MAE 598 Design Optimization

Project 2 Report

DESIGN OPTIMIZATION OF BRAKE DISC GEOMETRY

Submitted By

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Abstract

The purpose of this project is to learn how to implement the design optimization techniques in Ansys using the provided tutorial and the knowledge gained over the course of study. In this project we are determine the optimum dimensions of the brake disc for a four-wheeler vehicle using Ansys. The dimensions of the brake disc are determined by minimizing the stress and temperature, and maximizing the first natural frequency of the disc. Here the final values obtained are compared with those in the tutorial.

Design Problem Statement

The main objective of this design is to minimize the volume of the brake disc for emergency braking conditions by minimizing the maximum stress and maximum temperature in the brake disc, and maximizing the first natural frequency of the brake disc. The parameter used for this setup are outer diameter of the brake disc, inner diameter of the brake disc, thickness of the brake disc, and diameter of the cylindrical vents. This simulation is performed to get an understanding of why it is important to select the parameters carefully while performing design optimization and it can be observed in the results of this simulation.

Problem Setup

In this setup we are conducting structural analysis, modal analysis, and thermal analysis on the brake disc.

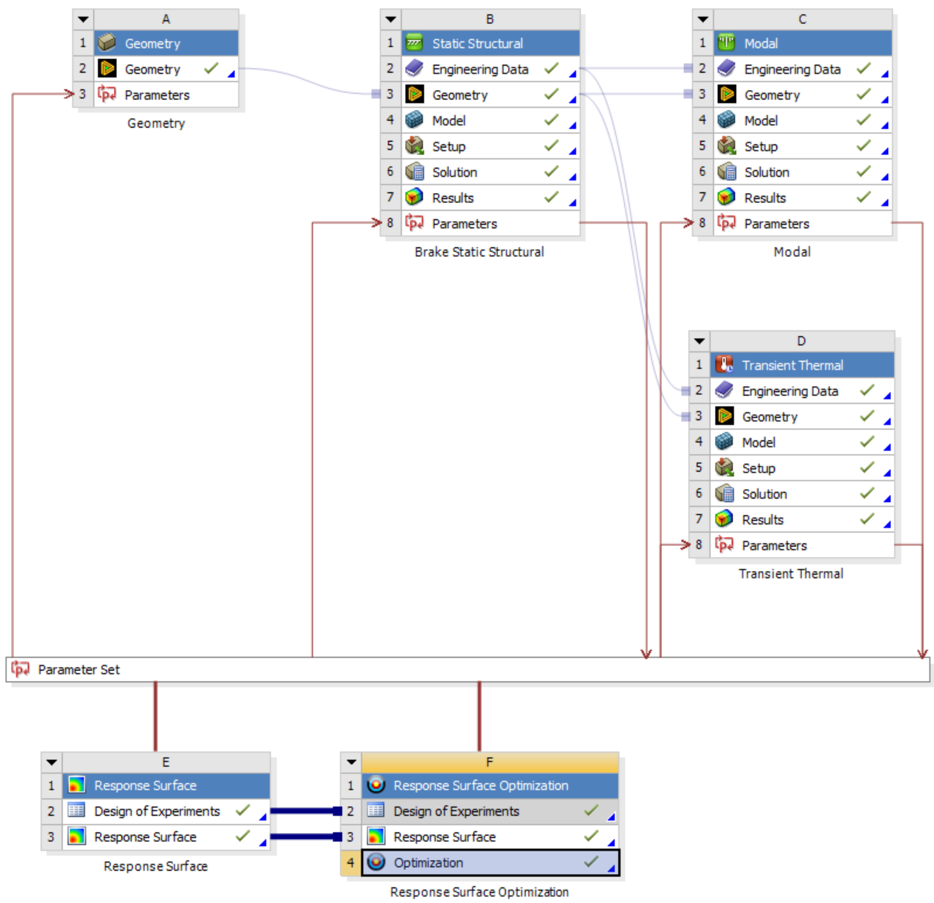

Fig. 1 Ansys Optimization Flowchart

Design variables

The variables for this optimization as Outer diameter of the disc, Inner diameter of the disc, Rotor thickness, and Diameter of the cylindrical vents on the contact surface of the disc.

Constraints

The constraints for this analysis are maximum equivalent stress, total deformation reported frequency and maximum temperature which were obtained by performing an analysis on the initial geometrical setup. But for this project I have only used maximum equivalent stress.

Objective

The objective of this analysis is to minimize the maximum equivalent stress by constraining the values of outer diameter, and thickness of the disc.

Mesh setup

The type of mesh element used for this geometry was tetrahedrons which was set using patch conforming method and an element size of 0.003 m was used. Face sizing feature was employed to obtain a refined mesh between the contacting surfaces.

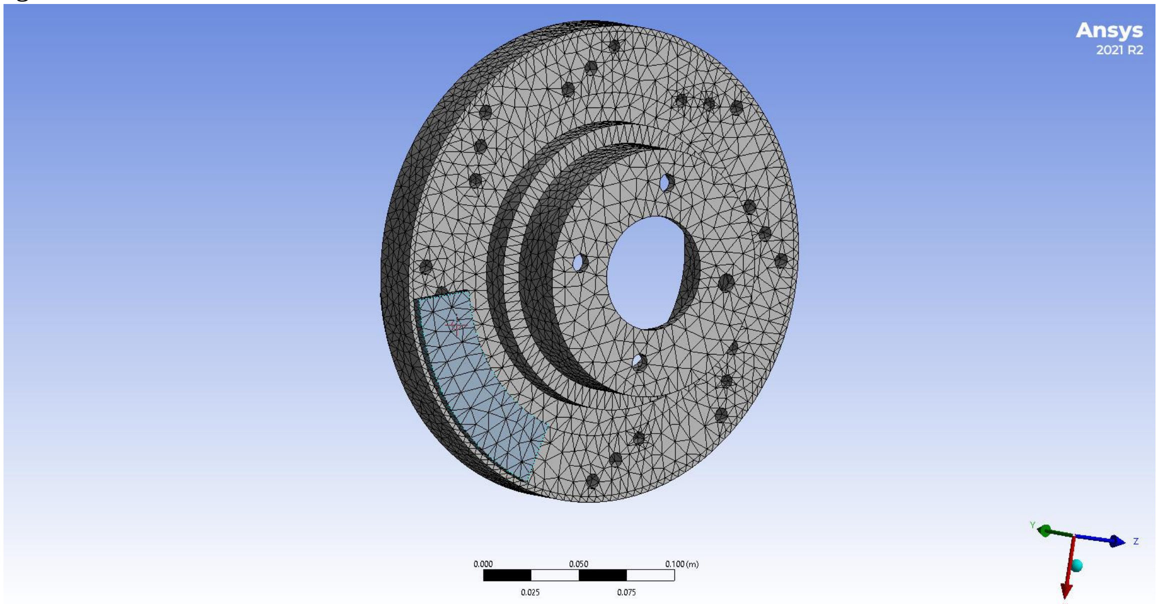

Fig. 2 Mesh

Potential trade-offs

In this optimization we are ignoring fatigue loading of the brake disc and brake pads which occurs as the braking action takes place n number of times over the life cycle of the brake disc and brake pads. We are assuming that the surrounding temperature is constant and doesn't vary over time.

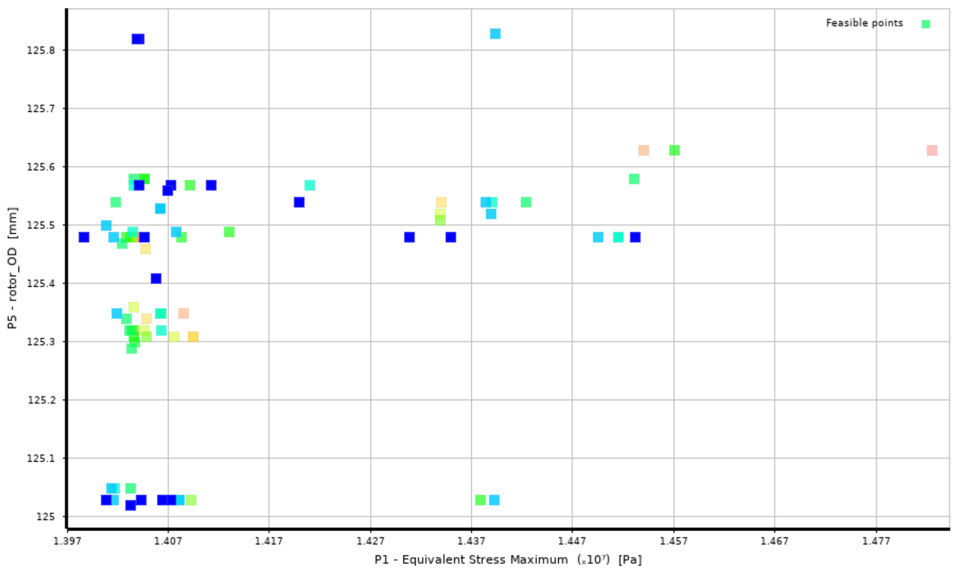

Fig. 3 Tradeoffs

Design of experiments

In this setup I have employed Latin Hypercube Sampling Design with User defined samples set to 50. It can be seen from the below parallel chart the upper and lower bounds of each parameters and they are spread out for all the parameters except for equivalent stress.

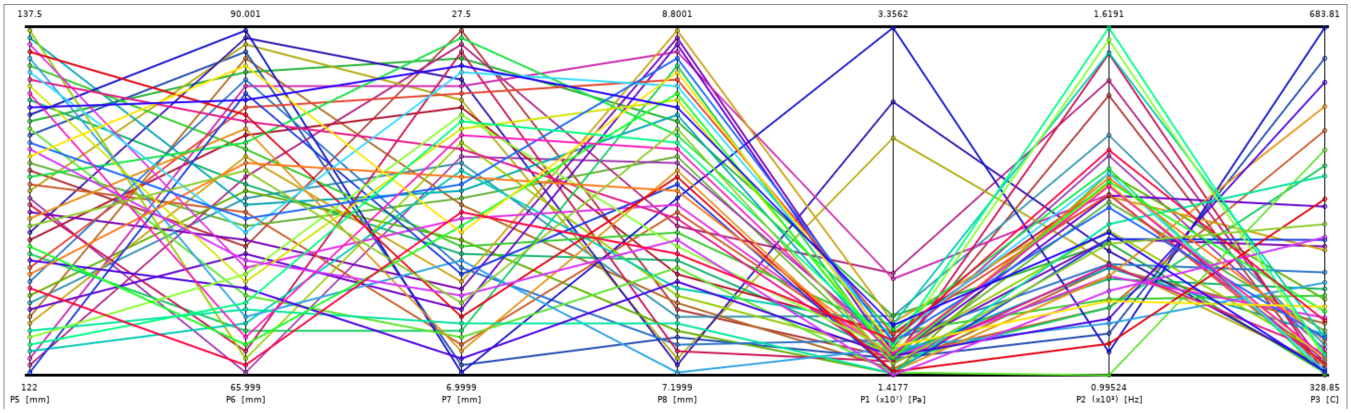

Fig. 4 Parameters parallel chart

Optimization method based on above parameters

Initial optimization method used is Screening to randomly sampling the space and picking the good ones and after that switched to proceed Multiobjective Genetic Algorithm with an initial sample size of 100 and the optimization converged after 732 evaluations.

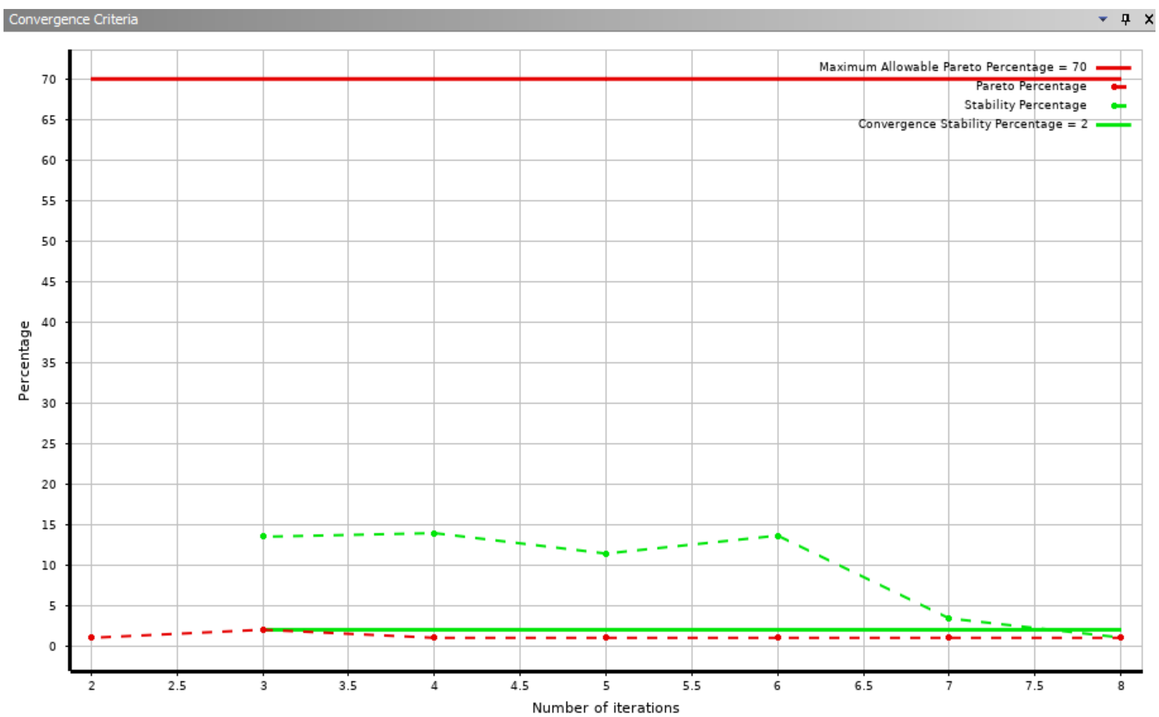

Fig. 5 Convergence Criteria.

Property	Value
Design Points	
Preserve Design Points After DX Run	☐
Failed Design Points Management	
Number of Retries	0
Optimization	
Method Selection	Manual
Method Name	MOGA
Estimated Number of Evaluations	2000
Tolerance Settings	☑
Verify Candidate Points	☐
Number of Initial Samples	100
Number of Samples Per Iteration	100
Maximum Allowable Pareto Percentage	70
Convergence Stability Percentage	2
Maximum Number of Iterations	20
Maximum Number of Candidates	3
Optimization Status	
Converged	Yes
Pareto Percentage	1
Stability Percentage	1.0342
Number of Iterations	8
Number of Evaluations	732
Number of Failures	0
Size of Generated Sample Set	100
Number of Candidates	3

Fig. 6 Optimization method

Table of Schematic F4: Optimization

	A	B	C	D	E	F	G	H	I
1	Name	Parameter	Objective			Constraint			
2			Type	Target	Tolerance	Type	Lower Bound	Upper Bound	Tolerance
3	Minimize P1; P1 <= 1.5232E+07 Pa	P1 - Equivalent Stress Maximum	Minimize	1.1E+07		Values <= Upper Bound		1.5232E+07	0.001
4	Seek P5 = 125 mm	P5 - rotor_OD	Seek Target	125	0.001	No Constraint			
5	Seek P7 = 20 mm	P7 - rotor_thickness	Seek Target	20	0.001	No Constraint			
*		Select a Parameter							

Fig. 7 Optimization parameters

Sensitivity analysis

It can be observed how changing variables of the disc plays a major role in the analysis. Changing the outer and internal dimeter of the disc produces the observable change in the objective. I have as also included cylindrical vent on the contact surface of the disc which closely resembles the brake discs that are in use, and it can be observed that it barely effects any of the parameters so this gives us an overview of how important it is to select the variables when performing a design optimization.

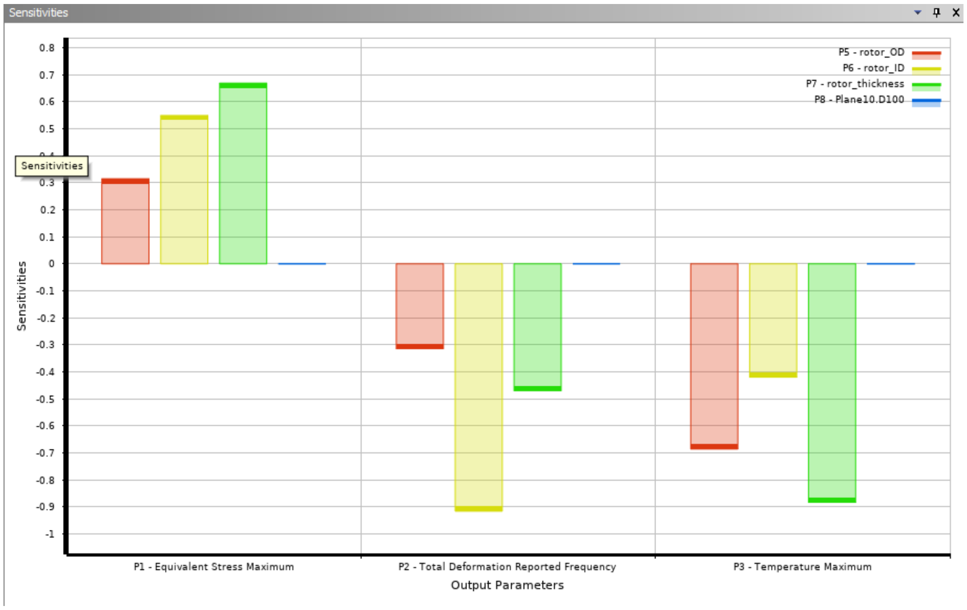

Fig. 8 Local sensitivity

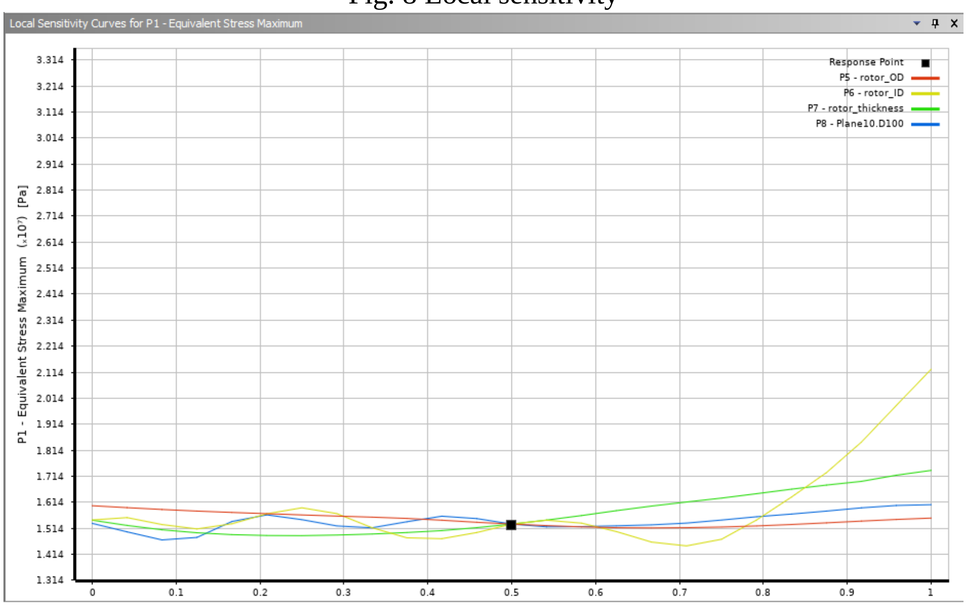

Fig. 9 Local sensitivity curves

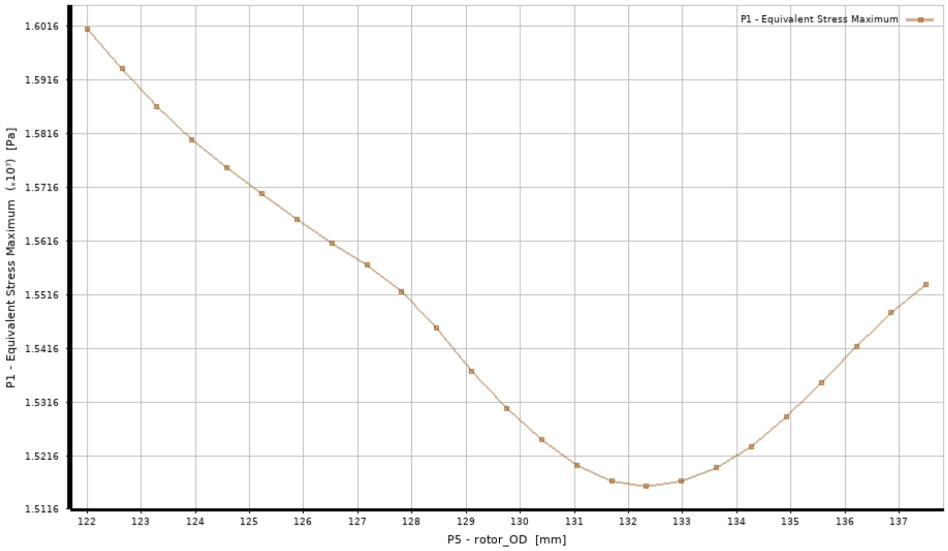

Fig. 10 Response curve

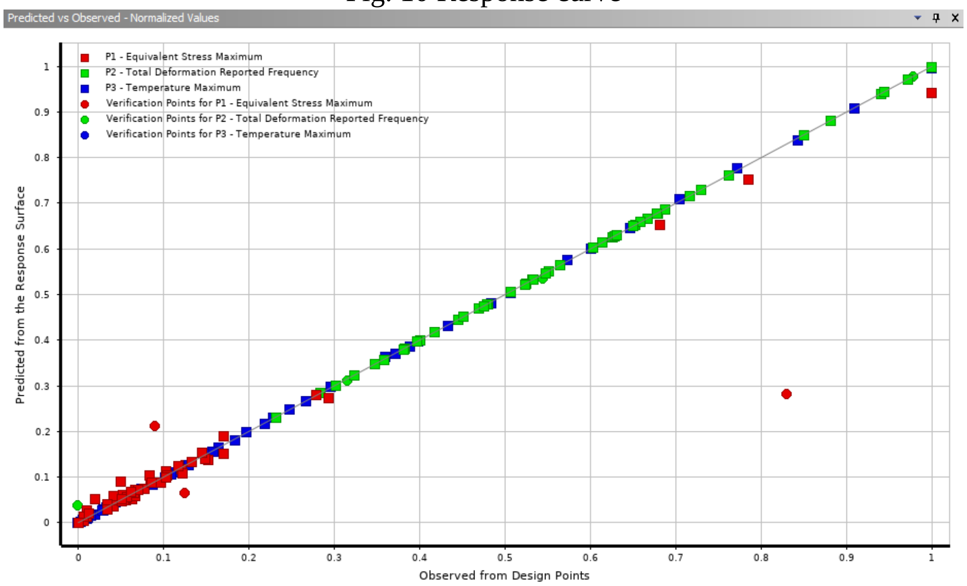

Fig. 11 Goodness of fit

Table of Schematic E3: Response Surface

	A	B	C	D
1		P1 - Equivalent Stress Maximum	P2 - Total Deformation Reported Frequency	P3 - Temperature Maximum
2	Coefficient of Determination (Best Value = 1)			
3	Learning Points	0.99364	1	0.99994
4	Cross-Validation on Learning Points	0.37046	0.99968	0.99976
5	Root Mean Square Error (Best Value = 0)			
6	Learning Points	2.9246E+05	0.0078451	0.70981
7	Verification Points	5.4711E+06	16.147	0.22243
8	Cross-Validation on Learning Points	2.91E+06	2.6276	1.4634
9	Relative Maximum Absolute Error (Best Value = 0%)			
10	Learning Points	29.568	0.018865	1.8163
11	Verification Points	264.23	18.964	0.34775
12	Cross-Validation on Learning Points	484.48	5.364	7.5975
13	Relative Average Absolute Error (Best Value = 0%)			
14	Learning Points	5.3199	0	0.60121
15	Verification Points	88.092	6.0595	0.21079
16	Cross-Validation on Learning Points	37.558	1.3067	0.95255

Fig. 12 Response surface

Table of Schematic F4: Optimization

	A	B	C	D
1	⊟ Optimization Study			
2	Minimize P1; P1 <= 1.5232E+07 Pa	Goal, Minimize P1 (Default importance); Strict Constraint, P1 values less than or equals to 1.5232E+07 Pa (Default importance)		
3	Seek P7 = 20 mm	Goal, Seek P7 = 20 mm (Default Importance)		
4	Seek P5 = 125 mm	Goal, Seek P5 = 125 mm (Default Importance)		
5	⊟ Optimization Method			
6	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.		
7	Configuration	Generate 100 samples initially, 100 samples per iteration and find 3 candidates in a maximum of 20 iterations.		
8	Status	Converged after 732 evaluations.		
9	⊟ Candidate Points			
10		Candidate Point 1	Candidate Point 2	Candidate Point 3
11	P5 - rotor_OD (mm)	125.03	125.03	125.48
12	P6 - rotor_ID (mm)	83.44	83.32	83.89
13	P7 - rotor_thickness (mm)	18.3	18.25	18.4
14	P8 - Plane10.D100 (mm)	8.103	8.063	8.032
15	P1 - Equivalent Stress Maximum (Pa)	1.4072E+07	1.408E+07	1.4349E+07

Fig. 13 Candidate points

Result and Conclusion

Initial volume of the brake disc: 9.6791e+05 mm^3

Final volume of the brake disc: 7.5194e+05 mm^3

Volume reduction: 22.3%

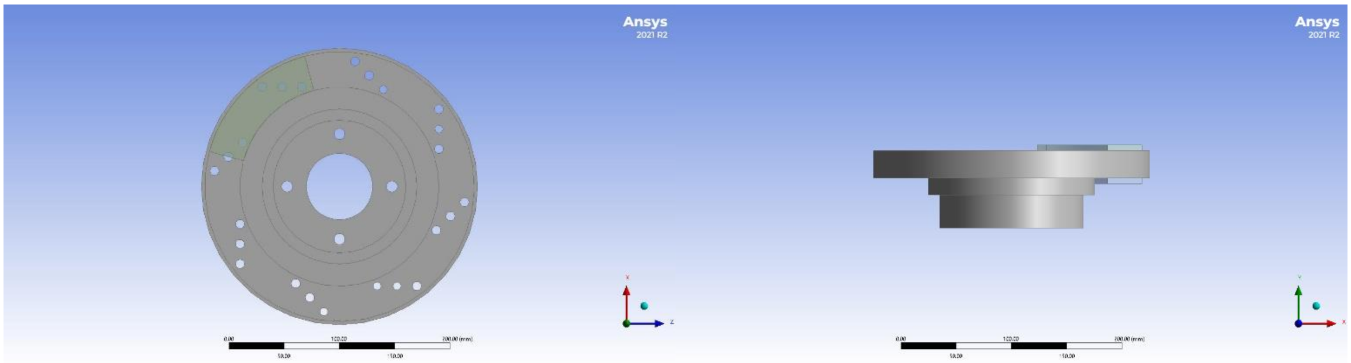

Fig. 14 Initial Geometry

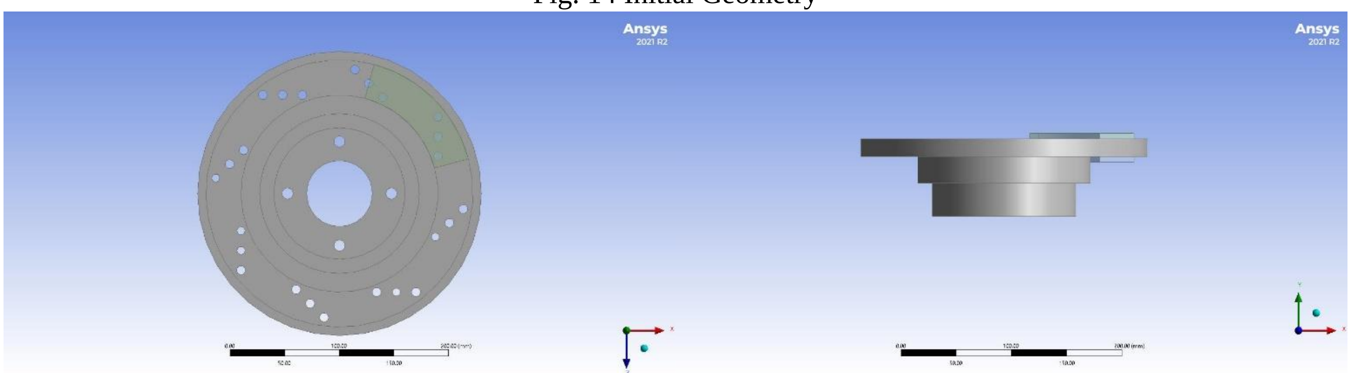

Fig. 15 Final Geometry

It can be observed from the above images that the volume reduction is close to $1/4^{th}$ of the initial design and variable that has significant effect on the volume is thickness and the internal diameter of the disc. From above analysis we can't right away conclude that the optimal design is reasonable as the number of samples used is 25 for the DOE, number of verification points is 4, and number of initial samples used in response surface is 100.

I feel using a larger sample size for DOE, larger verification and response surface set might yield reasonable design but only after testing the design in reality can we conclude that the final optimized design is reasonable, and the dimensions have to be rounded up to be able to manufacture that optimal design.

Results	
Minimum	29302 Pa
P Maximum	1.5232e+007 Pa
Average	3.0823e+006 Pa
Minimum Occurs On	Brake Disc
Maximum Occurs On	Brake Disc

Results	
Minimum	1.9218e-003 m
Maximum	0.82886 m
Average	0.31378 m
Minimum Occurs On	Brake Disc
Maximum Occurs On	Brake Disc
Information	
P Frequency	1575.4 Hz

Results	
Minimum	35. °C
P Maximum	336.21 °C
Average	134.44 °C
Minimum Occurs On	Brake Disc
Maximum Occurs On	Brake Disc
Minimum Value Over Time	
Minimum	16.53 °C
Maximum	35. °C
Maximum Value Over Time	
Minimum	49.603 °C
Maximum	336.21 °C

Fig. 16 Maximum Equivalent stress, Maximum Total deformation reported frequency, and Maximum Temperature for the initial model.

Table of Outline A23: Response Points

	A	B	C	D	E	F	G	H
1	Name	P5 - rotor_OD (mm)	P6 - rotor_ID (mm)	P7 - rotor_thickness (mm)	P8 - Plane10.D100 (mm)	P1 - Equivalent Stress Maximum (Pa)	P2 - Total Deformation Reported Frequency (Hz)	P3 - Temperature Maximum (C)
2	Response Point	129.75	78	16.25	8	1.5303E+07	1291.2	394.08
*	New Response Point							

Fig. 17 Maximum Equivalent stress, Maximum Total deformation reported frequency, and Maximum Temperature for the optimized model with cylindrical vents.

Table of Outline A2: Response Points

	A	B	C	D	E	F	G
1	Name	P5 - rotor_OD (mm)	P6 - rotor_ID (mm)	P7 - rotor_thickness (mm)	P1 - Equivalent Stress Maximum (Pa)	P2 - Total Deformation Reported Frequency (Hz)	P3 - Temperature Maximum (C)
2	Response Point	129.75	78	16.25	1.1342E+07	1306.7	381.73
*	New Response Point						

Fig. 18 Maximum Equivalent stress, Maximum Total deformation reported frequency, and Maximum Temperature for the optimized model without cylindrical vents.

It can be observed from the above figures that optimized model without cylindrical vents for the same dimensions have lower maximum value from this we can say that having large number of sample sets might produce an optimized model and we have to carefully pick the parameters for the optimization process and screening as first level of optimization will give us and over view of how the results will look for different optimization methods.

Table of Outline A16: Min-Max Search

	A	B	C	D	E	F	G	H
1	Name	P5 - rotor_OD (mm)	P6 - rotor_ID (mm)	P7 - rotor_thickness (mm)	P8 - Plane10.D100 (mm)	P1 - Equivalent Stress Maximum (Pa)	P2 - Total Deformation Reported Frequency (Hz)	P3 - Temperature Maximum (C)
2	Output Parameter Minimums							
3	P1 - Equivalent Stress Maximum	125.82	76.105	5	7.2	**8.2781E+06**	1100.3	939.5
4	P2 - Total Deformation Reported Frequency	137.5	66	5	7.2	1.6594E+07	**475.48**	929.81
5	P3 - Temperature Maximum	137.5	73.768	25.474	7.2	1.4188E+07	1392.4	**315.4**
6	Output Parameter Maximums							
7	P1 - Equivalent Stress Maximum	122	90	27.5	7.8152	**3.2493E+07**	1227.4	347.56
8	P2 - Total Deformation Reported Frequency	122	66	27.5	8.687	2.249E+07	**1814.4**	348.65
9	P3 - Temperature Maximum	122	66	5	7.8064	1.7029E+07	936.64	**962.84**

Fig. 19 Maximum and minimum values of equivalent stress, total deformation frequency and temperature.

Initial result for reference

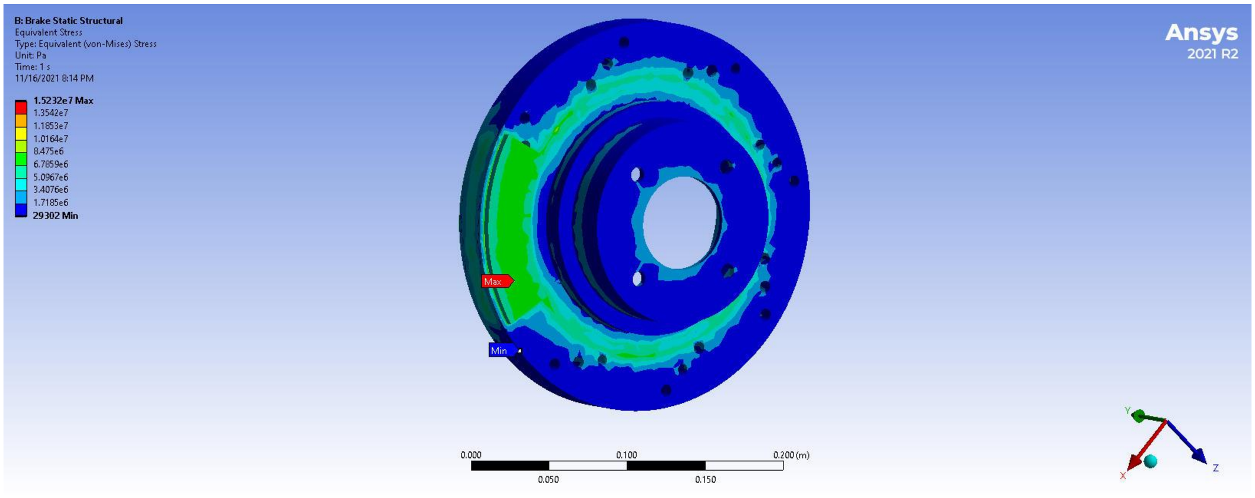

Fig. 20 Equivalent Stress

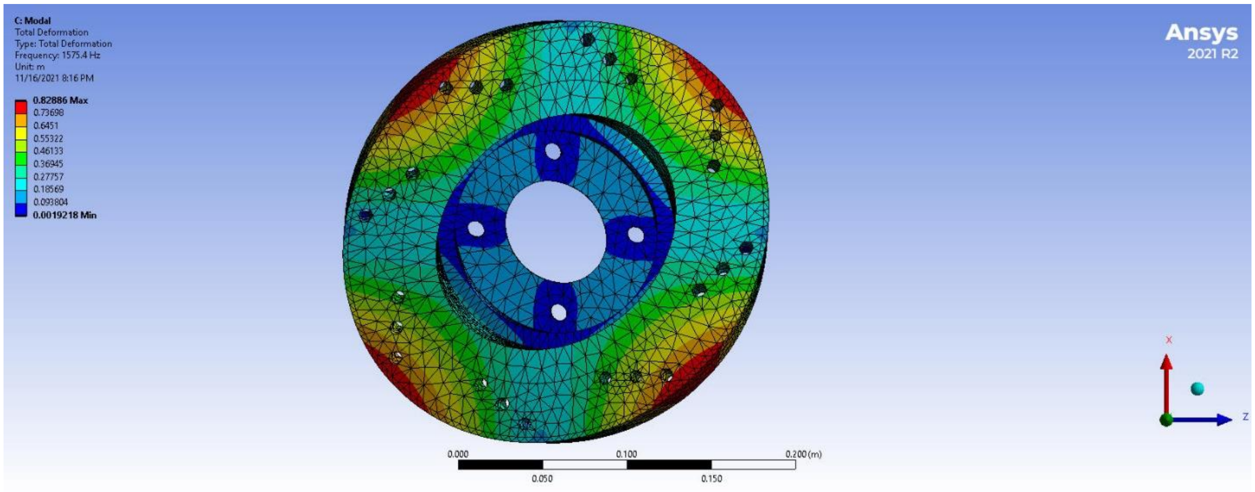

Fig. 21 Total Deformation

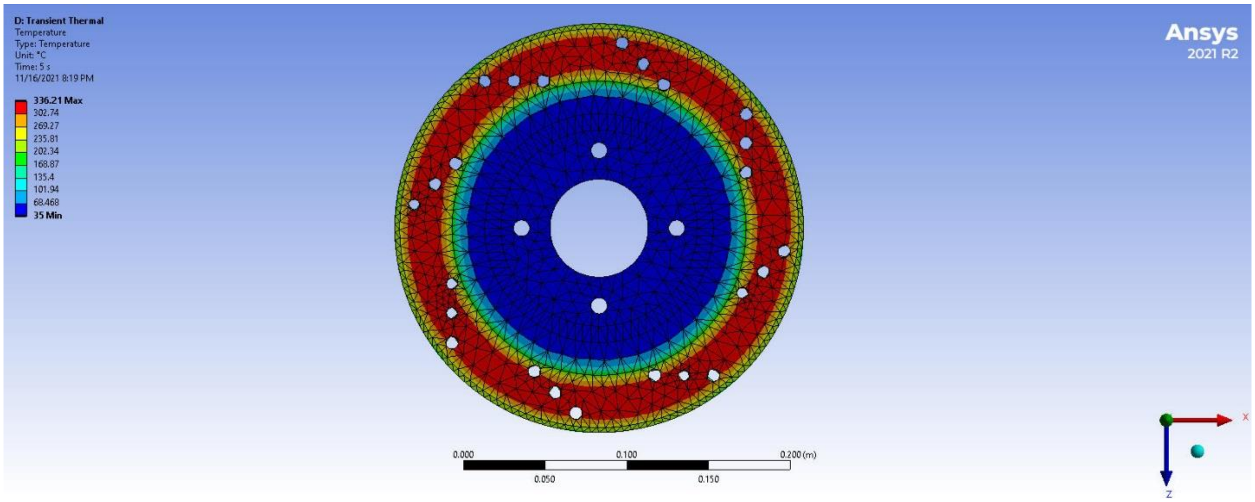

Fig. 22 Temperature