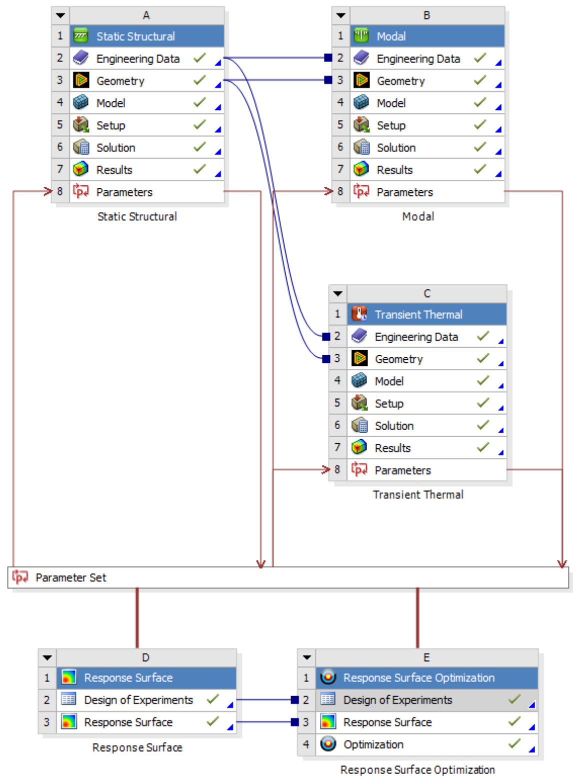
Introduction

In this project analysis and optimization of Brake disks were carried out using Ansys Workbench software. The Static structural analysis was run on the brake disks, where pressure was on the brake disks through the pads to obtain the equivalent stresses on the system. Modal analysis was performed on the braking system to determine its free natural frequency. Using Transient Thermal analysis, the maximum temperature of the system due to friction during the braking operation was simulated. For the optimum functioning of a system, it is necessary to make sure that the induced stresses in the system are minimized, the vibrations due to natural frequency are less than that of the resonance of the system and minimize the increase in temperature to prevent damage to the brake pads and disk material during the application of brakes.

Setup

The Brake disk and Brake Pad are shown in the below mesh geometry figure. From the imported CAD model assembly, the brake disk and geometry were considered as separate bodies. The material chosen for the brake pads was structural steel and that of the brake disk body was grey cast iron. All the three-analysis carried out in this project followed the same part geometry and respective material properties.



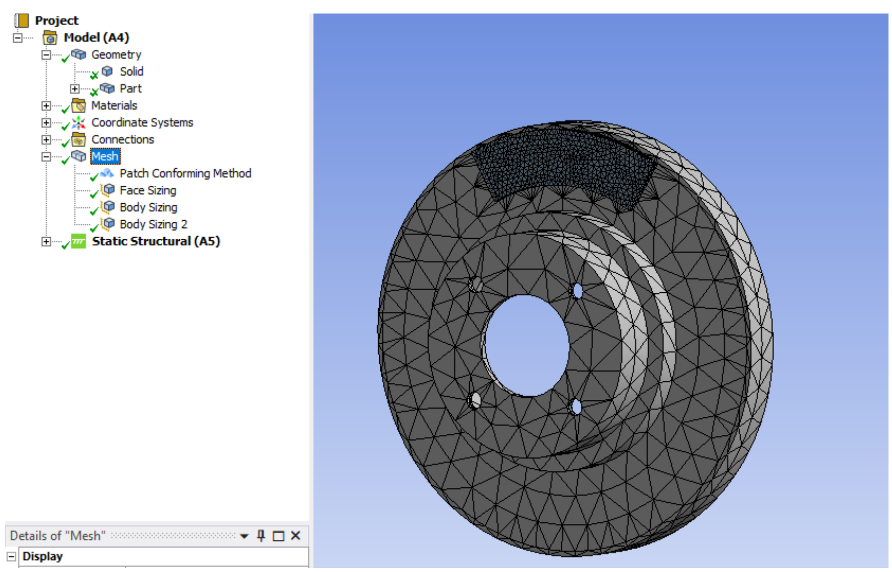


Figure 1: Mesh of the CAD model

Structural analysis

To simulate the stresses on the braking system, frictional contact was set between the brake pads and brake disks with a coefficient of friction of 0.22. The motion of the brake pads was restricted to the y axis alone. The entire brake disk system was rotated along y-axis with a rotational velocity of 250 rad/s. A pressure of 10.45 MPa is applied by the brake pads on the brake disks and the Von Mises stresses in the system is obtained.

Boundary Conditions

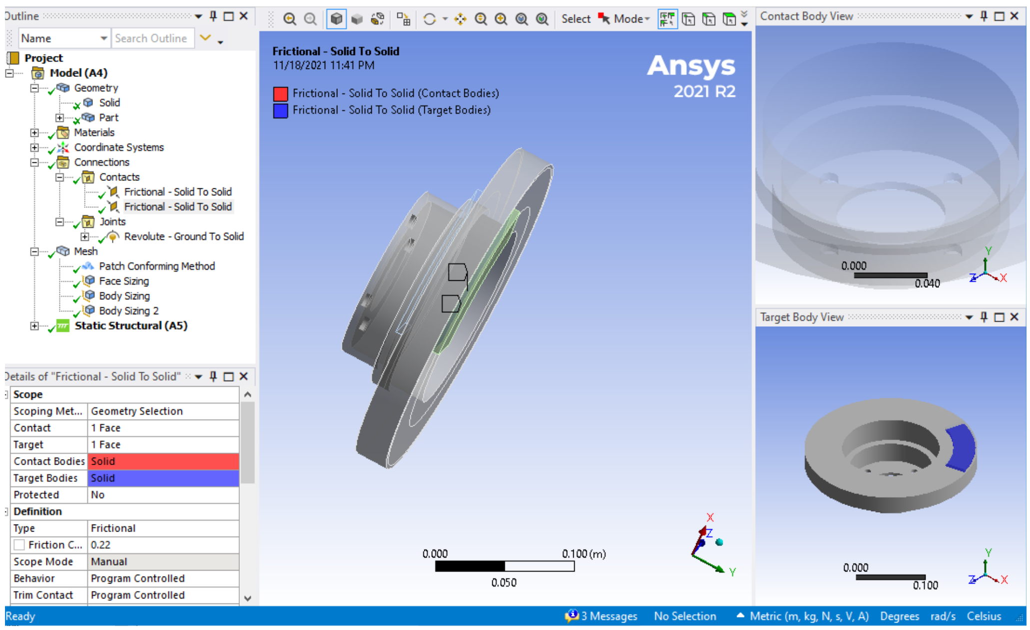


Figure 2: Contact region between brake pad and disk

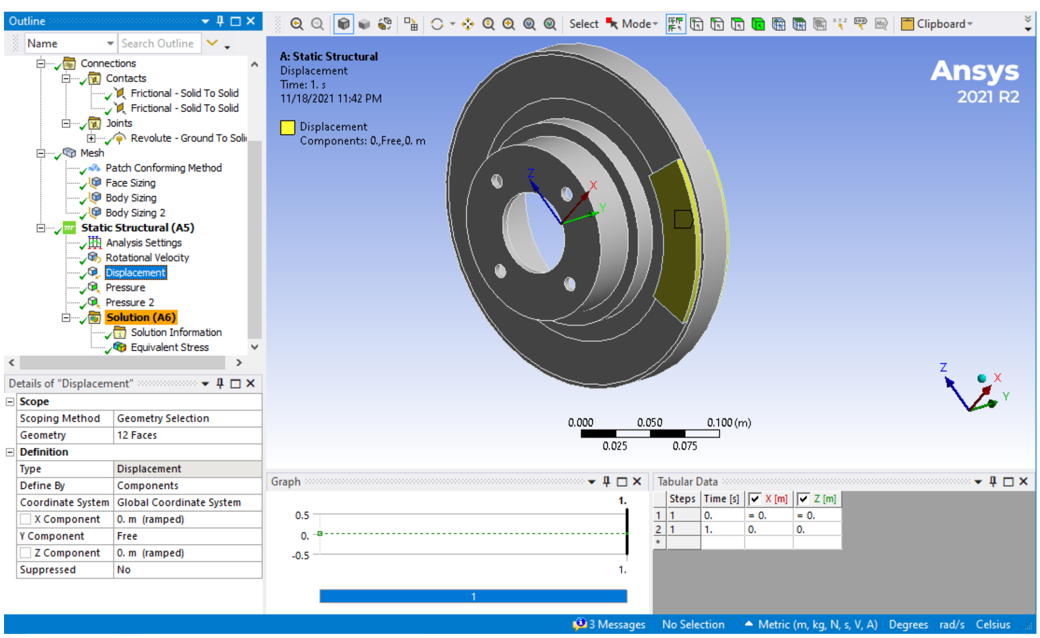


Figure 3: Displacement boundary condition

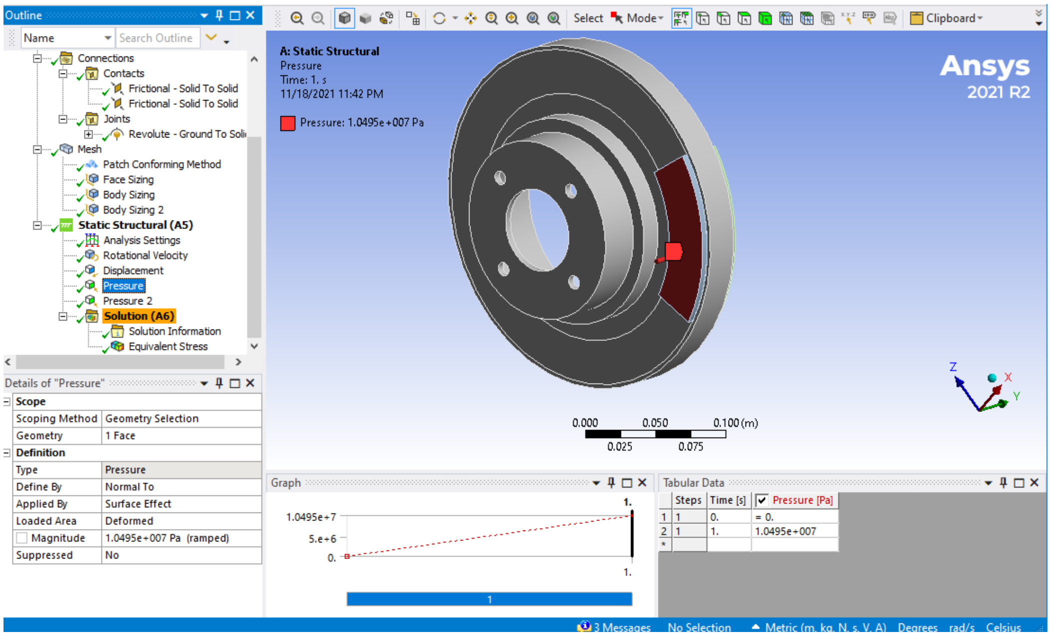


Figure 4: Pressure applied on the brake pads

Von-Misses Stresses

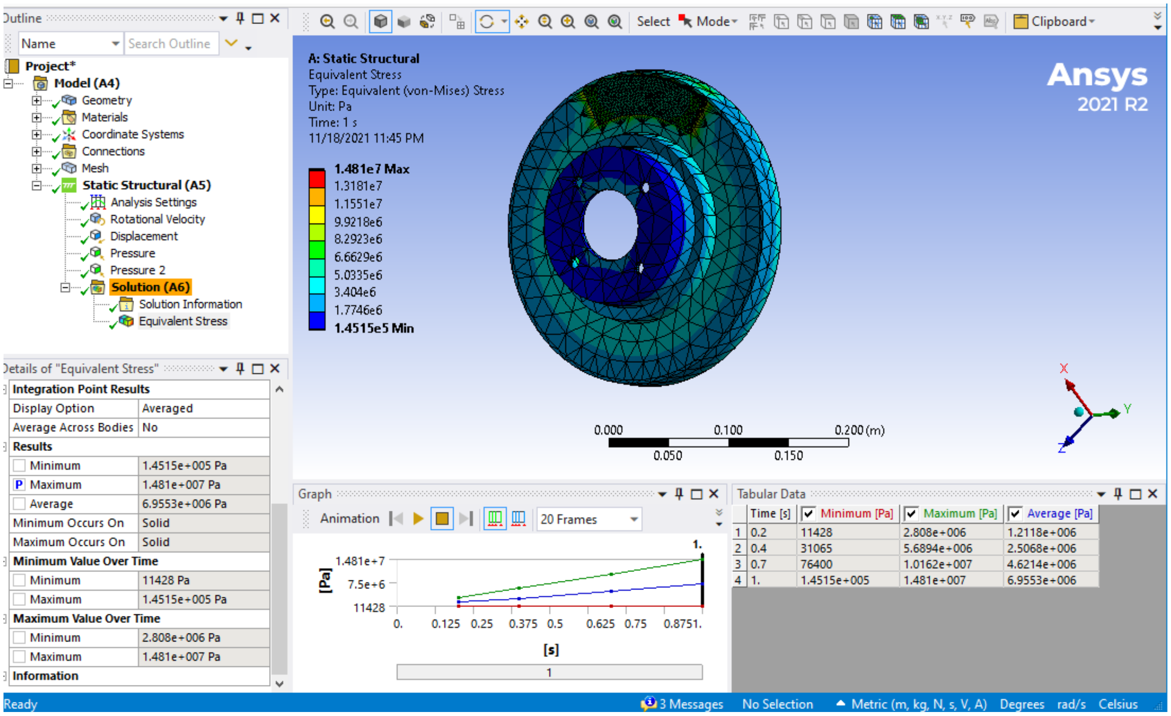


Figure 5: Equivalent stresses (Von-Mises)

The maximum Von-Mises stress obtained in the system is 14.81 MPa.

Modal Analysis

The geometry and material properties were adopted from that of the structural analysis. The Brake pads are suppressed during the calculation of Modal Analysis. The natural frequency of the system is calculated. The total deformation of the brake at the 7th mode is obtained.

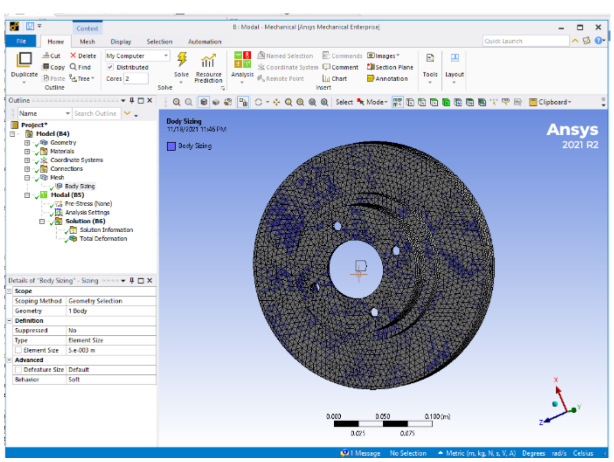


Figure 6: Geometry of mesh for MODAL analysis

Total Deformation

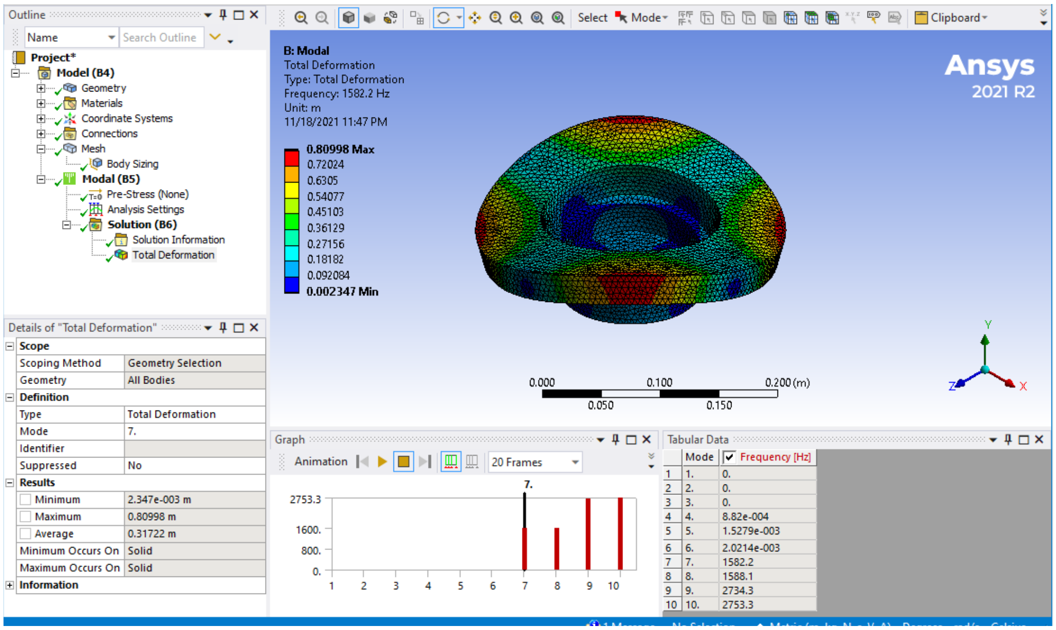


Figure 7: Contour plot of total deformation

The obtained natural frequency of the brake disk 1582.2 Hz

Thermal analysis

Heat flux was applied on both surfaces of the brake disks the brake pads and disk meet during braking operation. The temperature distribution on the system is obtained

Boundary Conditions

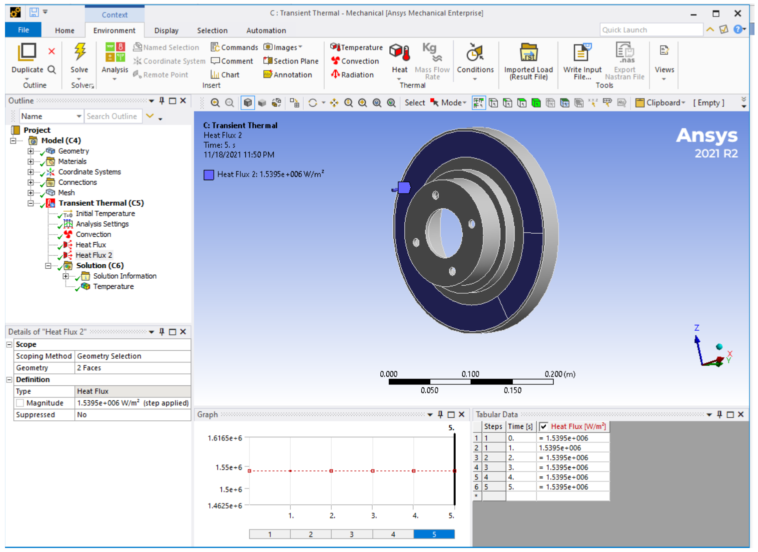


Figure 8: Heat flux

Temperature

The maximum temperature on the system obtained is 334.47 K.

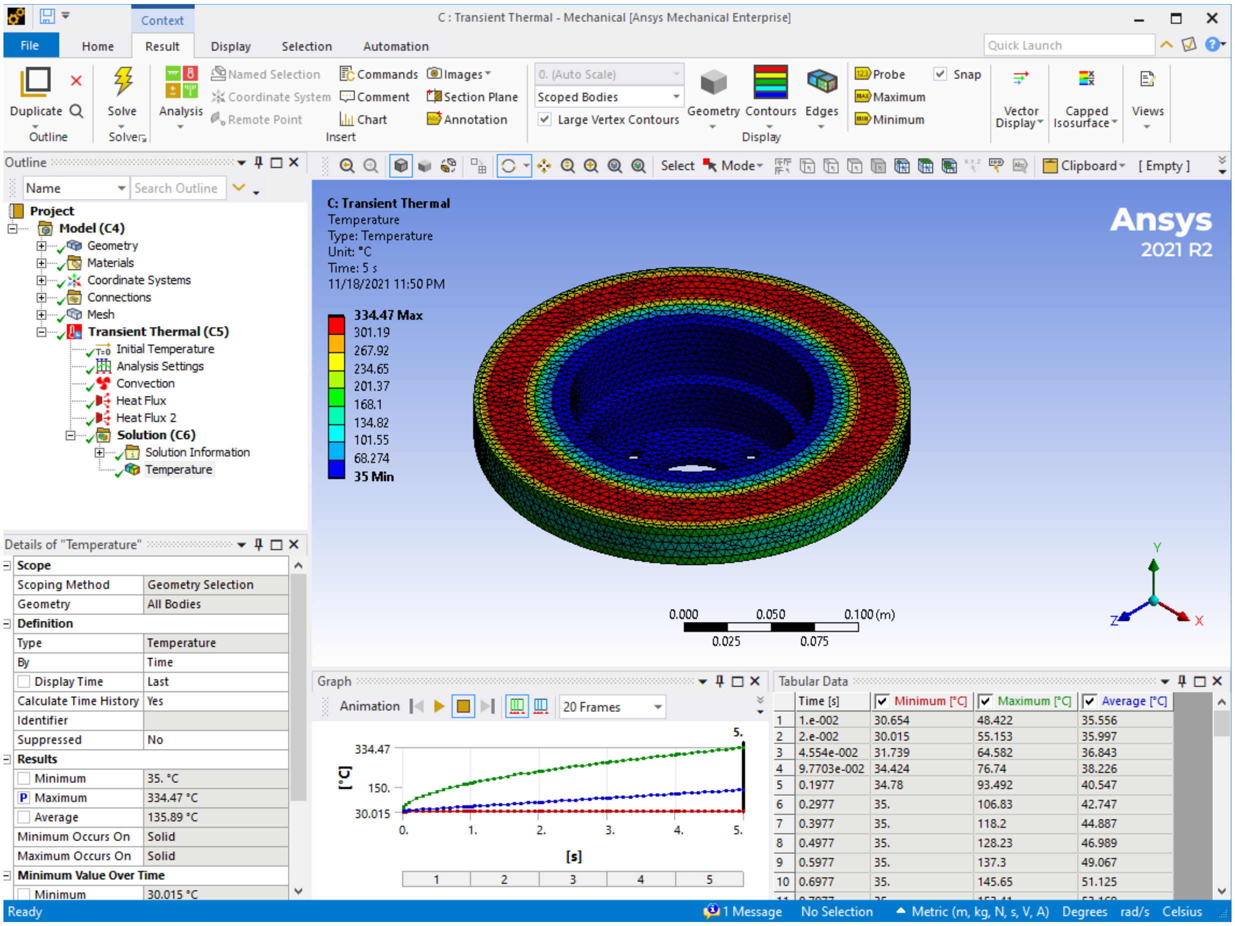


Figure 9: Temperature distribution plot

Optimization using Response Surface Methodology

Using the concepts of Response surface methodology from the Design of experiments, Optimum input parameters are chosen to minimize the temperature and stresses on the braking system during operation. The brake thickness, brake disk outer diameter and the brake disk inner diameter are considered as input parameters. LHS method is used to generate 30 design points.

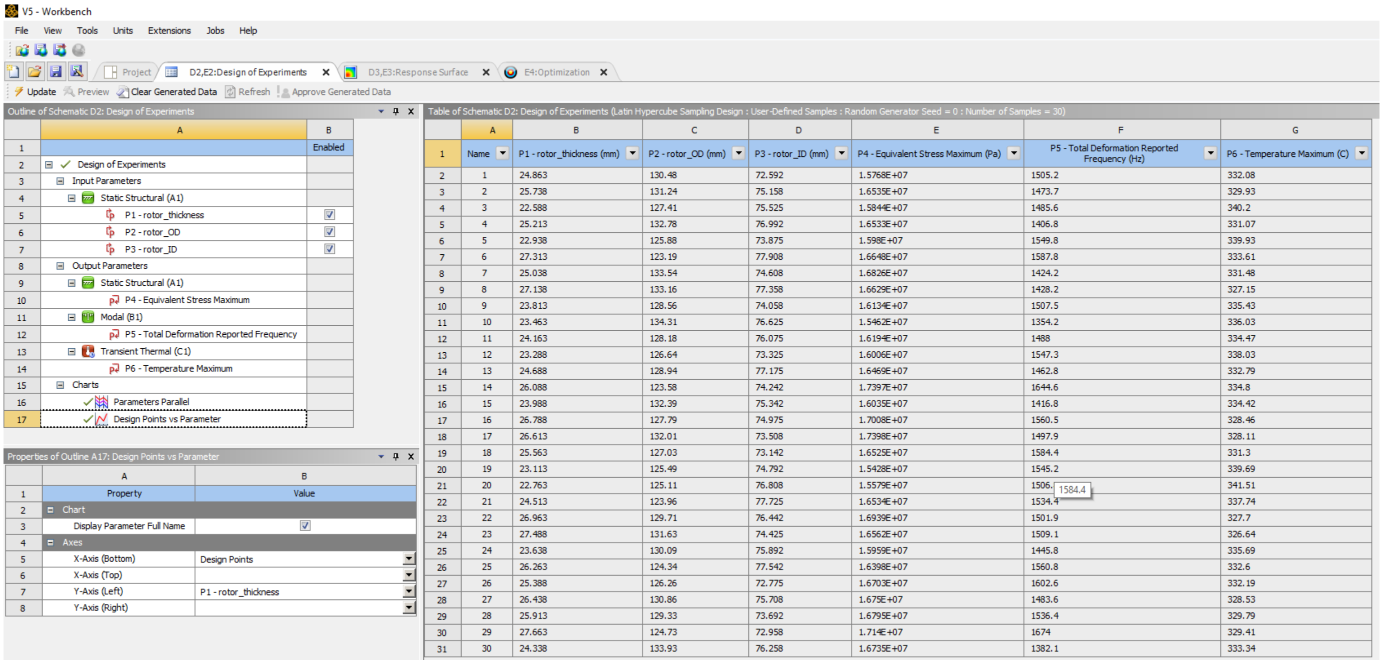


Table of Schematic D2: Design of Experiments (Latin Hypercube Sampling Design : User-Defined Samples : Random Generator Seed = 0 : Number of Samples = 30)

	A	B	C	D	E	F	G
1	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P5 - Total Deformation Reported Frequency (Hz)	P6 - Temperature Maximum (C)
2	1	24.863	130.48	72.592	1.5768E+07	1505.2	332.08
3	2	25.738	131.24	75.158	1.6535E+07	1473.7	329.93
4	3	22.588	127.41	75.525	1.5844E+07	1485.6	340.2
5	4	25.213	132.78	76.992	1.6533E+07	1406.8	331.07
6	5	22.938	125.88	73.875	1.598E+07	1549.8	339.93
7	6	27.313	123.19	77.908	1.6648E+07	1587.8	333.61
8	7	25.038	133.54	74.608	1.6826E+07	1424.2	331.48
9	8	27.138	133.16	77.358	1.6629E+07	1428.2	327.15
10	9	23.813	128.56	74.058	1.6134E+07	1507.5	335.43
11	10	23.463	134.31	76.625	1.5462E+07	1354.2	336.03
12	11	24.163	128.18	76.075	1.6194E+07	1488	334.47
13	12	23.288	126.64	73.325	1.6006E+07	1547.3	338.03
14	13	24.688	128.94	77.175	1.6469E+07	1462.8	332.79
15	14	26.088	123.58	74.242	1.7397E+07	1644.6	334.8
16	15	23.988	132.39	75.342	1.6035E+07	1416.8	334.42
17	16	26.788	127.79	74.975	1.7008E+07	1560.5	328.46
18	17	26.613	132.01	73.508	1.7398E+07	1497.9	328.11
19	18	25.563	127.03	73.142	1.6525E+07	1584.4	331.3
20	19	23.113	125.49	74.792	1.5428E+07	1545.2	339.69
21	20	22.763	125.11	76.808	1.5579E+07	1506.[illegible]	341.51
22	21	24.513	123.96	77.725	1.6534E+07	1534.4	337.74
23	22	26.963	129.71	76.442	1.6939E+07	1501.9	327.7
24	23	27.488	131.63	74.425	1.6562E+07	1509.1	326.64
25	24	23.638	130.09	75.892	1.5959E+07	1445.8	335.69
26	25	26.263	124.34	77.542	1.6398E+07	1560.8	332.6
27	26	25.388	126.26	72.775	1.6703E+07	1602.6	332.19
28	27	26.438	130.86	75.708	1.675E+07	1483.6	328.53
29	28	25.913	129.33	73.692	1.6795E+07	1536.4	329.79
30	29	27.663	124.73	72.958	1.714E+07	1674	329.41
31	30	24.338	133.93	76.258	1.6735E+07	1382.1	333.34

Figure 10: Design of experiments table

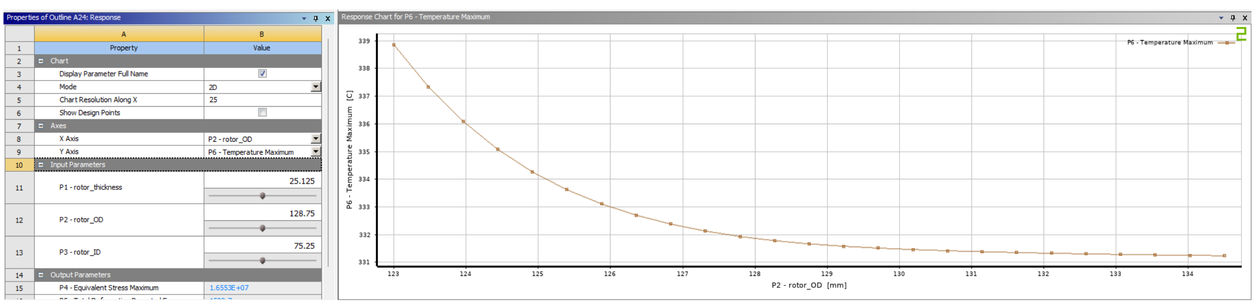


Figure 11: Response curve of max. stress with change in Disk outer diameter

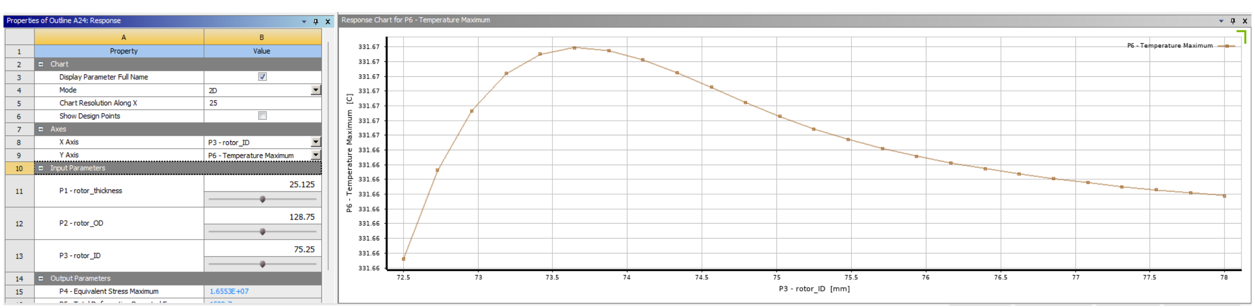


Figure 12: Response curve of max. stress with change in disk inner diameter

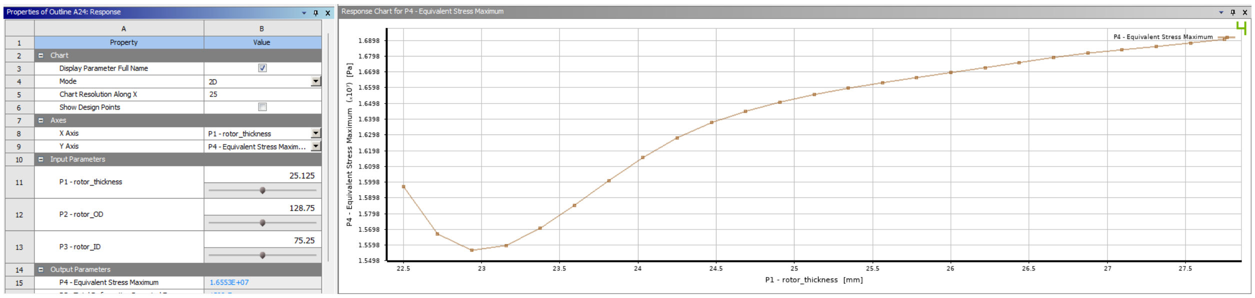


Figure 13: Response curve of max. stress with change in Disk Thickness

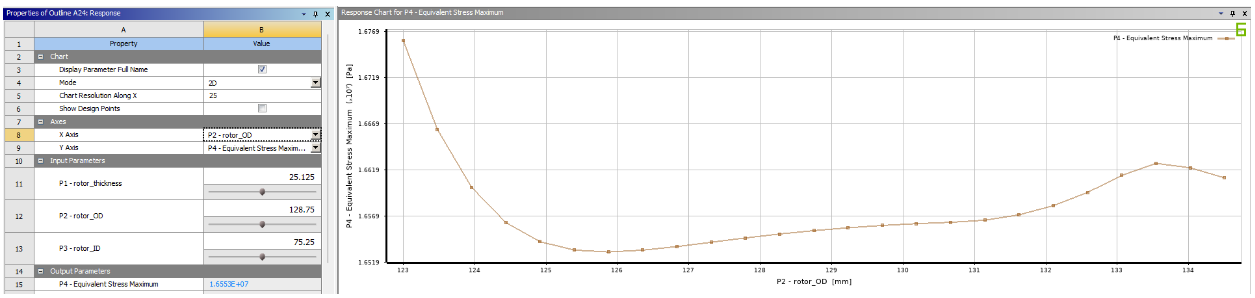


Figure 14: Response curve of max. temperature with change in Disk outer diameter

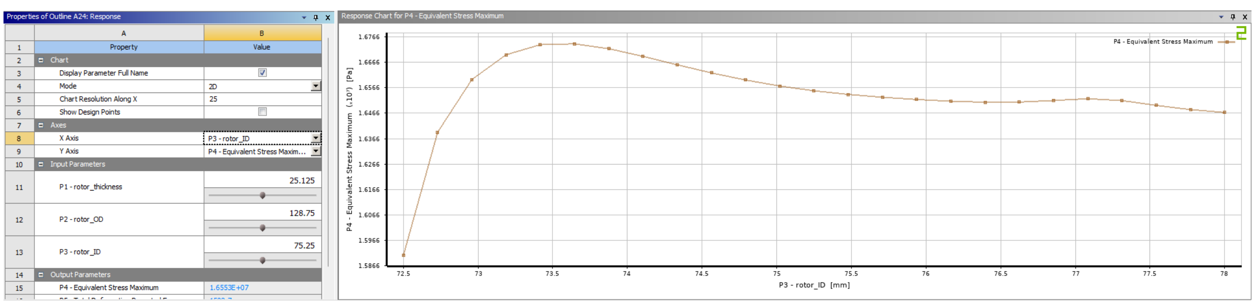


Figure 15: Response curve of max. temperature with change in Disk inner diameter

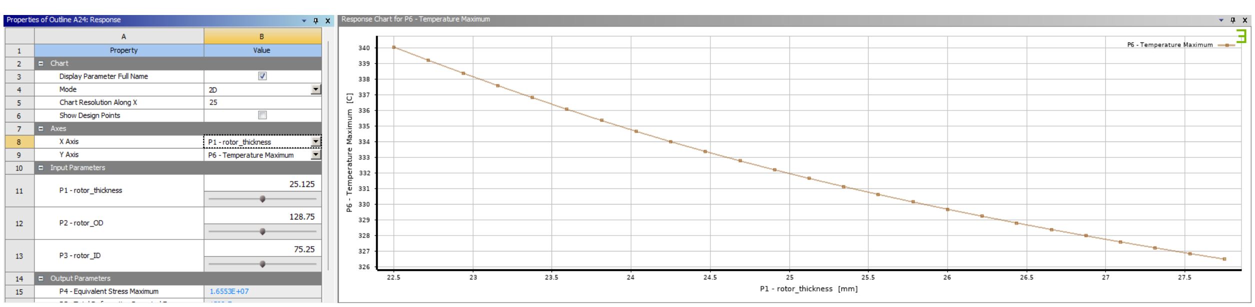


Figure 16:Response curve of max. temperature with change in Disk thickness

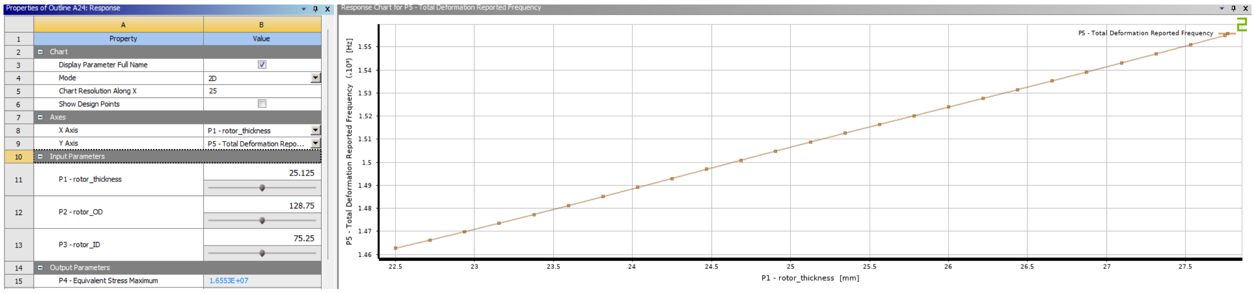


Figure 17:Response curve of Total Deformation with change in Disk outer diameter

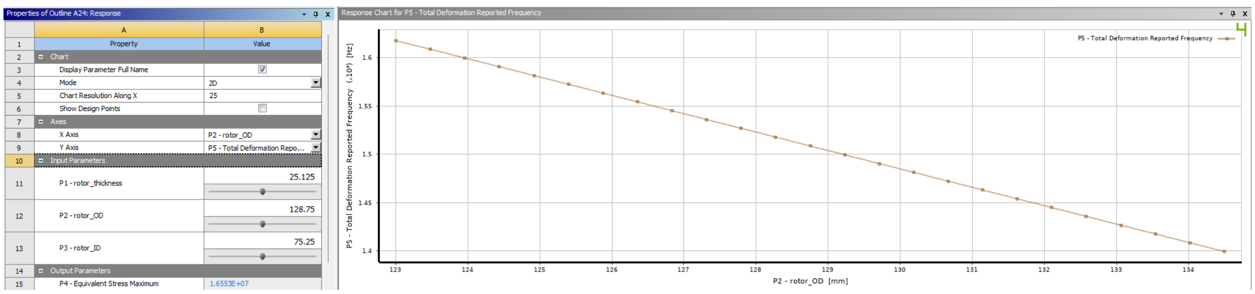


Figure 18: Response curve of Total Deformation with change in Disk outer diameter

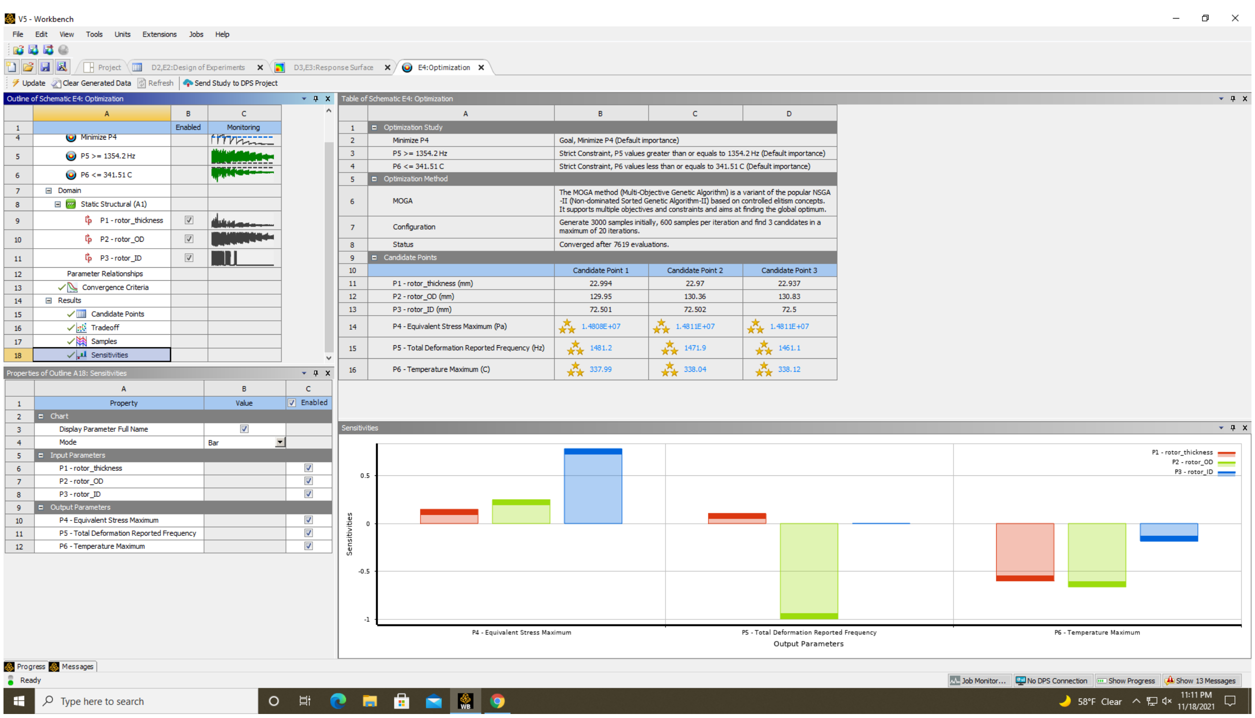


Figure 19: Local sensitivity curve

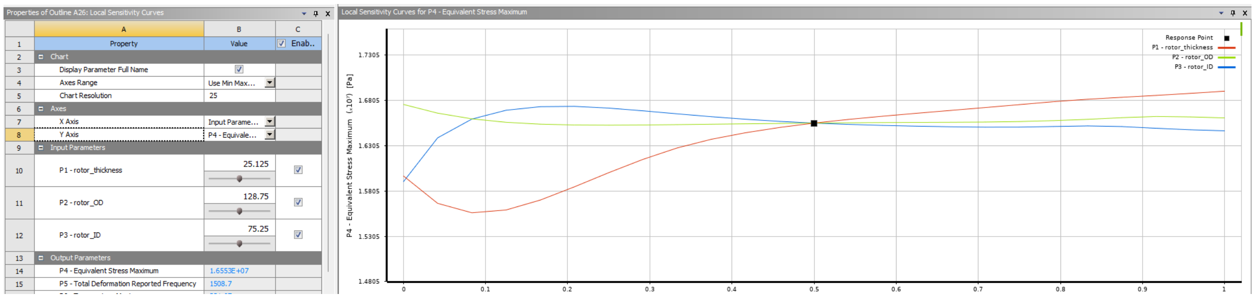


Figure 20: Local sensitivity curve of max. stresses

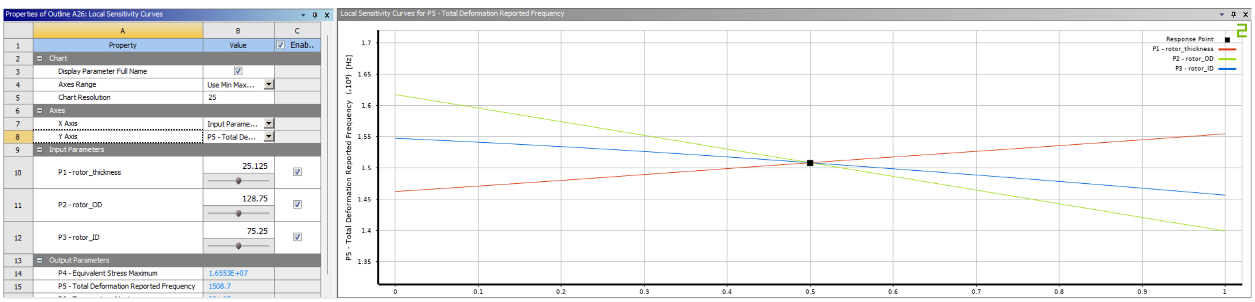


Figure 21: Local sensitivity curve of total deformation

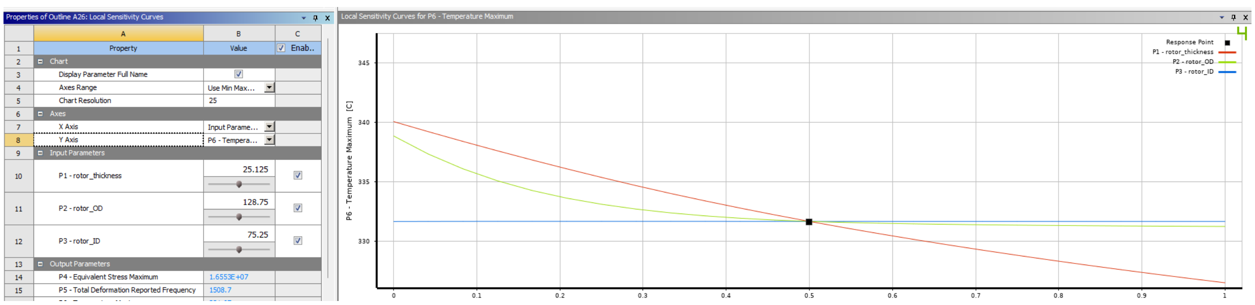


Figure 22: Local Sensitivity curve of max. temperature

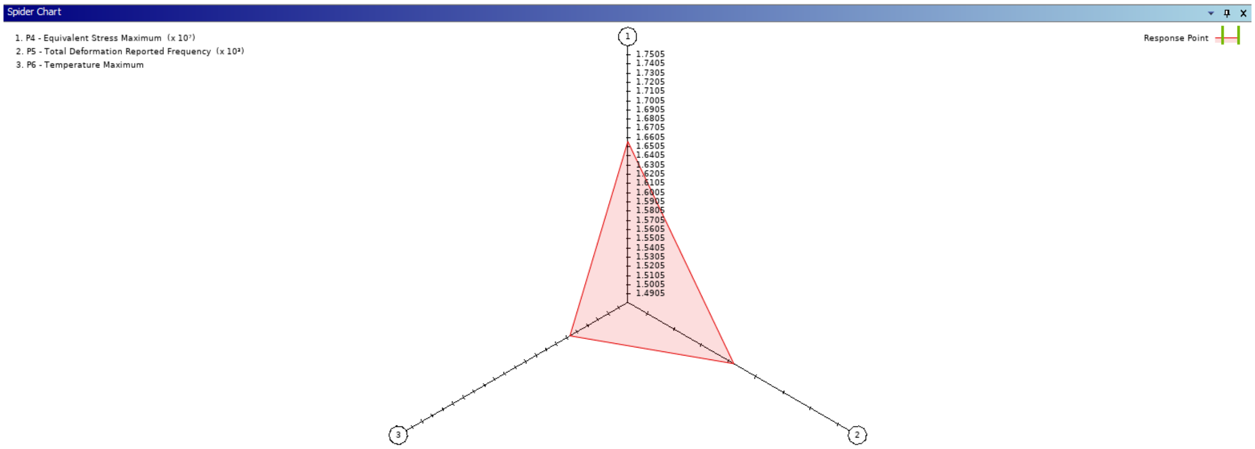


Figure 23: Spider chart

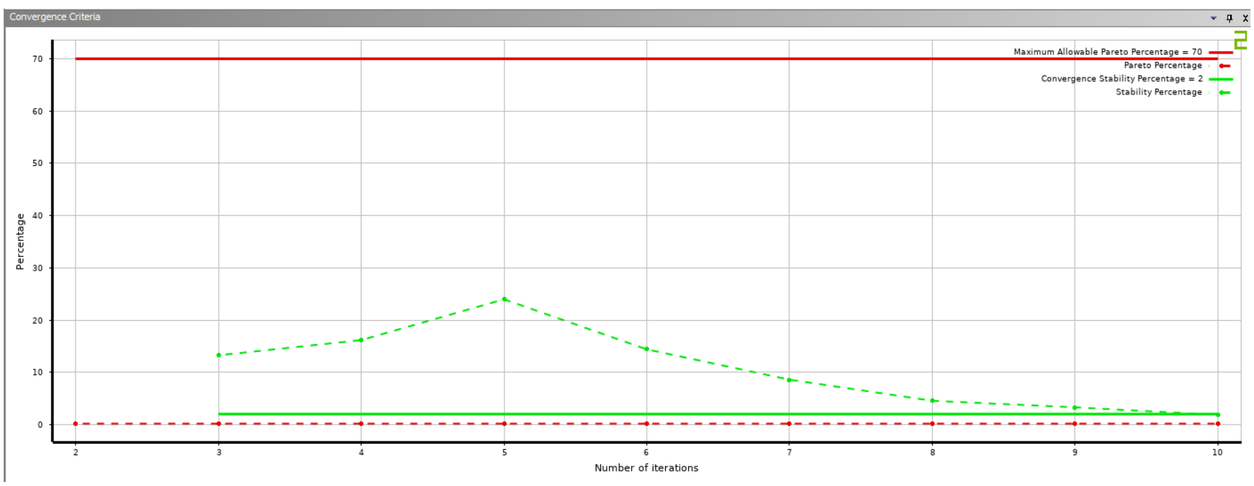


Figure 24: Convergence criteria

Table of Schematic E4: Optimization

	A	B	C	D
1	Optimization Study			
2	Minimize P4	Goal, Minimize P4 (Default importance)		
3	P5 >= 1354.2 Hz	Strict Constraint, P5 values greater than or equals to 1354.2 Hz (Default importance)		
4	P6 <= 341.51 C	Strict Constraint, P6 values less than or equals to 341.51 C (Default importance)		
5	Optimization Method			
6	MOGA	The MOGA method (Multi-Objective Genetic Algorithm) is a variant of the popular NSGA-II (Non-dominated Sorted Genetic Algorithm-II) based on controlled elitism concepts. It supports multiple objectives and constraints and aims at finding the global optimum.		
7	Configuration	Generate 3000 samples initially, 600 samples per iteration and find 3 candidates in a maximum of 20 iterations.		
8	Status	Converged after 7619 evaluations.		
9	Candidate Points			
10		Candidate Point 1	Candidate Point 2	Candidate Point 3
11	P1 - rotor_thickness (mm)	22.994	22.97	22.937
12	P2 - rotor_OD (mm)	129.95	130.36	130.83
13	P3 - rotor_ID (mm)	72.501	72.502	72.5
14	P4 - Equivalent Stress Maximum (Pa)	1.4808E+07	1.4811E+07	1.4811E+07
15	P5 - Total Deformation Reported Frequency (Hz)	1481.2	1471.9	1461.1
16	P6 - Temperature Maximum (C)	337.99	338.04	338.12

Figure 25: Final Optimum design points

Verification

	Disc Thickness (mm)	Outer Diameter(mm)	Inner Diameter (mm)	Von Mises Stress (10^7)Pa	Frequency (Hz)	Temperature (deg C)
Point1	22.994	129.95	72.5	1.4808	1481.2	337.99
Simulation Values				1.5756	1479	338.42
Error(%)				6.0168	-0.1487	0.1271
Point2	22.97	130.36	72.502	1.4811	1471.9	338.04
Simulation Values				1.5494	1470.5	338.65
Error(%)				4.4082	-0.0952	0.1801
point3	22.937	130.83	72.5	1.4811	1461.1	338.12
Simulation Values				1.5651	1459.7	337.78
Error(%)				5.3671	-0.0959	-0.1007

Table1

From figure 19 we can conclude that on increasing the outer and inner diameter there is a rise in the max stress values. The temperature produced is more dependent on the outer diameter and thickness of the brake disk, on increasing both outer diameter and thickness the temperature produced during operation can be reduced. Based on results produced by ANSYS candidate point 1 can be chosen as a final design parameter as the reported frequency is comparatively higher among other candidate points. The results have been verified (table1) by doing simulation for the predicted optimal value dimensions.