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MAE-598 Design Optimization

Project 2: Design Optimization of a Brake disk

Problem definition

To optimize a brake pad, design some changes in the geometric parameters viz. inner radius, outer radius and thickness are performed. The output of the design mainly comprises of the von mises stress, frequency and the temperature difference. The main objective of this project is to have a higher vibration and lower temperature.

All the analysis for this project is carried out on Ansys software, version R21.

Ansys

Ansys offers structural model, transit thermal and various other analysis. Basically, it is a software which provide solution that enables engineers of all levels and backgrounds to solve complex structural engineering problems faster and more efficiently. Ansys mechanical finite element analysis software is used to simulate computer models of structures, electronics or machine components for analyzing strength, toughness, electricity, temperature distribution, electromagnetism, fluid flow and other attributes and sizes used to determine how product will function with different specifications without building test products or conducting crash tests.

For example, in this project we have used ANSYS software to optimize an already existing brake pad design to simulate how a brake pad will hold up after years of its use.

Model setup

A brake disc Part is obtained from Professor Yi Ren's repository. It is then opened in Ansys. It basically has three modes;

1. Static Structural Analysis

2. Modal Analysis

3. Transient Thermal Analysis

Here is an overview of how the project schematic looks like

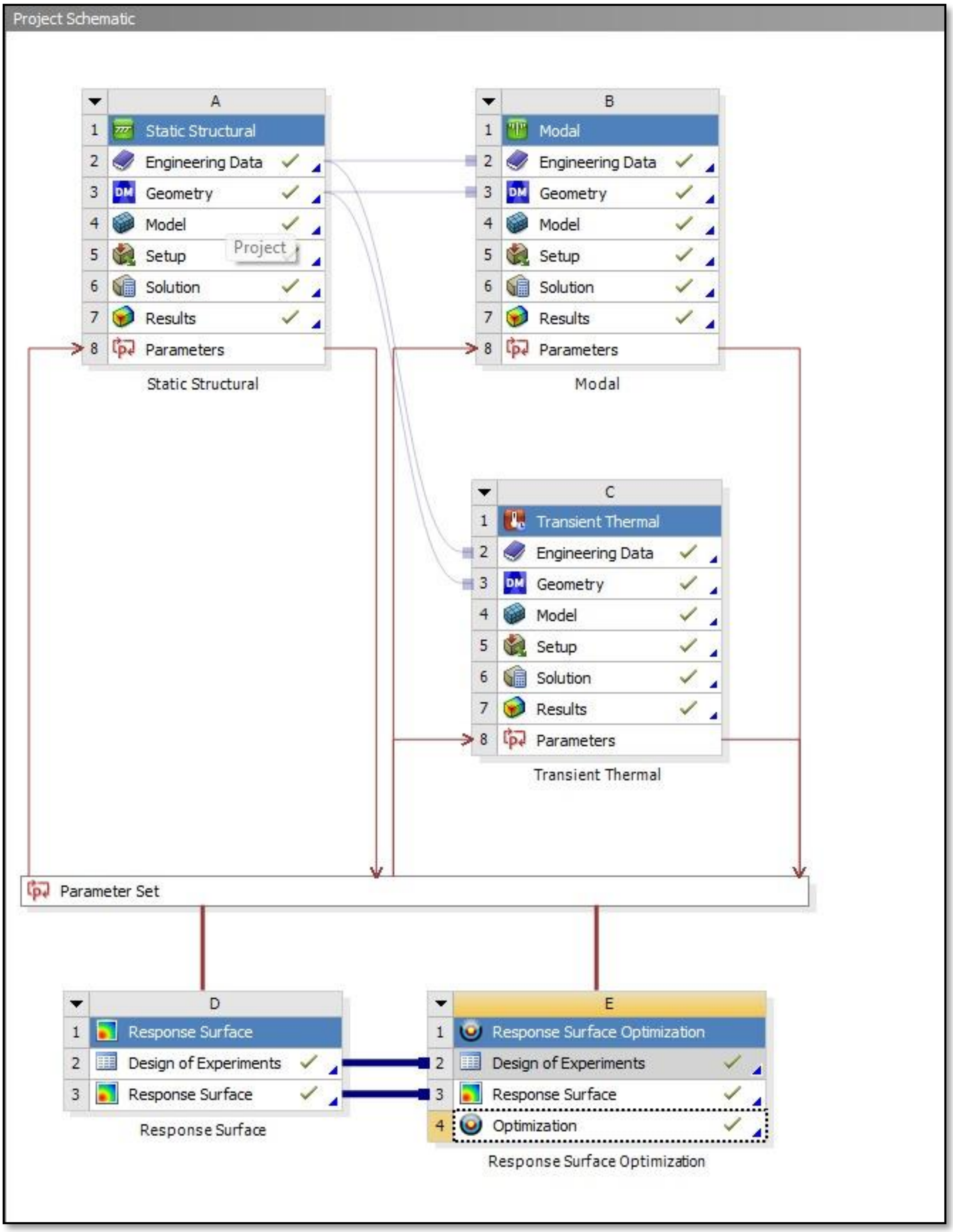


Fig 1: Project schematic window

We are using two materials in this project. First is the gray cast iron which is assigned for the main body. Second is structural steel which is assigned to the brake pads.

Initial setup

The geometry of the disk brake is imported into the static structural analysis. The body has predefined dimensions which can be changed according to the need. The analysis is carried out in static structural, modal and transient thermal.

Static Mechanical Analysis

Static structural analysis:

The mesh is carried out by the method 'tetrahedron' by using the Patch conforming algorithm

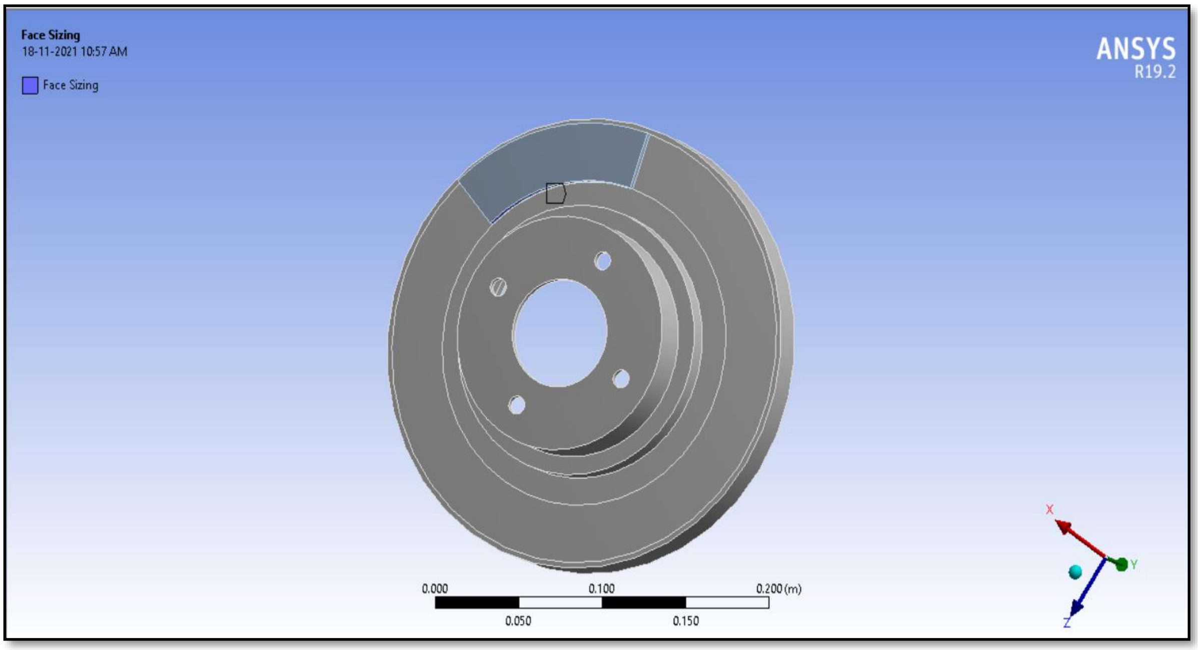


Fig 2: Meshing

The inner face of the brake pad is meshed with 3mm element size.

The rotational velocity of 250 rad/s is provided on the Y-axis. Frictional contact is applied between the main body with the value of 0.22. A pressure of 10.5 MPa is provided to both outer faces of the brake pads.

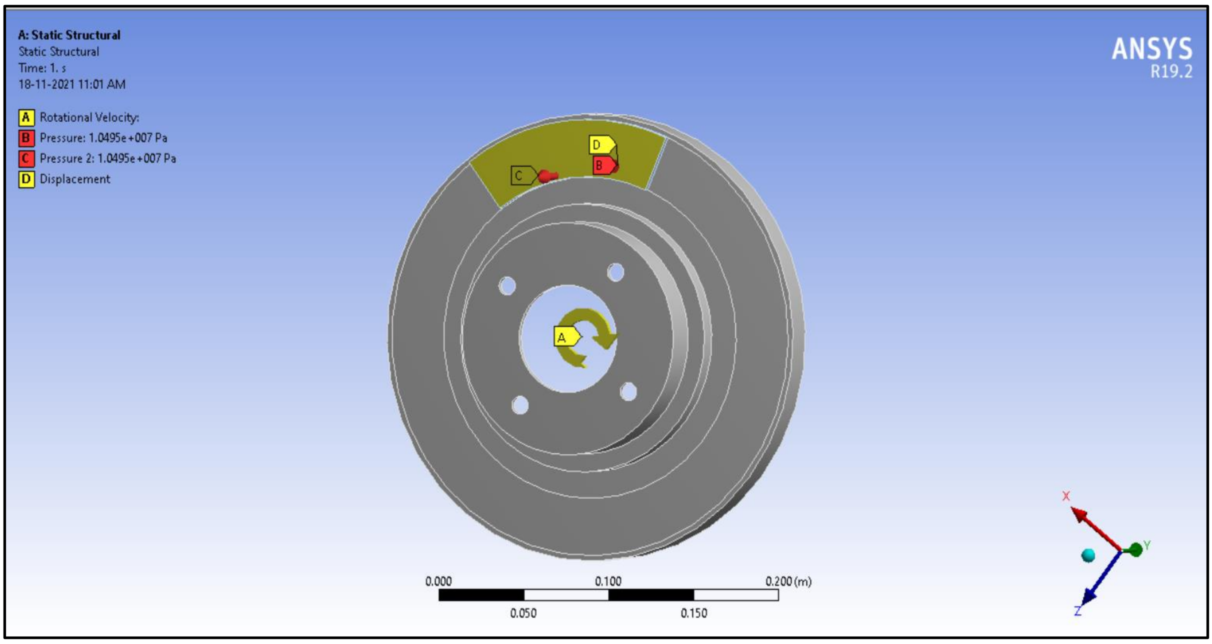


Fig 3: Displacement, Pressure and rotational velocity

The equivalent von mises stresses the calculated acting on the geometry.

Modal Analysis

The next step after the structural analysis is the modal analysis in which the same geometry with the same material assignment is used and the two brake pads are removed for and effect result. The maximum number of modes to find is set to 10. In the next step the total deformation is calculated where the mode is set 7. The frequency is used as the output for the modal analysis.

Transient Thermal

The same geometry is used for this step with the brake pads being removed from the simulation. The initial temperature value is set to 35 ^{o}C. For the convection the film coefficient is set to 5 W/m^2 C. Heat flux is provided to the outer face of the disk with the value of 1500 W/m^2. The value for maximum temperature is taken as the output here.

Design Performances

The geometry has the given dimensions inner diameter = 75mm, outer diameter = 125 mm, rotor thickness = 25 mm. The von misses stress calculated is 14.231 MPa

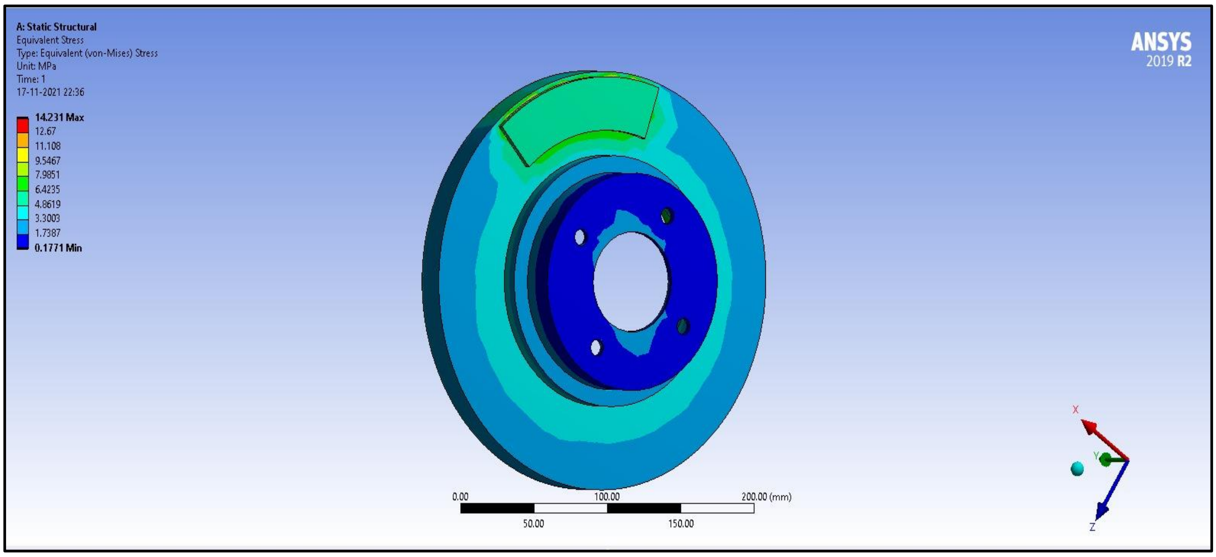


Fig 4: Distribution of Von mises stress

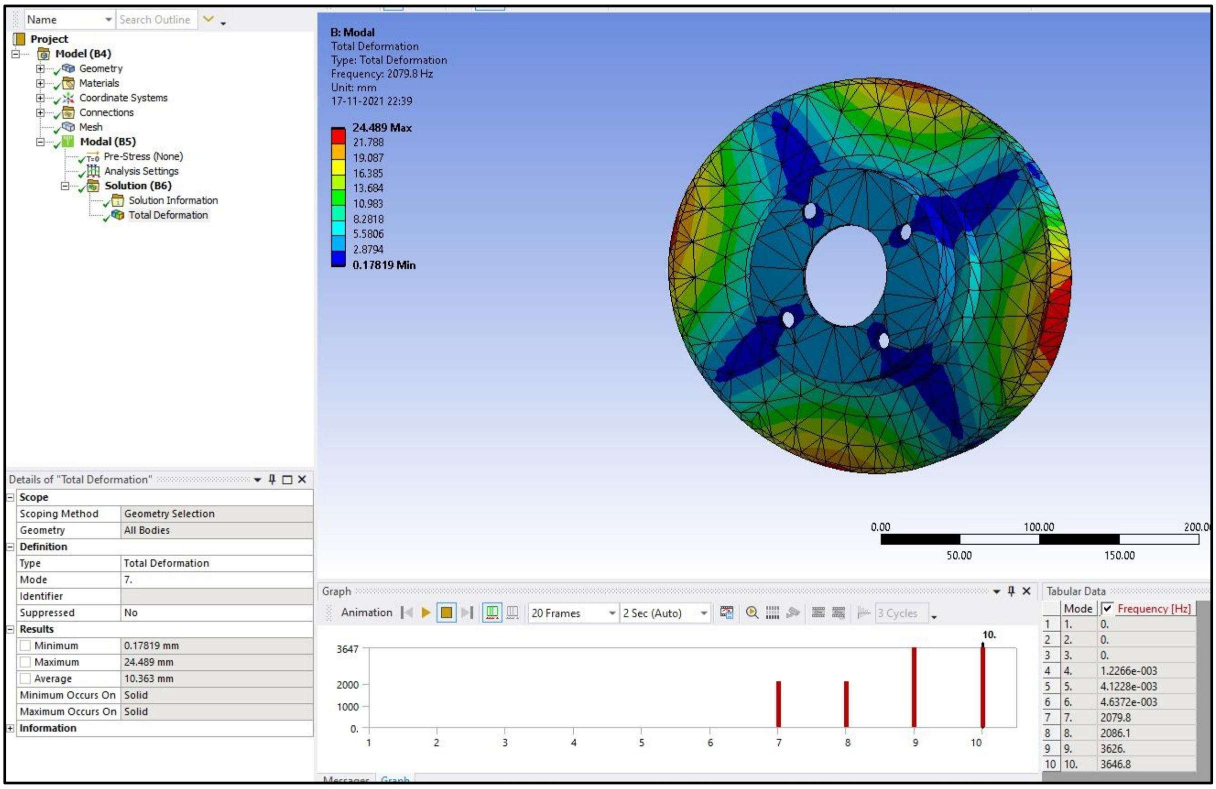


Fig 5: Total Deformation

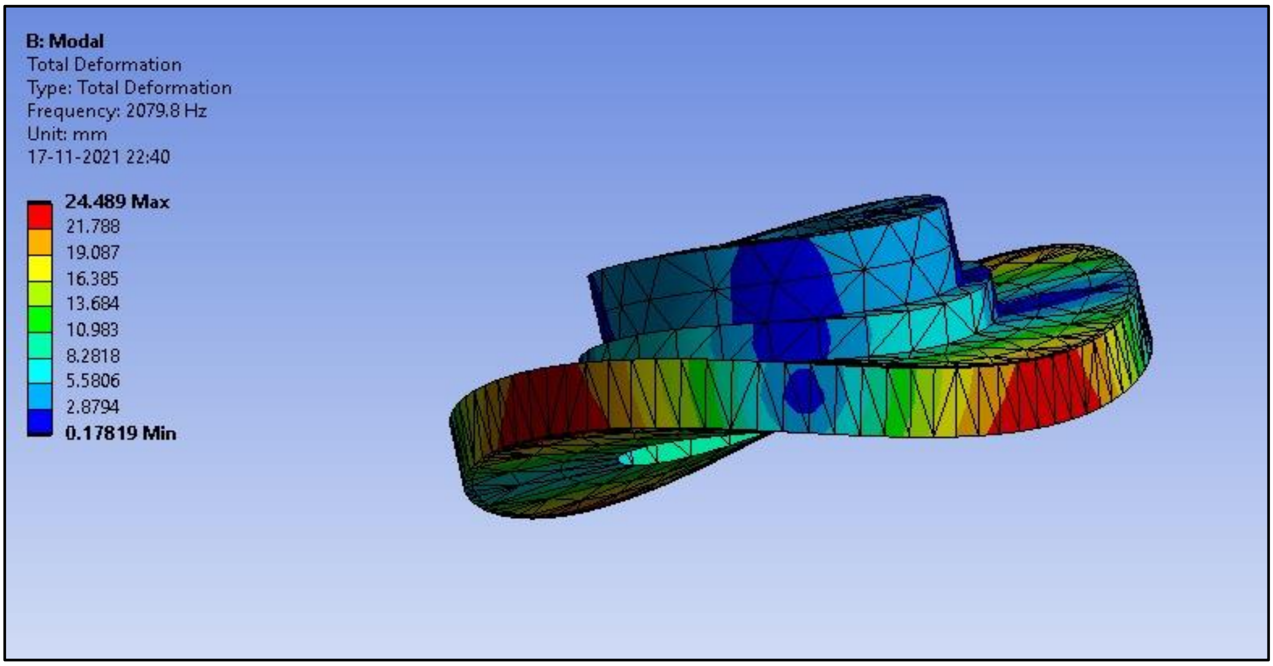


Fig 6: Distribution of total deformation

After performing the modal analysis, the frequency is 2079.8 Hz.

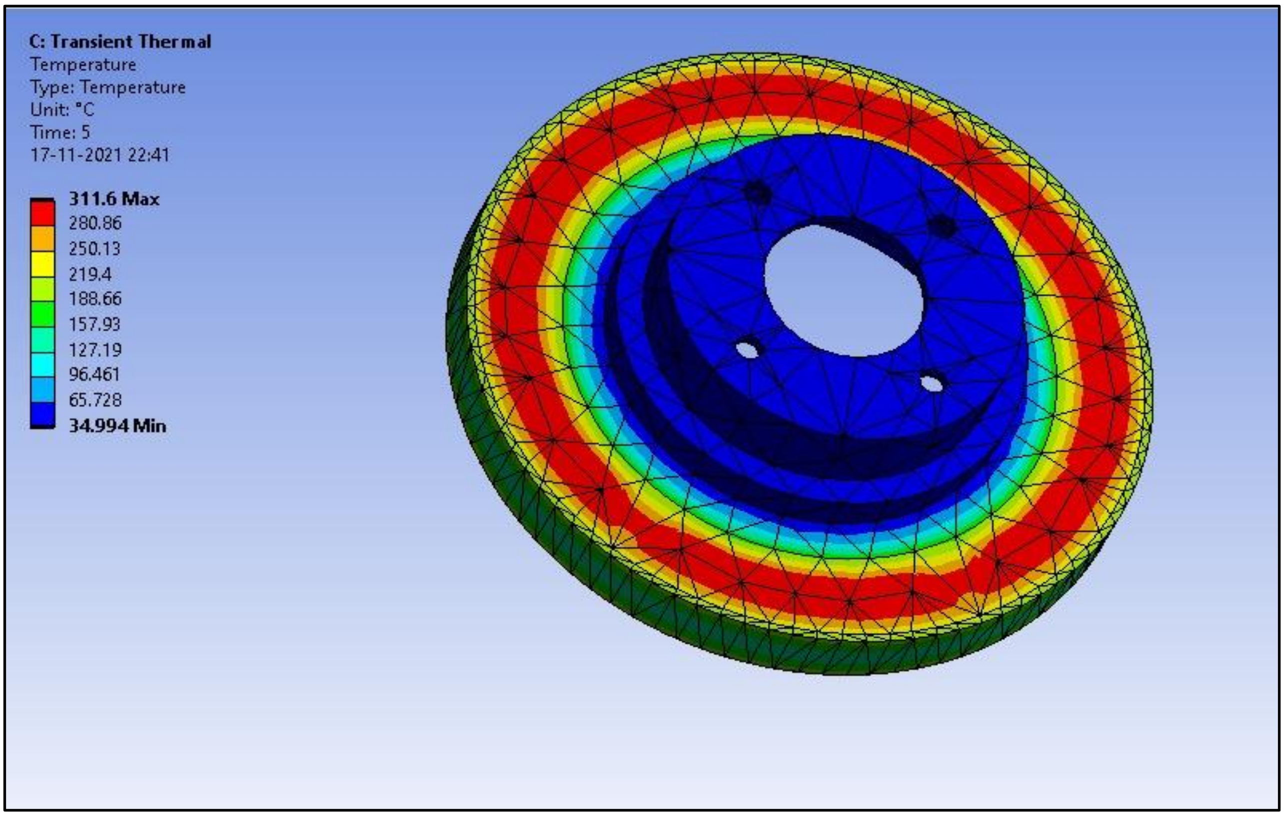
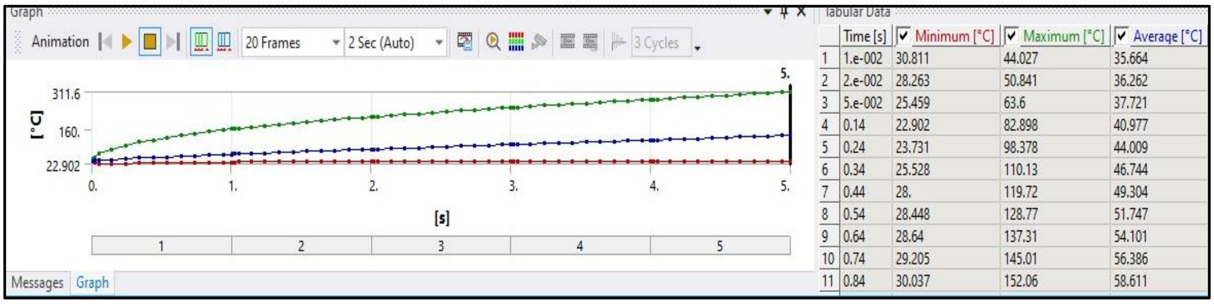


Fig 7: Distribution of temperature.



	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	1.e-002	30.811	44.027	35.664
2	2.e-002	28.263	50.841	36.262
3	5.e-002	25.459	63.6	37.721
4	0.14	22.902	82.898	40.977
5	0.24	23.731	98.378	44.009
6	0.34	25.528	110.13	46.744
7	0.44	28.	119.72	49.304
8	0.54	28.448	128.77	51.747
9	0.64	28.64	137.31	54.101
10	0.74	29.205	145.01	56.386
11	0.84	30.037	152.06	58.611

Fig 8: Values for temperature.

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CALCULATIONS ASSUME ELEMENT MASS AT ELEMENT CENTROID

TOTAL MASS = 7.8239

XC =0.50878E-06	IXX = 0.4186E-01	IXX = 0.3823E-01
YC = 0.21534E-01	IYY = 0.7234E-01	IYY = 0.7234E-01
ZC = 0.10442E-05	IZZ = 0.4186E-01	IZZ = 0.3823E-01

IXY = -0.1205E-07 IXY = 0.7367E-07

IYZ = 0.1706E-05 IYZ = 0.1882E-05

IZX = -0.8565E-06 IZX = -0.8565E-06

After performing the transient thermal analysis, the calculated value for the maximum temperature is found to be 311.6^{o} C

Design Of Experiments

For computing we have altered and found out the best fit values

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	22
8	Upper Bound	28
9	Allowed Values	Any

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
8	Upper Bound	79
9	Allowed Values	Any

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	122.5
8	Upper Bound	136
9	Allowed Values	Any

Fig 9: Lower and upper bound values

Table of Outline A6: Design Points of Design of Experiments

	A	B	C	D	E	F	G
1	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Total Deformation Reported Frequency (Hz)	P5 - Temperature Maximum (C)	P6 - Equivalent Stress Maximum (MPa)
2	1	25	129.25	75.5	1988.6	311.14	14.79
3	2	22	129.25	75.5	1934.3	320.84	15.261
4	3	23.5	129.25	75.5	1960.8	315.32	15.565
5	4	28	129.25	75.5	2048	305.25	14.842
6	5	26.5	129.25	75.5	2016.9	307.51	15.36
7	6	25	122.5	75.5	2117.1	316.33	29.568
8	7	25	125.88	75.5	2047.9	307.2	14.76
9	8	25	136	75.5	1840.6	308.46	15.287
10	9	25	132.63	75.5	1901.3	309.21	15.738
11	10	25	129.25	72	2030.3	309.25	15.171
12	11	25	129.25	73.75	2019.7	310.56	14.908
13	12	25	129.25	79	1915.3	311.16	15.456
14	13	25	129.25	77.25	1954.6	311.19	15.035
15	14	22	122.5	72	2141.9	329.24	36.956
16	15	23.5	125.88	73.75	2058.8	311.13	14.918
17	16	28	122.5	72	2275.1	309.86	32.371
18	17	26.5	125.88	73.75	2117.5	303.86	14.629
19	18	22	136	72	1781.6	319.77	15.784
20	19	23.5	132.63	73.75	1903.5	313.09	15.892
21	20	28	136	72	1927.9	304.36	15.316
22	21	26.5	132.63	73.75	1965.1	307.13	15.624
23	22	22	122.5	79	1959.6	327.8	36.298
24	23	23.5	125.88	77.25	1980.5	312.67	14.953
25	24	28	122.5	79	2070.6	311.24	33.592
26	25	26.5	125.88	77.25	2033.4	303.94	14.893
27	26	22	136	79	1741.2	319.79	15.822
28	27	23.5	132.63	77.25	1847.3	313.05	15.689
29	28	28	136	79	1851.5	306.07	15.695
30	29	26.5	132.63	77.25	1902.3	308.98	15.584

Fig 10: Design points of design of experiments

Response surface

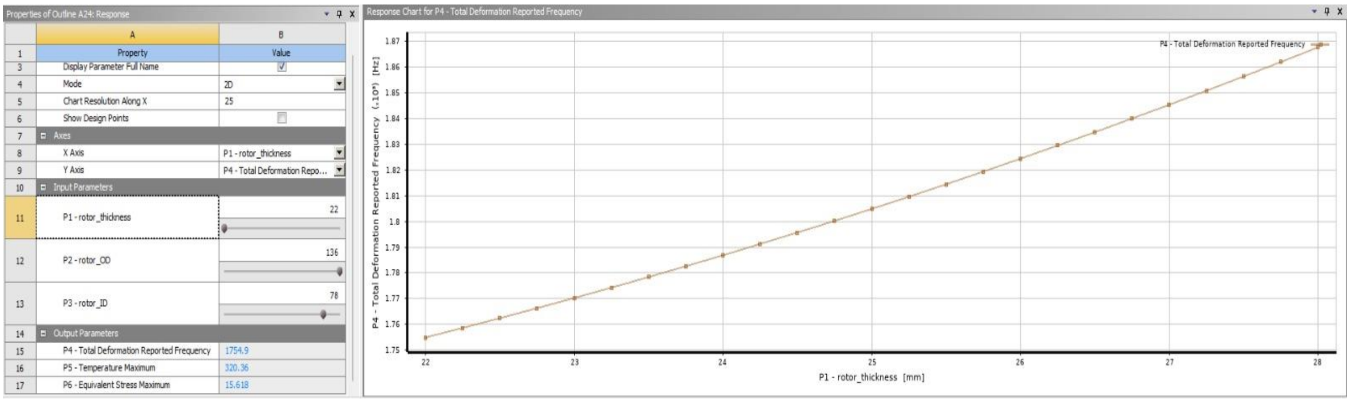

Fig 11: Response

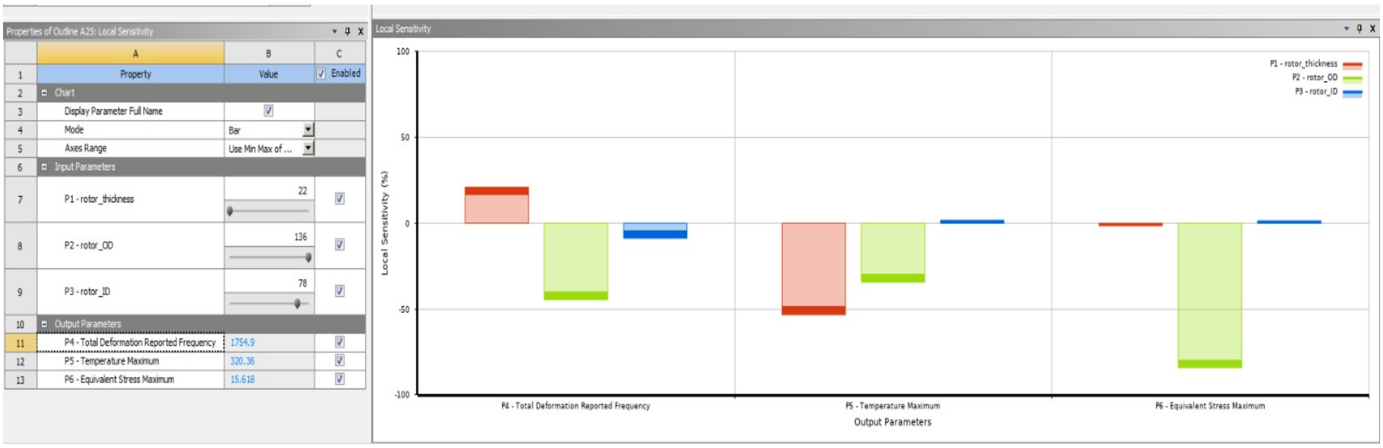

Fig 12: Local sensitivity

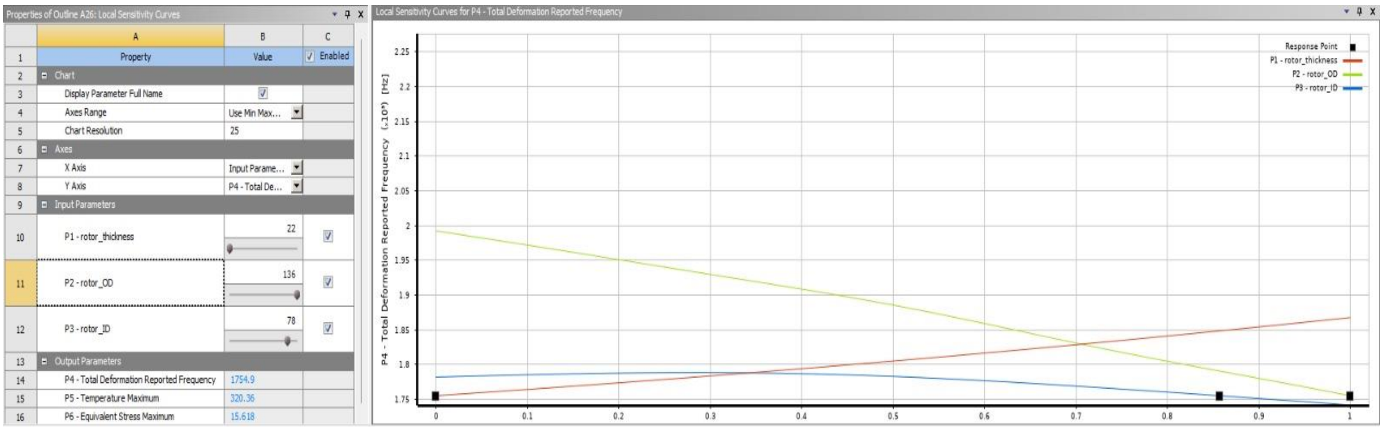

Fig 13: Local sensitivity curves

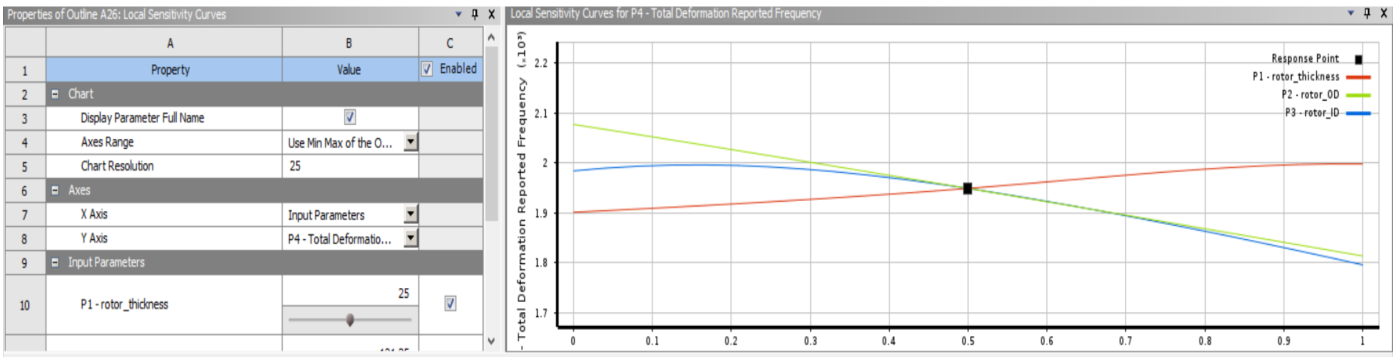

Fig 14: Local sensitivity curves with iterated values

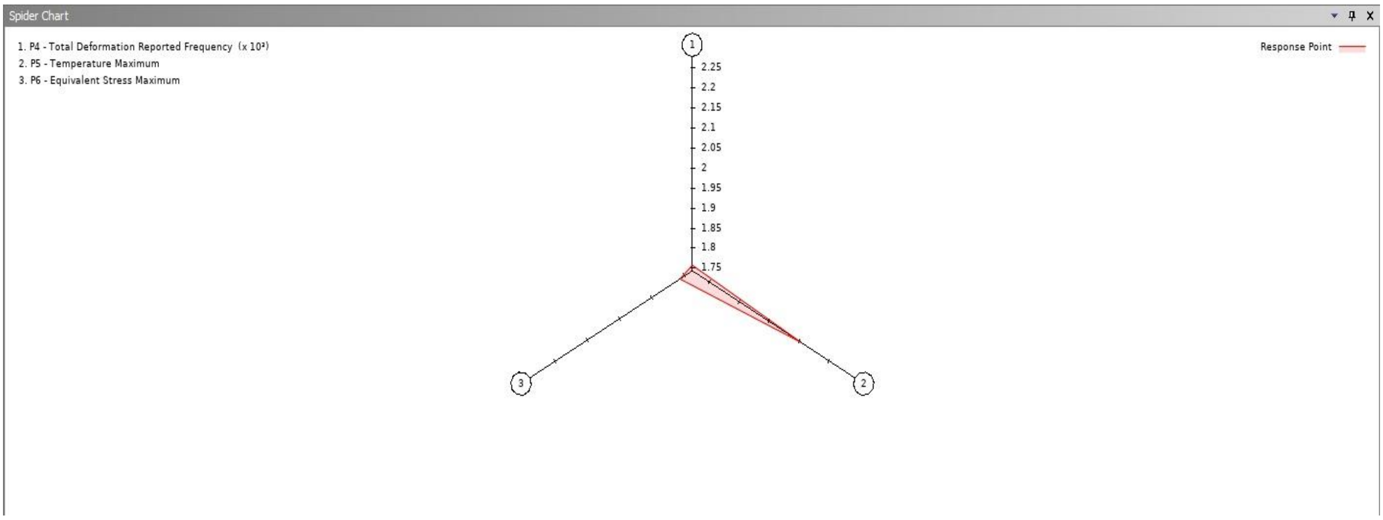

Fig 15: Spider

Optimization of design

As a main objective of this project was to optimize the already existing brake pad and to find the minimum volume, stress, temperature and to maximize the frequency. Compared with the design provided by Professor Yi Ren, a slight reduction in temperature and performance on stress relief are better in this case. Based on engineering parameters and response surfaces, the final design can be explained by this model. If we increase the thickness the temperature will slightly be reduced and a slight change in frequency will be observed. Altering lower and upper bounds will also play a vital role on this optimization project.

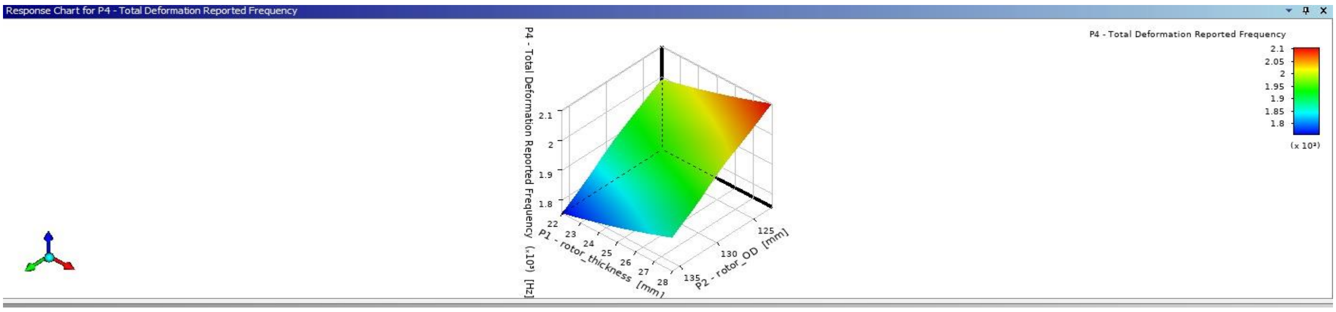

Fig 16: Response for deformation

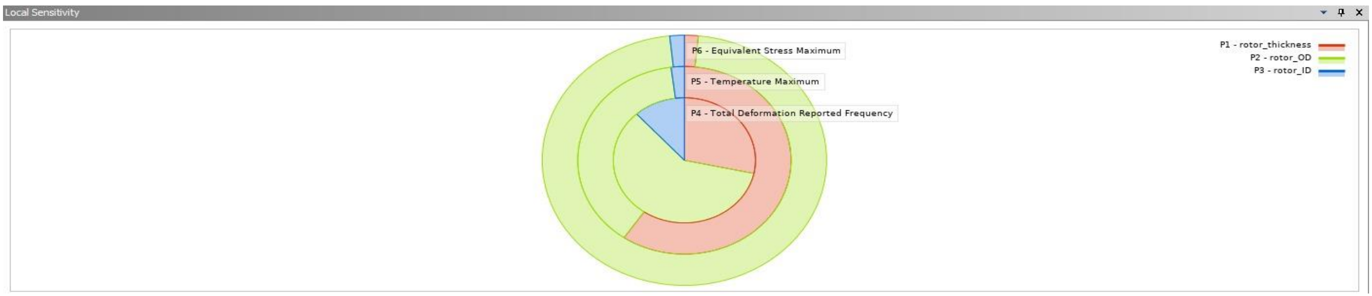

Fig 17: Local sensitivity for optimization

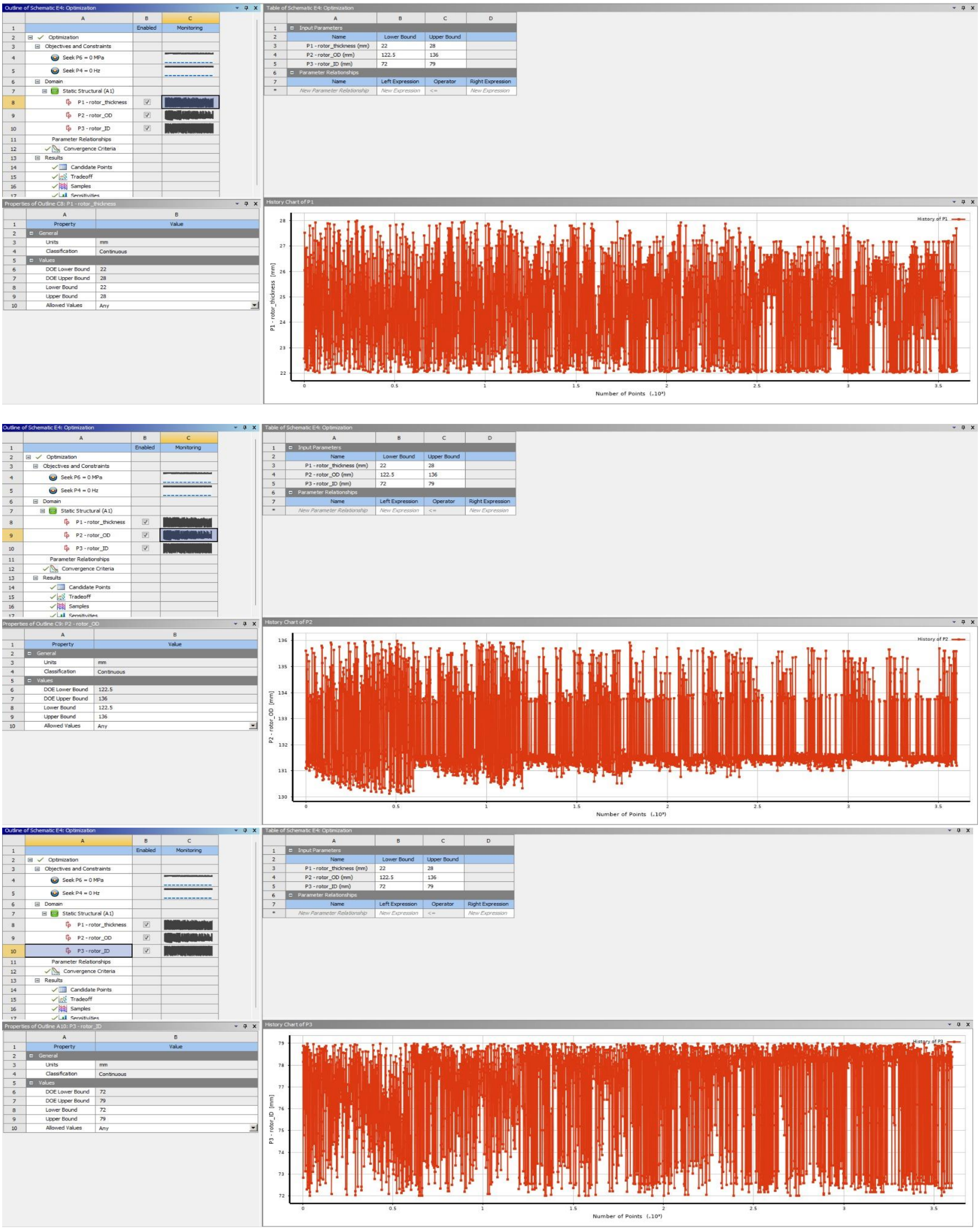

Fig 18: history chart

Best design candidates

Table of Schematic E4: Optimization				
	A	B	C	D
1	⊟ Optimization Study			
2	Seek P4 = 0 Hz	Goal, Seek P4 = 0 Hz (Default Importance)		
3	Seek P6 = 0 MPa	Goal, Seek P6 = 0 MPa (Default Importance)		
4	⊟ Optimization Method			
5	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.		
6	Configuration	Generate 3000 samples initially, 600 samples per iteration and find 3 candidates in a maximum of 20 iterations.		
7	Status	Converged after 5584 evaluations.		
8	⊟ Candidate Points			
9		Candidate Point 1	Candidate Point 2	Candidate Point 3
10	P1 - rotor_thickness (mm)	22.073	22.049	22.187
11	P2 - rotor_OD (mm)	135.58	134.78	133.67
12	P3 - rotor_ID (mm)	78.883	78.353	78.942
13	P4 - Total Deformation Reported Frequency (Hz)	✕✕✕ 1751.6	✕✕✕ 1773.5	✕✕✕ 1786.5
14	P6 - Equivalent Stress Maximum (MPa)	✕ 15.548	✕ 15.106	✕ 14.691

Fig 19: Best design candidates and their performances

The above shown are the best design candidates for the given geometry.