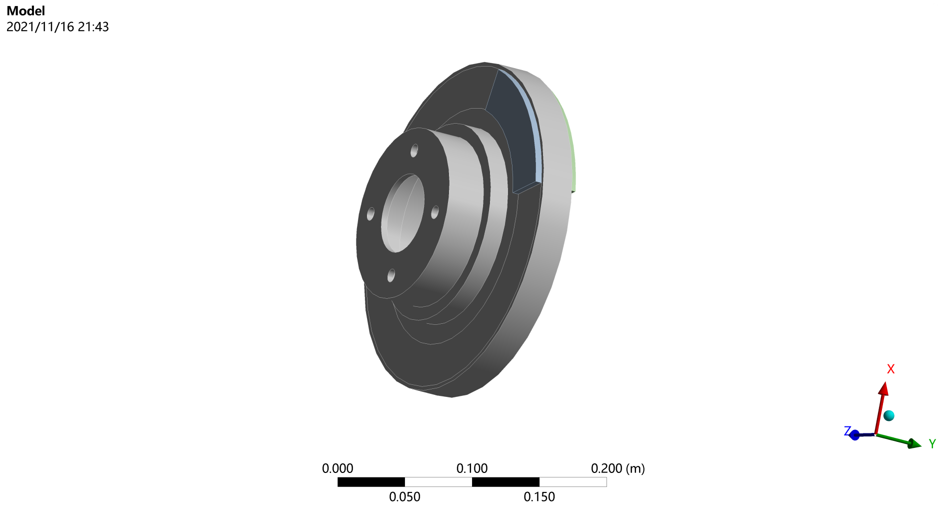


Figure 2: Disk brake CAD model

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, revolted 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 12.882 MPa.

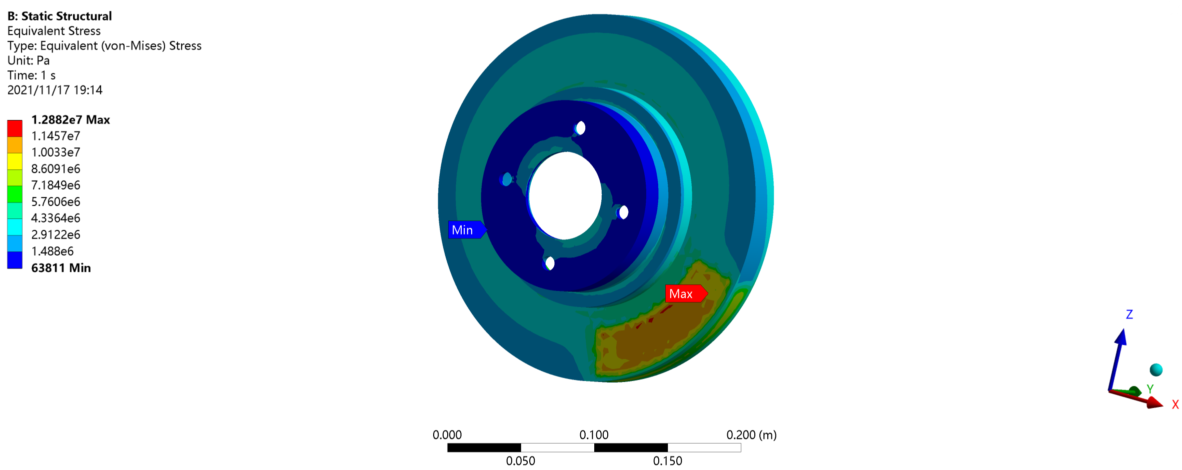


Figure 3: Static structural analysis for initial condition

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 1579.3 Hz and the maximum deformation is 0.81019 m.

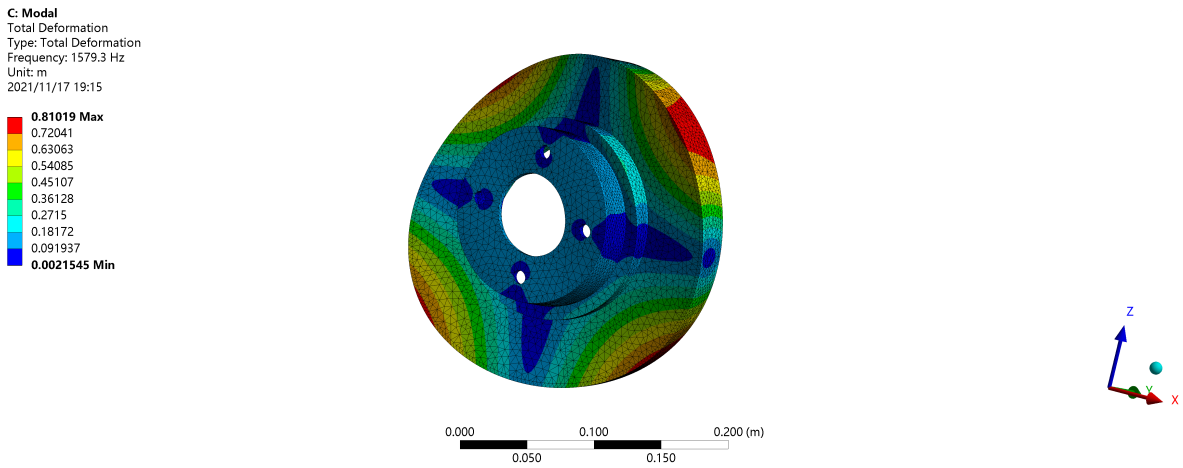


Figure 4: Modal analysis for initial condition

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 1.5395×10^6 W/m^2 is applied on the two surfaces of the brake disk. Figure 5 shows the analysis result. The maximum temperature is 334.66 °C

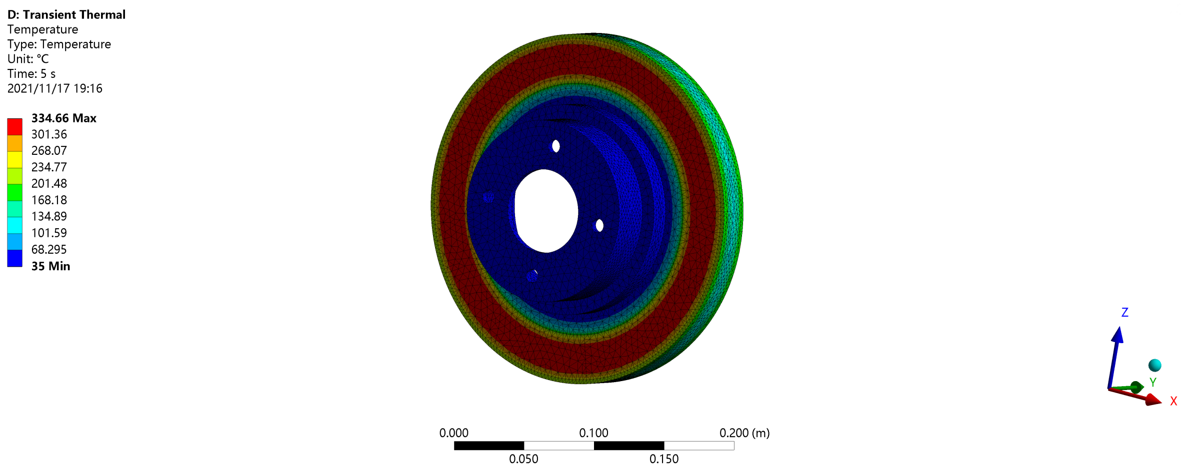


Figure 5: Thermal analysis for initial condition

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, volume, frequency and temperature 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. 14 total DOE points are generated shown in the figure 6.

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

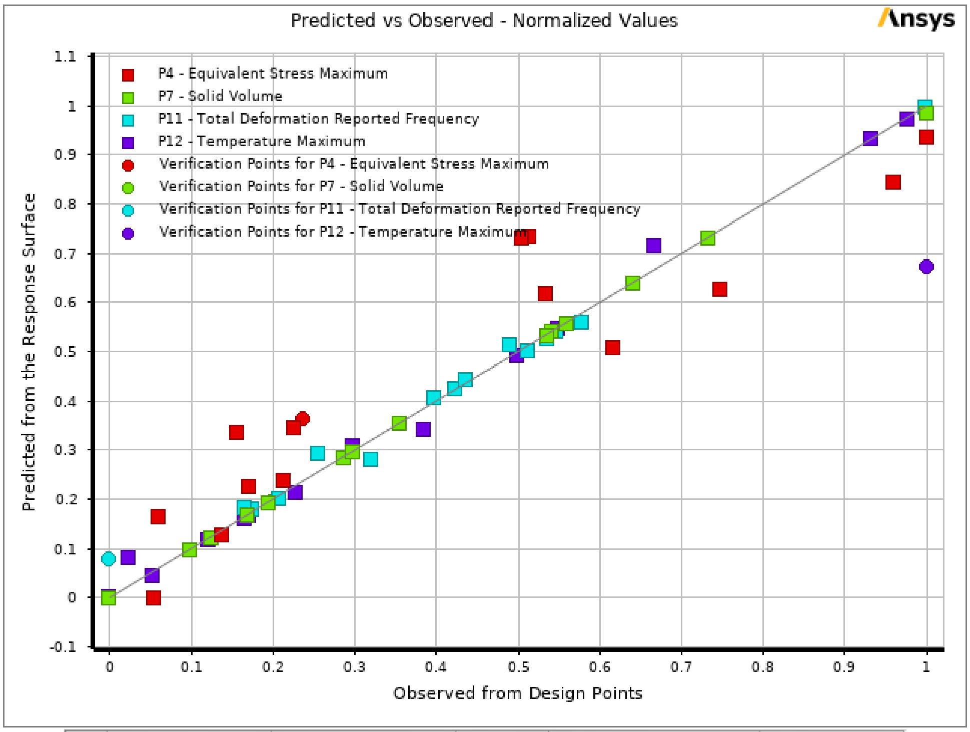
Design Variable	**Lower Bound** (mm)	**Upper Bound** (mm)
Thickness (P1)	14	28
Outer Diameter (P2)	120	140
Inner Diameter (P3)	70	85

	A	B	C	D	E	F	G	H
1	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P7 - Solid Volume (m^3)	P11 - Total Deformation Reported Frequency (Hz)	P12 - Temperature Maximum (C)
2	1	21.933	135.33	78.5	1.5158E+07	0.001061	1284.5	342.05
3	2	24.733	130	79.5	1.4986E+07	0.0010492	1402	332.65
4	3	14.467	131.33	72.5	1.1651E+07	0.00074776	1239.7	409.05
5	5	15.4	123.33	73.5	1.0928E+07	0.00068068	1463.1	405.44
6	6	27.533	122	71.5	1.7059E+07	0.0010446	1755.2	342.42
7	7	22.867	138	82.5	1.8942E+07	0.0011172	1207.3	338.34
8	8	26.6	134	81.5	1.9291E+07	0.0011798	1338.9	328.31
9	9	18.2	124.67	77.5	1.0973E+07	0.00076522	1434.4	369.56
10	10	17.267	132.67	84.5	1.5903E+07	0.00081293	1184.1	373.65
11	11	20.067	127.33	75.5	1.1943E+07	0.00087579	1441.6	352.91
12	12	16.333	136.67	74.5	1.2325E+07	0.00088316	1177.7	383.47
13	13	21	128.67	76.5	1.2438E+07	0.0009226	1417.5	347.08
14	14	25.667	139.33	70.5	1.4903E+07	0.0013607	1356.6	330.2
15	15	19.133	126	80.5	1.1822E+07	0.00079552	1364.6	360.14

Figure 6: LHS DOE points

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 4 verification points. The goodness of fit plot for the structural analysis is shown below.



	A	B	C	D	E
1		P4 - Equivalent Stress Maximum	P7 - Solid Volume	P11 - Total Deformation Reported Frequency	P12 - Temperature Maximum
2	Coefficient of Determination (Best Value...				
3	Learning Points	0.83996	0.99982	0.99244	0.99363
4	Root Mean Square Error (Best Value =...				
5	Learning Points	1.1033E+06	2.4795E-06	12.561	2.048
6	Verification Points	1.1303E+06	4.9965E-08	56.149	26.769
7	Relative Maximum Absolute Error (Best Value = ...				
8	Learning Points	70.254	4.8127	17.742	19.055
9	Verification Points	40.515	0.026483	34.272	92.172
10	Relative Average Absolute Error (Best Value =...				
11	Learning Points	33.038	0.36471	6.3434	4.4816
12	Verification Points	40.515	0.026483	34.272	92.172

Figure 7: 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 actuating structural, modal and thermal analysis for the brake disc.

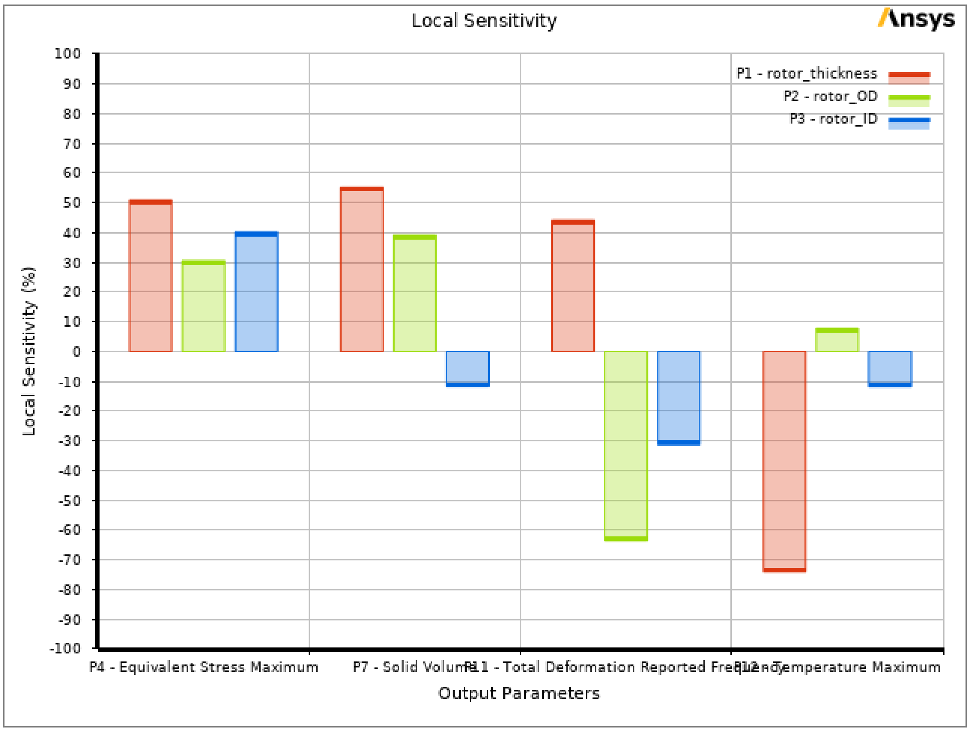


Figure 8: Local sensitivity analysis

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

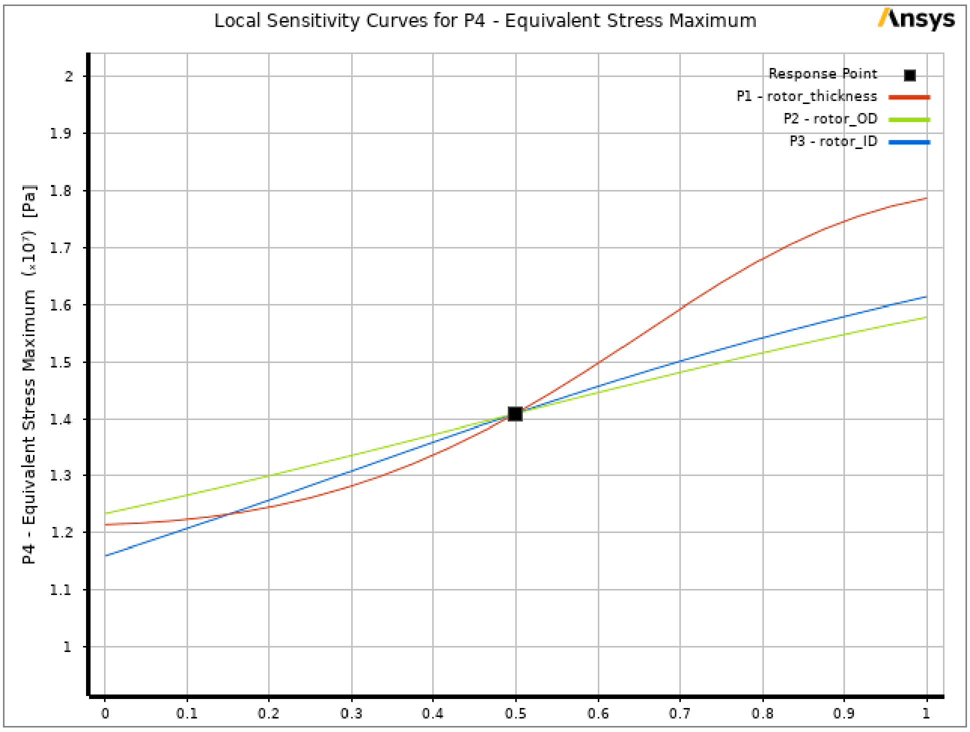


Figure 9: Stress sensitivity analysis

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

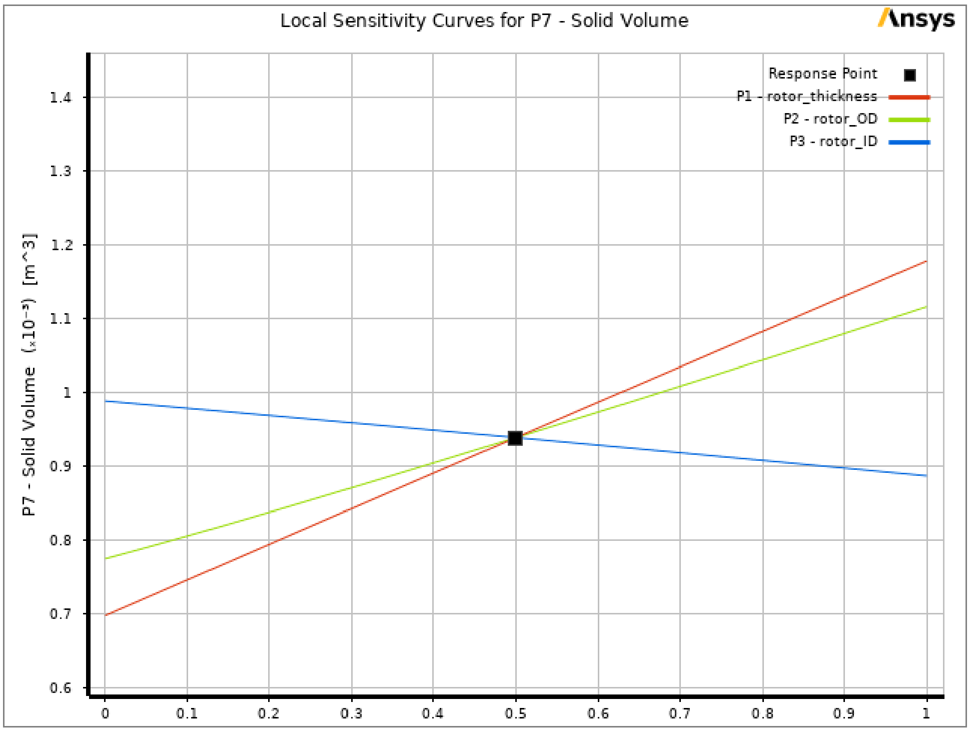


Figure 10: Volume sensitivity analysis

Figure 11 shows the response curve of volume (y-axis) with respect to the design variables (P1, P2, P3, x-axis).

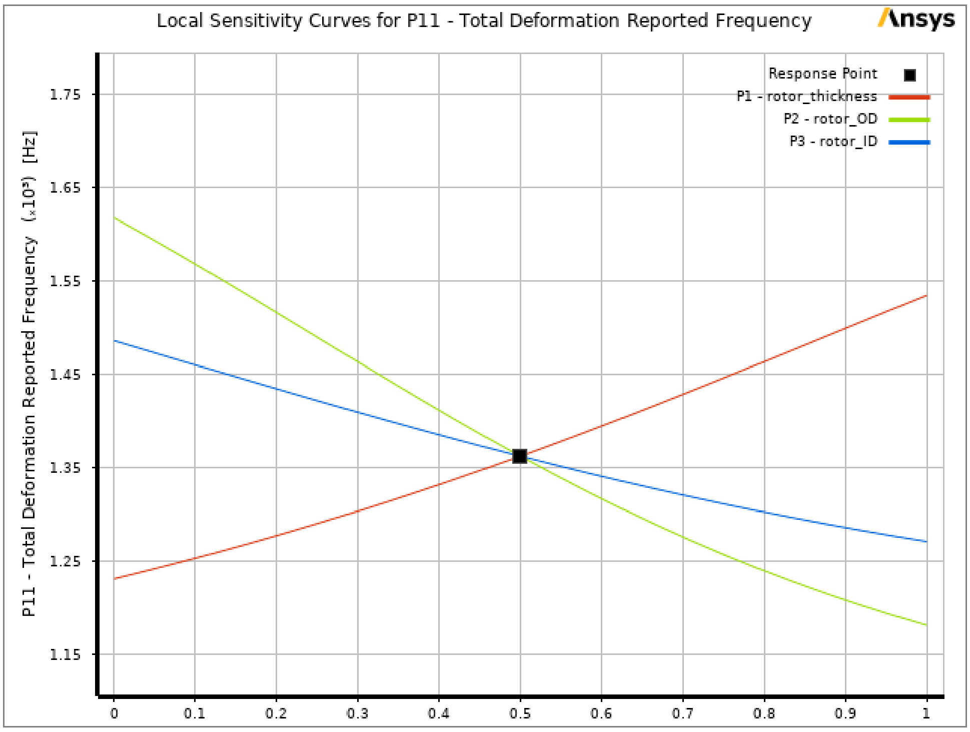


Figure 11: Frequency sensitivity analysis

Figure 12 shows the response curve of volume (y-axis) with respect to the design variables (P1, P2, P3, x-axis).

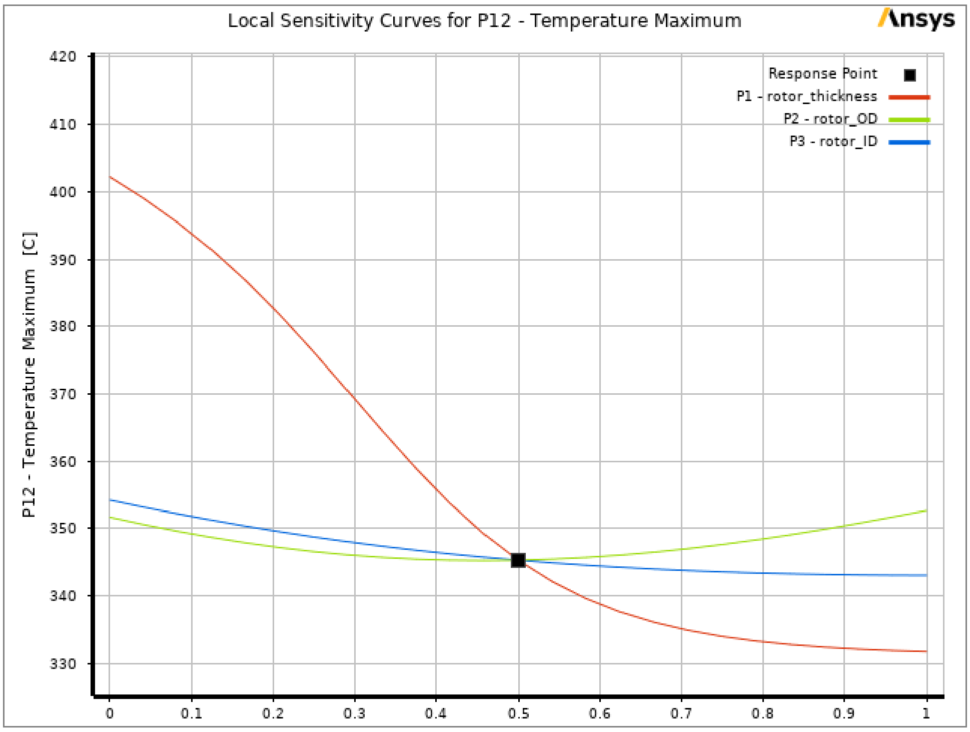


Figure 12: Temperature sensitivity analysis

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 , volume, frequency and temperature of the brake disc. Through the analysis, we can find that the volume of the brake disc is reduced from 0.00099667 m^3 to 0.00093871 m^3, which volume reeducation is 5.82 %. The comparison between initial and final design variables (output response) 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** (m^3)	**Frequency** (Hz)	**Temperature** (°C)
Initial	25	125	75	12.882	0.00099667	1579.3	334.66
Final	21	130	77.5	14.093	0.00093871	1362.5	345.29