Introduction

In this project we optimize the temperature, stress, and natural frequency. The main core of this optimization is to understand how optimization work in industrial world. For example, we have break disc for vehicles with pads. We are interested in knowing the result of optimization. We setup static structure, model, and transient thermal and parameters. The schematics below shows how the project connected to each ether.

The formation is for minimize the stress in the break disc

$$Minimize\ F = \sum_{n=1}^{n=21} B_n x_n + \sum_{1}^{21} B_n n_n^2 + B_n$$

We have two constaines

$$p1 \leq 22.5$$

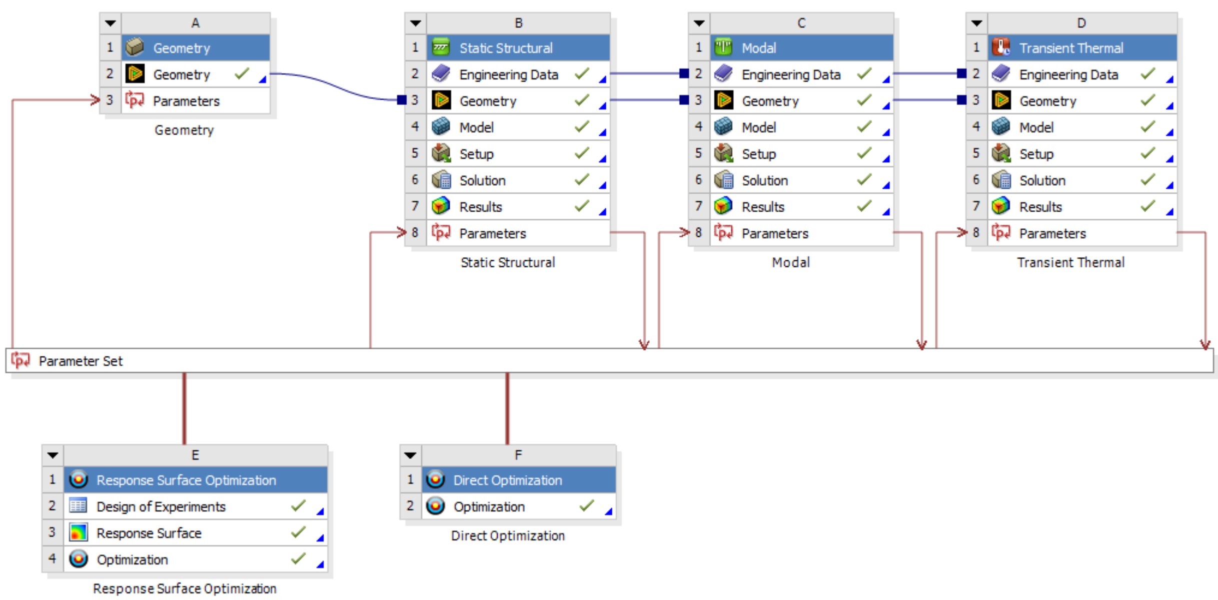
P1 is the rotor for thinkness

$$p2 \leq 122$$

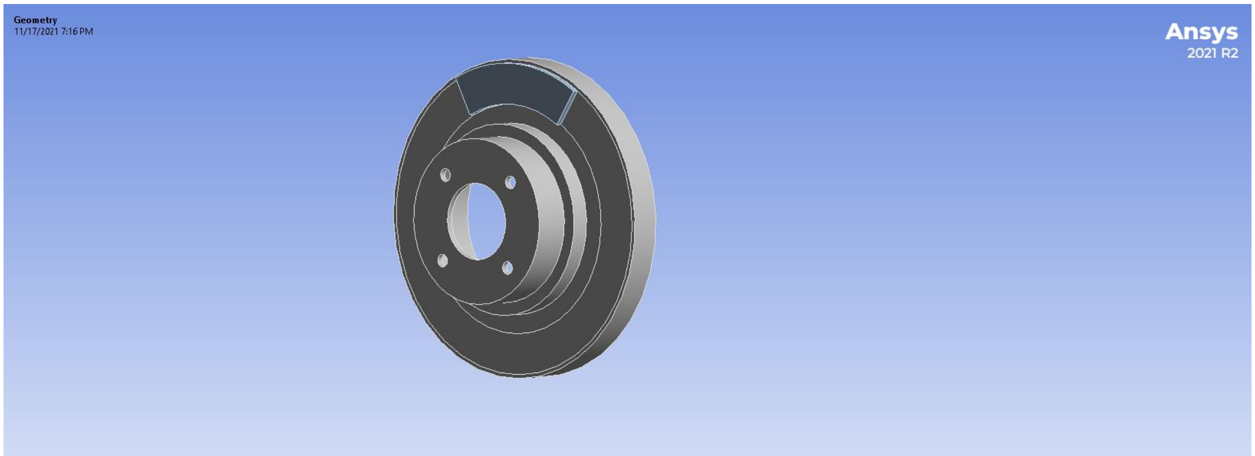
P2 is inner rotor for diameter

Model desgin

We used Ansys for soliving this optimization problem

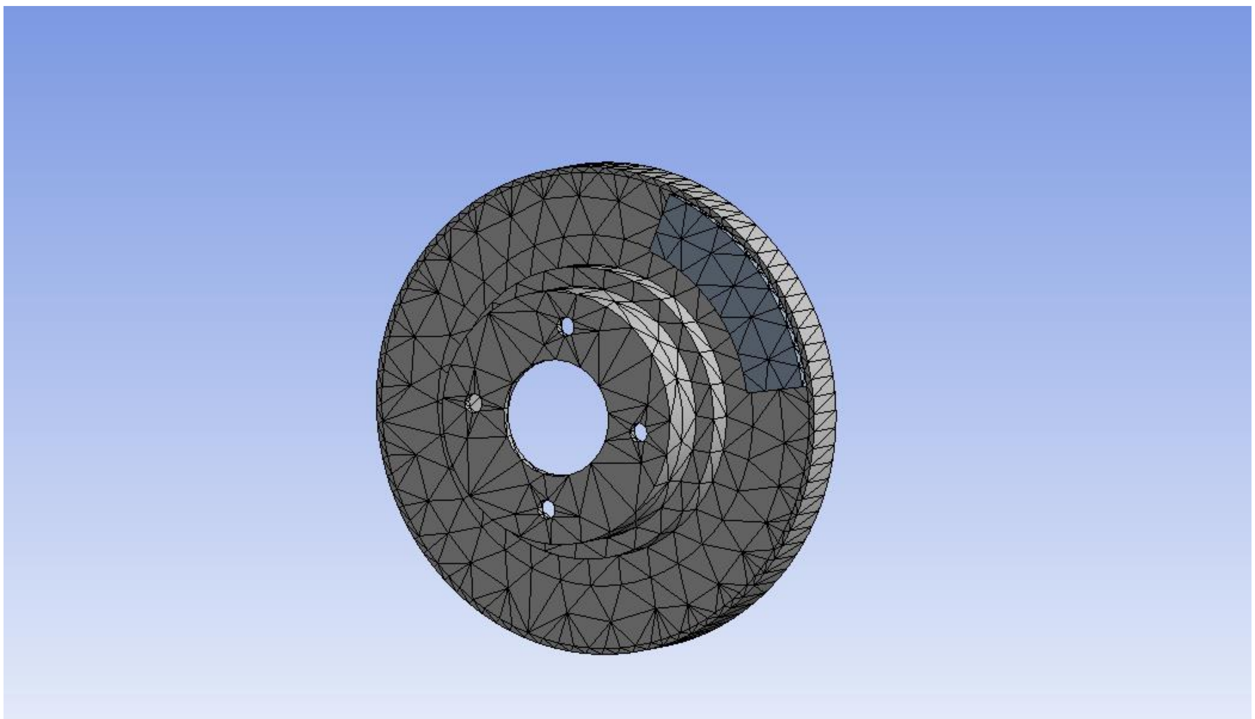


This is the schematic of optimization design in Ansys.

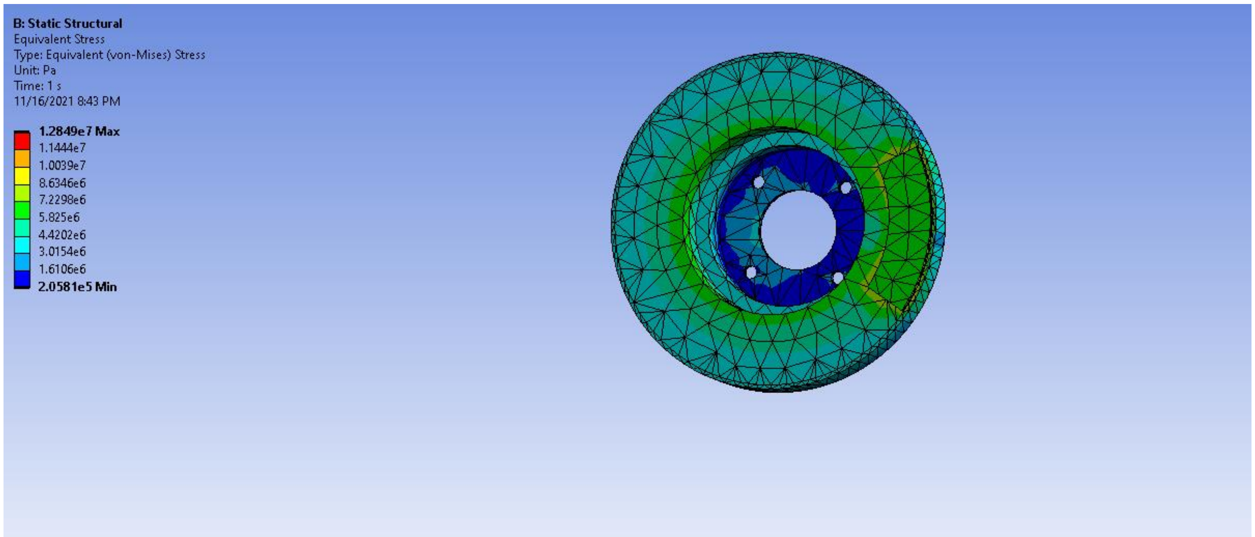


The design shows in Ansys

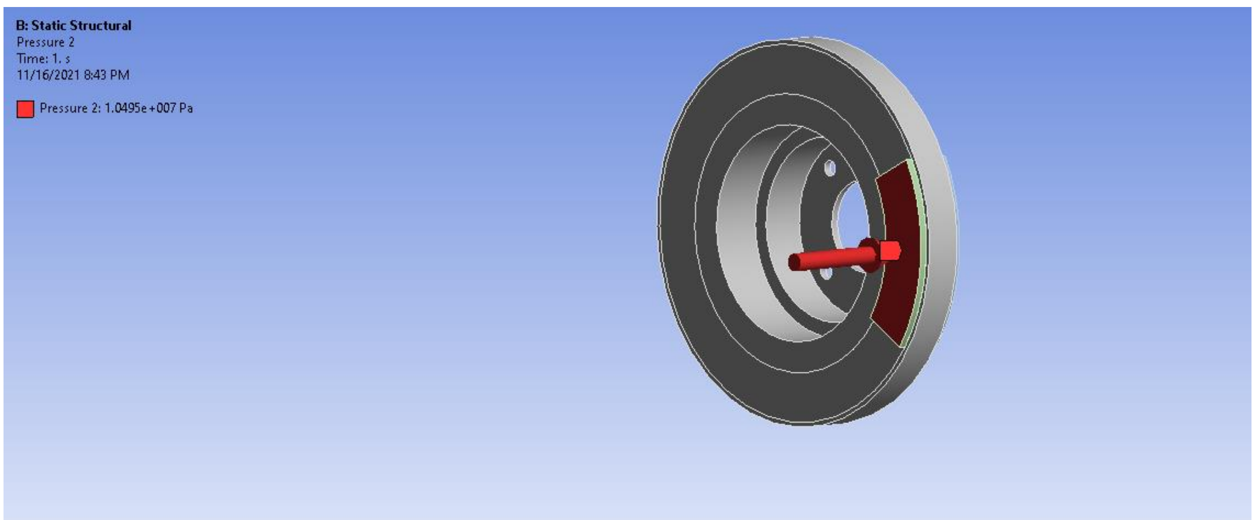
We design this disc and run it static structure and using mesh



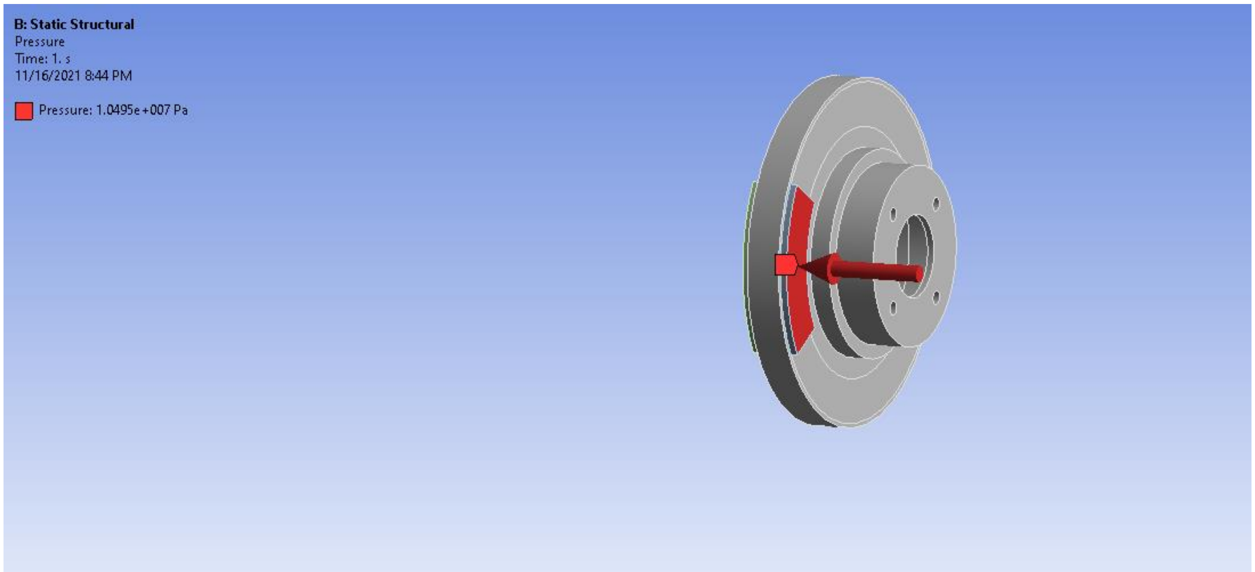
This is for the mesh design with 0.0003 m of size meshing



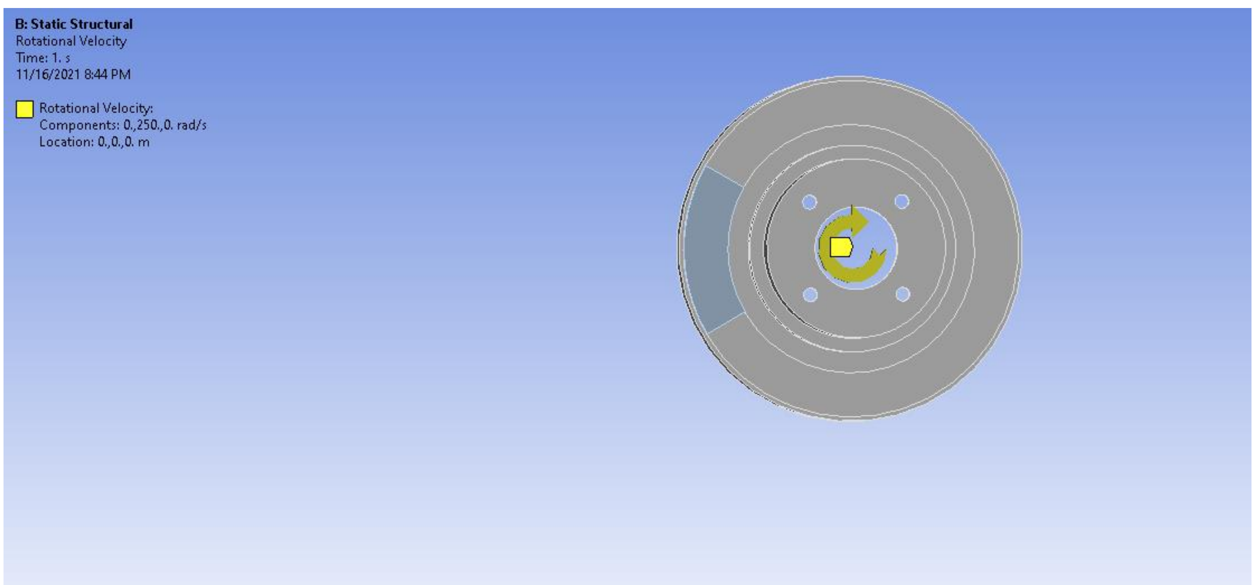
This shows the equivalent stress for von-mises. That shows the pressure level in the disc



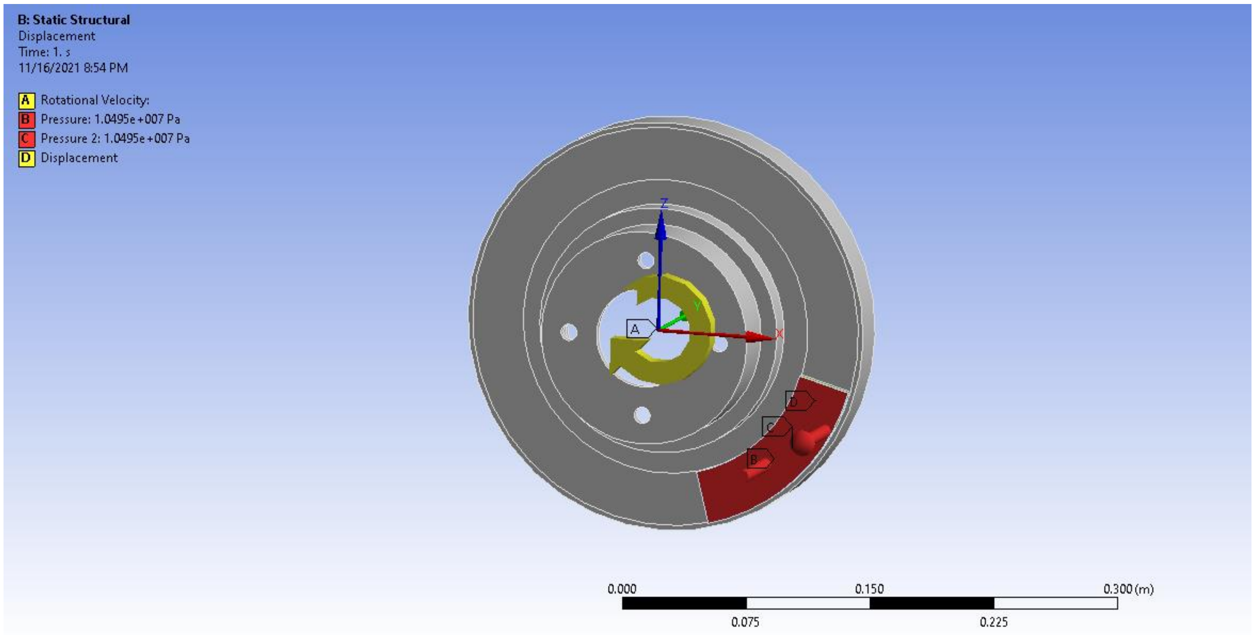
The direction of pressure in the pads of the break. The pressure was applied in the system as the problem required.



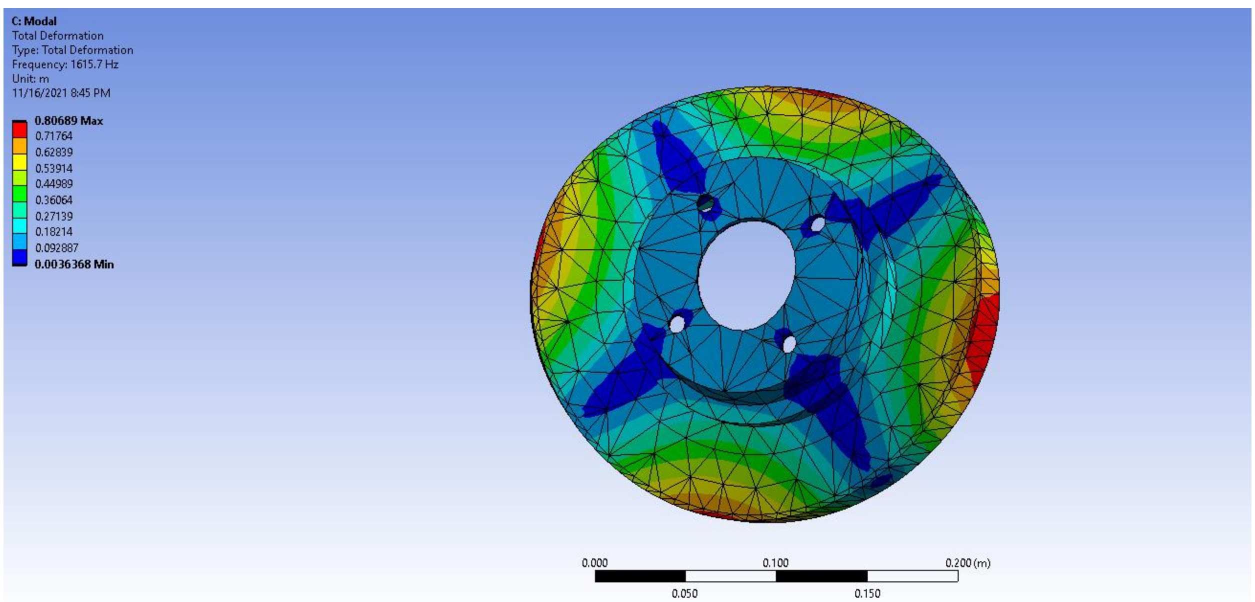
The direction of pressure in the pads of the break.



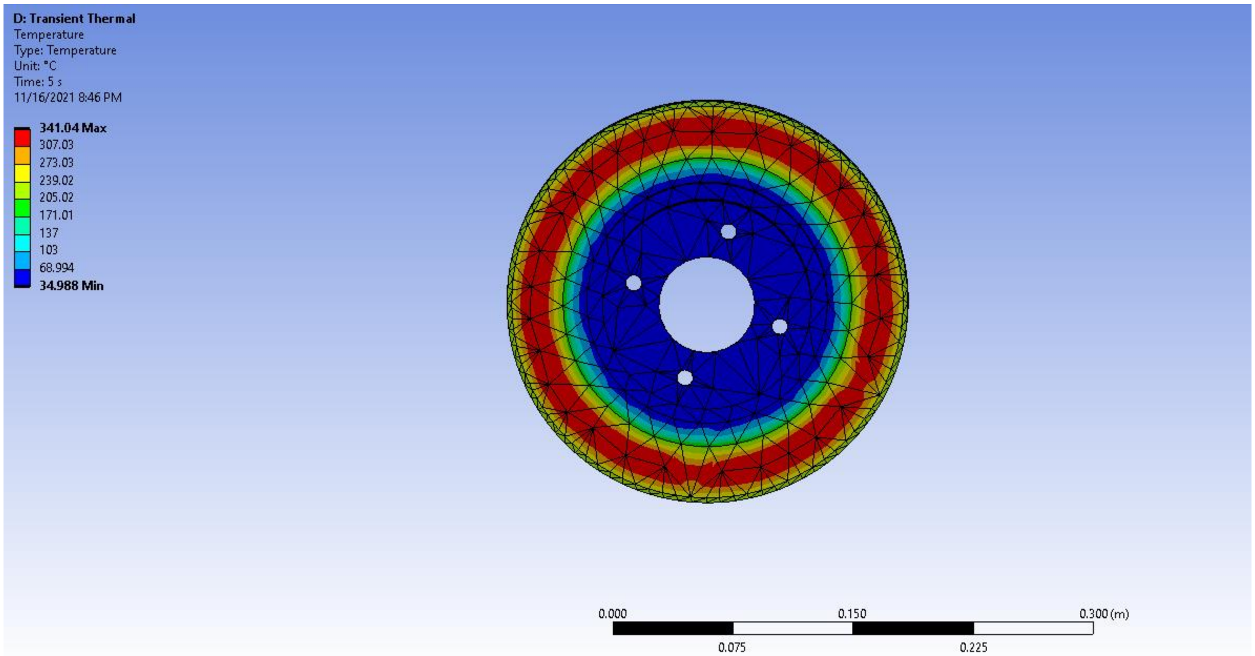
The direction of rotation on y direction. It required rotation of the disc because the car moving with different speed.



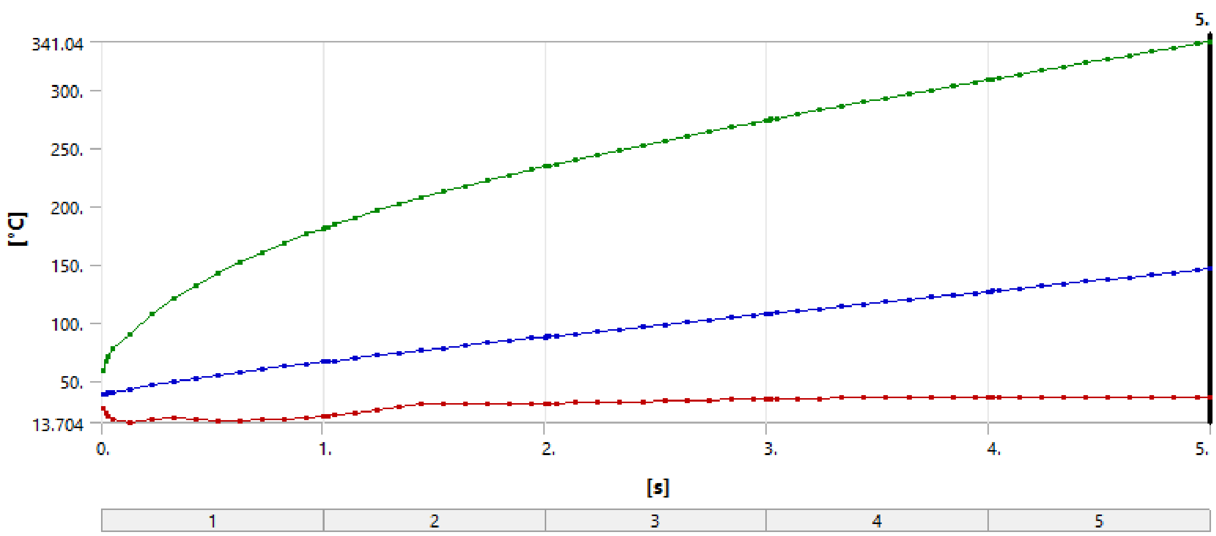
These show the pressure 1 and 2 rotation of velocity at 250 rad/s.



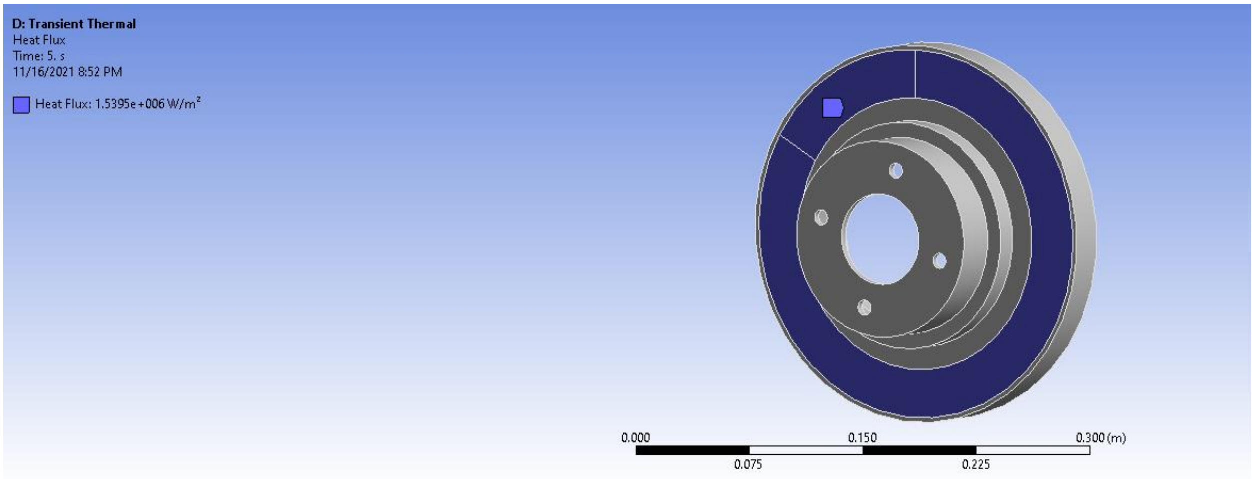
The total deformation for the break as showing here. This shows how the frequency impacting the system. And that can determent how we can reduce the stress in some part of the break.



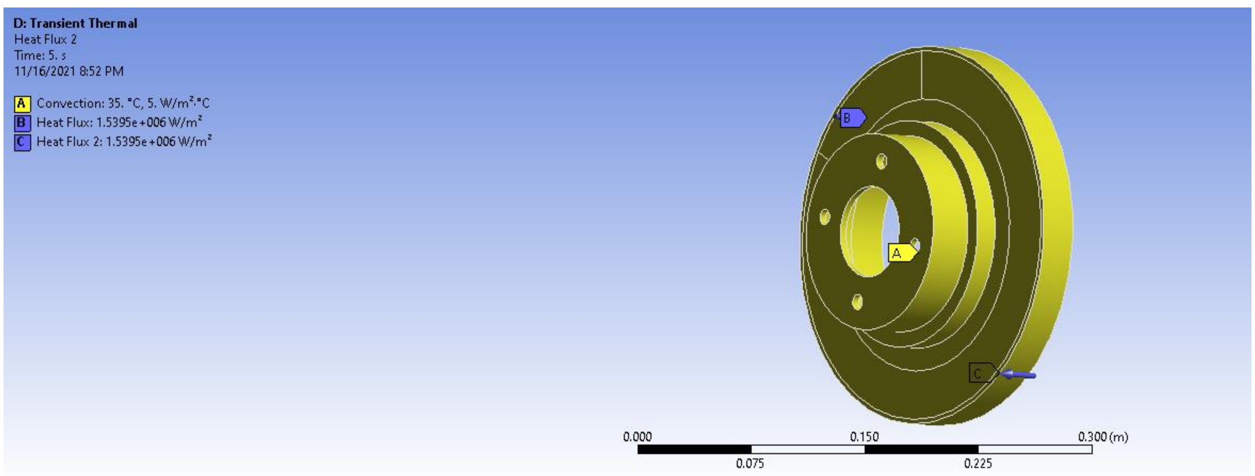
The temperature in c as shown here. We know that the temperature will be very high in the surface of the disc.



For the temperature and time in s



This the heat flus 1 for transient thermal



This the heat flus 2 for transient thermal

Design of Experiment part

	A	B
1		Enabled
2	Design of Experiments	
3	Input Parameters	
4	Geometry (A1)	
5	P1 - rotor_thickness	☑
6	P2 - rotor_OD	☑
7	P3 - rotor_ID	☑
8	Output Parameters	
9	Static Structural (B1)	
10	P4 - Equivalent Stress Maximum	
11	Transient Thermal (D1)	
12	P5 - Temperature Maximum	
13	Modal (C1)	

Properties of Outline A2: Design of Experiments

	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	☐
4	Failed Design Points Management	
5	Number of Retries	0
6	Design of Experiments	
7	Design of Experiments Type	Latin Hypercube Sampling Design
8	Samples Type	User-Defined Samples
9	Random Generator Seed	0
10	Number of Samples	20
11	Design Point Report	
12	Report Image	None

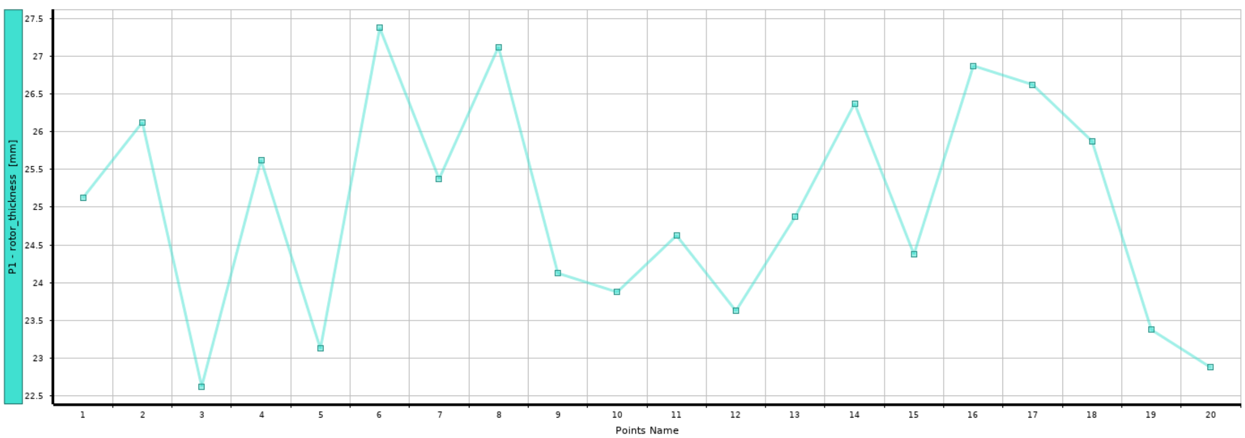
Setup for design experiment

We used the type of design experiment is ***Latin Hypercube Sampling Design*** and User-Defined Samples with 20 number of samples. We found the temperature has minimum and maximum values are 334.24 and 348.27 C. Also, for the natural frequency minimum and maximum are 1259.60 and 1737.16 Hz. The stress for minimum and maximum are 11199862.83 and 23599292.79 Pa.

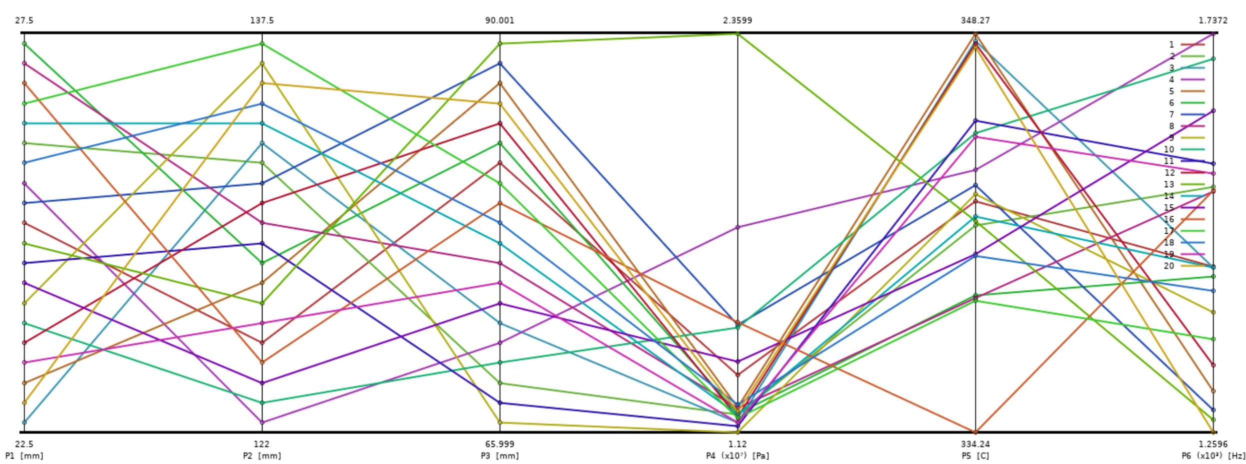
Table of Outline A12: Design Points of Design of Experiments

	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

These are the samples which are 21 iterations. We can use more but it will take time. Only 21 samples taken with me a lot of house and I redo it again it took very long time.



This is for design points and parameter. This design shows how different samples can impact the system result.



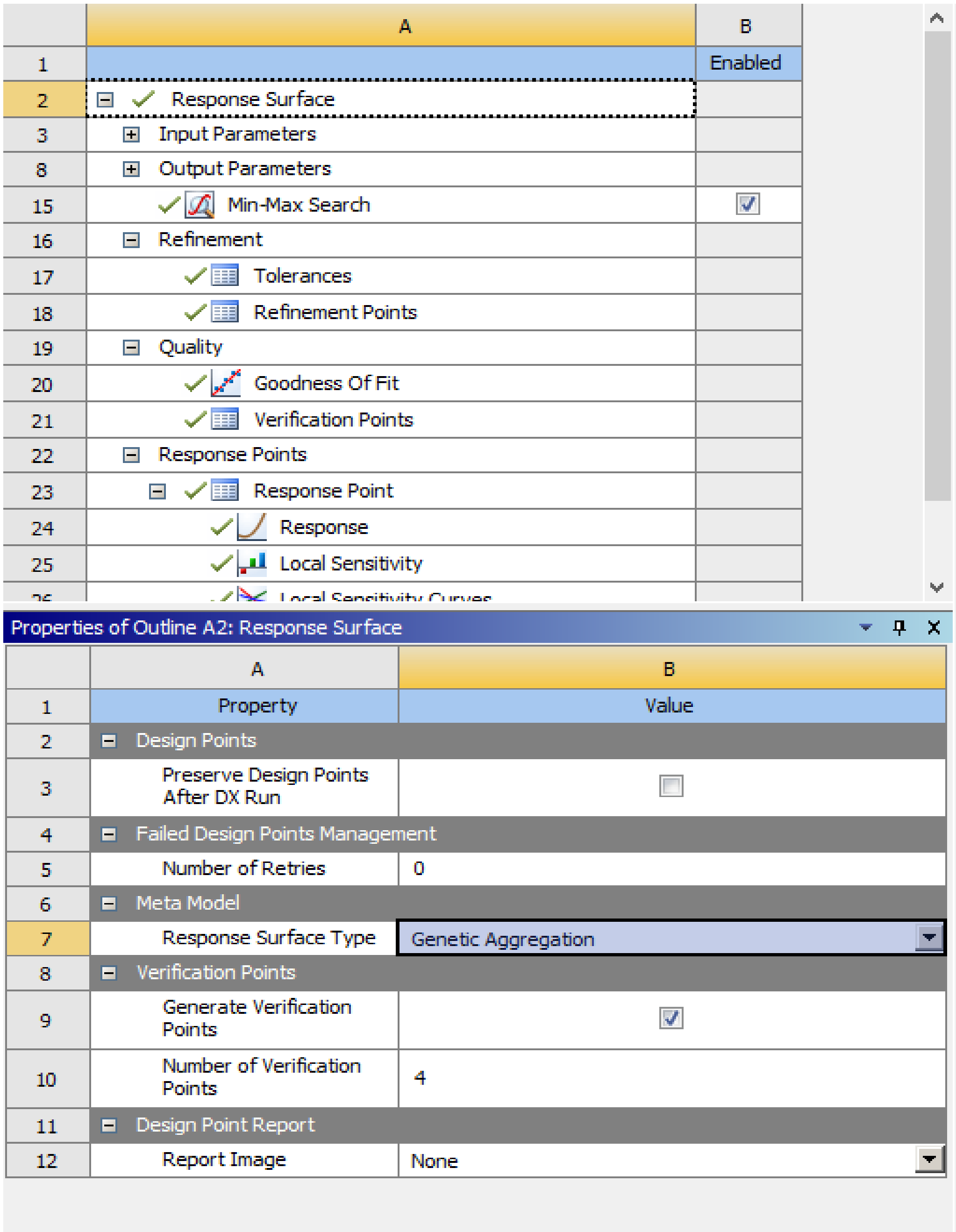
Parameters parallel

The values of parameters:

Parameters	Lower Bound	Upper Bound
P1 - rotor_thickness	22.5	27.5
P2 - rotor_OD	122	137.5
P3 - rotor_ID	66	90

We set up these values depends on our range of values. These are the values we used in this simulation.

Respond Surface part



	A	B
1		Enabled
2	Response Surface	
3	Input Parameters	
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	
23	Response Point	
24	Response	
25	Local Sensitivity	

Properties of Outline A2: Response Surface

	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	☐
4	Failed Design Points Management	
5	Number of Retries	0
6	Meta Model	
7	Response Surface Type	Genetic Aggregation
8	Verification Points	
9	Generate Verification Points	☑
10	Number of Verification Points	4
11	Design Point Report	
12	Report Image	None

This is the set

We used ***genetic aggregation*** for the type of surface response. And we select generate verification points and number verification points 4. This part is very important because it shows how the samples can get in a line that can determinant and can easily solve the problem and find the optimal solution of the problem.

Table of Schematic E3: Response Surface: Tolerances

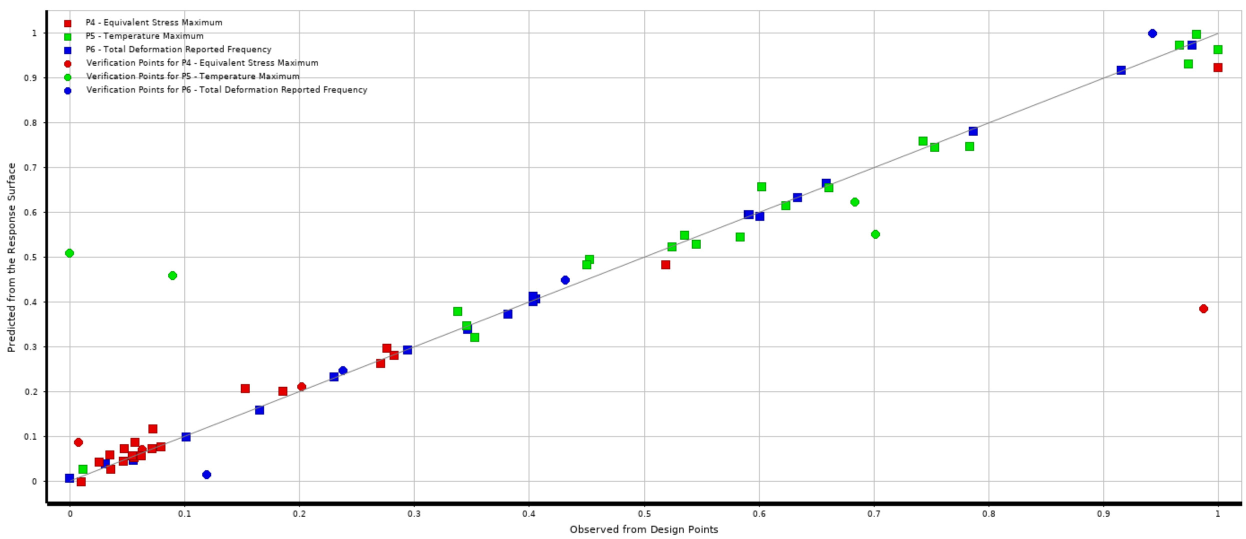
	A	B	C	D	E	F
1	Name	Calculated Minimum	Calculated Maximum	Maximum Predicted Error	Refinement	Tolerance
2	P4 - Equivalent Stress Maximum (Pa)	1.1001E+07	2.3599E+07	5.6473E+06		
3	P5 - Temperature Maximum (C)	333.64	349.64	7.2833		
4	P6 - Total Deformation Reported Frequency (Hz)	1172.5	1879.5	26.277		

This table for respaces surface. These are very important result because we used them in the optimization part us we setup the constraints. These have to be very accuracy.

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**

This is for parameters and min and max values



This is predicted from response surface and observed from design points. It is showing striate line and the points for the very accuracy as we found. This plot shows the solution us very closed to the optimal solution.

Table of Schematic E3: Response Surface				
	A	B	C	D
1		P4 - Equivalent Stress Maximum	P5 - Temperature Maximum	P6 - Total Deformation Reported Frequency
2	⊟ Coefficient of Determination (Best Value = 1)			
3	Learning Points	0.98522	0.98745	0.99956
4	Cross-Validation on Learning Points	0	0.83258	0.99803
5	⊟ Root Mean Square Error (Best Value = 0)			
6	Learning Points	3.4644E+05	0.39875	2.8591
7	Verification Points	3.8014E+06	4.619	29.27
8	Cross-Validation on Learning Points	2.8615E+06	1.4564	6.0751
9	⊟ Relative Maximum Absolute Error (Best Value = 0%)			
10	Learning Points	32.007	21.37	3.5106
11	Verification Points	219.26	178.55	35.457
12	Cross-Validation on Learning Points	357.58	73.848	8.7787
13	⊟ Relative Average Absolute Error (Best Value = 0%)			
14	Learning Points	8.2924	8.9916	1.7573
15	Verification Points	63.703	95.371	15.981
16	Cross-Validation on Learning Points	58.509	36.728	3.558

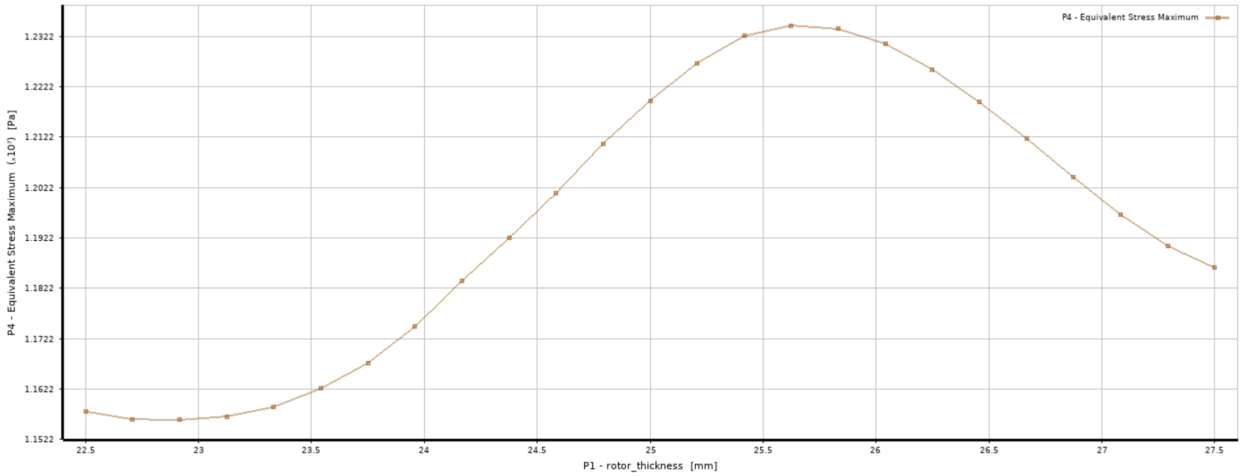
This is the respond surface as shown above

	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	27.473	126.18	67.447	1.3606E+07	334.07	1720.6
3	2	27.012	122.11	89.688	2.3449E+07	344.04	1317.9
4	3	27.489	137.24	67.016	1.1869E+07	335.35	1470.6
5	4	23.968	137.3	76.944	1.1176E+07	343.79	1376.1
*	New Verification Point						

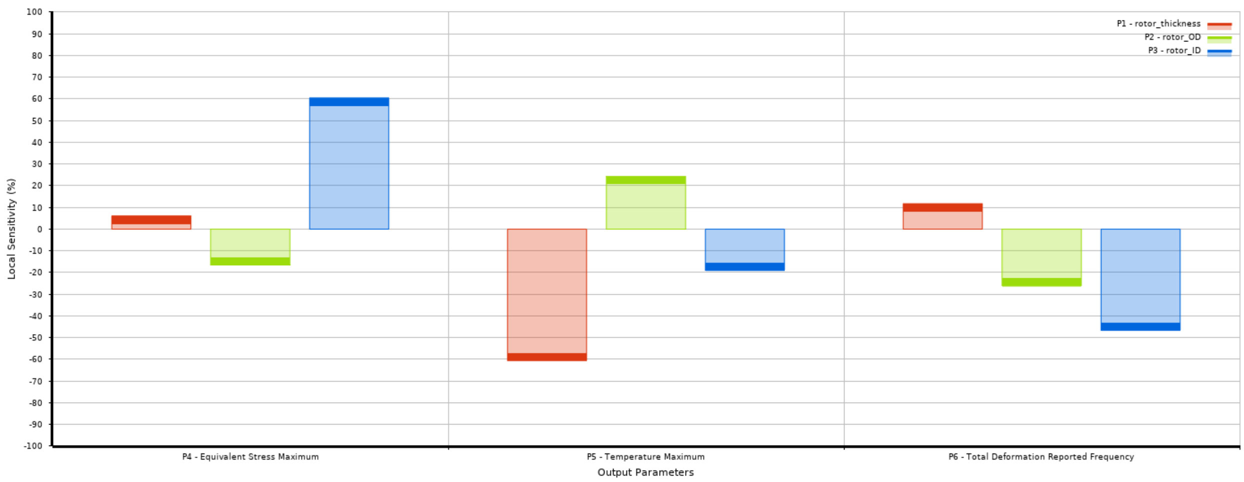
This for the verification points

	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	Response Point	25	129.75	78	1.2194E+07	341.06	1489.9
*	New Response Point						

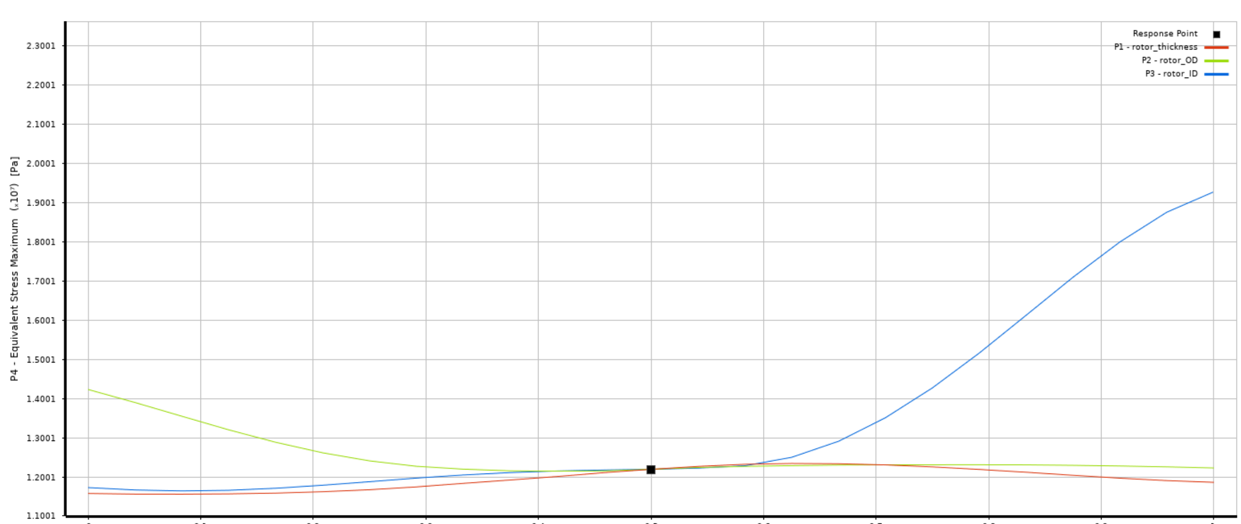
This is response points for both parameters and values of stress, temperature and natural frequency.



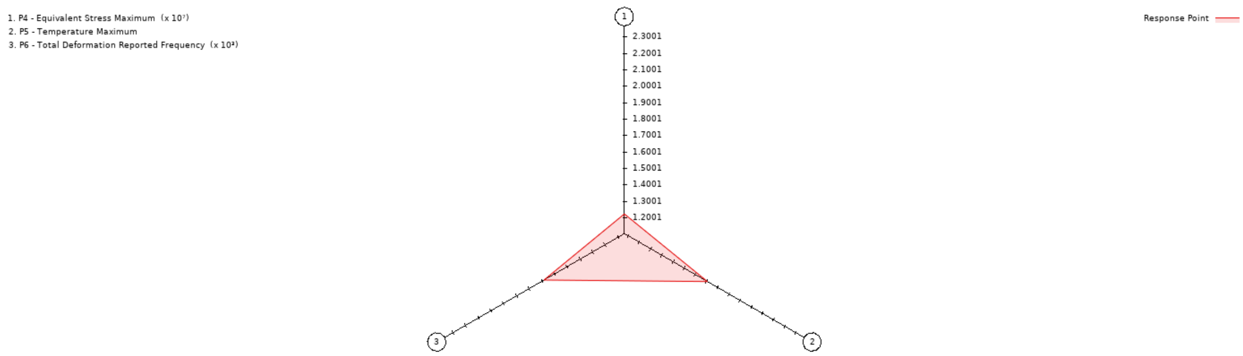
This is maximum stress and parameter for thickness. We can understand from this plot where is the mix stress in the system.



The local sensitivity and output parameters for p1, p2, and p3.



Stress maximum and respond points



Spider and respond points

optimization part

in optimization we used two methods:

1-method section manual.

2- Auto with multiples objective.

We setup the objective and constants in optimization part. We select the min the stress with two parameters as constraints such as p1 thickness and p2 inner diameter.

We did the optimization in two different way and found that multiples objective is the most accuracy result. However, all these results good output but multiples objective take more time and that can help a lot for get very good outcomes.

Method section manual (MOGA)

	A	B	C
1		Enabled	Monitoring
2	Optimization		
3	Objectives and Constraints		
4	Minimize P5; P5 <= 348.27 C		
5	Seek P4 = 0 Pa; P4 <= 2.3599E+07 Pa		
6	Seek P6 = 0 Hz; P6 >= 1259.6 Hz		
7	Domain		
8	Geometry (A1)		
9	P1 - rotor_thickness	☑	
10	P2 - rotor_OD	☑	
11	P3 - rotor_ID	☑	
12	Parameter Relationships		
13	Convergence Criteria		
14	Results		
15	Candidate Points		
16	Tradeoff		
17	Samples		
18	Sensitivities		

Properties of Outline A2: Optimization

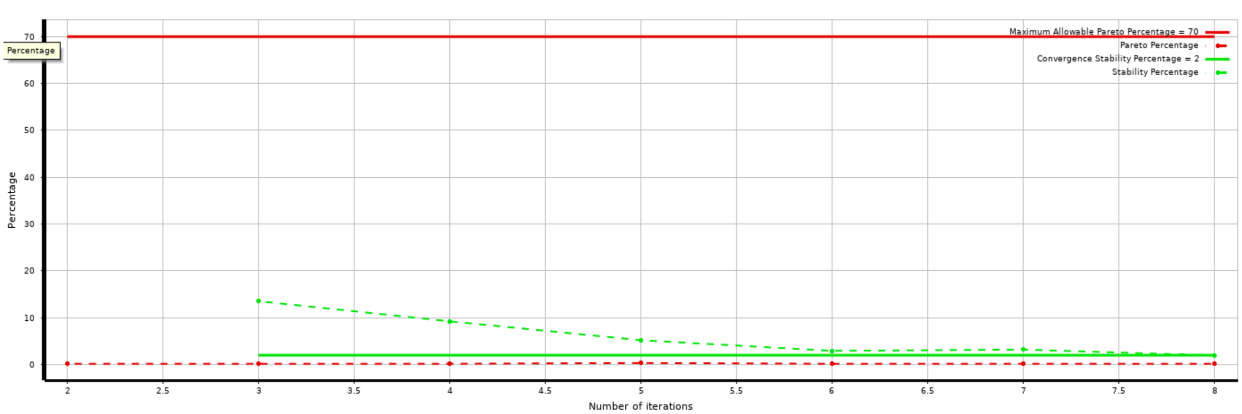
	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	☐
4	Failed Design Points Management	
5	Number of Retries	0
6	Optimization	
7	Method Selection	Manual
8	Method Name	MOGA
9	Estimated Number of Evaluations	14400
10	Tolerance Settings	☑
11	Verify Candidate Points	☐
12	Number of Initial Samples	3000
13	Number of Samples Per Iteration	600
14	Maximum Allowable Pareto Percentage	70
15	Convergence Stability Percentage	2

	A	B	C	D	E	F	G	H	I
1	Name	Parameter	Objective			Constraint			
2			Type	Target	Tolerance	Type	Lower Bound	Upper Bound	Tolerance
3	Minimize P4; P4 <= 2.3599E+07 Pa	P4 - Equivalent Stress Maximum	Minimize	0		Values <= Upper Bound		2.3599E+07	0.001
4	Seek P1 = 22.5 mm	P1 - rotor_thickness	Seek Target	22.5	0.001	No Constraint			
5	Seek P2 = 122 mm	P2 - rotor_OD	Seek Target	122	0.001	No Constraint			
*		Select a Parameter							

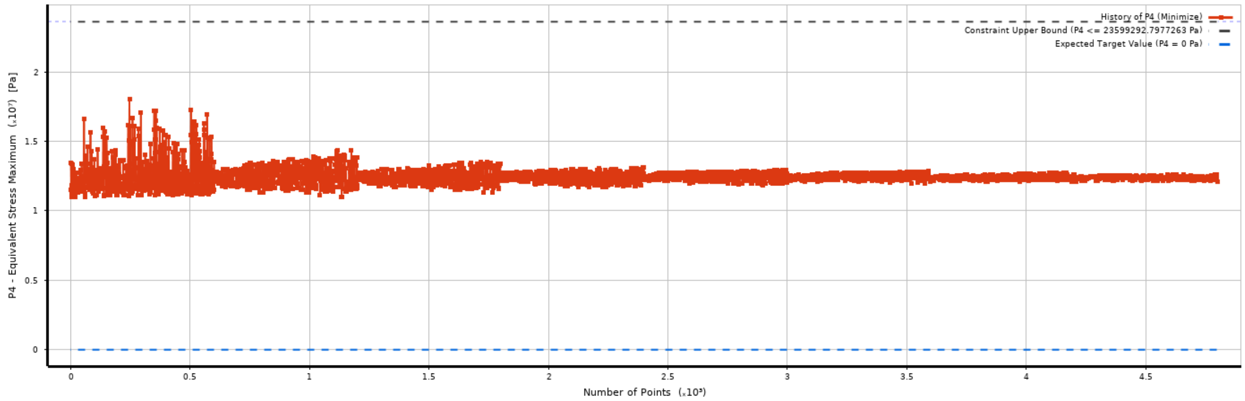
These are objective and constrained

	A	B	C	D
1	Optimization Study			
2	Minimize P4; P4 <= 2.3599E+07 Pa	Goal, Minimize P4 (Default importance); Strict Constraint, P4 values less than or equals to 2.3599E+07 Pa (Default importance)		
3	Seek P2 = 122 mm	Goal, Seek P2 = 122 mm (Default Importance)		
4	Seek P1 = 22.5 mm	Goal, Seek P1 = 22.5 mm (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 6609 evaluations.		
9	Candidate Points			
10		Candidate Point 1	Candidate Point 2	Candidate Point 3
11	P1 - rotor_thickness (mm)	★★★ 22.501	★★★ 22.5	★★★ 22.5
12	P2 - rotor_OD (mm)	★★★ 123.17	★★ 123.45	★★ 123.45
13	P3 - rotor_ID (mm)	79.145	79.651	79.369
14	P4 - Equivalent Stress Maximum (Pa)	★ 1.2522E+07	★ 1.2441E+07	★ 1.2442E+07

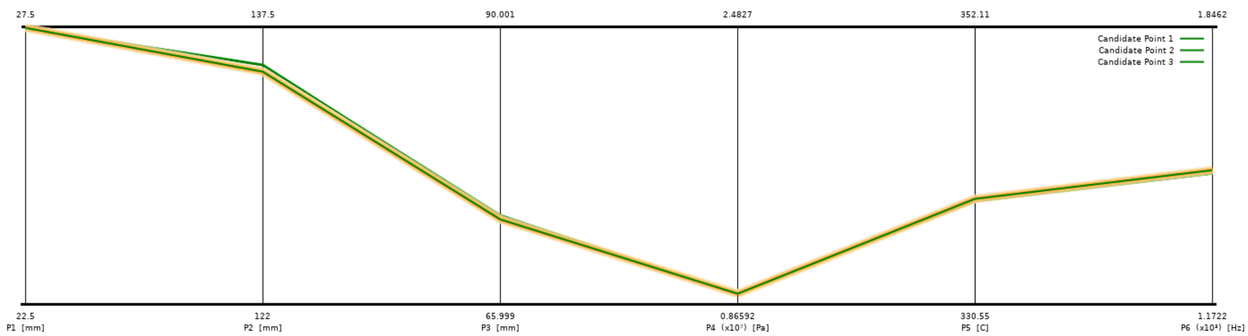
Candidate points



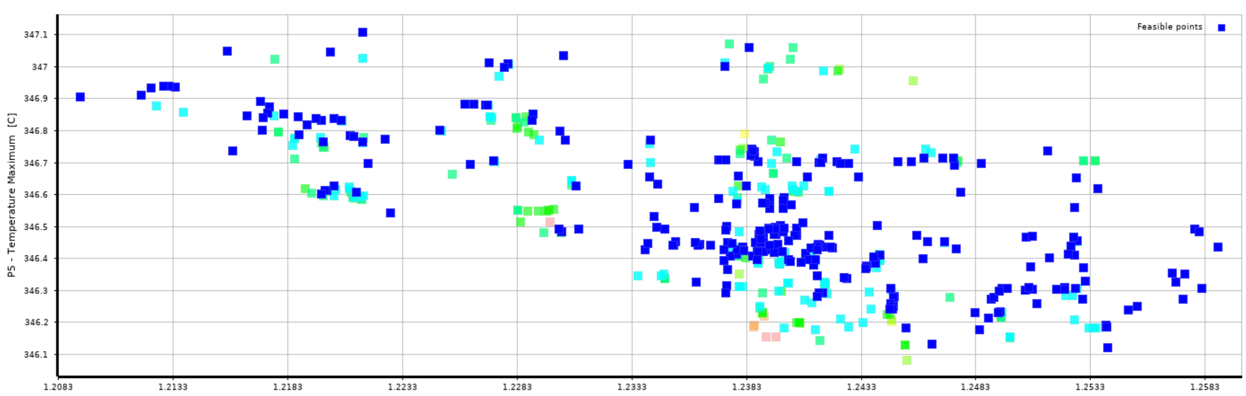
This is for the optimization stability percentage



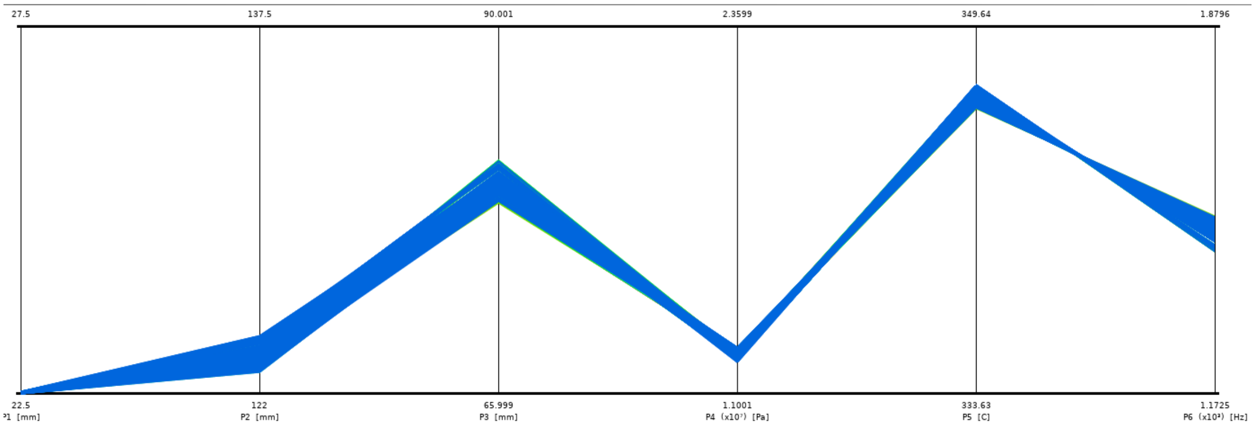
For minimizes the stress

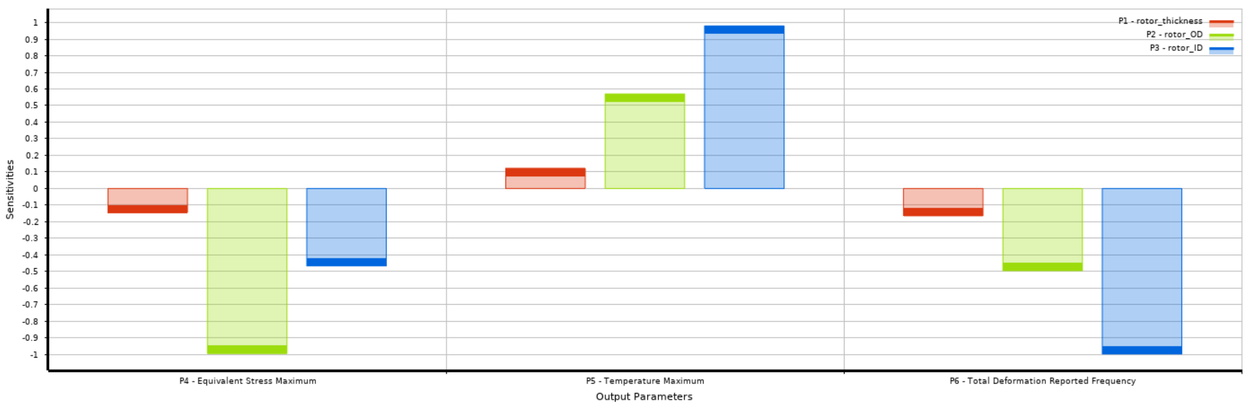


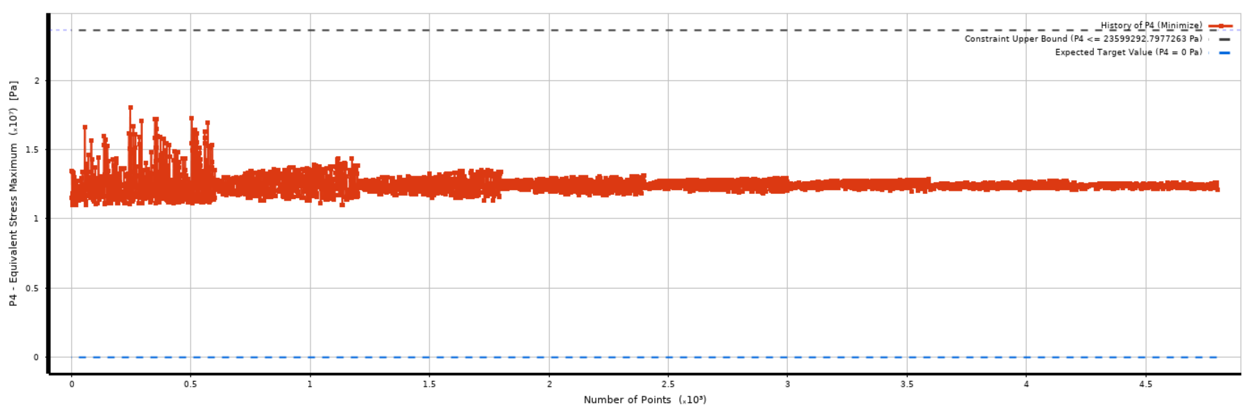
This shows the parameters and natural frequency (candidate points)



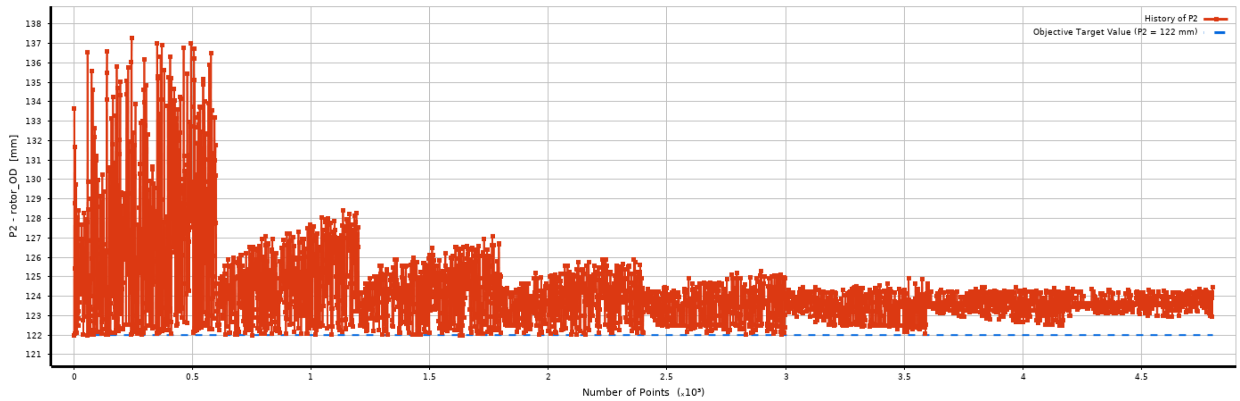
Target point for optimization



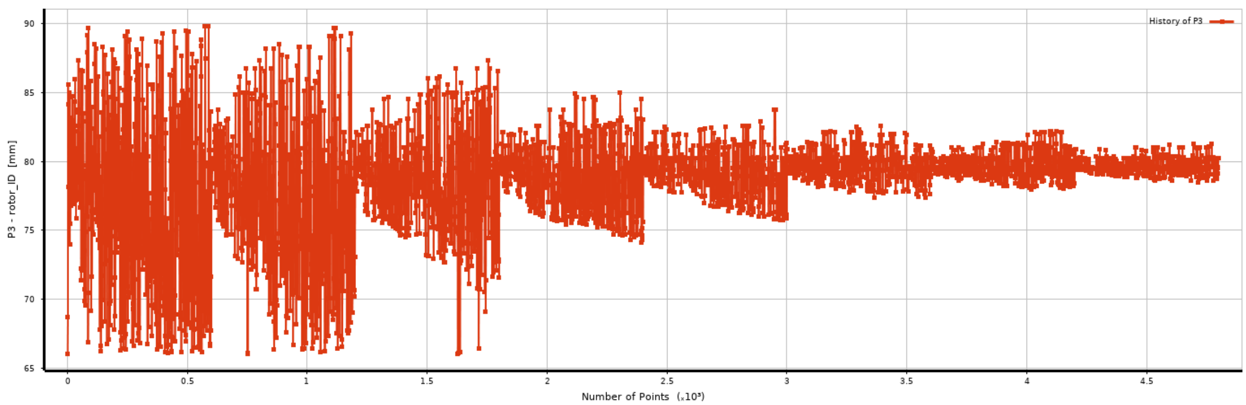




The parameter for P1 - rotor_thickness



For parameter for P2 - rotor_OD



The parameter for P3 - rotor_ID

Table of Schematic E4: Optimization , Candidate Points

	A	B	C	D	E	F	G	H	I	J	K
1	Reference	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			Parameter Value	Variation from Reference	Parameter Value	Variation from Reference		Parameter Value	Variation from Reference		
3		Candidate Point 1	22.501	0.00%	123.17	-0.22%	79.145	1.2522E+07	0.65%	346.31	1499.3
4		Candidate Point 2	22.5	0.00%	123.45	0.00%	79.651	1.2441E+07	-0.01%	346.5	1486.6
5		Candidate Point 3	22.5	0.00%	123.45	0.00%	79.369	1.2442E+07	0.00%	346.4	1493.4
*		New Custom Candidate Point	25		129.75		78				

Optimization

Auto with multiple objective method.

	A	B	C
1		Enabled	Monitoring
2	⊟ ✓ Optimization		
3	⊟ Objectives and Constraints		
4	Minimize P4; P4 <= 2.3599E+07 Pa		
5	Seek P1 = 22.5 mm		
6	Seek P2 = 122 mm		
7	⊟ Domain		
8	⊟ Geometry (A1)		
9	P1 - rotor_thickness	☑	
10	P2 - rotor_OD	☑	
11	P3 - rotor_ID	☑	

Properties of Outline A2: Optimization

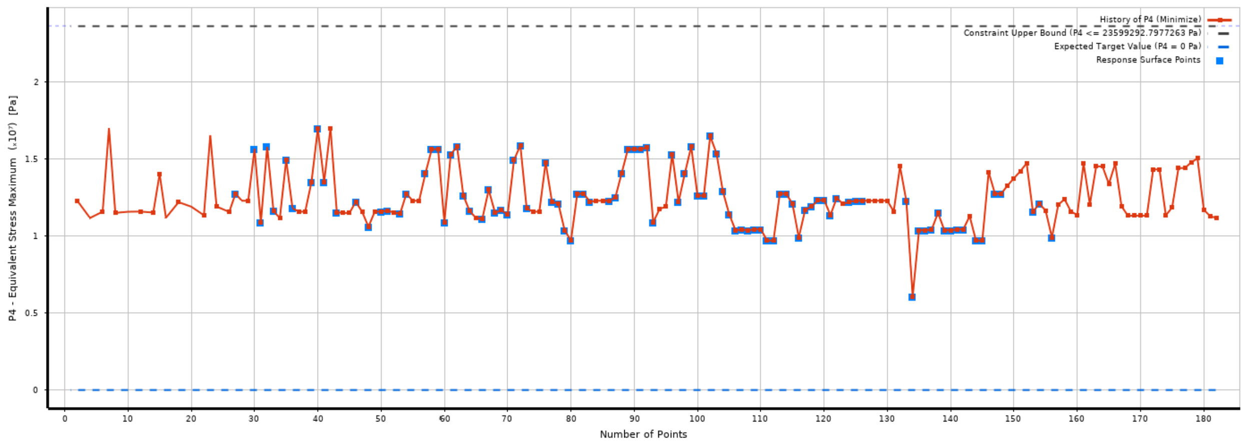
	A	B
1	Property	Value
2	⊟ Design Points	
3	Preserve Design Points After DX Run	☐
4	⊟ Failed Design Points Management	
5	Number of Retries	0
6	⊟ Optimization	
7	Method Selection	Auto
8	Run Time Index	5 - Medium
9	Estimated Number of Design Points	149
10	Method Name	Adaptive Multiple-Objective
11	Tolerance Settings	☑
[illegible]	Number of Initial	[illegible]

This shows the setup for multiple objective method

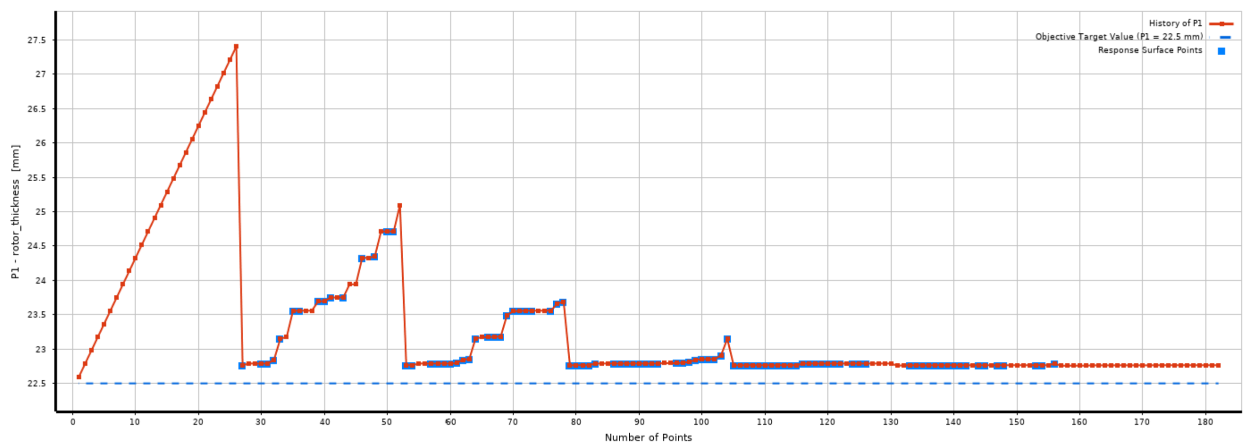
Table of Schematic F2: Optimization

	A	B	C	D	E	F	G	H	I
1	Name	Parameter	Objective			Constraint			
2			Type	Target	Tolerance	Type	Lower Bound	Upper Bound	Tolerance
3	Minimize P4; P4 <= 2.3599E+07 Pa	P4 - Equivalent Stress Maximum	Minimize	0		Values <= Upper Bound		2.3599E+07	0.001
4	Seek P1 = 22.5 mm	P1 - rotor_thickness	Seek Target	22.5	0.001	No Constraint			
5	Seek P2 = 122 mm	P2 - rotor_OD	Seek Target	122	0.001	No Constraint			
*		Select a Parameter							

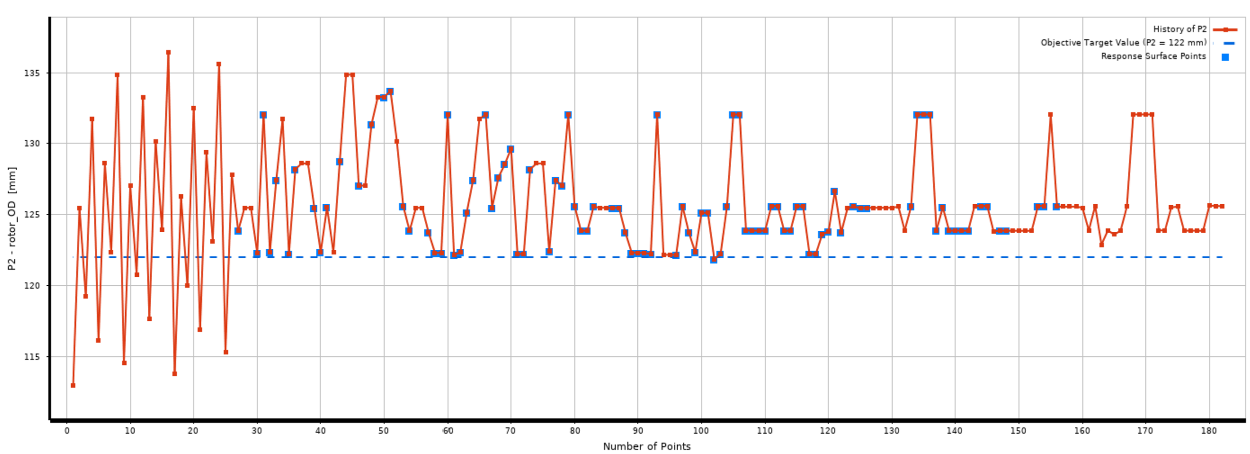
Objective and constraints for the system



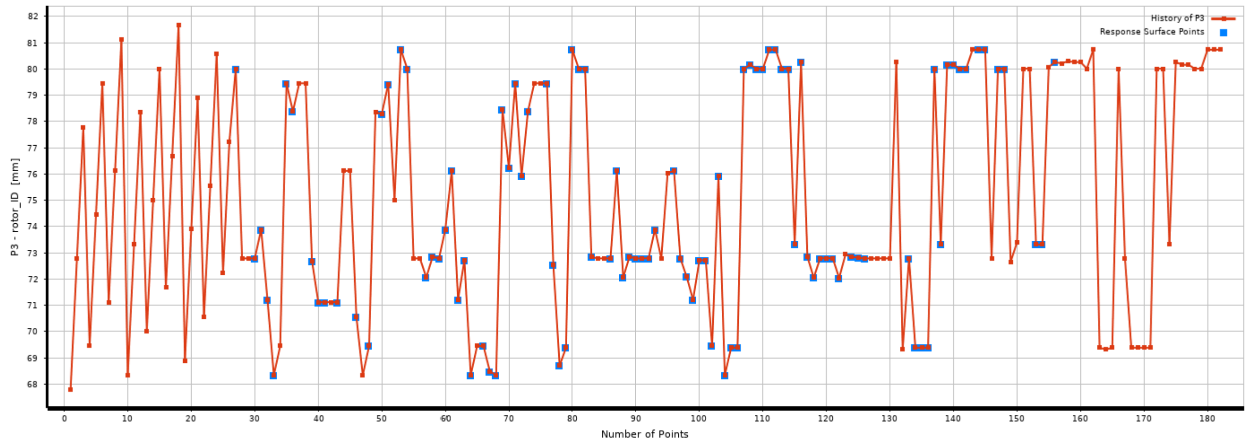
Stress and number of points



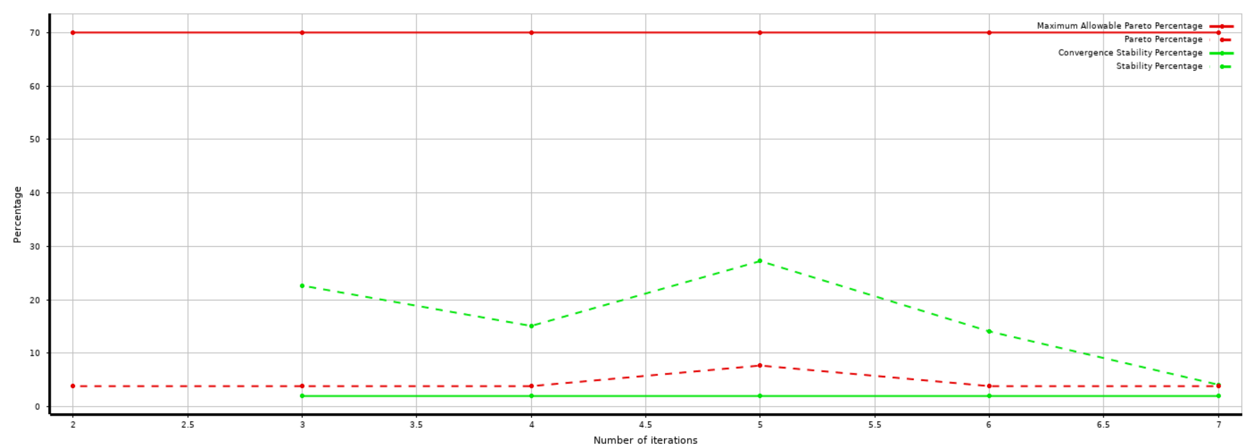
Rotor thickness and number of points



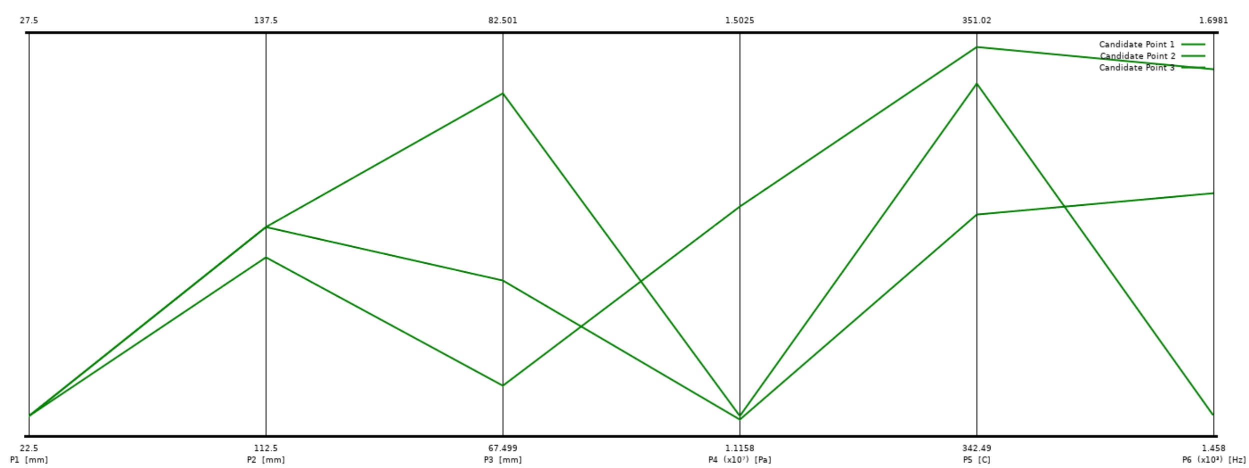
Parameter for p2 and number of points



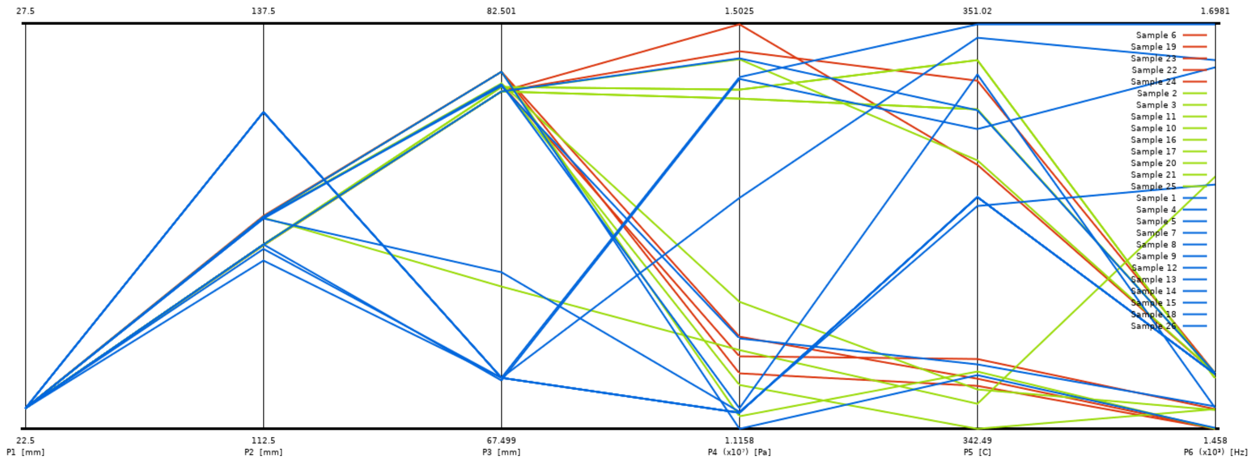
Parameter for inner and number of points



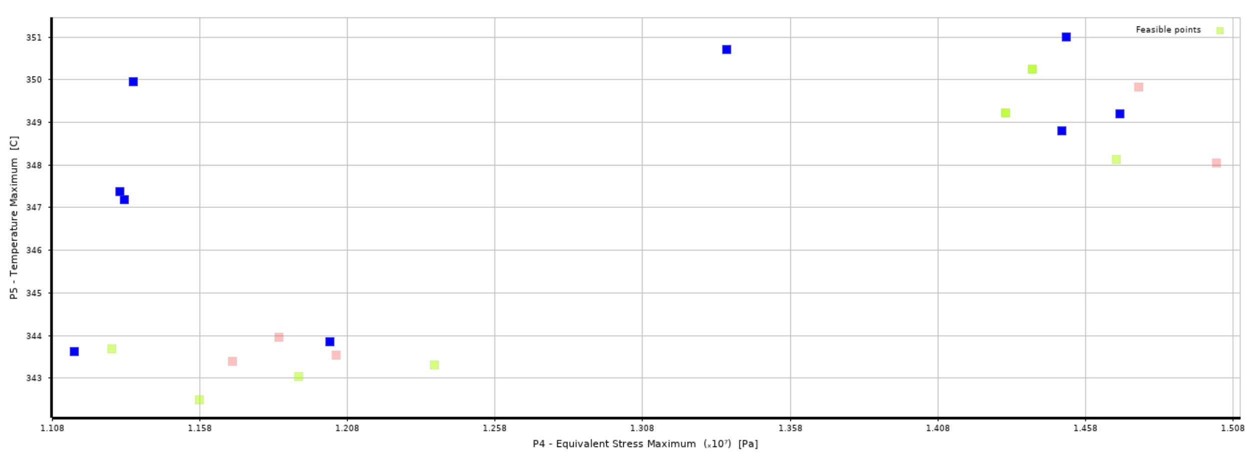
Convergys criteria



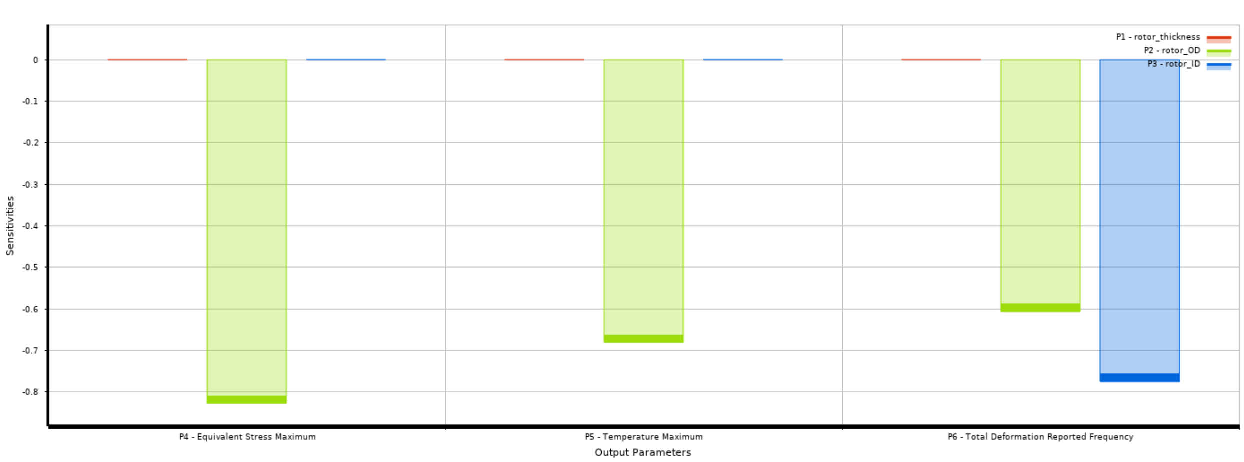
Candidate points



Sample plots



Stress and temperature



Sensitivity and output parameters

	A	B	C	D
1	Optimization Study			
2	Minimize P4; P4 <= 2.3599E+07 Pa	Goal, Minimize P4 (Default importance); Strict Constraint, P4 values less than or equals to 2.3599E+07 Pa (Default importance)		
3	Seek P2 = 122 mm	Goal, Seek P2 = 122 mm (Default Importance)		
4	Seek P1 = 22.5 mm	Goal, Seek P1 = 22.5 mm (Default Importance)		
5	Optimization Method			
6	Adaptive Multiple-Objective	The Adaptive Multiple-Objective method 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. It is limited to continuous and manufacturable input parameters.		
7	Configuration	Generate 26 samples initially, 26 samples per iteration and find 3 candidates in a maximum of 7 iterations.		
8	Status	Not Converged.		
9	Candidate Points			
10		Candidate Point 1	Candidate Point 2	Candidate Point 3
11	P1 - rotor_thickness (mm)	22.763	22.758	22.764
12	P2 - rotor_OD (mm)	123.6	125.49	125.51
13	P3 - rotor_ID (mm)	69.39	80.263	73.316
14	P4 - Equivalent Stress Maximum (Pa)	1.3367E+07	1.1357E+07	1.1327E+07

Candidate points

	A	B	C	D	E	F	G	H	I	J	K
1	Reference	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			Parameter Value	Variation from Reference	Parameter Value	Variation from Reference		Parameter Value	Variation from Reference		
3	◉	Candidate Point 1	22.763	0.00%	123.6	0.00%	69.39	1.3367E+07	0.00%	350.72	1676.7
4	○	Candidate Point 2	22.758	-0.02%	125.49	1.53%	80.263	1.1357E+07	-15.04%	349.97	1470.5
5	○	Candidate Point 3	22.764	0.00%	125.51	1.55%	73.316	1.1327E+07	-15.26%	347.2	1603.1
*		New Custom Candidate Point	25		125		75				

Candidate points