MAE 598
Design Optimization
Project 2

Submitted by:

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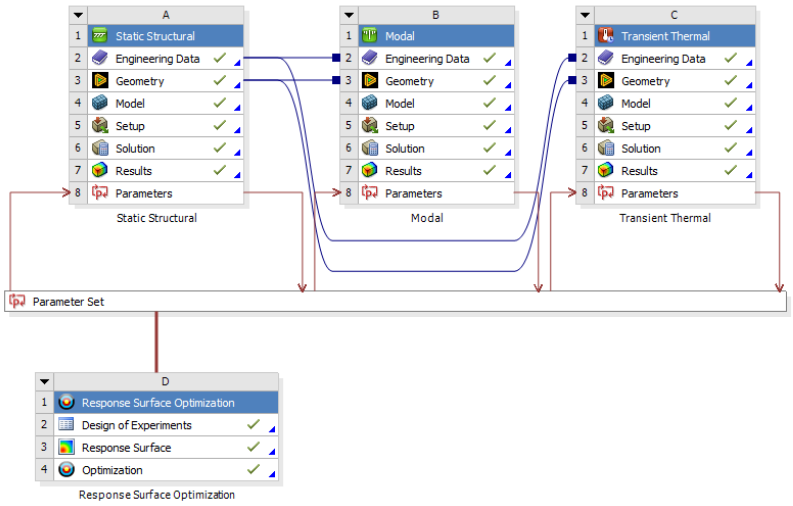
Introduction

In this project, we attempt to optimize the design of a brake disc. The Objectives of this problem are:

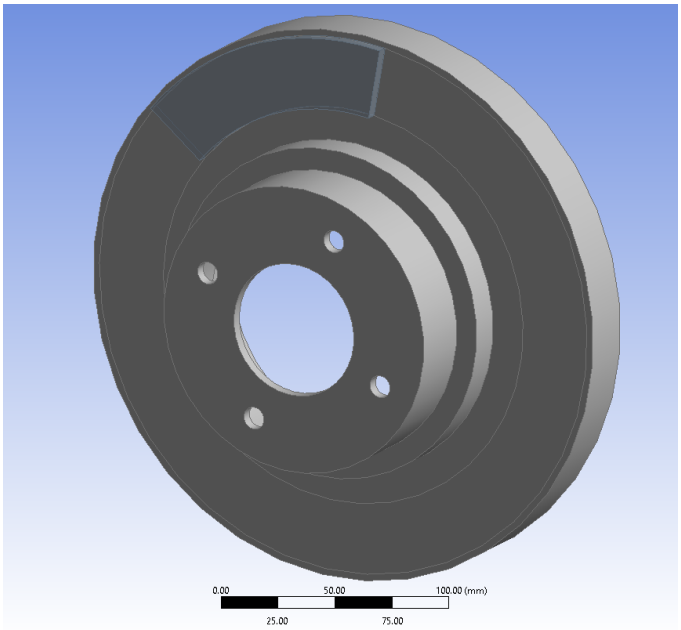
1. Minimize the volume of the brake disc
2. Minimize the Maximum stress in the brake disc
3. Maximize the first natural frequency of the brake disc
4. Minimize the maximum temperature in the brake disc.

To do this, 3 subsystems are considered in Ansys, Structural Analysis, Modal Analysis and Thermal Analysis. The Project Schematic is given below.



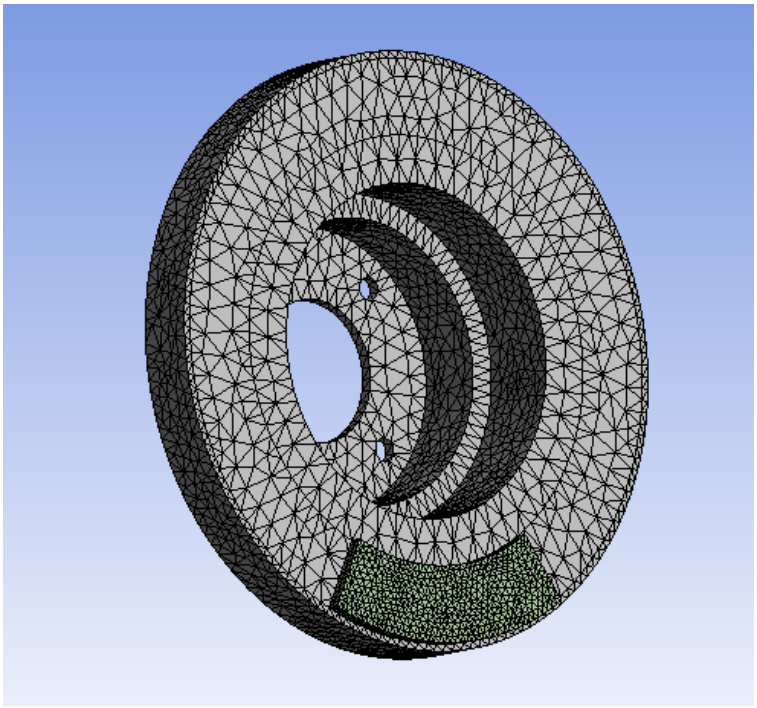
The material for the brake disc is chose to be Gray cast iron and for the brake pads, structural steel is chosen. The properties for Structural Steel & Gray Cast Iron are taken from the Ansys Database.

The geometry of the brake disc is given below.



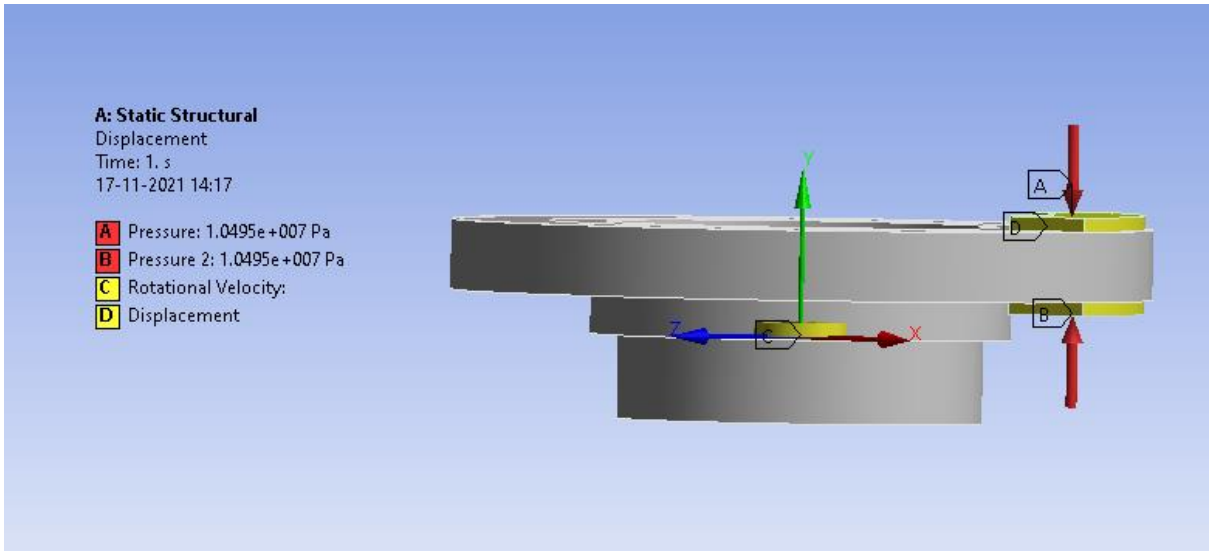
The design input variables considered are the outer radius, inner radius, and thickness of the disc

For the mesh, Body sizing with element size 3 mm is used to refine the mesh at the brake pads. The element size for the mesh is 5mm. The mesh is given below.

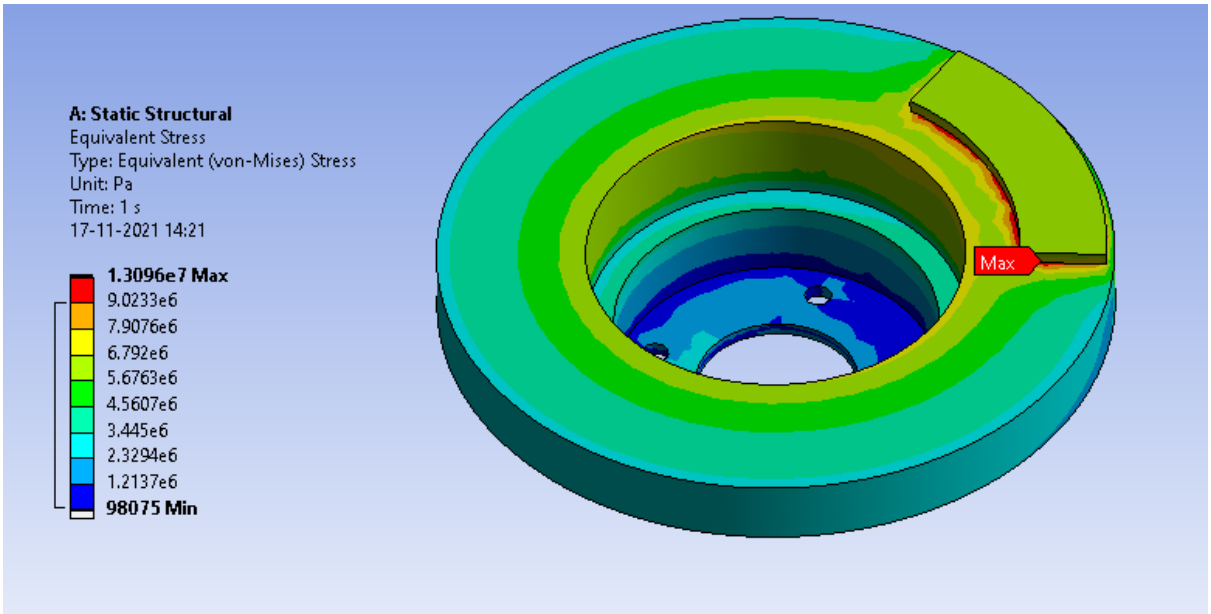


Structural Analysis

The conditions for Static structural Analysis are given below. In addition to these conditions, the friction coefficient between the disc and brake pads was set to 0.22.



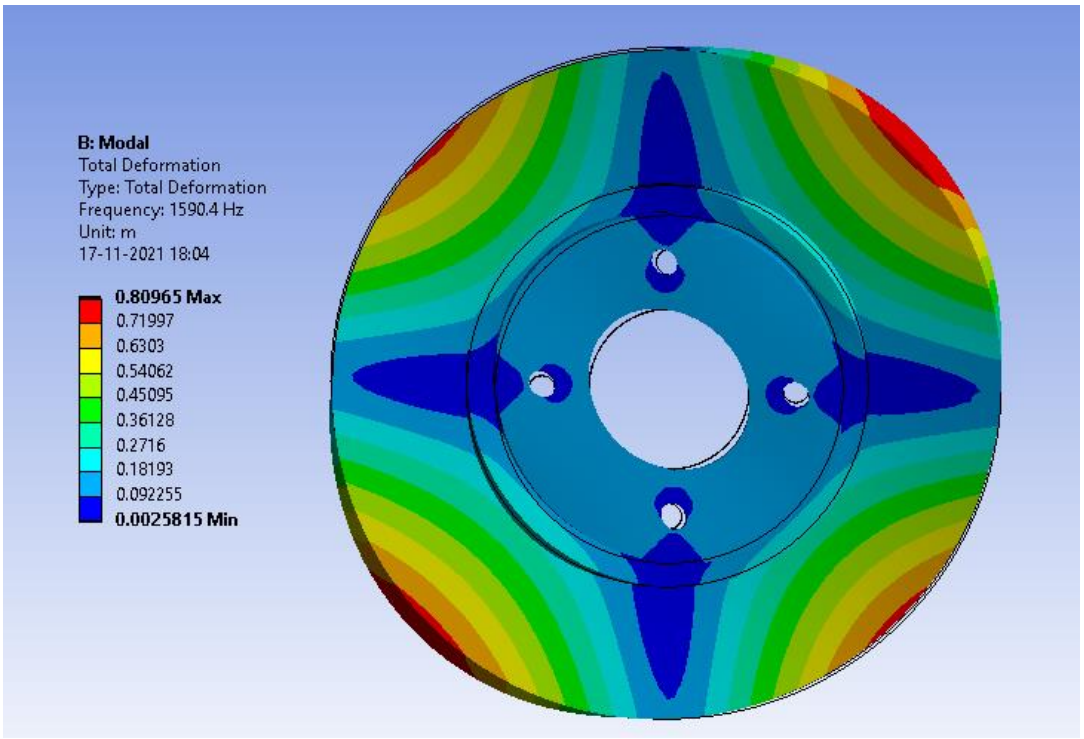
The contour plot for Von-Mises stress is given below.



For the given setting, the maximum value of von-Mises stress was found to be 13.096 MPa.

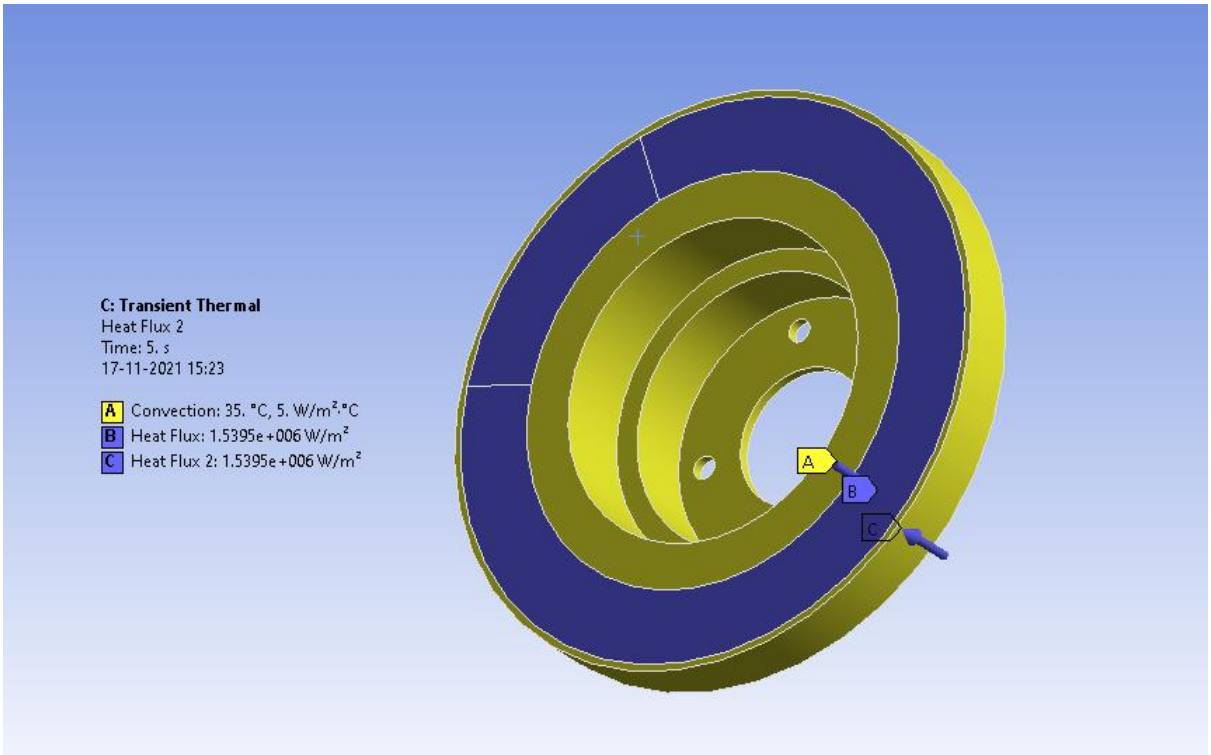
Modal Analysis

The Contour plot of total deformation is given below.

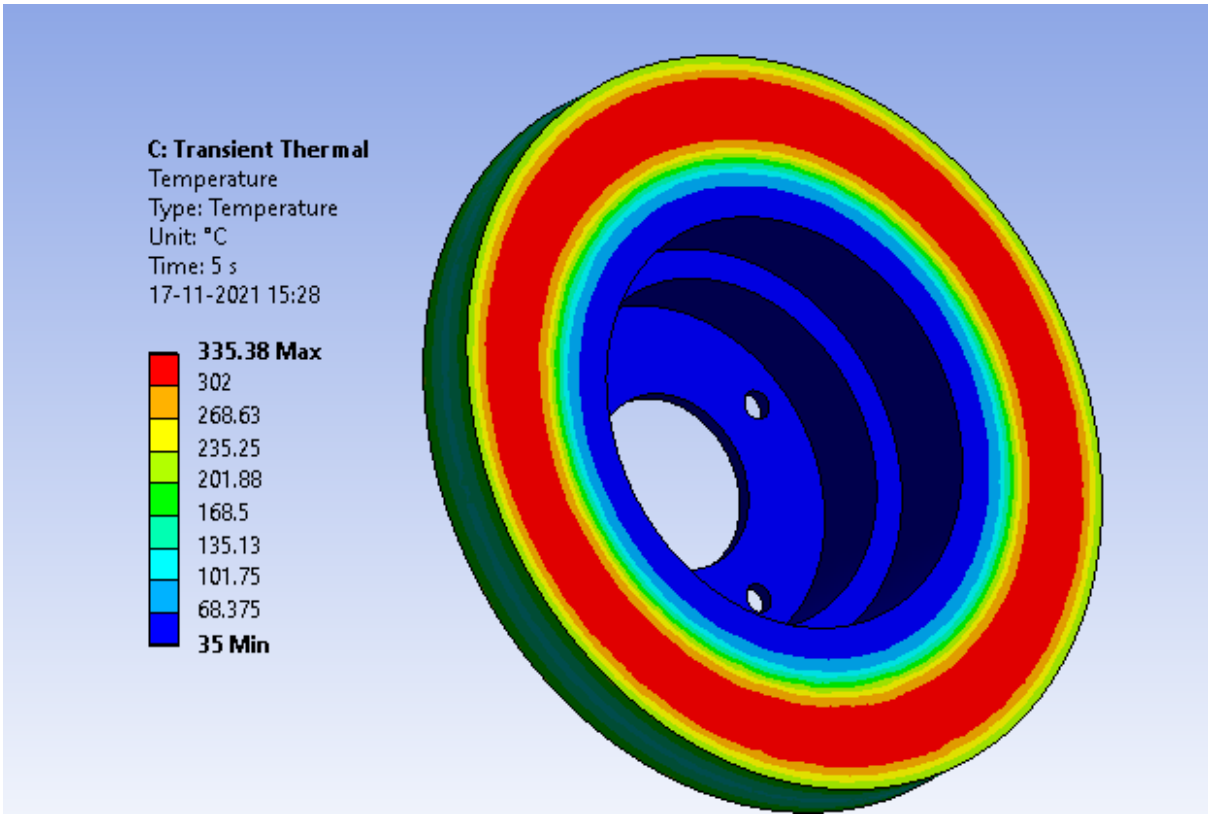


The first natural frequency is 1590.4 Hz

Transient Thermal Analysis



The contour plot of temperature is given below.



The maximum temperature is 335.38 ^{o}C.

Design of Experiments

For the DOE, the Latin Hypercube Sampling Design with User-Defined Samples is chosen, and the number of samples is set to 30. The Design Points are given in the table below.

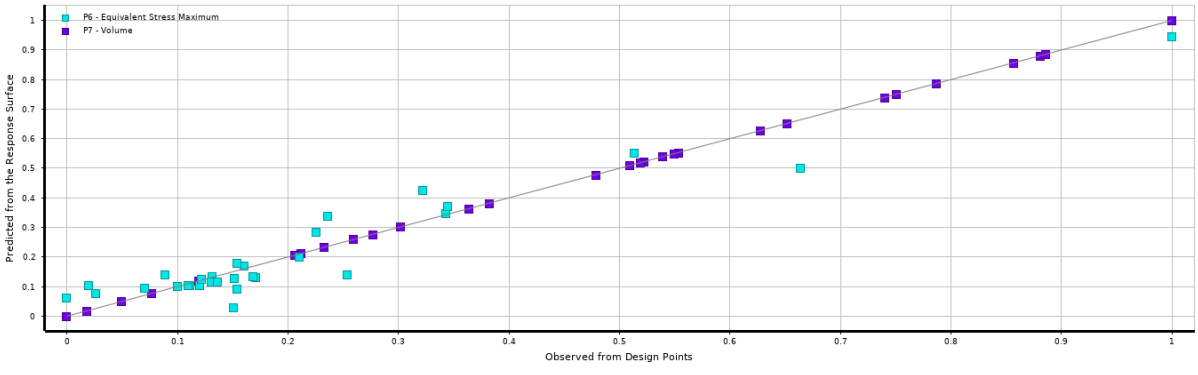
Table of Outline A2: Design Points of Design of Experiments

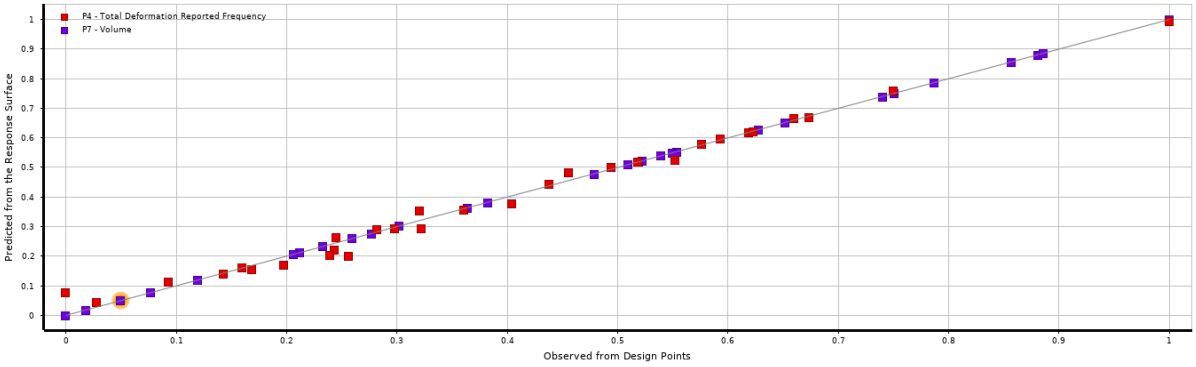
	A	B	C	D	E	F	G	H
1	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Total Deformation Reported Frequency (Hz)	P5 - Temperature Maximum (C)	P6 - Equivalent Stress Maximum (Pa)	P7 - Volume (m^3)
2	1	16.25	130.8	70.25	1305.1	385.18	1.1394E+07	0.00081669
3	2	20.417	131.6	77.25	1357.9	350.61	1.165E+07	0.00094719
4	3	5.4167	127.6	78.25	1057	873.49	1.0811E+07	0.00039554
5	4	17.917	133.2	82.25	1225.5	368.16	1.1617E+07	0.00085503
6	5	7.0833	126	73.75	1120.7	694	1.1614E+07	0.00043923
7	6 DP 75	27.917	123.2	84.75	1436.3	333	1.6032E+07	0.0009477
8	7	17.083	134	75.75	1261.7	376.03	1.1703E+07	0.0008696
9	8	27.083	133.6	83.25	1335	328.5	1.3491E+07	0.0011698
10	9	11.25	128.8	74.25	1224.5	480.76	1.144E+07	0.00060016
11	10	9.5833	134.8	81.25	1076.1	538.86	1.1693E+07	0.00058181
12	11	12.917	128.4	79.75	1278.6	438.99	1.1334E+07	0.00063897
13	12	8.75	126.8	72.25	1155.1	581.85	1.0913E+07	0.00050037
14	13	15.417	129.2	82.75	1251	395.73	1.1497E+07	0.00071583
15	14	22.083	123.6	74.75	1572.8	348	1.1911E+07	0.00088263
16	15	12.083	132.8	77.75	1173.1	457.16	1.1446E+07	0.00066089
17	16	25.417	128	76.75	1510.7	332.23	1.2042E+07	0.0010553
18	17	24.583	132.4	72.75	1464.5	333.89	1.1601E+07	0.0011487
19	18	19.583	127.2	71.75	1482.5	356.89	1.1494E+07	0.00087892
20	19	7.9167	125.6	76.25	1221.5	633.5	1.0947E+07	0.00046337
21	20	6.25	125.2	81.75	1233.2	776.36	1.16E+07	0.00041187
22	21	14.583	124	84.25	1277.1	414.97	1.1525E+07	0.00062384
23	22	26.25	130	80.75	1413.3	330.25	1.4279E+07	0.0010876
24	23	28.75	132	75.25	1519.9	326.37	1.2603E+07	0.0012744
25	24	10.417	130.4	79.25	1193	507.11	1.1181E+07	0.00057717
26	25	22.917	124.4	83.75	1370	342.79	1.2493E+07	0.00085188
27	26	18.75	126.4	70.75	1485	363.23	1.1386E+07	0.00084314
28	27	23.75	131.2	78.75	1396.8	336.43	1.1988E+07	0.0010461
29	28	21.25	129.6	73.25	1453.1	346.61	1.2135E+07	0.00096837
30	29	29.583	124.8	71.25	1744.2	327.95	1.2611E+07	0.0011743
31	30	13.75	134.4	80.25	1166.9	421.45	1.1276E+07	0.00073194

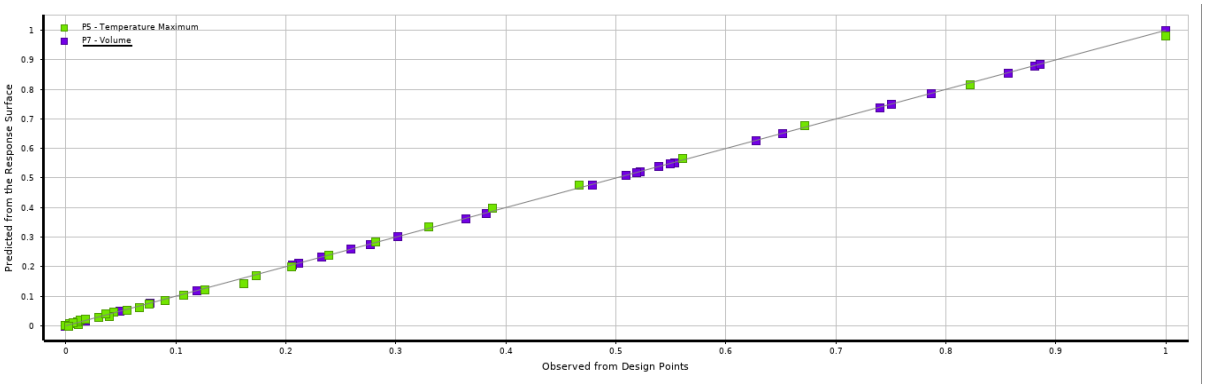
A Standard response surface is chosen. The goodness of fit is given below.

Table of Schematic D3: Response Surface

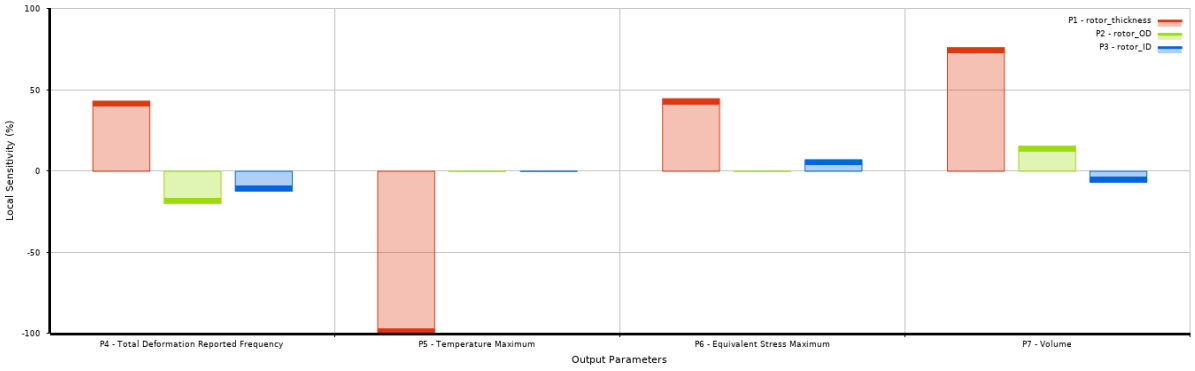
	A	B	C	D	E
1		P4 - Total Deformation Reported Frequency	P5 - Temperature Maximum	P6 - Equivalent Stress Maximum	P7 - Volume
2	Coefficient of Determination (Best Value = 1)				
3	Learning Points	0.98892	0.9993	0.9076	1
4	Root Mean Square Error (Best Value = 0)				
5	Learning Points	16.621	3.7187	3.1816E+05	1.9166E-07
6	Relative Maximum Absolute Error (Best Value = 0%)				
7	Learning Points	33.187	6.737	80.314	0.2021
8	Relative Average Absolute Error (Best Value = 0%)				
9	Learning Points	7.1976	2.0662	21.999	0.059871







Sensitivity Analysis



From the sensitivity Analysis, we can see that the properties are very sensitive to the rotor thickness.

Optimization

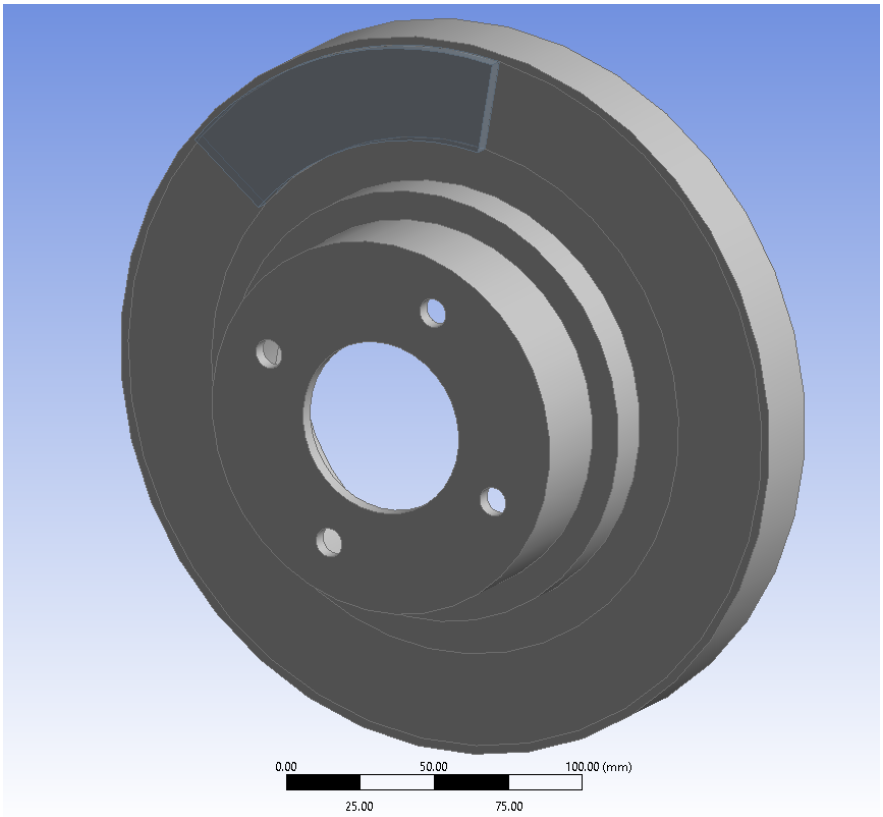
The multi objective genetic algorithm (MOGA) is used in Ansys.

The conditions were set to minimize the volume, Maximum Von-Mises Stress, and Maximum temperature and to maximize the Disc Frequency. The candidate points are given in image below

Table of Schematic D4: Optimization , Candidate Points

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Reference	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Total Deformation Reported Frequency (Hz)		P5 - Temperature Maximum (C)		P6 - Equivalent Stress Maximum (Pa)		P7 - Volume (m^3)	
2						Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
3		Candidate Point 1	15.048	130.94	84.955	1199.9	1%	398.25	-1%	1.1542E+07	-3%	0.00071603	0%
4	◉	Candidate Point 1 (verified)				1190.8	0%	400.58	0%	1.1887E+07	0%	0.00071658	0%
5		Candidate Point 2	15.347	131.19	84.917	1200.2	1%	394.07	-2%	1.1574E+07	-3%	0.00072868	2%
6		Candidate Point 2 (verified)				1190.8	0%	396.42	-1%	1.1523E+07	-3%	0.00072918	2%
7		Candidate Point 3	15.019	131.33	84.413	1201.7	1%	398.67	0%	1.1541E+07	-3%	0.00072227	1%
8		Candidate Point 3 (verified)				1193.3	0%	401.01	0%	1.1421E+07	-4%	0.00072275	1%

Candidate point 1 with least volume is chose as the optimum point. The original Design is given below.



The new design has a volume reduction of 28.1% over the original design. It is given below.