DESIGN OPTIMIZATION OF BRAKE DISCGEOMETRY

by
Venkata Sai Pramod Kumar Kasturi
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ABSTRACT

The objective of this project is to optimize the volume of the emergency brake disc in order to minimize the maximum von mises stress in the emergency brake disk, during its application. The following constrains were also considered during the optimization: maximum first natural frequency of the disc brake, minimize the maximum temperature in the brake disc. The simulation, surface optimization is performed using ANSYS software.

ACKNOWLEDGMENTS

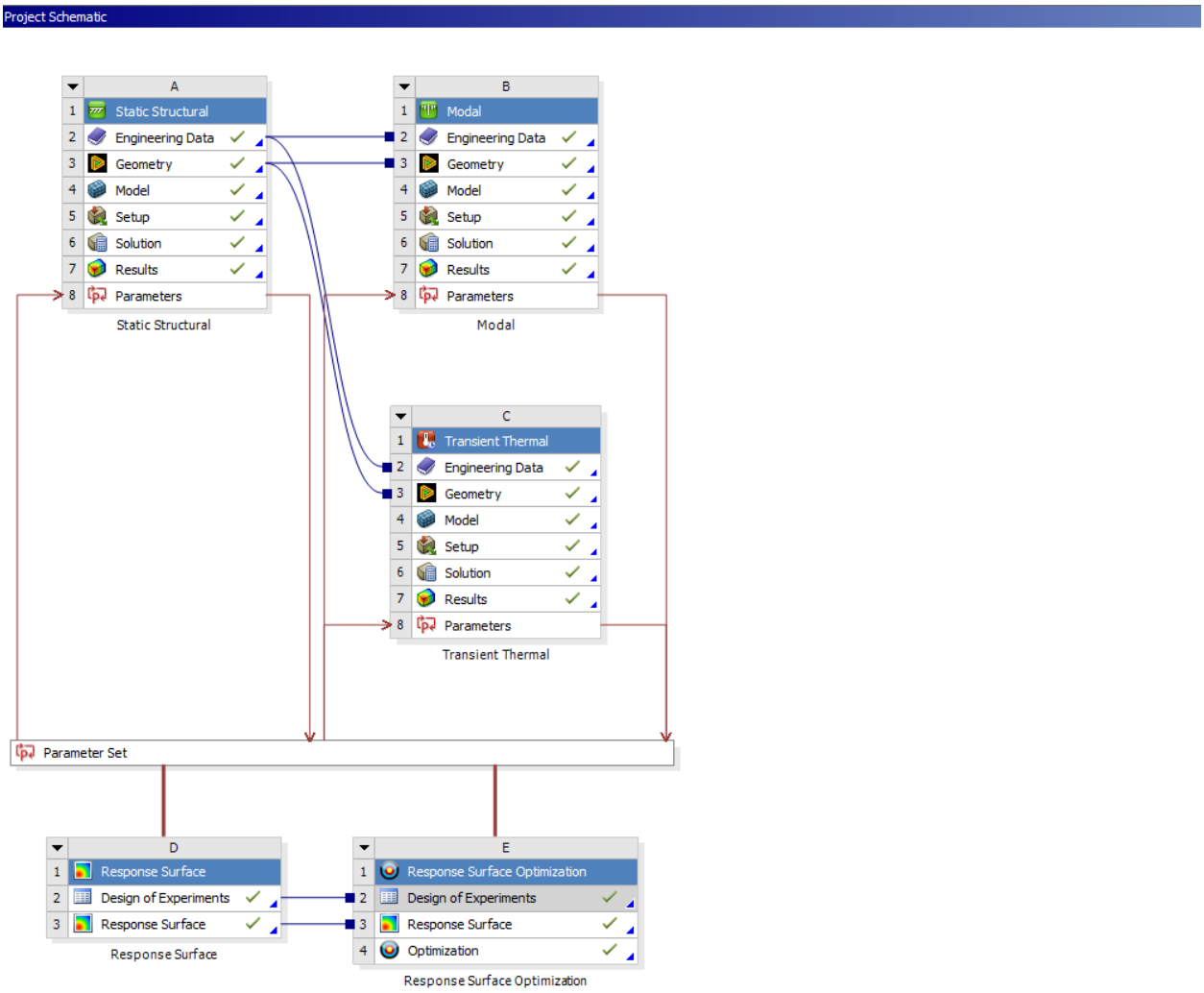
I thank our professor Dr. Yi Ren for giving us the knowledge regarding optimization through his design optimization subject. Moreover, this work would not have been possible without the assistance and resources of the Arizona State University laboratories.

Table of Contents:

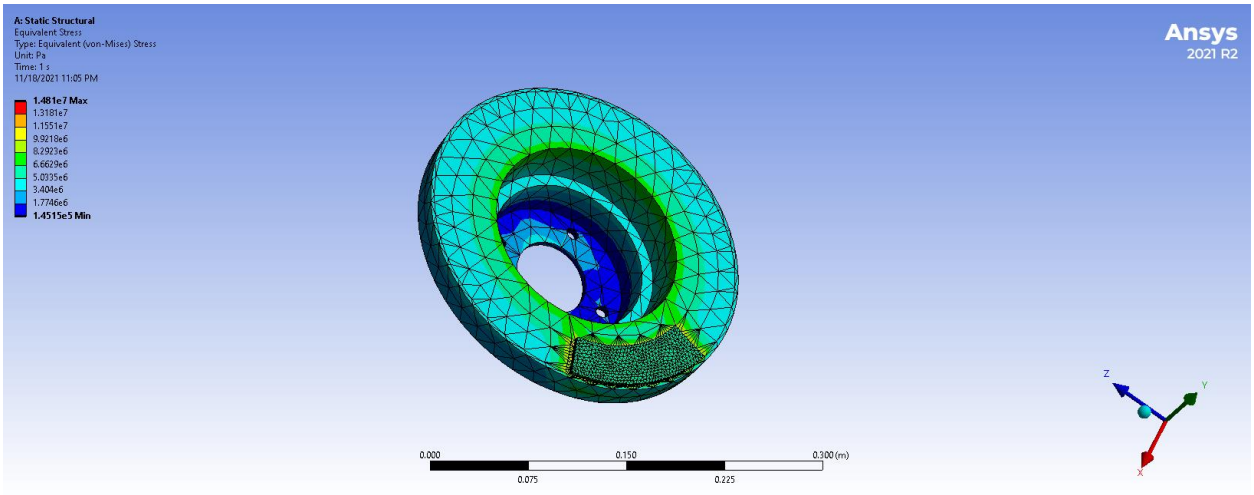
1.Introduction:

The geometry of the brake is taken and uploaded the same in the Ansys software, the following analys are done:

1. Static Structural Analysis- To find the maximum von Mysis stress in the brake disk
2. Modal Analyses- To find first natural frequency of the disc
3. Thermal Analysis- To find maximum temperature on the brake disc



1.a. After performing the static structural analysis on the given geometry, maximum stress value obtained is 1.481e+007 Pa



1.b.After performing the modal analysis the first natural frequency (considering 10 modes and max at mode 7) is 1582.2 Hz

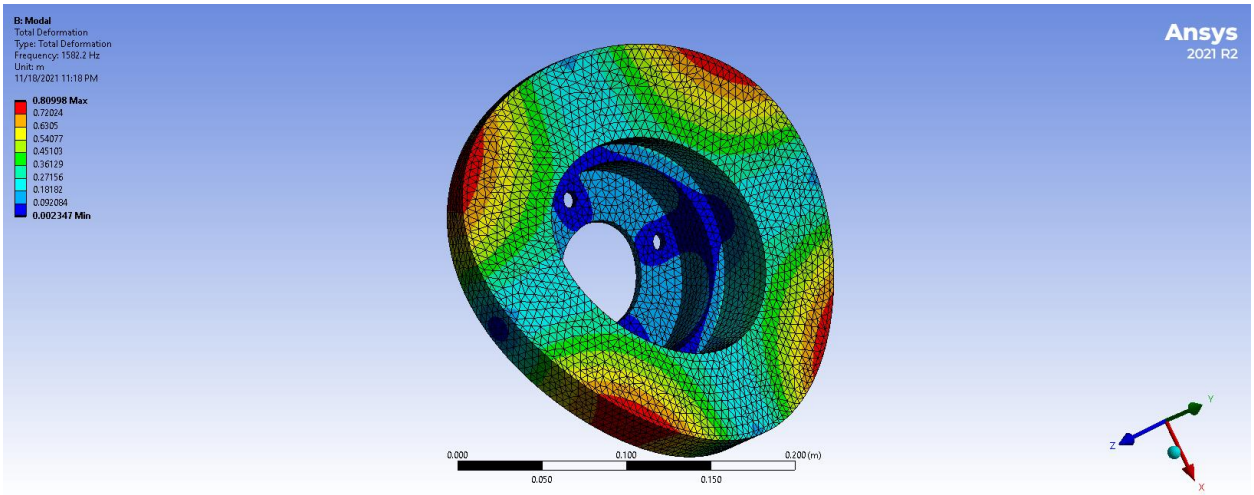
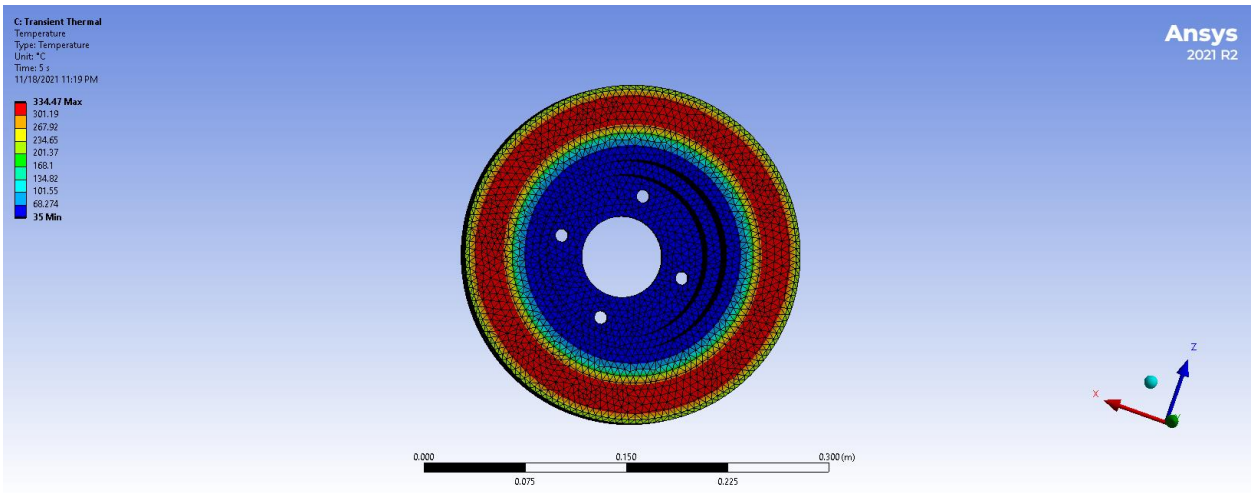


Table of Schematic E4: Optimization , Candidate Points

	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	21.81	129.2	72.352	1.4696E+07	0.00%	1476.1	0.00%	342.9	0.00%
4	○	Candidate Point 2	21.897	129.07	72.352	1.4696E+07	0.01%	1480.5	0.30%	342.54	-0.10%
5	○	Candidate Point 3	21.927	129.47	72.352	1.4697E+07	0.01%	1472.2	-0.26%	342.34	-0.16%
*		*New Custom Candidate Point*	*24.65*	*129*	*75.175*						

1.c.The maximum temperature of obtained after performing the analysis is 334.47 °C



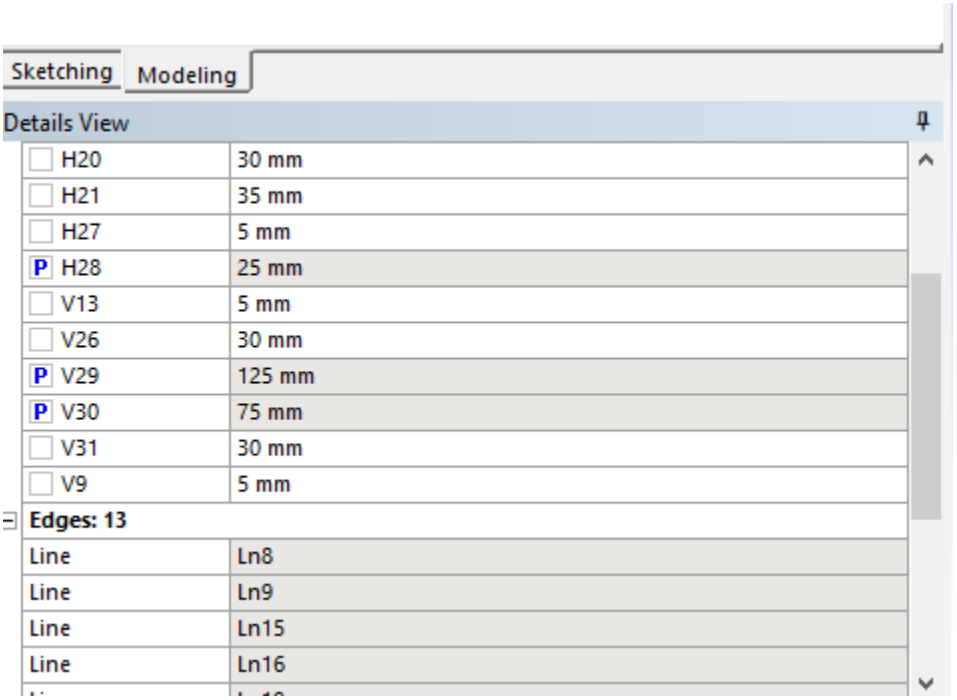
2.Design of Experiments:

2.a. After performing the Ansys analysis of static structural, thermal, Modal analysis on brake disc of given dimensions, now 3 design parameters are considered as input parameters:

1. Brake Disc Thickness- H28

2.Brake Disc Outer Diameter- V29

3.Brake Disc Inner Diameter- V30



2.b. Now we will vary the input parameters and find the variation of following output Parameters:

1. Equivalent Maximum Stress
2. Total Deformation at first natural frequency
3. Maximum Temperature

Outline of Schematic D2: Design of Experiments

	A	B
1		Enabled
2	Design of Experiments	
3	Input Parameters	
4	Static Structural (A1)	
5	P1 - rotor_thickness	☑
6	P2 - rotor_OD	☑
7	P3 - rotor_ID	☑
8	Output Parameters	
9	Static Structural (A1)	
10	P4 - Equivalent Stress Maximum	
11	Modal (B1)	
12	P5 - Total Deformation Reported Frequency	
13	Transient Thermal (C1)	
14	P6 - Temperature Maximum	
15	Charts	
16	Parameters Parallel	
17	Design Points vs Parameter	

The input parameters are varied in the following ranges:

I. For Brake disc thickness- H28 min: 21.8mm, max: 27.5mm

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	21.8
8	Upper Bound	27.5
9	Allowed Values	Any

II. Brake Disc Outer Diameter- V29 min: 123mm max: 135mm

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	123
8	Upper Bound	135
9	Allowed Values	Any

III. Brake Disc Inner Diameter- V30 min: 72.35mm max: 78

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	72.35
8	Upper Bound	78
9	Allowed Values	Any

2.c. Design of Experiments Type: Latin Hypercube Sampling Design

Samples Type: User Defined samples

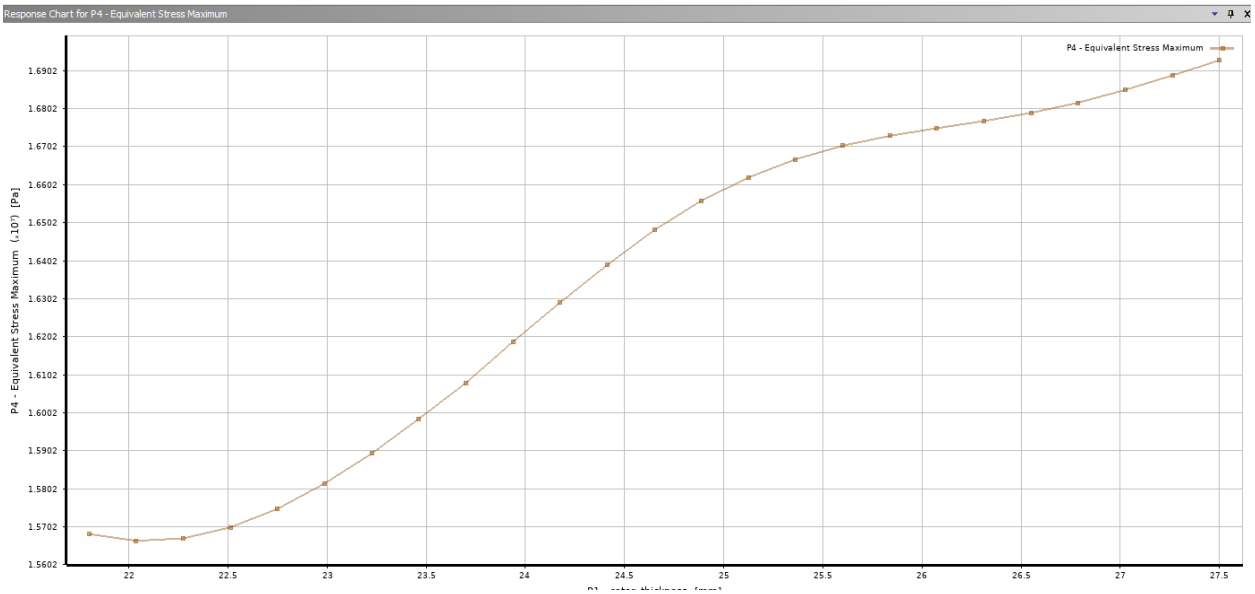
No of Sample Points: 30

Table of Outline A7: Design Points of Design of Experiments

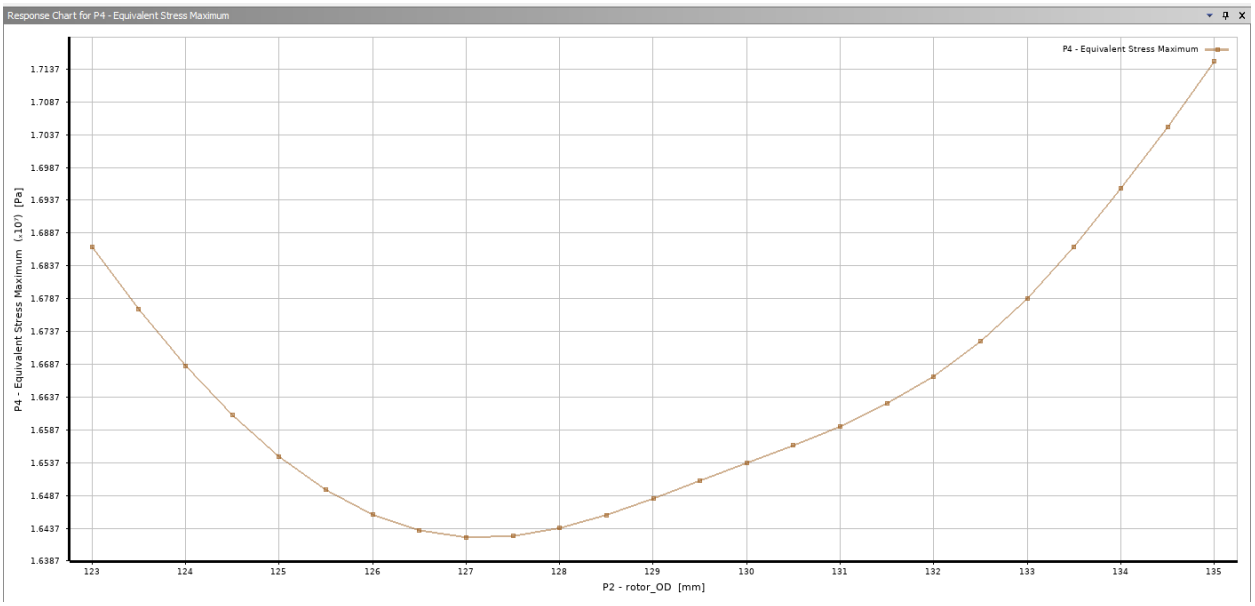
	A	B	C	D	E	F	G
1	Name	P1 - rotor_thickness (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)	P5 - Total Deformation Reported Frequency (Hz)	P6 - Temperature Maximum (C)
2	1	24.365	130.8	72.444	1.5607E+07	1489.8	333.41
3	2	25.315	131.6	75.081	1.6955E+07	1460.1	330.88
4	3	21.895	127.6	75.458	1.5588E+07	1471.7	343.02
5	4	24.745	133.2	76.964	1.6285E+07	1391.5	332.23
6	5	22.275	126	73.763	1.5847E+07	1537	342.44
7	6	27.025	123.2	77.906	1.689E+07	1583	334.1
8	7	24.555	134	74.516	1.708E+07	1407.6	332.73
9	8	26.835	133.6	77.341	1.656E+07	1415.3	327.65
10	9	23.225	128.8	73.951	1.614E+07	1493.3	337.33
11	10	22.845	134.8	76.588	1.5803E+07	1335	338.2
12	11	23.605	128.4	76.023	1.5778E+07	1475.3	336.15
13	12	22.655	126.8	73.198	1.556E+07	1533.8	340.28
14	13	24.175	129.2	77.153	1.6168E+07	1450.3	334.18
15	14	25.695	123.6	74.139	1.7291E+07	1639.6	335.6
16	15	23.415	132.8	75.269	1.5941E+07	1399.6	336.22
17	16	26.455	128	74.893	1.6716E+07	1552.5	329.02
18	17	26.265	132.4	73.386	1.7304E+07	1484.4	328.77
19	18	25.125	127.2	73.009	1.6388E+07	1574.3	332.26
20	19	22.465	125.6	74.704	1.5684E+07	1533.5	342.07
21	20	22.085	125.2	76.776	1.536E+07	1495.6	344.18
22	21	23.985	124	77.718	1.532E+07	1525.8	339.25
23	22	26.645	130	76.399	1.6406E+07	1491.5	328.23
24	23	27.215	132	74.328	1.7236E+07	1498.1	327.06
25	24	23.035	130.4	75.834	1.5724E+07	1430.7	337.72
26	25	25.885	124.4	77.529	1.6119E+07	1553.6	333.29
27	26	24.935	126.4	72.633	1.6284E+07	1593.1	333.21
28	27	26.075	131.2	75.646	1.6713E+07	1471.8	329.21
29	28	25.505	129.6	73.574	1.7258E+07	1524.5	330.63
30	29	27.405	124.8	72.821	1.7163E+07	1670.1	329.71
31	30	23.795	134.4	76.211	1.6473E+07	1364.1	334.95

27.405

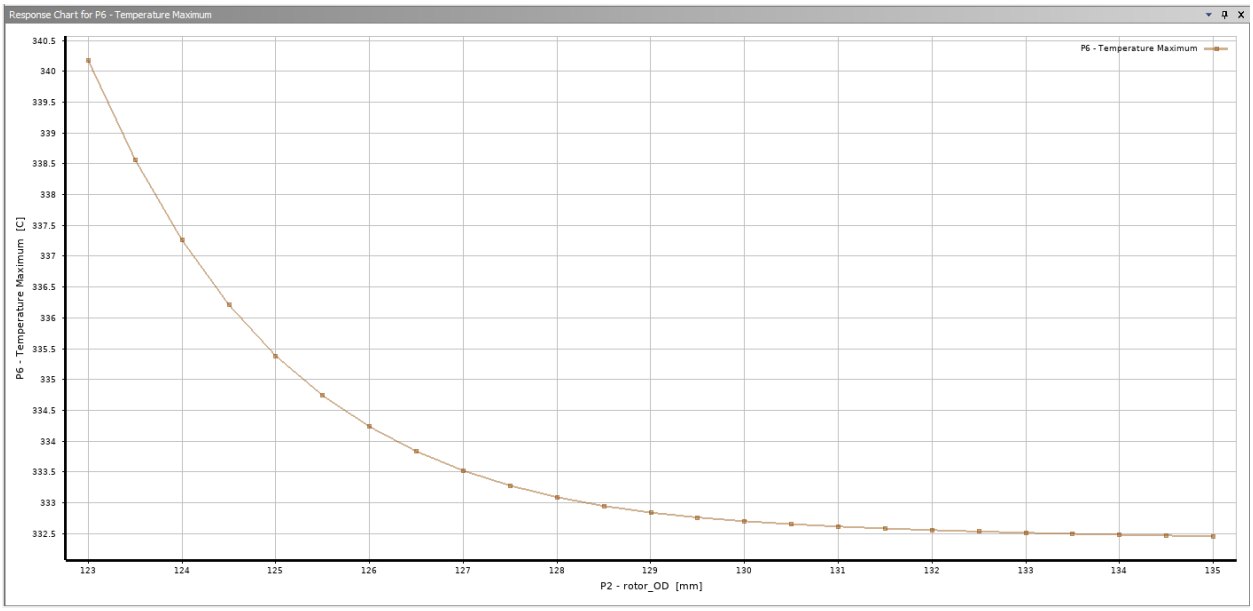
2.d. The response of maximum stress as per varying disc thickness is as follows:



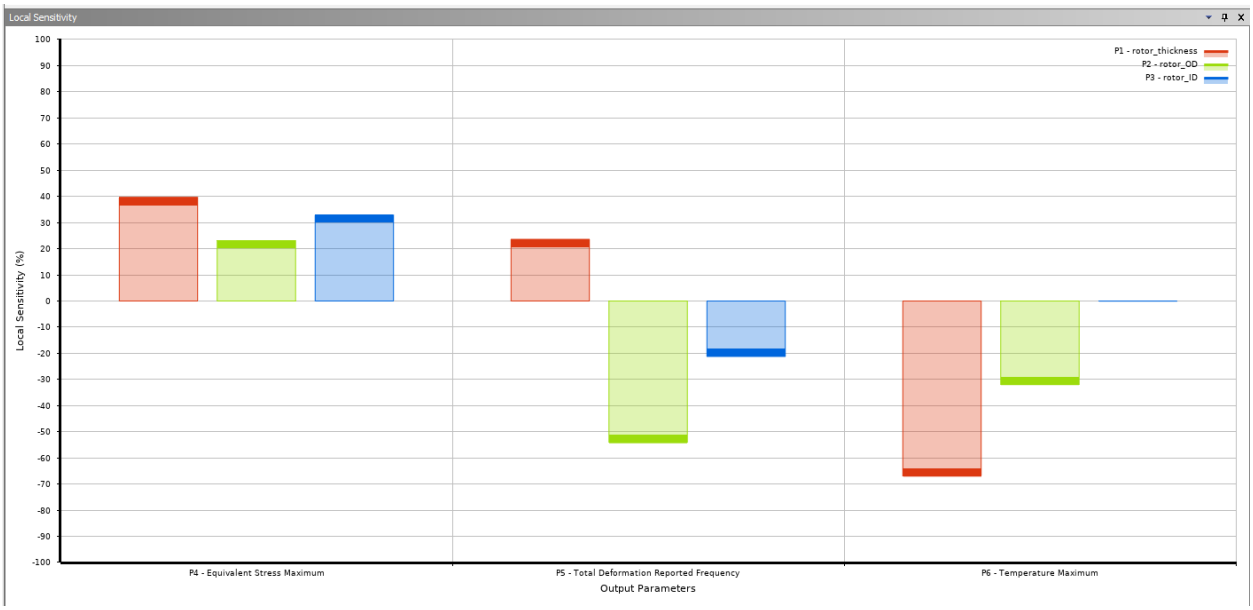
The response of maximum stress as per varying disc outer diameter is as follows:



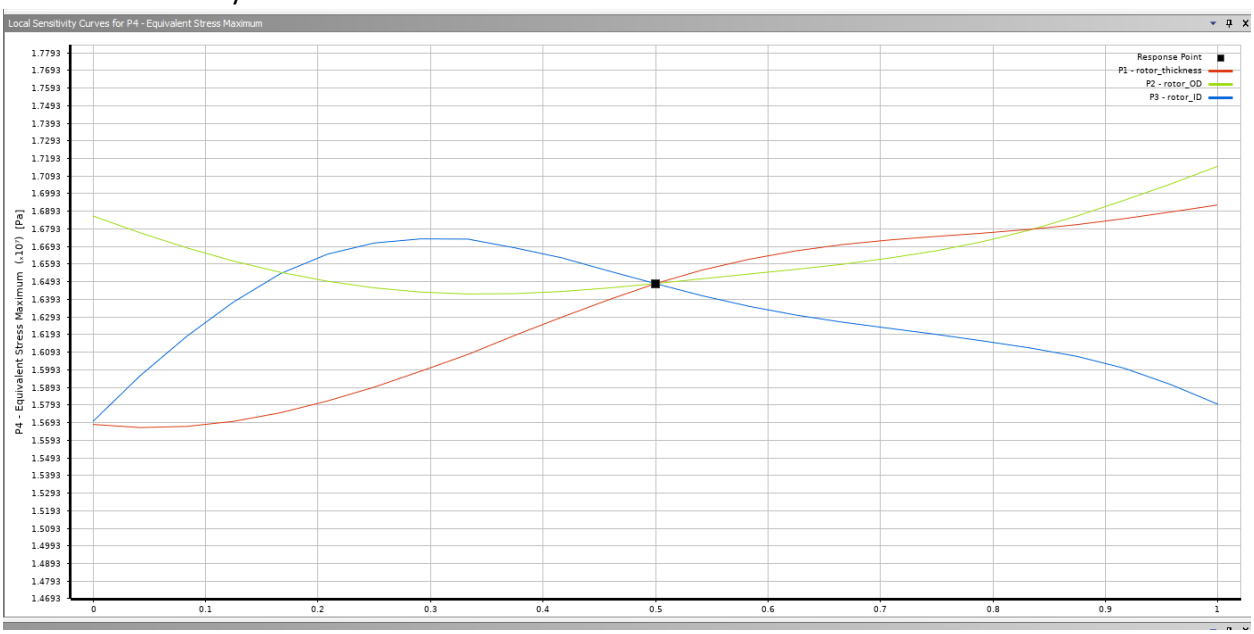
The response of maximum stress as per varying disc inner diameter is as follows:



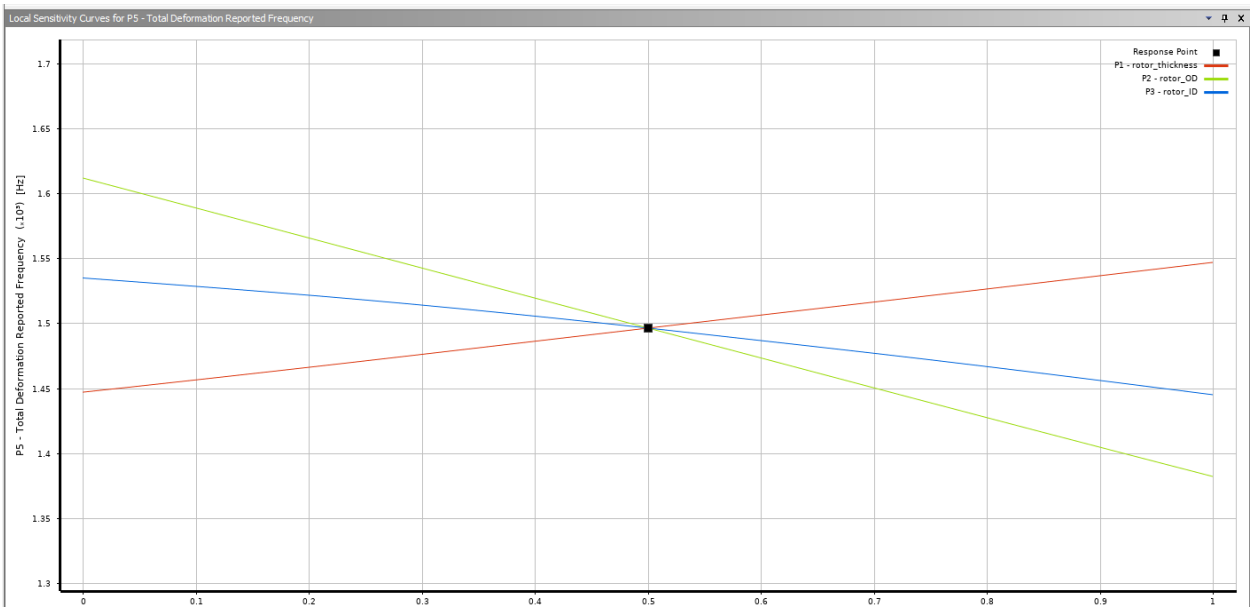
2.e. The Local Sensitivity variation is:



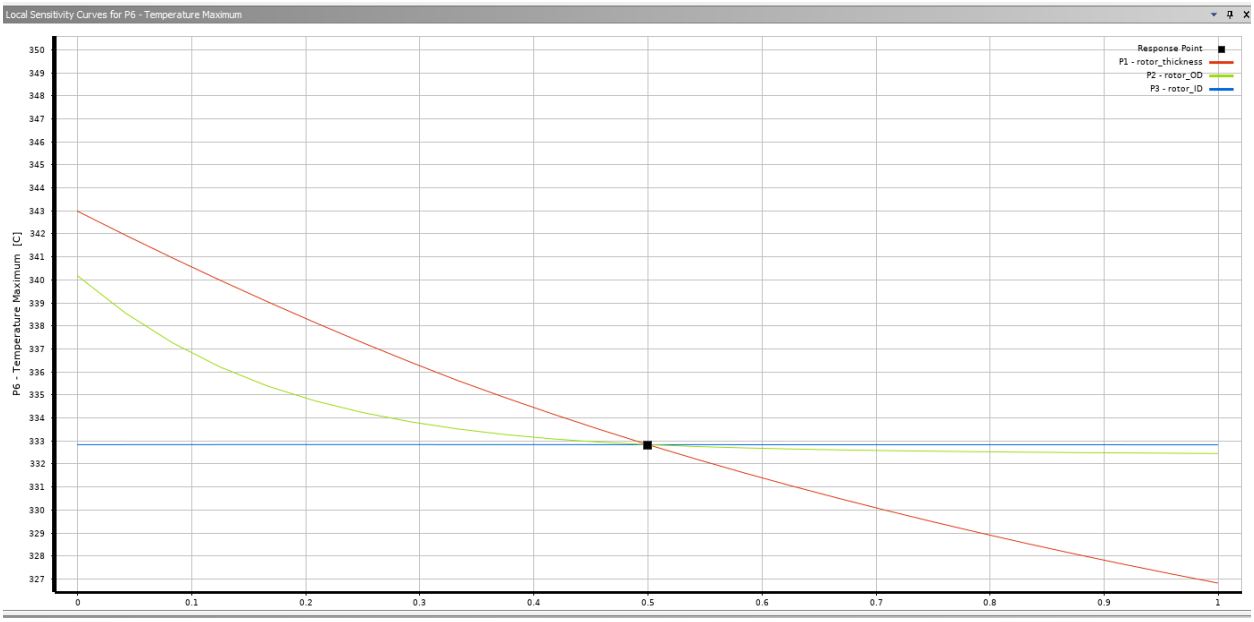
The Local Sensitivity of maximum stress is:



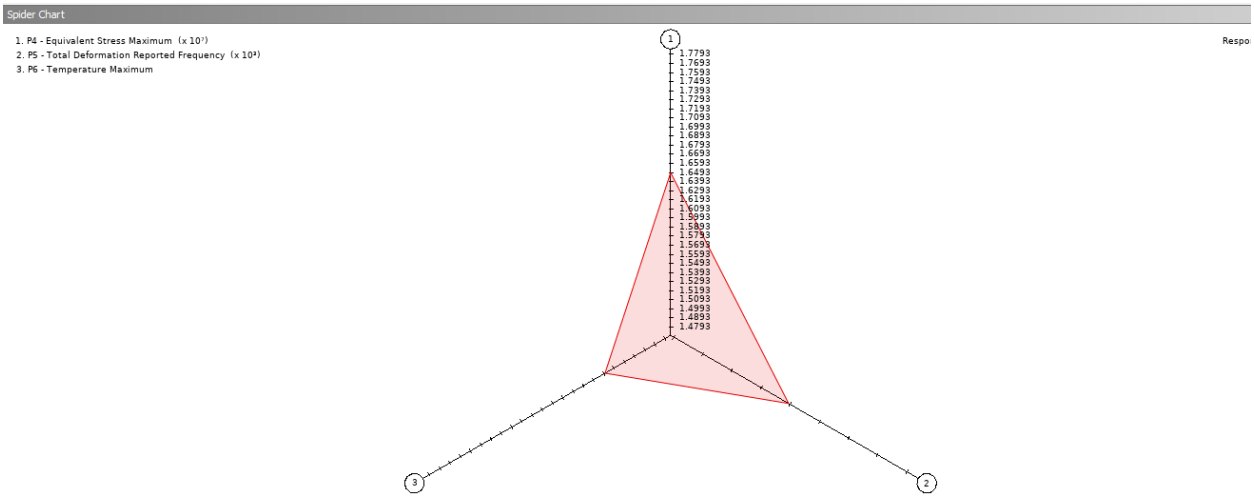
The Local Sensitivity of maximum total deformation at first natural frequency is:



The Local Sensitivity of maximum temperature is:



2.f. The Spider chat for three input parameters:



3Optimization:

3.a. The final objective function is to minimize the maximum equivalent stress subjected to the following constrains: total deformation of natural frequency, maximum temperature. The lower and upper bounds are taken from response surface min and max values of natural frequency 1294.3 Hz and max temperature 350.56 respectively.

Table of Schematic E4: Optimization

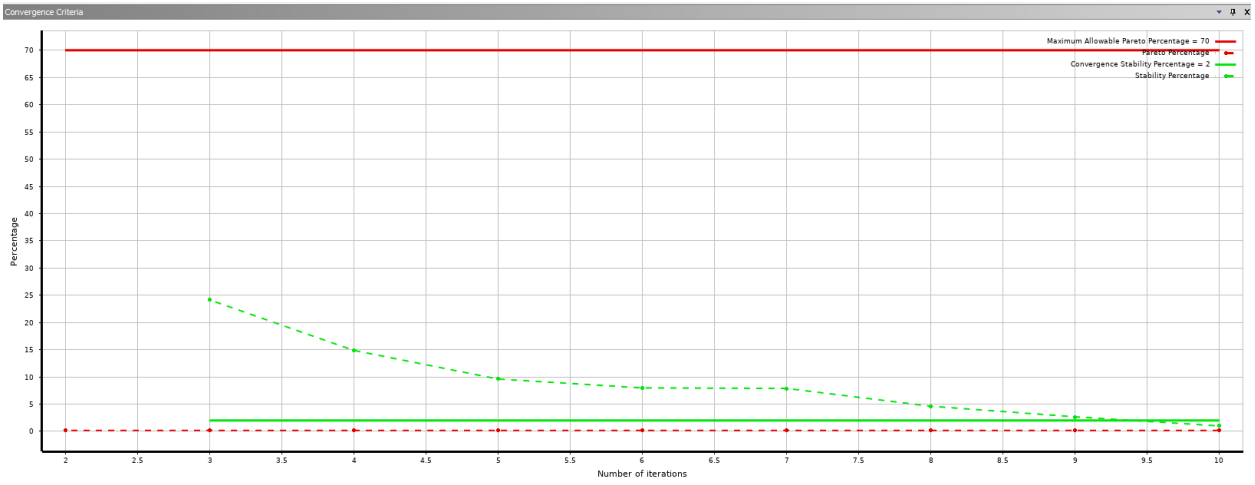
	A	B	C	D	E	F	G	H	I
1	Name	Parameter	Objective			Constraint			
2			Type	Target	Tolerance	Type	Lower Bound	Upper Bound	Tolerance
3	Minimize P4	P4 - Equivalent Stress Maximum	Minimize	1.4693E+07		No Constraint			
4	P5 >= 1294.3 Hz	P5 - Total Deformation Reported Frequency	No Objective			Values >= Lower Bound	1294.3		0.001
5	P6 <= 350.56 C	P6 - Temperature Maximum	No Objective			Values <= Upper Bound		350.56	0.001
*		Select a Parameter							

The final optimum points are as follows:

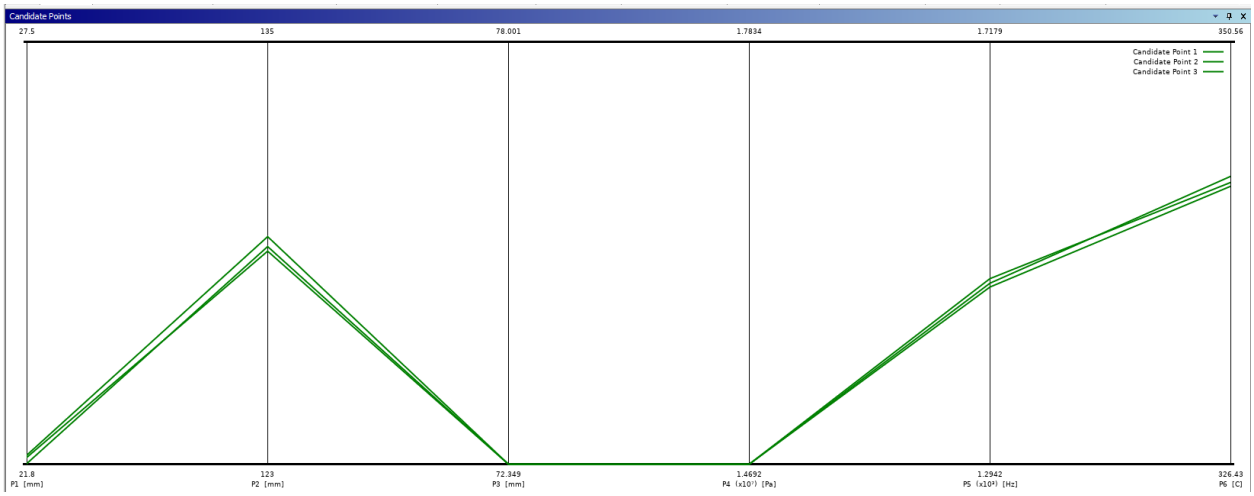
Table of Schematic E4: Optimization , Candidate Points

	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	21.81	129.2	72.352	1.4696E+07	0.00%	1476.1	0.00%	342.9	0.00%
4	○	Candidate Point 2	21.897	129.07	72.352	1.4696E+07	0.01%	1480.5	0.30%	342.54	-0.10%
5	○	Candidate Point 3	21.927	129.47	72.352	1.4697E+07	0.01%	1472.2	-0.26%	342.34	-0.16%
*		*New Custom Candidate Point*	*24.65*	*129*	*75.175*						

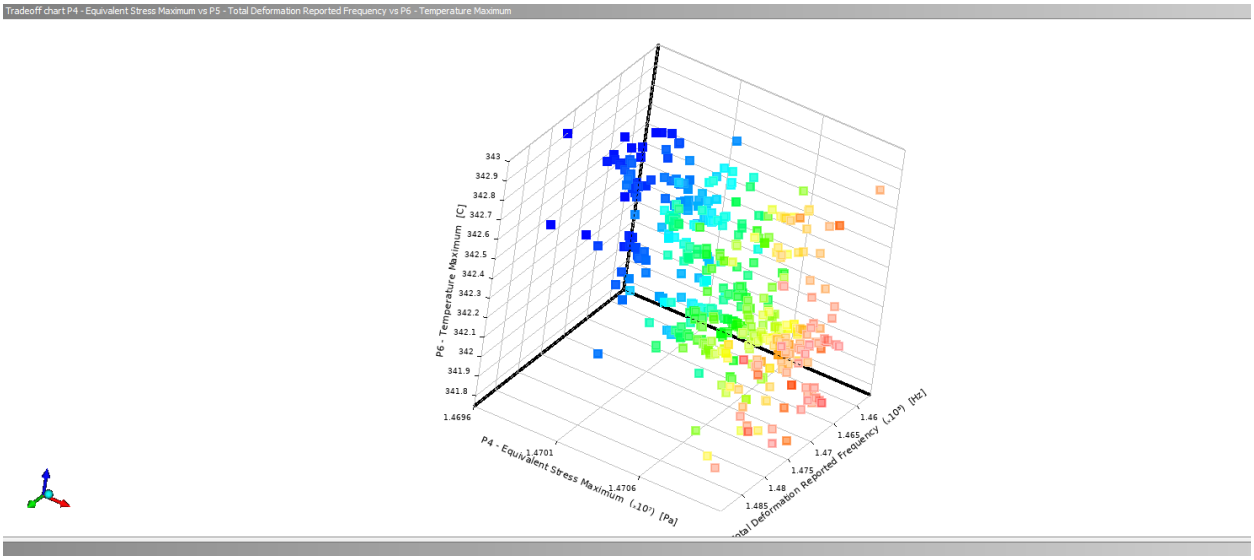
3.b. Convergence Criteria:



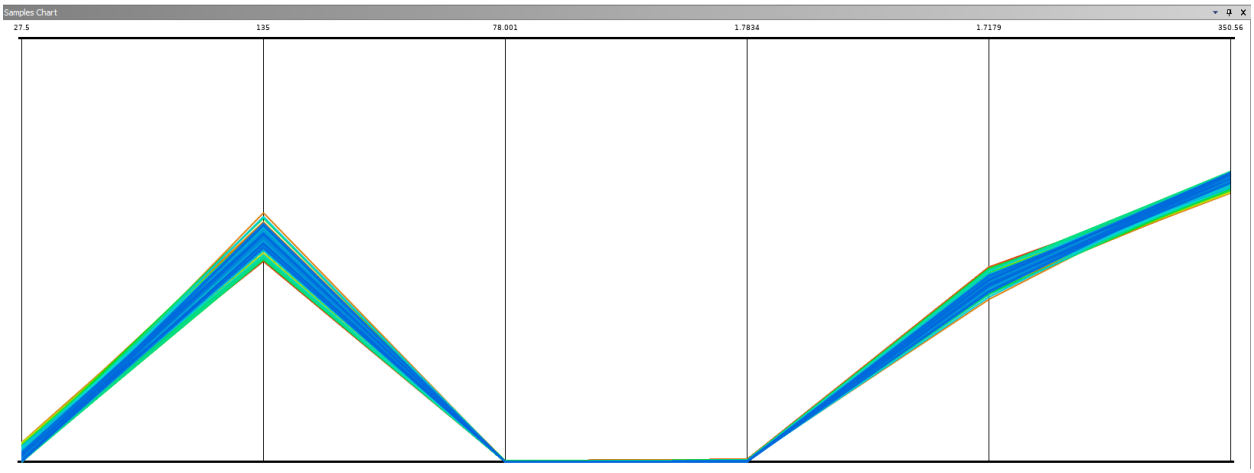
3.c. Candidate Points



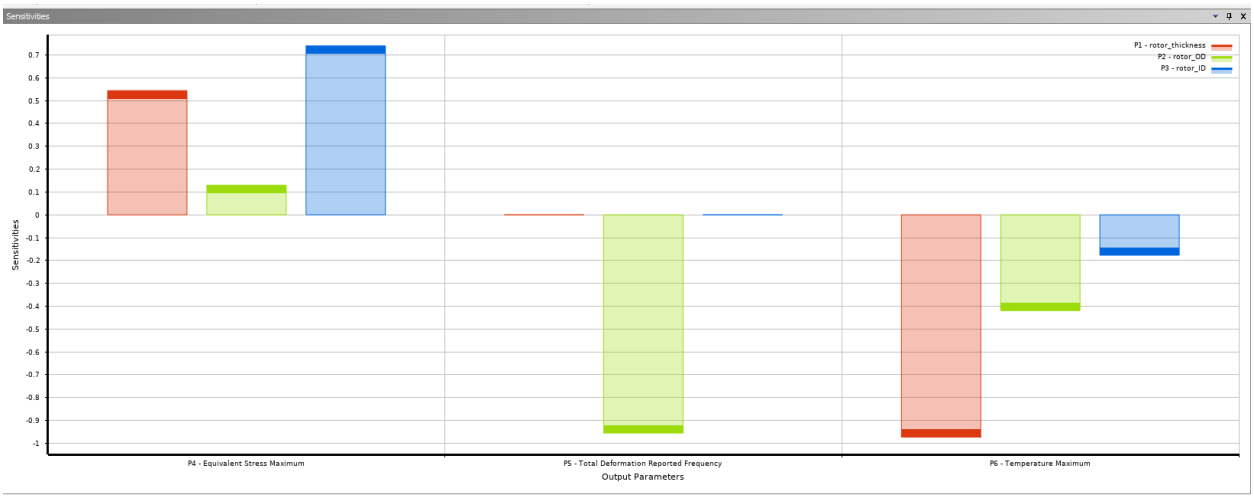
3.d.TradeOff Chart:



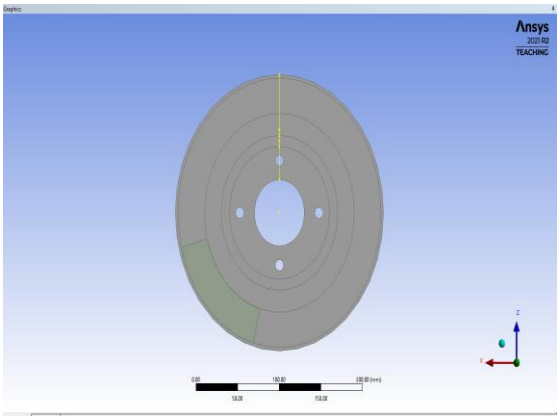
3.e. Sample Chat:

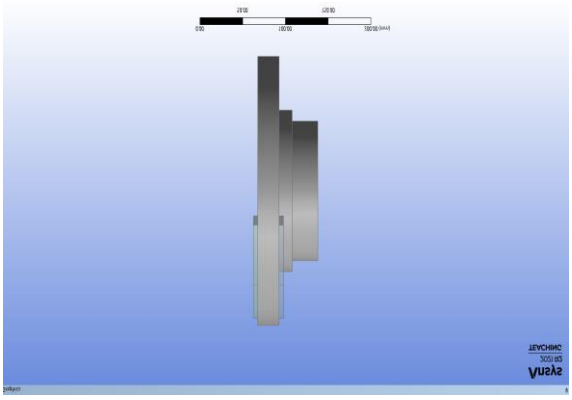


3.f.Sesistivity Chat:

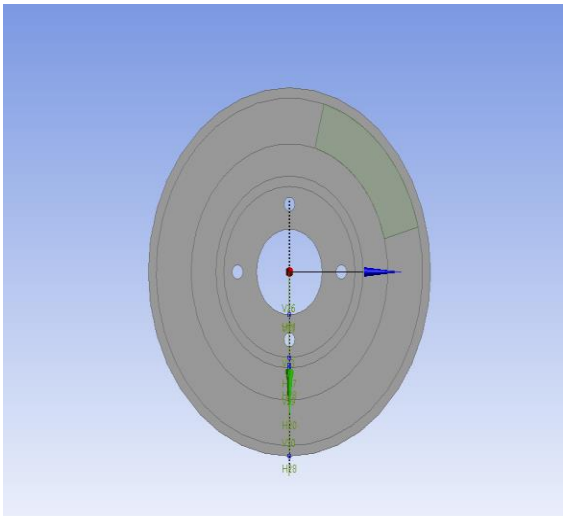


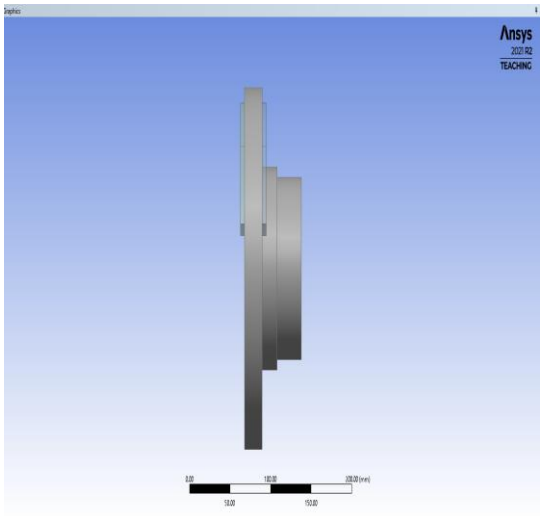
4.Initial Dimensions:





Final Dimensions:





Details View	
H20	30 mm
H21	35 mm
H27	5 mm
P H28	21.81 mm
V13	5 mm
V26	30 mm
P V29	129.2 mm
P V30	72.352 mm
V31	30 mm
V9	5 mm
Edges: 13	
Line	Ln8
Line	Ln9
Line	Ln15
Line	Ln16

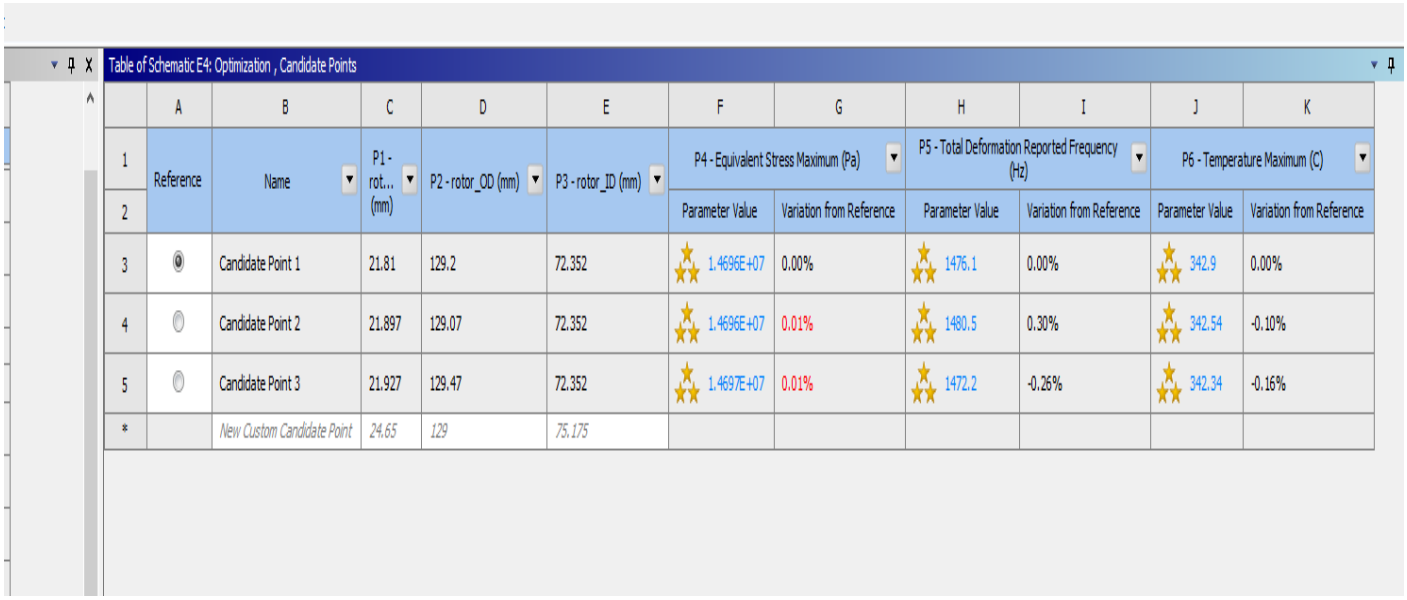
Details View	
Details of Sketch1	
Sketch	Sketch1
Sketch Visibility	Show Sketch
Show Constraints?	No
Dimensions: 11	
H18	5 mm
H20	30 mm
H21	35 mm
H27	5 mm
P H28	25 mm
V13	5 mm
V26	30 mm
P V29	125 mm
P V30	75 mm
V31	30 mm

Optimal Dimenstions **Initial Dimentions**

Verification:

As we know that we got the optimum values from the response curve and not by performing the actual simulation. So, we are verifying the result points by calculating the error between the simulated result and result from the response surface.

Results from the response surface:



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	A	B	C	D	E	F	G	H	I	J	K
1	Reference	Name	P1 - rot... (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 Reference
3	◉	Candidate Point 1	21.81	129.2	72.352	1.4696E+07	0.00%	1476.1	0.00%	342.9	0.00%
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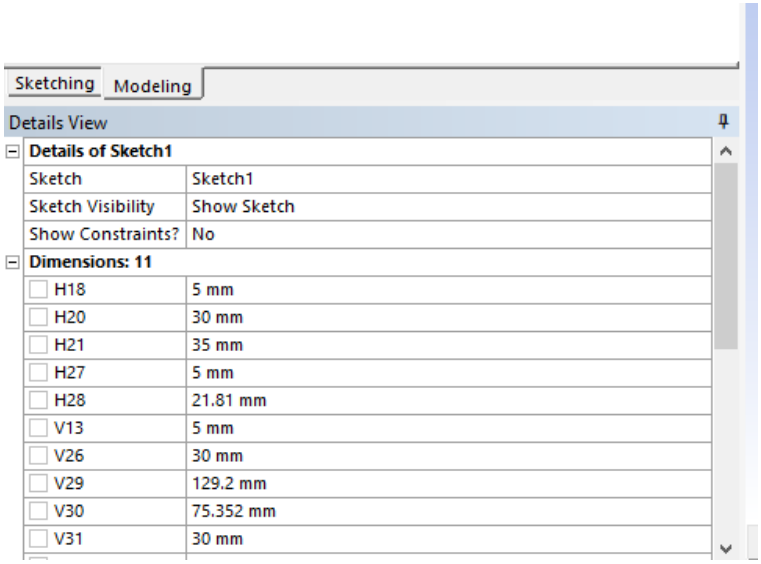
5	○	Candidate Point 3	21.927	129.47	72.352	1.4697E+07	0.01%	1472.2	-0.26%	342.34	-0.16%
*		*New Custom Candidate Point*	*24.65*	*129*	*75.175*						

Verifying Point1:

Changing the dimensions of the geometry as per the point 1

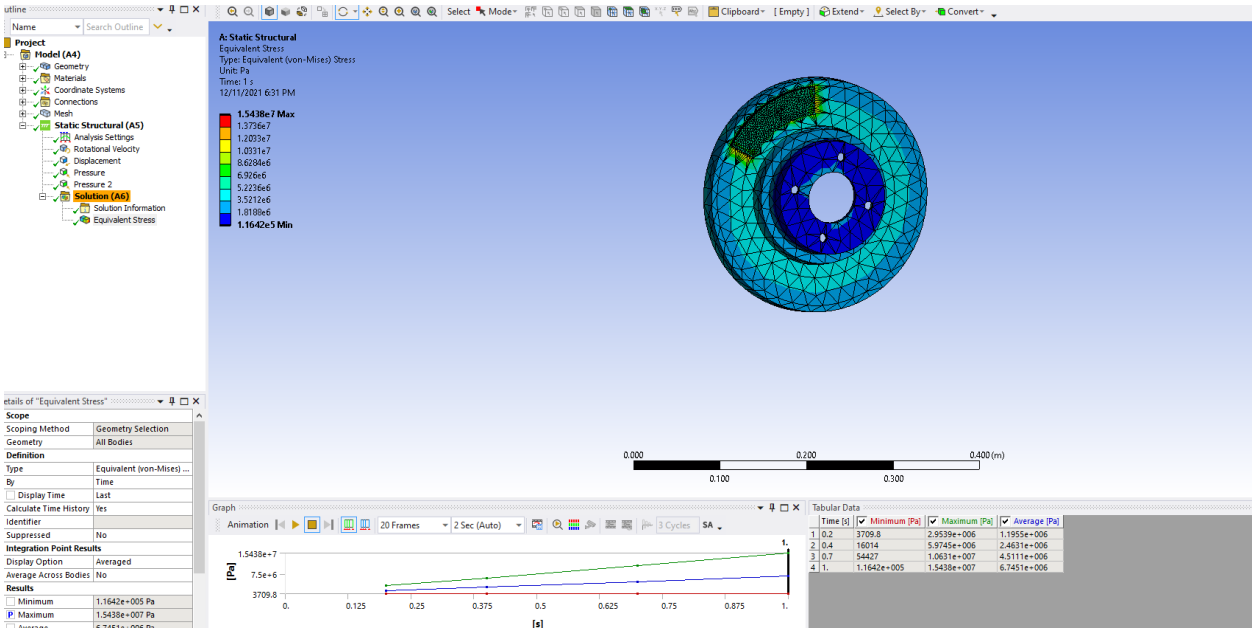


Sketching | Modeling

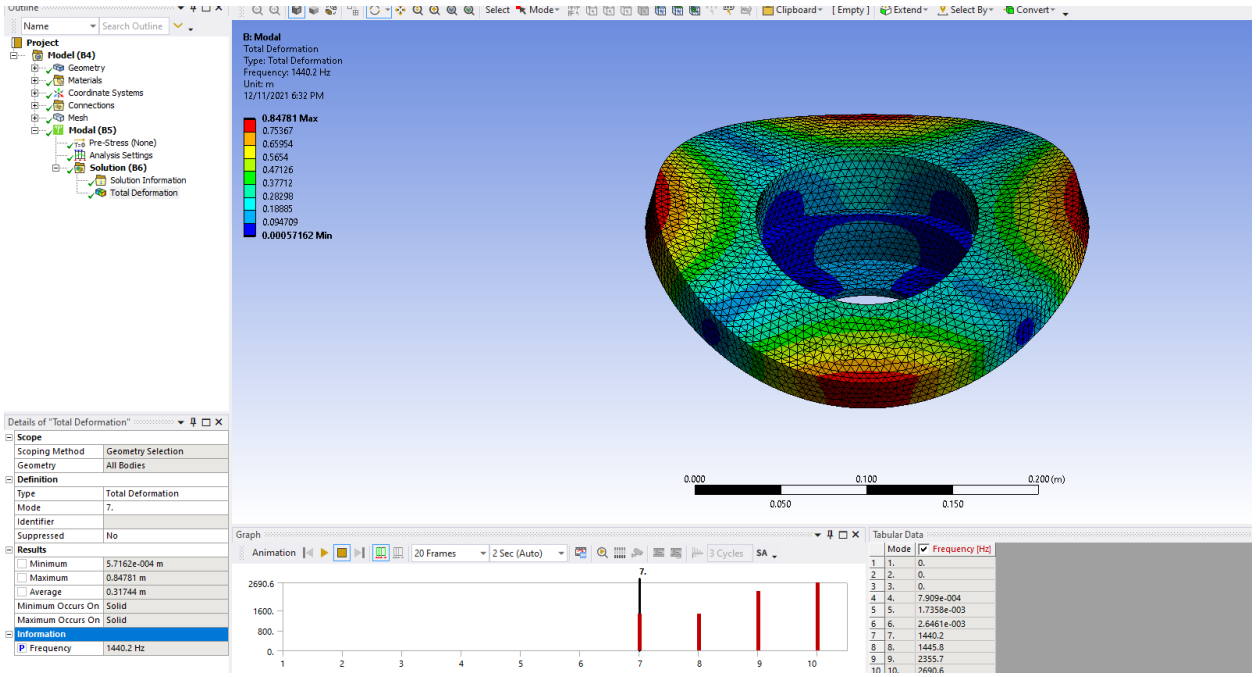
Details View

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
H28	21.81 mm
V13	5 mm
V26	30 mm
V29	129.2 mm
V30	75.352 mm
V31	30 mm

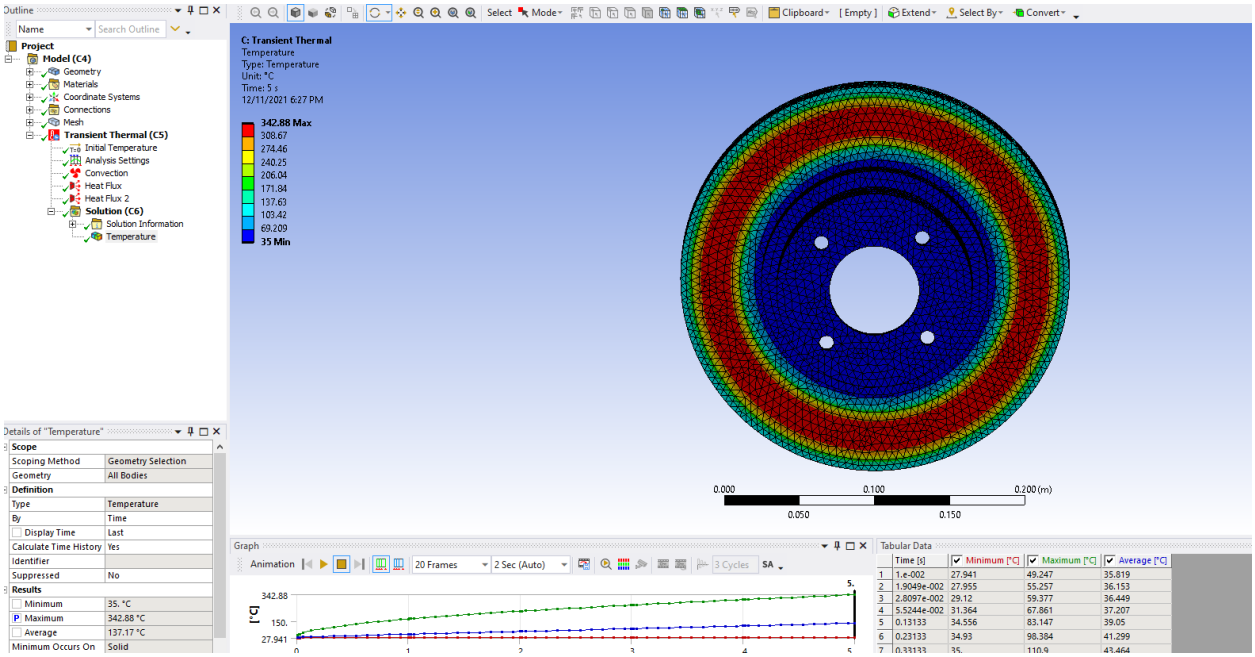
Static Structural Results for Point 1:



Modal Analysis Results for Point1:



Thermal Analysis Results for Point1:

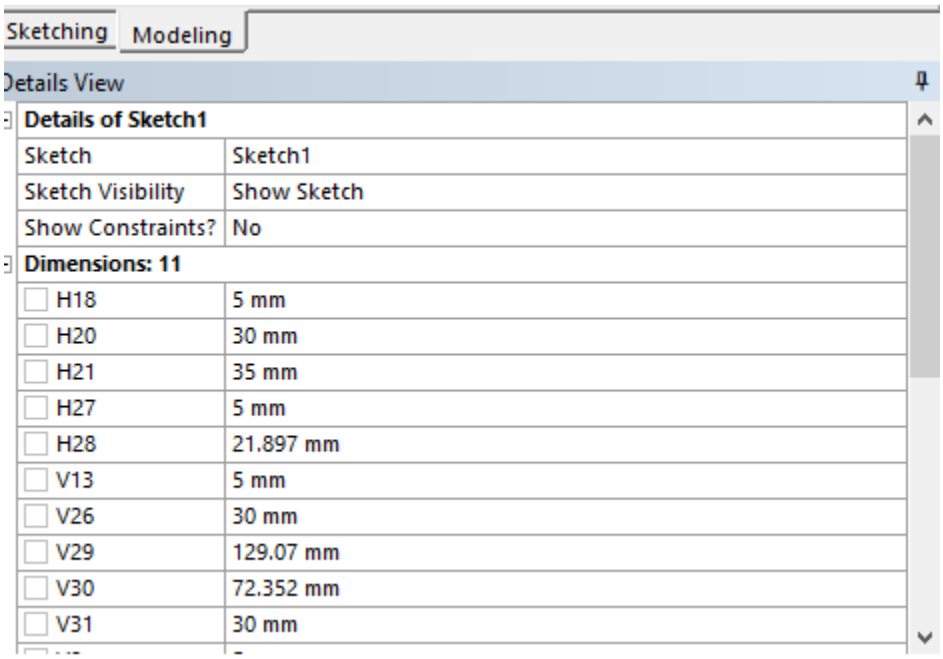


	Disc Thickness	Outer Diameter	Inner Diameter	Von Mises Stress (10^7)Pa	Frequency (Hz)	Temperature (deg C)
Point1	21.81	129.2	75.352	1.4696	1476.1	342.9
Verification				1.5438	1440.2	342.88
% Error				4.81	-2.49	-0.01

As we can observe that for point 1 both values are almost the same.

Verifying Point2:

Changing the dimensions of the geometry as per the point 2

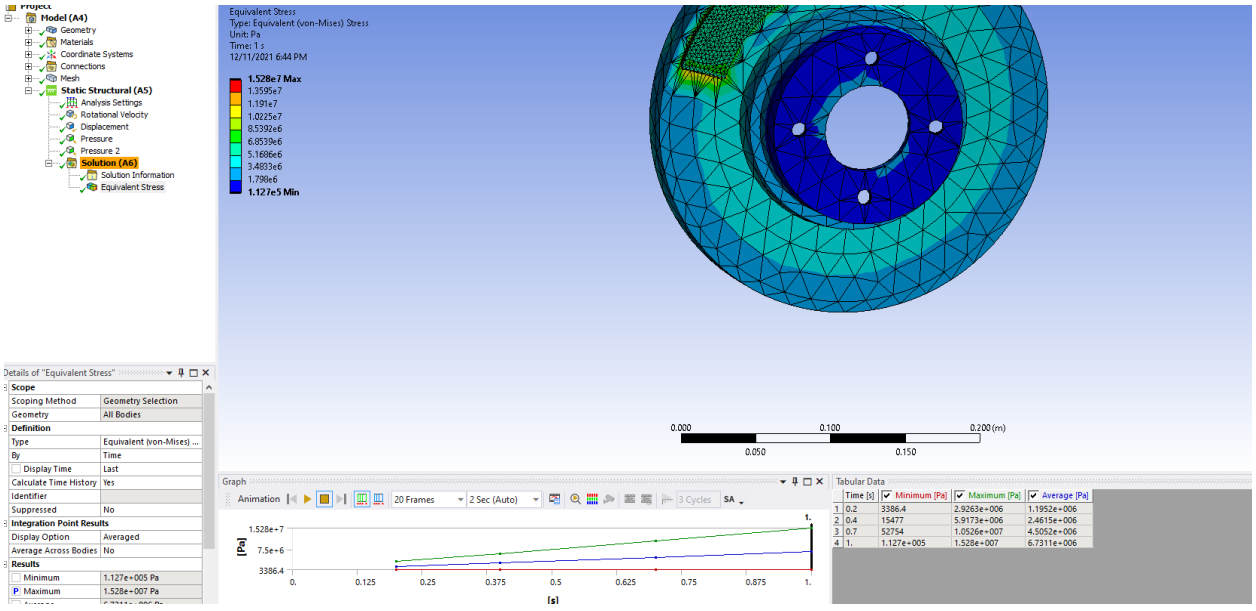


Sketching | Modeling

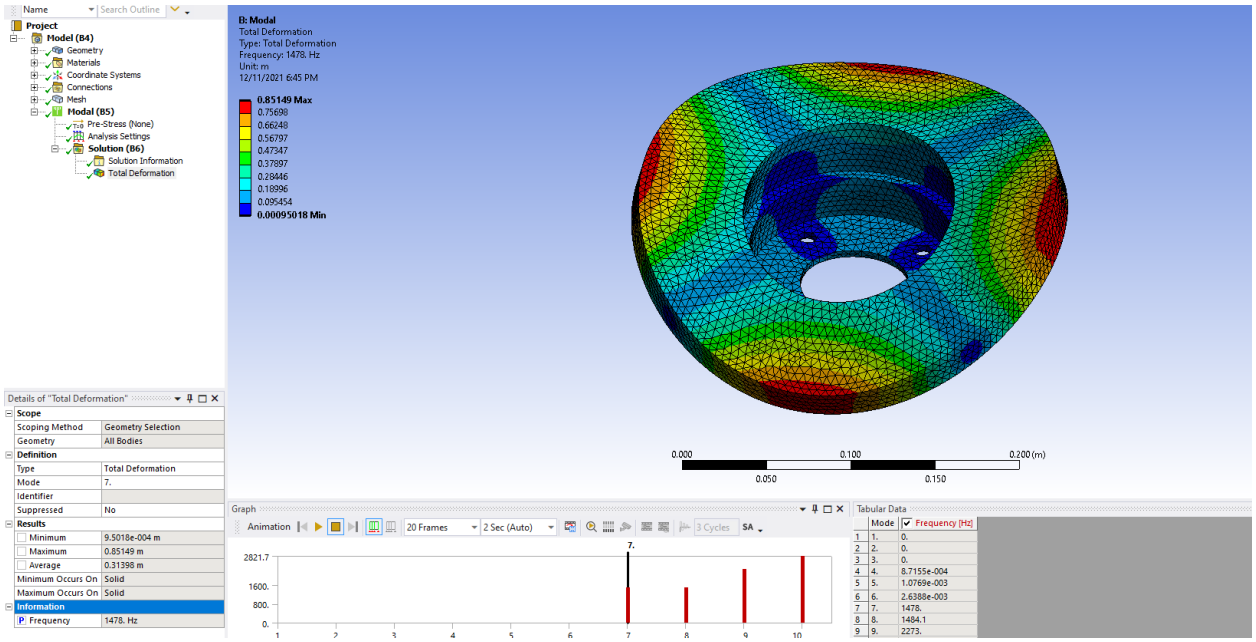
Details View

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
H28	21.897 mm
V13	5 mm
V26	30 mm
V29	129.07 mm
V30	72.352 mm
V31	30 mm

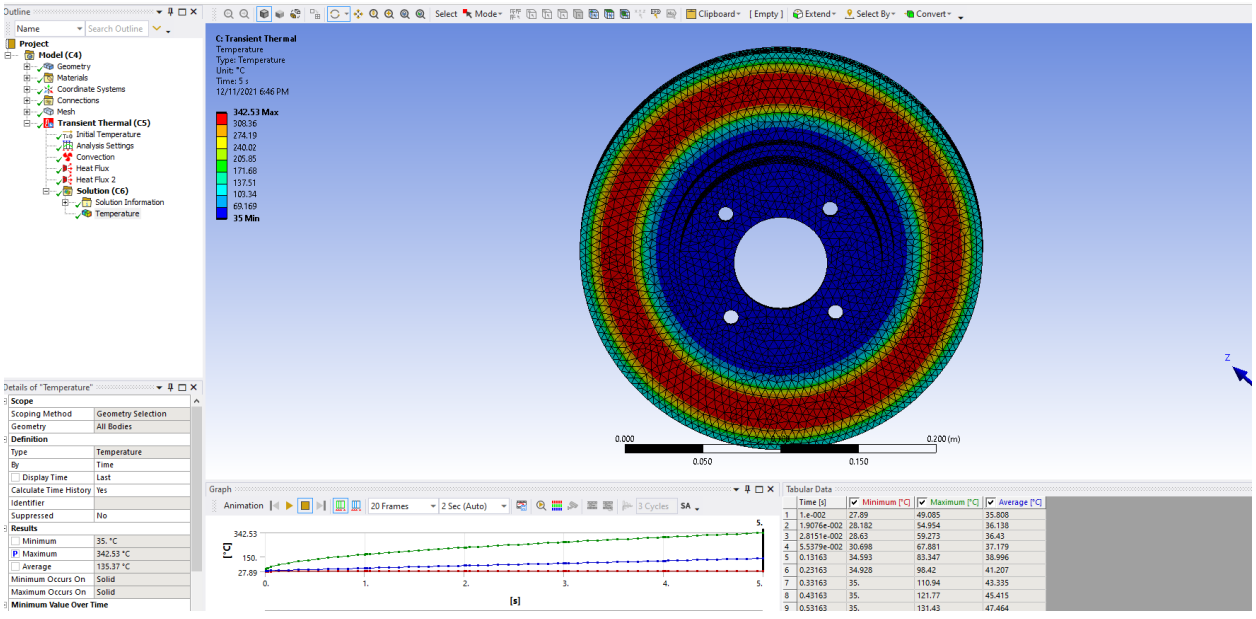
Static Structural Results for Point 2:



Modal Analysis Results for Point 2:



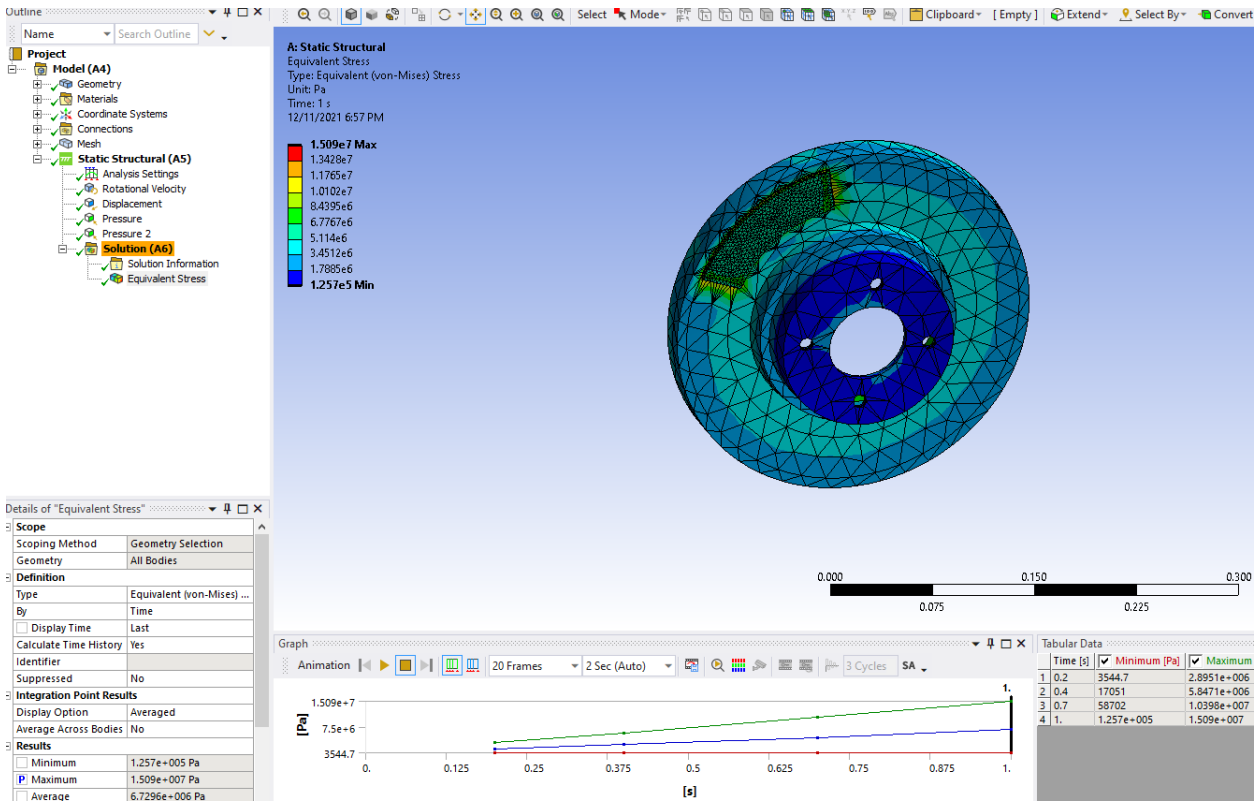
Thermal Analysis Results for Point2:



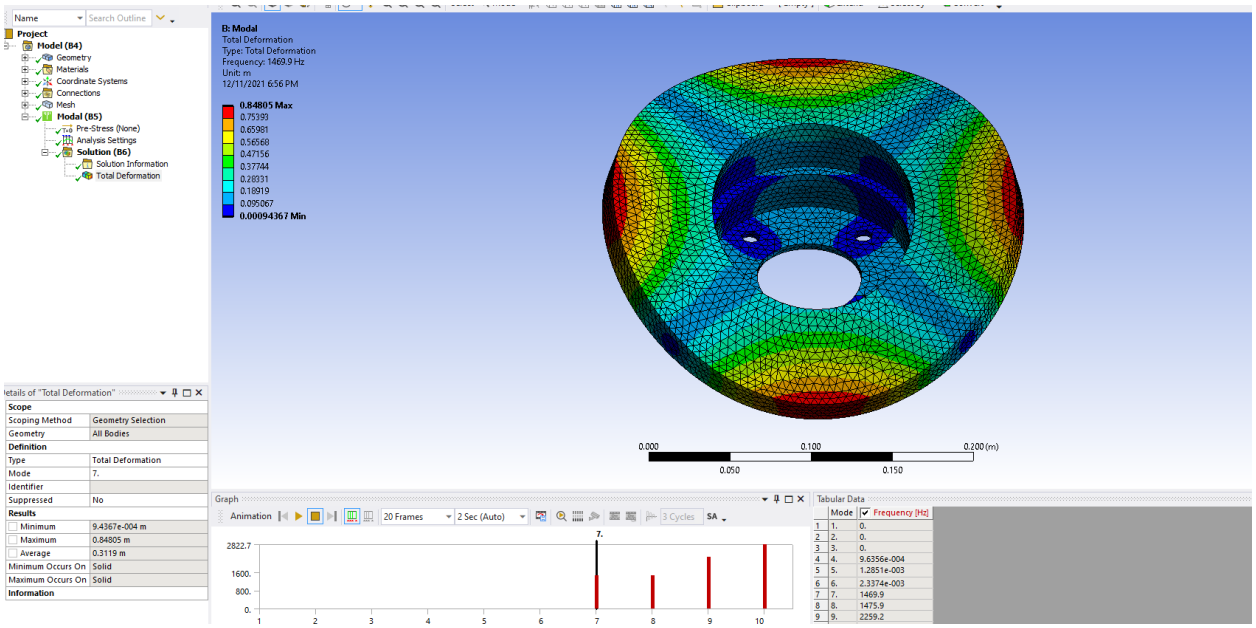
	Disc Thickness	Outer Diameter	Inner Diameter	Von Mises Stress (10^7)Pa	Frequency (Hz)	Temperature (deg C)
Point2	21.897	129.07	72.352	1.4696	1480.5	342.54
Verification				1.528	1478	342.53
% Error				**3.82**	**-0.17**	**0.00**

As we can observe that for point 2 both values are almost the same.

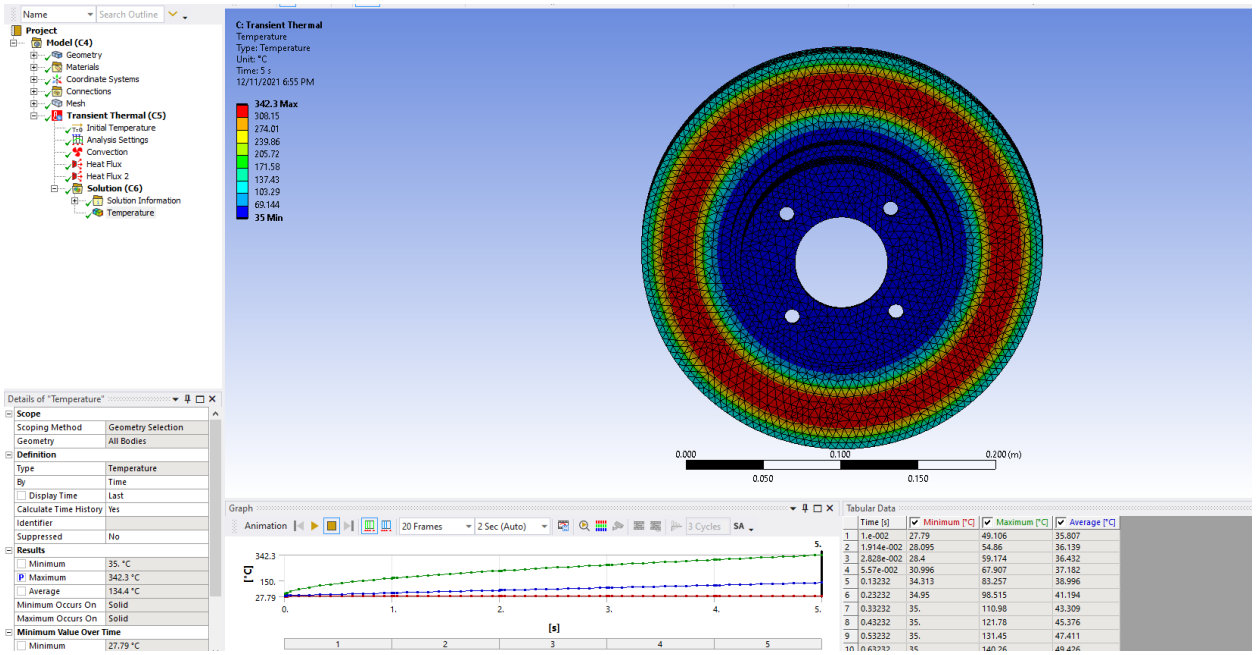
Static Structural Results for Point 3:



Modal Analysis Results for Point 3:



Thermal Analysis Results for Point3:



	Disc Thickness	Outer Diameter	Inner Diameter	Von Mises Stress (10^7)Pa	Frequency (Hz)	Temperature (deg C)
Point1	21.927	129.47	72.352	1.4697	1472.2	342.34
Verification				1.509	1469.9	342.3
% Error				**2.6**	**-0.2**	**0.0**

As we can observe that for point 3 both values are almost the same.

Final Verification Table:

	Disc Thickness	Outer Diameter	Inner Diameter	Von Mises Stress (10^7)Pa	Frequency(Hz)	Temperature (deg C)
Point1	21.81	129.2	75.352	1.4696	1476.1	342.9
Verification				1.5438	1440.2	342.88
% Error				**4.81**	**-2.49**	**-0.01**
Point2	21.897	129.07	72.352	1.4696	1480.5	342.54
Verification				1.528	1478	342.53
% Error				**3.82**	**-0.17**	**0.00**
Point3	21.927	129.47	72.352	1.4697	1472.2	342.34
Verification				1.509	1469.9	342.3
% Error				**2.6**	**-0.2**	**0.0**
			Avg Error	**3.74**	**-0.94**	**-0.01**

Therefore, the average error for von mises stress is 3.74%, natural frequency is 0.94% and Max Temperature is 0.01%.