PROJECT 2: DESIGN OPTIMIZATION OF BRAKE DISC

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Abstract

The scope of this study is to use ANSYS to determine the optimal dimensions of a brake disc for a four-wheeler vehicle. These measurements include the inner radius, outer radius, and thickness of the disc. These dimensions are determined by individually considering structural, modal, and thermal load cases for emergency braking conditions. The optimization objective is to lower the volume of the brake disc, while other goals are to reduce stress, temperature, and maximize the disc's first natural frequency. These objectives are achieved by using ANSYS workbench and Design of Exploration Module.

Introduction

The project mainly focuses on design optimization of an emergency Brake Disc in an automobile carried out on Ansys Design of Experiments (DOE). The objective is to minimize temperature and stress, to maximize the first natural frequency. To obtain maximum stress, natural frequency, and maximum temperature Structural, Modal, and Thermal analysis were performed on the CAD model assembly which was provided. The material assigned for the brake pads is structural steel and for the brake disc is grey cast iron. The geometry is meshed using 3 mm-sized tetrahedrons.

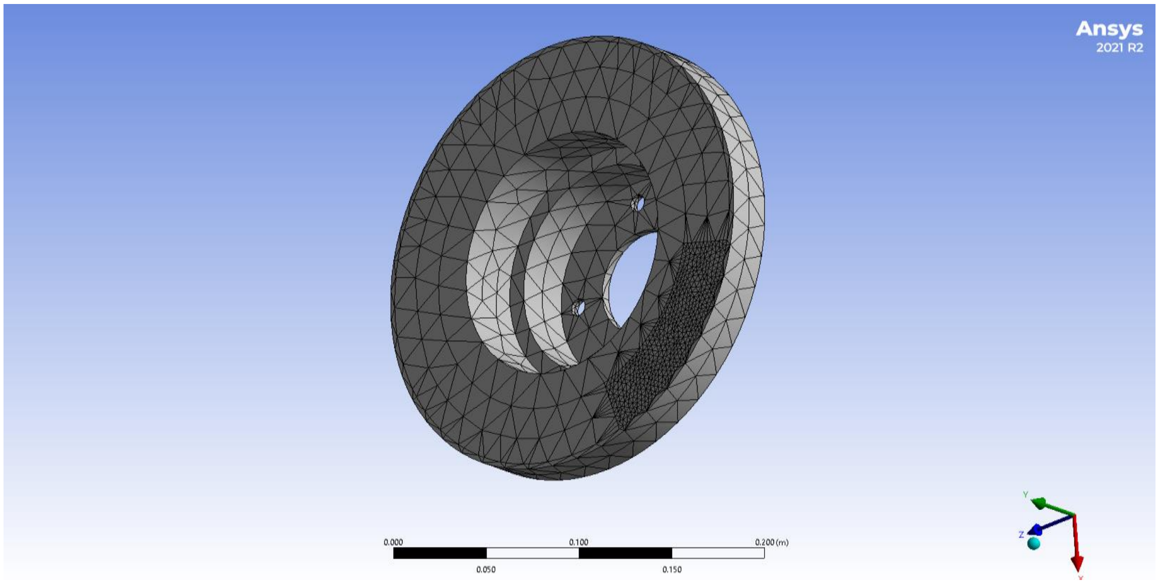


Fig1: Meshing for the given CAD model

Structural Analysis

During sudden braking, the brake disc should withstand the pressure exerted by the hydraulically actuated brake pads. Friction between the brake pads and the disc causes stress. Because of its rotation, the disc also experiences centrifugal body forces. The stresses produced as a result of these forces can end up causing material failure. As a result, it is important to ensure that the stresses in the disc are kept to a minimum.

In this project, to obtain the stresses we have taken the coefficient of friction as 0.22, rotational velocity along y-axis 250 rad/s also the motion of the brake pads is restricted in this direction. Actuating pressure of 10.496 MPa.

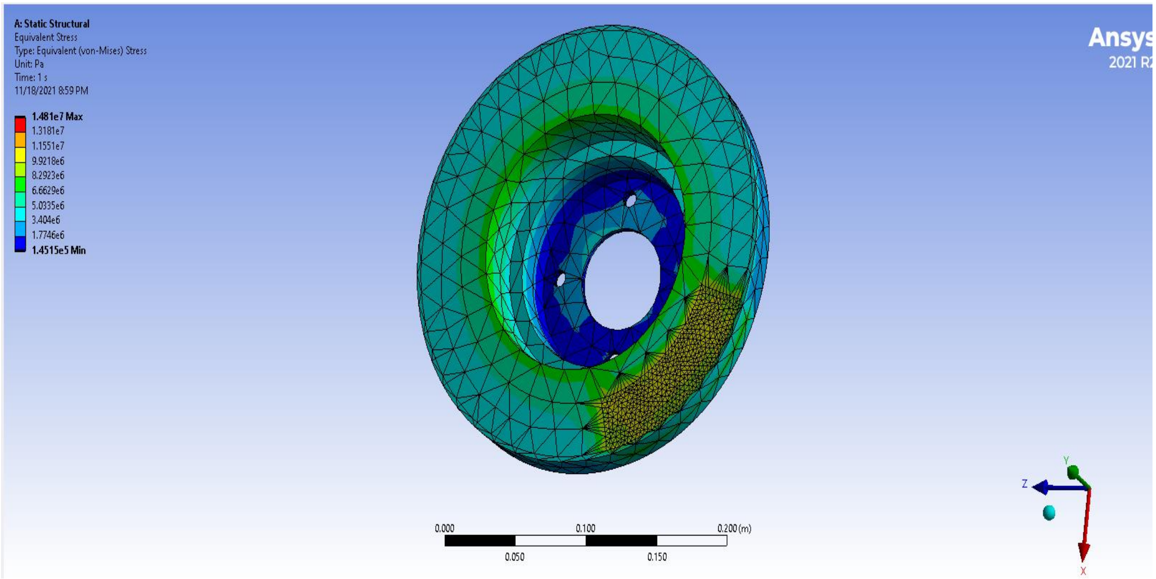


Fig2: Stress Plot

From the analysis, we obtained that the maximum equivalent stress is 1.481e7 Pa.

Modal analysis

Modal analysis is carried out to ensure that the disc's first natural frequency is higher than the resonant frequency. This ensures that failure does not occur due to firing frequency.

Obtaining the geometry and material properties from the structural analysis, in this module, we are determining the natural frequency at mode 7.

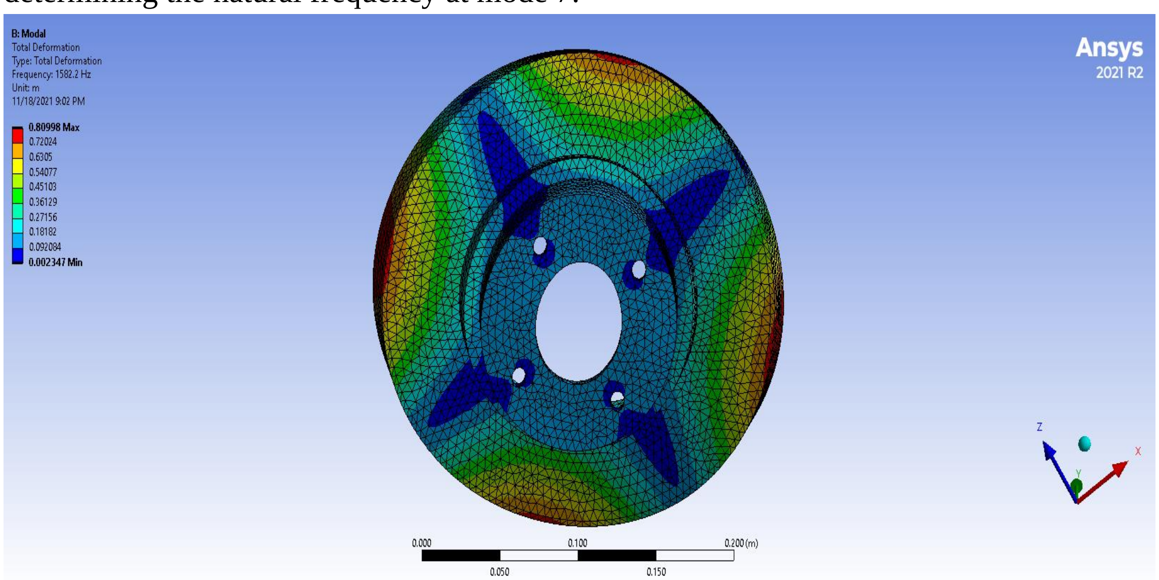


Fig 3: Mode Shape Plot

From the analysis, we have obtained the first natural frequency as 1582.2 Hz at mode 7.

Thermal analysis

Friction between the brake pads and the rotor disc causes braking in a vehicle. This causes heat flux generation in the disc, leading to an increase in temperature and thermal stresses. High temperatures are generated during emergency braking, causing damage to the contact surfaces. To avoid disc wear and tear, it is critical to keep the temperature as low as possible.

Obtaining the geometry and material properties from the structural analysis, in this module, we are determining the maximum temperature.

Where the ambient temperature is given as 35deg Celsius, heat flux is 1.5935 W/mm2, and convection is applied on all the surfaces with the air film coefficient of 5 W/m2K.

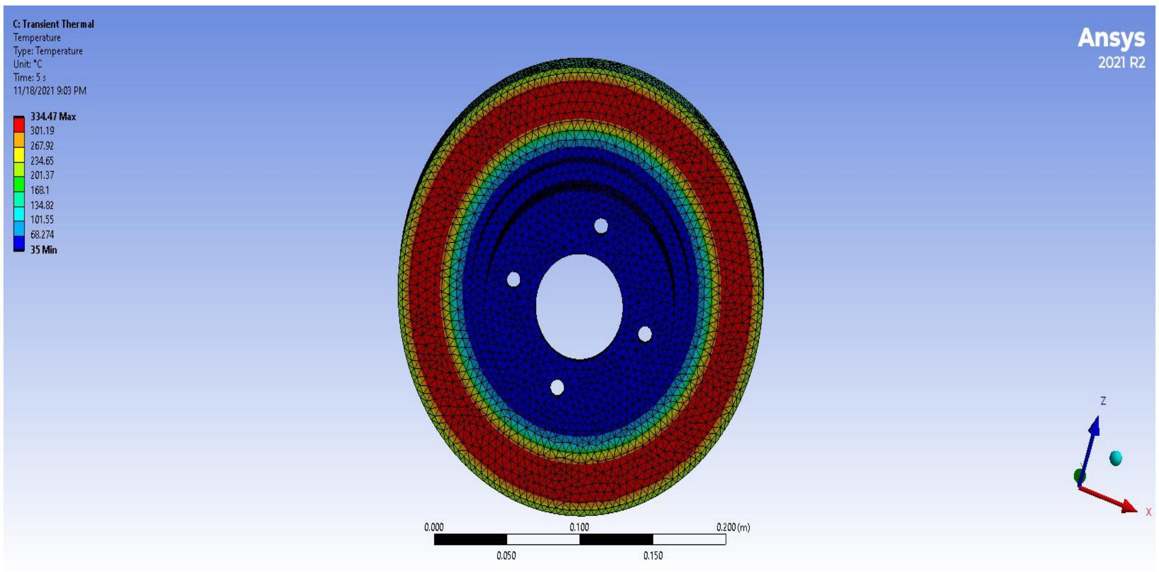


Fig 4: Temperature Plot

From the analysis, the maximum temperature is obtained that is 334.47deg Celsius.

Optimization and Design of Experiments

Generally, for an optimization we need an objective function, parameters and constraints, in this project the objective is goodness of the design like the performance of design, how safe is the part or how much load it can withstand with respect to time (longevity). Parameters are the inner radius, outer radius, and thickness of the disc and constraints can be set as stress, natural frequency and temperature.

Ansys DOE has various methods in this project we are using Latin Hypercube Sampling (LHS) to define sample points.

The input parameters were varied in the following range,

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	21.75
8	Upper Bound	27.5
9	Allowed Values	Any

Fig 5: Input for Rotor Thickness

Properties of Outline A6: P2 - rotor_OD

	A	B
1	Property	Value
2	General	
3	Units	mm
4	Type	Design Variable
5	Classification	Continuous
6	Values	
7	Lower Bound	122.75
8	Upper Bound	134
9	Allowed Values	Any

Fig6: Input for rotor Outer Diameter

Properties of Outline A7: P3 - rotor_ID

	A	B
1	Property	Value
2	General	
3	Units	mm
4	Type	Design Variable
5	Classification	Continuous
6	Values	
7	Lower Bound	72.3
8	Upper Bound	77.8
9	Allowed Values	Any

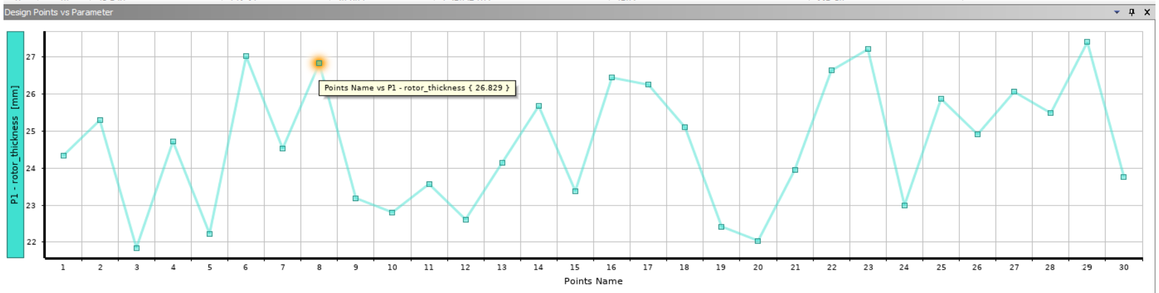
Fig7: Input for Rotor Inner Diameter

Using Latin Hypercube Sampling we obtain 30 sample points,

Table of Schematic D2: Design of Experiments (Latin Hypercube Sampling Design : User-Defined Samples : Random Generator Seed = 0 : Number of Samples = 30)

	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 - Total Deformation Reported Frequency (Hz)	P6 - Temperature Maximum (C)
2	1	24.338	130.06	72.392	1.5623E+07	1505.8	333.55
3	2	25.296	130.81	74.958	1.6894E+07	1476.2	330.97
4	3	21.846	127.06	75.325	1.6237E+07	1483.7	343.51
5	4	24.721	132.31	76.792	1.6248E+07	1409.8	332.34
6	5	22.229	125.56	73.675	1.6226E+07	1546.8	343.09
7	6	27.021	122.94	77.708	1.6686E+07	1591.6	335.18
8	7	24.529	133.06	74.408	1.669E+07	1426.3	332.83
9	8	26.829	132.69	77.158	1.6891E+07	1434	327.7
10	9	23.188	128.19	73.858	1.5765E+07	1506.4	337.63
11	10	22.804	133.81	76.425	1.6611E+07	1354.5	338.39
12	11	23.571	127.81	75.875	1.597E+07	1488.2	336.46
13	12	22.613	126.31	73.125	1.5914E+07	1544.3	340.79
14	13	24.146	128.56	76.975	1.6173E+07	1464.4	334.42

Design Points vs Parameter



The respective plots are obtained,

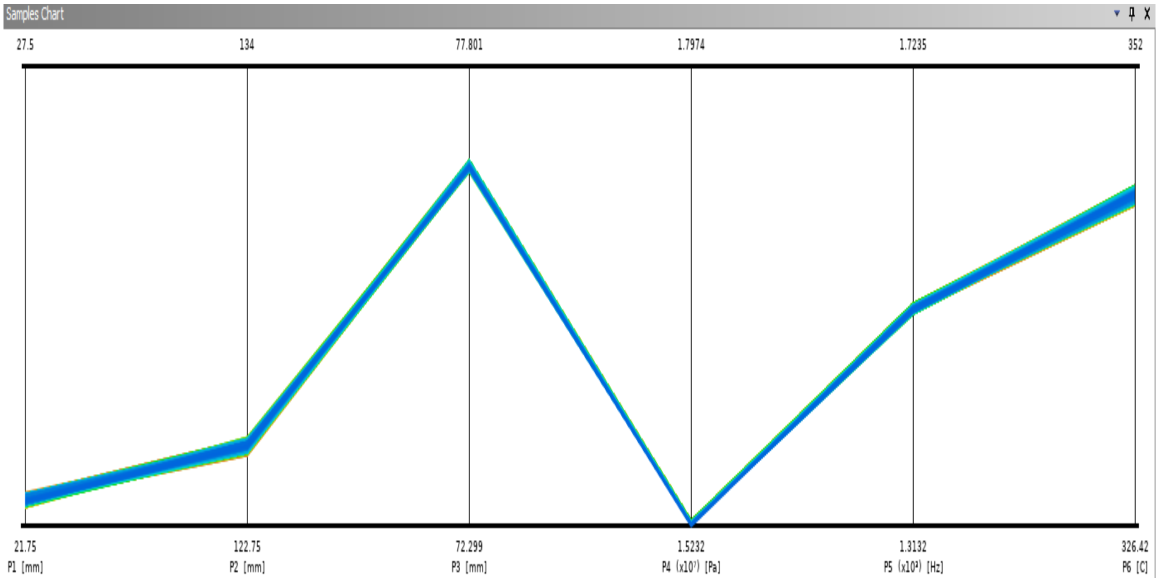


Fig 8: Sample Chart

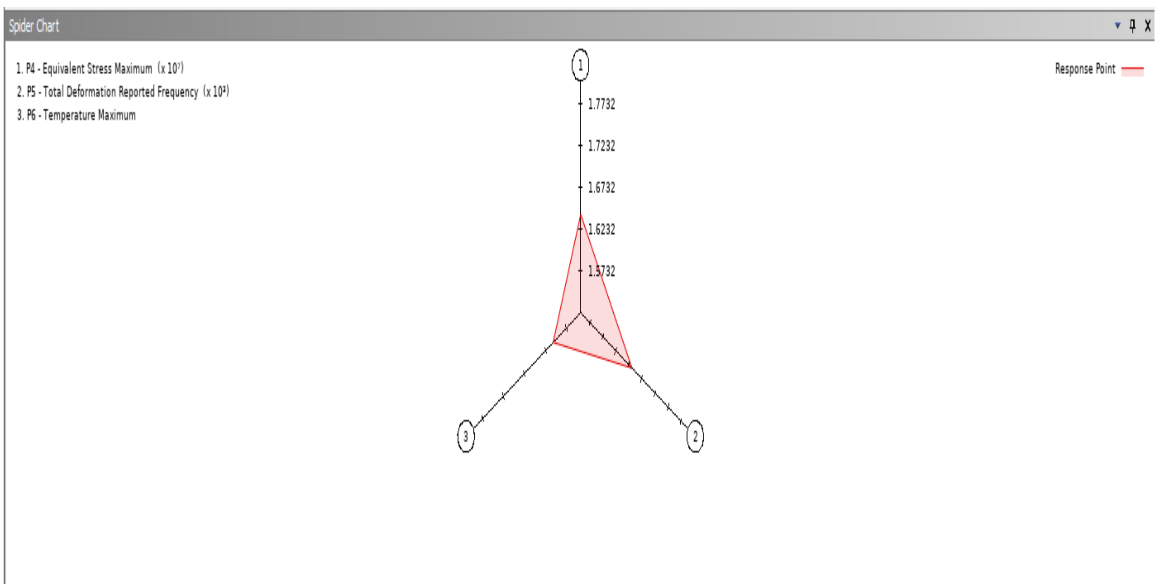


Fig 9: Spider Chart

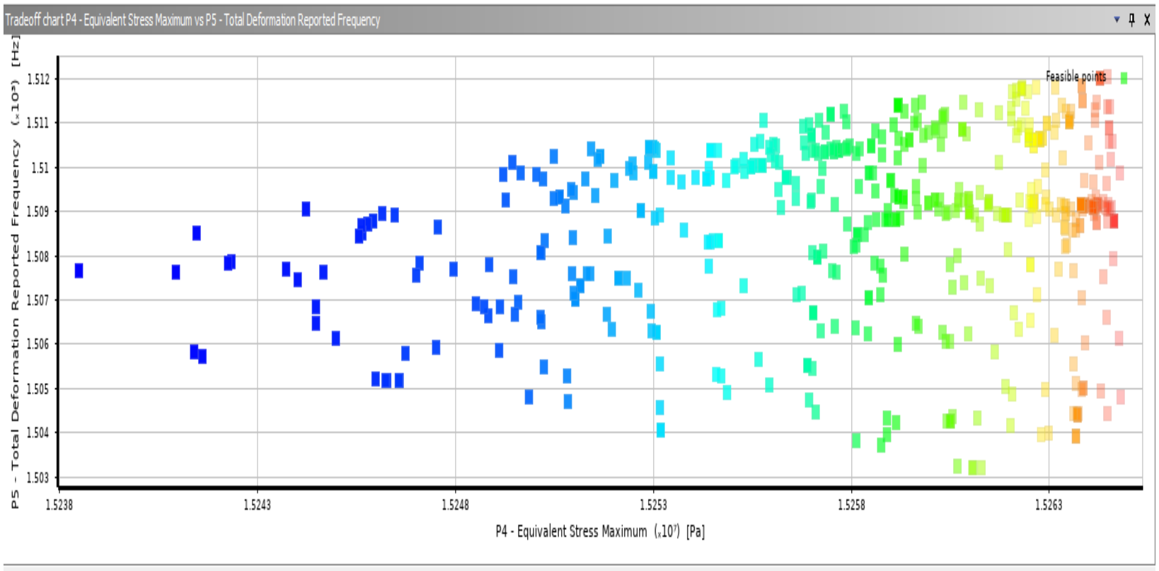


Fig 10: Trade Off

Finally, in this project the objective function is to minimize equivalent stress where constraints are total deformation due to natural frequency and maximum temperature.

Results obtained after optimization are:

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 - Total Deformation Reported Frequency (Hz)		P6 - Temperature Maximum (C)	
2						Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Refe
3	◉	Candidate Point 1	22.08	124.72	76.613	1.5239E+07	0.00%	1507.7	0.00%	344.94	0.00%
4	○	Candidate Point 2	22.057	124.7	76.616	1.5241E+07	0.02%	1507.6	0.00%	345.08	0.04%
5	○	Candidate Point 3	22.082	124.82	76.612	1.5242E+07	0.02%	1505.9	-0.12%	344.77	-0.05%
*		New Custom Candidate Point	24.625	128.38	75.05						

Fig 11: Final Optimal Values

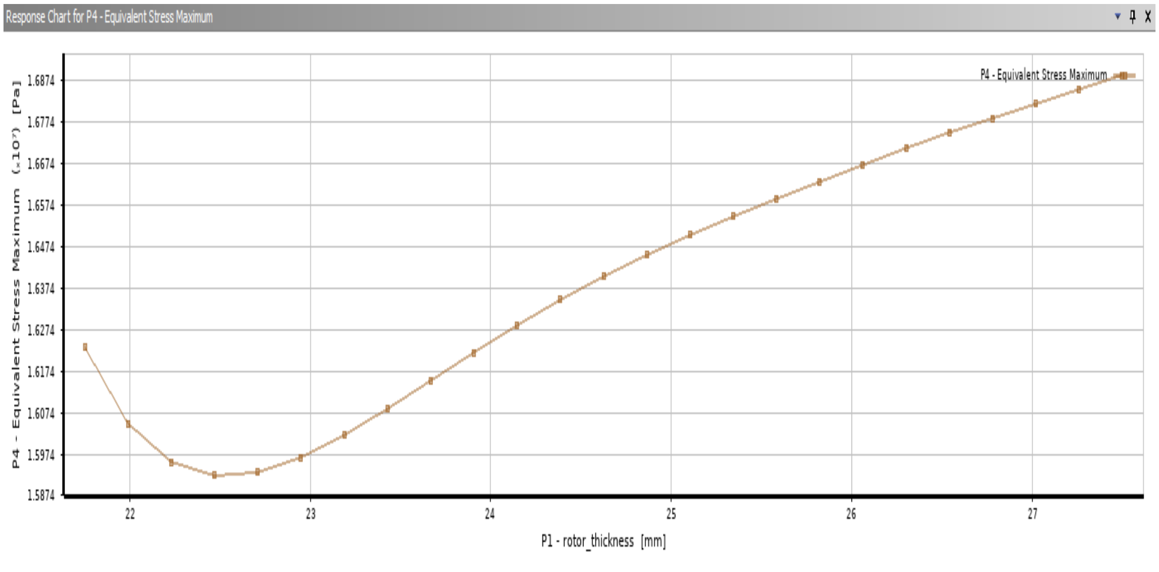


Fig 11: Response graph

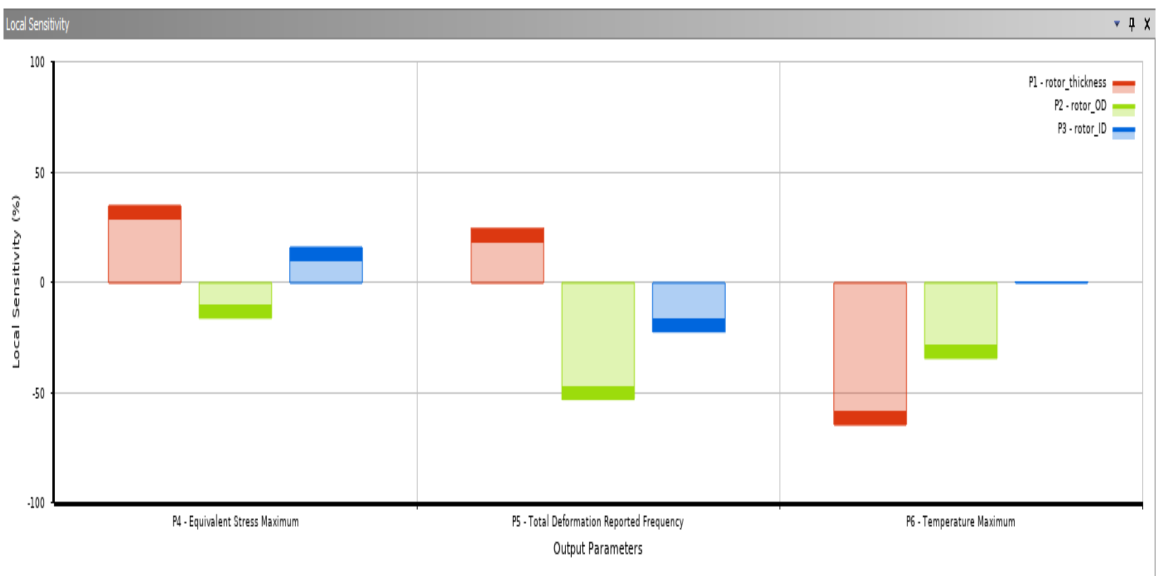


Fig 12: Sensitivity graph

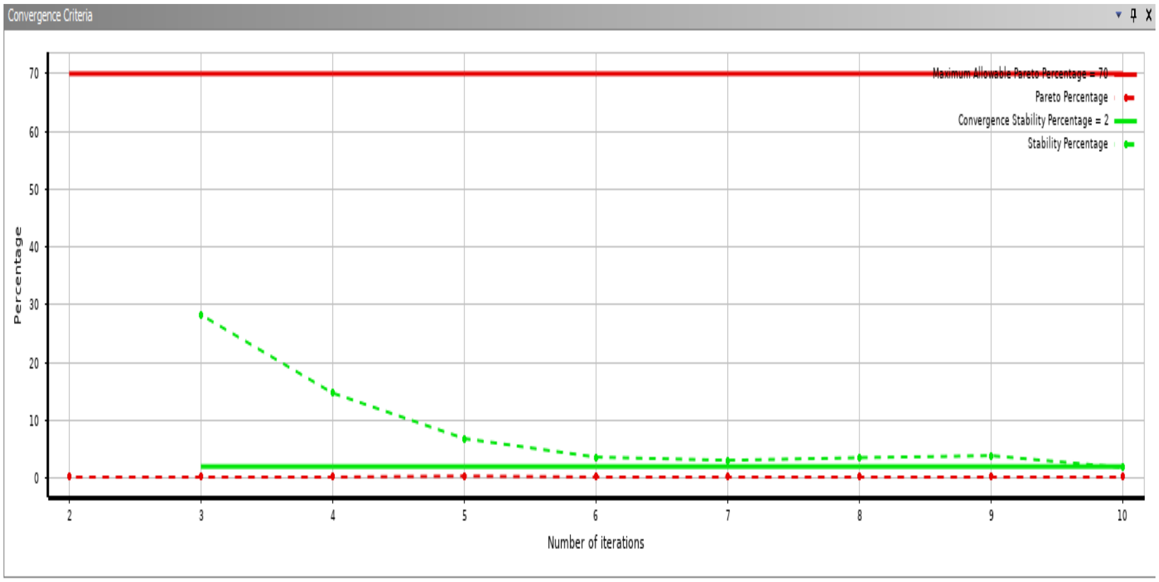
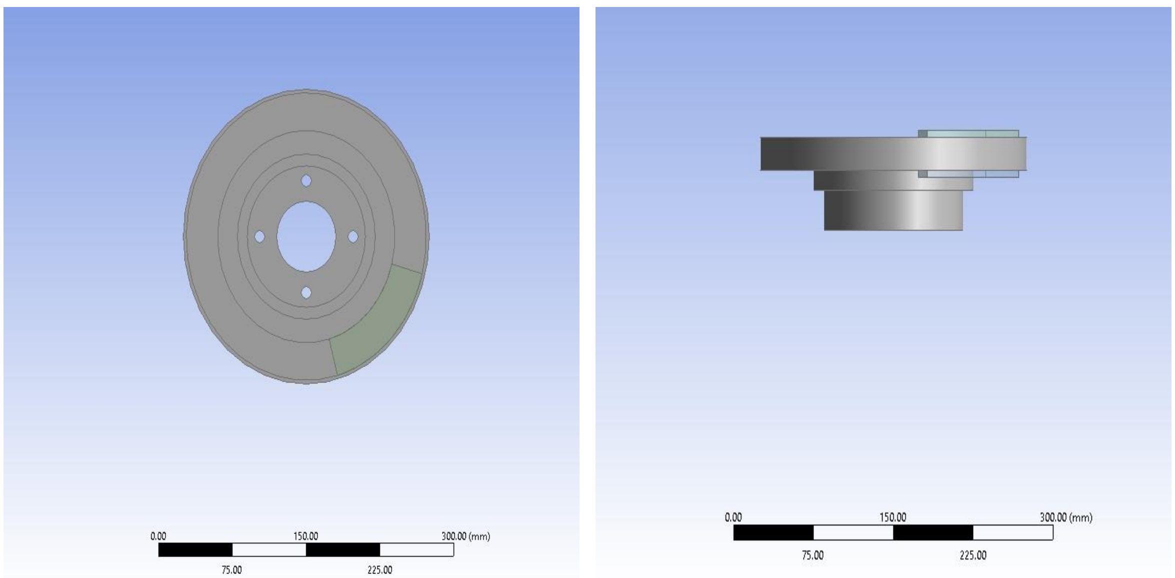


Fig 13: Convergence Criteria graph

Results

Final Dimension obtained after optimization are:



Column1	Diameter Thickness (mm)	Outer Diameter (mm)	Inner Diameter (mm)	Von Misses Stress (10^7 MPA)	Natural Frequency (Hz)	Max. Temperature (Deg Centigrade)
Point1	22.08	124.72	76.613	1.5239	1507.7	344.94
Simulation Value				1.5372	1507.6	308.18
Error				0.865209472	-0.006633059	-11.92809397
Point2	22.057	124.7	76.616	1.5241	1507.6	345.08
Simulation Value				1.5512	1507.5	308.26
Error				1.747034554	-0.006633499	-11.94446247
Point3	22.082	124.82	76.612	1.5242	1505.9	344.77
Simulation Value				1.5146	1505.8	308.07
Error				-0.633830714	-0.006640988	-11.91287694

Verification of Values for 3 Points and Error is calculated

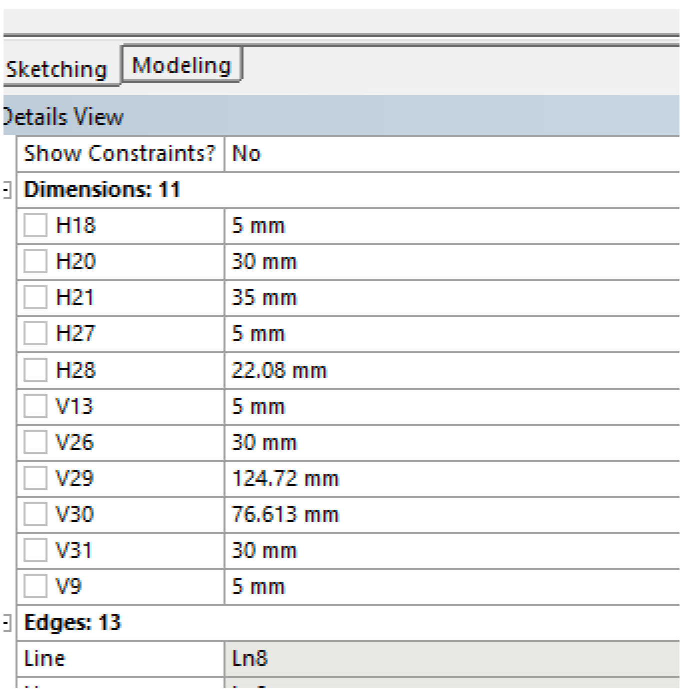
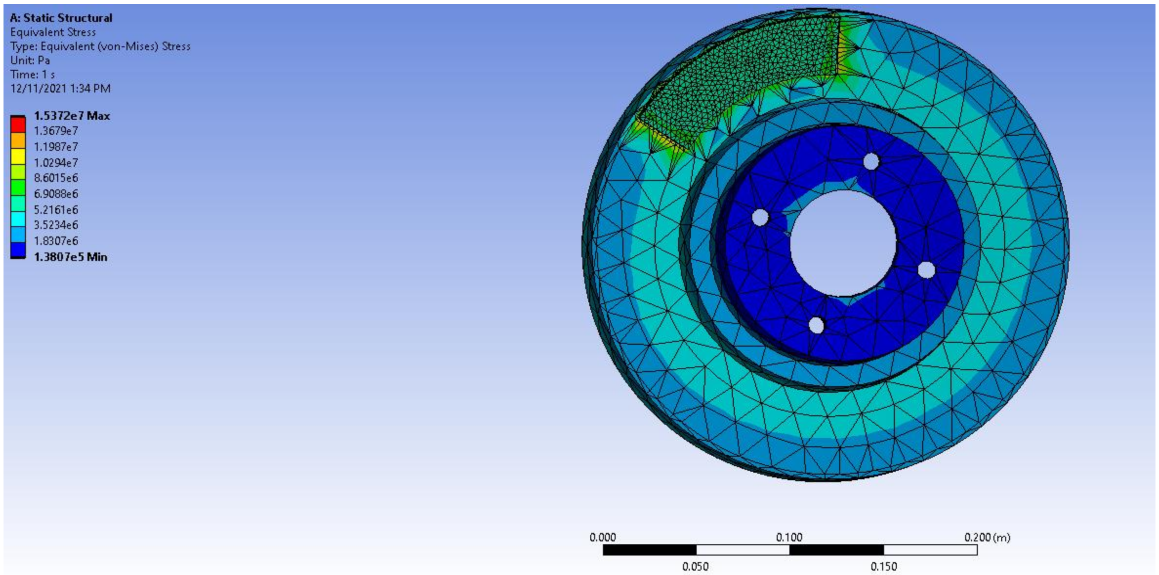
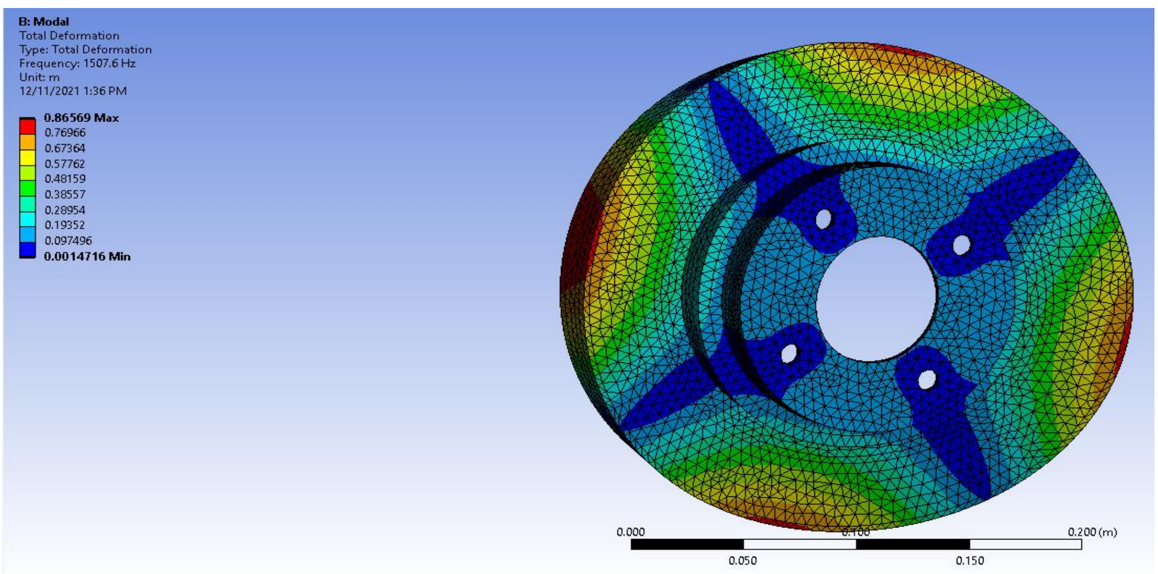


Fig 14: Dimensions for Point1 values


A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1 s
12/11/2021 1:34 PM
1.5372e7 Max
1.3679e7
1.1987e7
1.0294e7
8.6015e6
6.9088e6
5.2161e6
3.5234e6
1.8307e6
1.3807e5 Min
0.000
0.100
0.200 (m)
0.050
0.150


B: Modal
Total Deformation
Type: Total Deformation
Frequency: 1507.6 Hz
Unit: m
12/11/2021 1:36 PM
0.86569 Max
0.76966
0.67364
0.57762
0.48159
0.38557
0.28954
0.19352
0.097496
0.0014716 Min
0.000
0.100
0.200 (m)
0.050
0.150

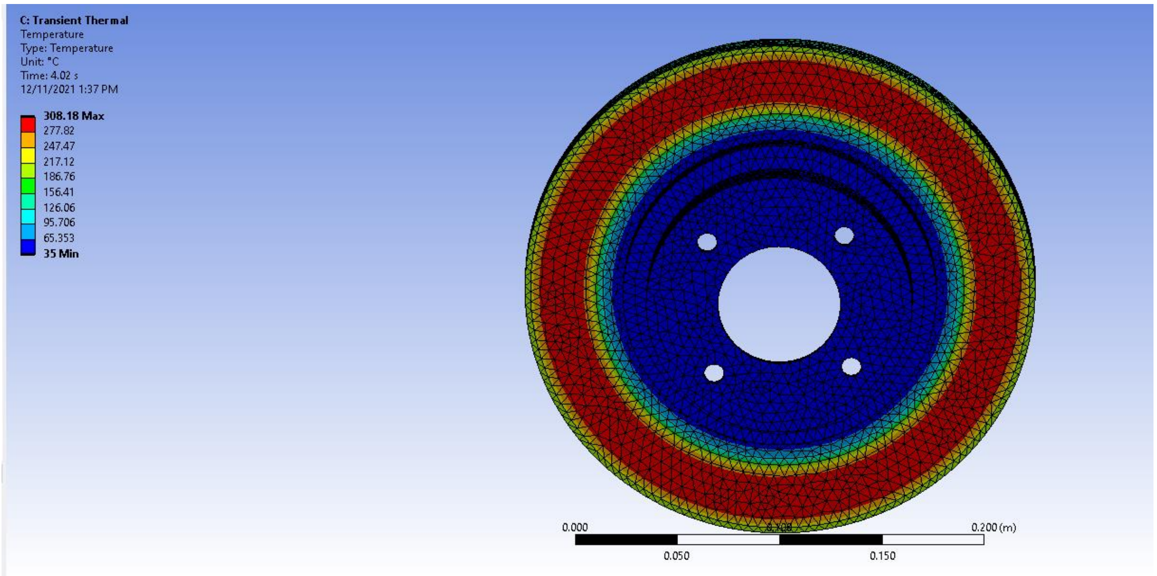


Fig 15: Simulation Results for Point1 Values

Similarly, simulation is done for all the 3 points obtained. From this we can observe the error is less with obtained optimized values.

Acknowledgement:

I would like to express my sincere gratitude to Prof. Yi (Max) Ren for his unwavering support for this project. Furthermore, without the assistance and resources of the Arizona State University laboratories, this work would not have been possible.

References:

- Design Optimization of Brake Disc Geometry by Abhijeet Durgude, Aditya Vipradas, Sharan Kishore, Swapnil Nimse.
- https://designinformaticslab.github.io/productdesign_tutorial/2016/11/20/ansys.html