Project 2

Design Optimization

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Abstract:

A disk break is to be optimized to achieve the following objectives: (1) minimize the overall volume of the component, (2) minimize the maximum stress in the rotor, (3) maximize the 1st deformation frequency response of the break, (4) Minimize the maximum temperature of the brake rotor. Ansys is used to simulate brake pads applying a pressure onto the brake rotor to extract mechanical, thermal, and harmonic responses of the system.

Model:

Model of the braking pads and rotors were provided, and materials were specified as Gray Cast Iron for the rotor and structural steel at the brake pads.

- Brake pad material: Structural Steel
- Brake rotor: Gray Cast Iron

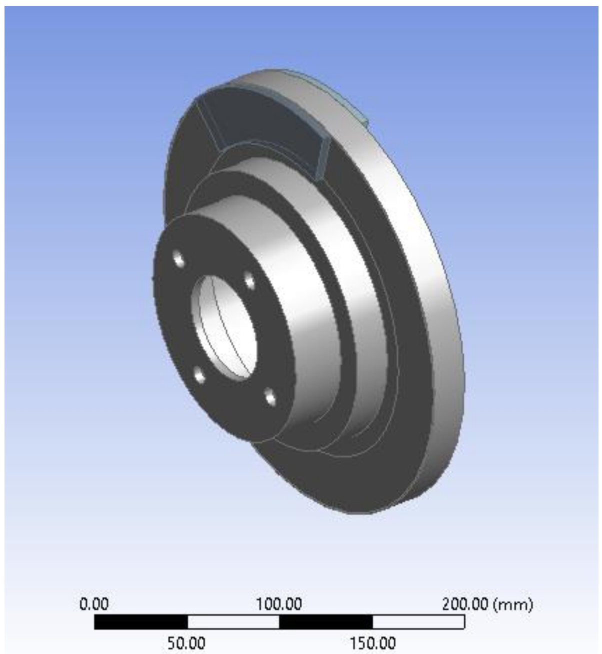


Figure 1: System Geometry

Mesh:

A patch conforming tetrahedron method was implemented to mesh the rotor geometry. Mesh sizing refinement was implemented at the face-face contact region of the brake pads and brake rotor. Figure2 and figure3 illustrate the meshed brake system.

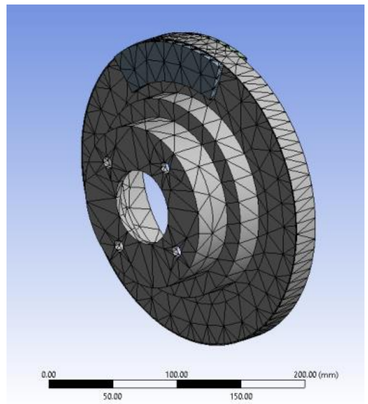


Figure 2:

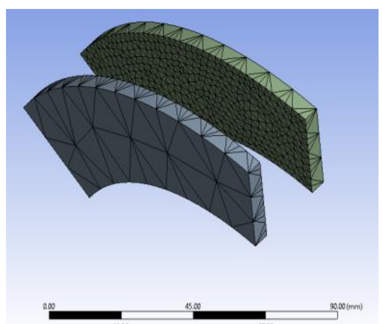


Figure 3

Static Structural:

A Static Structural simulation was implemented to extract both the maximum von-misses stress and total system volume. System boundary conditions were set as:

1. rotational velocity: 250 rad/s at the y-axis
2. Revolute Joint: Body to ground connection type at the inner diameter interface
3. Displacement of the system was fixed in the x-axis and z-axis
4. Frictional contact points at the break bad and brake rotor interface. A coefficient of frication of .22 was set for both components

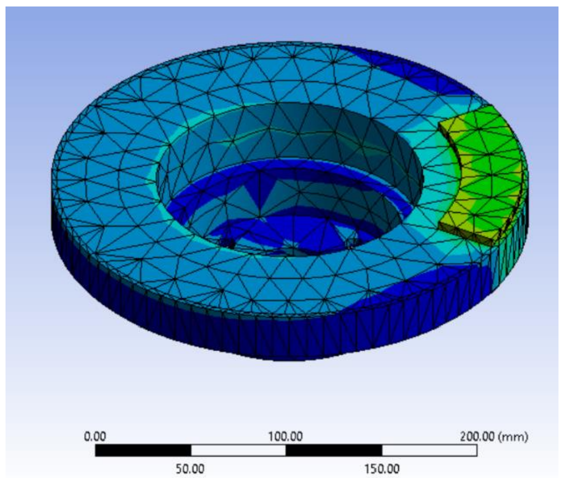


Figure 4

Modal:

A modal analysis was implemented to extract the first frequency of deformation. Ten modes were extracted, and the 7^{th} mode was determined to be the first frequency of deformation and was set the output.

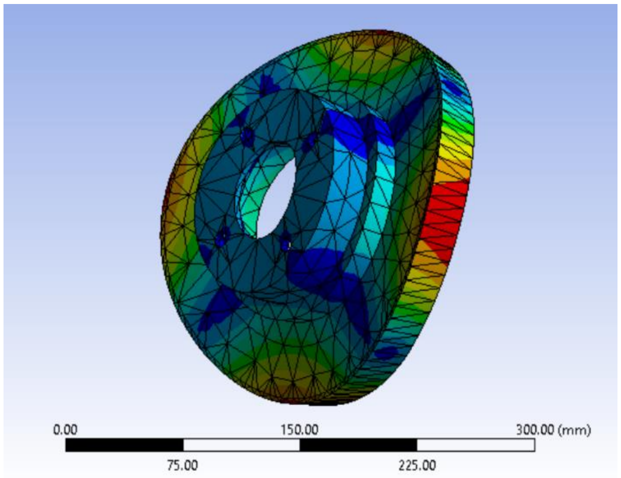


Figure 5

Transient Thermal:

A 5 second transient thermal analysis was run to extract the maximum temperature experience at the brake rotor. The following condition were set for the simulation:

1. Initial temperature:35c
2. Convection: 5. W/m^2
3. Heat Flux: Defined at the contact face = 1.5395 W/m^2

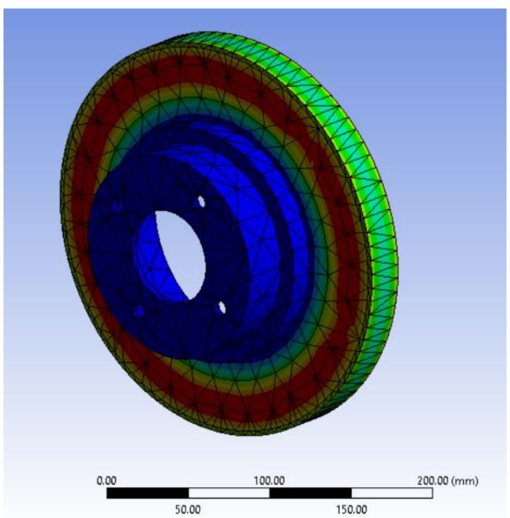


Figure 6

Optimization:

The applied design optimization considered: total volume, maximum Von-Misses stress, maximum temperature, and the first frequency of modal deformation. The respective system characteristic objectives are listed in table 1. Table 2 details the parameterization of the brake rotor geometry and the corresponding objective outcome for optimization of the rotor system. For this optimization the brake parameters were limited to a dimensional range that would eliminate any geometric conflict. Furthermore, the system parameters were each defined by manufacturable increments of .2mm by implementing a snap to feature in Ansys optimization tool.

Table 1

Volume Total	Minimize
With consideration to:	
Equivalent Stress Maximum	Minimize
Total Deformation Reported Frequency	Maximize
Temperature Maximum	Minimize
rotor_thickness	Bounded
rotor_OD	Bounded
rotor_ID	Bounded

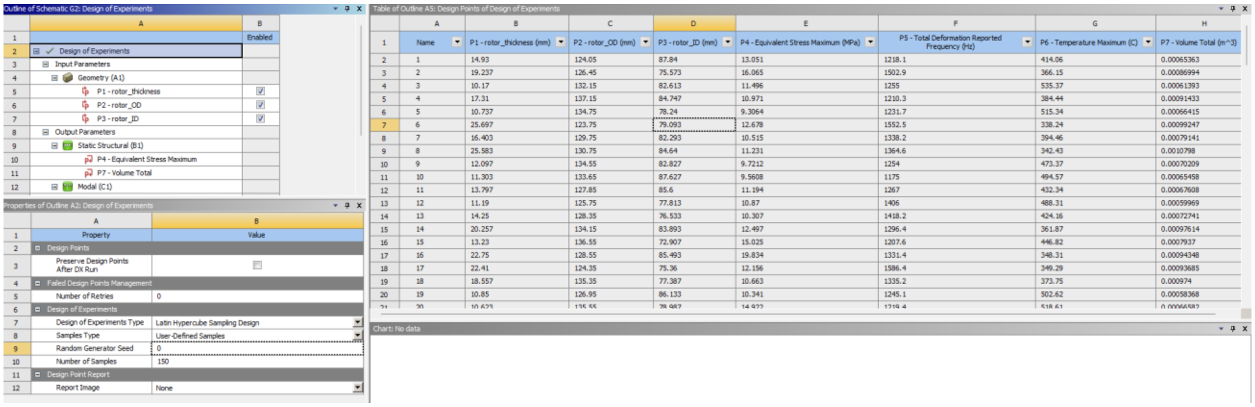
Table 2

Input Parameter	Lower Bound (mm)	Upper Bound (mm)	Incriment Delta (mm)	Objective:
Rotor Thickness	10	27	.2	Minimize
Inside Diameter	72	88	.2	Maximize
Outside Rotor Diameter	123	138	.2	Minimize

Optimization procedure:

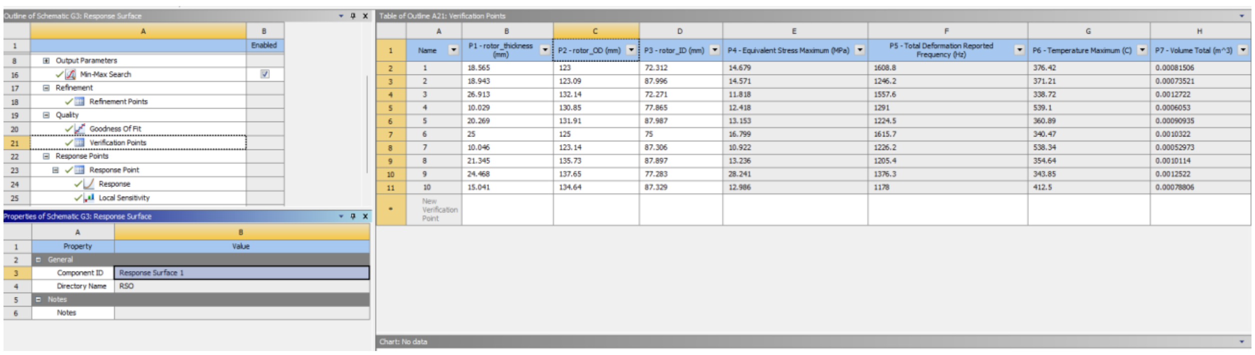
DOE:

A design of experiments (DOE) of type Latin Hyper Cube sampling was implemented with user defined sampling being set to 150 samples. Design parameters for the DOE were continuous through the defined bounds as established in table 2 (no specified step increment for DOE). Sampling point for the DOE were incremented during optimization after investigation of the response surface and Goodness of Fit.

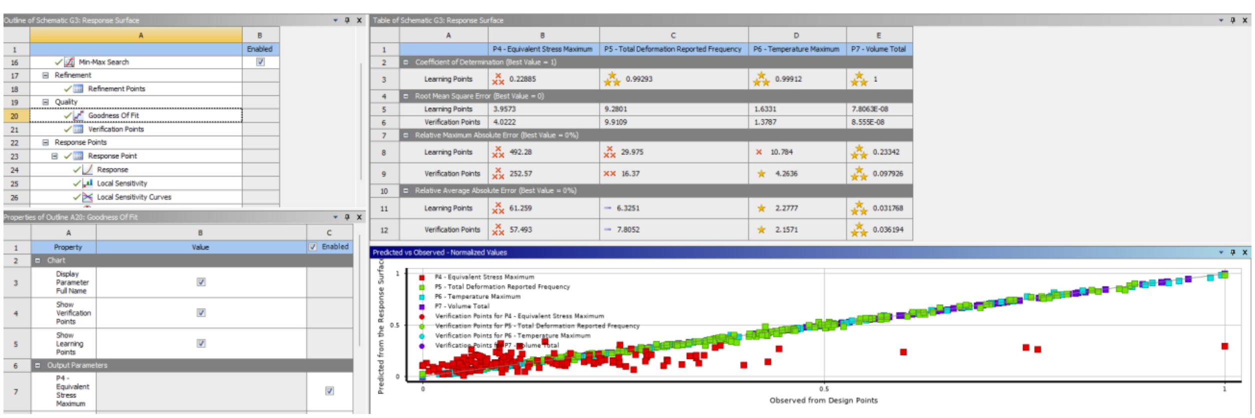


Surface Plot:

The DOE was used to generate a response surface of the brake system. The Metas model implemented was “Standard Response Surface – Full second order polynomial”. Moreover, the refinement type was set to manual, and 10 verification points were generated for model assessment. Additionally, the initial deign geometry as a verification point and the corresponding verification points were set as refinement points on the model.



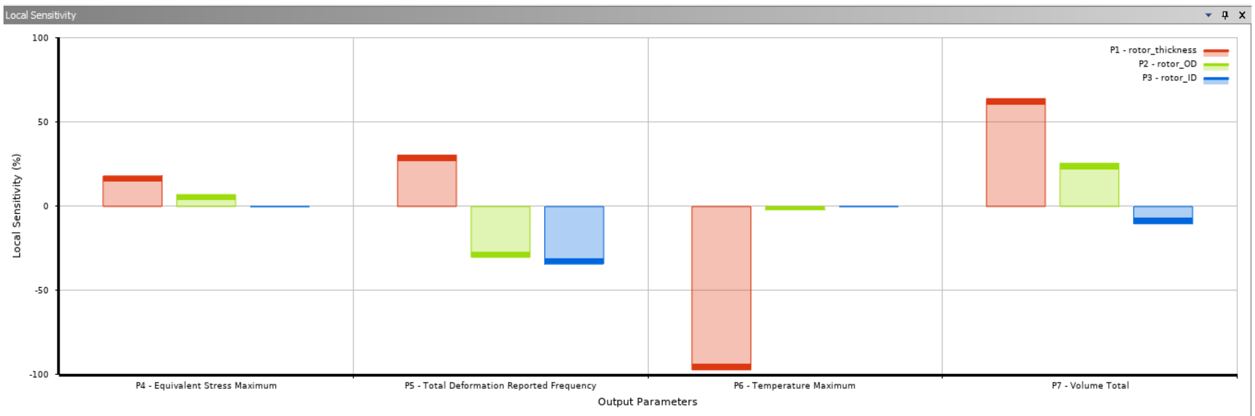
Although, the goodness fit for the “Standard Response Surface – Full second order polynomial” model was a perfect fit as seen in other model types, verification of optimal configuration showed the best result when compared to other models.



Sensitivity:

Investigating the system sensitivities generated through direct optimization show the following:

1. Rotor thickness has the largest impact on equivalent stress, rotor temperature, and total system volume.
2. Rotor inside diameter has a large impact on equivalent stress and modal deformation frequency onset
3. Rotor outside diameter has a large impact on modal deformation frequency onset



Surface Plot Optimization:

A Multi Objective Genetic Algorithm (MOGA) was implemented with manual sampling selection set to Initial sample 10,000 and samples per iteration to 2000 after experimentation showed improvements in the result at the higher sampling rate. All other settings were left as set by ANSYS. T

	A	B	C	D	E	F
1	⊟ Optimization Study					
2	Minimize P7	Goal, Minimize P7 (Higher importance)				
3	Minimize P4	Goal, Minimize P4 (Default importance)				
4	Maximize P5	Goal, Maximize P5 (Default importance)				
5	Minimize P4	Goal, Minimize P6 (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 10000 samples initially, 2000 samples per iteration and find 4 candidates in a maximum of 40 iterations.				
9	Status	Converged after 20242 evaluations.				

roperties of Outline A2: Optimization

	A	B	C
1	Property	Value	Unit
8	⊟ Optimization		
9	Method Selection	Manual	
10	Method Name	MOGA	
11	Estimated Number of Evaluations	88000	
12	Tolerance Settings	☑	
13	Verify Candidate Points	☐	
14	Number of Initial Samples	10000	
15	Number of Samples Per Iteration	2000	
16	Maximum Allowable Pareto Percentage	70	
17	Convergence Stability Percentage	2	
18	Maximum Number of Iterations	40	
19	Maximum Number of Candidates	4	

As expected, the many defined objectives resulted in trade-off in optimizations of the system. To achieve a more robust optimization a practical analysis of the brake system and its application was considered to characterize objectives by criticality shown in table 3. Additional consideration was given to the starting geometry as defined by the problem statement, this led to targets being set for modal and thermal responses due to their variability in volume optimization.

Table 3

Objective criticality table:				
Objective:	Criticality:	Type:	Target	Notes:
Thermal:	Neutral	minimize	350C	Thermal expansion, fowling, and other..
Modal deformation:	Neutral	maximize	1700Hz	Simulated freq. << Experienced RPM
Von Misses stress:	Neutral	minimize	none	Simulated values << Tensile strength, Ultimate
Volume	High	minimize	none	material and weight savings, form factor

Optimization Results and Discussion:

The optimization was run, and the corresponding result table shows three candidate point for design given the parameters set in table 3. Design point 1 was chosen as the solution point and a verification of the design point was run.

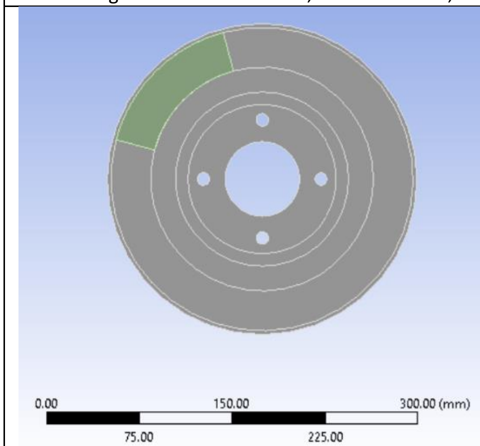
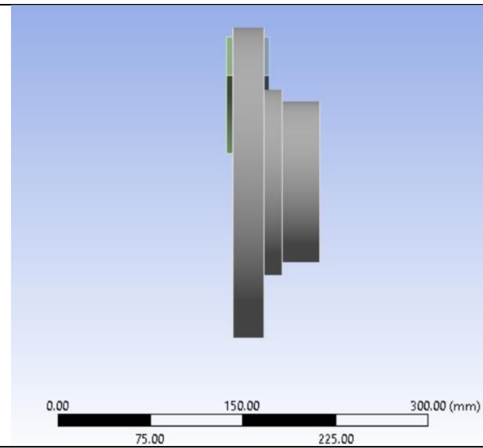
Table of Schematic G4: Optimization , Candidate Points

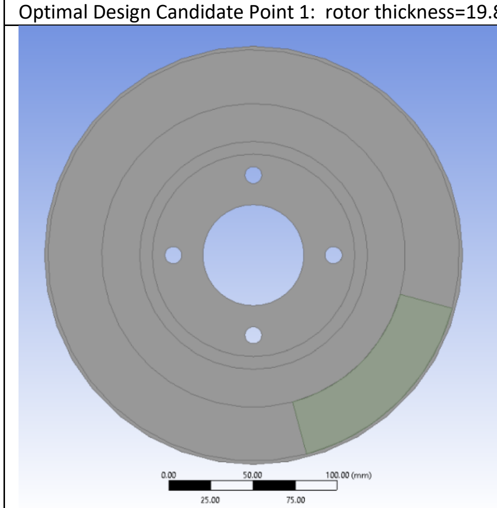
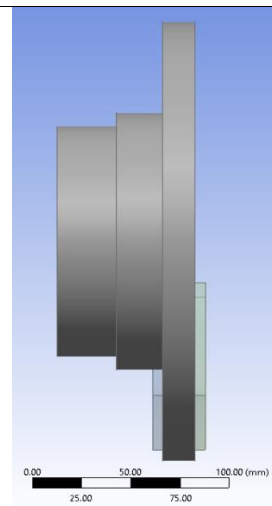
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Reference	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (MPa)		P5 - Total Deformation Reported Frequency (Hz)		P6 - Temperature Maximum (C)		P7 - Volume Total (m^3)	
2						Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
3		Candidate Point 1	19.8	123	72	12.953	-22.89%	1614.2	-0.09%	365.44	7.34%	0.00085522	-17.15%
4		Candidate Point 1 (verified) DP 238				12.36	-26.42%	1631.5	0.98%	365.21	7.27%	0.00085519	-17.15%
5		Candidate Point 2	19.8	123	72.4	12.976	-22.75%	1610.4	-0.33%	365.44	7.34%	0.00085293	-17.37%
6		Candidate Point 3	19.8	123	72.8	13	-22.61%	1606.2	-0.59%	365.44	7.34%	0.00085063	-17.59%
7		Candidate Point 4	19.8	123	72.8	13	-22.61%	1606.2	-0.59%	365.44	7.34%	0.00085063	-17.59%
8		Starting Geometry	25	125	75	14.159	-15.72%	1625.8	0.62%	339.63	-0.25%	0.0010322	0.00%
9		Starting Geometry (verified)				16.799	0.00%	1615.7	0.00%	340.47	0.00%	0.0010322	0.00%
*		*New Custom Candidate Point*	*18.5*	*130.5*	*80*								

Verification:

3		Candidate Point 1	19.8	123	72	12.953	-22.89%	1614.2	-0.09%	365.44	7.34%	0.00085522	-17.15%
4		Candidate Point 1 (verified) DP 238				12.36	-26.42%	1631.5	0.98%	365.21	7.27%	0.00085519	-17.15%

Modeled results:

Initial Design: rotor thickness=25, rotor ‘OD’=125, rotor ‘ID’=75	
	

Optimal Design Candidate Point 1: rotor thickness=19.8, rotor ‘OD’=123, rotor ‘ID’=72	
	

Direct Optimization:

For contrast a direct optimization was run to investigate solution, convergence time and trad-offs when compared to the response surface optimization. Due to the multiple objectives defined in the project instructions an Adaptive Multi Objective Direct optimization was implemented using and Ansys recommended automated configuration with a run time index of “5”. The optimization routine was run until convergence for a total number of 69 samples.

Sensitivities and Trade-off’s:

Investigating the system sensitivities generated through direct optimization show similar behavior to the response surface:

1. Rotor thickness has the largest impact on equivalent stress, rotor temperature, and total system volume.
2. Rotor inside diameter has a large impact on equivalent stress and modal deformation frequency onset
3. Rotor outside diameter has a large impact on modal deformation frequency onset

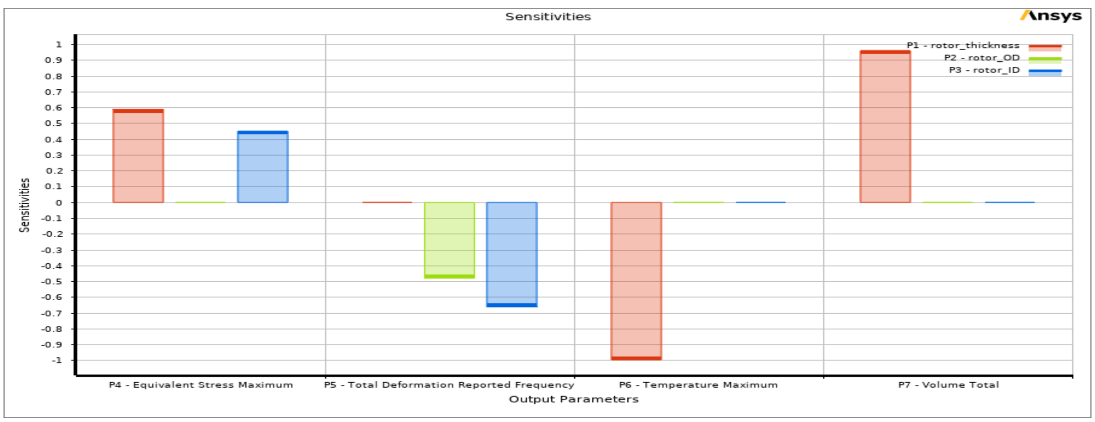
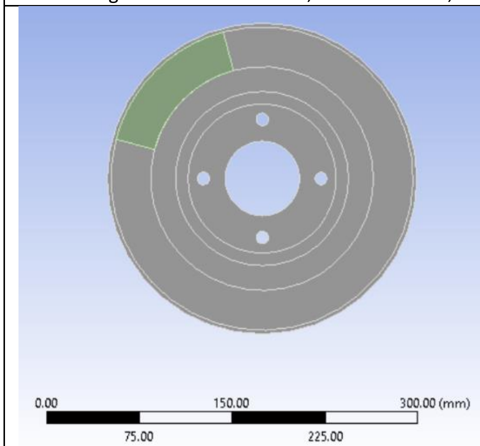


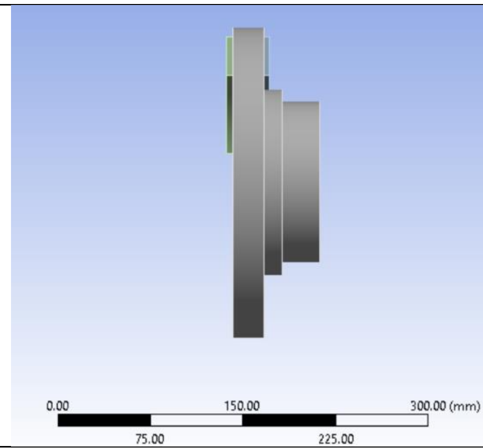
Figure 7

Optimization Results:

	rotor_thickness (mm)	rotor_OD (mm)	rotor_ID (mm)	Equivalent Stress Maximum (MPa)		Total Deformation Reported Frequency (Hz)		Temperature Maximum (C)		Volume Total (m^3)	
	value:	value:	value:	value:	Ref. Δ:	value:	Ref. Δ:	value:	Ref. Δ:	value:	Ref. Δ:
Candidate Point 1	21	123.5	82	13.41388899	-20.15%	1424.817076	-11.81%	355.3607178	4.37%	0.000834398	-19.16%
Candidate Point 2	15.5	124	86.5	11.6796132	-30.47%	1257.329788	-22.18%	405.5568237	19.12%	0.000672999	-34.80%
Candidate Point 3	11	125	77.5	10.89576816	-35.14%	1403.39965	-13.14%	501.3153076	47.24%	0.000587932	-43.04%
Reference Geometry	25	125	75	16.79858173	0.00%	1615.686627	0.00%	340.4679871	0.00%	0.001032196	0.00%

Initial Design: rotor thickness=25, rotor ‘OD’=125, rotor ‘ID’=75





Optimal Design: rotor thickness=11, rotor ‘OD’=125, rotor ‘ID’=77.5