# Project 2: ANSYS DOE

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Design Optimization Fall 2021: Yi Ren

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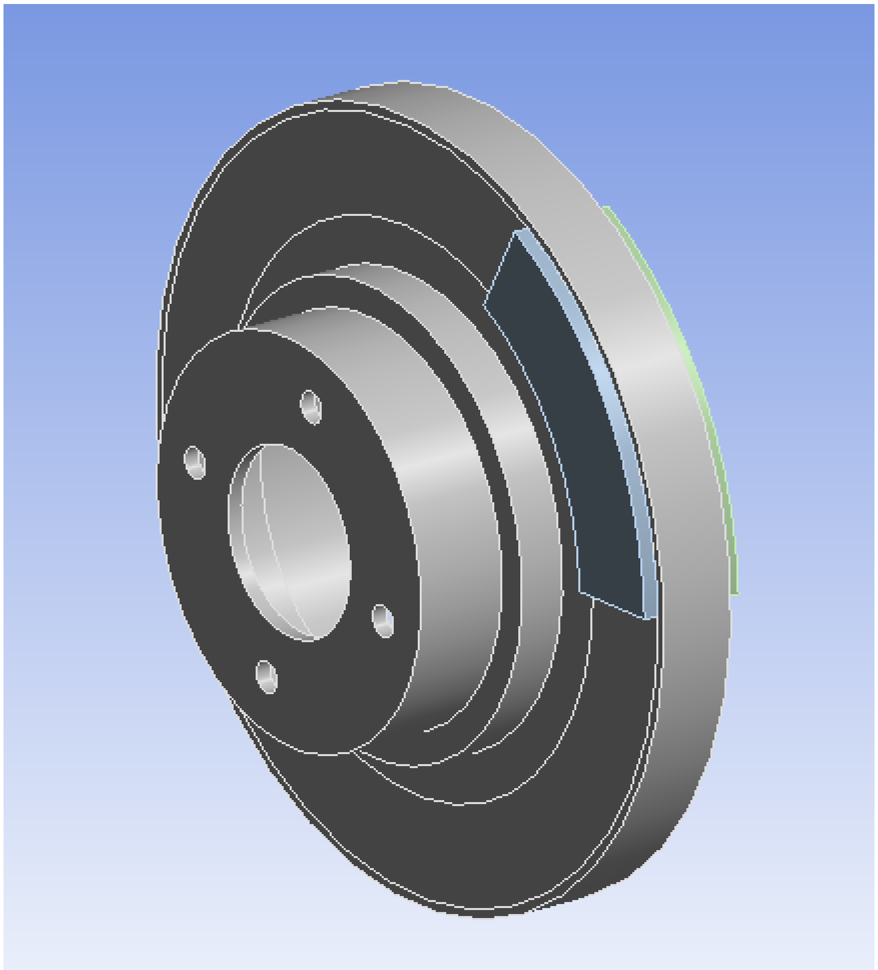
## Initial Setup

The following setup outlines the input and output parameters as well as the initial settings of the design experiment outlined for a brake disc and pads. Here the system was designed to minimize thermal loading as well as the maximum Von-Misses stress experienced by the system while simultaneously maximizing the first natural frequency experienced by the brake disk.

**Geometry:**



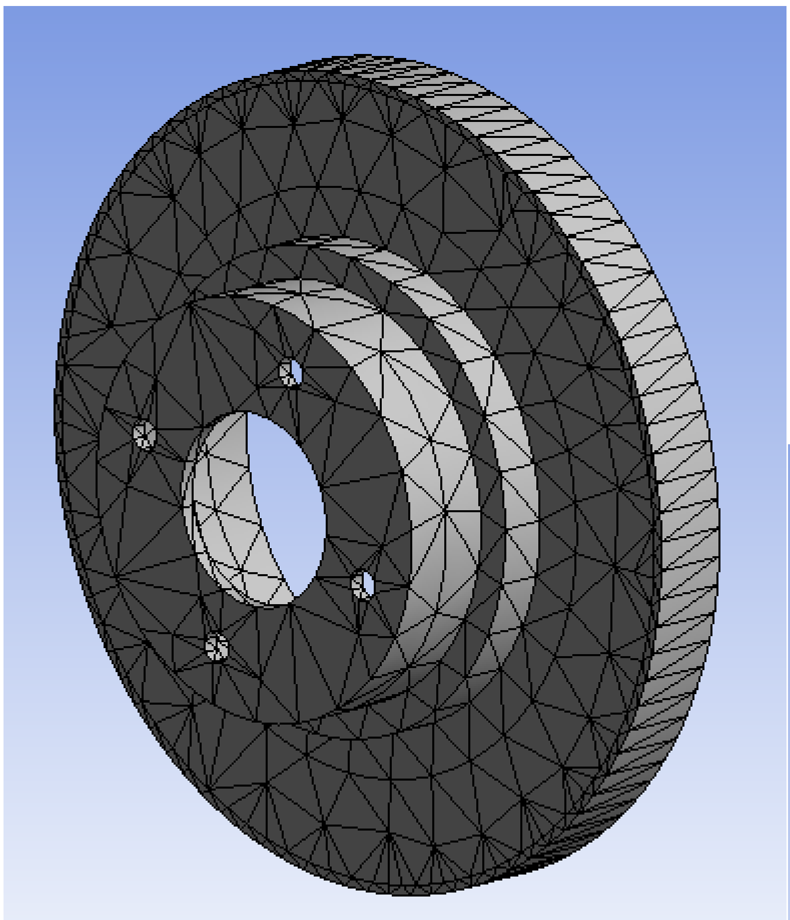
**Mesh:**

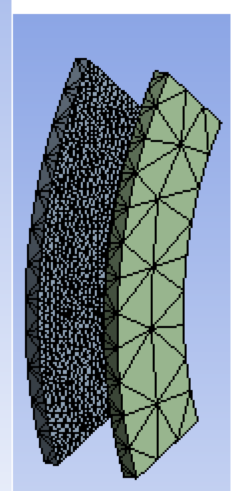
Details of "Patch Conforming Method" - Met

| | |
|---|---|
| **Scope** | |
| Scoping Method | Geometry Selection |
| Geometry | 3 Bodies |
| **Definition** | |
| Suppressed | No |
| Method | Tetrahedrons |
| Algorithm | Patch Conforming |
| Element Order | Use Global Setting |

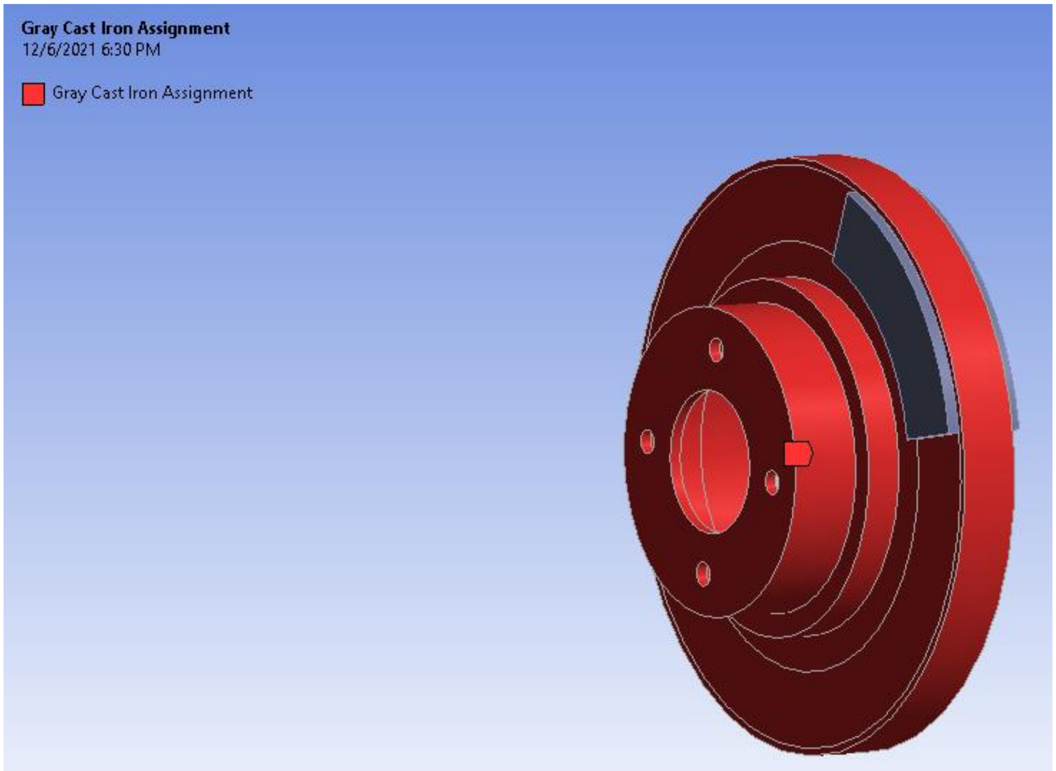
Details of "Face Sizing" - Sizing

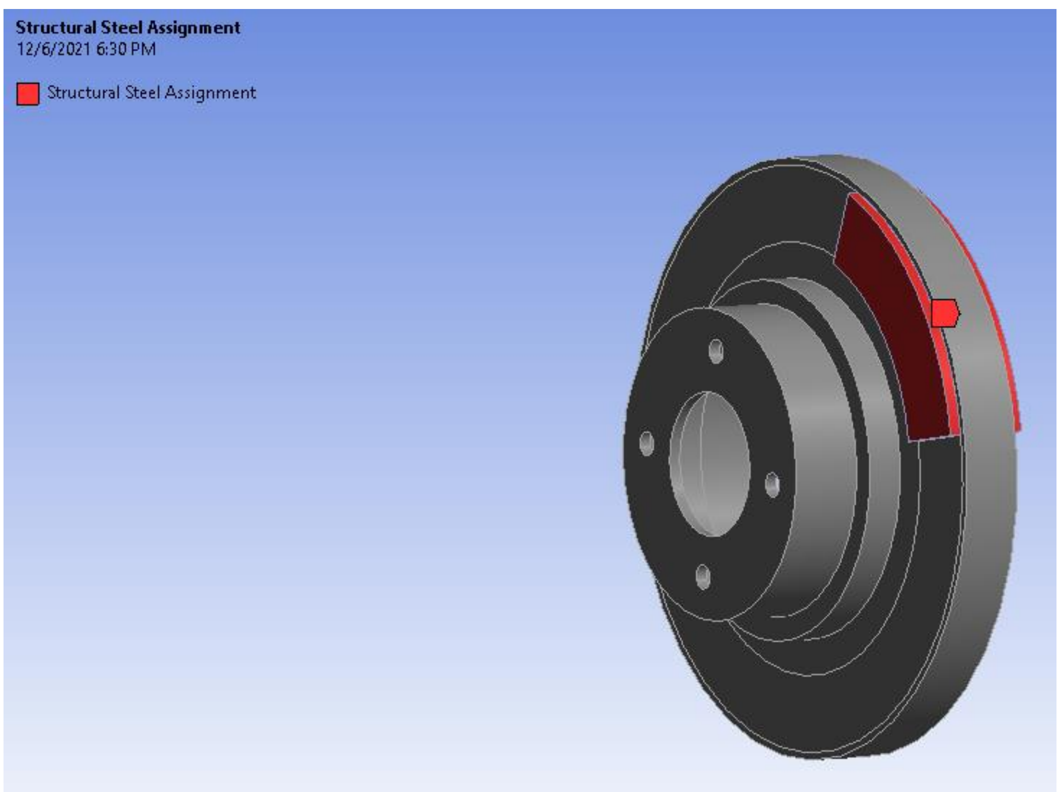
| | |
|---|---|
| **Scope** | |
| Scoping Method | Geometry Selection |
| Geometry | 2 Faces |
| **Definition** | |
| Suppressed | No |
| Type | Element Size |
| Element Size | 3.e-003 m |
| **Advanced** | |
| Defeature Size | Default |
| Influence Volume | No |
| Behavior | Soft |



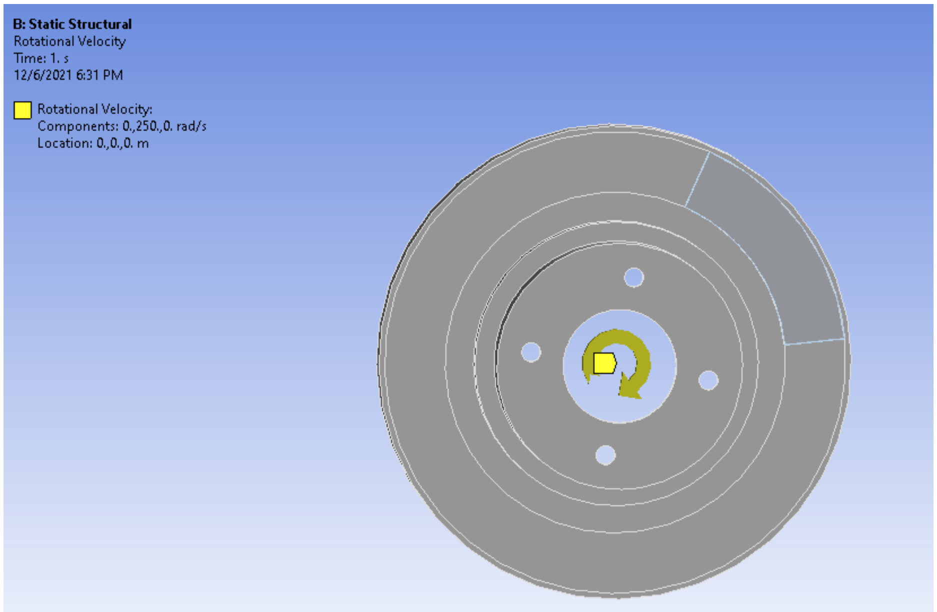


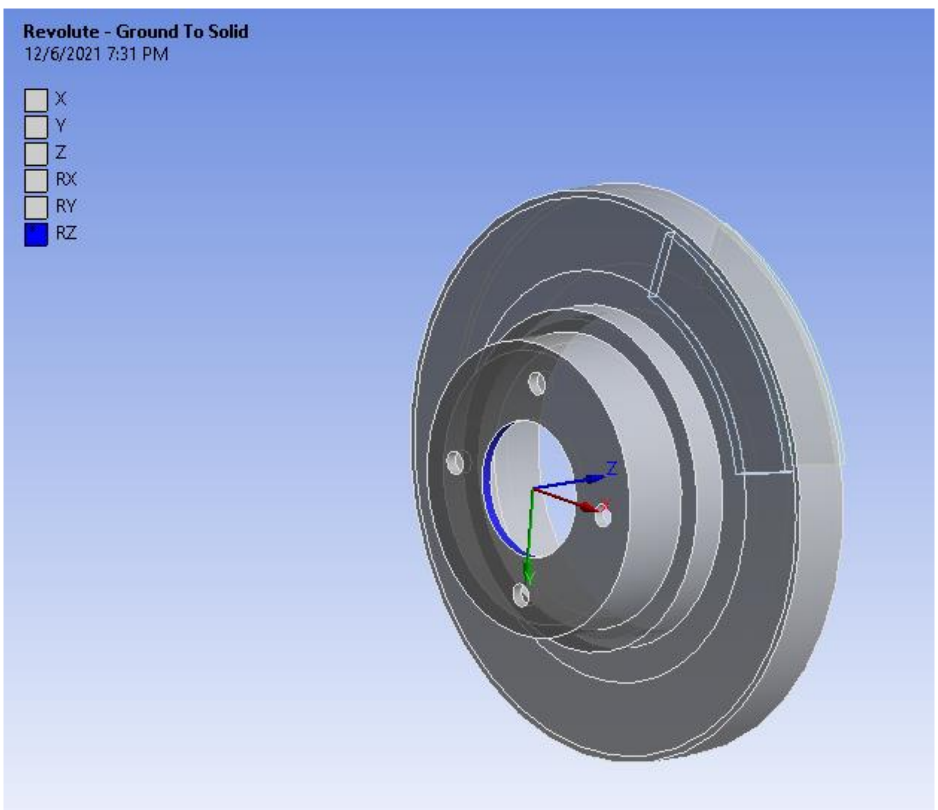
## **Material Assignment:**

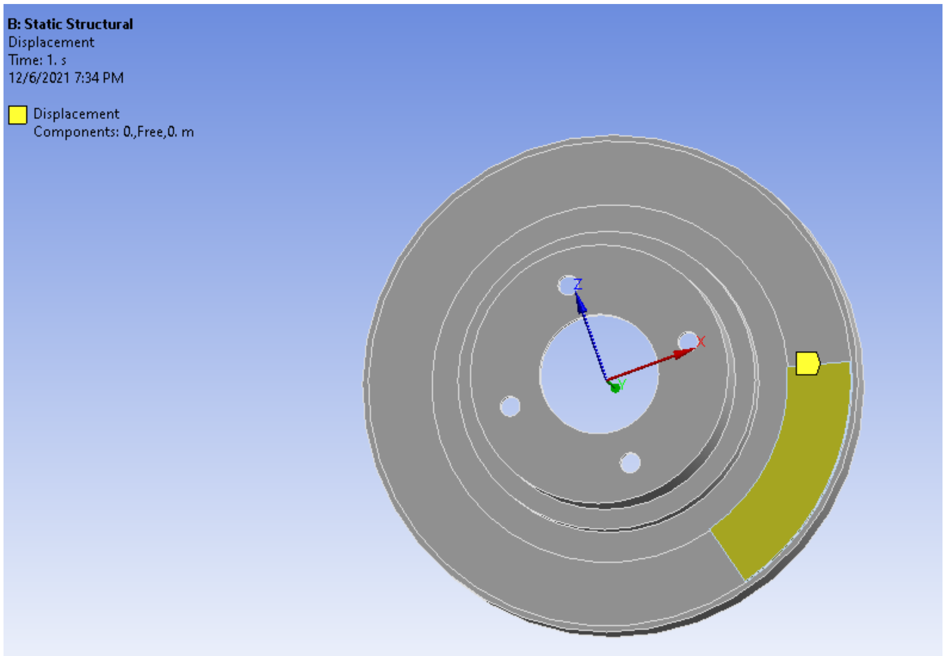


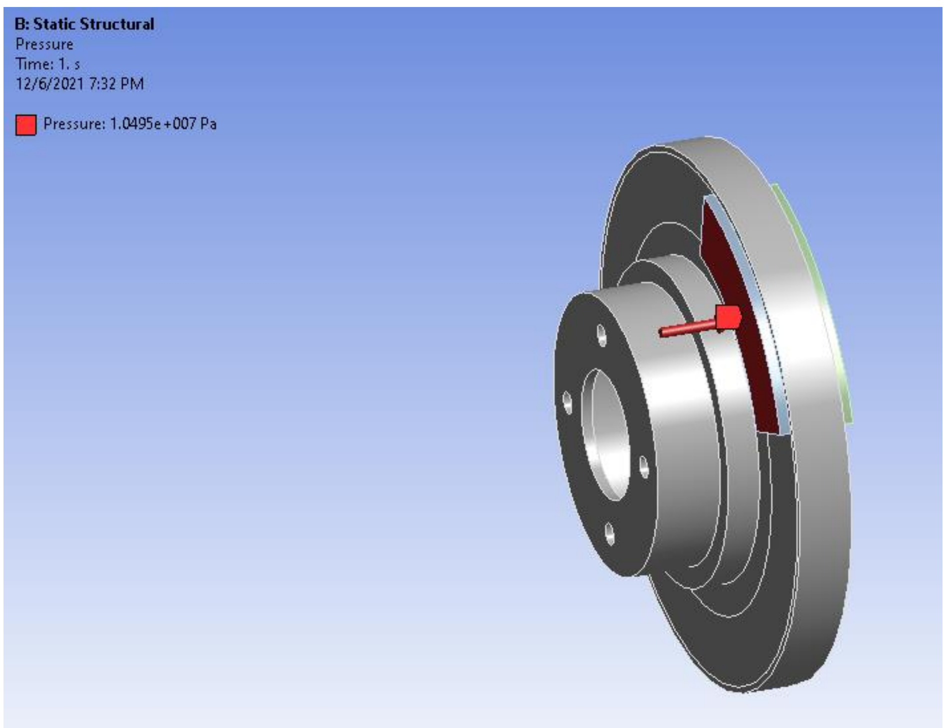
**Boundary Conditions:**

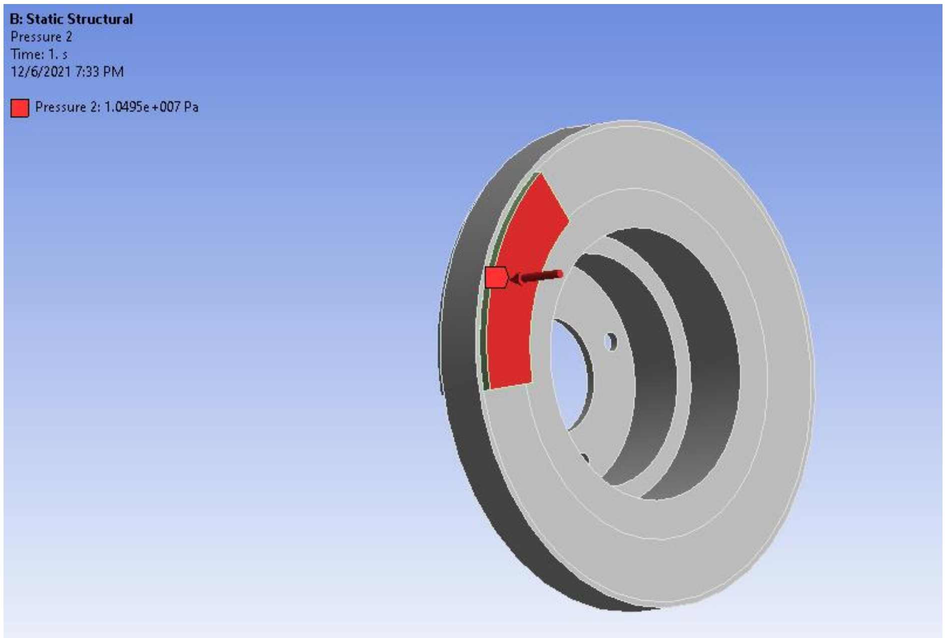


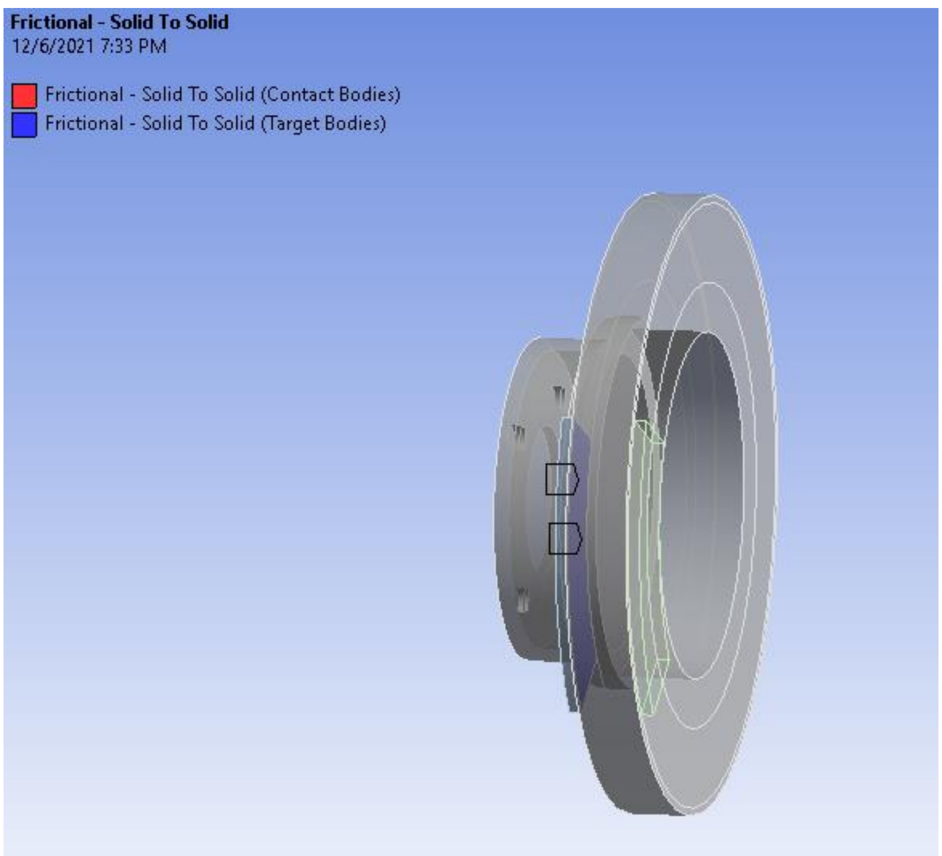



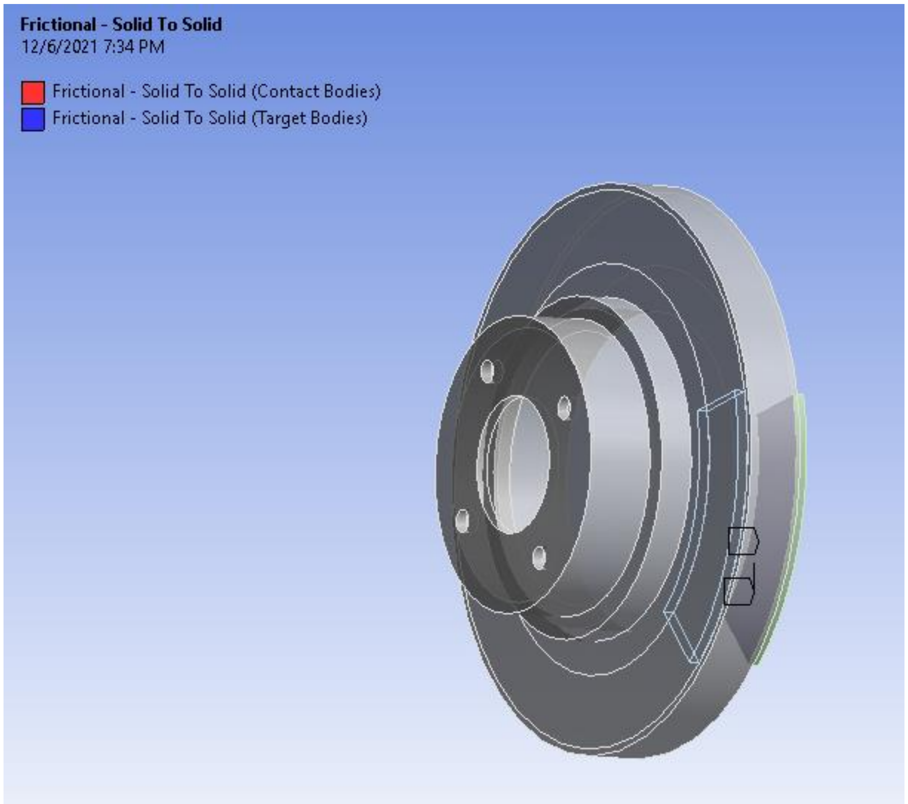



## Loads and Contacts




B: Static Structural
Pressure 2
Time: 1. s
12/6/2021 7:33 PM
Pressure 2: 1.0495e+007 Pa


Frictional - Solid To Solid
12/6/2021 7:33 PM
Frictional - Solid To Solid (Contact Bodies)
Frictional - Solid To Solid (Target Bodies)



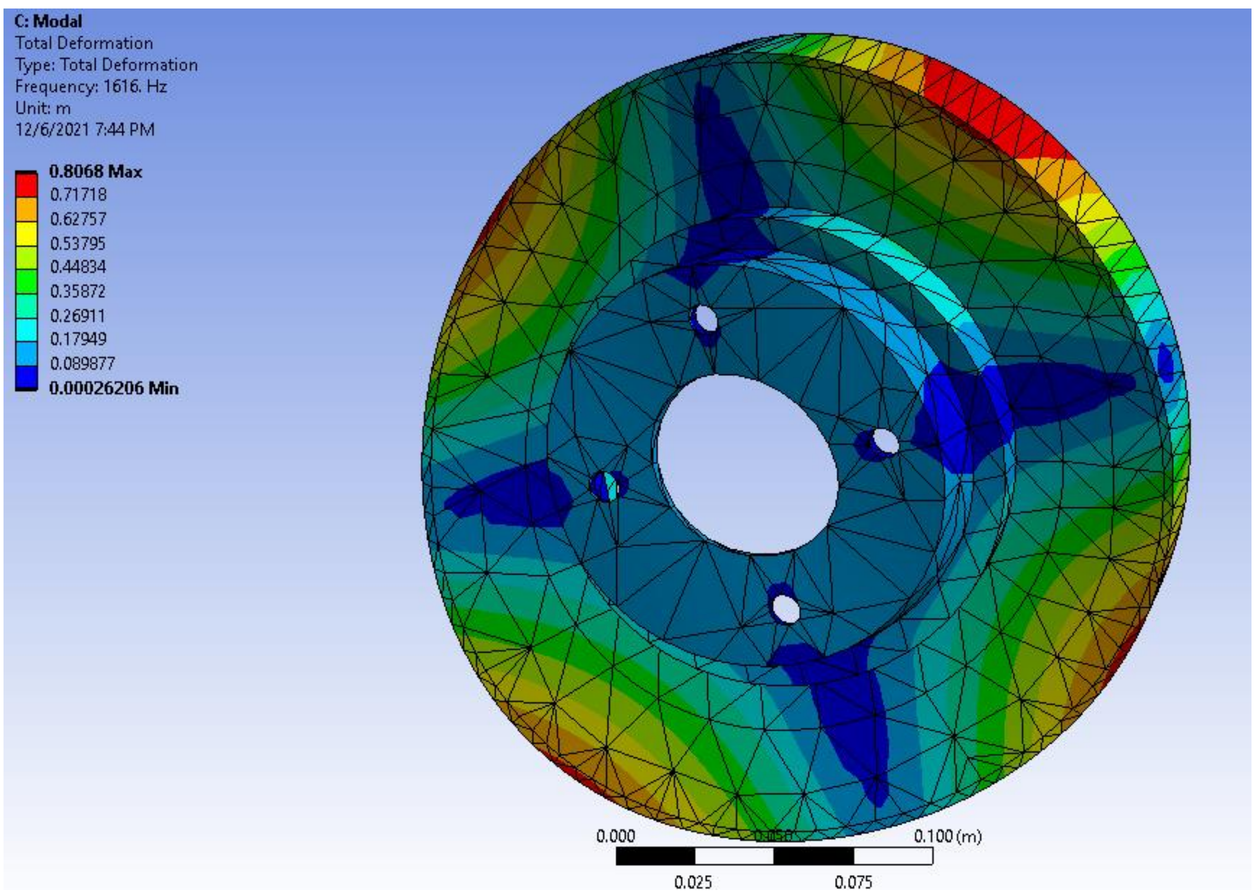

Details of "Equivalent Stress"

| | |
|---|---|
| Identifier | |
| Suppressed | No |
| **Integration Point Results** | |
| Display Option | Averaged |
| Average Across Bodies | No |
| **Results** | |
| Minimum | 1.9084e+005 Pa |
| P Maximum | 1.3503e+007 Pa |
| Average | 5.1069e+006 Pa |
| Minimum Occurs On | Solid |
| Maximum Occurs On | Solid |
| **Minimum Value Over Time** | |
| Minimum | 10879 Pa |
| Maximum | 1.9084e+005 Pa |
| **Maximum Value Over Time** | |
| Minimum | 2.3995e+006 Pa |
| Maximum | 1.3503e+007 Pa |
| **Information** | |

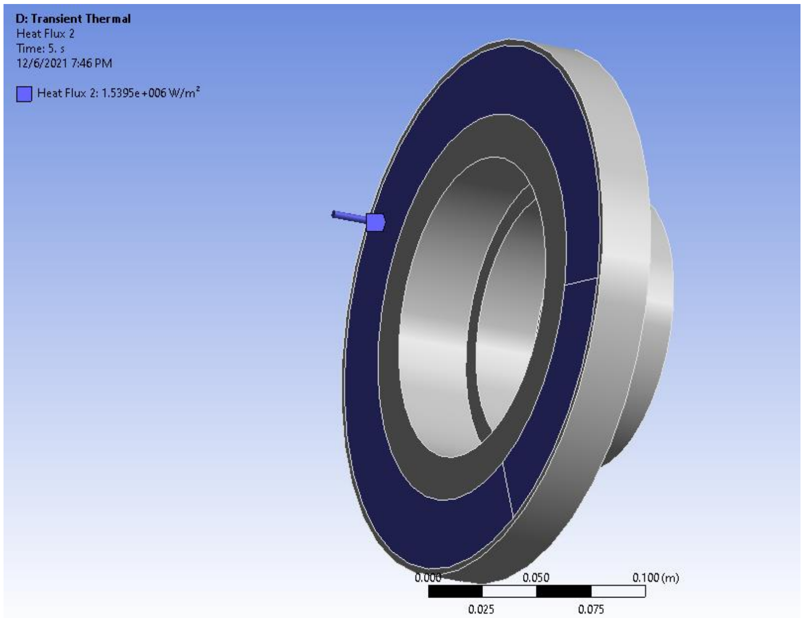
## Modal setup:

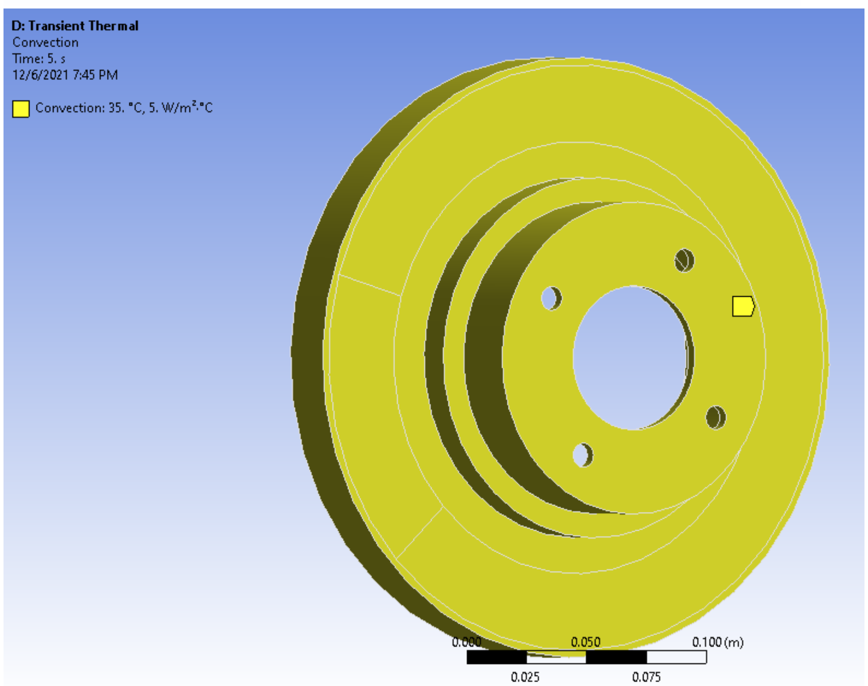
Details of "Total Deformation"

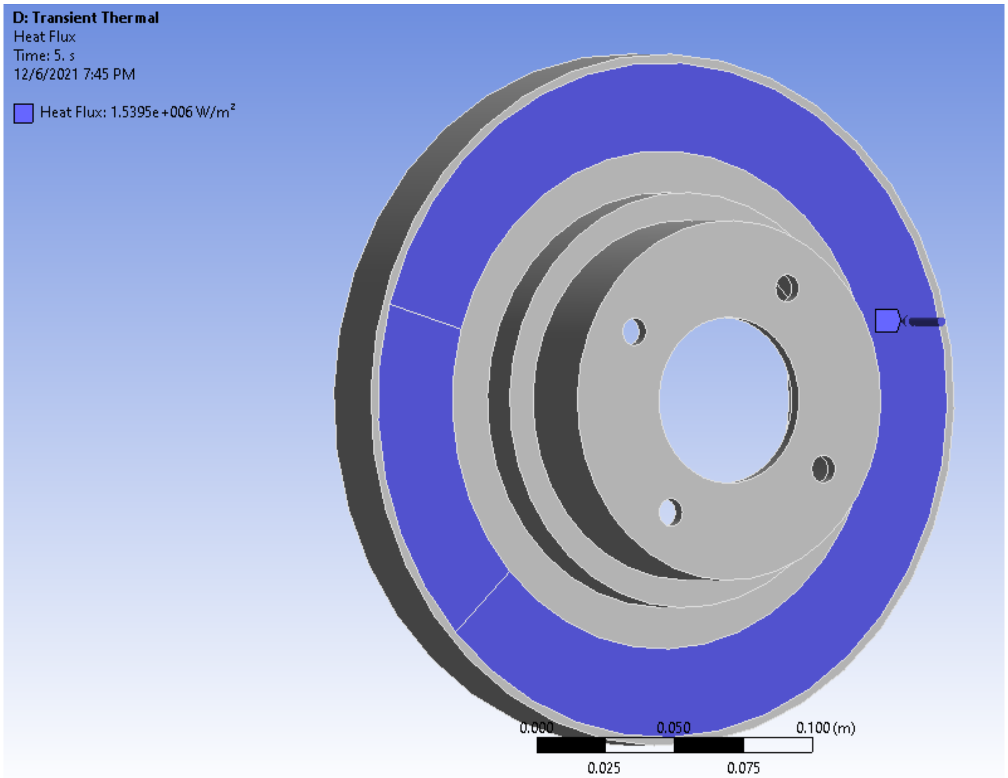
| | |
|---|---|
| **Scope** | |
| Scoping Method | Geometry Selection |
| Geometry | All Bodies |
| **Definition** | |
| Type | Total Deformation |
| Mode | 7. |
| Identifier | |
| Suppressed | No |
| **Results** | |
| Minimum | 2.6206e-004 m |
| Maximum | 0.8068 m |
| Average | 0.34276 m |
| Minimum Occurs On | Solid |
| Maximum Occurs On | Solid |
| **Information** | |
| Frequency | 1616. Hz |



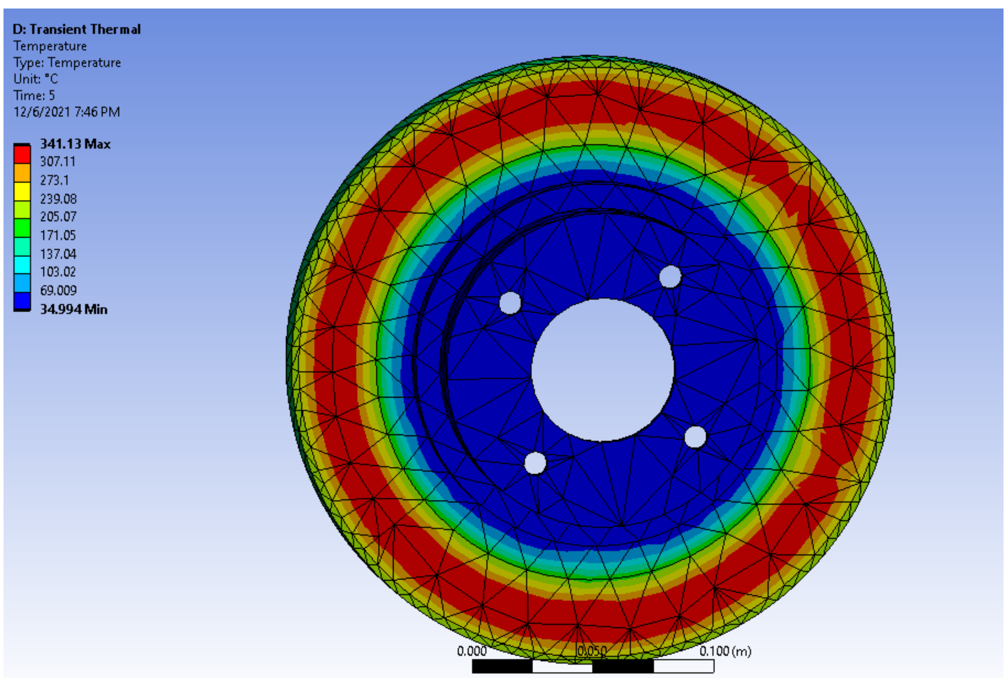
## Transient Thermal:





D: Transient Thermal
Heat Flux
Time: 5. s
12/6/2021 7:45 PM
Heat Flux: 1.5395e+006 W/m²
0.000
0.050
0.100 (m)
0.025
0.075

D: Transient Thermal
Temperature
Type: Temperature
Unit: °C
Time: 5
12/6/2021 7:46 PM
341.13 Max
307.11
273.1
239.08
205.07
171.05
137.04
103.02
69.009
34.994 Min
0.000
0.050
0.100 (m)
0.025
0.075

| 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 | 34.994 °C |
| P Maximum | 341.13 °C |
| Average | 145.71 °C |
| Minimum Occurs On | Solid |
| Maximum Occurs On | Solid |
| **Minimum Value Over Time** | |
| Minimum | 10.476 °C |
| Maximum | 34.995 °C |
| **Maximum Value Over Time** | |
| Minimum | 60.307 °C |

**Input Parameters:**

| Details View | |
|---|---|
| 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 |
| **Edges: 13** | |
| Line | Ln8 |
| Line | Ln9 |

## Design of Experiments:

The design of experiments method used is optimal space filling with user defined samples as was recommended in the tutorial and ran 50 samples to ensure a decent sample size was reached.

| | A | B |
|---|---|---|
| 1 | | Enabled |
| 2 | Design of Experiments | |
| 3 | Input Parameters | |
| 4 | Geometry (A1) | |
| 5 | P1 - rotor_thickness | ☑ |
| 6 | P2 - rotor_OD | ☑ |
| 7 | P3 - rotor_ID | ☑ |
| 8 | Output Parameters | |
| 9 | Static Structural (B1) | |
| 10 | P4 - Equivalent Stress Maximum | |
| 11 | Modal (C1) | |
| 12 | P5 - Total Deformation Reported Frequency | |
| 13 | Transient Thermal (D1) | |
| 14 | P6 - Temperature Maximum | |
| 15 | Charts | |
| 16 | Parameters Parallel | |
| 17 | Design Points vs Parameter | |

Properties of Outline A2: Design of Experiments

| | A | B |
|---|---|---|
| 1 | Property | Value |
| 2 | Design Points | |
| 3 | Preserve Design Points After DX Run | ☐ |
| 4 | Failed Design Points Management | |
| 5 | Number of Retries | 0 |
| 6 | Design of Experiments | |
| 7 | Design of Experiments Type | Optimal Space-Filling Design |
| 8 | Design Type | Max-Min Distance |
| 9 | Maximum Number Of Cycles | 10 |
| 10 | Samples Type | User-Defined Samples |
| 11 | Random Generator Seed | 0 |
| 12 | Number of Samples | 50 |
| 13 | Design Point Report | |
| 14 | Report Image | None |

Properties of Outline A5: P10 - rotor_thickness

| | A | B |
|---|---|---|
| 1 | Property | Value |
| 2 | ⊟ General | |
| 3 | Units | mm |
| 4 | Type | Design Variable |
| 5 | Classification | Continuous |
| 6 | ⊟ Values | |
| 7 | Lower Bound | 20 |
| 8 | Upper Bound | 30 |
| 9 | Allowed Values | Any |

Properties of Outline A6: P11 - 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 |
| 8 | Upper Bound | 150 |
| 9 | Allowed Values | Any |

Properties of Outline A7: P12 - rotor_ID

| | A | B |
|---|---|---|
| 1 | Property | Value |
| 2 | ⊟ General | |
| 3 | Units | mm |
| 4 | Type | Design Variable |
| 5 | Classification | Continuous |
| 6 | ⊟ Values | |
| 7 | Lower Bound | 61 |
| 8 | Upper Bound | 88 |
| 9 | Allowed Values | Any |

Table of Outline A2: Design Points of Design of Experiments

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | Name | P10 - rotor_thickness (mm) | P11 - rotor_OD (mm) | P12 - rotor_ID (mm) | P4 - Equivalent Stress Maximum (Pa) | P5 - Total Deformation Reported Frequency (Hz) | P6 - Temperature Maximum (C) |
| 2 | 1 | 24.1 | 124.52 | 83.95 | 1.416E+07 | 1412.5 | 341.36 |
| 3 | 2 | 22.9 | 140.2 | 78.55 | 1.1502E+07 | 1301.2 | 348.21 |
| 4 | 3 | 20.5 | 139.64 | 66.67 | 1.093E+07 | 1242.3 | 359.22 |
| 5 | 4 | 26.7 | 142.44 | 87.73 | 1.2207E+07 | 1206.3 | 341.06 |
| 6 | 5 | 20.9 | 130.12 | 65.05 | 1.1183E+07 | 1427.6 | 357.44 |
| 7 | 6 | 29.1 | 128.44 | 73.15 | 1.1854E+07 | 1663.1 | 333.97 |
| 8 | 7 | 23.7 | 143 | 86.65 | 1.1748E+07 | 1175.1 | 346.94 |
| 9 | 8 | 24.9 | 143.56 | 62.35 | 1.1607E+07 | 1232.3 | 340.91 |
| 10 | 9 | 23.5 | 131.8 | 76.93 | 1.1186E+07 | 1454.5 | 347.34 |
| 11 | 10 | 22.3 | 136.84 | 61.81 | 1.1145E+07 | 1280.4 | 349.8 |
| 12 | 11 | 23.1 | 126.2 | 63.97 | 1.1147E+07 | 1572.6 | 344.9 |
| 13 | 12 | 21.1 | 134.04 | 72.61 | 1.1106E+07 | 1423.9 | 355.75 |
| 14 | 13 | 29.9 | 135.16 | 78.01 | 1.24E+07 | 1495.8 | 336.72 |
| 15 | 14 | 26.1 | 129.56 | 72.07 | 1.1829E+07 | 1596.3 | 339.79 |
| 16 | 15 | 22.1 | 135.72 | 85.57 | 1.1459E+07 | 1252.6 | 351.44 |
| 17 | 16 | 25.3 | 148.04 | 82.33 | 1.1978E+07 | 1186 | 340.06 |
| 18 | 17 | 29.7 | 144.68 | 71.53 | 1.2839E+07 | 1374.8 | 331.87 |
| 19 | 18 | 28.7 | 146.36 | 81.79 | 1.29E+07 | 1262.2 | 333.75 |
| 20 | 19 | 20.3 | 129 | 79.09 | 1.1333E+07 | 1436.7 | 360.44 |
| 21 | 20 | 20.7 | 144.12 | 73.69 | 1.1393E+07 | 1219 | 360 |
| 22 | 21 | 20.1 | 137.4 | 80.17 | 1.1097E+07 | 1295.9 | 363.23 |
| 23 | 22 | 22.7 | 123.4 | 77.47 | 1.3737E+07 | 1555.4 | 349.34 |
| 24 | 23 | 28.1 | 141.88 | 62.89 | 1.2509E+07 | 1362.8 | 335.76 |
| 25 | 24 | 21.3 | 125.64 | 70.99 | 1.1443E+07 | 1597.1 | 349.78 |
| 26 | 25 | 24.5 | 148.6 | 67.75 | 1.1406E+07 | 1188.8 | 343.22 |
| 27 | 26 | 24.7 | 132.92 | 86.11 | 1.2143E+07 | 1305.1 | 345.3 |
| 28 | 27 | 26.5 | 131.24 | 79.63 | 1.1625E+07 | 1465.4 | 340.15 |
| 29 | 28 | 25.9 | 126.76 | 64.51 | 1.1324E+07 | 1645 | 337.45 |
| 30 | 29 | 25.5 | 134.6 | 61.27 | 1.1325E+07 | 1419.1 | 338.56 |
| 31 | 30 | 22.5 | 149.16 | 76.39 | 1.1435E+07 | 1160.4 | 350.32 |
| 32 | 31 | 21.5 | 145.8 | 83.41 | 1.1354E+07 | 1159.2 | 357 |
| 33 | 32 | 28.3 | 132.36 | 63.43 | 1.1892E+07 | 1574 | 335.16 |
| 34 | 33 | 23.9 | 133.48 | 68.29 | 1.1172E+07 | 1477.5 | 345.54 |
| 35 | 34 | 29.5 | 136.28 | 68.83 | 1.219E+07 | 1549.7 | 338.23 |
| 36 | 35 | 23.3 | 141.32 | 69.91 | 1.1382E+07 | 1321.4 | 346.9 |
| 37 | 36 | 28.5 | 125.08 | 66.13 | 1.3862E+07 | 1771.3 | 334.73 |
| 38 | 37 | 28.9 | 138.52 | 84.49 | 1.2403E+07 | 1327.6 | 335.61 |
| 39 | 38 | 29.3 | 127.32 | 81.25 | 1.2494E+07 | 1521.7 | 334.28 |
| 40 | 39 | 24.3 | 122.84 | 70.45 | 1.4286E+07 | 1719.6 | 343.7 |
| 41 | 40 | 27.1 | 122.28 | 74.23 | 1.2748E+07 | 1725 | 344.42 |
| 42 | 41 | 25.1 | 145.24 | 74.77 | 1.1509E+07 | 1276.5 | 340.18 |
| 43 | 42 | 27.5 | 147.48 | 67.21 | 1.2635E+07 | 1278 | 335.06 |
| 44 | 43 | 26.9 | 123.96 | 82.87 | 1.2595E+07 | 1479.1 | 339.31 |
| 45 | 44 | 21.7 | 127.88 | 85.03 | 1.1357E+07 | 1334.5 | 354.49 |
| 46 | 45 | 27.7 | 130.68 | 87.19 | 1.2322E+07 | 1348 | 338.82 |
| 47 | 46 | 26.3 | 137.96 | 69.37 | 1.1432E+07 | 1445.7 | 336.87 |
| 48 | 47 | 27.3 | 149.72 | 75.31 | 1.2222E+07 | 1235.4 | 335.16 |
| 49 | 48 | 27.9 | 140.76 | 75.85 | 1.2083E+07 | 1393.2 | 334.37 |
| 50 | 49 | 21.9 | 146.92 | 65.59 | 1.1289E+07 | 1125 | 352.37 |
| 51 | 50 | 25.7 | 139.08 | 80.71 | 1.1653E+07 | 1334.8 | 339.77 |

## Response Surface:

For the response surface algorithm I chose kriging because I was not worried about the computation times as my sample size is not particularly large and I wanted my model to fit right through my data points because I trusted I followed the tutorial and got the simulation results I needed

Properties of Outline A2: Response Surface

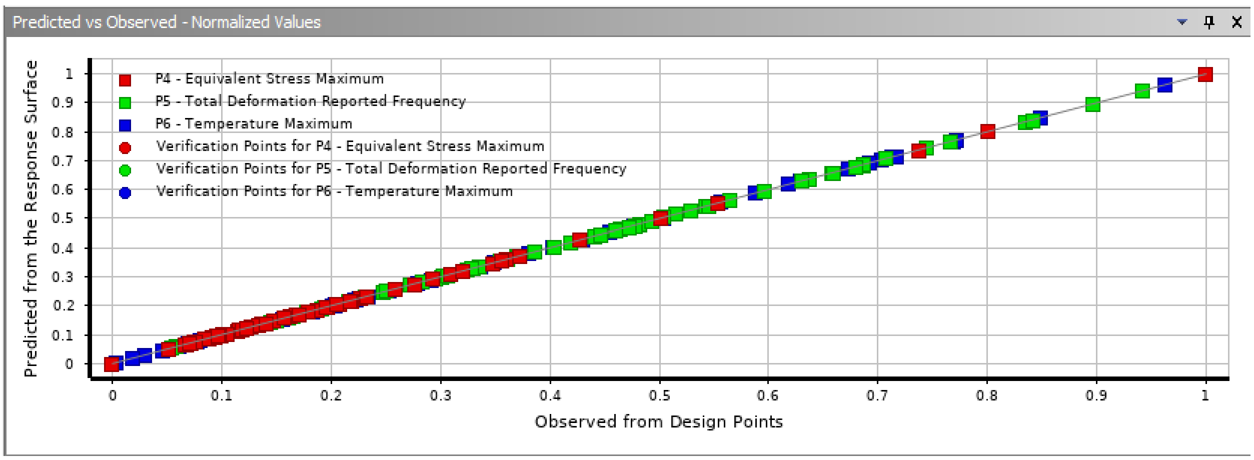
| | A | B |
|---|---|---|
| 1 | Property | Value |
| 2 | Design Points | |
| 3 | Preserve Design Points After DX Run | ☐ |
| 4 | Failed Design Points Management | |
| 5 | Number of Retries | 0 |
| 6 | Meta Model | |
| 7 | Response Surface Type | Kriging |
| 8 | Kernel Variation Type | Variable |
| 9 | Refinement | |
| 10 | Refinement Type | Manual |
| 11 | Verification Points | |
| 12 | Generate Verification Points | ☑ |
| 13 | Number of Verification Points | 17 |
| 14 | Design Point Report | |
| 15 | Report Image | None |

Table of Outline A20: Verification Points

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | Name | P10 - rotor_thickness (mm) | P11 - rotor_OD (mm) | P12 - rotor_ID (mm) | P4 - Equivalent Stress Maximum (Pa) | P5 - Total Deformation Reported Frequency (Hz) | P6 - Temperature Maximum (C) |
| 2 | 1 | 29.925 | 149.85 | 87.874 | 1.8404E+07 | 1164.4 | 335.46 |
| 3 | 2 | 20.316 | 149.54 | 61.307 | 1.0358E+07 | 1026.8 | 351.24 |
| 4 | 3 | 20.936 | 122.03 | 62.297 | 1.1697E+07 | 1590.7 | 366.35 |
| 5 | 4 | 29.978 | 149.53 | 62.143 | 1.3563E+07 | 1272.9 | 332.05 |
| 6 | 5 | 29.86 | 122.13 | 62.047 | 1.3372E+07 | 1856 | 340.96 |
| 7 | 6 | 29.706 | 123.18 | 71.086 | 1.2739E+07 | 1808.3 | 333.08 |
| 8 | 7 | 20.054 | 147.81 | 87.319 | 2.126E+07 | 1075.8 | 363.08 |
| 9 | 8 | 20.238 | 122.05 | 75.329 | 1.1426E+07 | 1613.6 | 370.97 |
| 10 | 9 | 26.193 | 122.02 | 86.344 | 1.4418E+07 | 1397.3 | 346.08 |
| 11 | 10 | 29.939 | 149.8 | 75.744 | 1.3185E+07 | 1281.3 | 332.67 |
| 12 | 11 | 29.024 | 122.2 | 87.649 | 1.5824E+07 | 1409.4 | 342.14 |
| 13 | 12 | 20.027 | 122.27 | 86.828 | 1.4248E+07 | 1299.7 | 372.45 |
| 14 | 13 | 20.266 | 140.32 | 87.81 | 1.9092E+07 | 1152.2 | 360.83 |
| 15 | 14 | 20.09 | 149.19 | 78.61 | 1.12E+07 | 1112.5 | 363.23 |
| 16 | 15 | 22.87 | 149.57 | 87.767 | 1.6393E+07 | 1072.1 | 349.32 |
| 17 | 16 | 27.42 | 149.16 | 87.538 | 1.5018E+07 | 1146.8 | 337.34 |
| 18 | 17 | 20.204 | 149.57 | 69.85 | 1.1134E+07 | 1110 | 360.99 |
| * | New Verification Point | | | | | | |

Table of Schematic E3: Response Surface

| | A | B | C | D |
|---|---|---|---|---|
| 1 | | P4 - Equivalent Stress Maximum | P5 - Total Deformation Reported Frequency | P6 - Temperature Maximum |
| 2 | Coefficient of Determination (Best Value = 1) | | | |
| 3 | Learning Points | 1 | 1 | 1 |
| 4 | Root Mean Square Error (Best Value = 0) | | | |
| 5 | Learning Points | 0.19662 | 2.148E-05 | 3.1029E-07 |
| 6 | Verification Points | 0.158 | 1.7628E-05 | 3.8641E-07 |
| 7 | Relative Maximum Absolute Error (Best Value = 0%) | | | |
| 8 | Learning Points | 0 | 0 | 0 |
| 9 | Verification Points | 0 | 0 | 0 |
| 10 | Relative Average Absolute Error (Best Value = 0%) | | | |
| 11 | Learning Points | 0 | 0 | 0 |
| 12 | Verification Points | 0 | 0 | 0 |



## Optimization:

For my optimization algorithm I did a combination of SQP and MOGA across multiple runs to find the optimum result. I used MOGA for the run where I was running all three output parameters as optimization objectives and then SQP for when I was running one objective and multiple constraints.

### 1.Run for all 3 output parameters

Table of Schematic F4: Optimization

| | A | B | C | D |
|---|---|---|---|---|
| 1 | ⊟ Optimization Study | | | |
| 2 | Minimize P4 | Goal, Minimize P4 (Default importance) | | |
| 3 | Maximize P5 | Goal, Maximize P5 (Default importance) | | |
| 4 | Minimize P6 | Goal, Minimize P6 (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 | P10 - rotor_thickness (mm) | 24.448 | 24.436 | 24.424 |
| 12 | P11 - rotor_OD (mm) | 135.26 | 135.09 | 135.57 |
| 13 | P12 - rotor_ID (mm) | 65.402 | 65.464 | 65.537 |
| 14 | P4 - Equivalent Stress Maximum (Pa) | 1.0217E+07 | 1.0216E+07 | 1.0214E+07 |
| 15 | P5 - Total Deformation Reported Frequency (Hz) | ★★★ 1410.2 | ★★★ 1414.6 | ★★★ 1404.9 |
| 16 | P6 - Temperature Maximum (C) | ✕✕✕ 342.39 | ✕✕✕ 342.46 | ✕✕✕ 342.5 |

Design Changes:

Rotor Thickness: 25 mm → 24.448 mm

Outer Diameter: 125 mm → 135.26 mm

Inner Diameter:  75 mm → 65.402 mm

Objective Improvements:

Maximum Von-Mises stress: 1.3503e+007 Pa →1.0217e+007

Percent improvement: 24.33%

Total Deformation Reported Frequency: 1616 Hz → 1396.7 Hz

Percent Improvement: -13.5%

Temperature Maximum: 341.13 C ➔ 342.39 C

Percent Improvement: -0.37%

Percent Improvement overall: 10.46%

## 2.Run to minimize stress with Freq > 1200 Hz and Temp < 350 C

Table of Schematic F4: Optimization

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | Optimization Study | | | | |
| 2 | Minimize P4 | Goal, Minimize P4 (Default importance) | | | |
| 3 | P5 >= 1200 Hz | Strict Constraint, P5 values greater than or equals to 1200 Hz (Default importance) | | | |
| 4 | P6 <= 350 C | Strict Constraint, P6 values less than or equals to 350 C (Default importance) | | | |
| 5 | Optimization Method | | | | |
| 6 | MISQP | The MISQP method (Mixed-Integer Sequential Quadratic Programming) solves mixed-integer nonlinear programming problems by a modified sequential quadratic programming (SQP) method . Under the assumption that integer variables have a smooth influence on the model functions, i .e., that function values do not change drastically when in- or decrementing an integer variable, successive quadratic approximations are applied. It supports a single objective and multiple constraints. The starting point must be specified to determine the region of the design space to explore. | | | |
| 7 | Configuration | Approximate derivatives by Central difference and find 3 candidates in a maximum of 20 iterations. | | | |
| 8 | Status | Converged after 69 evaluations. | | | |
| 9 | Candidate Points | | | | |
| 10 | | Starting Point | Candidate Point 1 | Candidate Point 2 | Candidate Point 3 |
| 11 | P10 - rotor_thickness (mm) | 25 | 24.062 | 24.018 | 23.906 |
| 12 | P11 - rotor_OD (mm) | 136 | 136.44 | 136.7 | 137.14 |
| 13 | P12 - rotor_ID (mm) | 74.5 | 75.752 | 75.67 | 75.911 |
| 14 | P4 - Equivalent Stress Maximum (Pa) | 1.0773E+07 | 1.0377E+07 | 1.0379E+07 | 1.039E+07 |
| 15 | P5 - Total Deformation Reported Frequency (Hz) | 1433.2 | 1400.5 | 1396.3 | 1385.5 |
| 16 | P6 - Temperature Maximum (C) | 341 | 344.39 | 344.4 | 344.73 |

Design Changes:

Rotor Thickness: 25 mm ➔ 24.062 mm

Outer Diameter: 125 mm ➔ 136.44 mm

Inner Diameter:  75 mm ➔ 75.752 mm

Objective Improvements:

Maximum Von-Mises stress: 1.3503e+007 Pa ➔1.0773e+007

Percent improvement: 20.21%

Total Deformation Reported Frequency: 1616 Hz ➔ 1433.2 Hz

Percent Improvement: -11.3%

Temperature Maximum: 341.13 C ➔ 341 C

Percent Improvement: 0.00%

Percent Improvement Total: 8.91%

## 3.Run to maximize Frequency with Stress < 1.5e+7 Pa and Temp < 350 C

Table of Schematic F4: Optimization

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | ⊟ Optimization Study | | | | |
| 2 | Maximize P5 | Goal, Maximize P5 (Default importance) | | | |
| 3 | P4 <= 1.5E+07 Pa | Strict Constraint, P4 values less than or equals to 1.5E+07 Pa (Default importance) | | | |
| 4 | P6 <= 370 C | Strict Constraint, P6 values less than or equals to 370 C (Default importance) | | | |
| 5 | ⊟ Optimization Method | | | | |
| 6 | MISQP | The MISQP method (Mixed-Integer Sequential Quadratic Programming) solves mixed-integer nonlinear programming problems by a modified sequential quadratic programming (SQP) method. Under the assumption that integer variables have a smooth influence on the model functions, i.e., that function values do not change drastically when in- or decrementing an integer variable, successive quadratic approximations are applied. It supports a single objective and multiple constraints. The starting point must be specified to determine the region of the design space to explore. | | | |
| 7 | Configuration | Approximate derivatives by Central difference and find 3 candidates in a maximum of 20 iterations. | | | |
| 8 | Status | Converged after 39 evaluations. | | | |
| 9 | ⊟ Candidate Points | | | | |
| 10 | | Starting Point | Candidate Point 1 | Candidate Point 2 | Candidate Point 3 |
| 11 | P10 - rotor_thickness (mm) | 25 | 30 | 30 | 28.14 |
| 12 | P11 - rotor_OD (mm) | 136 | 122 | 122 | 122 |
| 13 | P12 - rotor_ID (mm) | 74.5 | 65.972 | 63.76 | 62.282 |
| 14 | P4 - Equivalent Stress Maximum (Pa) | 1.0773E+07 | 1.4576E+07 | 1.3774E+07 | 1.298E+07 |
| 15 | P5 - Total Deformation Reported Frequency (Hz) | 1433.2 | 1880.7 | 1873.3 | 1804.7 |
| 16 | P6 - Temperature Maximum (C) | 341 | 336.74 | 339.31 | 342.72 |

Design Changes:

Rotor Thickness: 25 mm → 30 mm

Outer Diameter: 125 mm → 122 mm

Inner Diameter: 75 mm → 65.972 mm

Objective Improvements:

Maximum Von-Mises stress: 1.3503e+007 Pa →1.4576e+007

Percent improvement: -7.94%

Total Deformation Reported Frequency: 1616 Hz → 1876.2 Hz

Percent Improvement: 16.44%

Temperature Maximum: 341.13 C → 338.28 C

Percent Improvement: 1.29%

Percent Improvement Total: 9.79%

# 4.Run to Minimize Temp with Stress < 1.4e+7 Pa and Freq >1200 Hz

Table of Schematic F4: Optimization

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | Optimization Study | | | | |
| 2 | Minimize P6; P6 <= 370 C | Goal, Minimize P6 (Default importance); Strict Constraint, P6 values less than or equals to 370 C (Default importance) | | | |
| 3 | P5 >= 1200 Hz | Strict Constraint, P5 values greater than or equals to 1200 Hz (Default importance) | | | |
| 4 | P4 <= 1.4E+07 Pa | Strict Constraint, P4 values less than or equals to 1.4E+07 Pa (Default importance) | | | |
| 5 | Optimization Method | | | | |
| 6 | MISQP | The MISQP method (Mixed-Integer Sequential Quadratic Programming) solves mixed-integer nonlinear programming problems by a modified sequential quadratic programming (SQP) method. Under the assumption that integer variables have a smooth influence on the model functions, i.e., that function values do not change drastically when in- or decrementing an integer variable, successive quadratic approximations are applied. It supports a single objective and multiple constraints. The starting point must be specified to determine the region of the design space to explore. | | | |
| 7 | Configuration | Approximate derivatives by Central difference and find 3 candidates in a maximum of 20 iterations. | | | |
| 8 | Status | Converged after 63 evaluations. | | | |
| 9 | Candidate Points | | | | |
| 10 | | Starting Point | Candidate Point 1 | Candidate Point 2 | Candidate Point 3 |
| 11 | P10 - rotor_thickness (mm) | 25 | 29.928 | 30 | 30 |
| 12 | P11 - rotor_OD (mm) | 136 | 138.74 | 138.51 | 138.19 |
| 13 | P12 - rotor_ID (mm) | 74.5 | 69.867 | 71.383 | 72.619 |
| 14 | P4 - Equivalent Stress Maximum (Pa) | ★★★ 1.0773E+07 | ★★★ 1.2225E+07 | ★★★ 1.2214E+07 | ★★★ 1.22E+07 |
| 15 | P5 - Total Deformation Reported Frequency (Hz) | ★★★ 1433.2 | ★★★ 1503.8 | ★★★ 1498.2 | ★★★ 1495.3 |
| 16 | P6 - Temperature Maximum (C) | - 341 | - 332.2 | - 332.9 | - 333.45 |

Design Changes:

Rotor Thickness: 25 mm → 29.928 mm

Outer Diameter: 125 mm → 138.74 mm

Inner Diameter: 75 mm → 69.867 mm

Objective Improvements:

Maximum Von-Mises stress: 1.3503e+007 Pa →1.2225e+007

Percent improvement: 9.46%

Total Deformation Reported Frequency: 1616 Hz → 1503.8 Hz

Percent Improvement: -6.94%

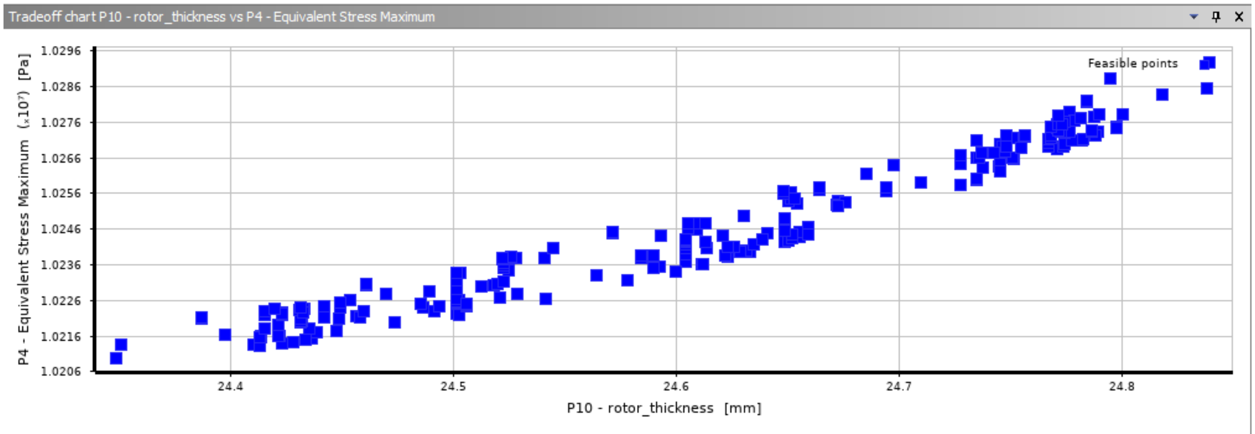
Temperature Maximum: 341.13 C → 332.2 C

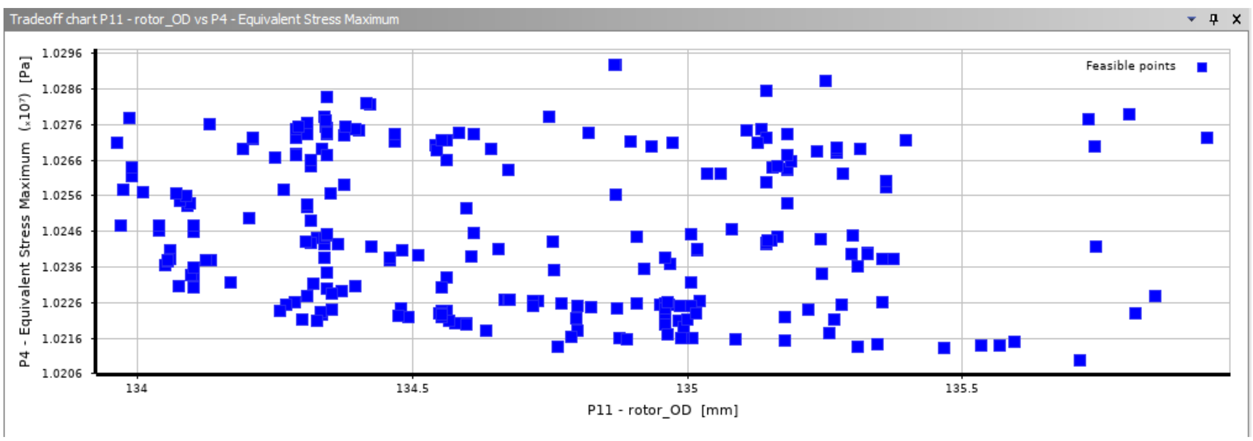
Percent Improvement: 2.69%

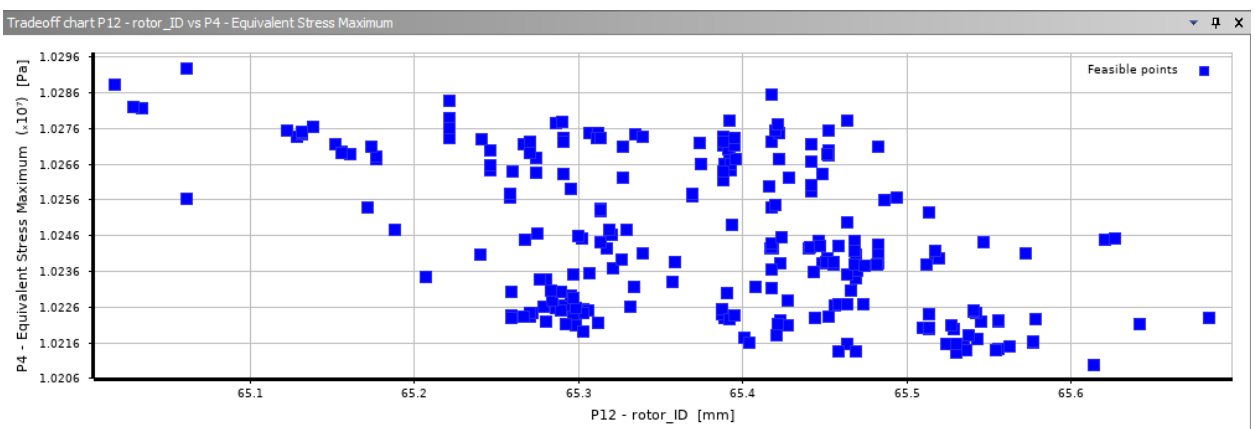
Percent Improvement Total: 5.21%

## Trade Offs:

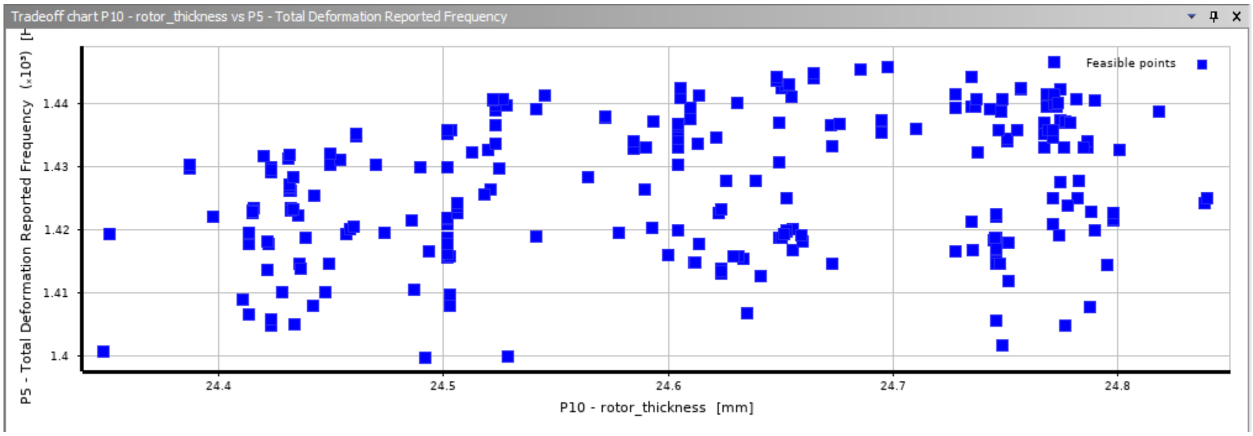
### Equivalent stress Maximum:

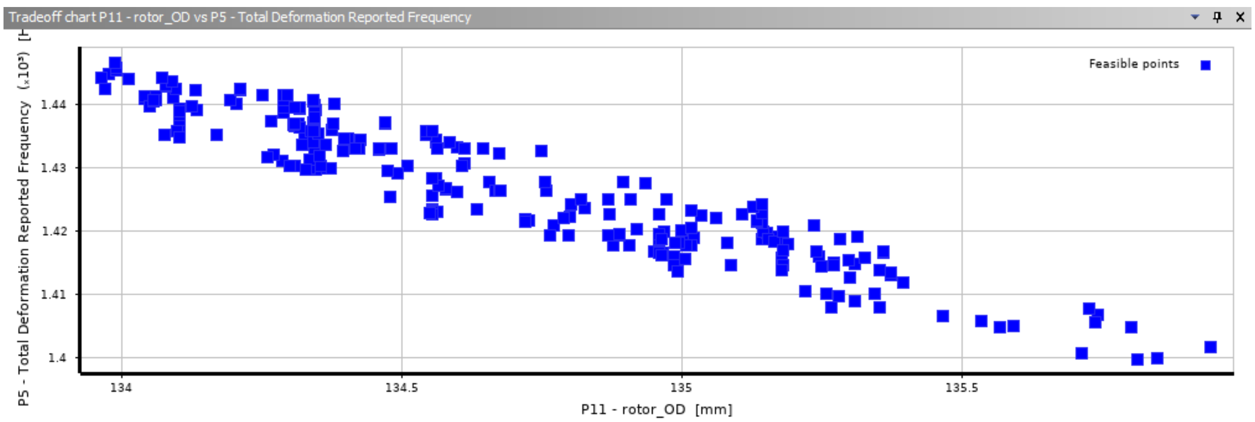


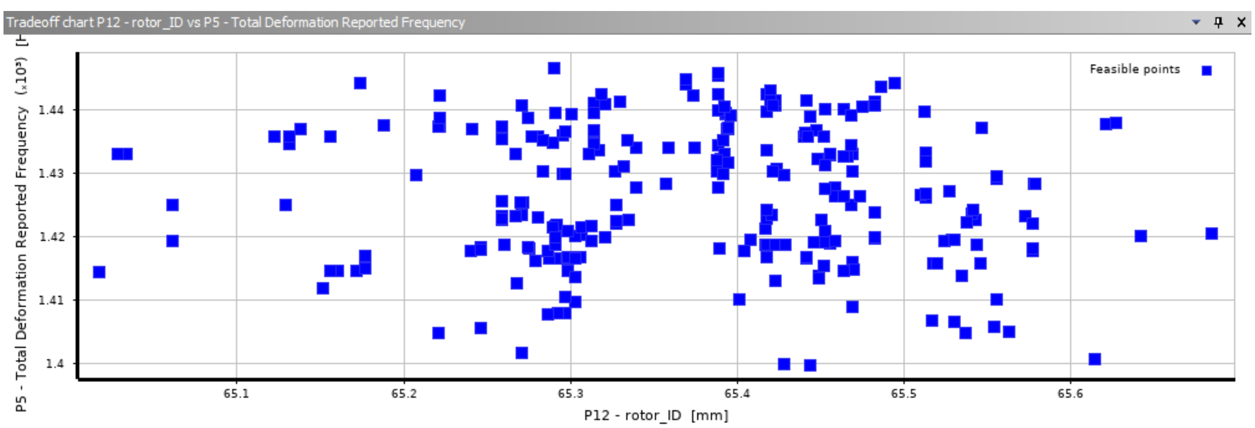



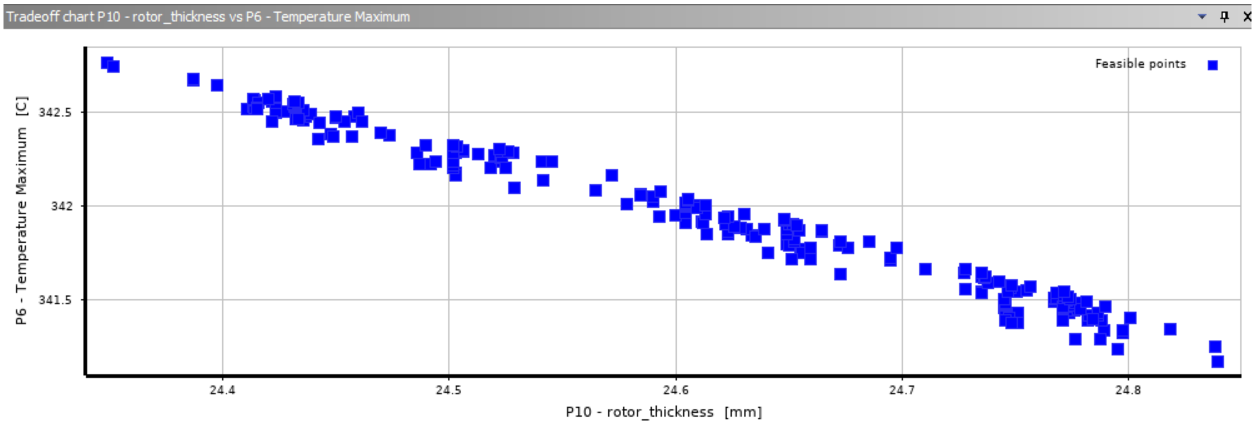
Total Deformation Reported Frequency:

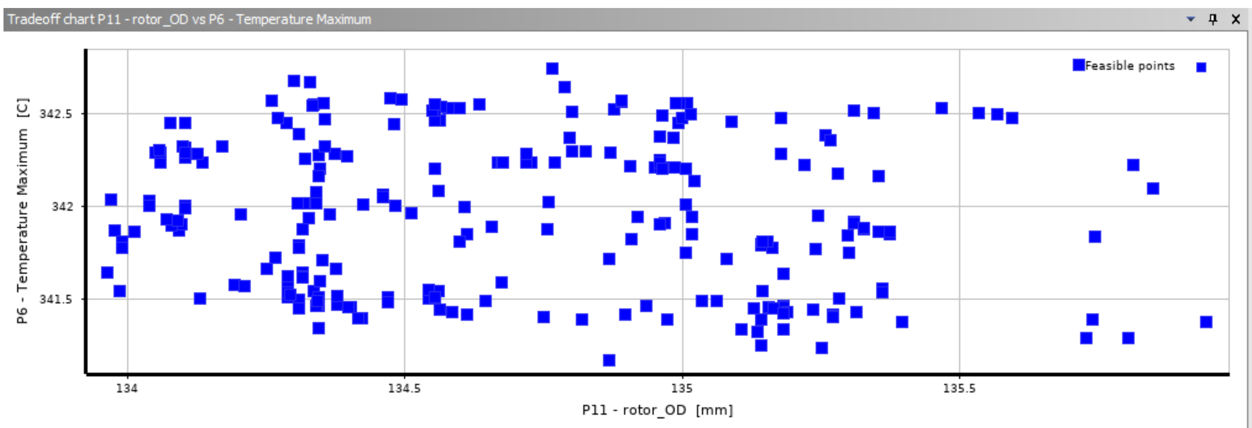


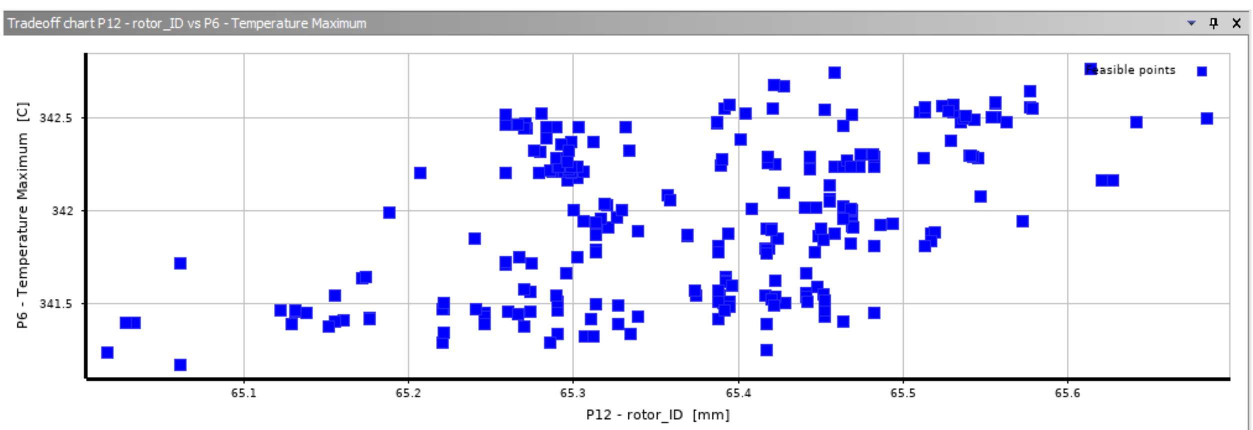



Temperature Maximum:



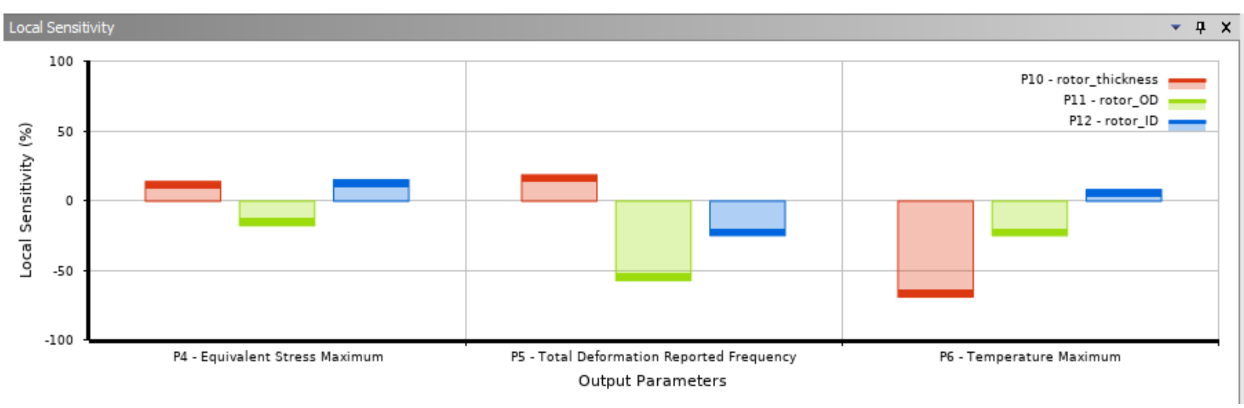
## Analysis

### Pareto Curve/ Trade-offs:

When optimizing for multiple objectives there will more than likely be trade-offs associated with the design. The trade-offs for these objectives are outlined in the above pareto curves. Here we can see that as we increase the rotor thickness the maximum temperature reached by the rotor decreases however the maximum Von-Mises stress experienced increases, furthermore the first modal frequency seems to have little to no correlation when it come to the thickness of the brake disc. On the subject of rotor outer diameter, it seems that the first modal frequency has a very strong correlation, as the outer diameter increases the first frequency decreases, and the other objectives remain unaffected. Lastly for the rotor inner diameter there seems to be a very slight increase in the maximum temperature and a very slight decrease in the maximum von mises stress.

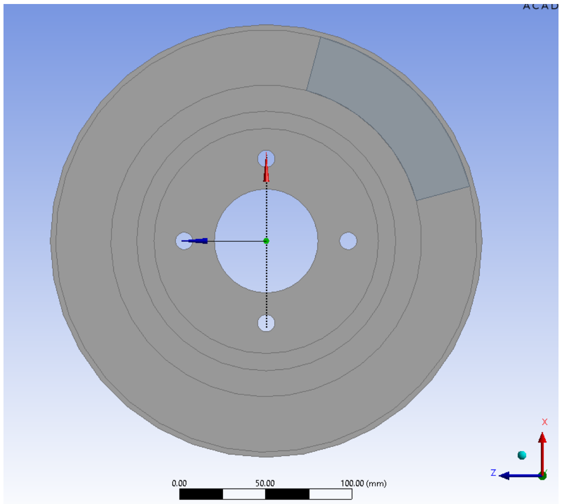
### Sensitivity:

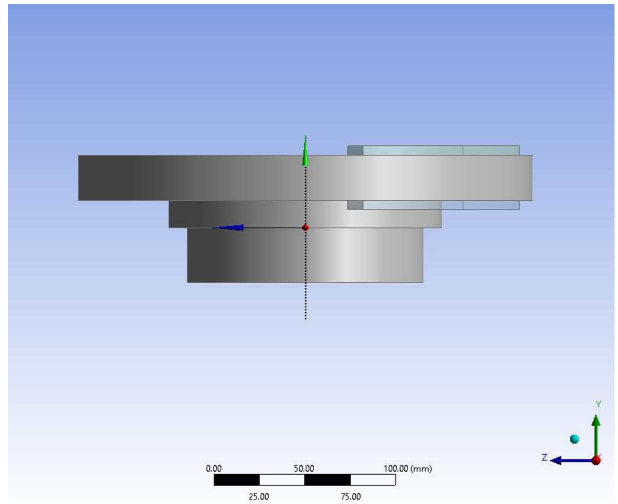
The below graph shows the sensitivity or how much a change in the input parameter effects the output parameter we can see that equivalent stress is not particularly sensitive to any one input parameter however the first modal frequency has a high sensitivity to the rotor outer diameter meaning small changes in the outer diameter can affect the output of the first modal frequency significantly this correlation was also outlined in the pareto curves discussed above. Another section of this graph that stands out is the maximum temperature where a change in the thickness has the most effect by far on the rotor temperature and this was also outlined in the above pareto curves. The variables with the most impact in order are rotor thickness, outer diameter then inner diameter.



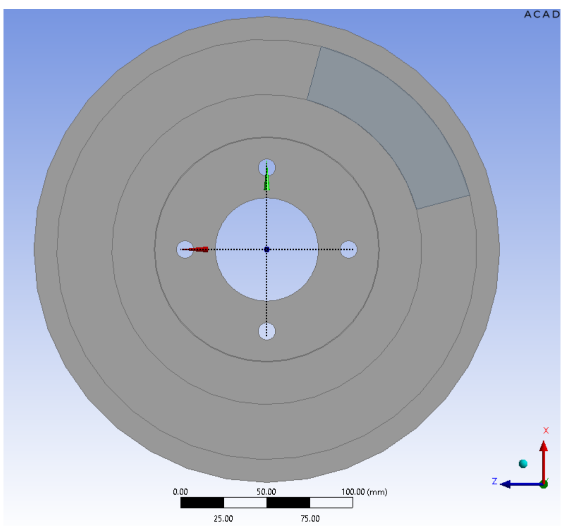
**Optimal Design:**

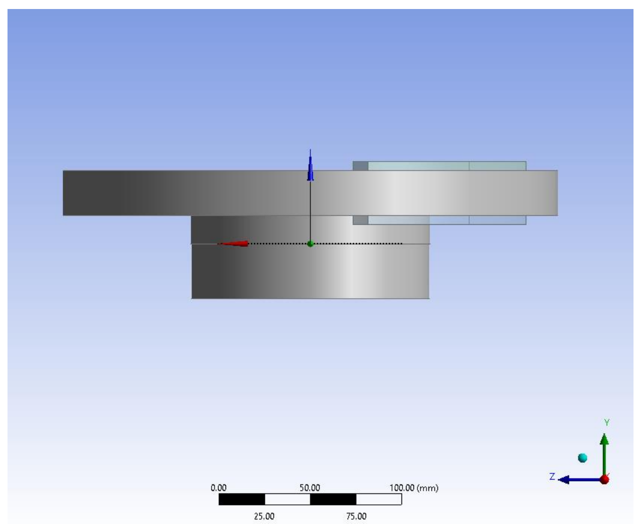
Initial Geometry




Final Geometry




Design Changes:

Rotor Thickness: 25 mm ➔ 24.448 mm

Outer Diameter: 125 mm ➔ 135.26 mm

Inner Diameter:  75 mm ➔ 65.402 mm

Objective Improvements:

Maximum Von-Mises stress: 1.3503e+007 Pa ➔1.0217e+007

Percent improvement: 24.33%

Total Deformation Reported Frequency: 1616 Hz ➔ 1396.7 Hz

Percent Improvement: -13.5%

Temperature Maximum: 341.13 C ➔ 342.39 C

Percent Improvement: -0.37%

Percent Improvement overall: 10.46%

Overall, this design seems feasible the only issue that might arise is that during manufacturing the small lip that exists between the main barrel where the rotor is mounted, and the inner diameter may be more expensive than it is worth to produce or potentially the rotor may be too large to fit inside of the wheel of the car.