PROJECT REPORT

DESIGN OPTIMIZATION OF BRAKE DISC GEOMETRY

BY

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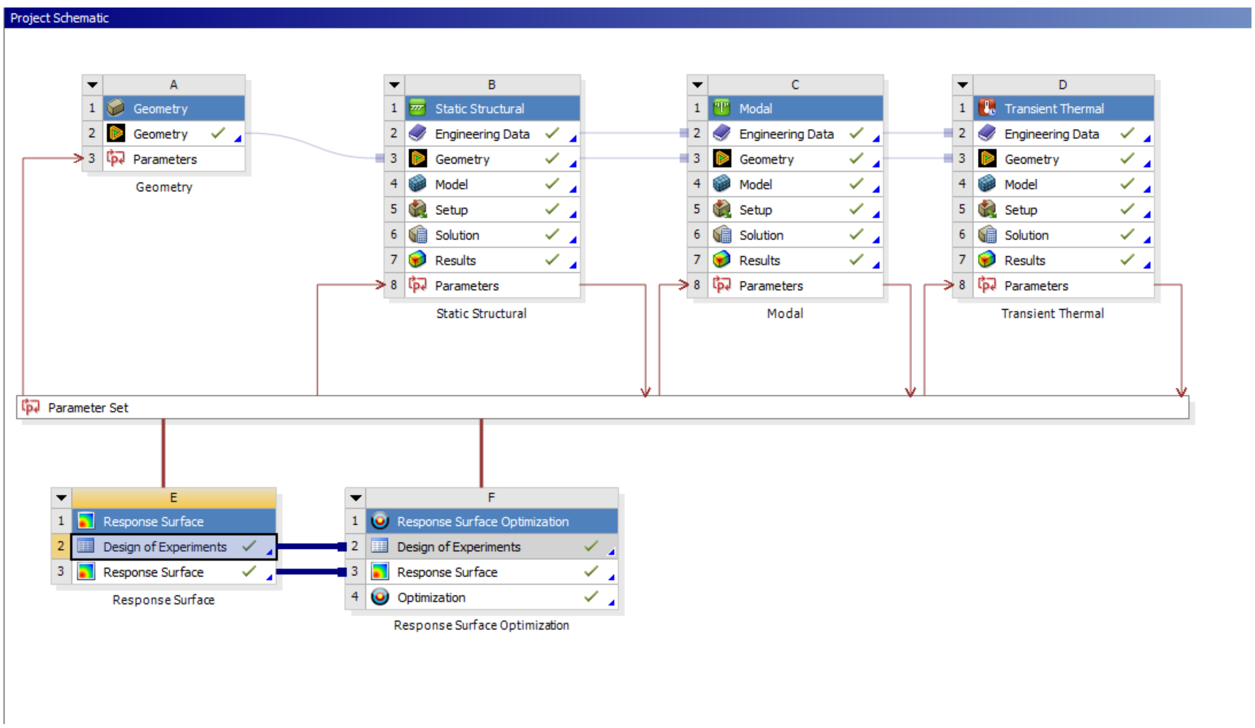
❖ DESIGN STATEMENT:

- PRIMARY OBJECTIVE STATEMENT:

  To minimize the brake disc volume for emergency braking conditions.

- SECONDARY OBJECTIVE STATEMENTS:

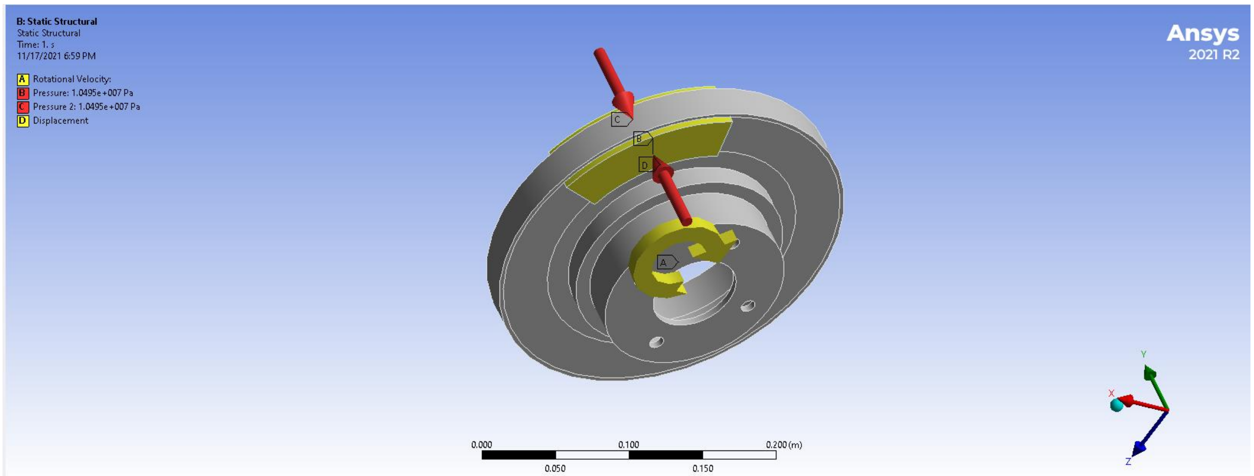
  1. Minimize the maximum stress in the brake disc.
  2. Maximize the first natural frequency of the brake disc.
  3. Minimize the maximum temperature in the brake disc.



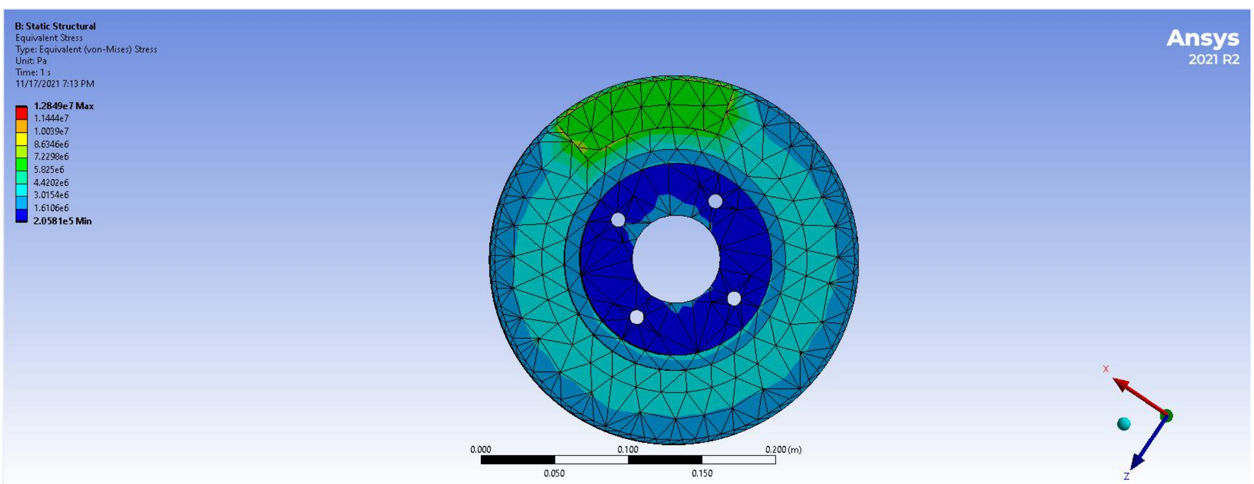
Ansys Flowchart

❖ STRUCTURAL ANALYSIS:

The brake disc has to sustain the pressure from the hydraulically actuated brake pads during sudden braking conditions. Stresses are induced due to friction between the brake pads and the disc. The disc also experiences centrifugal body forces due to its rotation. Resultant stresses generated due these forces can lead to material failure. Therefore, it is of prime importance to make sure that the stresses in the disc are minimized.



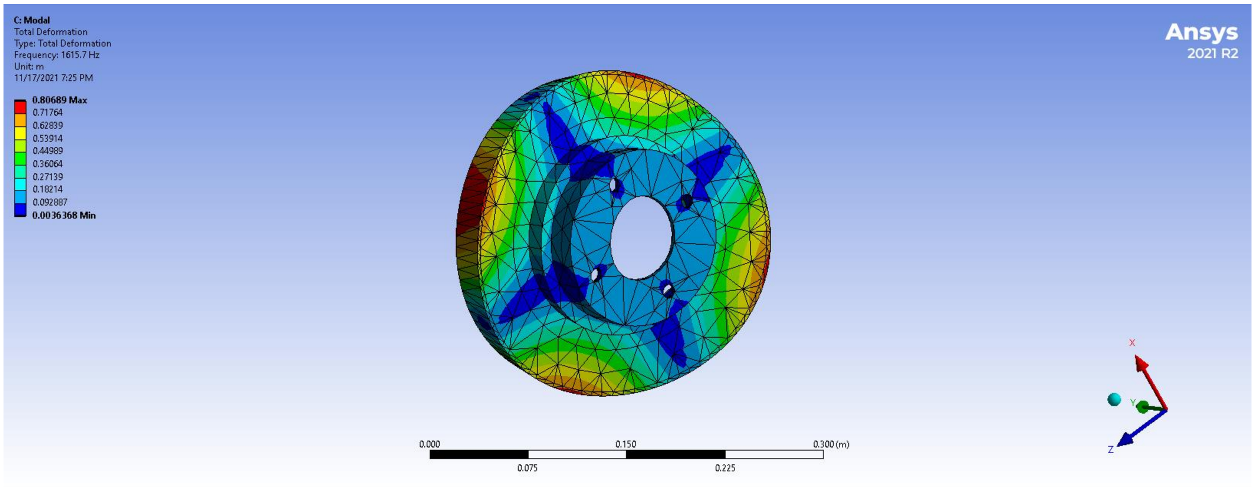
Static Structural boundary conditions



Static Structural stress plot

❖ MODAL ANALYSIS:

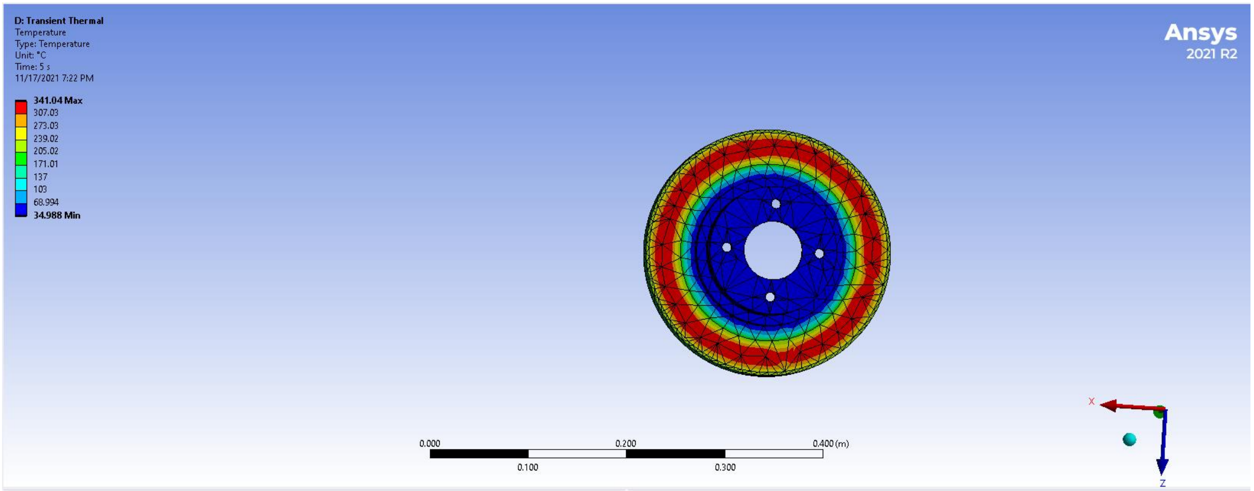
Free modal analysis is performed to ensure that the disc's first natural frequency is higher than the engine firing frequency. This guarantees that the disc does not experience failure due to resonance.



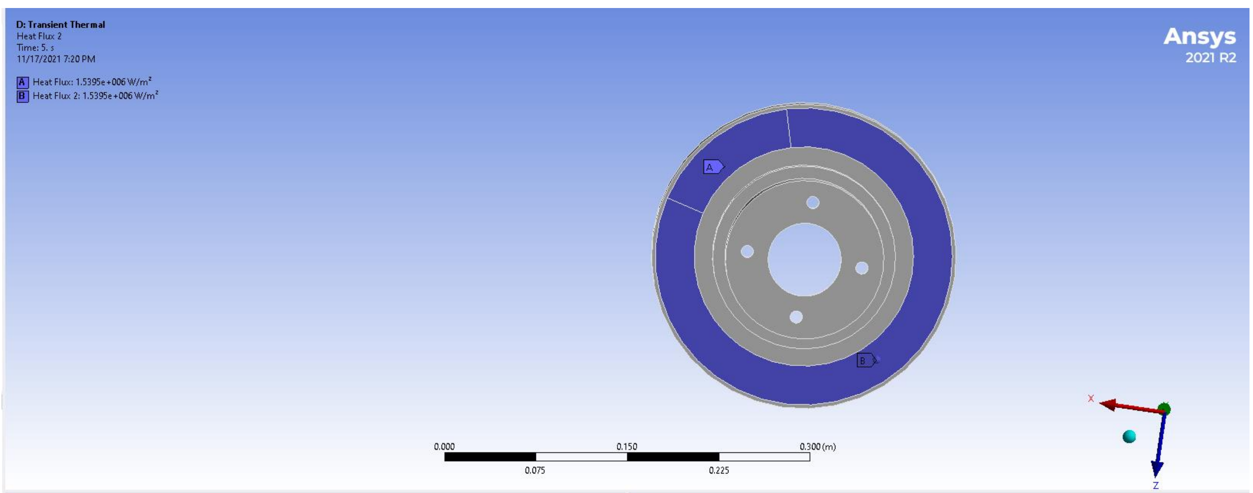
Total Deformation of the brake disc

❖ THERMAL ANALYSIS:

Braking in a vehicle takes place due to friction between the brake pads and the rotor disc. This leads to heat flux generation in the disc which consequently results in increase in its temperature and thermal stresses. Emergency braking conditions induce high temperatures that damage the contact surfaces. It is therefore essential to minimize the temperature to prevent disc wear and tear.



Transient Thermal Analysis temperature plot



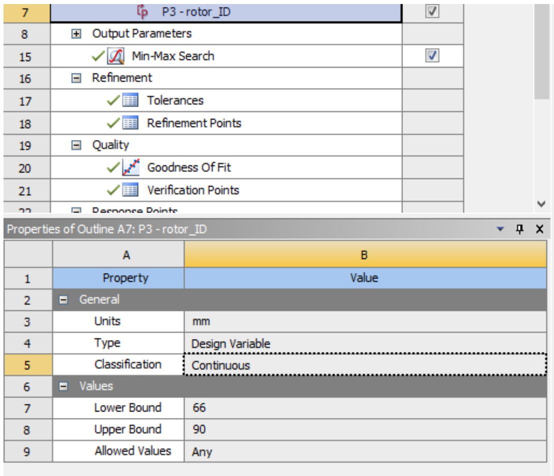
Transient Thermal Analysis Heat-flux plot

❖ DESIGN CONSTRAINTS:

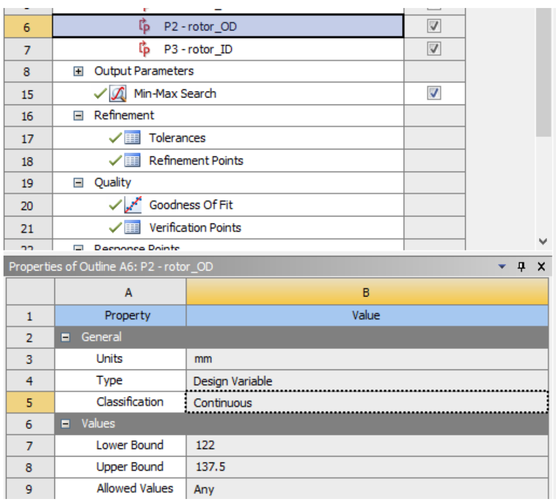
- : S ≤ 23.599 M Pa
- F ≥ 1259.6 Hz
- T ≤ 348.27° C

❖ ROTOR DIMENSIONS:

- Rotor Inner Diameter



- Rotor Outer Diameter



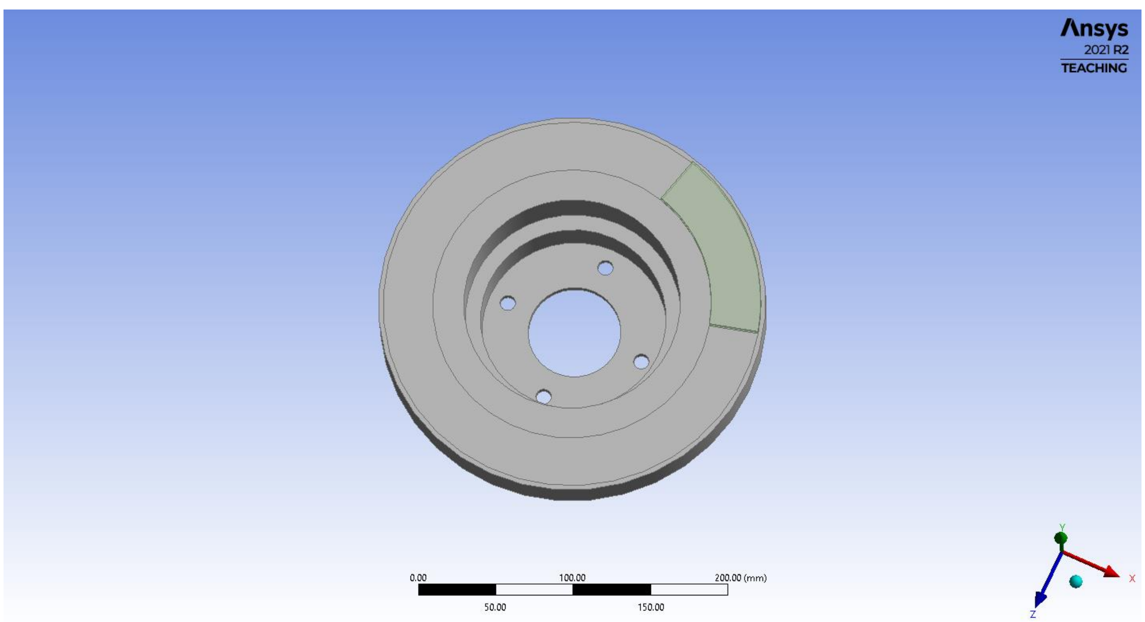
- Rotor Thickness

5	P1 - rotor_thickness	☑
6	P2 - rotor_OD	☑
7	P3 - rotor_ID	☑
8	⊞ Output Parameters	
15	Min-Max Search	☑
16	⊟ Refinement	
17	Tolerances	
18	Refinement Points	
19	⊟ Quality	
20	Goodness Of Fit	
21	Verification Points	
22	⊟ Response Points	

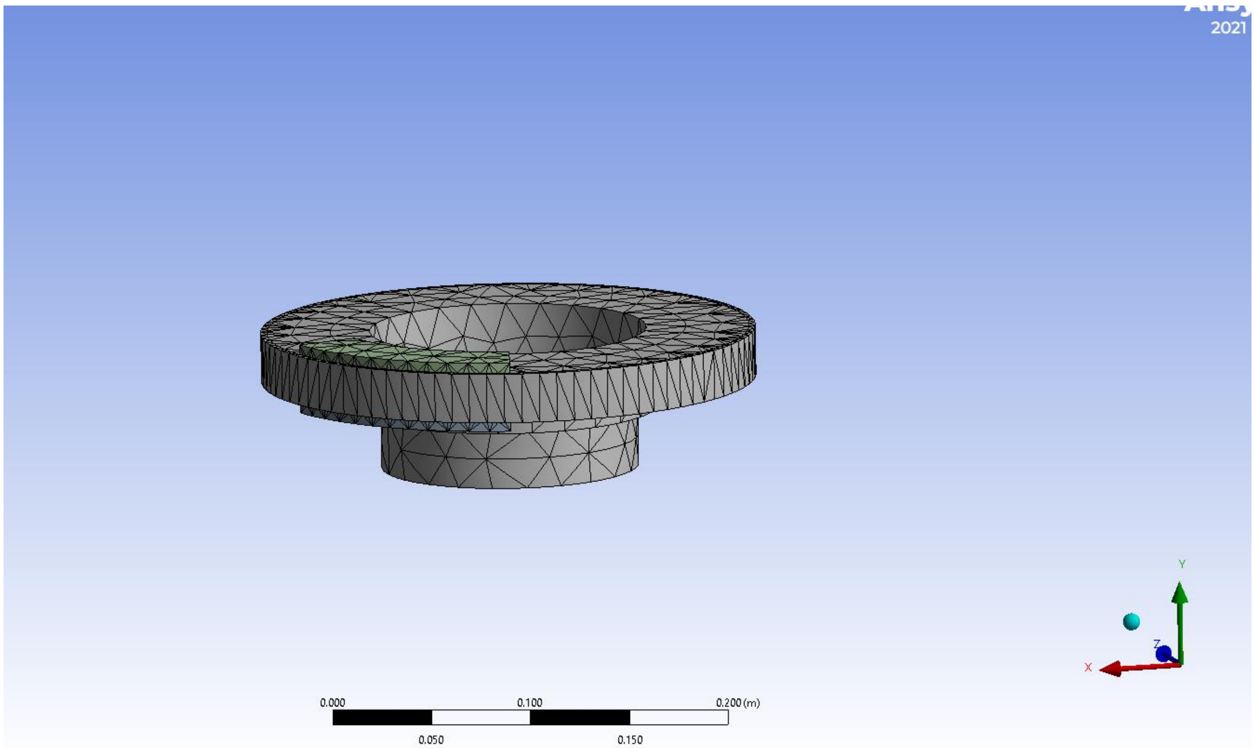
Properties of Outline A5: P1 - rotor_thickness

	A	B
1	Property	Value
2	⊟ General	
3	Units	mm
4	Type	Design Variable
5	Classification	Continuous
6	⊟ Values	
7	Lower Bound	22.5
8	Upper Bound	27.5
9	Allowed Values	Any

- Rotor Geometry



- Rotor Geometry with Meshing



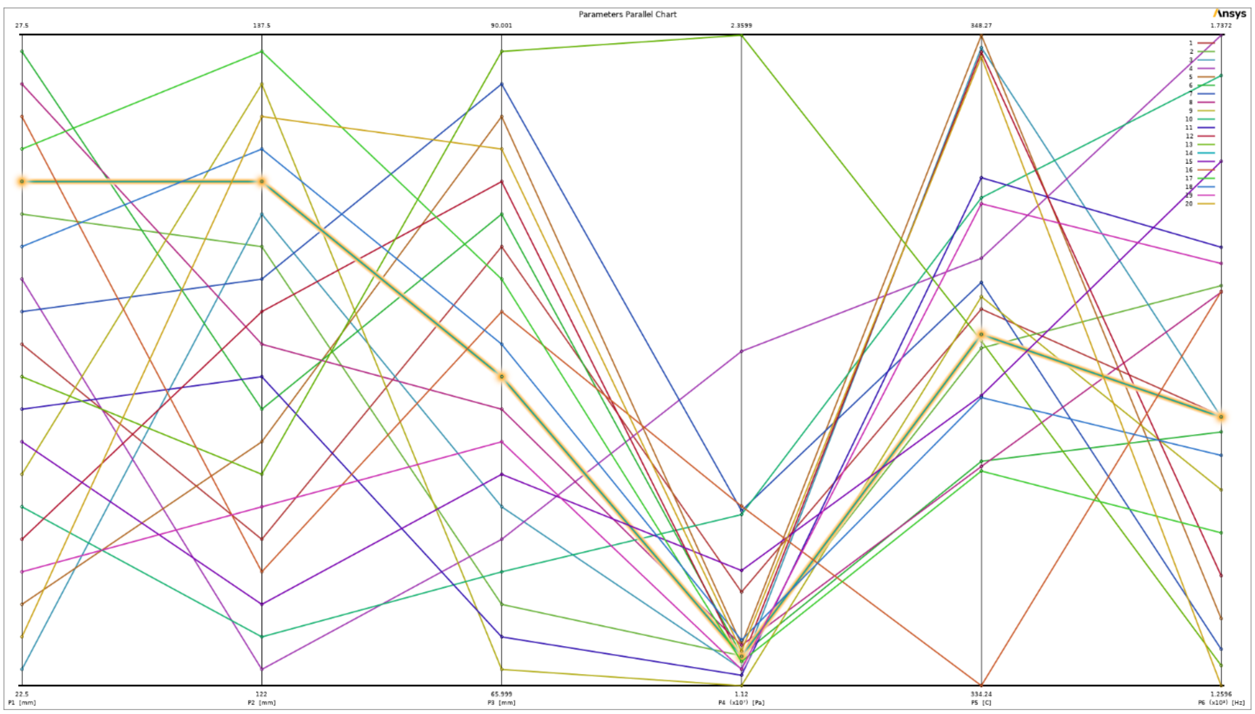
❖ DESIGN OF EXPERIMENTS:

After the initial analysis of each subsystem, the relationship between the design variables and output response is determined. All of the input variables are quantitative and continuous in nature. To obtain the accurate response surface, minimum number of design points from the given sample space is required. Latin Hypercube Sampling (LHS) technique with user defined sample points are used to create the response surface. The main advantage of LHS is that all the sample points are varying in nature. The figure below shows the table of 21 DOE points using LHS method.

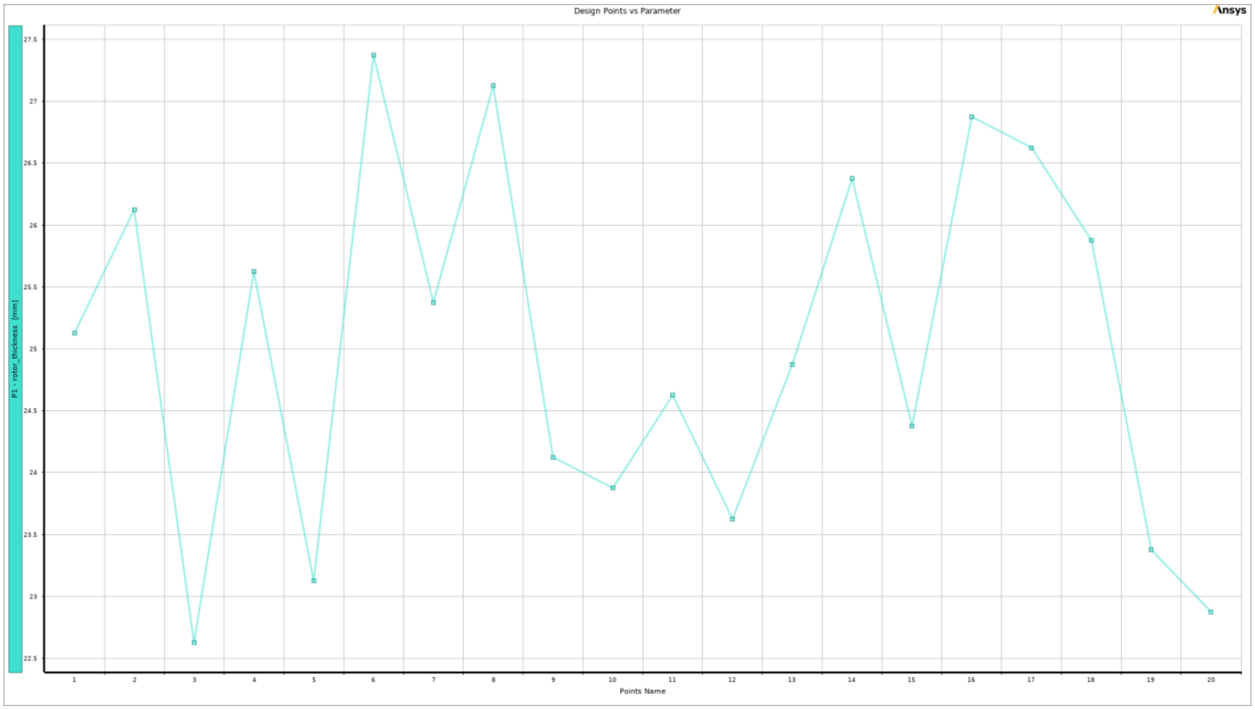
Table of Outline A10: Design Points of Design of Experiments

	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 - Temperature Maximum (C)	P6 - Total Deformation Reported Frequency (Hz)
2	1	25.125	125.49	82.2	1.2995E+07	342.36	1458.1
3	2	26.125	132.46	69	1.178E+07	341.52	1553.3
4	3	22.625	133.24	72.6	1.1524E+07	348	1457
5	4	25.625	122.39	71.4	1.7574E+07	343.46	1737.2
6	5	23.125	127.81	87	1.1984E+07	348.27	1309
7	6	27.375	128.59	83.4	1.1791E+07	339.08	1446.1
8	7	25.375	131.69	88.2	1.454E+07	342.93	1286.7
9	8	27.125	130.14	76.2	1.1973E+07	338.98	1548.5
10	9	24.125	136.34	66.6	1.12E+07	342.63	1403.4
11	10	23.875	123.16	70.2	1.447E+07	344.76	1707.2
12	11	24.625	129.36	67.8	1.1399E+07	345.2	1581.5
13	12	23.625	130.91	84.6	1.1676E+07	347.91	1340.4
14	13	24.875	127.04	89.4	2.3599E+07	341.68	1274.7
15	14	26.375	134.01	77.4	1.1761E+07	341.82	1456.9
16	15	24.375	123.94	73.8	1.3401E+07	340.5	1644.2
17	16	26.875	124.71	79.8	1.462E+07	334.24	1548.9
18	17	26.625	137.11	81	1.1659E+07	338.87	1372
19	18	25.875	134.79	78.6	1.2077E+07	340.46	1428.9
20	19	23.375	126.26	75	1.1517E+07	344.63	1569.5
21	20	22.875	135.56	85.8	1.1862E+07	347.8	1259.6

Design of Experiments points using LHS method.



Parallel parameters



Design points vs Parameters Curve

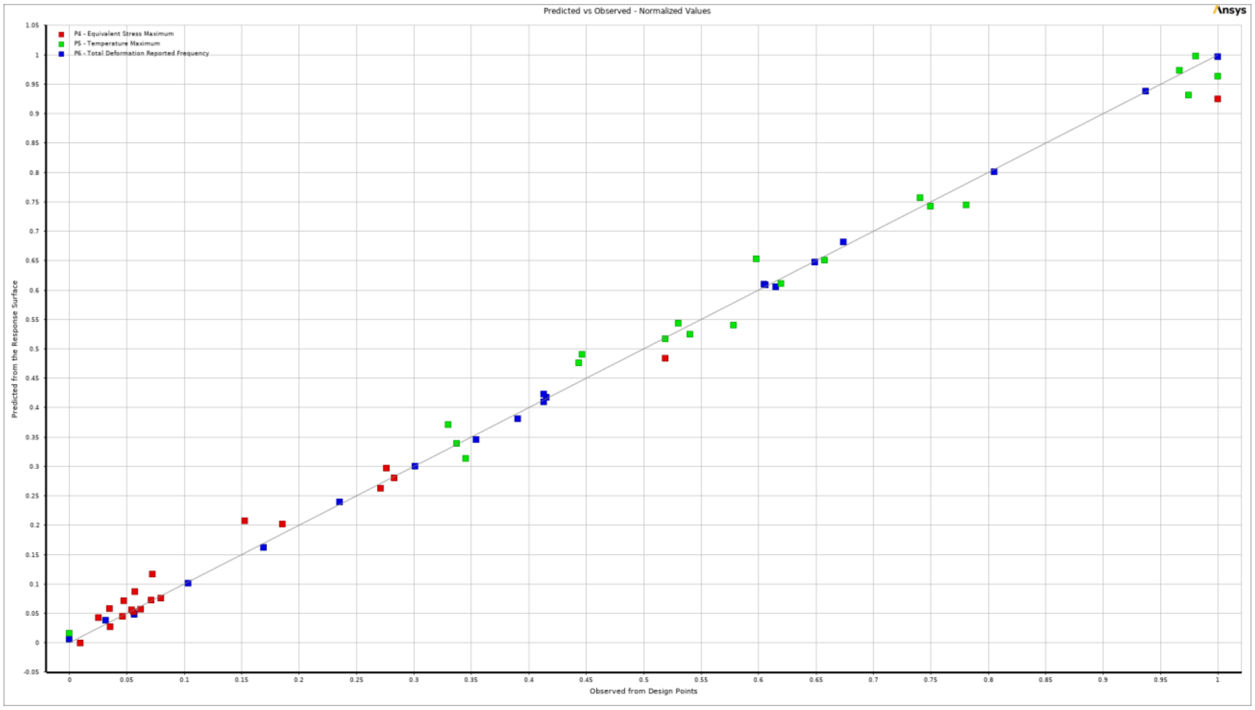
Table of Schematic F4: Optimization

	A	B	C	D
1	Input Parameters			
2	Name	Lower Bound	Upper Bound	
3	P1 - rotor_thickness (mm)	22.5	27.5	
4	P2 - rotor_OD (mm)	122	137.5	
5	P3 - rotor_ID (mm)	66	90	
6	Parameter Relationships			
7	Name	Left Expression	Operator	Right Expression
*	New Parameter Relationship	New Expression	<=	New Expression

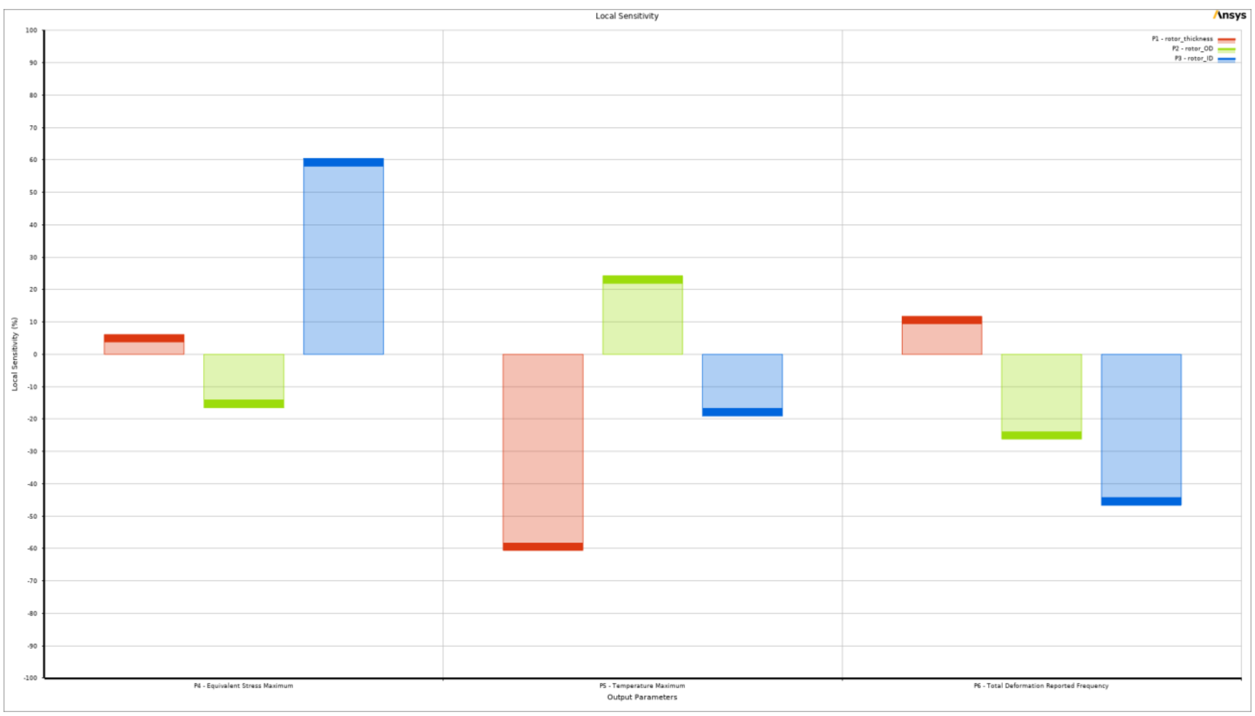
Parameters

❖ RESPONSE SURFACE

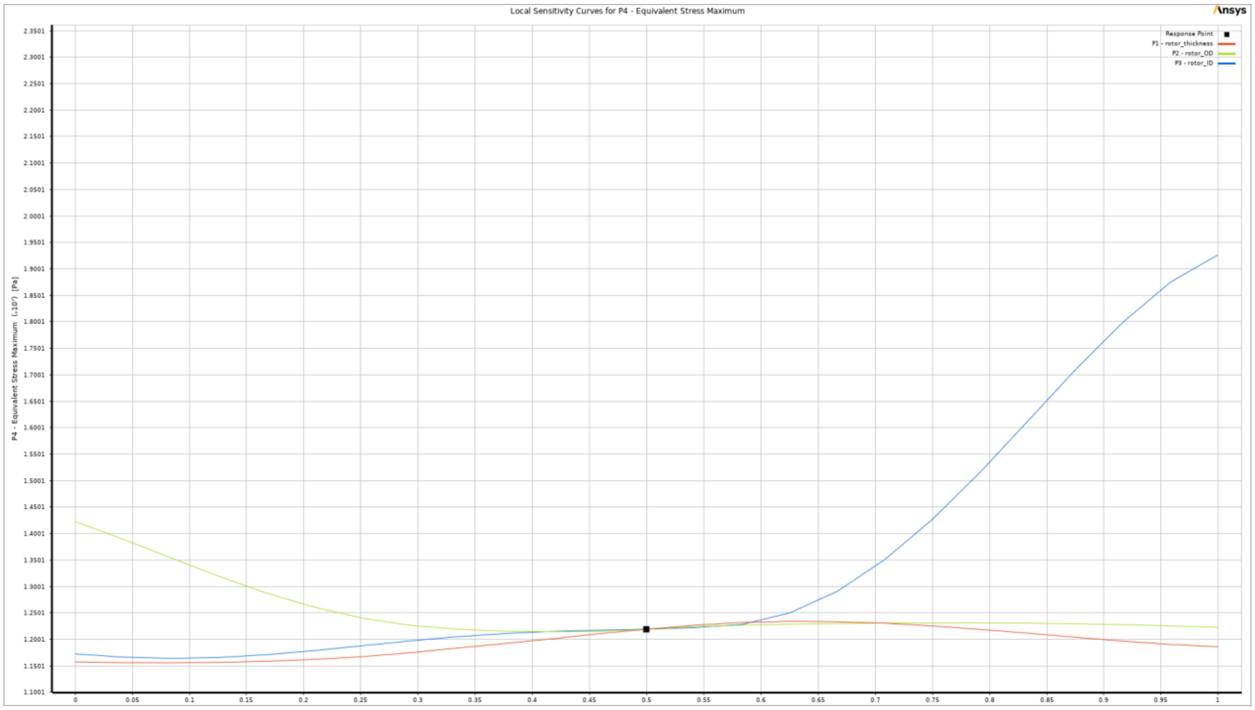
After DOE, a response surface is generated for all the input and output values using the least squares methodology. The data points are fitted with a standard 2nd order model. The points generated on the response surface are then used to perform the optimization. The figures below show some important results from response surface analysis.



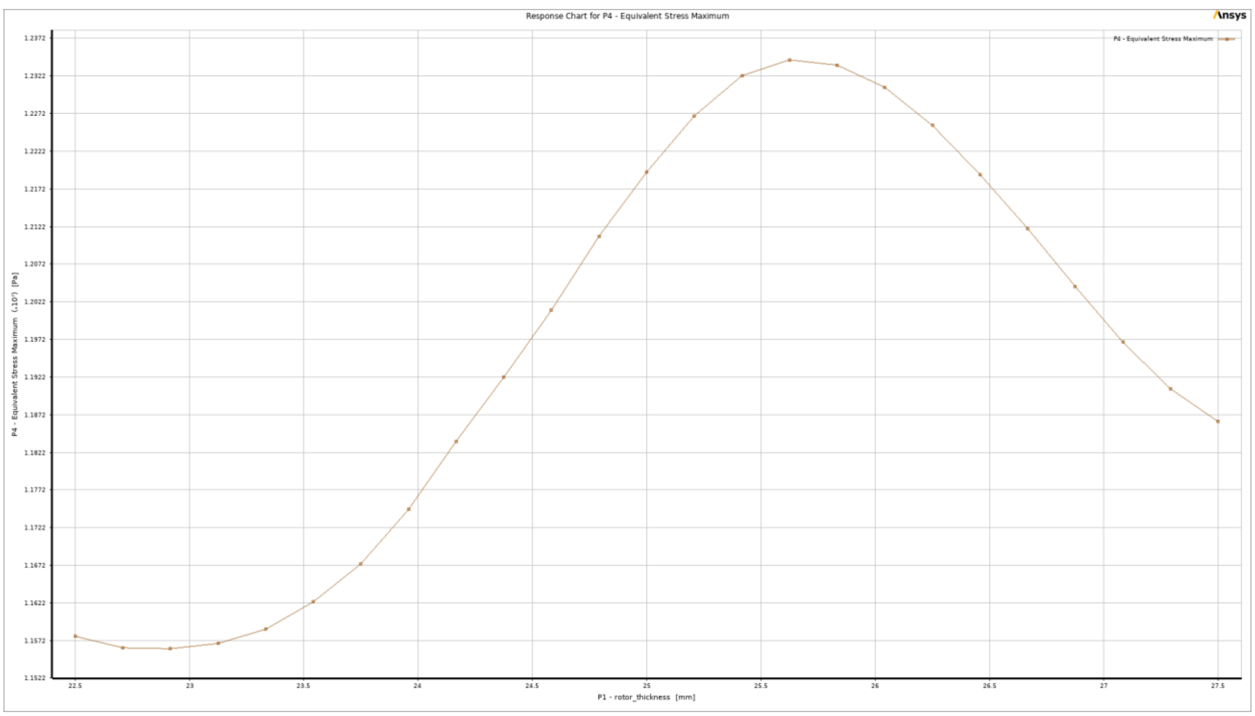
Goodness Fit curve obtained from predicted vs observed design points.



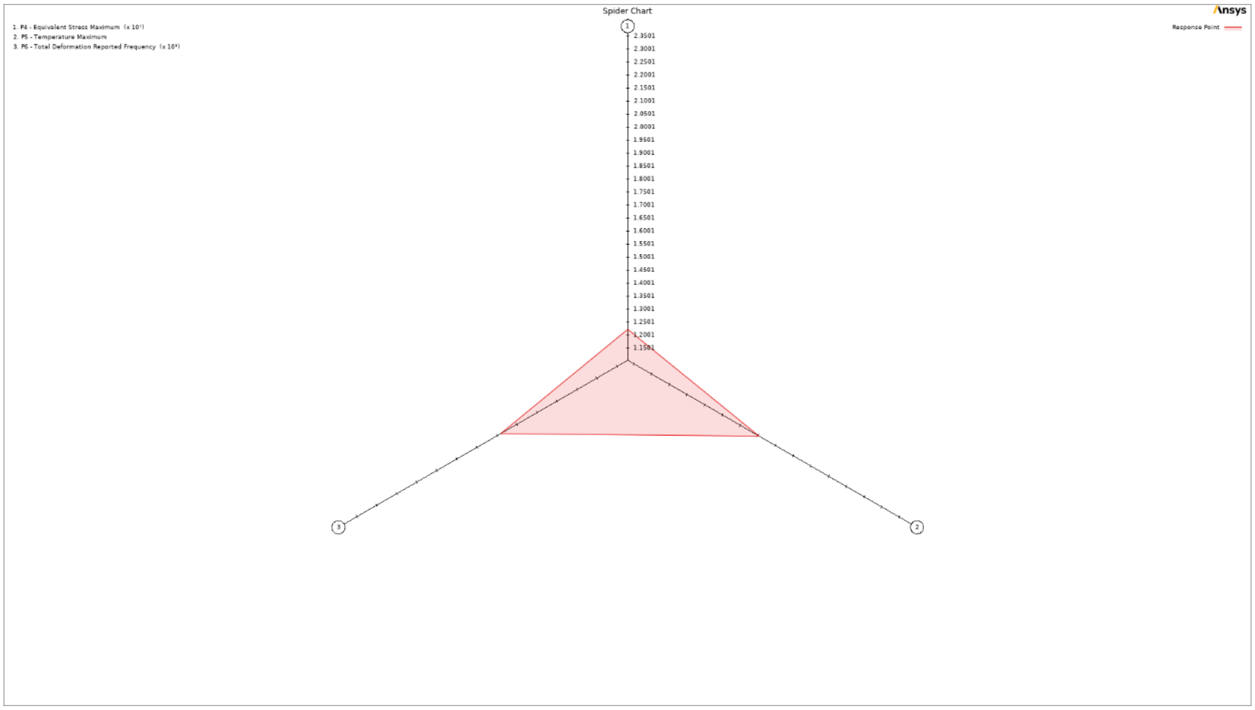
Local Sensitivity



Local Sensitivity Curve



Response Graph Rotor thickness vs Equivalent Maximum Stress



Spider Graph obtained from stress, temperature and frequency values.

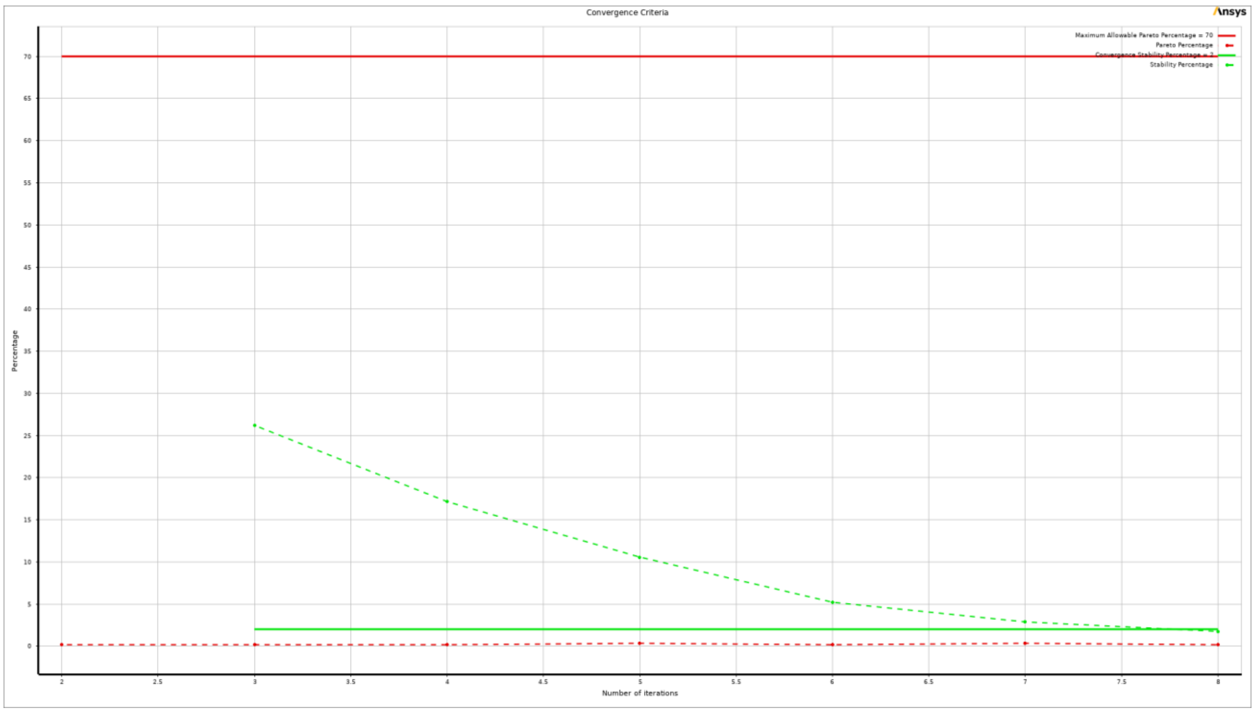
Table of Outline A15: Min-Max Search

	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 - Temperature Maximum (C)	P6 - Total Deformation Reported Frequency (Hz)
2	Output Parameter Minimums						
3	P4 - Equivalent Stress Maximum	22.5	129.7	83.806	**1.1001E+07**	349.2	1350
4	P5 - Temperature Maximum	27.091	124.4	78.13	1.478E+07	**333.64**	1595.6
5	P6 - Total Deformation Reported Frequency	22.5	137.5	90	1.2314E+07	346.41	**1172.5**
6	Output Parameter Maximums						
7	P4 - Equivalent Stress Maximum	24.91	126.66	90	**2.3037E+07**	341.33	1264.7
8	P5 - Temperature Maximum	22.5	130.7	85.663	1.1151E+07	**349.64**	1305.2
9	P6 - Total Deformation Reported Frequency	27.5	122	66	1.4324E+07	344.35	**1879.5**

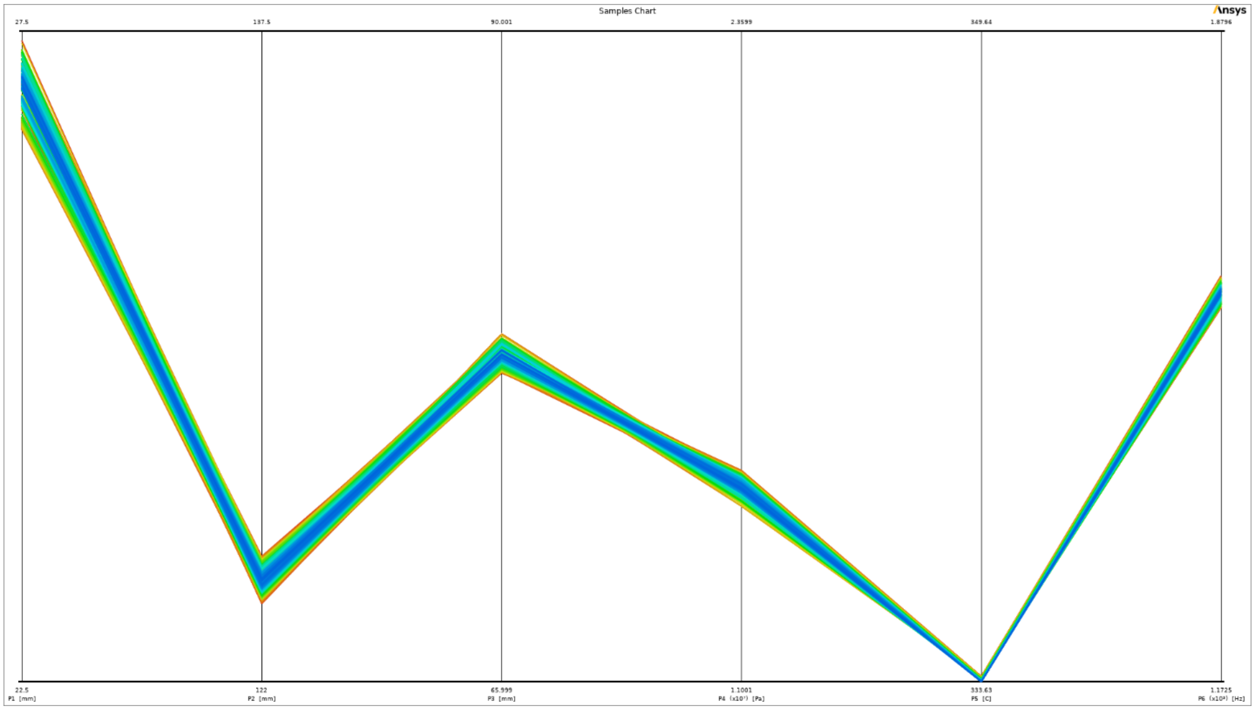
Maximum-Minimum values of all the constraints are shown in the Min-Max search

❖ OPTIMIZATION:

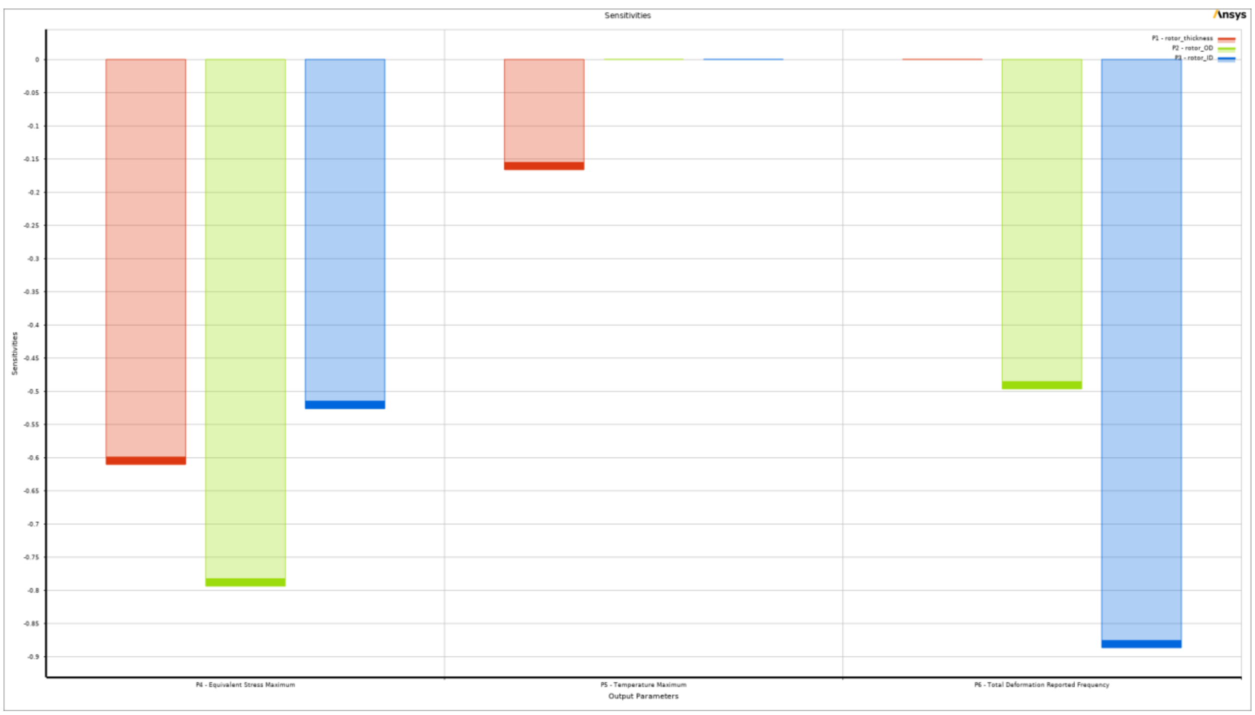
Optimization is the iterative process for finding a design that maximizes or minimizes the objective by searching the design space. There are two major schools of optimization algorithms: gradient-based methods are useful when the objective is differentiable (in many mathematical and machine learning problems). They are fast but can only find local solutions; Gradient-free methods are useful when the evaluation of the objective (and its gradient) is expensive or when the gradient is noisy. Here are some important results from Optimization. We use Multi-Objective Genetic Algorithm (MOGA) to obtain the final optimality.



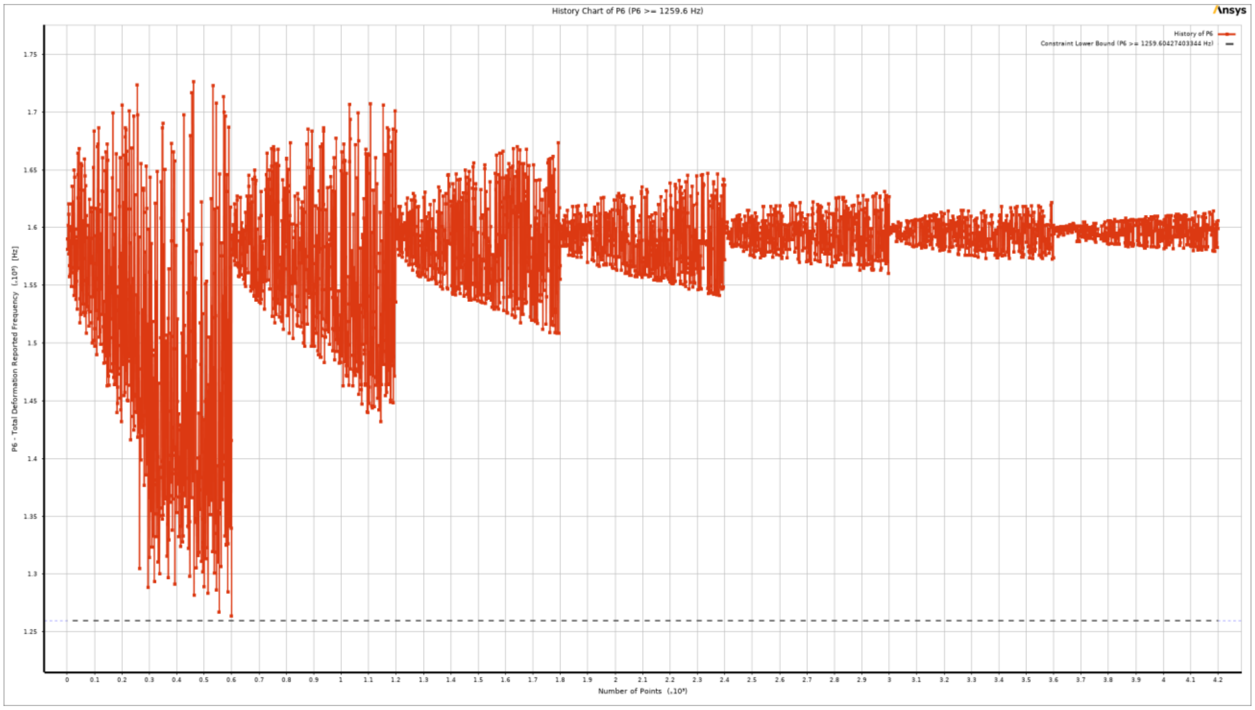
Convergence Criteria



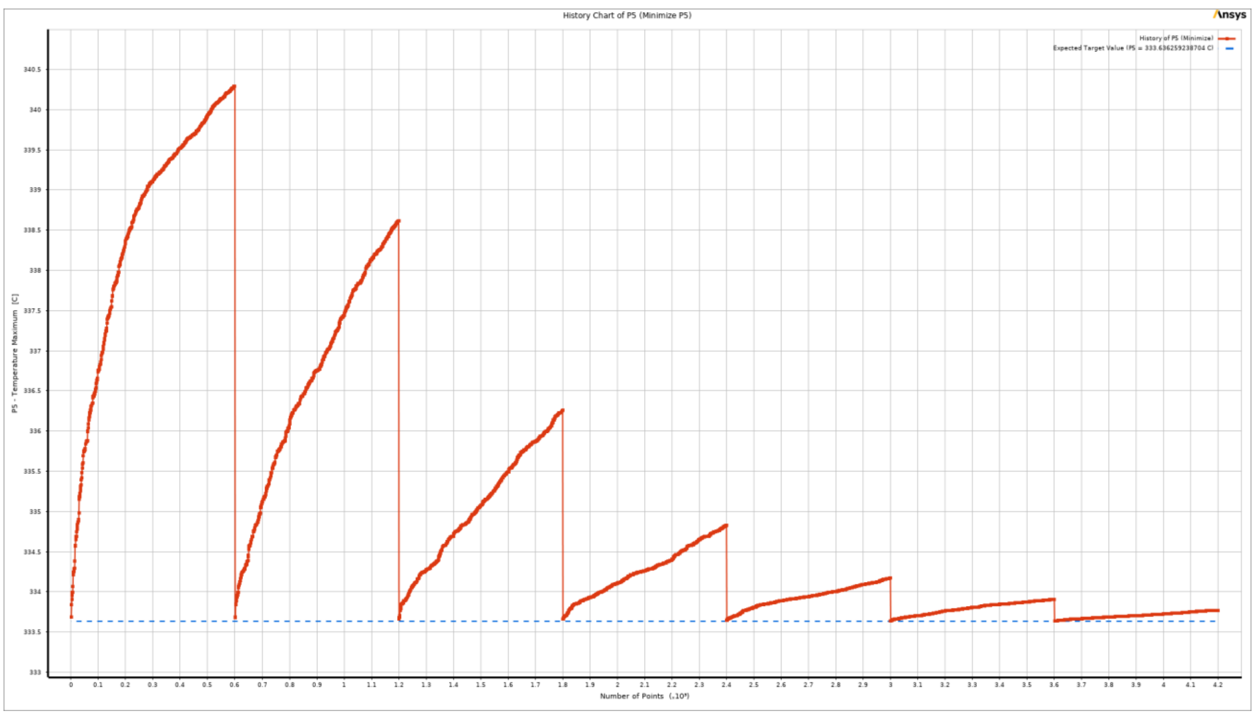
Samples Chart



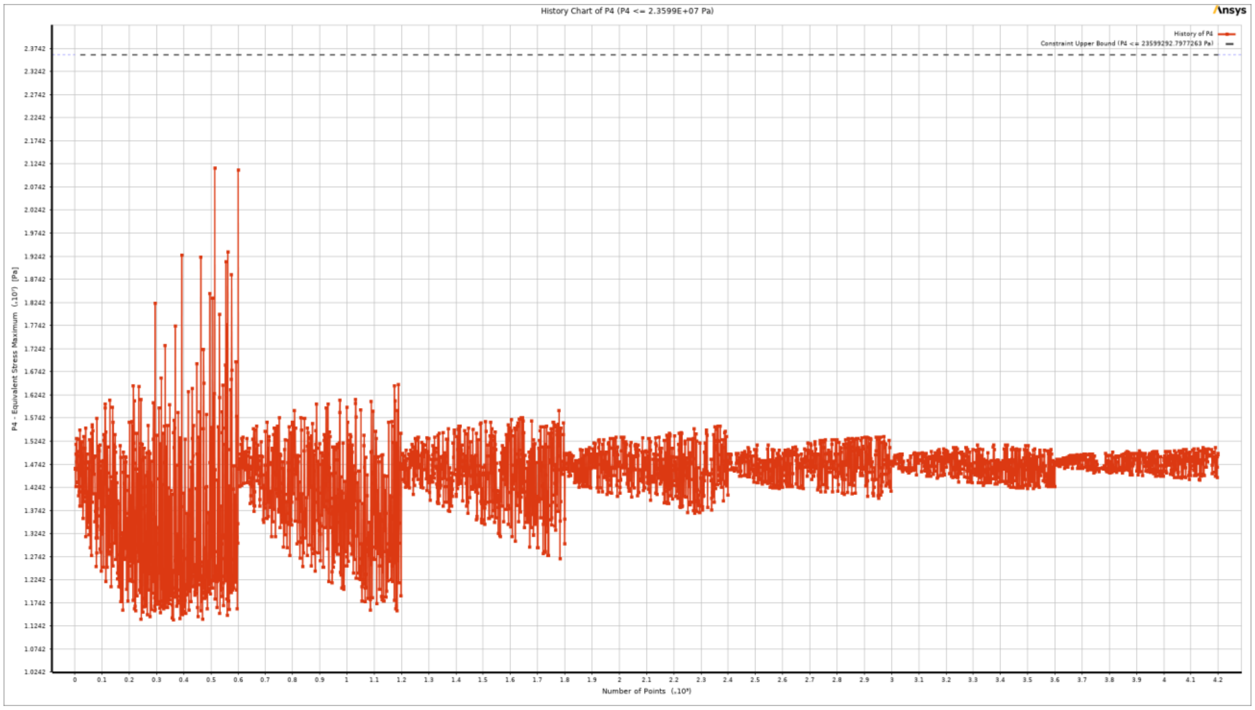
Sensitivities vs Output Parameters



Optimal Frequency Graph



Optimal Temperature Graph



Optimal Stress Graph

Table of Schematic F4: Optimization				
	A	B	C	D
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 6111 evaluations.		
9	⊟ Candidate Points			
10		Candidate Point 1	Candidate Point 2	Candidate Point 3
11	P1 - rotor_thickness (mm)	27.086	27.153	27.154
12	P2 - rotor_OD (mm)	124.47	124.42	124.41
13	P3 - rotor_ID (mm)	78.071	78.102	78.232
14	P4 - Equivalent Stress Maximum (Pa)	★★★ 1.4763E+07	★★★ 1.473E+07	★★★ 1.4724E+07
15	P5 - Temperature Maximum (C)	★★★ 333.64	★★★ 333.64	★★★ 333.64
16	P6 - Total Deformation Reported Frequency (Hz)	★★★ 1596.3	★★★ 1597.3	★★★ 1594.4

Final Optimality