MAE 598 - Design Optimization
Project 2 - disc design optimization using Ansys Design of Experiment and Design Optimization Tutorial

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Abstract:
This project conducts structural optimization of the brake disc using ANSYS software. The input variables are disc inner radius, disc outer radius and disc thickness. The main goal of the project is to minimize the volume of the disc, minimize the maximum von-mises stress, minimize the temperature and maximize the first natural frequency of the disc. These will be accomplished by using the optimization algorithms and design of experiments function in the ANSYS.

Introduction:

There are three main aspects that need to be optimized in the design. They are stress analysis, modal analysis and thermal analysis respectively.
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.

Problem description and general steps
The disc for optimization was shown in figure 1. It has one pad on each side of the disc.The dimension of the disc is shown in the figure 2, in which inner radius, outer radius and thickness are selected as input parameters. In the design of the experiments, the dimension of these three parameters are changed to find the optimal design. The material for the pad is structural steel and the material for disc is gray cast iron.

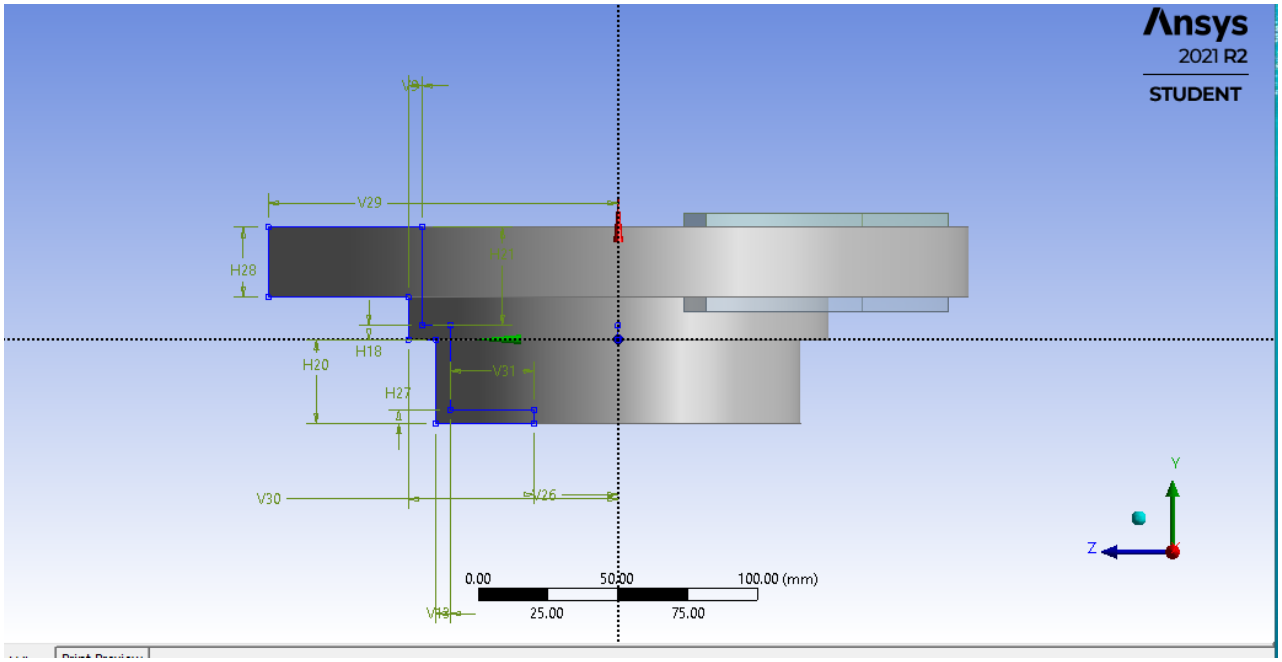


Fig. 1 - Geometry of the model.

Details View

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	25 mm
V13	5 mm
V26	30 mm
P V29	125 mm
P V30	75 mm
V31	30 mm
V9	5 mm

Fig. 2 - Dimensions of model. H28 is thickness, V29 is outer radius, V30 is inner radius

The geometry and the material has been set up, and the three modules are shown below.

Statical Analysis:

Mesh is shown in figure 3. The method for mesh is patch conforming method. The mesh for the inner surface of the pads are refined to conform the higher stress at these surfaces.

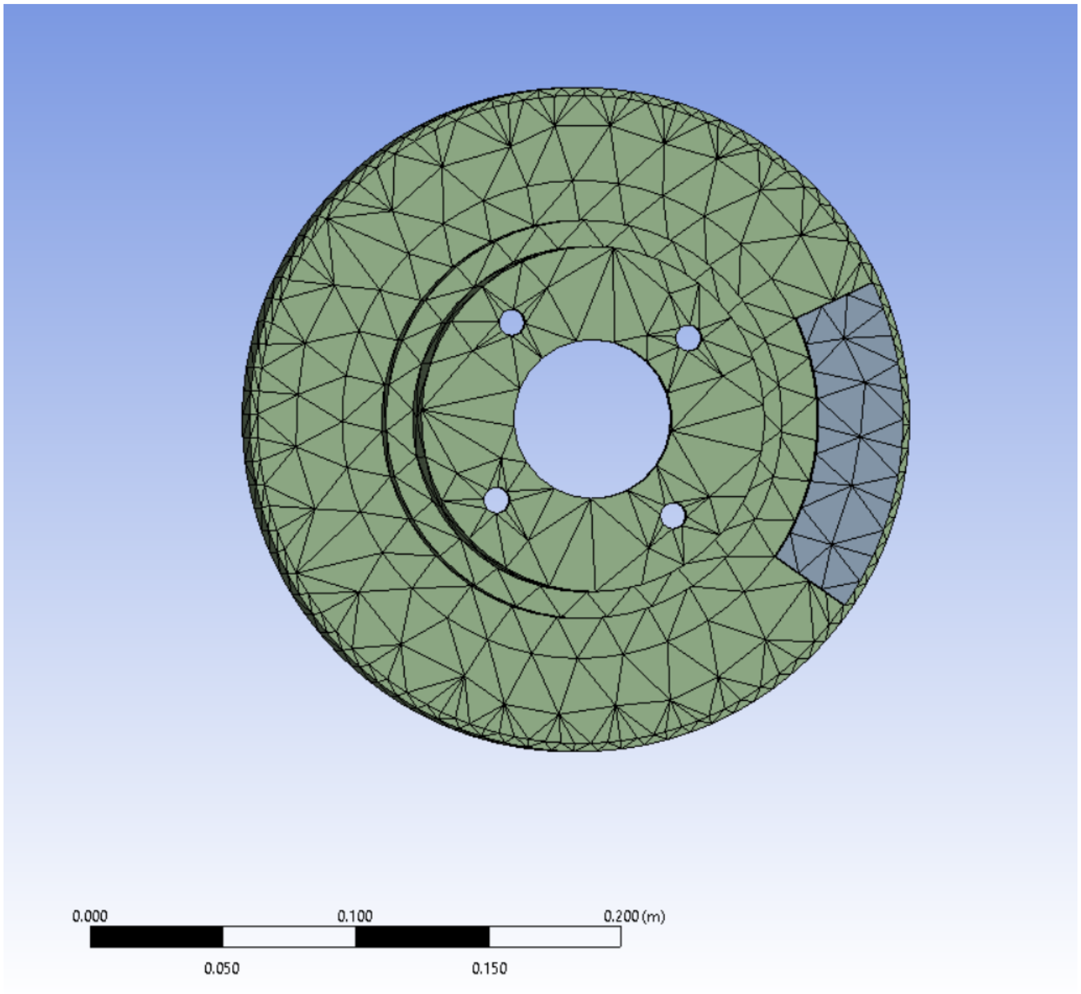


Fig.3 Mesh

There is a contact region between the disc and the pad. The setup is shown in figure 4.

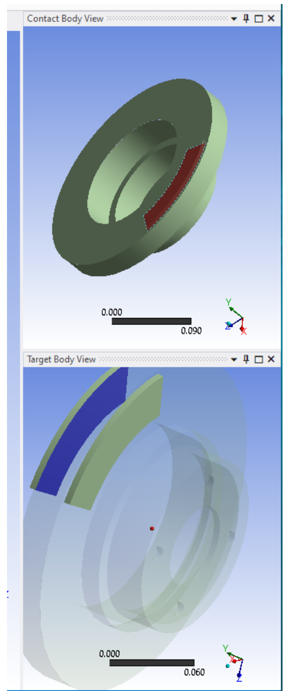


Fig. 4 - Frictional Contact definition

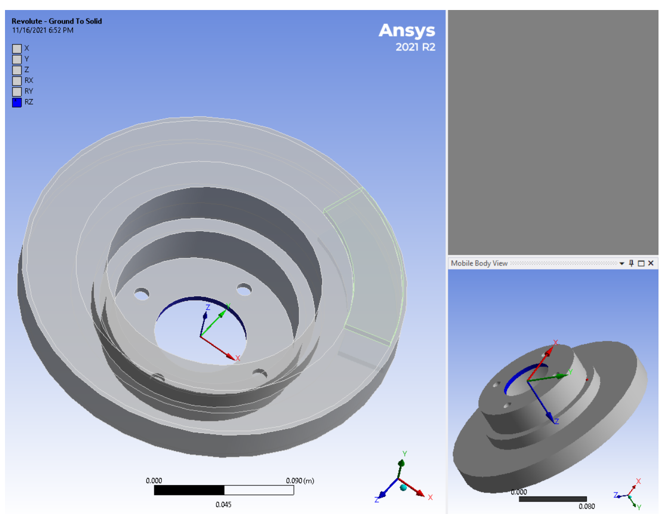


Fig. 5 - Rotational Joint

The rotational joint is used to indicate that the disc can only rotate on a fixed y axis. Next, we define the boundary condition of the problem. The rotational velocity around y axis, with magnitude of 250 rad/s.

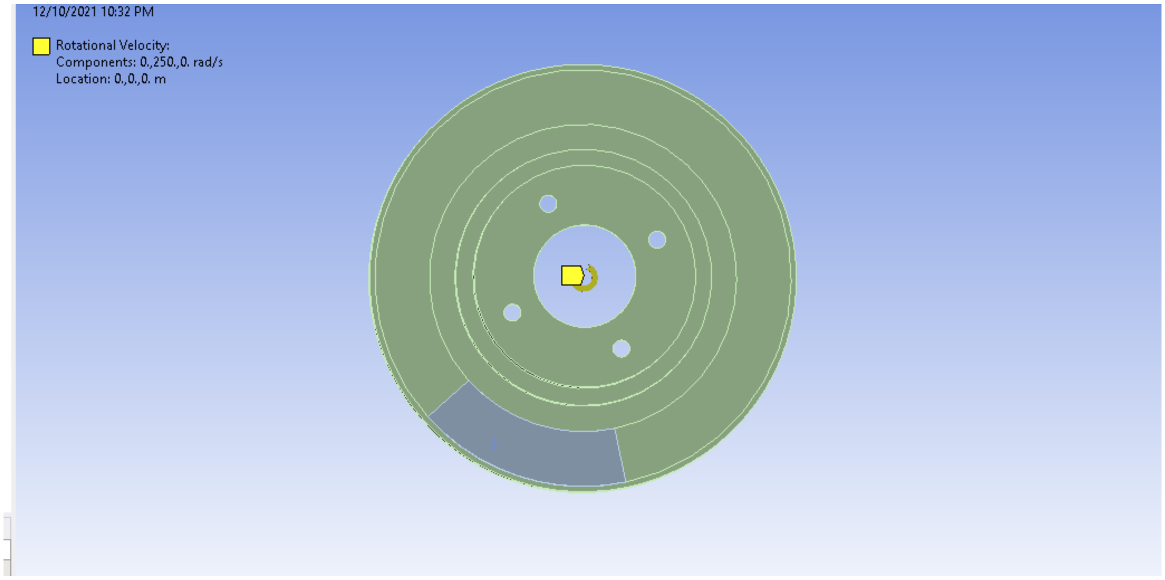


Fig. 6 - Rotational Constraint.

The pressure is applied to the outer surface of the pad.

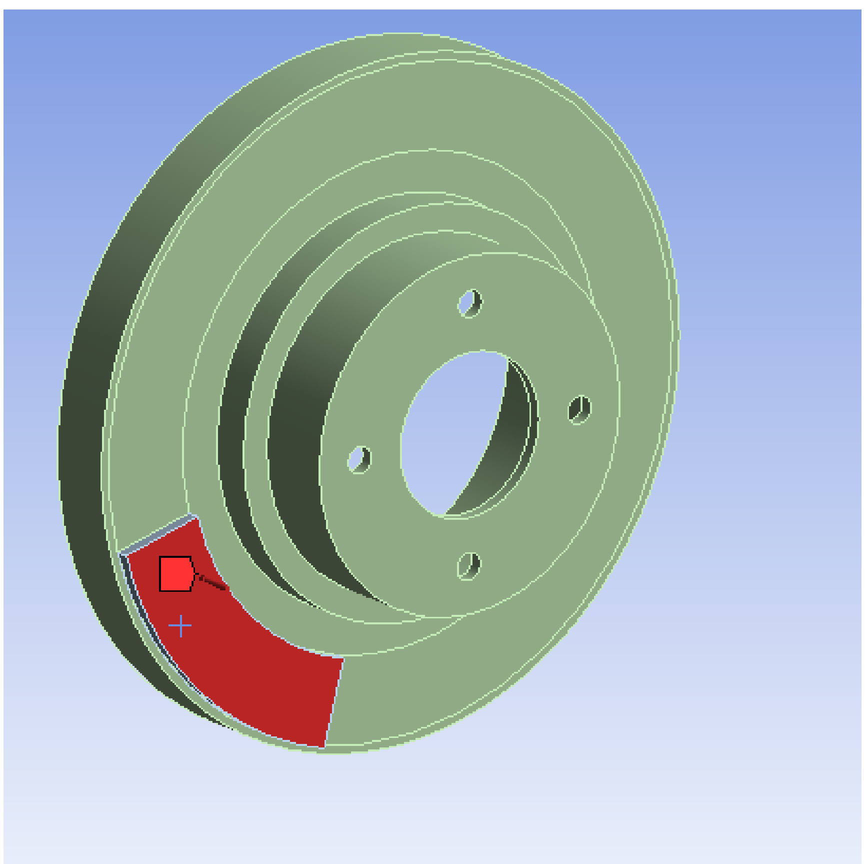
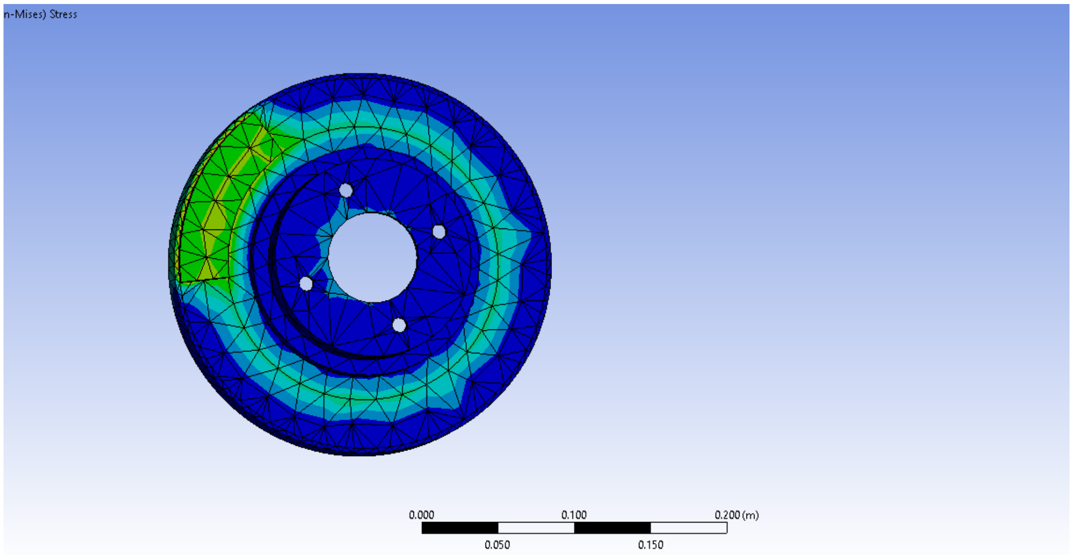


Fig. 7 - Pressure applied by brake pad.

The result of stress analysis is shown below. Von-Mises equivalent stresses are shown. The maximum stress before optimizing the system is 1.325e7 Pascals.



Details of "Equivalent Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent (von-Mises) Stress
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Average Across Bodies	No
Results	
Minimum	97997 Pa
P Maximum	1.3248e+007 Pa
Average	4.3795e+006 Pa
Minimum Occurs On	Solid

Fig. 8 - Stress contour plot of Brake.and maximum stress

Modal Analysis:

The results of modal analysis are shown in the figure 9, 10, 11

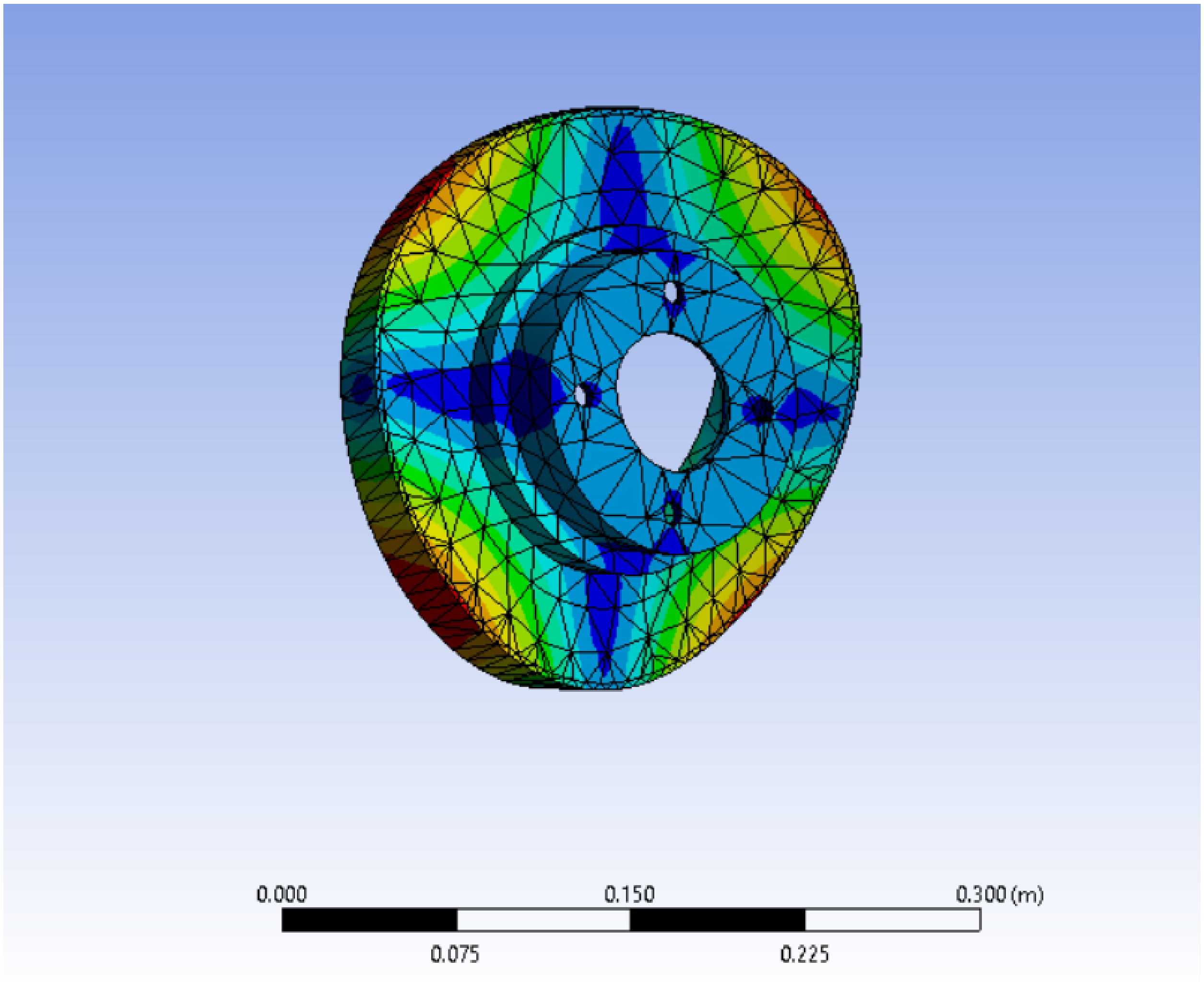


Fig. 9 - Seventh Vibrational mode deformation.

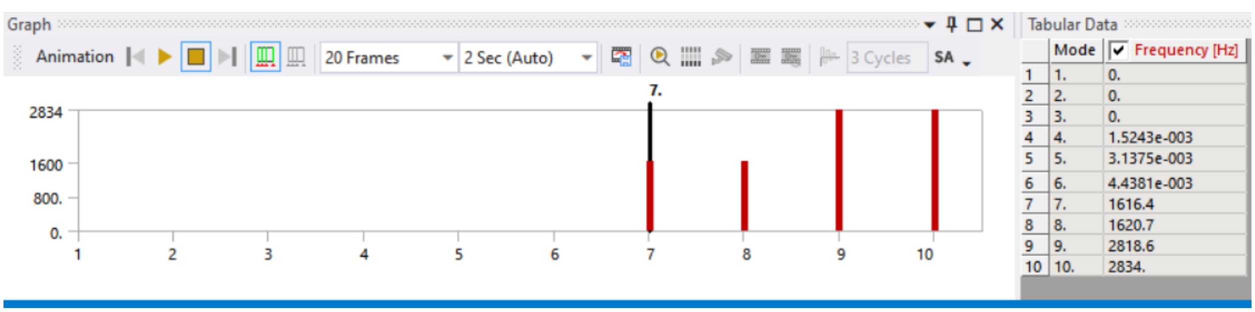
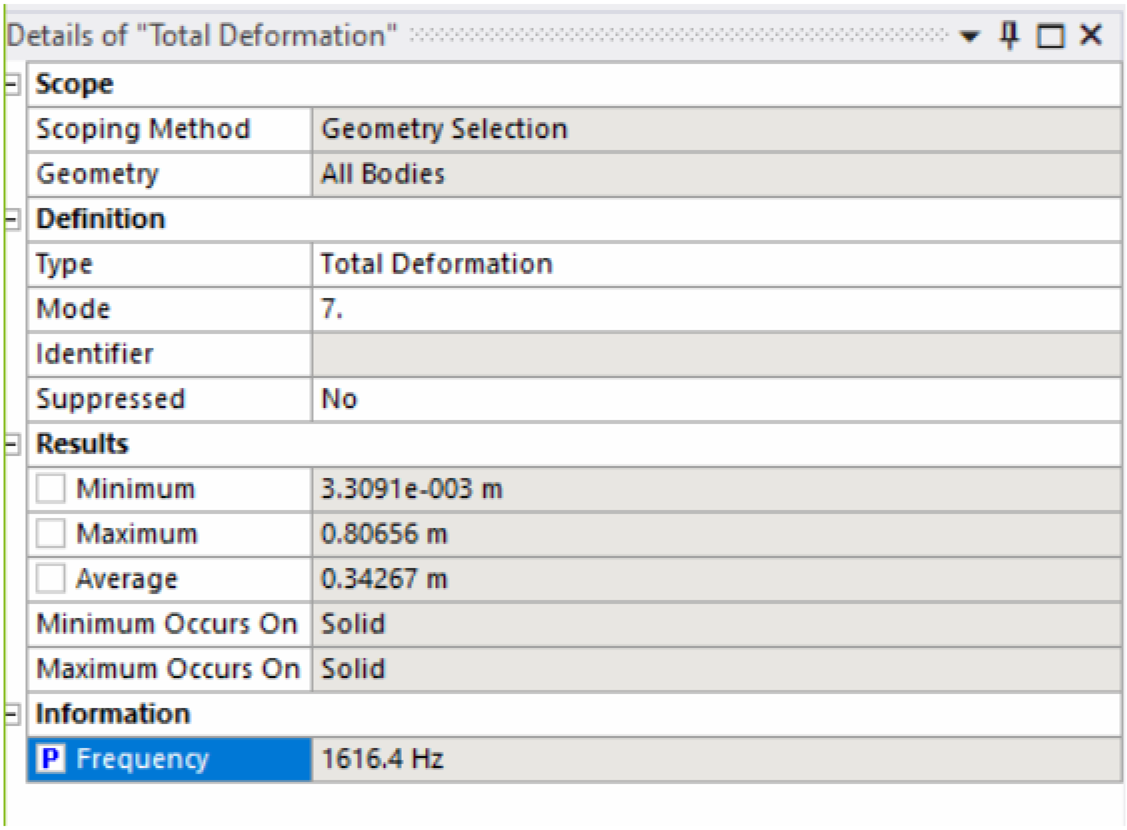


Figure 10 - Vibrational mode values.



Details of "Total Deformation"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
Mode	7.
Identifier	
Suppressed	No
Results	
Minimum	3.3091e-003 m
Maximum	0.80656 m
Average	0.34267 m
Minimum Occurs On	Solid
Maximum Occurs On	Solid
Information	
Frequency	1616.4 Hz

Figure 11 - Vibrational frequency.

The frequency for disc deformation is 1616.4HZ.

<u>Thermal Analysis:</u>

The setup is the same in the tutorial. The maximum temperature is 341.03 in the setup case.

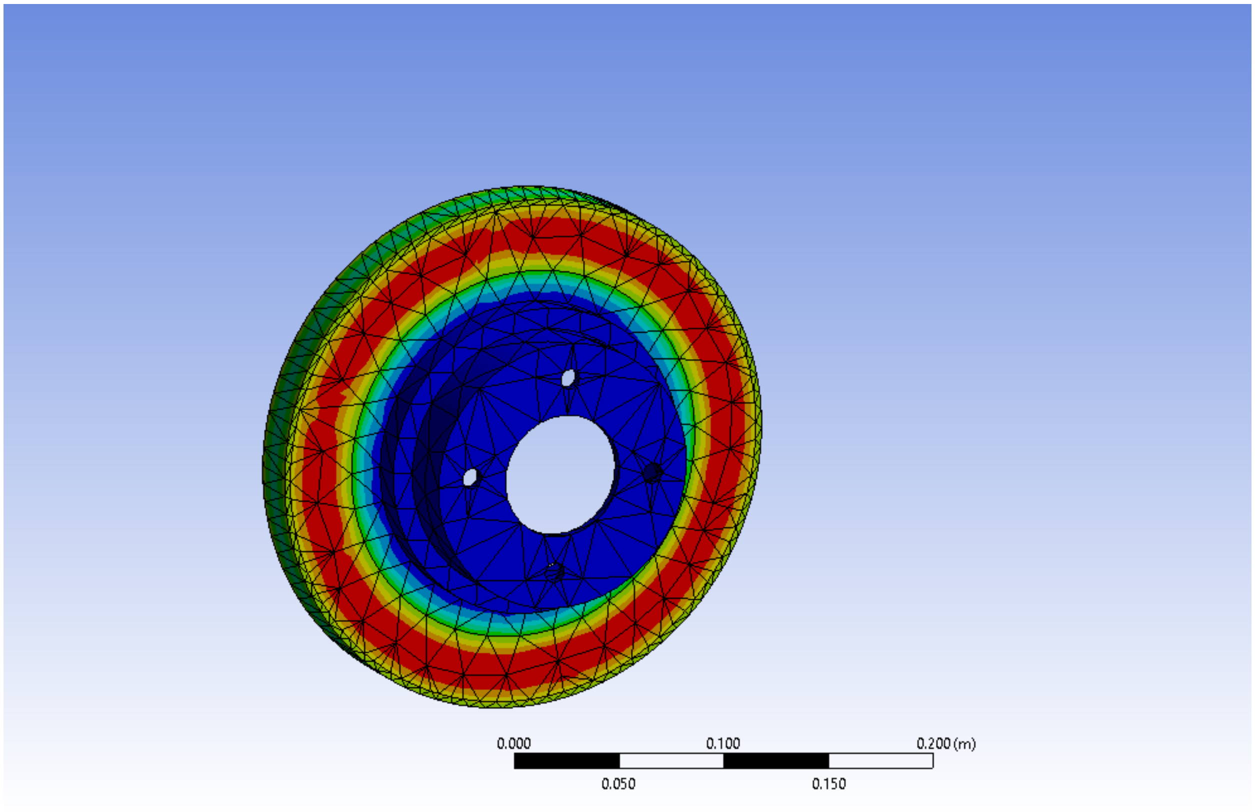
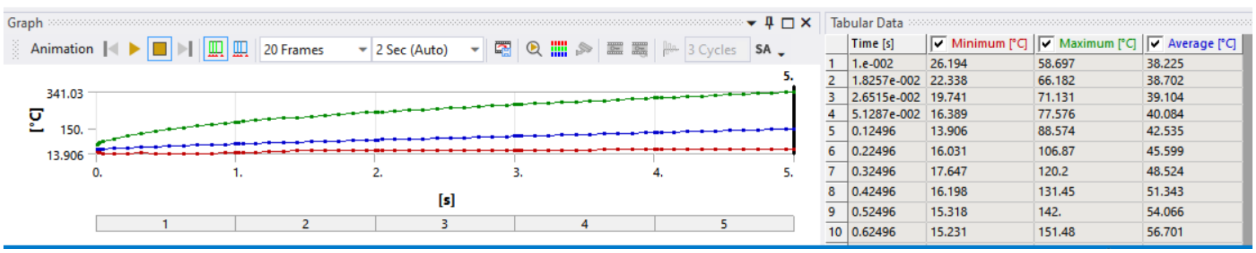


Fig. 12 - Temperature contour plot.



	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	1.e-002	26.194	58.697	38.225
2	1.8257e-002	22.338	66.182	38.702
3	2.6515e-002	19.741	71.131	39.104
4	5.1287e-002	16.389	77.576	40.084
5	0.12496	13.906	88.574	42.535
6	0.22496	16.031	106.87	45.599
7	0.32496	17.647	120.2	48.524
8	0.42496	16.198	131.45	51.343
9	0.52496	15.318	142.	54.066
10	0.62496	15.231	151.48	56.701

Fig. 13 - Temperature chart.

Design of Experiment:

The Latin Hypercube Sampling Design method is chosen for DOE. The sample type os user-defined samples. The range of the parameter considered in the project is shown in the table 1 below. The disc outer diameter is selected to be larger than the outer diameter of the pad. 15 experimental points are chosen in this analysis**.** Results of DOE are shown in table 2.

	Disc Thickness (mm)	Disc Outer Diameter (mm)	Disc Inner Diameter (mm)
Lower Bound	22.5	125	67.5
Higher Bound	27.5	137.5	82.5

Table 1 - Lower and Higher Bounds for input parameters

Table of Schematic H2: Design of Experiments (Latin Hypercube Sampling Design : User-Defined Samples : Random Generator Seed = 0 : Number of Samples = 15)

	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	DP 2	25.333	134.58	76	1.1601E+07	340.41	1456
3	2	DP 2	26.333	131.25	77	1.1906E+07	341.93	1504.6
4	3	DP 1	22.667	132.08	70	1.1269E+07	347.85	1491.5
5	4	DP 2	26	125.42	81	1.3379E+07	339.93	1497.7
6	5	DP 1	23	127.08	71	1.1504E+07	346.72	1592.6
7	6	DP 3	27.333	126.25	69	1.1682E+07	335.41	1710.6
8	7	DP 2	25.667	136.25	80	1.1583E+07	339.69	1383.8
9	8	DP 2	27	133.75	79	1.1743E+07	339.66	1449.3
10	9	DP 2	24	127.92	75	1.1533E+07	345.4	1561.6
11	10	DP 1	23.667	132.92	82	1.1749E+07	347.35	1363.9
12	11	DP 2	24.667	129.58	73	1.1738E+07	345.18	1564.8
13	12	DP 1	23.333	135.42	72	1.1708E+07	345.65	1425.2
14	13	DP 2	25	130.42	74	1.1513E+07	343.76	1542.1
15	14	DP 2	26.667	137.08	68	1.178E+07	337.13	1456
16	15	DP 2	24.333	128.75	78	1.1547E+07	344.64	1505.5

Table 2 - DOE Sample and Solutions

The parameters parallel chart is shown below. The input and output parameters are shown in the x axis, and the y axis shows the relative magnitude among different experiment points. A closer and more detailed look at the output value are shown in 15, 16, 17, 18, where the volume, equivalent stress, deformation frequency, maximum temperature are plotted with respect to the design points.

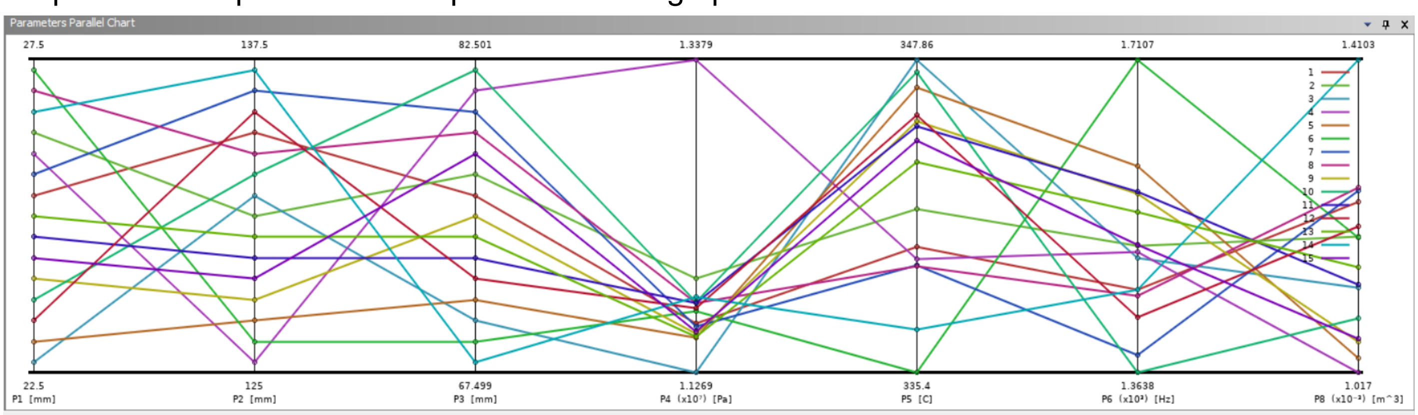


Figure 14 - Parameters Parallel Chart.

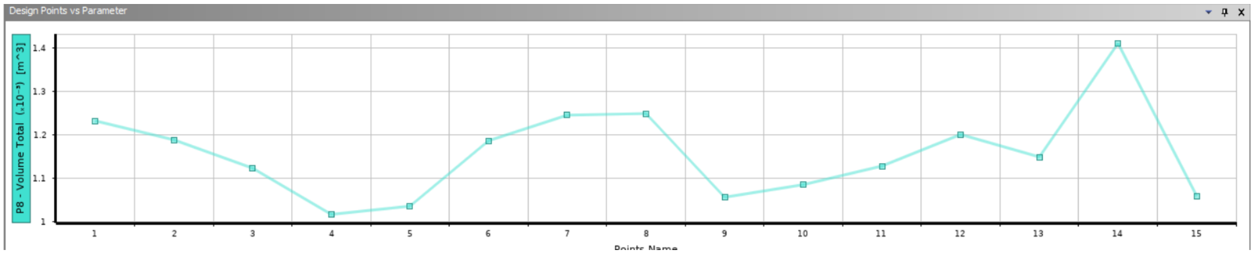


Figure 16 - Design Points vs. Volume

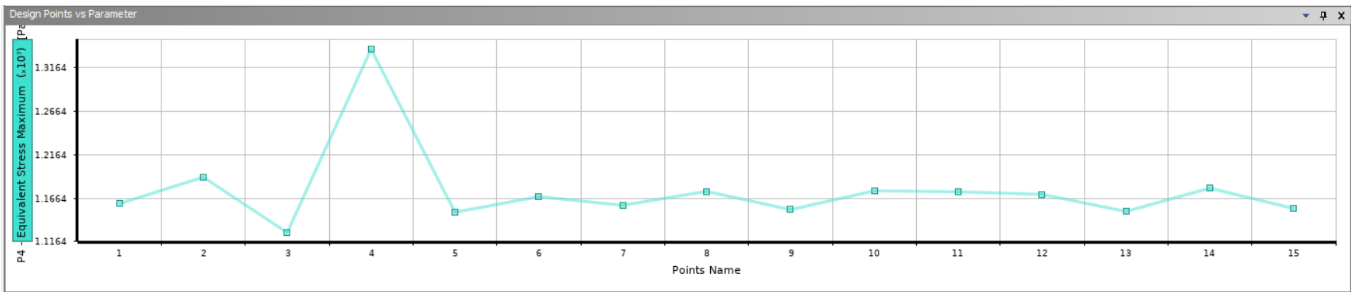


Figure 16 - Design Points vs. Equivalent Stress

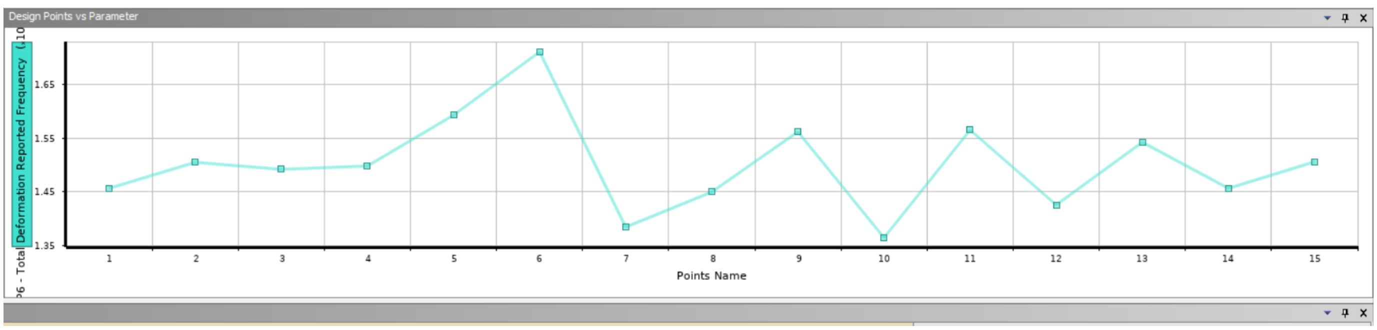


Figure 17 - Design points vs. Deformation Frequency.

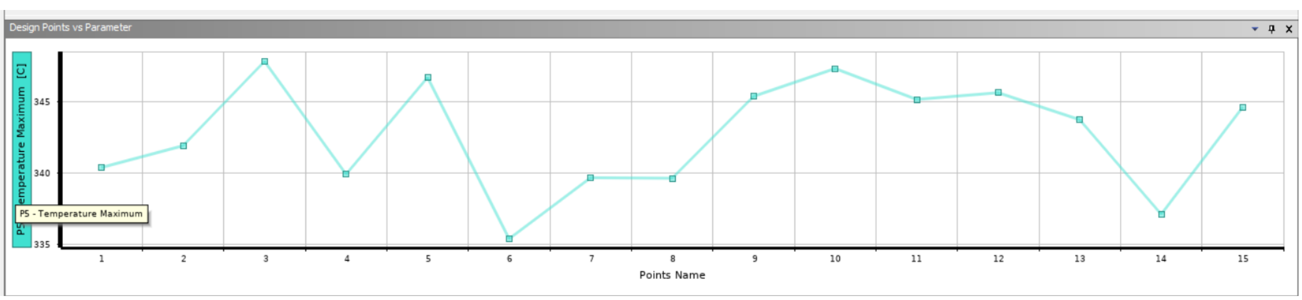
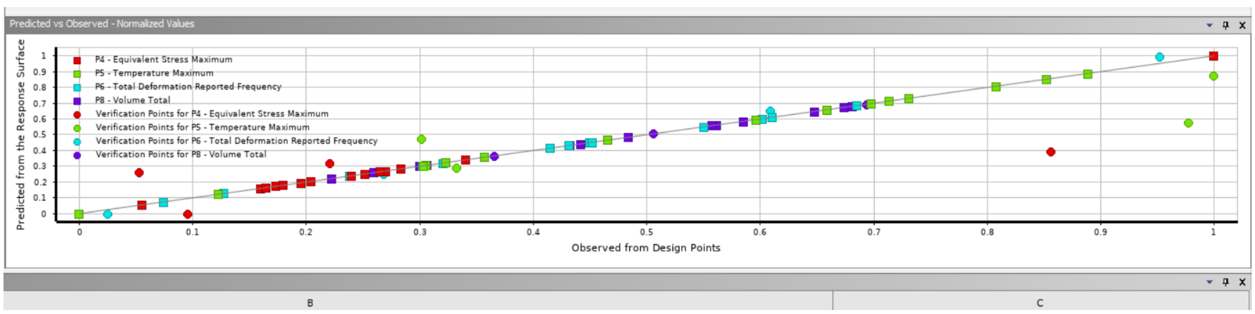


Figure 18 - Design Points vs. Maximum Temperature.

From figures above, based on the optimization criteria set before, 6th points is the best points among them, where it has the smallest stress, maximum frequency and lowest temperature. The values are 1.1504E+7pa, 346.72C, 1592.6Hz and 0.00104m^3.

Response Surface:

Response surfaces are used for prediction purposes, for this project it was decided to use a genetic aggregation surface response, which is great for nonlinear mapping from inputs to the outputs and since we don’t require our model to fit right through the data it is a good option. It was also necessary to generate verification points, for which 8 points were created. The result of the response surface is displayed in table 4.
In this project, Krigging is chosen for hte response surface. Because the data points are limited and the model is nonlinear.
A goodness of fit plot is shown



Response Point	Disc Thickness (mm.)	Disc Outer Diameter (mm.)	Disc Inner Diameter (mm.)	Equivalent Maximum Stress (Pa)	Vibrational Frequency (Hz)	Maximum Temperature (C)
1	16.25	129.75	78	1.2592e7	1800	344.6

Table 4 - Neural Network output of Response surface