DESIGN OPTIMIZATION OF BRAKE DISC

Project-2 report submitted

By

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Under the esteemed guidance of

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I wish to express deep sense of gratitude to my professor. Yi (Max) Ren, for his whole-hearted co-operation, unfailing inspirational and valuable guidance. Throughout the project work, his useful suggestions and constant encouragement has gone a long way and proved very useful for us at odd hours.

ABSTRACT

The main aim of this project is to determine the optimum dimensions of the brake disc for a four-wheeler vehicle using AUTO CAD and ANSYS software. These dimensions include the disc inner radius, outer radius and thickness. To determine these dimensions, we are performing structural, modal and thermal load cases for emergency braking conditions. The optimization objective is to minimize the brake disc volume, whereas the other objectives are to minimize the stress, temperature and maximize the first natural frequency of the disc. Optimization of the model is done in the ANSYS and the results were provided accordingly.

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OBJECTIVE:

- Design a brake disc for emergency braking conditions with minimal volume
- Minimize the maximum stress in the brake disc
- Maximize the first natural frequency of the brake disc
- Minimize the maximum temperature in the brake disc

MODEL DESIGN:

- The design of the brake disc was designed in the AUTO CAD previously, with considering the minimum volume conditions. Uploading the model in the Ansys and performing the analysis were given below.

The three subsystems are as follows:

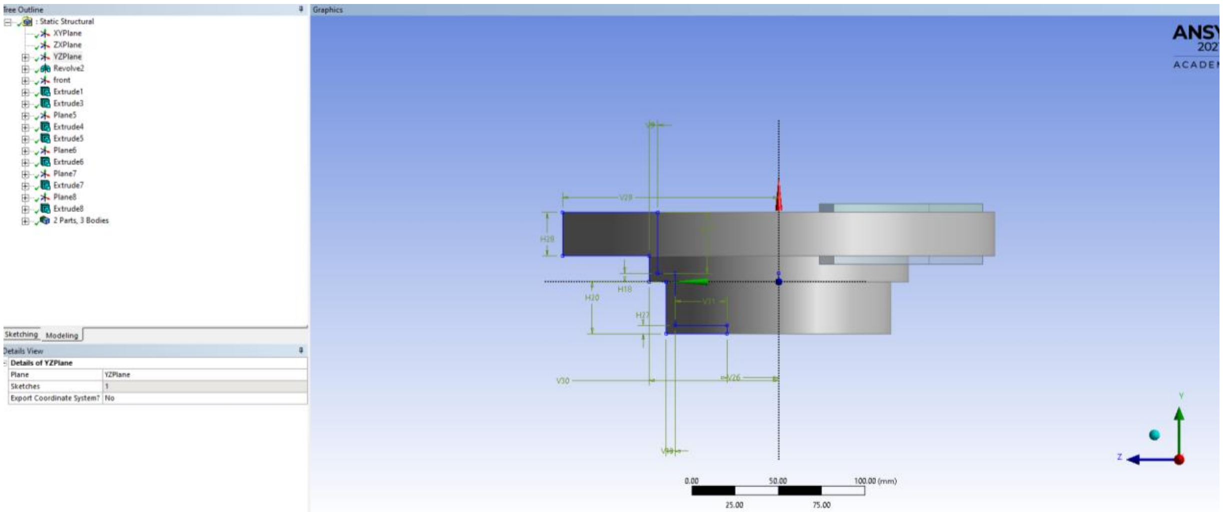
- **Structural Analysis**: The brake disc has to sustain the pressure from the hydraulically actuated brake pads during sudden braking conditions. Stresses are induced due to friction between the brake pads and the disc. The disc also experiences centrifugal body forces due to its rotation. Resultant 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.

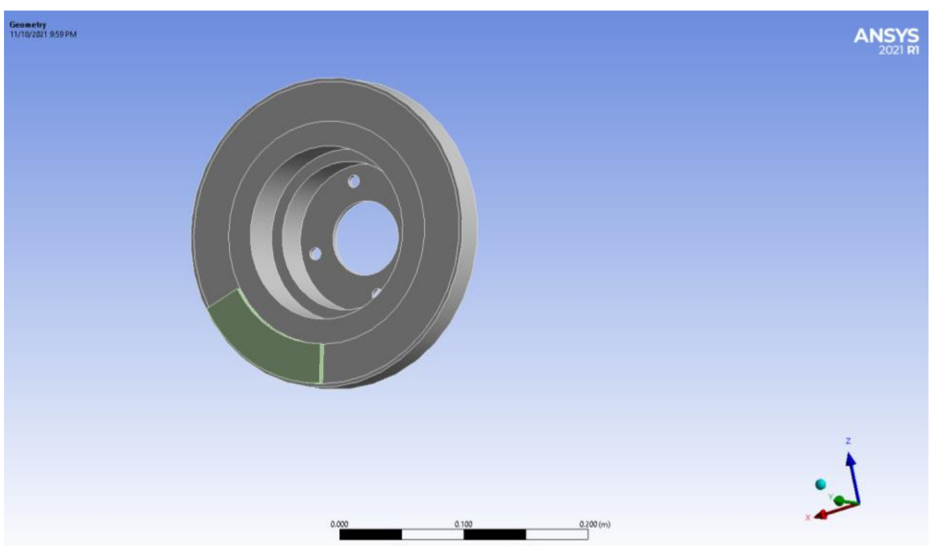
- **Modal Analysis**: Free modal analysis is performed to ensure that the disc's first natural frequency is higher than the engine firing frequency. This guarantees that the disc does not experience failure due to resonance.

- **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.

Sketch details and Model

The given below pictures shows the sketch dimensions and the design of the brake disc with brake pads



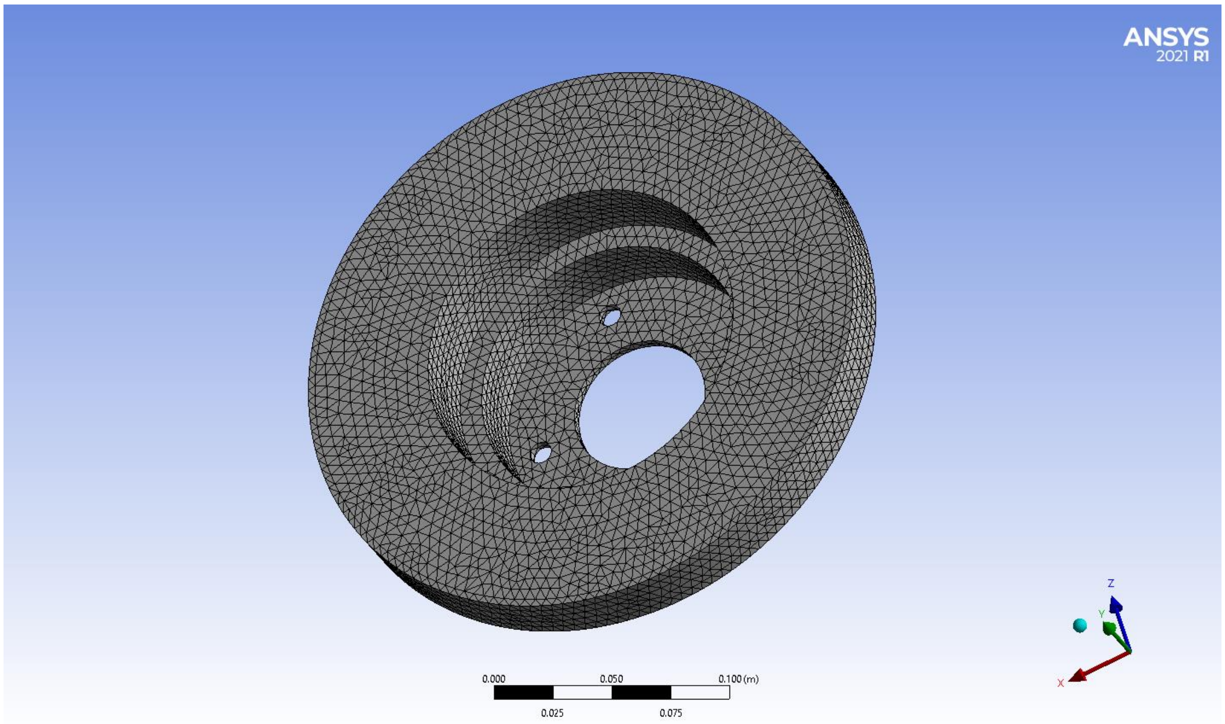


ANSYS Initial set up:

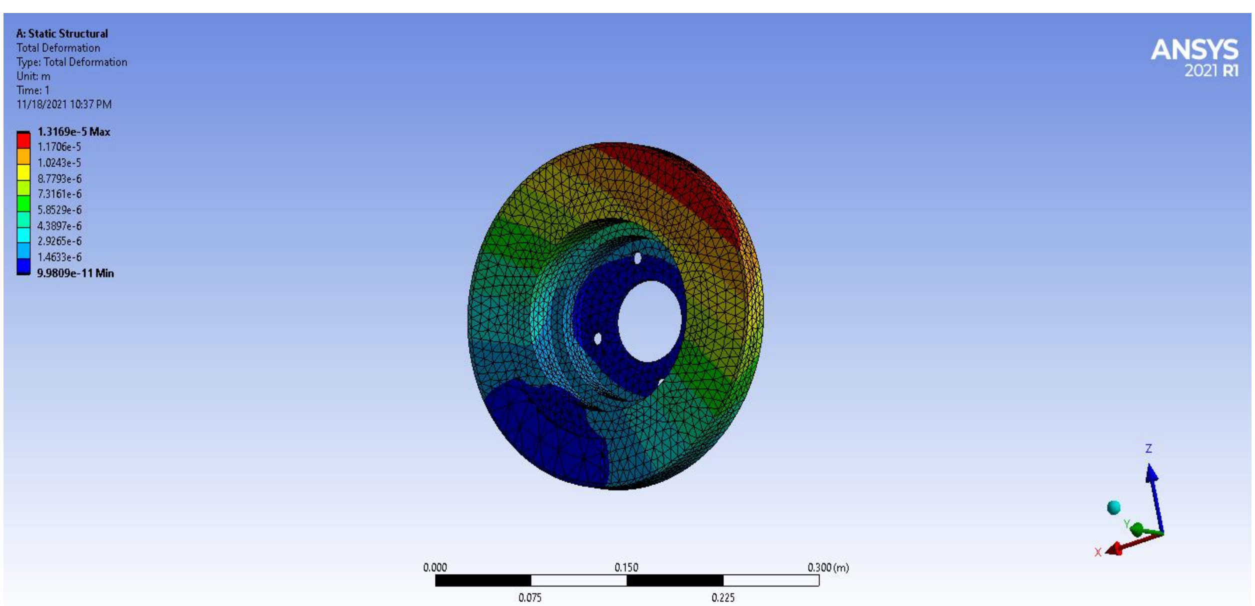
Static Structural:

- Initial model was imported into geometry in **Design Modeler** and generating the **Mesh**, **material assignment**, **contact regions** and solving the **static structural** gives the below showed result.

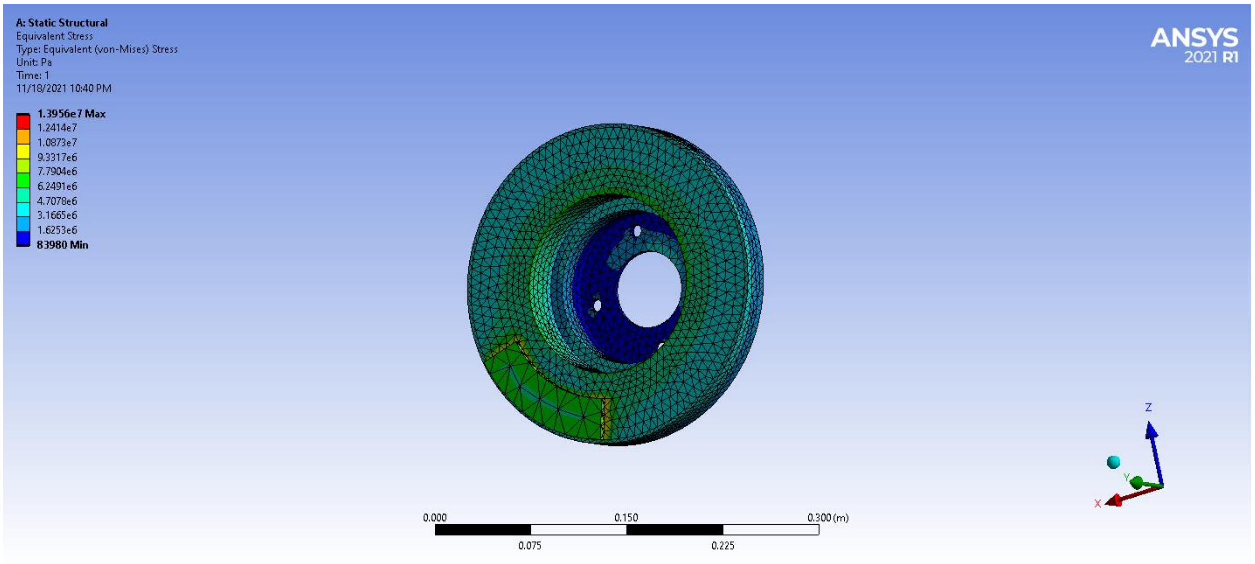
MESH VIEW:



TOTAL DEFORMATION



EQUIVALENT STRESS



Result:

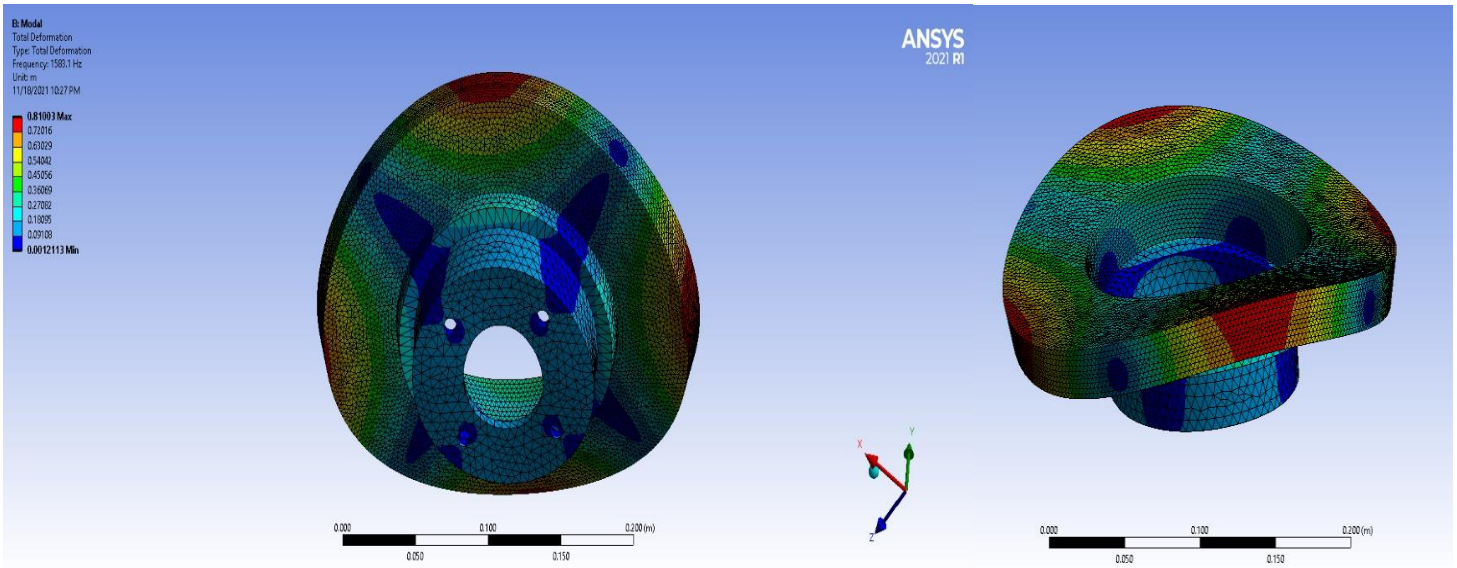
Details of "Equivalent Stress"

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	83980 Pa
P Maximum	1.3956e+007 Pa
Average	4.356e+006 Pa
Minimum Occurs On	Solid
Maximum Occurs On	Solid
Minimum Value Over Time	
Minimum	5308.6 Pa
Maximum	83980 Pa
Maximum Value Over Time	
Minimum	2.7207e+006 Pa
Maximum	1.3956e+007 Pa
Information	
Time	1. s
Load Step	1
Substep	4
Iteration Number	8

Modal Analysis:

- After doing with the static structural analysis, connecting the modal analysis to the geometry and performing the steps follows. Same geometry and mesh settings like previous, Analysis Settings and solving it to know the natural frequency of the solid disc.

TOTAL DEFORMATION:



NATURAL FREQUENCY:

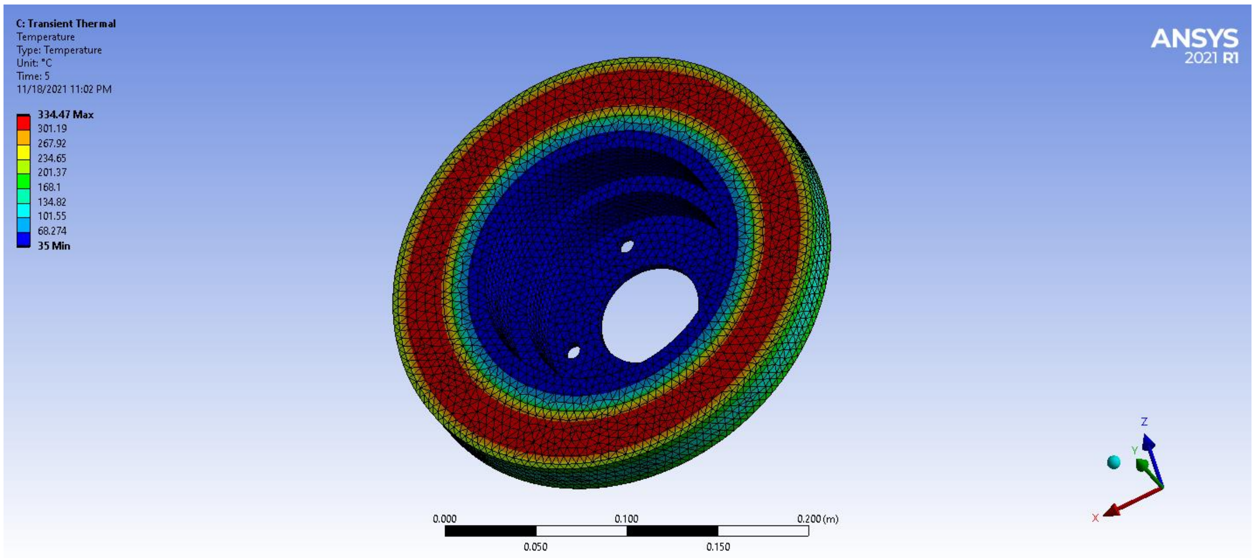
Details of "Total Deformation"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
Mode	7.
Identifier	
Suppressed	No
Results	
Minimum	1.2113e-003 m
Maximum	0.81003 m
Average	0.34296 m
Minimum Occurs On	Solid
Maximum Occurs On	Solid
Information	
Frequency	1583.1 Hz

Transient thermal setup:

- After doing with the model analysis, thermal analysis of the given model is performed. In this, putting the **Initial Temperature, Analysis Settings, Convection, Heat flux** and solving solution. The results were uploaded below.

Temperature:

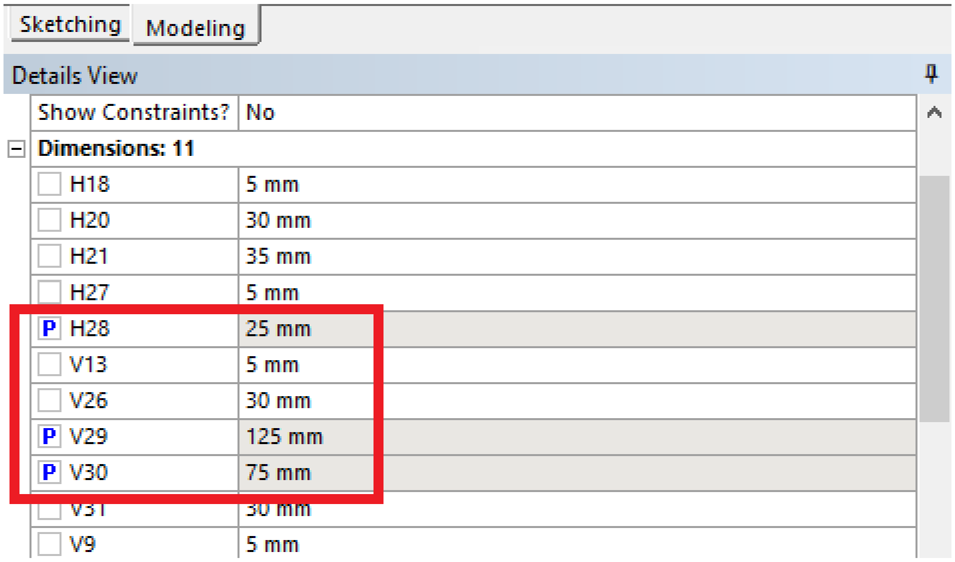


The final maximum temperature of the disc is showed below

Details of "Temperature"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Temperature
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
Minimum	35. °C
Maximum	334.47 °C
Average	135.84 °C
Minimum Occurs On	Solid
Maximum Occurs On	Solid
Minimum Value Over Time	
Minimum	26.569 °C
Maximum	35. °C
Maximum Value Over Time	
Minimum	49.15 °C
P Maximum	334.47 °C
Information	

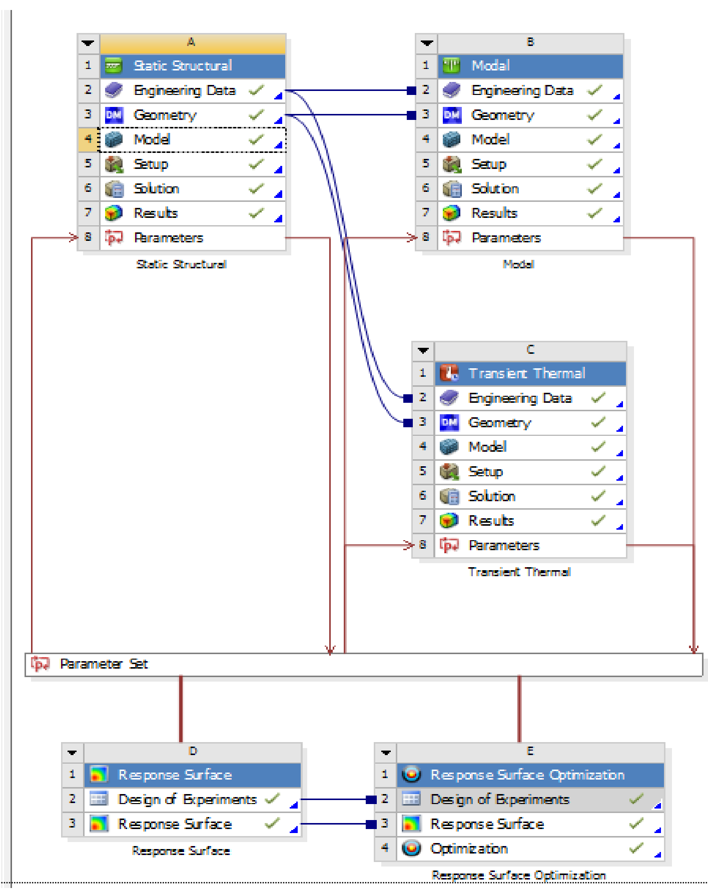
Defining Input Parameters:



Design of Experiments:

DOE is used to effectively sample a design space (e.g., all design parameters for the brake disc) so that a statistical model can be built to predict responses (e.g., the maximum stress, or the first natural frequency, or the maximum temperature) of a given design. DOE is useful when one can only sample a limited number of points (i.e., run a limited number of simulations). The key idea of DOE is to ``spread out'' the samples so that the resultant statistical model has low uncertainty in its model estimation and thus high accuracy in prediction.

Project Schematic:



DOE METHOD:

While ANSYS provides various DOE methods, we suggest Latin Hypercube Sampling (LHS) and Optimal space filling with user defined sample points. The main advantage of these methods is that the number of samples is independent from the number of parameters. Another (more advanced) choice is sparse grid, which only samples a few points initially and adaptively add new sample points based on the response surface. Kriging with auto-refinement has a similar effect. Note, we do not recommend Central Composite Design (CCD) because in many cases, the objective cannot be approximated as a quadratic function, and CCD requires a large number of samples for relatively small number of variables.

Input and Output parameters:

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 Maximum Value Over Time	
15	Charts	
16	Parameters Parallel	
17	Design Points vs Parameter	

Lower and Upper Bound Values:

The given showed vales are the lower and upper bound values for the inner and outer diameters, thickness.

Properties of Outline A7: P3 - rotor_ID

	A	B
1	Property	Value
5	Classification	Continuous
6	Values	
7	Lower Bound	72
8	Upper Bound	80
9	Allowed Values	Any

Properties of Outline A6: P2 - rotor_OD

	A	B
1	Property	Value
5	Classification	Continuous
6	Values	
7	Lower Bound	122
8	Upper Bound	129
9	Allowed Values	Any

Continuous

Properties of Outline A5: P1 - rotor_thickness

	A	B
1	Property	Value
5	Classification	Continuous
6	Values	
7	Lower Bound	23
8	Upper Bound	28
9	Allowed Values	Any

Candidate Points

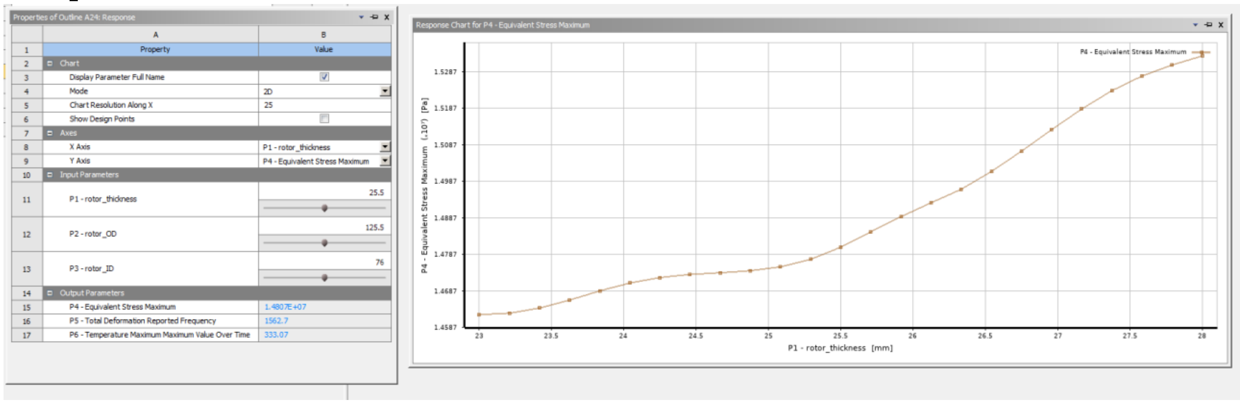
	Candidate Point 1	Candidate Point 2	Candidate Point 3
P1 - rotor_thickness (mm)	23.714	23.757	23.73
P2 - rotor_OD (mm)	124.67	124.66	124.66
P3 - rotor_ID (mm)	75.664	75.583	75.504

Design Points of Design of Experiments:

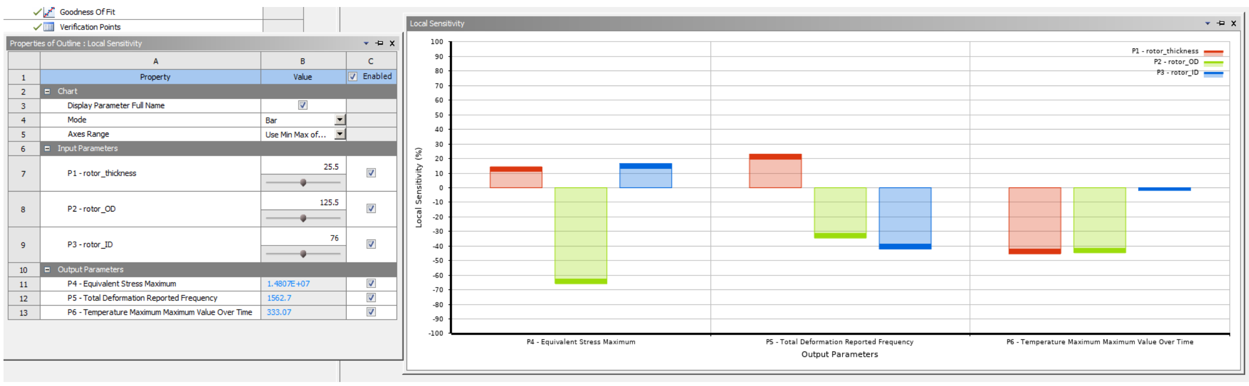
Table of Outline A2: Design Points of Design of Experiments

	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 Maximum Value Over Time (C)
2	1	25.625	123.58	77.4	1.4991E+07	1567.9	335.83
3	2	26.625	126.73	73	1.5025E+07	1612.8	329.25
4	3	23.125	127.08	74.2	1.4653E+07	1522.9	338.35
5	4	26.125	122.18	73.8	1.7884E+07	1681.4	345.33
6	5	23.625	124.63	79	1.4822E+07	1485.8	339.14
7	6	27.875	124.98	77.8	1.5338E+07	1575.1	328.73
8	7	25.875	126.38	79.4	1.5035E+07	1485.8	331
9	8	27.625	125.68	75.4	1.538E+07	1608.6	328.33
10	9	24.625	128.48	72.2	1.4593E+07	1548.1	333.08
11	10	24.375	122.53	73.4	1.8918E+07	1651.8	344
12	11	25.125	125.33	72.6	1.4659E+07	1620.5	333.73
13	12	24.125	126.03	78.2	1.4949E+07	1488.6	335.78
14	13	25.375	124.28	79.8	1.5412E+07	1498.4	334.75
15	14	26.875	127.43	75.8	1.4994E+07	1555.1	328.45
16	15	24.875	122.88	74.6	1.8403E+07	1629.3	340.44
17	16	27.375	123.23	76.6	1.6974E+07	1621.1	333.39
18	17	27.125	128.83	77	1.4969E+07	1512.7	327.57
19	18	26.375	127.78	76.2	1.4822E+07	1532.5	329.25
20	19	23.875	123.93	75	1.4742E+07	1584.5	339.79
21	20	23.375	128.13	78.6	1.5001E+07	1435.3	337

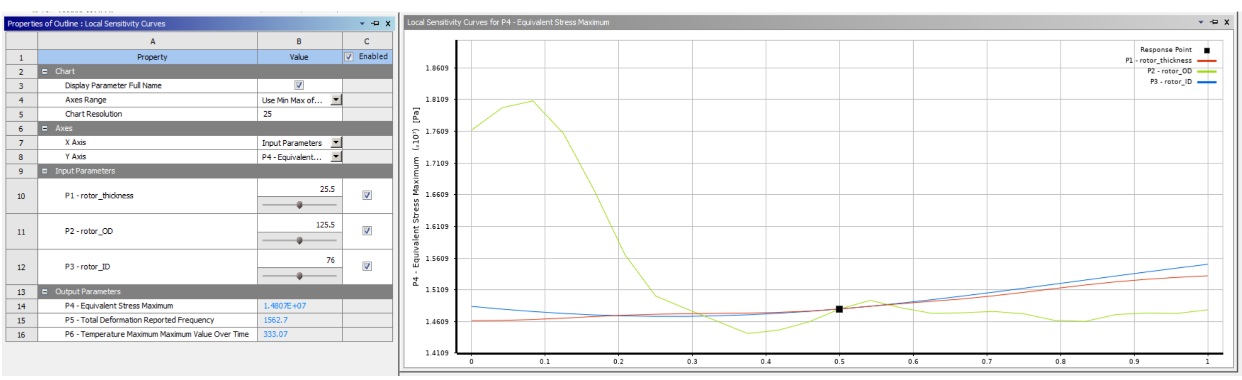
Response Surface:



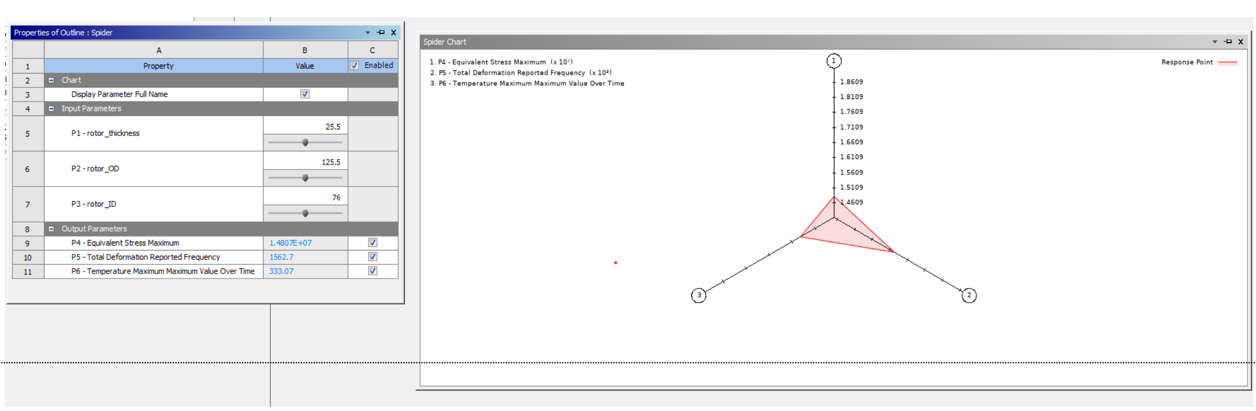
Local Sensitivity:



Local Sensitivity Curves:



Spider:



OPTIMIZATION:

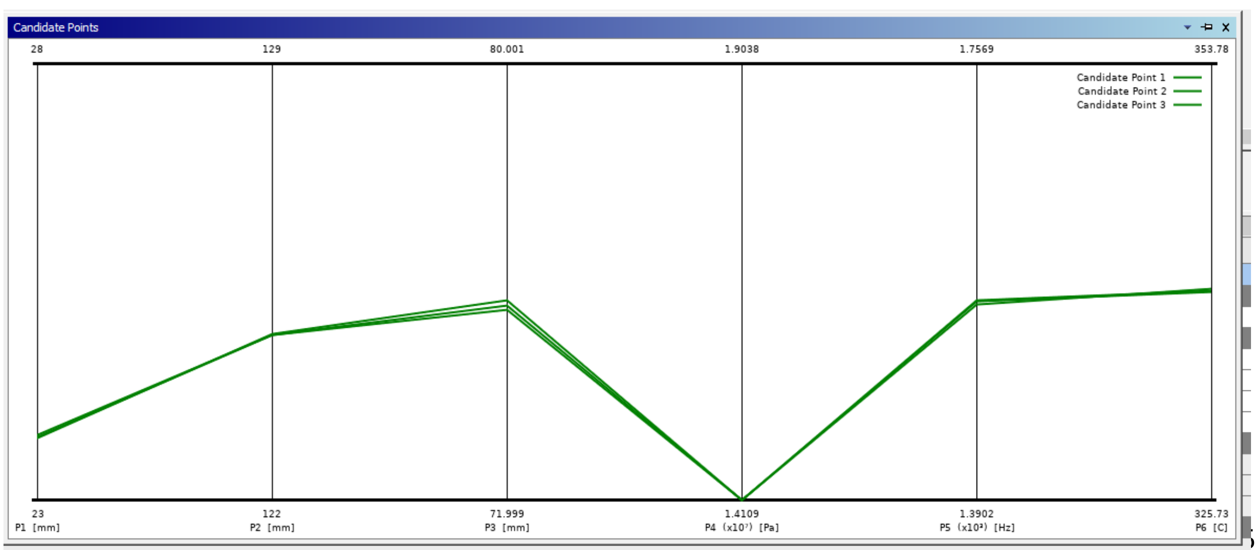
It is the main process where the optimization of the given deign is performed and determining the optimization graphs for different parts

Outline of Schematic E4: Optimization

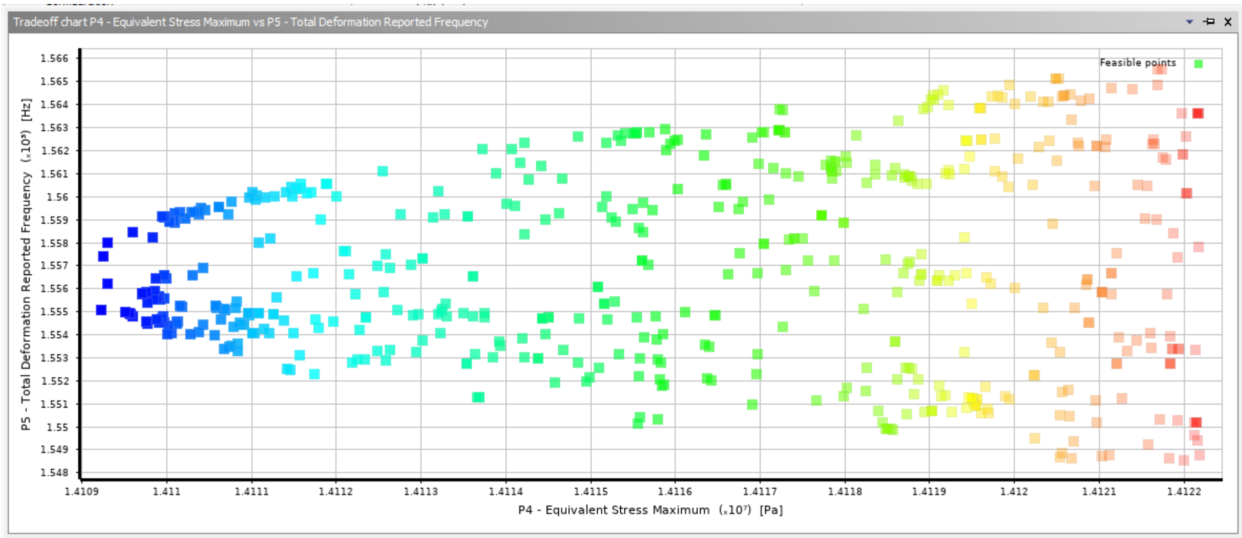
	A	B	C
1		Enabled	Monitoring
4	Minimize P4		
5	P5 >= 1435.3 Hz		
6	P6 <= 345.33 C		
7	Domain		
8	Static Structural (A1)		
9	P1 - rotor_thickness	☑	
10	P2 - rotor_OD	☑	
11	P3 - rotor_ID	☑	
12	Parameter Relationships		
13	Convergence Criteria		
14	Results		
15	Candidate Points		
16	Tradeoff		
17	Samples		
18	Sensitivities		

RESULT:

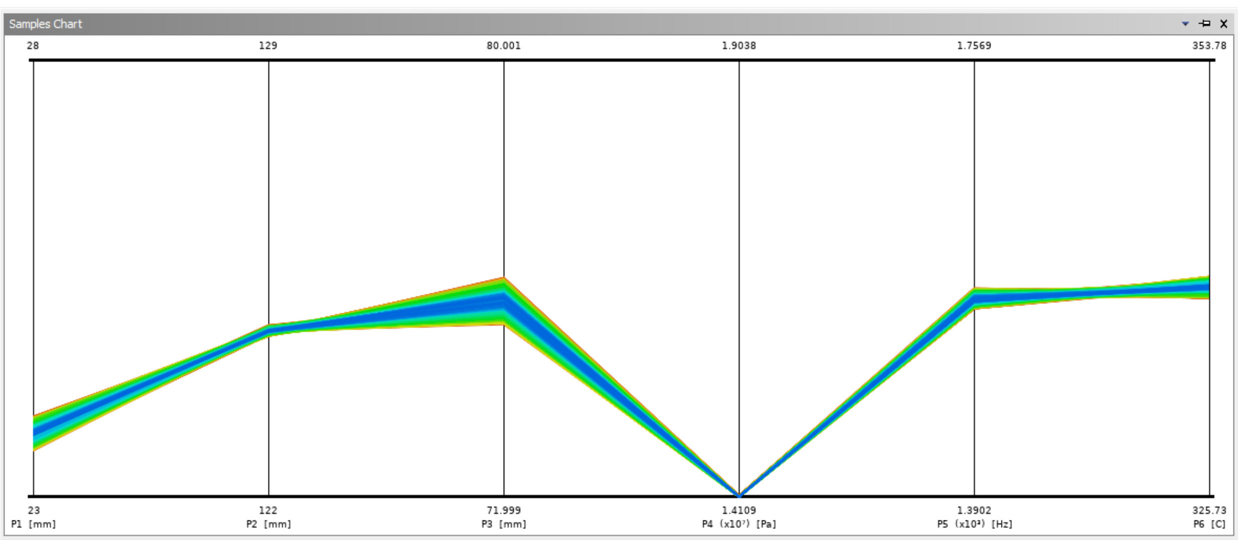
1.Candidate Points:



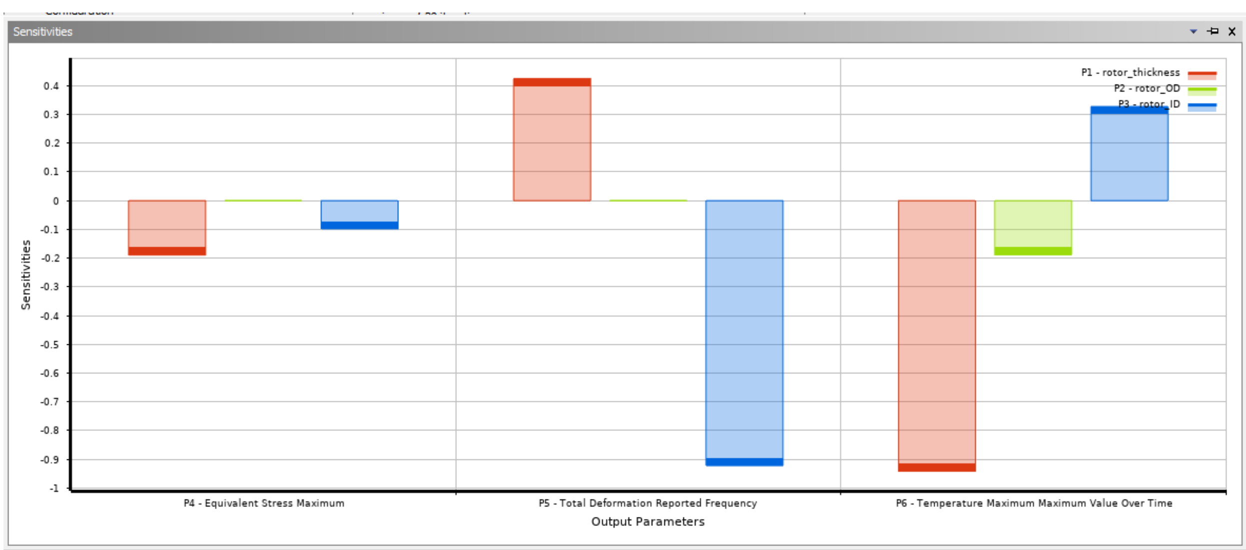
2.Trade off:



3.Sample Chart:



4.Sensitives:



Best Design Candidates:

The given below values with stars show the best candidate points of Equivalent stress, Reported frequency and Temperature maximum value

Table of Schematic E4: Optimization

	A	B	C	D
1	Optimization Study			
2	Minimize P4	Goal, Minimize P4 (Default importance)		
3	P5 >= 1435.3 Hz	Strict Constraint, P5 values greater than or equals to 1435.3 Hz (Default importance)		
4	P6 <= 345.33 C	Strict Constraint, P6 values less than or equals to 345.33 C (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 3000 samples initially, 600 samples per iteration and find 3 candidates in a maximum of 20 iterations.		
8	Status	Converged after 6609 evaluations.		
9	Candidate Points			
10		Candidate Point 1	Candidate Point 2	Candidate Point 3
11	P1 - rotor_thickness (mm)	23.714	23.757	23.73
12	P2 - rotor_OD (mm)	124.67	124.66	124.66
13	P3 - rotor_ID (mm)	75.664	75.583	75.504
14	P4 - Equivalent Stress Maximum (Pa)	1.4109E+07	1.4109E+07	1.411E+07
15	P5 - Total Deformation Reported Frequency (Hz)	1555.1	1557.4	1558.5
16	P6 - Temperature Maximum Maximum Value Over Time (C)	339.32	339.17	339.24

FINAL DIMENSIONS:

Final optimum dimensions were showed below by changing the model too.

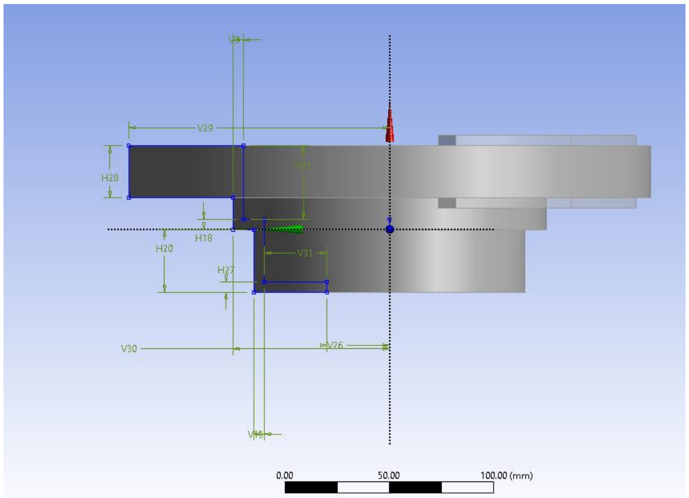
Details View

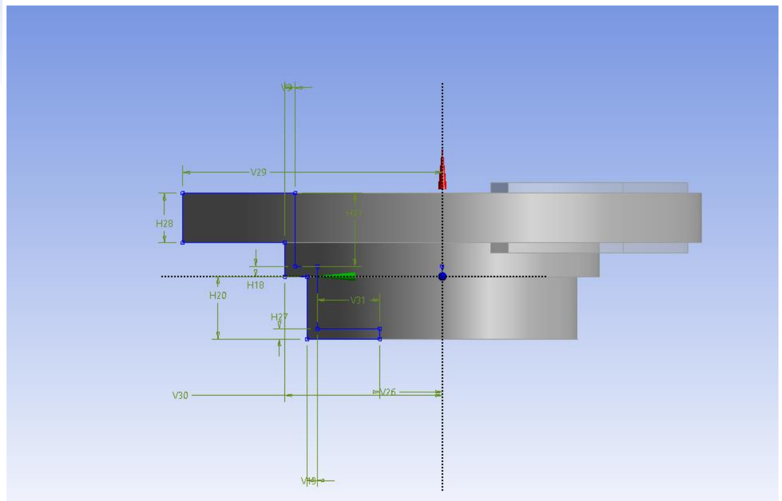
Details of Sketch1	
Sketch	Sketch1
Sketch Visibility	Show Sketch
Show Constraints?	No
Dimensions: 11	
H18	5 mm
H20	30 mm
H21	35 mm
H27	5 mm
P H28	25 mm
V13	5 mm
V26	30 mm
P V29	125 mm
P V30	75 mm
V31	30 mm

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
P H28	23.714 mm
V13	5 mm
V26	30 mm
P V29	124.67 mm
P V30	75.664 mm
V31	30 mm


V29
H28
H18
H20
H27
V31
V30
V26
0.00
50.00
100.00 (mm)


V29
H28
H18
H20
H27
V31
V30
V26

*************************************THE END***********************************