MAE:598 Design Optimization

Project 2-Report

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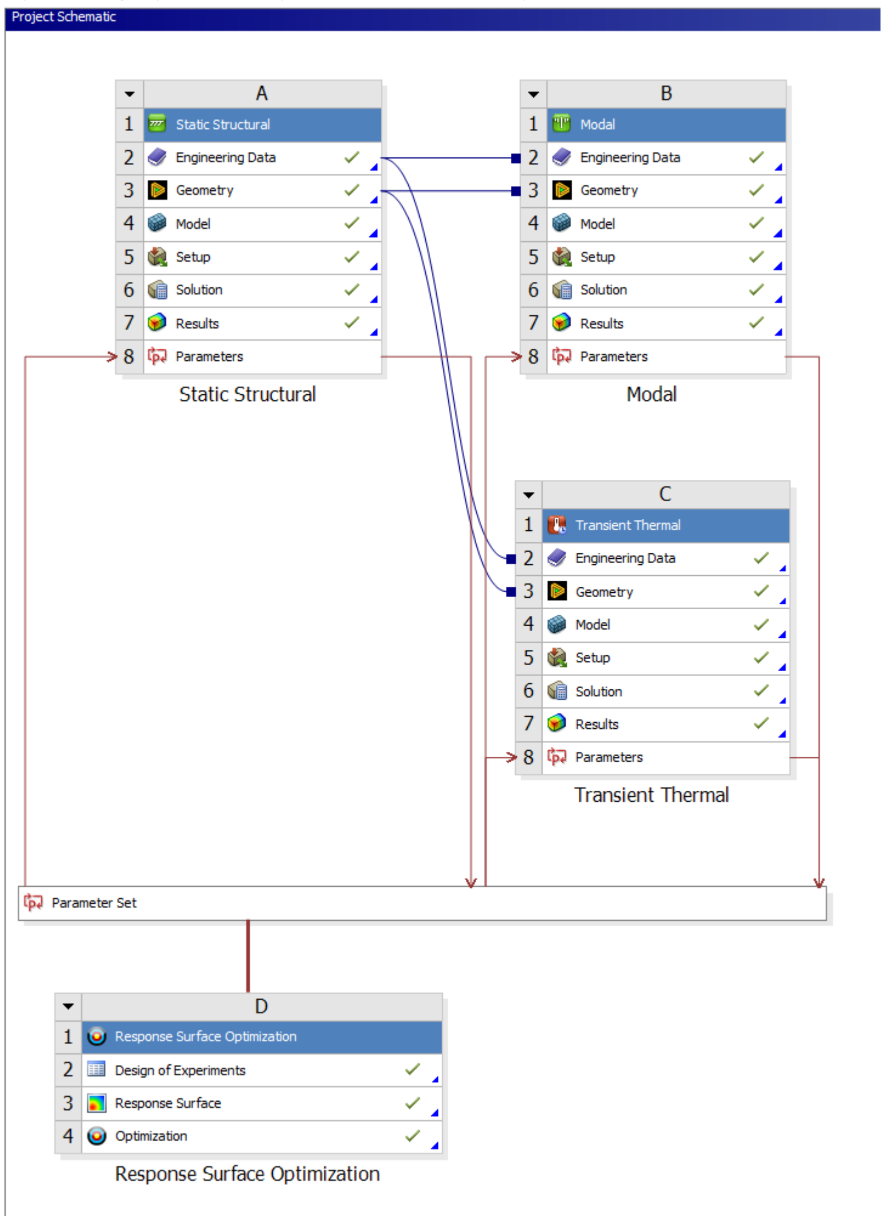
1. Problem Statement

The goal of this project is to design a brake disc model which satisfies certain optimal design properties, which are

a. Design brake disc with minimal volume
b. Minimize maximum stress on the disc
c. Maximize the first natural frequency of the disc
d. Minimize the maximum temperature in the disc

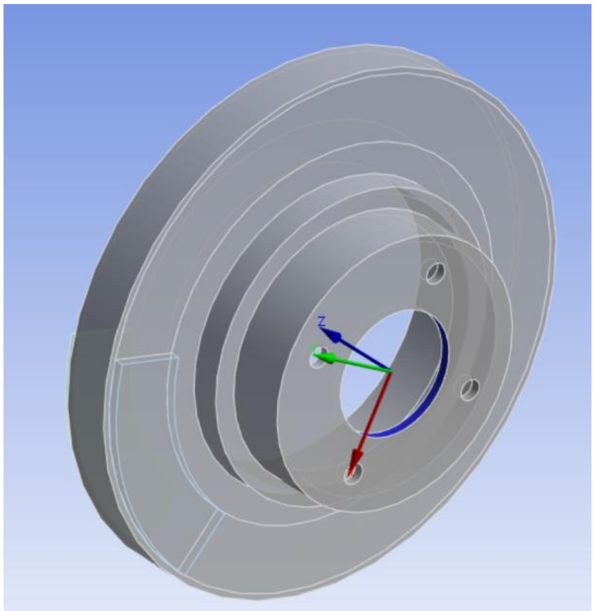
To perform the design optimization on the brake disc for these above parameters, we perform 3 types of analysis on the disc, Structural, Modal and Thermal Analysis

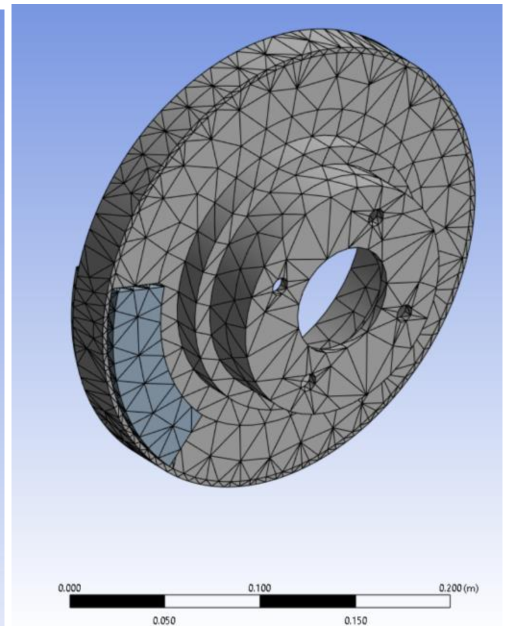
Beginning by setting up the Ansys workbench setup like this



2. Structural Analysis

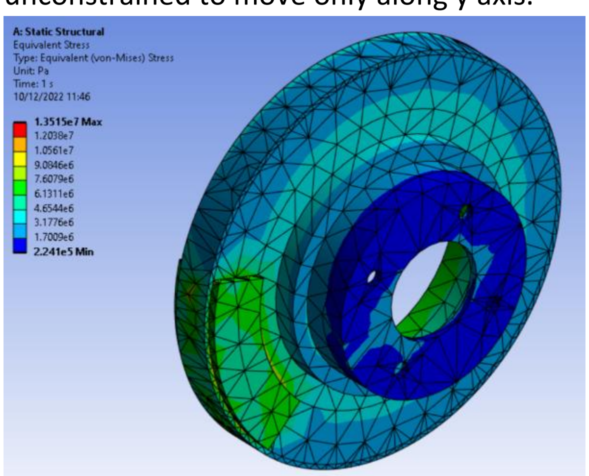
From the material properties, the gray cast iron has been imported and the material of the disc is set as gray cast iron and the brake pads as structural steel. Then the contacts are defined, the contact between the brake pads and the disc is set as frictional joint with co-efficient of friction as 0.22 and the inner part of the disc is set as an revolute joint with respect to ground.

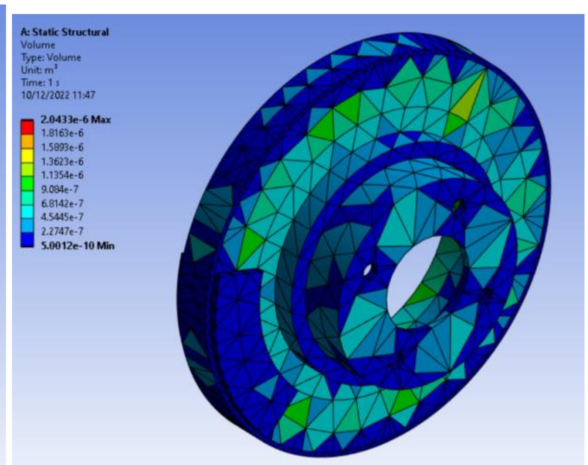




Then mesh sizing is adjusted for the disc and brakes, tetrahedron method is applied for all body parts and the element size of 3mm is applied to the both inner faces of the brake discs.

Then in Static Structural, rotational velocity of 250rad/s is given on y axis and pressure of 10495 kPa is applied to both outer faces of brakes towards the disc and the brake pads are unconstrained to move only along y axis.



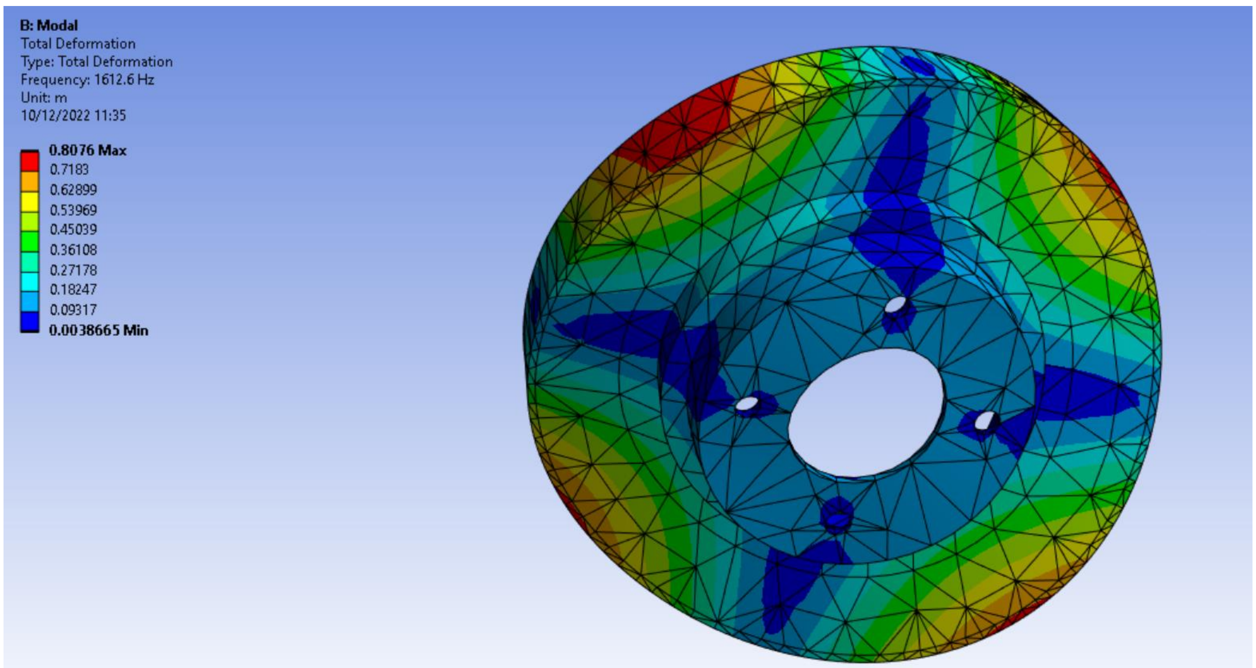


Then Equivalent Von-Mesis stresses and Volume are calculated as solution results and maximum values of stresses and volume are taken as input for design optimization.

3. Modal Analysis

Similarly, the same model geometry is inputted in modal analysis to calculate the natural resonant frequency of the disc brake system so that we can maximize this frequency so that it does not resonate with the vibration frequency of the engine or other parts.

Suppressing the disc, we find 10 modes of the disc and find the maximum natural frequency and use this for design optimization.

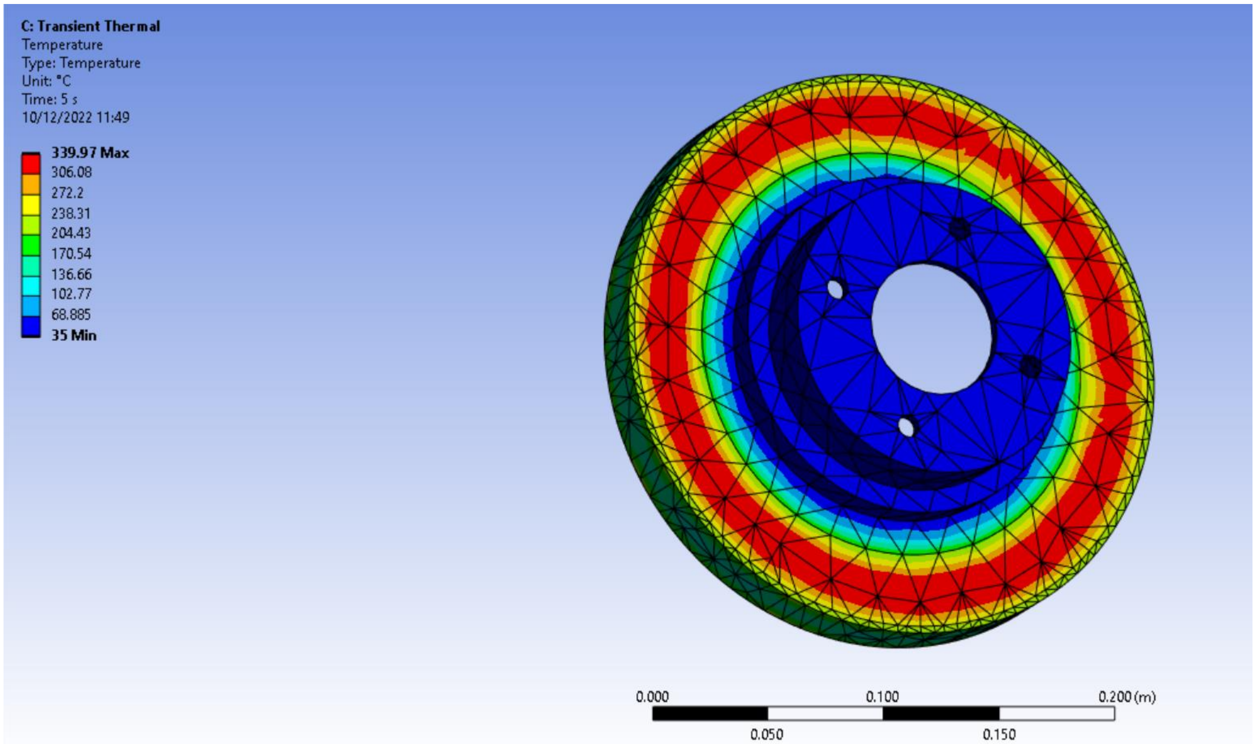


4. Thermal Analysis

To make sure that we minimize the maximum achieved temperature on the brake disc due to friction we perform the thermal analysis.

The heat flux input of 1.5395e6 W/m^2 is given to the both sides of the disc where the brake pads contact with the disc and heat loss through convection from the faces of the brake disc is set as 5 W/m^2 is set to find out the maximum achieved temperature of brake disc

The initial temperature of all the components and the ambient temperature is both set as 35 degrees Celsius. The Maximum temperature of the disc is used as the input for design optimization.



Once we are done with the setup of the system and figuring out decision parameters, we perform design optimization using the following methods.

5. Design of Experiments

Using the design variables from above we perform response surface optimization. Latin hypercube sampling is selected as the type of Design of Experiments and then 25 sample points are set to find out the optimal design parameters. Upper and lower bounds are set for the inner dia, outer dia and the thickness of the disc as follows.

Table of Schematic D4: Optimization

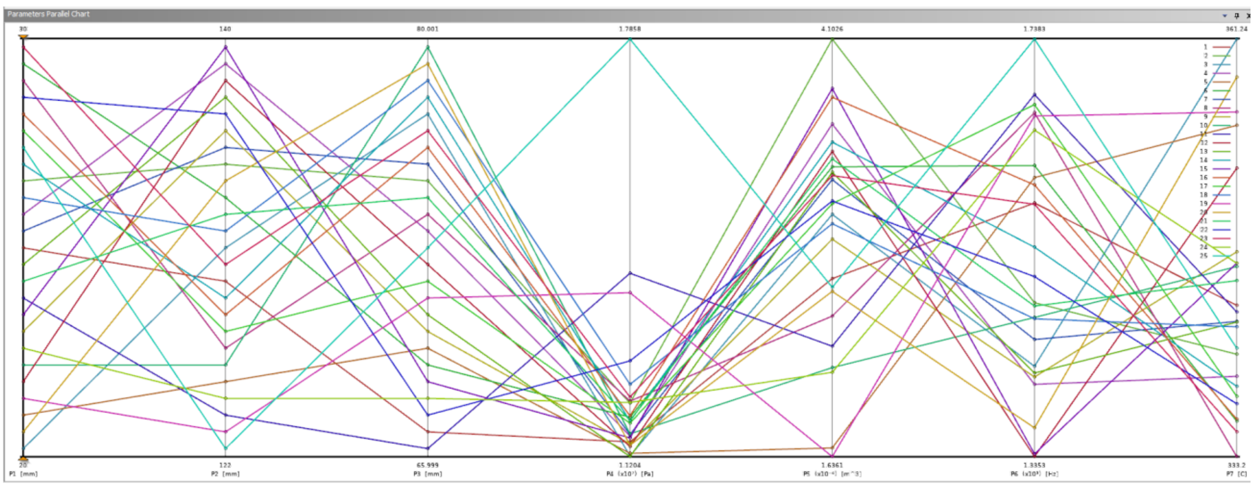
	A	B	C	D
1	Input Parameters			
2	Name	Lower Bound	Upper Bound	
3	P1 - rotor_thickness (mm)	20	30	
4	P2 - rotor_OD (mm)	122	140	
5	P3 - rotor_ID (mm)	66	80	
6	Parameter Relationships			
7	Name	Left Expression	Operator	Right Expression
*	New Parameter Relationship	New Expression	<=	New Expression

Bounds of rotor parameters

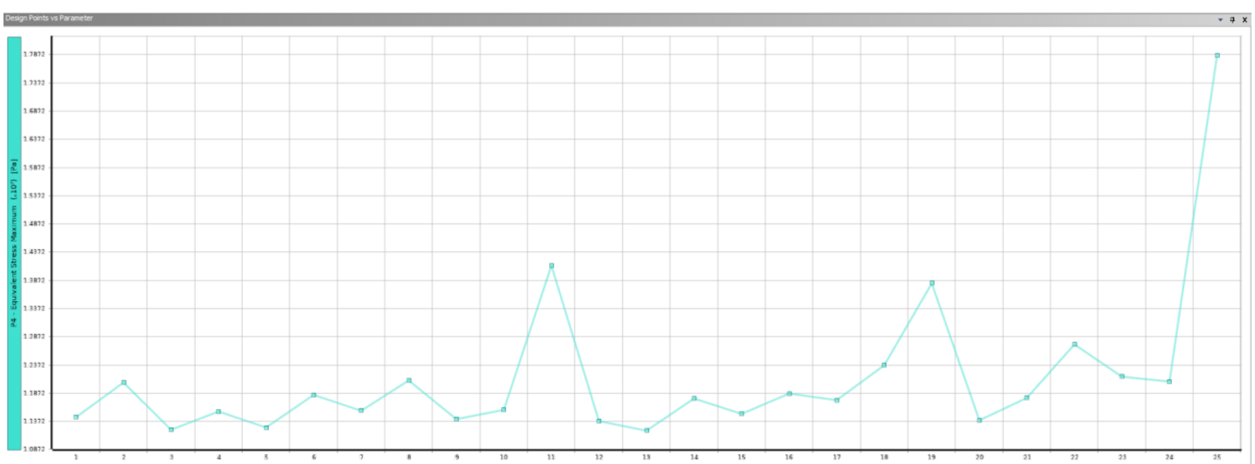
Table of Schematic D2: Design of Experiments (Latin Hypercube Sampling Design : User-Defined Samples : Random Generator Seed = 0 : Number of Samples = 25)

	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)	P5 - Volume Maximum (m^3)	P6 - Total Deformation Reported Frequency (Hz)	P7 - Temperature Maximum (C)
2	1	25	129.56	66.84	1.1442E+07	2.6882E-06	1580.2	343.36
3	2	26.6	134.6	75.24	1.2058E+07	4.1026E-06	1483.8	340.1
4	3	20.2	131	77.48	1.1221E+07	3.0665E-06	1422.6	361.24
5	4	25.8	138.92	73.56	1.1544E+07	3.5988E-06	1405.2	338.6
6	5	21	125.24	69.64	1.1261E+07	1.6908E-06	1604.8	355.41
7	6	29.4	133.16	69.08	1.1839E+07	3.3475E-06	1616.4	335.6
8	7	25.4	135.32	75.8	1.1558E+07	3.2727E-06	1448.3	342.29
9	8	29	126.68	74.12	1.2096E+07	2.4666E-06	1667.2	333.2
10	9	23	136.04	70.2	1.1409E+07	2.919E-06	1412.2	346.96
11	10	22.2	125.96	79.72	1.1573E+07	2.161E-06	1469.5	345.97
12	11	23.8	123.8	66.28	1.4131E+07	2.2893E-06	1684.3	342.93
13	12	21.8	138.2	72.44	1.1374E+07	3.4361E-06	1335.3	352.56
14	13	24.6	137.48	70.76	1.1204E+07	3.3159E-06	1416.4	342.24
15	14	27	128.84	78.04	1.1775E+07	3.4917E-06	1537.8	337.94
16	15	23.4	139.64	68.52	1.1503E+07	3.8097E-06	1338.5	346.18
17	16	28.2	128.12	76.36	1.1862E+07	3.7589E-06	1597.1	335.73
18	17	27.8	127.4	71.88	1.1746E+07	3.1314E-06	1675	337.28
19	18	26.2	131.72	78.6	1.2364E+07	3.0122E-06	1468.6	341.93
20	19	21.4	123.08	71.32	1.3816E+07	1.6361E-06	1663.8	356.31
21	20	20.6	133.88	79.16	1.1388E+07	2.6144E-06	1363.3	358.68
22	21	24.2	132.44	74.68	1.1786E+07	3.3948E-06	1480.7	345.01
23	22	28.6	136.76	67.4	1.2733E+07	3.1445E-06	1508.8	336.76
24	23	29.8	130.28	76.92	1.2162E+07	3.2955E-06	1578.7	334.87
25	24	22.6	124.52	67.96	1.2075E+07	2.1371E-06	1650.1	346.18
26	25	27.4	122.36	73	1.7858E+07	2.6369E-06	1738.3	340.51

Latin Hypercude Sampling values for all 25 sampling points parameter variables



Parameters Parallel



Design points vs parameters

6. Response Surface

Using the results from DOE, we perform the response surface analysis using Standard Response Surface- Full 2nd order Polynomials method.

Table of Outline A16: Min-Max Search

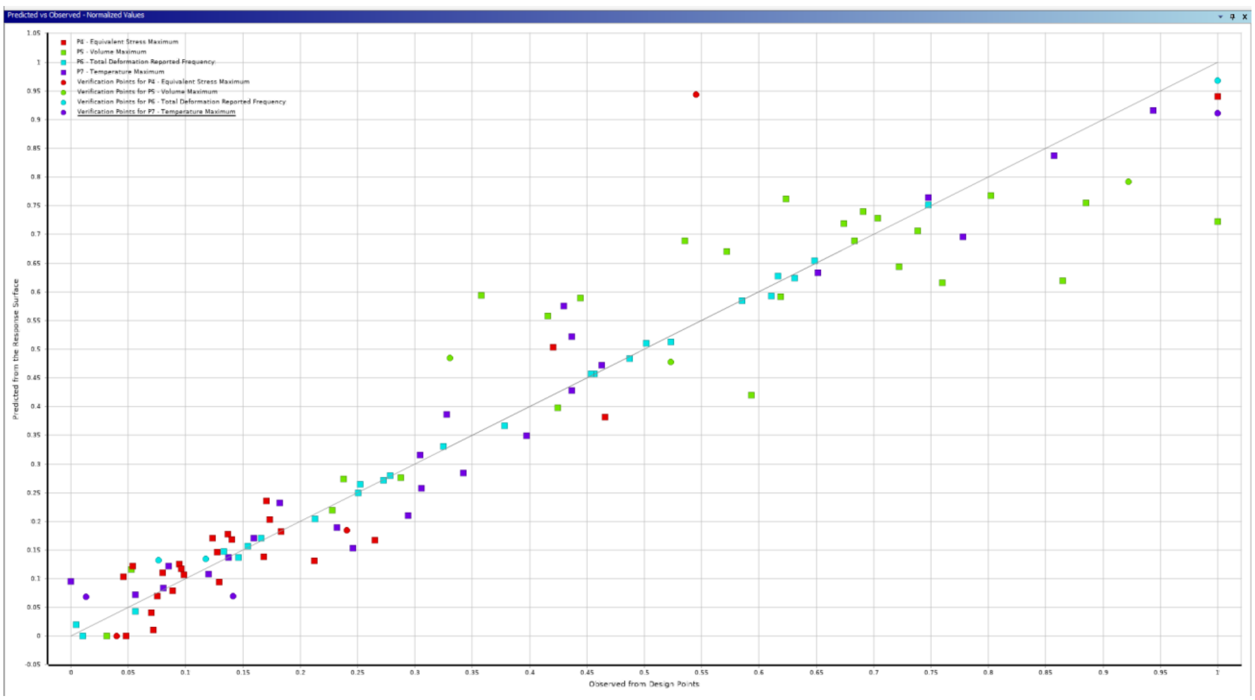
	A	B	C	D	E	F	G	H
1	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P5 - Volume Maximum (m^3)	P6 - Total Deformation Reported Frequency (Hz)	P7 - Temperature Maximum (C)
2	Output Parameter Minimums							
3	P4 - Equivalent Stress Maximum	20	131	67.626	**1.0848E+07**	2.5942E-06	1452.5	361.65
4	P5 - Volume Maximum	20	122	66.07	1.7481E+07	**9.1365E-07**	1672.6	361.65
5	P6 - Total Deformation Reported Frequency	20	140	66	1.0854E+07	3.3703E-06	**1211.3**	361.65
6	P7 - Temperature Maximum	30	136.01	67.165	1.2179E+07	3.4978E-06	1559	**335.18**
7	Output Parameter Maximums							
8	P4 - Equivalent Stress Maximum	30	122	71.601	**1.923E+07**	2.7414E-06	1818.7	335.18
9	P5 - Volume Maximum	30	140	77.535	1.2181E+07	**3.5763E-06**	1442.5	335.18
10	P6 - Total Deformation Reported Frequency	30	122	66	1.923E+07	2.7414E-06	**1870.7**	335.18
11	P7 - Temperature Maximum	20	122.09	66.07	1.7102E+07	9.3247E-07	1670.1	**361.65**

Min-Max Search

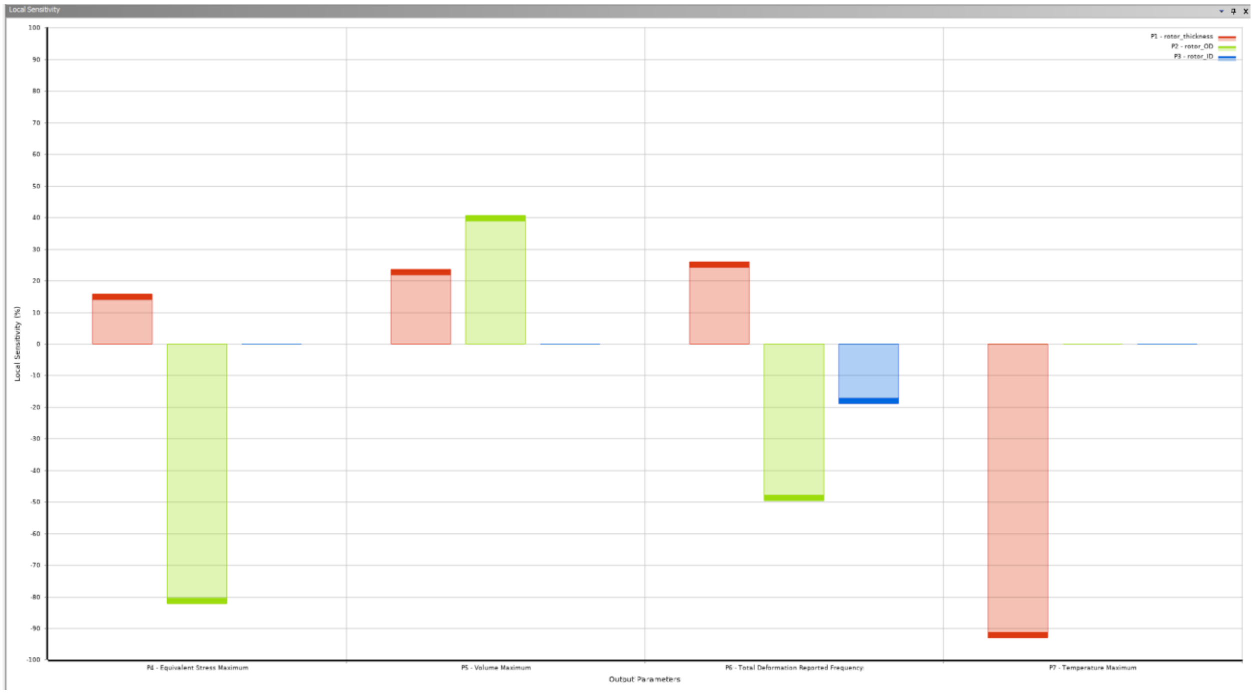
Table of Outline A21: Verification Points

	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)	P5 - Volume Maximum (m^3)	P6 - Total Deformation Reported Frequency (Hz)	P7 - Temperature Maximum (C)
2	1	29.925	139.9	79.935	1.2565E+07	3.9047E-06	1396.6	333.6
3	2	29.898	122.44	66.27	1.4686E+07	2.8889E-06	1875	337.41
4	3	20.221	132.41	66.349	1.1162E+07	2.3975E-06	1374.5	362.91
*	New Verification Point							

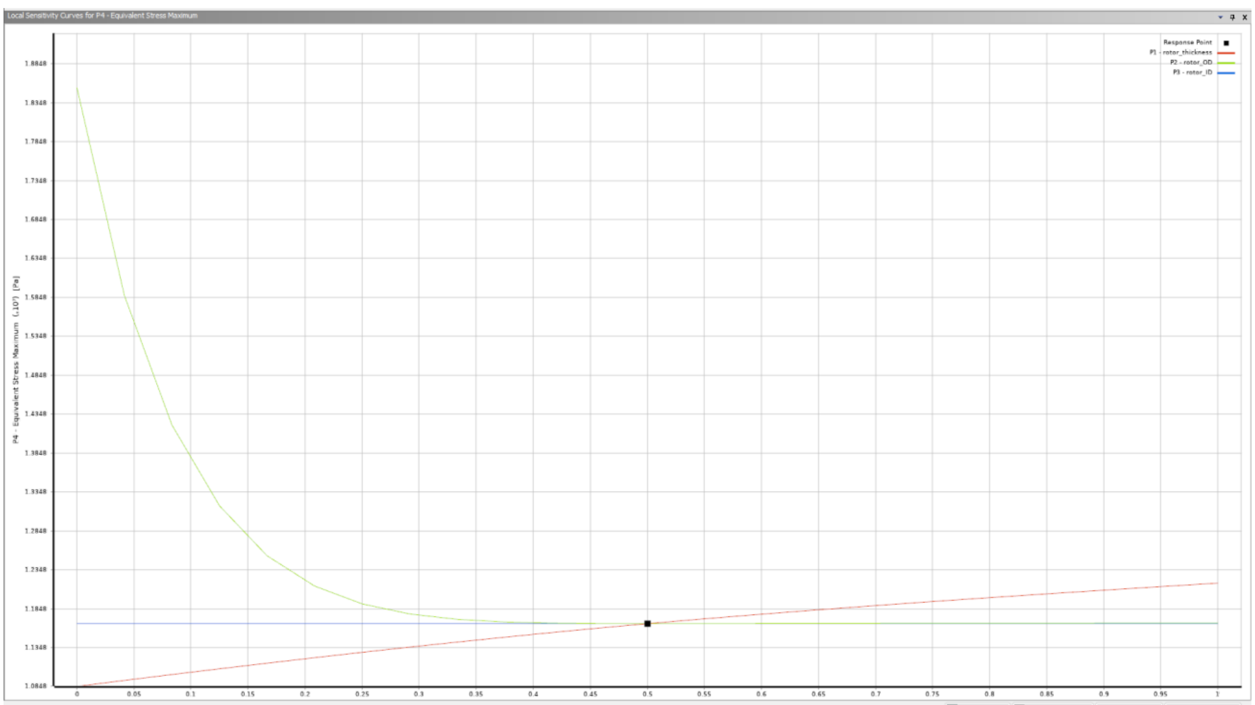
Verification Points



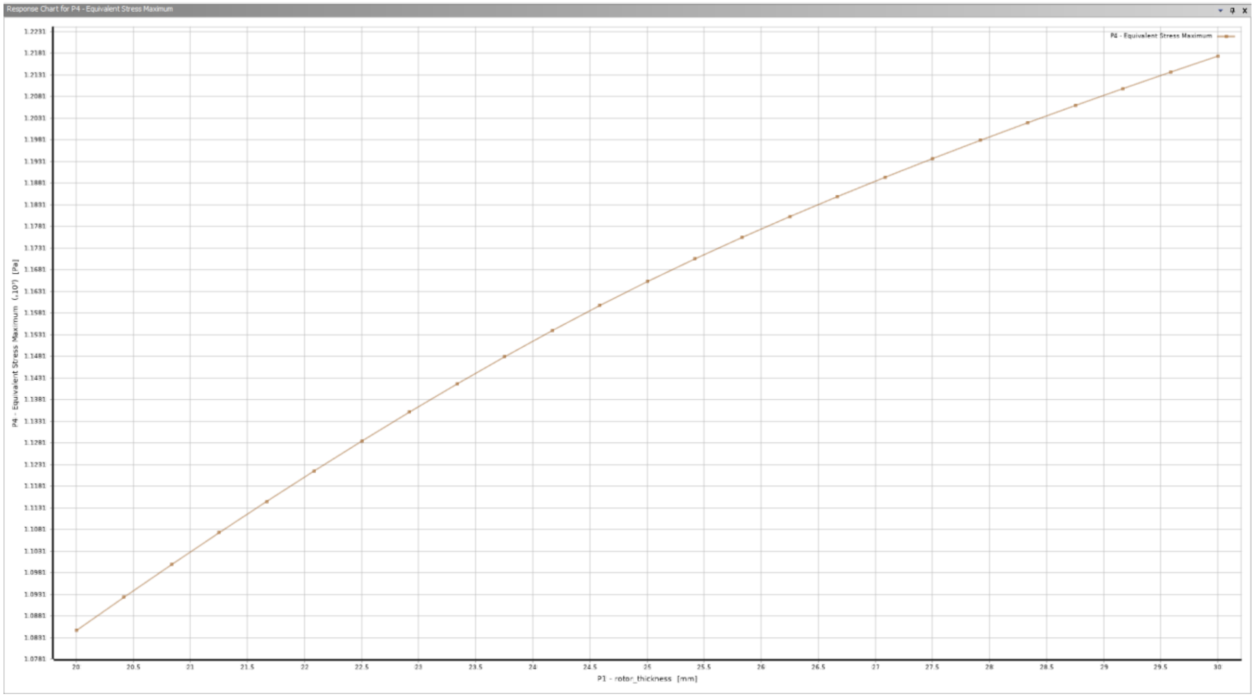
Response surface vs Design points



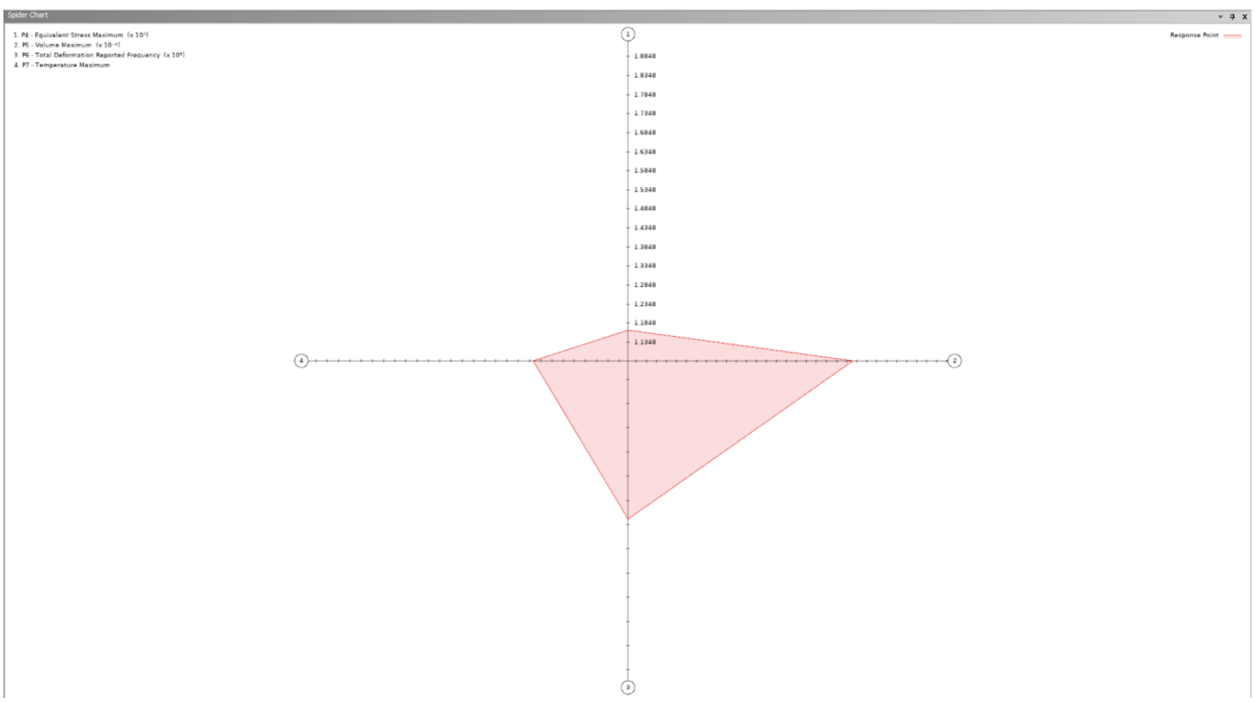
Local Sensitivity



Local Sensitivity curve



Response curves



Spider

7. Optimization

Using the results from Design of Experiments and Response surface we perform the optimization using Manual method and Multi Objective Genetic Algorithm(MOGA). Setting the Stresses, maximum temperature and Volume to minimize and the natural frequency to maximize, we get the optimization results for the different parameters.

Table of Schematic D4: Optimization , Candidate Points

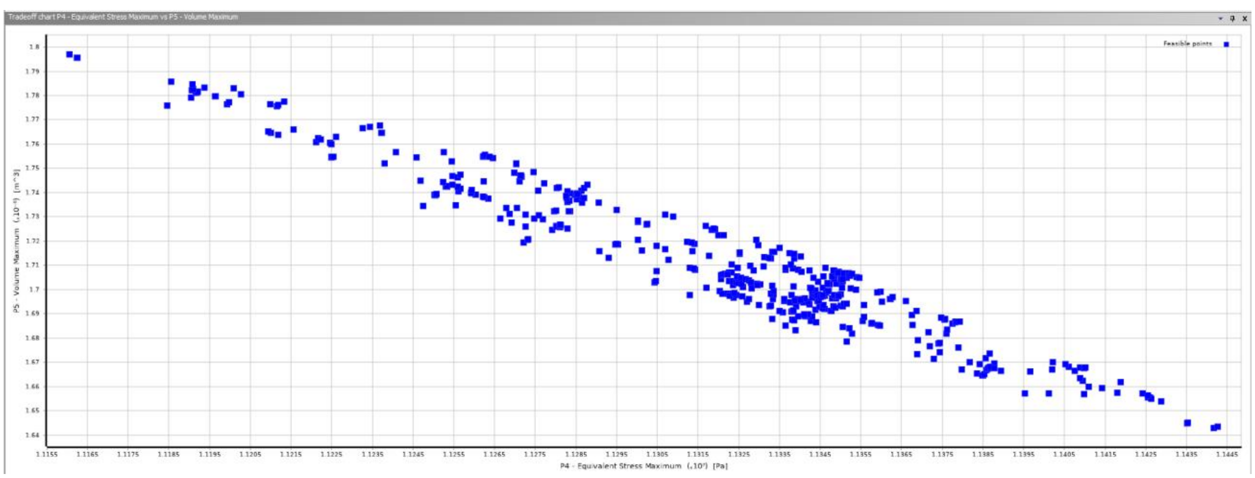
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Reference	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)		P5 - Volume Maximum (m^3)		P6 - Total Deformation Reported Frequency (Hz)		P7 - Temperature Maximum (C)	
2						Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
3	◉	Candidate Point 1	20.03	125.46	68.494	1.1442E+07	0.00%	1.6428E-06	0.00%	1595.9	0.00%	361.46	0.00%
4	○	Candidate Point 1 (verified)				1.1493E+07	0.45%	1.9325E-06	17.63%	1574.6	-1.34%	360.83	-0.17%
5	○	Candidate Point 2	20.027	125.47	70.962	1.1435E+07	-0.06%	1.6447E-06	0.11%	1594.6	-0.08%	361.48	0.00%
6	○	Candidate Point 2 (verified)				1.1861E+07	3.66%	1.8592E-06	13.18%	1570.8	-1.57%	361.25	-0.06%
7	○	Candidate Point 3	20.012	125.55	67.287	1.1395E+07	-0.41%	1.6572E-06	0.88%	1587	-0.56%	361.57	0.03%
8	○	Candidate Point 3 (verified)				1.1566E+07	1.08%	2.007E-06	22.17%	1557.1	-2.43%	358.32	-0.87%
*		New Custom Candidate Point	25	131	73								

Candidate points

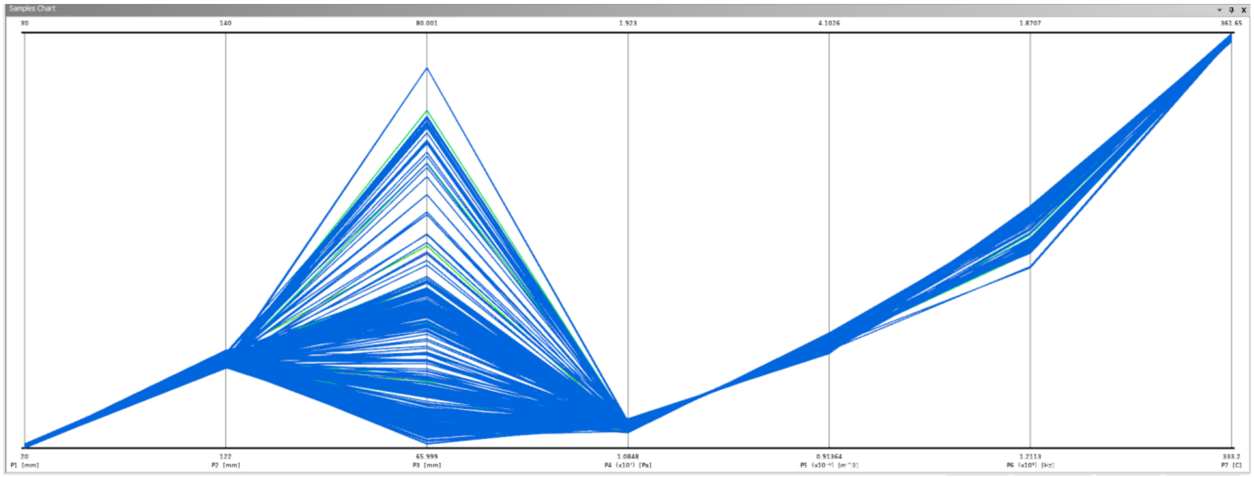
Table of Schematic D4: Optimization

	A	B	C	D	E	F	G
1	Optimization Study						
2	Minimize P4	Goal, Minimize P4 (Default importance)					
3	Minimize P5	Goal, Minimize P5 (Default importance)					
4	Maximize P6	Goal, Maximize P6 (Default importance)					
5	Minimize P7	Goal, Minimize P7 (Default importance)					
6	Optimization Method						
7	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.					
8	Configuration	Generate 3000 samples initially, 600 samples per iteration and find 3 candidates in a maximum of 20 iterations.					
9	Status	Converged after 6609 evaluations.					
10	Candidate Points						
11		Candidate Point 1	Candidate Point 1 (verified)	Candidate Point 2	Candidate Point 2 (verified)	Candidate Point 3	Candidate Point 3 (verified)
12	P1 - rotor_thickness (mm)	20.03		20.027		20.012	
13	P2 - rotor_OD (mm)	125.46		125.47		125.55	
14	P3 - rotor_ID (mm)	68.494		70.962		67.287	
15	P4 - Equivalent Stress Maximum (Pa)	1.1442E+07	1.1493E+07	1.1435E+07	1.1861E+07	1.1395E+07	1.1566E+07
16	P5 - Volume Maximum (m^3)	1.6428E-06	1.9325E-06	1.6447E-06	1.8592E-06	1.6572E-06	2.007E-06
17	P6 - Total Deformation Reported Frequency (Hz)	1595.9	1574.6	1594.6	1570.8	1587	1557.1
18	P7 - Temperature Maximum (C)	361.46	360.83	361.48	361.25	361.57	358.32

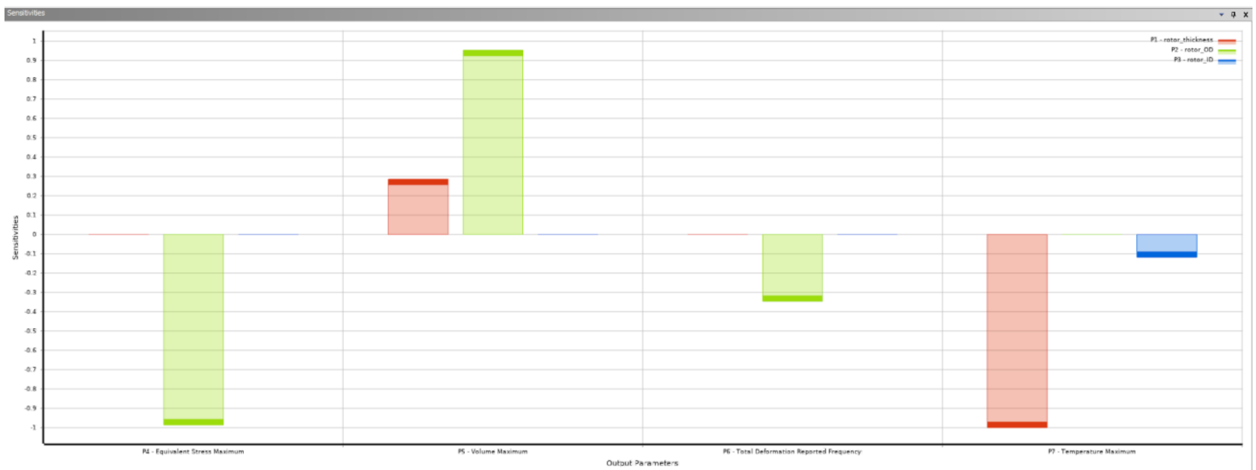
Optimization output



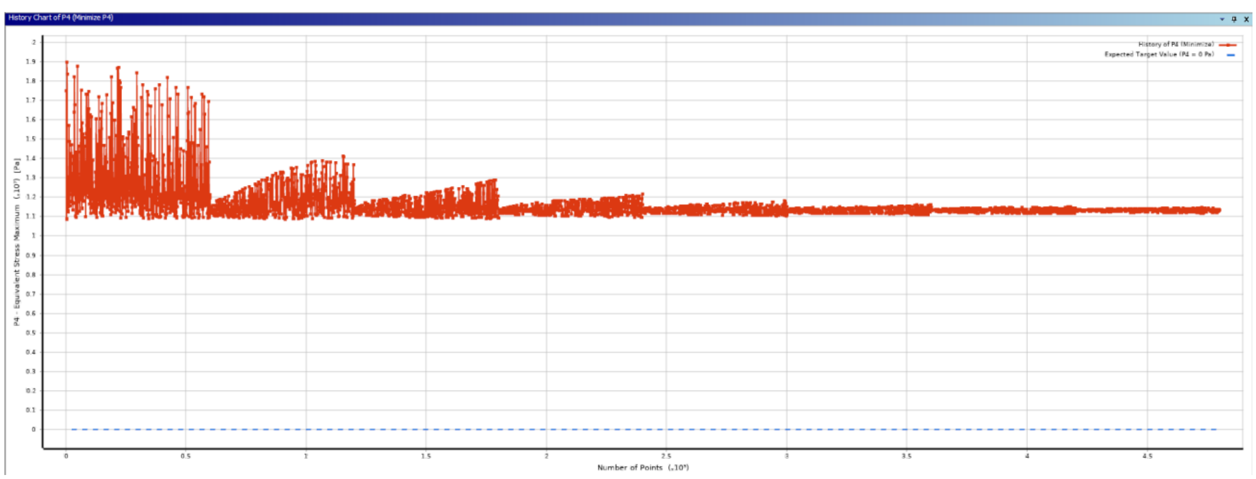
Trade Off



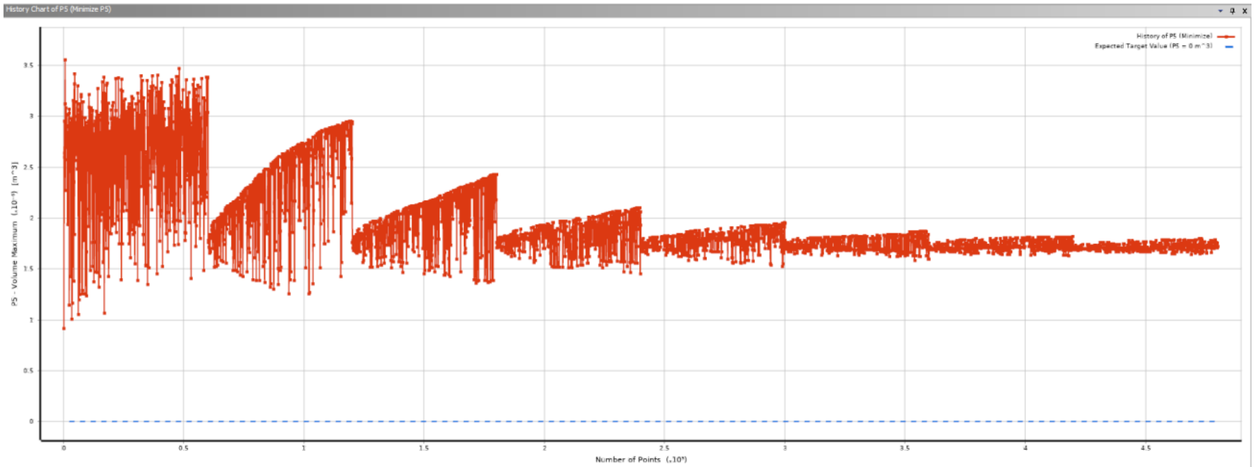
Samples Chart



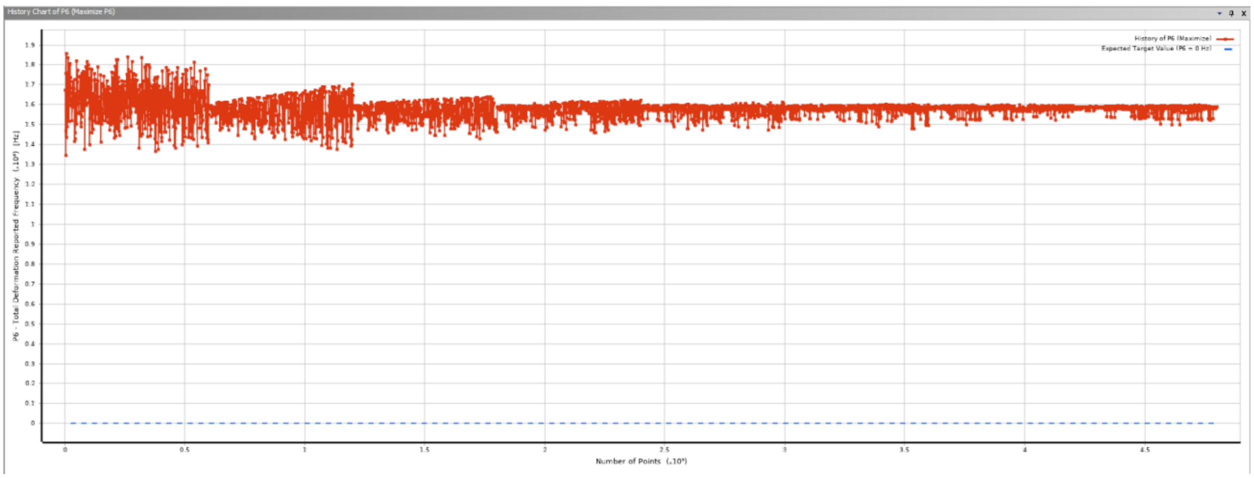
Sensitiveness



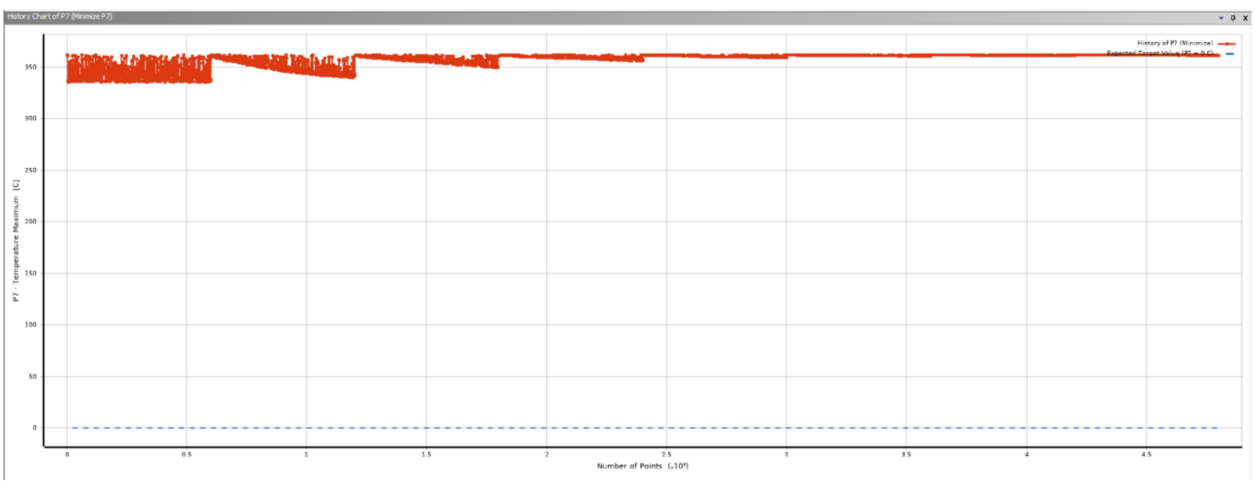
Equivalent Stresses



Volume Maximum



Total Deformation Frequency



Temperature Maximum

All the candidate points are verified with design points after optimization to verify the performance of the Optimization efforts.