Design Optimization Project 2

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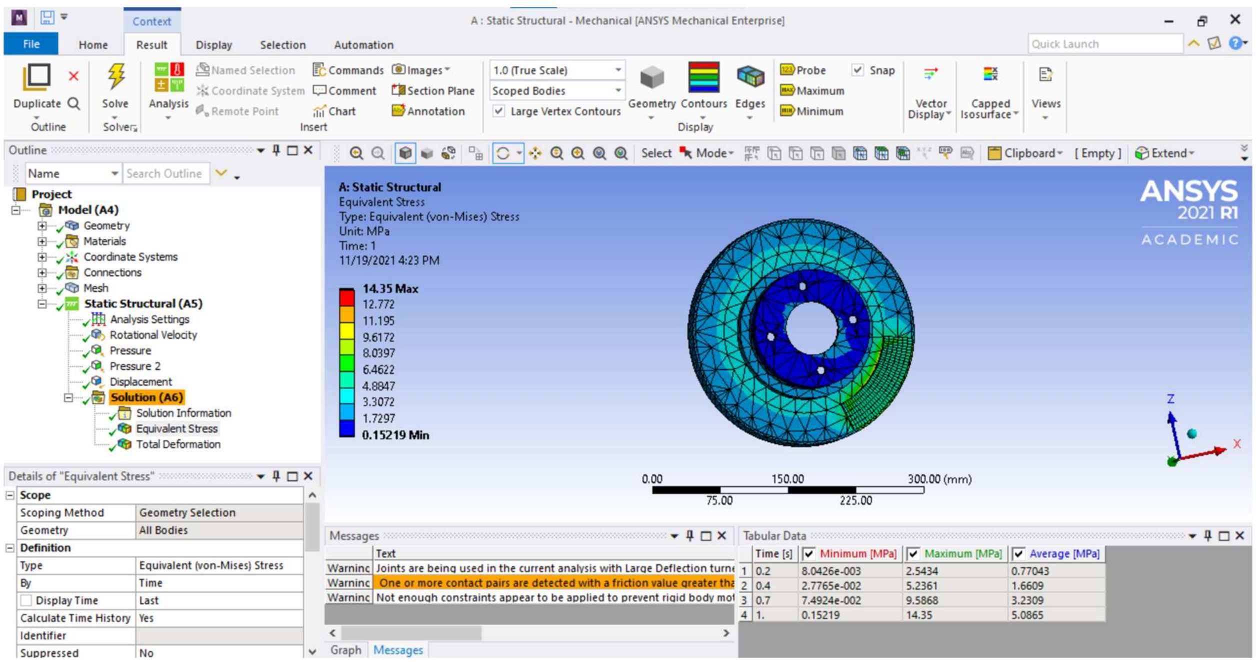
The aim of this optimization project was to design a brake for emergency conditions with minimal volume that would not only minimize the maximum stress in the brake disc, but also maximize the first natural frequency and minimize the maximum temperature of the brake disc.

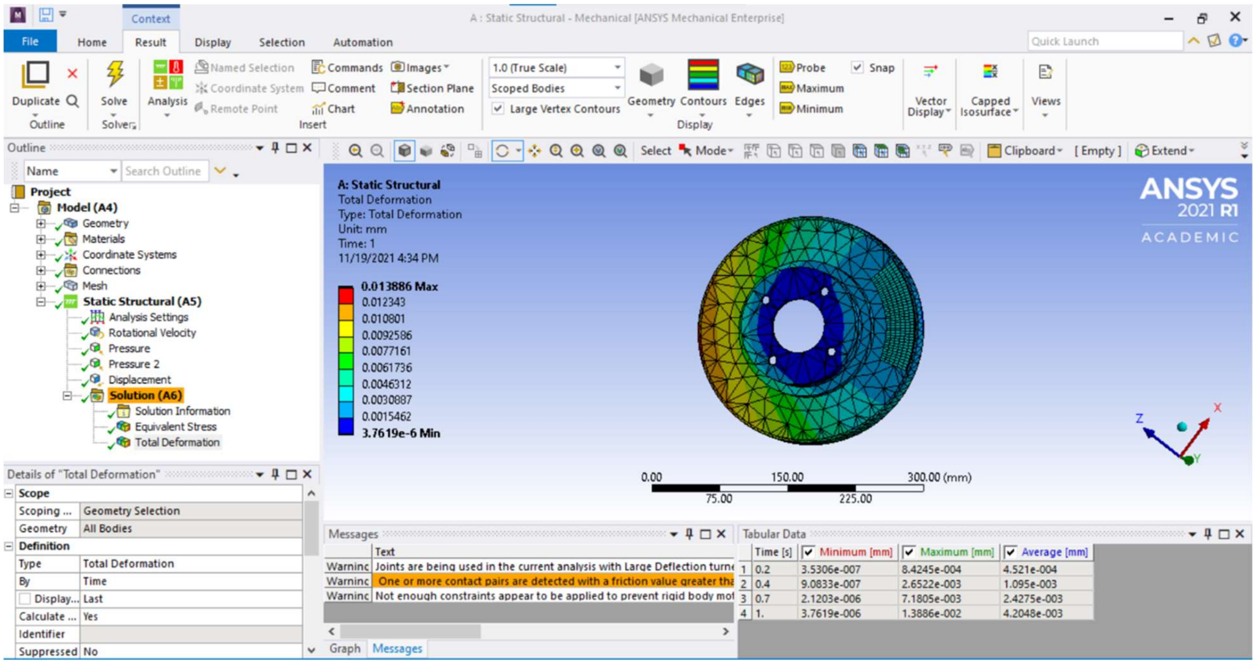
These conditions are desired because if not designed for the material failure could occur due to resultant stresses from centrifugal body forces, failure from resonance, and also wear and tear due to increase in its temperature and thermal stresses.

Thus, three studies were performed in ANSYS which are: Structural Analysis, Modal Analysis and Thermal Analysis. The results from each of these analyses are illustrated below. Furthermore, grey cast iron was the material used for the brake disc, and structural steel was used for the brake pads on the disc.

STATIC STURCTURAL

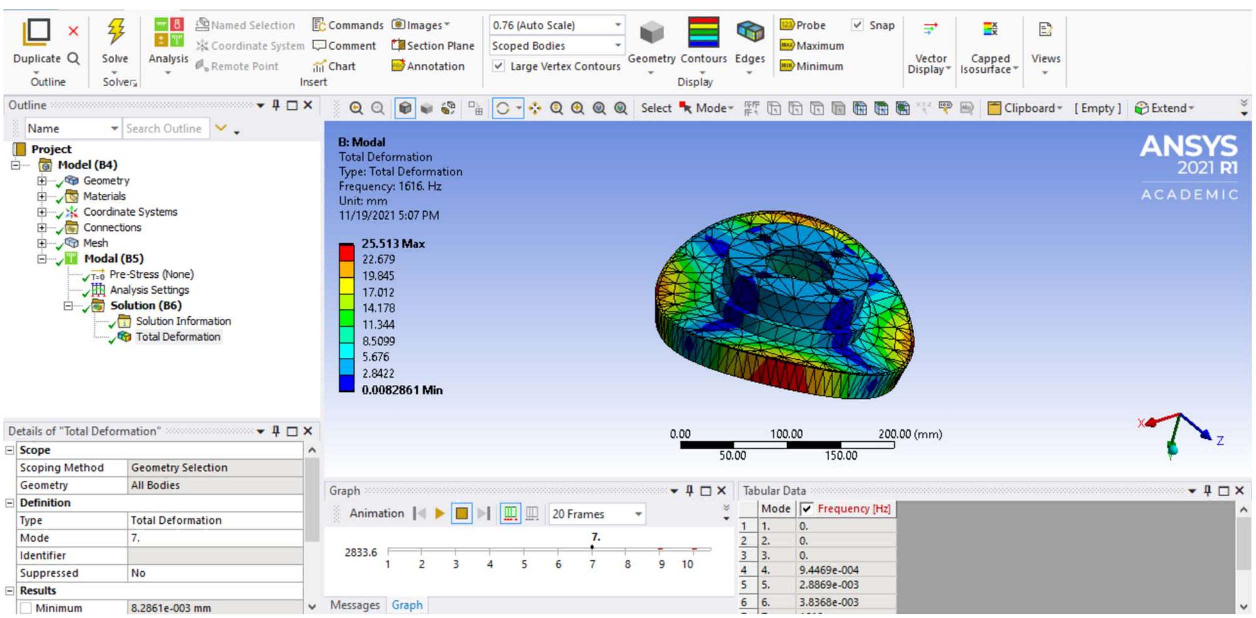


From the figure above, it can be seen from the initial analysis that the maximum stress is found in the region where the pads are in contact with the disc and the value is found to be about 14.35MPa.



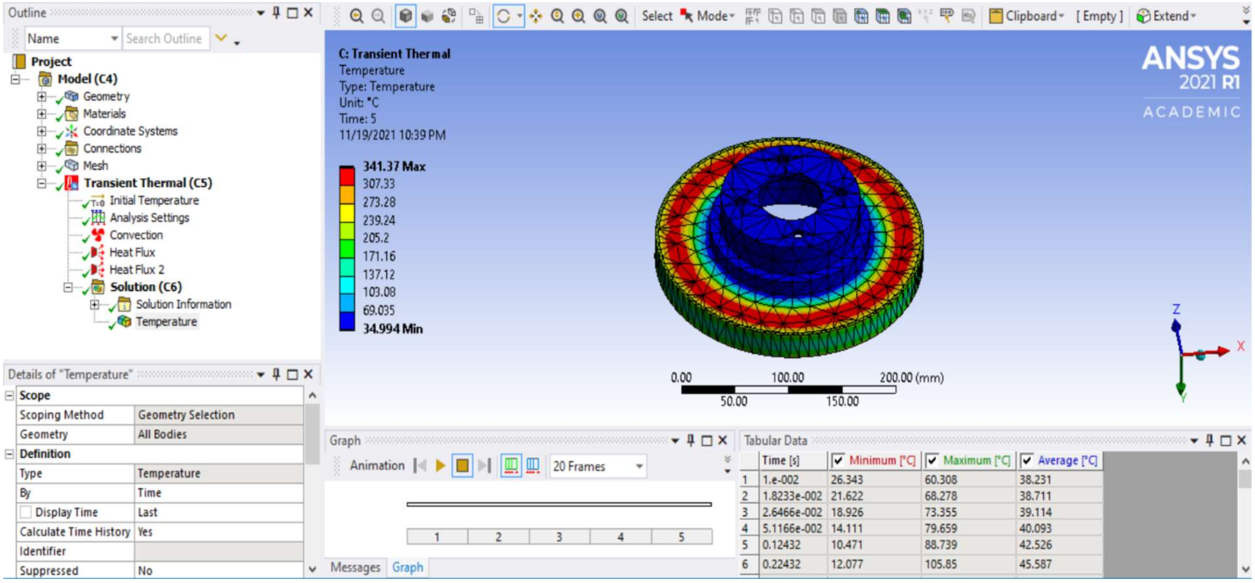
It can also be seen from the structural analysis that the maximum deformation in the disc under the load is 0.013886mm.

MODAL



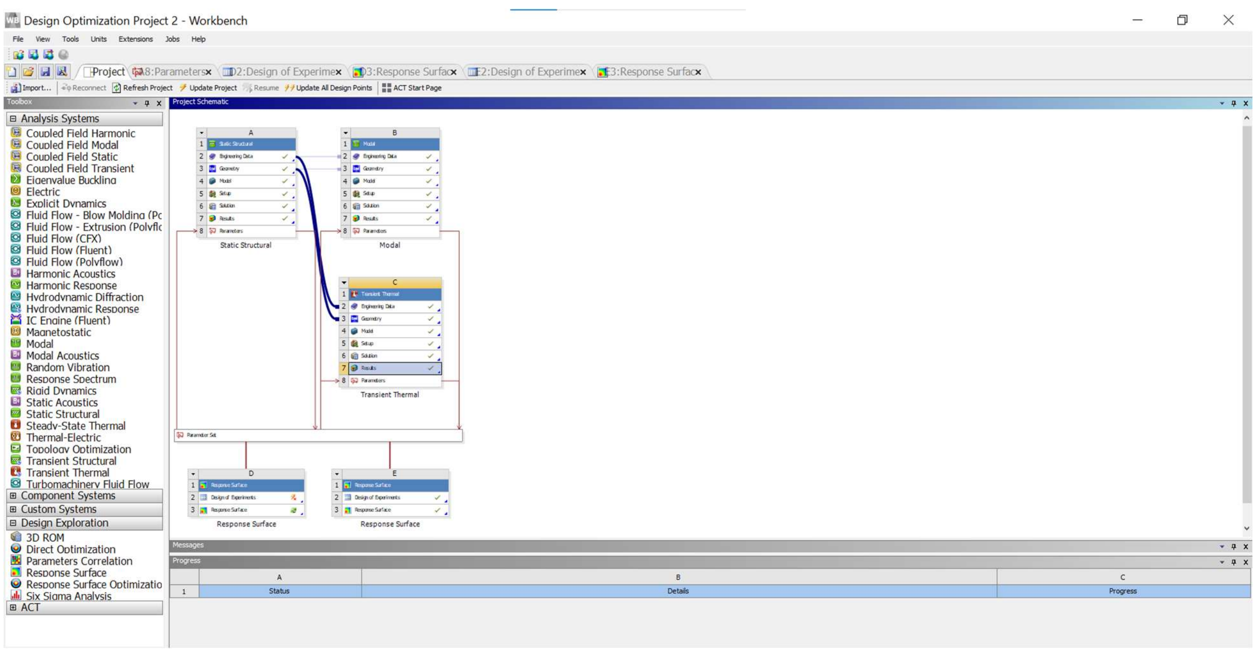
From the modal analysis, it can be seen that the maximum total deformation experienced by the body is 25.513mm and the frequency is 1616Hz.

THERMAL

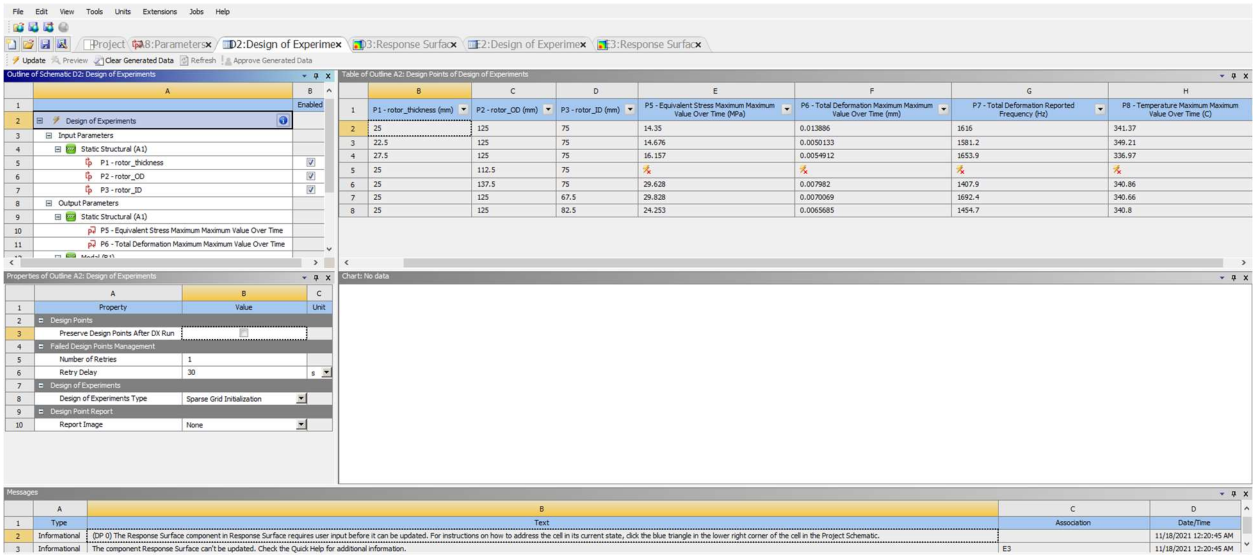


From the thermal analysis, it can be seen that the maximum temperature in the disc under the loading is 341.37ºC.

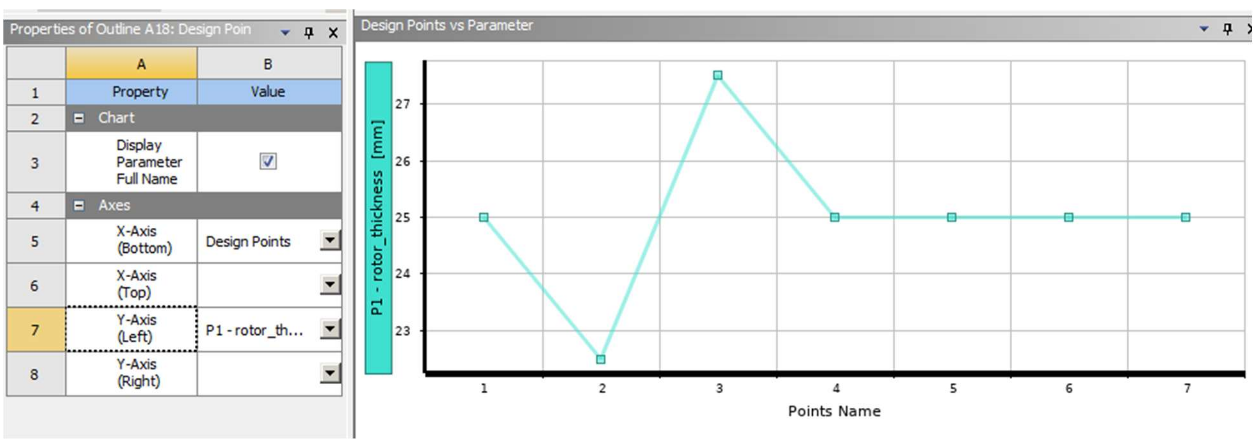
These are the main parameters that we will be optimizing and be utilizing later in the DOE.

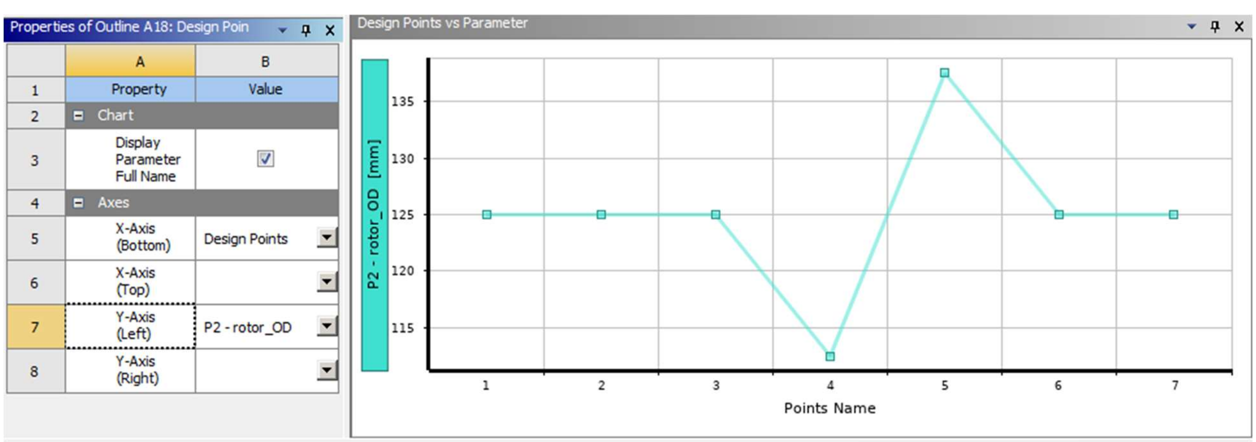


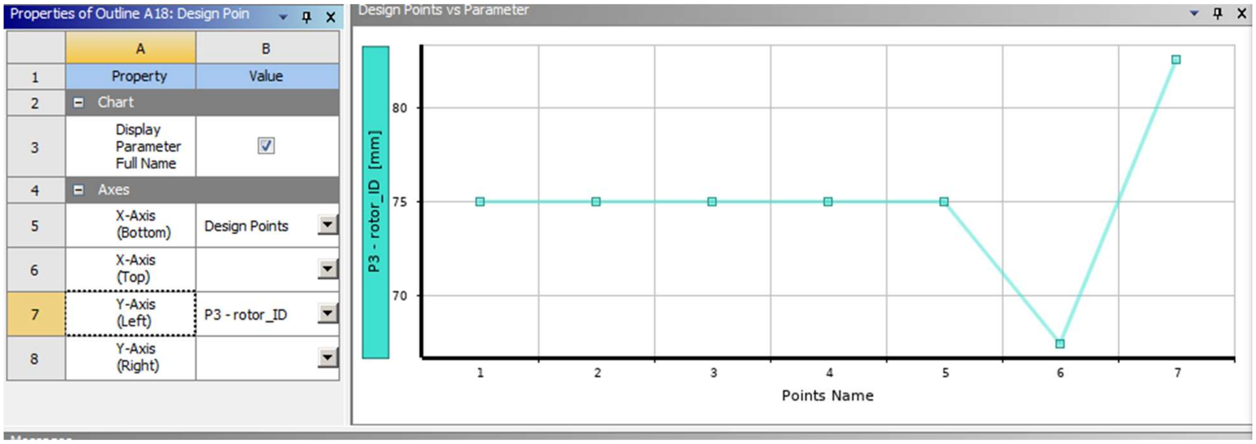
The ANSYS project schematic is shown in the figure above and as can be seen the input parameters are used for the structural, modal and thermal analysis and the output parameters from these analyses is then used for the response surface and design of experiments.

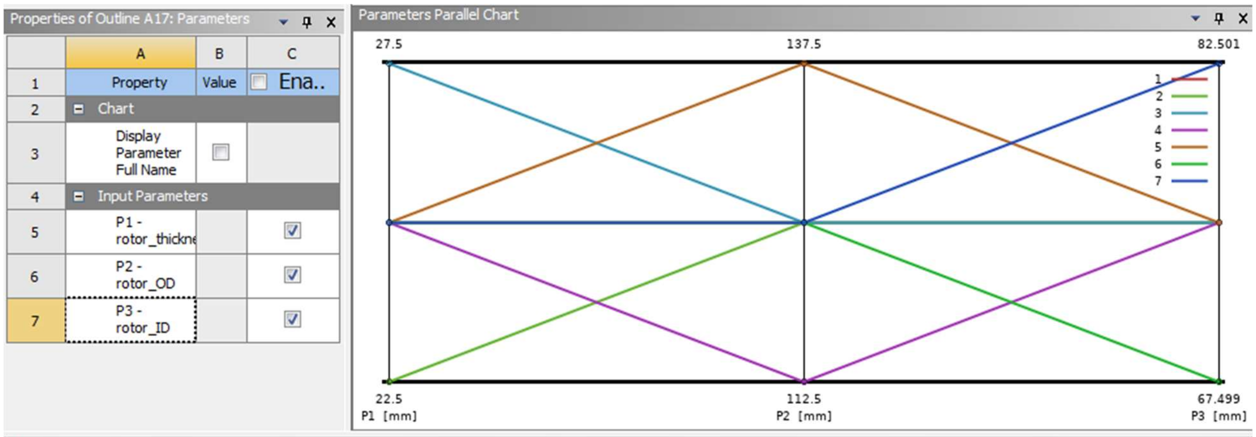


From the screenshot, it can be seen that the input parameters are rotor thickness, outer diameter and inner diameter. The output parameters from the static structural surface are the equivalent stress and the total deformation. From the modal, it is the total deformation reported frequency, and from the thermal it is the maximum temperature value over time.

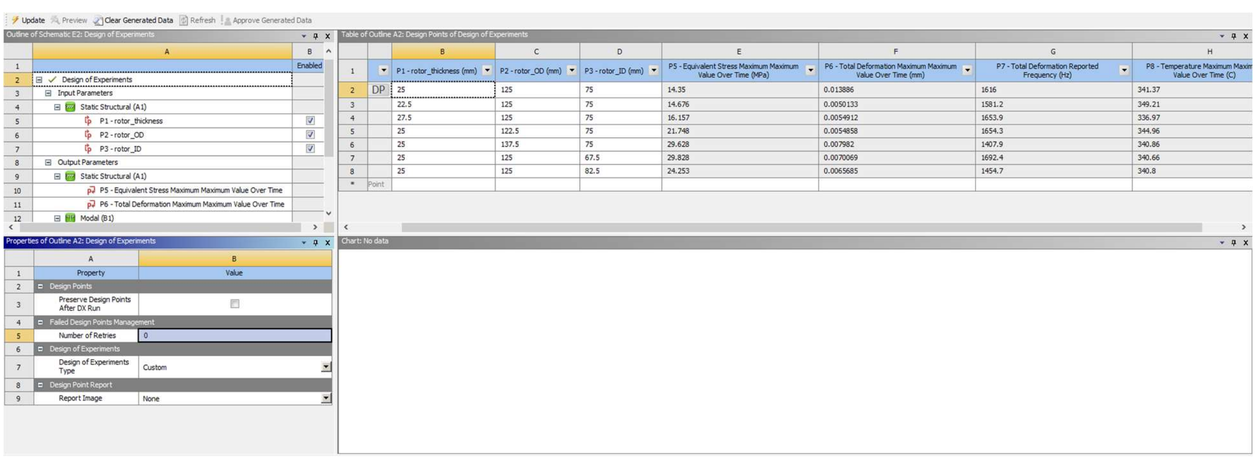




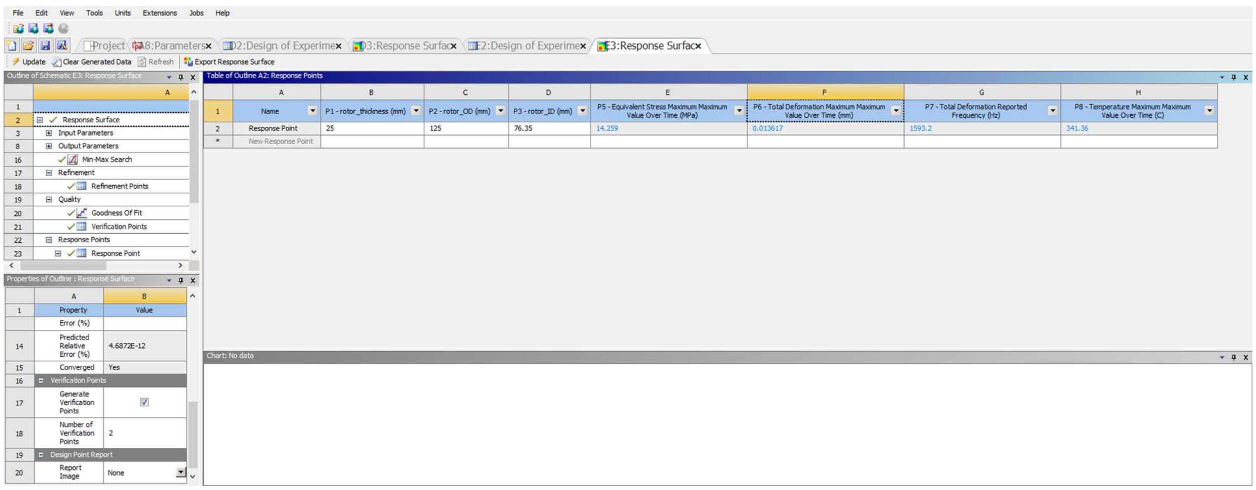




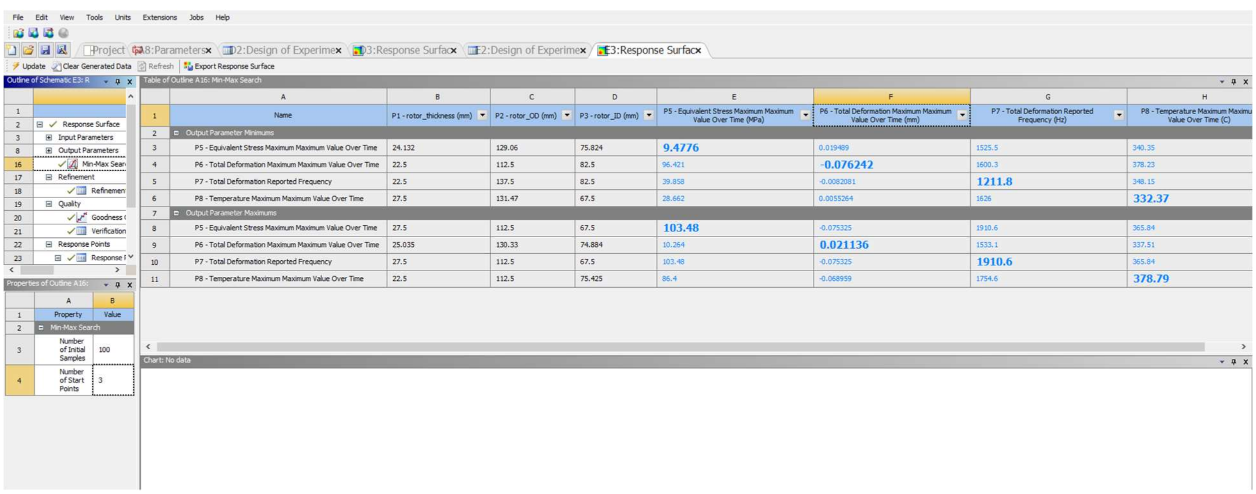
The Design of Experiments type that was used was Sparse Grid Initialization. Sparse grid is a more advanced sampling technique which only samples a few points initially and then depending on the response surface adaptively needs sample points. As can be seen from the DOE, one of the design points failed to compute due to the geometry and leaving the feasible space. To fix this issue, the .csv file was downloaded and manually adjusted before being uploaded back to ANSYS. This was then used for the response surface. The readjusted data table is illustrated in the figure below.

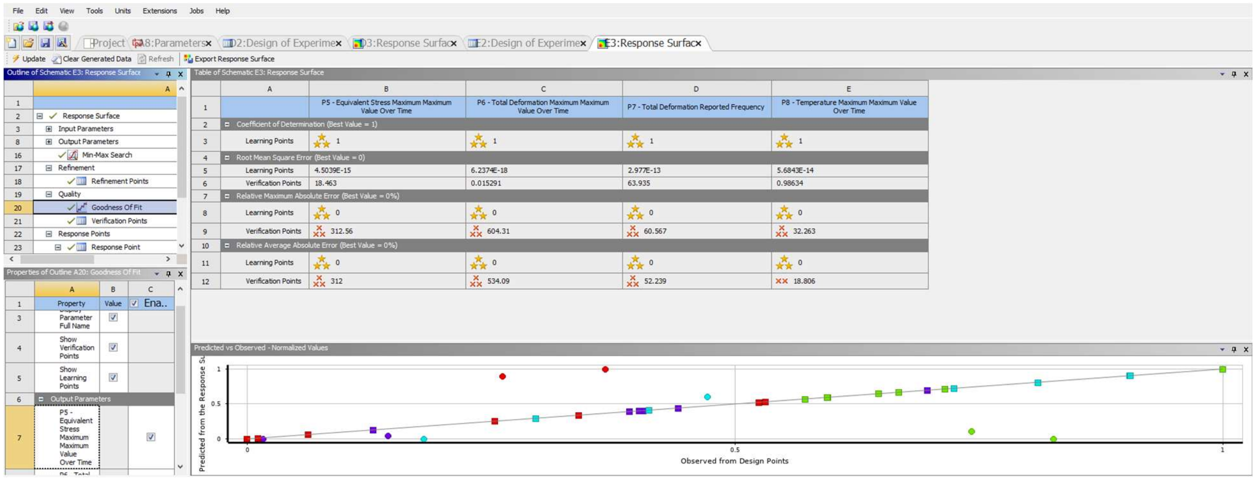


Due to the adjustment of the data table from the DOE, the Sparse grid type couldn't be used thus I used Kriging instead. I also used refinement to adjust the optimization process and also verification points as well. After running the response surface for a few minutes, it could be seen that the optimal rotor thickness is 25mm, the optimal outer diameter is 125mm, and the optimal inner diameter is 76.35mm. The optimal maximum equivalent stress was found to be 14.259MPa, optimal total deformation was 0.013617mm, and optimal total deformation reported frequency was 1593.2Hz, and finally optimal maximum temperature was found to be 341.36°C. These figures can all be confirmed and verified in the figure below.

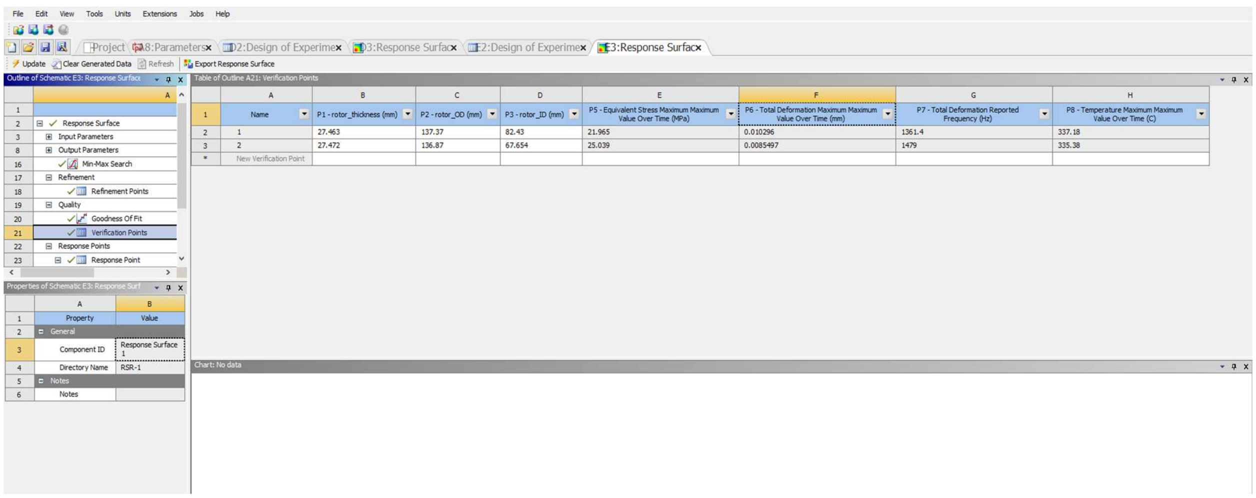


Some of the results from my response surface analysis can also be seen in the figures below:





	A	B	C	D	E
1		P5 - Equivalent Stress Maximum Maximum Value Over Time	P6 - Total Deformation Maximum Maximum Value Over Time	P7 - Total Deformation Reported Frequency	P8 - Temperature Maximum Maximum Value Over Time
2	Coefficient of Determination (Best Value = 1)				
3	Learning Points	1	1	1	1
4	Root Mean Square Error (Best Value = 0)				
5	Learning Points	4.5039E-15	6.2374E-18	2.977E-13	5.6843E-14
6	Verification Points	18.463	0.015291	63.935	0.98634
7	Relative Maximum Absolute Error (Best Value = 0%)				
8	Learning Points	0	0	0	0
9	Verification Points	312.56	604.31	60.567	32.263
10	Relative Average Absolute Error (Best Value = 0%)				
11	Learning Points	0	0	0	0
12	Verification Points	312	534.09	52.239	18.806



	A	B	C	D	E	F	G	H
1	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P5 - Equivalent Stress Maximum Maximum Value Over Time (MPa)	P6 - Total Deformation Maximum Maximum Value Over Time (mm)	P7 - Total Deformation Reported Frequency (Hz)	P8 - Temperature Maximum Maximum Value Over Time (C)
2	1	27.463	137.37	82.43	21.965	0.010296	1361.4	337.18
3	2	27.472	136.87	67.654	25.039	0.0085497	1479	335.38
*	New Verification Point							

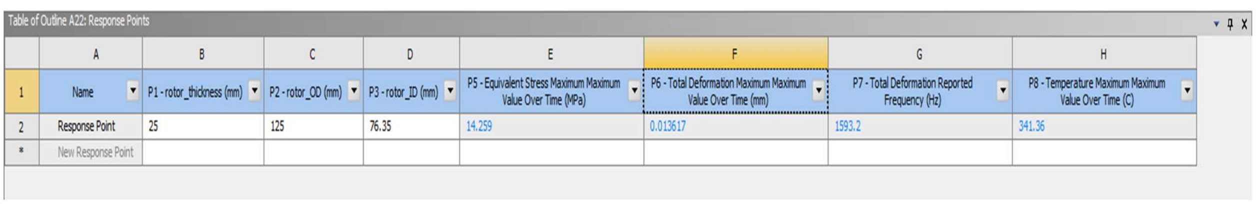
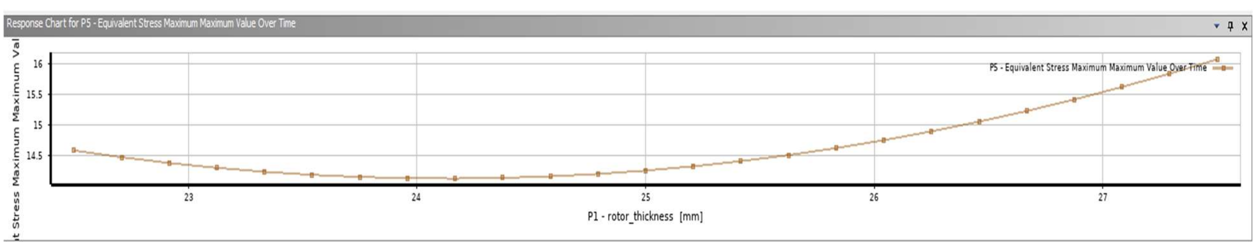
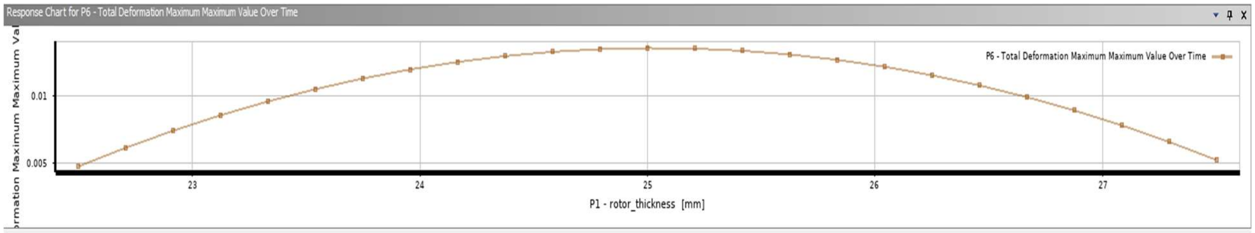
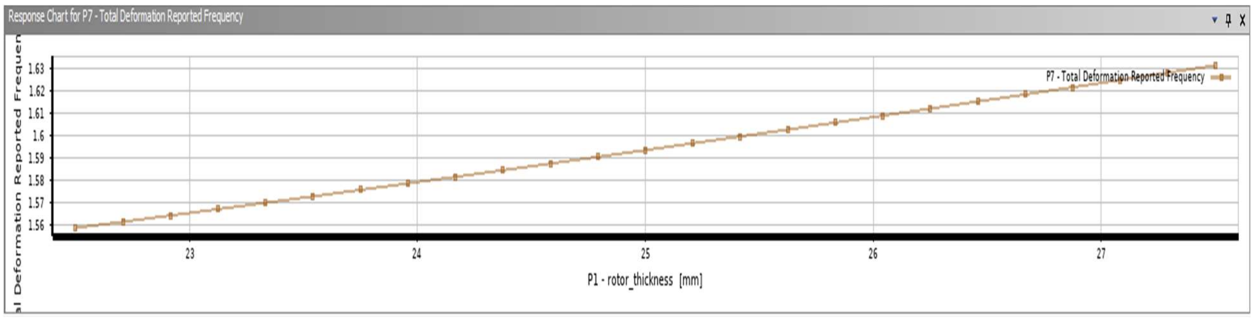


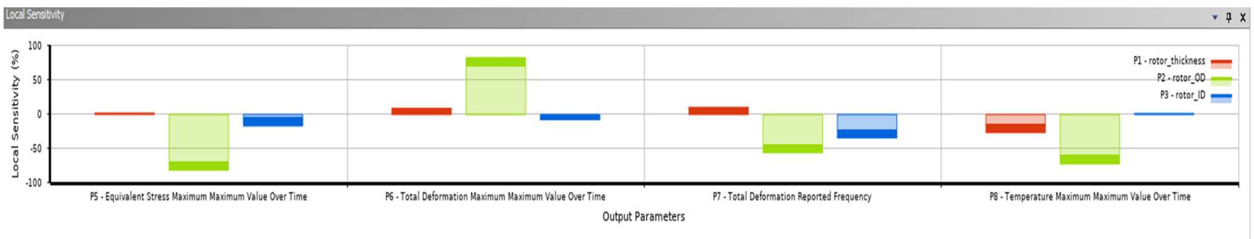
Table of Outline A22: Response Points

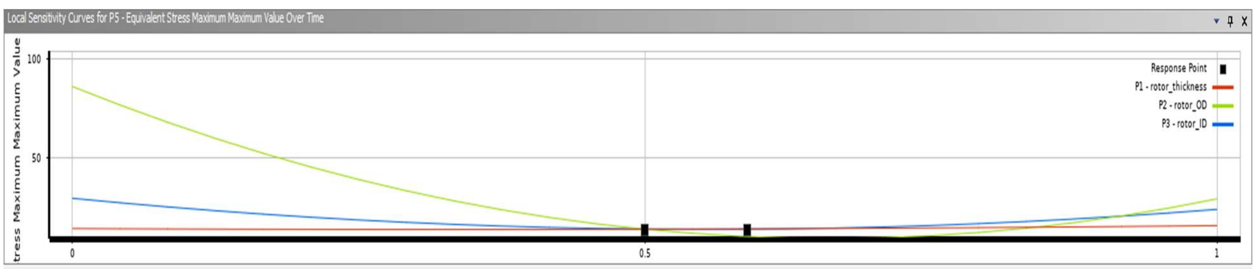
	A	B	C	D	E	F	G	H
1	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P5 - Equivalent Stress Maximum Maximum Value Over Time (MPa)	P6 - Total Deformation Maximum Maximum Value Over Time (mm)	P7 - Total Deformation Reported Frequency (Hz)	P8 - Temperature Maximum Maximum Value Over Time (C)
2	Response Point	25	125	76.35	14.259	0.013617	1593.2	341.36
*	New Response Point							

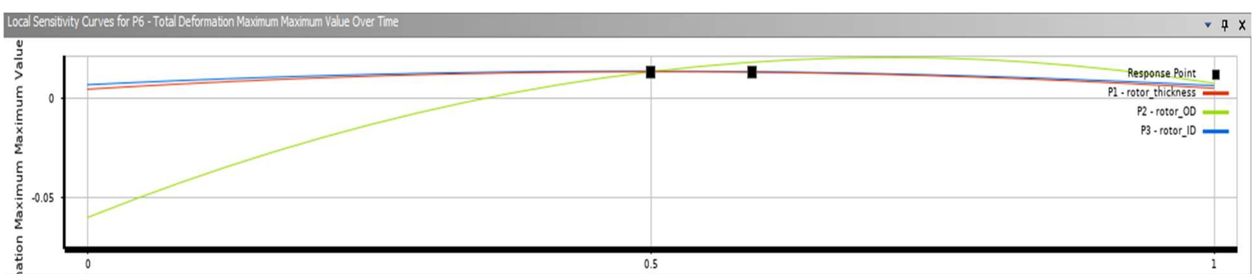


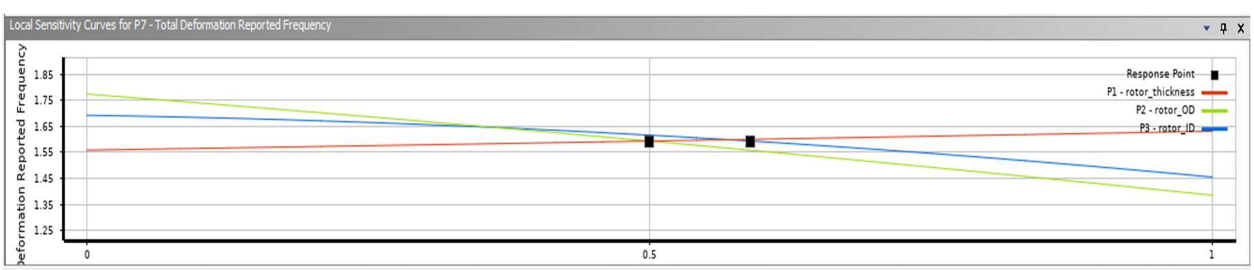

Response Chart for P6 - Total Deformation Maximum Maximum Value Over Time
P6 - Total Deformation Maximum Maximum Value Over Time
0.01
0.005
23
24
25
26
27
P1 - rotor_thickness [mm]

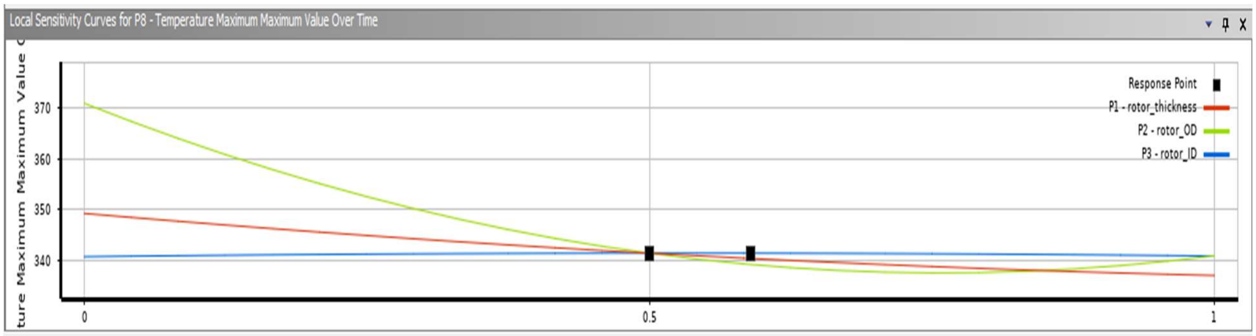

Response Chart for P7 - Total Deformation Reported Frequency
P7 - Total Deformation Reported Frequency
1.63
1.62
1.61
1.6
1.59
1.58
1.57
1.56
23
24
25
26
27
P1 - rotor_thickness [mm]


Local Sensitivity
Local Sensitivity (%)
100
50
0
-50
-100
P1 - rotor_thickness
P2 - rotor_OD
P3 - rotor_ID
P5 - Equivalent Stress Maximum Maximum Value Over Time
P6 - Total Deformation Maximum Maximum Value Over Time
P7 - Total Deformation Reported Frequency
P8 - Temperature Maximum Maximum Value Over Time
Output Parameters


Local Sensitivity Curves for P5 - Equivalent Stress Maximum Maximum Value Over Time
100
50
0
0.5
1
Response Point
P1 - rotor_thickness
P2 - rotor_OD
P3 - rotor_ID


Local Sensitivity Curves for P6 - Total Deformation Maximum Maximum Value Over Time
0
-0.05
0
0.5
1
Response Point
P1 - rotor_thickness
P2 - rotor_OD
P3 - rotor_ID


Local Sensitivity Curves for P7 - Total Deformation Reported Frequency
1.85
1.75
1.65
1.55
1.45
1.35
1.25
0
0.5
1
Response Point
P1 - rotor_thickness
P2 - rotor_OD
P3 - rotor_ID



Some of the observations that were made during the optimization analysis are as follows:

1.) There was some trade-off between the objectives when adjusting the parameters. After some trial and error, I noticed that I couldn't continue to minimize the upper bound of the temperature from the thermal analysis without compromising the input parameters from the static structural analysis. Design parameters that ran into this issue failed to compute.
2.) Furthermore, all the variables that were used for the DoE and response surface were continuous.
3.) My objective/constraint functions were analytical but due to some very sharp corners as can be seen in the design points vs parameter charts, they were not always differentiable.
4.) The optimization method I chose for the DoE was Sparse Grid Initialization, and I used Kriging for the response surface.
5.) Sensitivity Analysis was also performed, and this can be seen with the local sensitivity graphs and sensitivity curves. Monotonicity was only seen with the total deformation and rotor thickness and total deformation. As the rotor thickness increases, the total deformation increases linearly as well.
6.) After the optimization analysis, the parameters from the initial are compared with those after the analysis is completed. These values are reported in the table below.

	Rotor Thickness(mm)	Rotor O.D (mm)	Rotor I.D (mm)
Initial	25	125	75
After Analysis	25	125	76.35

Input Parameters

	Equivalent Stress	Total deformation	First natural frequency	Maximum Temperature
Initial	14.350MPa	0.013886mm	1616Hz	341.37ºC
After Analysis	14.259MPa	0.013617mm	1593.2Hz	341.36ºC

Output parameters