DESIGN OPTIMIZATION OF BRAKE DISC

Project-2 report submitted

By

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Under the esteemed guidance of Prof. Yi (Max) Ren



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ACKNOWLEDGEMENT

I wish to express deep sense of gratitude to my professor. Yi (Max) Ren, for his whole-hearted co-operation, unfailing inspirational and valuable guidance. Throughout the project work, his useful suggestions and constant encouragement has gone a long way and proved very useful for us at odd hours.

ABSTRACT

The main aim of this project is to determine the optimum dimensions of the brake disc for a four-wheeler vehicle using AUTO CAD and ANSYS software. These dimensions include the disc inner radius, outer radius and thickness. To determine these dimensions, we are performing structural, modal and thermal load cases for emergency braking conditions. The optimization objective is to minimize the brake disc volume, whereas the other objectives are to minimize the stress, temperature and maximize the first natural frequency of the disc. Optimization of the model is done in the ANSYS and the results were provided accordingly.

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OBJECTIVE:

- Design a brake disc for emergency braking conditions with minimal volume
- Minimize the maximum stress in the brake disc.
- Maximize the first natural frequency of the brake disc
- Minimize the maximum temperature in the brake disc

MODEL DESIGN:

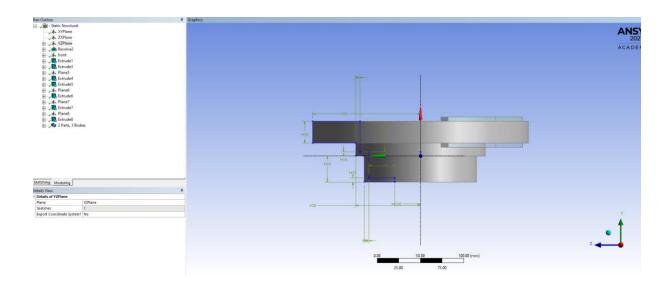
 The design of the brake disc was designed in the AUTO CAD previously, with considering the minimum volume conditions. Uploading the model in the Ansys and performing the analysis were given below.

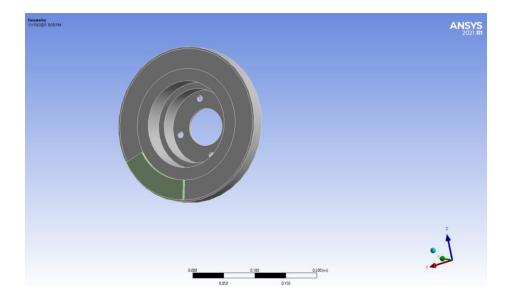
The three subsystems are as follows:

- 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.
- 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.
- 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.

Sketch details and Model

The given below pictures shows the sketch dimensions and the design of the brake disc with brake pads



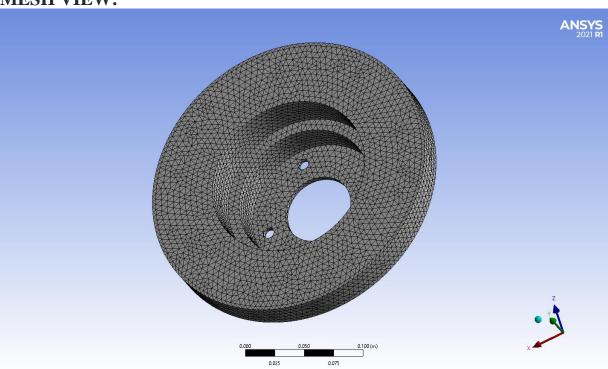


ANSYS Initial set up:

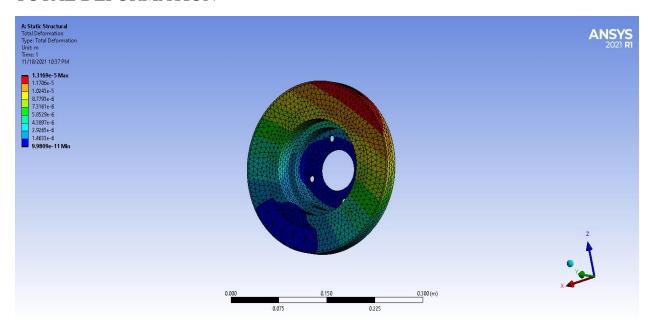
Static Structural:

• Initial model was imported into geometry in **Design Modeler** and generating the **Mesh**, **material assignment**, **contact regions** and solving the **static structural** gives the below showed result.

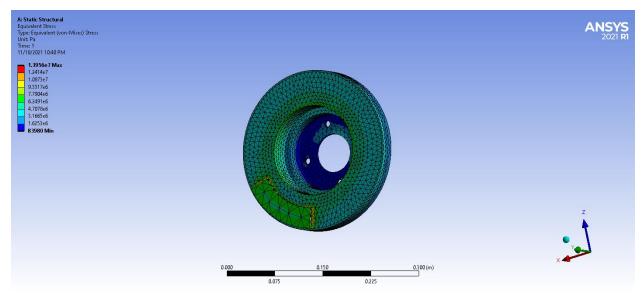
MESH VIEW:



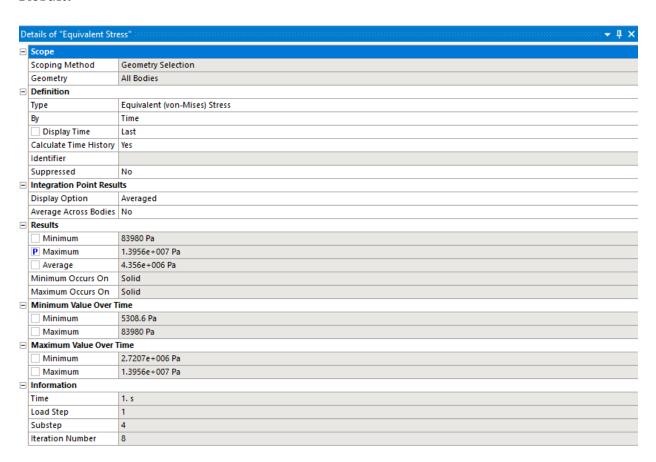
TOTAL DEFORMATION



EQUIVALENT STRESS



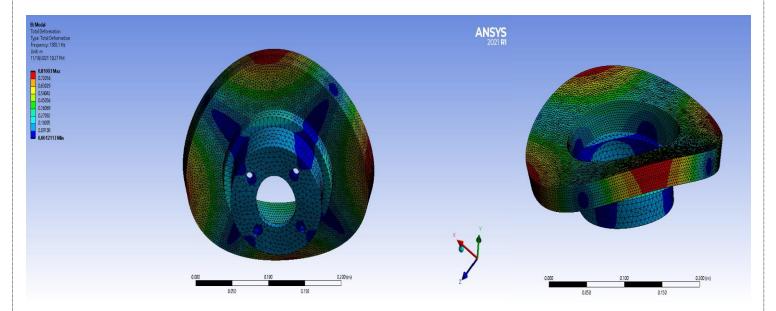
Result:



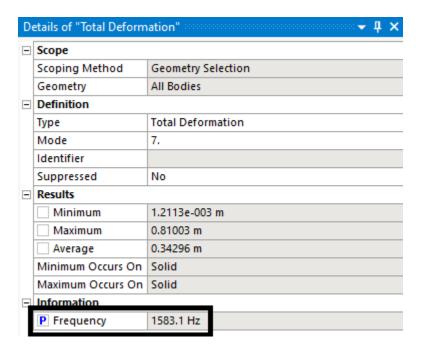
Modal Analysis:

 After doing with the static structural analysis, connecting the modal analysis to the geometry and performing the steps follows. Same geometry and mesh settings like previous, Analysis Settings and solving it to know the natural frequency of the solid disc.

TOTAL DEFORMATION:



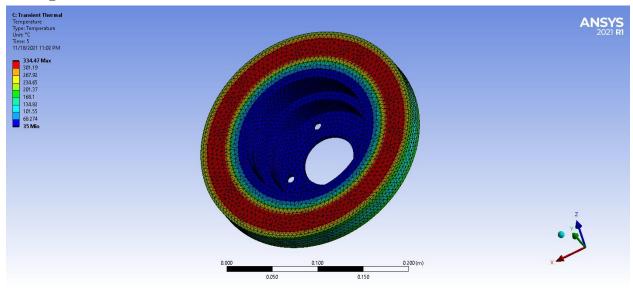
NATURAL FREQUENCY:



Transient thermal setup:

• After doing with the model analysis, thermal analysis of the given model is performed. In this, putting the **Initial Temperature**, **Analysis Settings**, **Convection**, **Heat flux** and solving solution. The results were uploaded below.

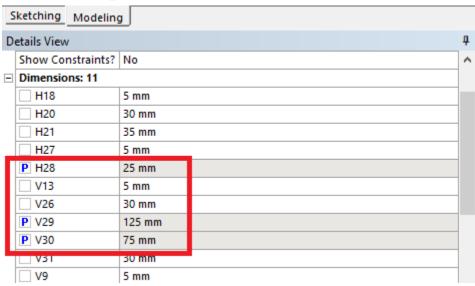
Temperature:



The final maximum temperature of the disc is showed below

Details of "Temperature"						
Scope						
Scoping Method	Geometry Selection					
Geometry	All Bodies					
□ Definition						
Type	Temperature					
Ву	Time					
Display Time	Last					
Calculate Time History	Yes					
Identifier						
Suppressed	No					
Results						
Minimum	35. °C					
Maximum	334.47 °C					
Average	135.84 °C					
Minimum Occurs On	Solid					
Maximum Occurs On	Solid					
■ Minimum Value Over 1	Fime .					
Minimum	26.569 °C					
Maximum	35. °C					
■ Maximum Value Over	Time					
Minimum	49.15 °C					
P Maximum	334.47 °C					
+ Information						

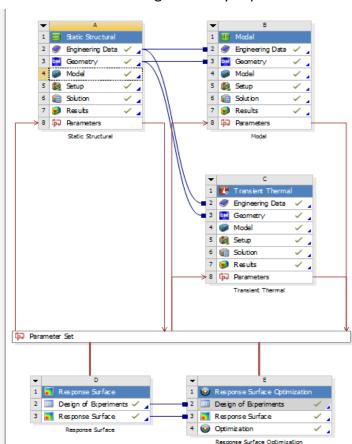
Defining Input Parameters:



Design of Experiments:

DOE is used to effectively sample a design space (e.g., all design parameters for the brake disc) so that a statistical model can be built to predict responses (e.g., the maximum stress, or the first natural frequency, or the maximum temperature) of a given design. DOE is useful when one can only sample a limited number of points (i.e., run a limited number of simulations). The key idea of DOE is to ``spread out'' the samples so that the resultant statistical model has low uncertainty in its model estimation and thus high accuracy in prediction.

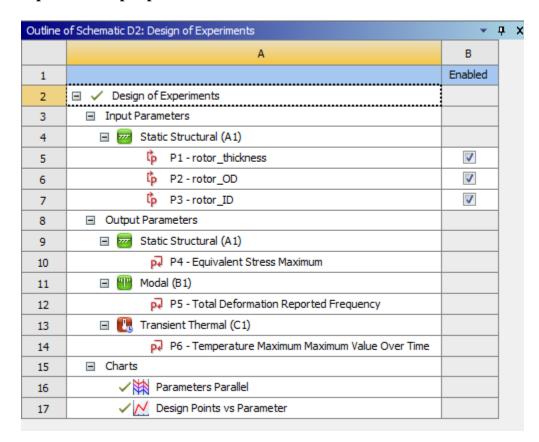
Project Schematic:



DOE METHOD:

While ANSYS provides various DOE methods, we suggest Latin Hypercube Sampling (LHS) and Optimal space filling with user defined sample points. The main advantage of these methods is that the number of samples is independent from the number of parameters. Another (more advanced) choice is sparse grid, which only samples a few points initially and adaptively add new sample points based on the response surface. Kriging with auto-refinement has a similar effect. Note, we do not recommend Central Composite Design (CCD) because in many cases, the objective cannot be approximated as a quadratic function, and CCD requires a large number of samples for relatively small number of variables.

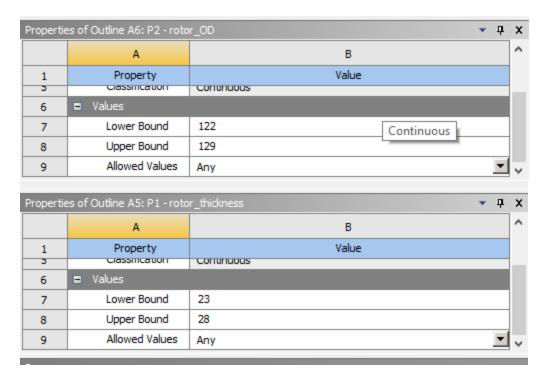
Input and Output parameters:



Lower and Upper Bound Values:

The given showed vales are the lower and upper bound values for the inner and outer diameters, thickness.

Propertie	r_ID	×	
	А	В	^
1	Property	Value	
3	Classification	Continuous]
6	■ Values		П
7	Lower Bound	72	
8	Upper Bound	80 Values	
9	Allowed Values	Any] ~

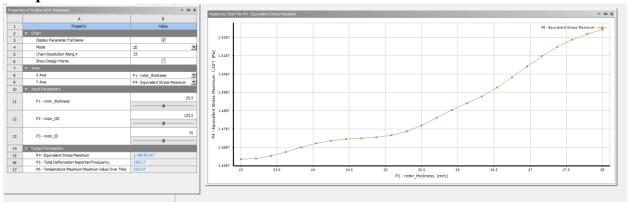


■ Candidate Points							
	Candidate Point 1	Candidate Point 2	Candidate Point 3 23.73				
P1 - rotor_thickness (mm)	23.714	23.757					
P2 - rotor_OD (mm)	124.67	124.66	124.66				
P3 - rotor ID (mm)	75.664	75.583	75.504				

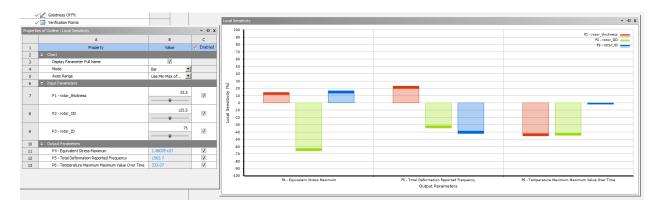
Design Points of Design of Experiments:

	А	В	С	D	E	F	G	
1	Name 💌	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P5 - Total Deformation Reported Frequency (Hz)	P6 - Temperature Maximum Maximum Value Over Time (C)	
2	1	25.625	123.58	77.4	1.4991E+07	1567.9	335.83	
3	2	26.625	126.73	73	1.5025E+07	1612.8	329.25	
4	3	23.125	127.08	74.2	1.4653E+07	1522.9	338.35	
5	4	26.125	122.18	73.8	1.7884E+07	1681.4	345.33	
6	5	23.625	124.63	79	1.4822E+07	1485.8	339.14	
7	6	27.875	124.98	77.8	1.5338E+07	1575.1	328.73	
8	7	25.875	126.38	79.4	1.5035E+07	1485.8	331	
9	8	27.625	125.68	75.4	1.538E+07	1608.6	328.33	
10	9	24.625	128.48	72.2	1.4593E+07	1548.1	333.08	
11	10	24.375	122.53	73.4	1.8918E+07	1651.8	344	
12	11	25.125	125.33	72.6	1.4659E+07	1620.5	333.73	
13	12	24.125	126.03	78.2	1.4949E+07	1488.6	335.78	
14	13	25.375	124.28	79.8	1.5412E+07	1498.4	334.75	
15	14	26.875	127.43	75.8	1.4994E+07	1555.1	328.45	
16	15	24.875	122.88	74.6	1.8403E+07	1629.3	340.44	
17	16	27.375	123.23	76.6	1.6974E+07	1621.1	333.39	
18	17	27.125	128.83	77	1.4969E+07	1512.7	327.57	
19	18	26.375	127.78	76.2	1.4822E+07	1532.5	329.25	
20	19	23.875	123.93	75	1.4742E+07	1584.5	339.79	
21	20	23.375	128.13	78.6	1.5001E+07	1435.3	337	

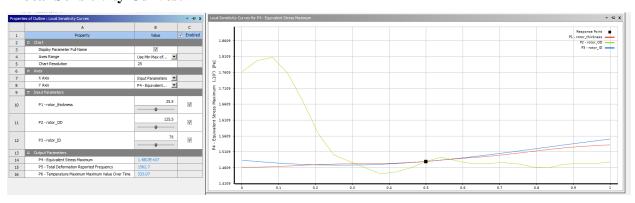
Response Surface:



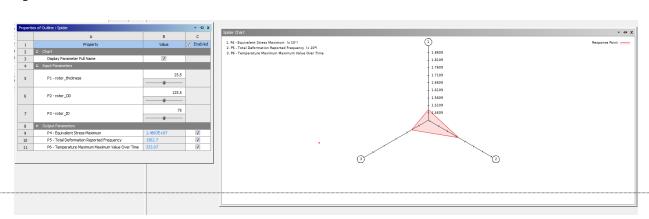
Local Sensitivity:



Local Sensitivity Curves:

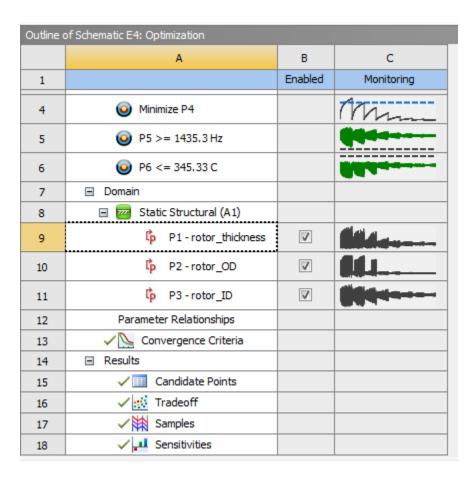


Spider:



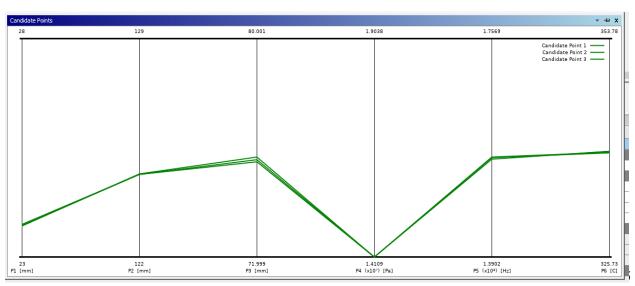
OPTIMIZATION:

It is the main process where the optimization of the given deign is performed and determining the optimization graphs for different parts

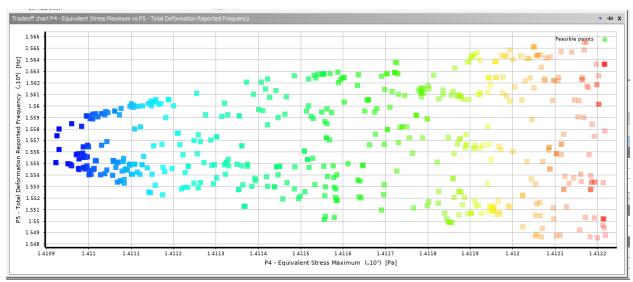


RESULT:

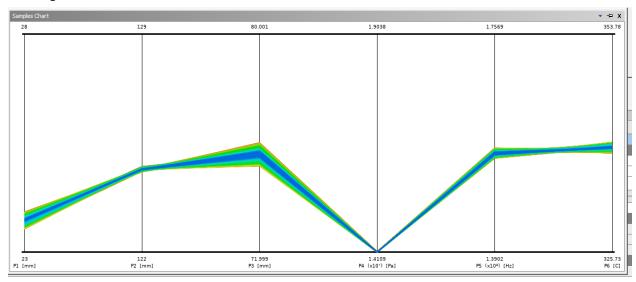
1. Candidate Points:



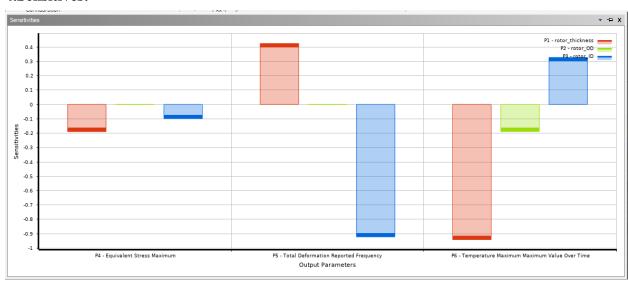
2.Trade off:



3.Sample Chart:



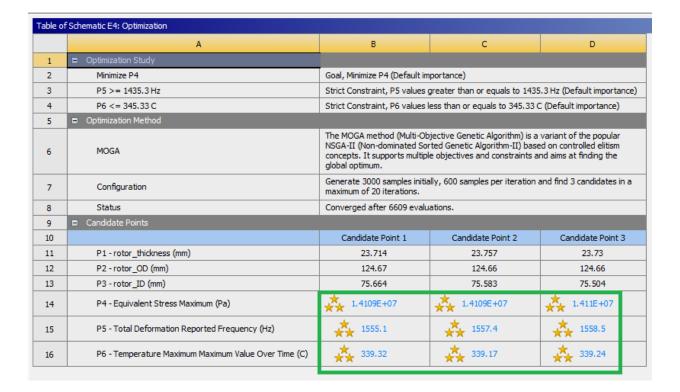
4. Sensitives:



PROJECT-2

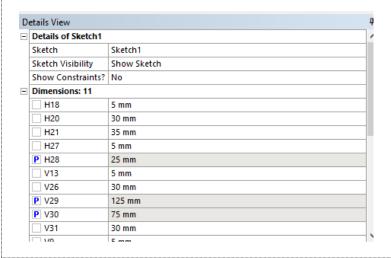
Best Design Candidates:

The given below values with stars show the best candidate points of Equivalent stress, Reported frequency and Temperature maximum value

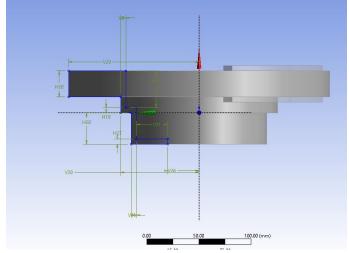


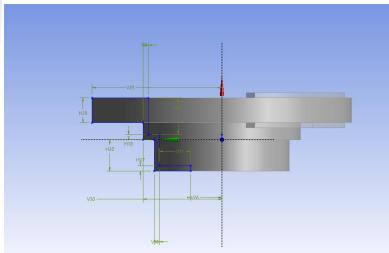
FINAL DIMENSIONS:

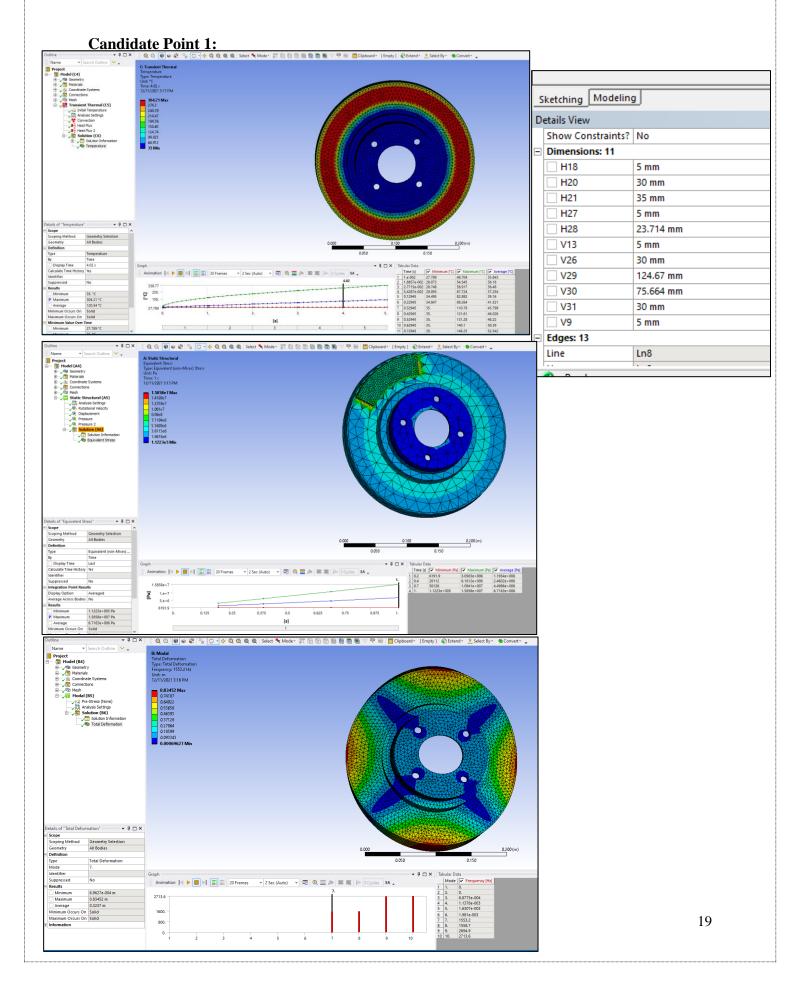
Final optimum dimensions were showed below by changing the model too.



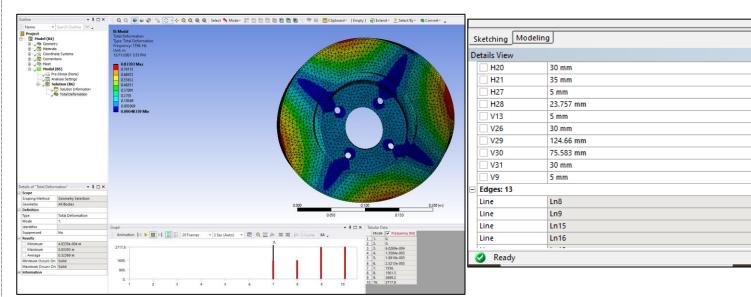
etails View		đ
Details of Sketch1		^
Sketch	Sketch1	
Sketch Visibility	Show Sketch	
Show Constraints	No	
Dimensions: 11		
☐ H18	5 mm	
☐ H20	30 mm	
☐ H21	35 mm	
☐ H27	5 mm	
P H28	23.714 mm	
☐ V13	5 mm	
☐ V26	30 mm	1
P V29	124.67 mm	
P V30	75.664 mm	
□ V31	30 mm	
□ v0	E mm	-

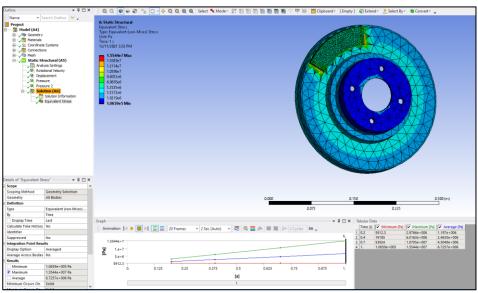


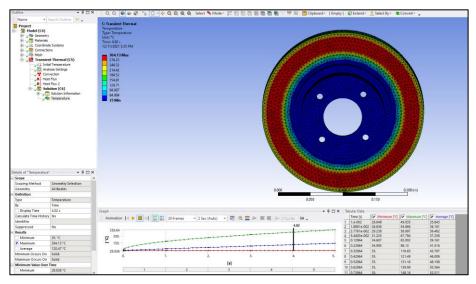




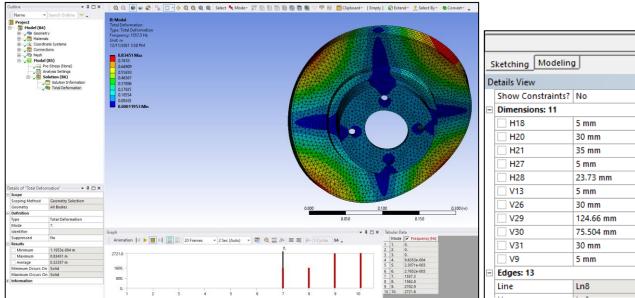
Candidate Point 2:

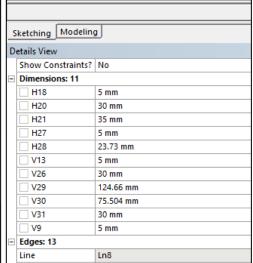


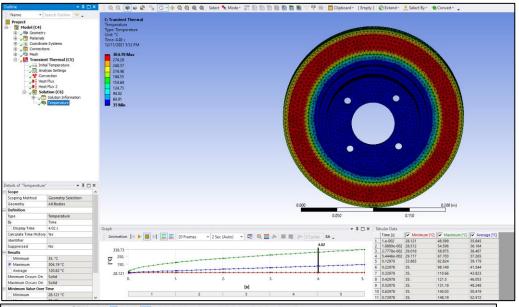


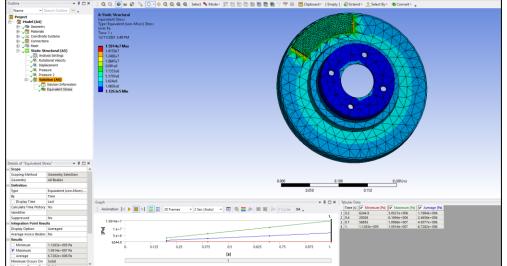


Candidate Point 3:









Final Result:

Verifying the performance of Final design:

By running the simulation again by putting the optimized values that we got before for the verification of the performance of the Final Design. Those pictures were showed above, and point values were showed below. We have also calculated the error percentage and updated it below.

Performance chart	Thickness(mm)	OD (mm)	ID (mm)	Equivalent stress 10^7(Pa)	Total deformation Frequency (Hz)	Temperate Maximum value (C)
Candidate 1	23.714	124.67	75.664	1.4109	1555.1	339.32
Verified values				1.5858	1553.2	304
Error percentage				11.02913%	-0.12233%	-11.6184%
Candidate 2	23.757	124.66	75.583	1.4109	1557.4	339.17
Verified values				1.5544	1556	304.13
Error percentage				9.231858%	-0.08997%	-11.5214%
Candidate 3	23.73	124.66	75.504	1.411	1558.5	339.24
Verified values				1.5914	1557.3	304.19
Error percentage				11.33593%	-0.07706%	-11.5224%