Project 2: Optimization of Brake Disc Geometry

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Problem setup:

The **objectives** of the problem are summarized as follows:

1. Optimize the design of a brake disc for emergency braking with minimal volume
2. Minimize the maximum stress in the brake disc
3. Maximize the first natural frequency of the brake disc
4. Minimize the maximum temperature in the brake disc

The problem has multiple objectives, with some being at odds with the others. This requires tradeoffs to be considered.

The overall geometry is shown in Figure 1. The model consists of two components, the brake disc, and the brake pads – The brake disc and pads are to be able to withstand the pressure and temperature loads resulting from the contact forces between the two parts. The parts were meshed with different resolutions, with the contact surfaces having a higher resolution, as shown in Figure 1. The original design parameters are: Inner diameter: 75 mm, Outer diameter : 125 mm, and thickness : 25 mm.

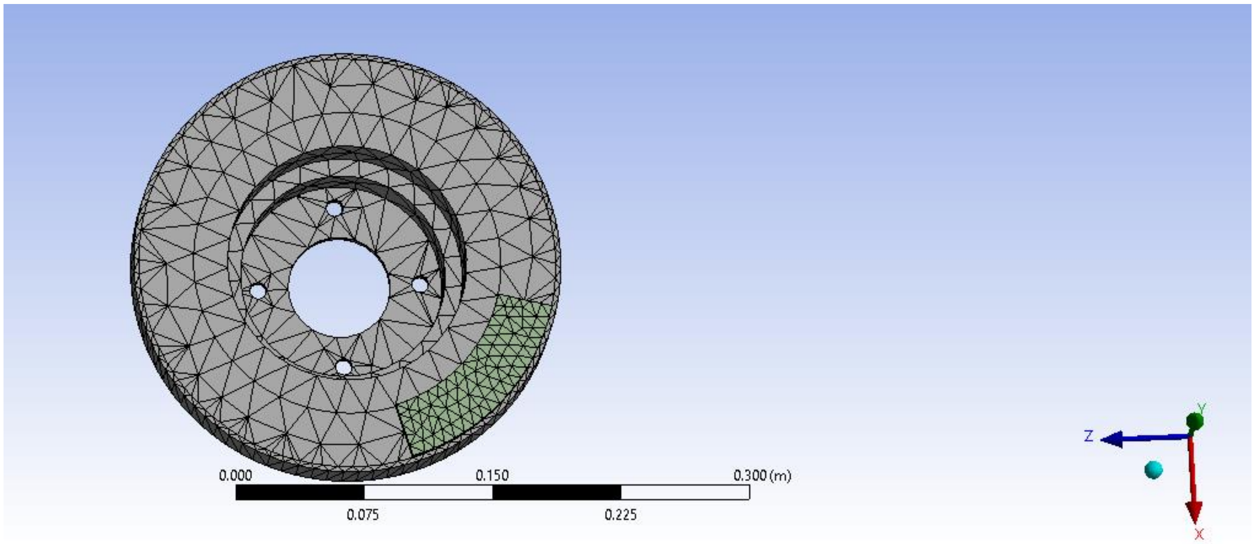

Figure 1: Meshing results for the brake disc and pad geometry

Static Structural Analysis

Boundary conditions:

1. Rotational velocity: The rotational velocity component is set to 250 rad/s (Y-component)
2. Contact pressure: Set to 1.0495 Mpa

3. Displacement constraints: Fix the X and Z components to 0 displacement.

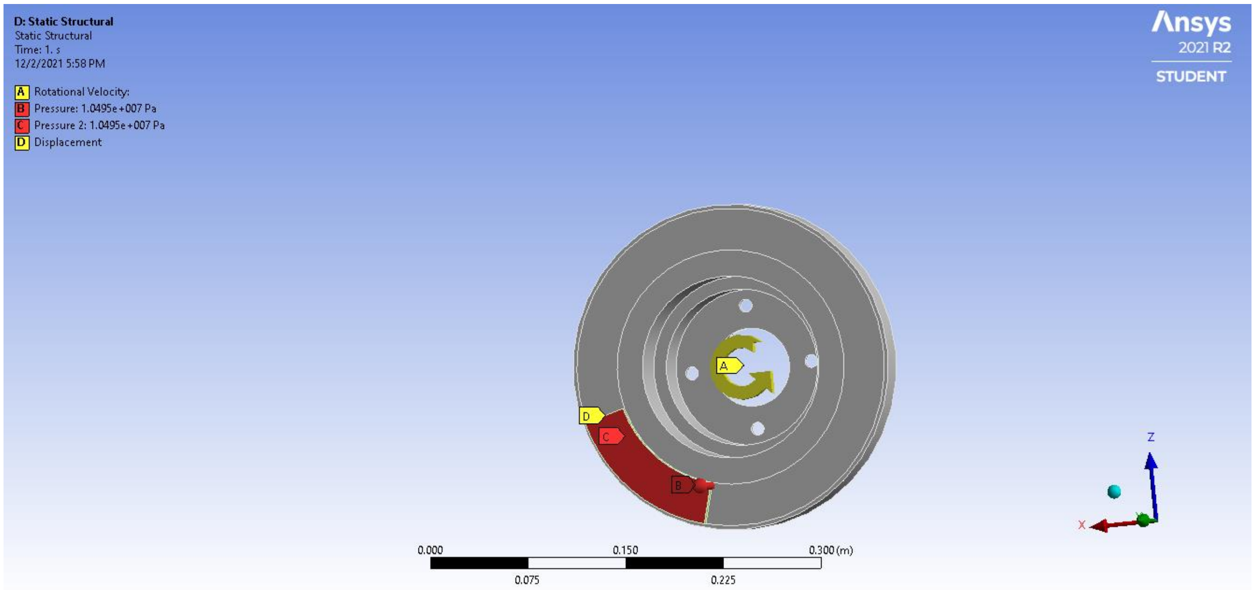

Figure 2: Boundary conditions for static structural analysis

Baseline results – Von Mises Stress:

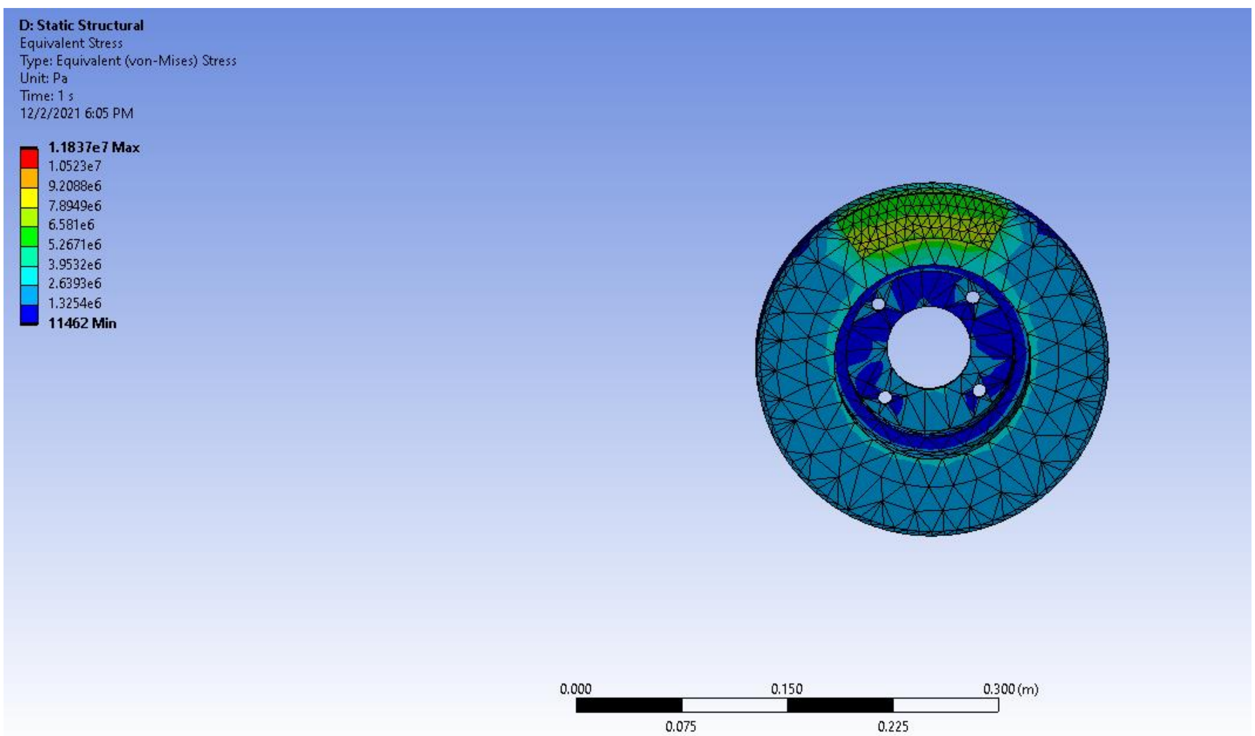

Figure 3: Results for the baseline configuration of the brake disc

Transient Thermal Analysis

Boundary conditions:

1. Convection:
   Ambient Temperature: 35 C
   Film Coefficient: 5 W/m^{2}C
2. Heat Flux:
   Heat Flux: 1.5395 E 6 W/m^2

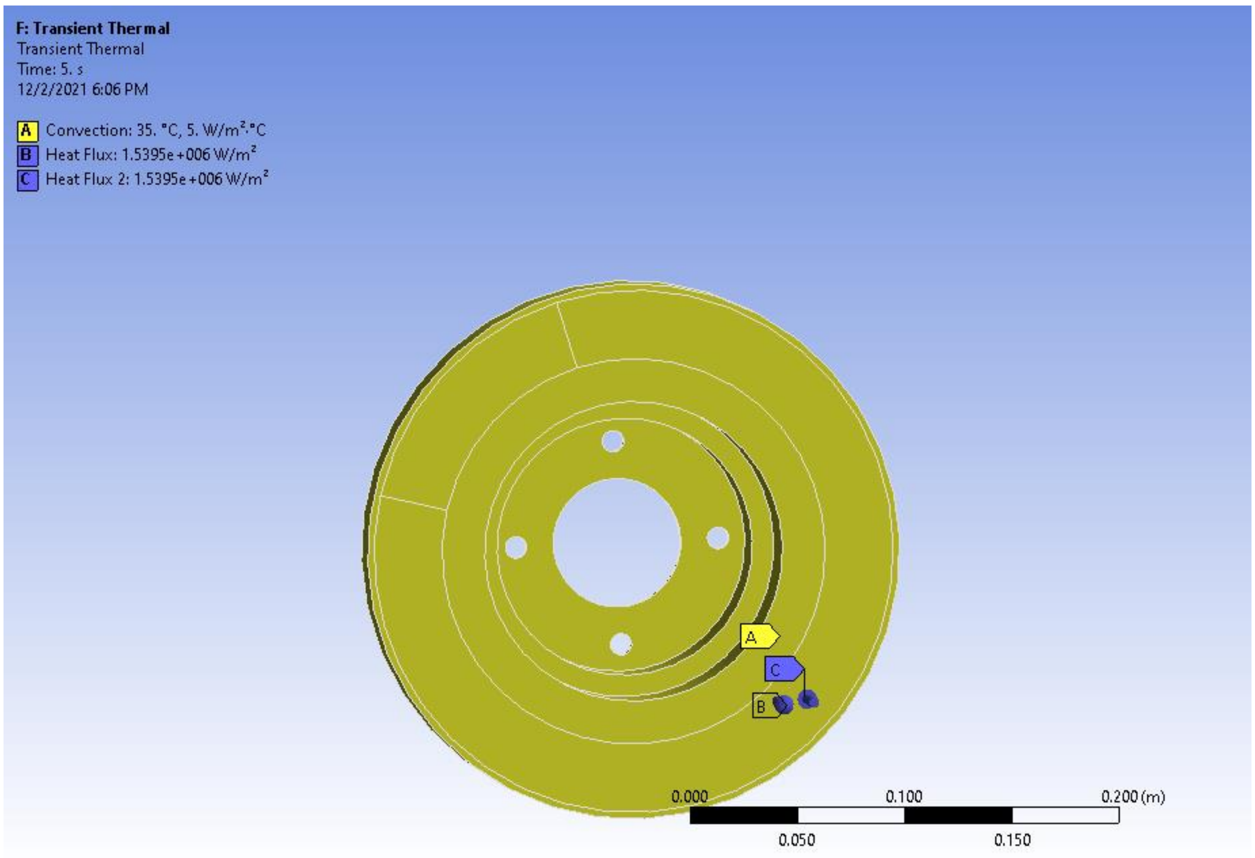

Figure 4: Boundary conditions for transient thermal analysis

Baseline Results:

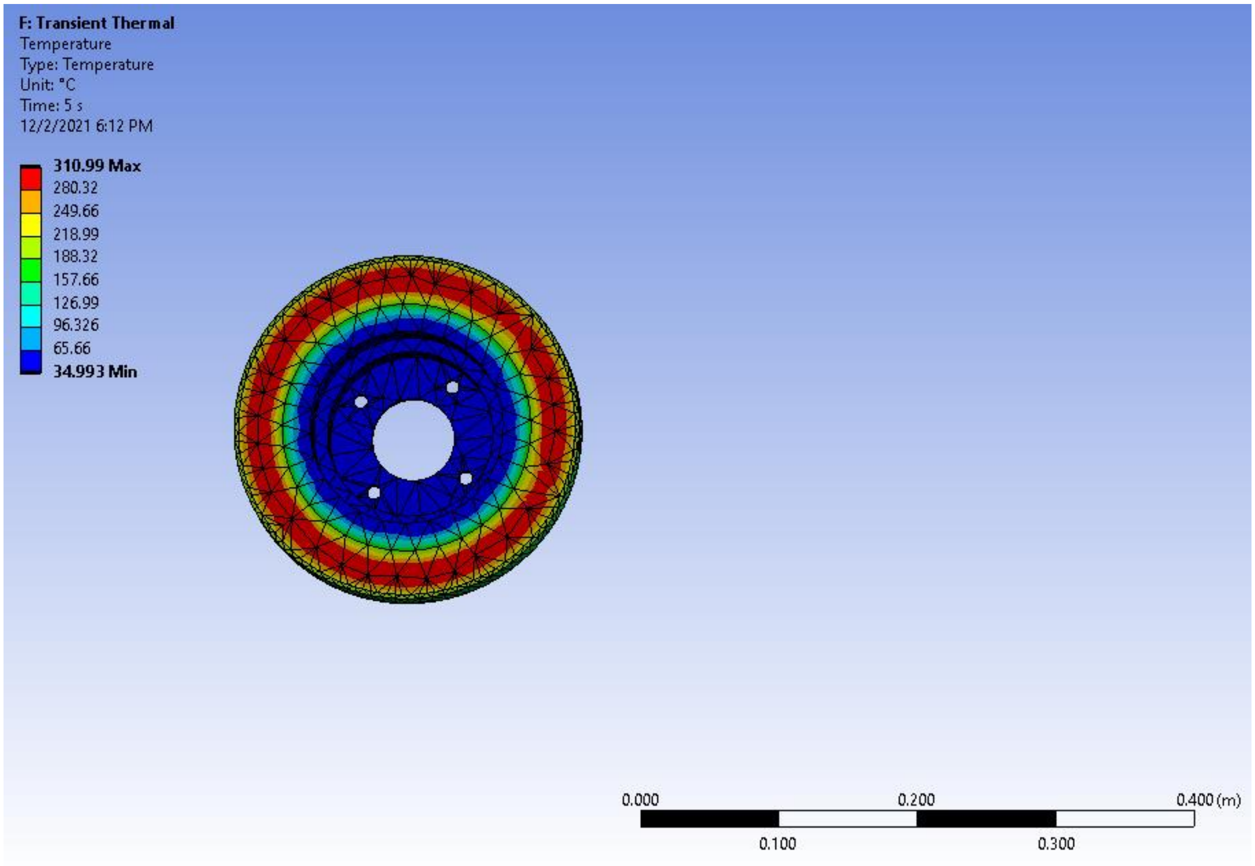

Figure 5: Baseline results for the transient thermal analysis

Modal Analysis

Baseline Results for the 7^{th} deformation mode:

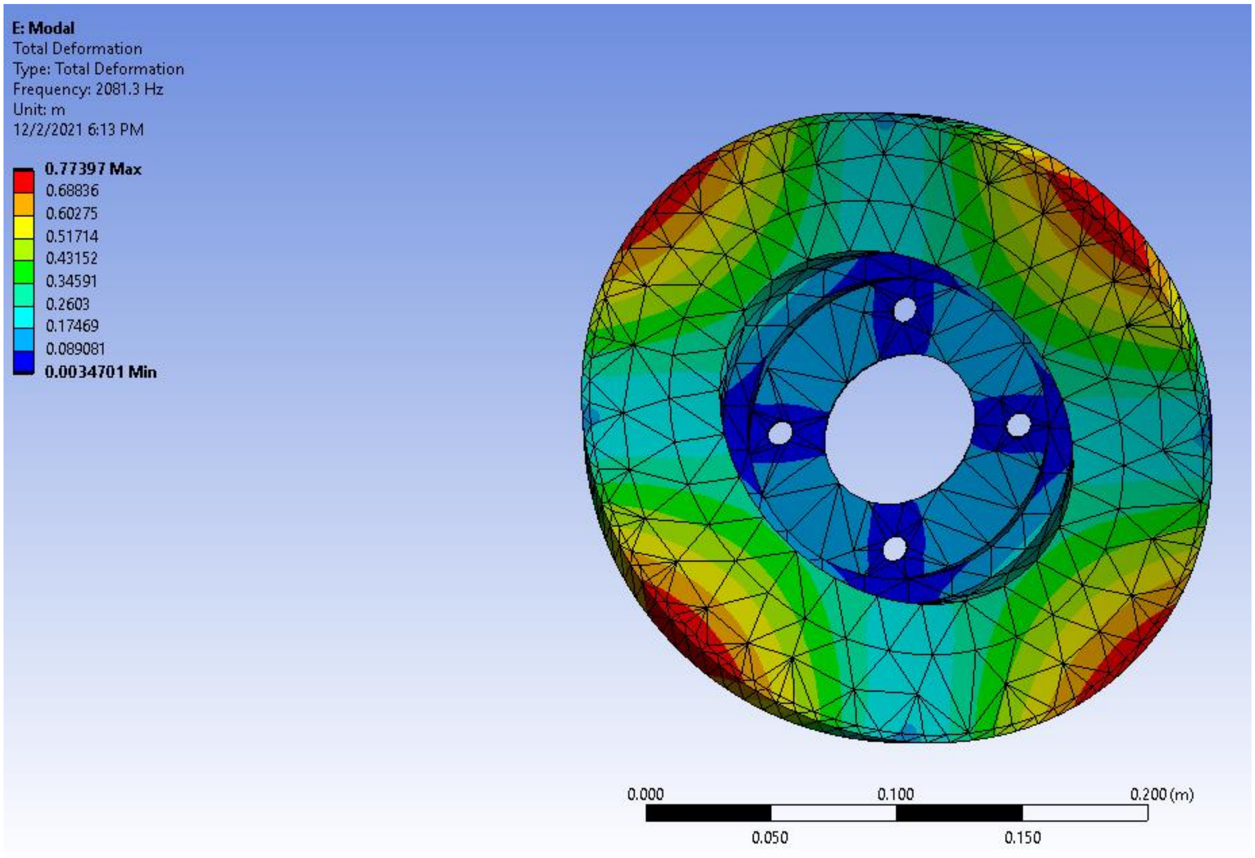

Figure 6: Baseline design results for the total deformation (7th mode)

Design variables:

- Rotor outer diameter
- Rotor inner diameter
- Rotor Thickness

Physics Constraints:

Equivalent stress maximum: <2 E7 Pa

Temperature maximum: < 350 C

Geometry Constraints:

60 mm < Rotor ID < 90 mm

126 mm < Rotor OD < 140 mm

6 mm < Rotor thickness < 38 mm

Tradeoffs:

For this study, some of the objectives are in conflict, so there are tradeoffs to be made. A disc with the lowest volume would potentially have higher stress concentrations, temperature loads, and vibrations compared to the disc with greater volume. Therefore, our choices would need to be conservative – The objective should be to prioritize minimizing the volume without exceeding critical stress and temperature limits, which are defined as upper bound constraints.

Results and Discussion:

Given the geometric constraints, a response surface analysis was performed using DoE points sampled using a kringing model to produce 16 design points. The sampling was done using the Latin Hypercube method, as shown in Figure 7.

Table of Outline A5: Design Points of Design of Experiments

	A	B	C	D	E	F	G	H	I
1	Name	Update Order	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - rotor_thickness (mm)	P5 - Equivalent Stress Maximum (Pa)	P6 - Disc Volume Maximum Volume (m^3)	P7 - Total Deformation Reported Frequency (Hz)	P8 - Temperature Maximum (C)
2	1	12	133.93	83	24.133	1.2524E+07	0.0010777	1737.6	313.93
3	2	8	136.73	75	26.267	1.2042E+07	0.0012899	1854.2	308.31
4	3	9	126.47	77	11.333	1.2317E+07	0.0005766	1772.4	455.2
5	4	1	135.8	61	34.8	1.2015E+07	0.0017757	2122.3	298.79
6	5	3	127.4	65	13.467	1.0211E+07	0.00068622	1647.8	404.22
7	6	2	139.53	63	9.2	1.046E+07	0.00062008	1033.9	532.83
8	7	14	134.87	87	32.667	1.5549E+07	0.0013449	1797.7	303.06
9	8	11	138.6	81	30.533	1.2503E+07	0.0014459	1819.4	302.42
10	9	4	130.2	67	22	1.163E+07	0.001046	1917.6	321.46
11	10	10	129.27	79	36.933	1.2635E+07	0.0014401	2182.9	300.29
12	11	6	132.07	71	17.733	1.1497E+07	0.00088857	1774.2	349.42
13	12	13	128.33	85	15.6	1.1572E+07	0.00070048	1657.8	372.31
14	13	7	133	73	19.867	1.1448E+07	0.00097588	1816.6	333.04
15	14	15	137.67	89	7.0667	1.0236E+07	0.00050764	1359	666.34
16	15	5	131.13	69	28.4	1.1553E+07	0.0013006	2102.7	305.44

Figure 7: Design of Experiments (DoE) points selected using Latin Hypercube sampling

Since this problem has multiple objectives, so the optimization method used for the analysis is the Multi Objective Genetic Algorithm (MOGA). The results produced 3 candidate points, as shown Figure 8.

Candidate Points

	Candidate Point 1	Candidate Point 2	Candidate Point 3
P2 - rotor_OD (mm)	126.01	126.02	126
P3 - rotor_ID (mm)	89.973	89.955	89.872
P4 - rotor_thickness (mm)	21.433	20.631	21.147
P5 - Equivalent Stress Maximum (Pa)	★ 1.103E+07	★ 1.1051E+07	★ 1.102E+07
P6 - Disc Volume Maximum Volume (m^3)	★★ 0.00079504	★★ 0.00077497	★★ 0.00078856
P7 - Total Deformation Reported Frequency (Hz)	★ 1510.3	★ 1507.3	★ 1513
P8 - Temperature Maximum (C)	– 297.77	– 305.15	– 300.36

Figure 8: Selected candidate points after performing MOGA

The configuration with the minimum disc volume was candidate 2, with an equivalent stress maximum at 1.1 MPa, and a natural frequency of 1507.3 Hz. Compared to the original design, the natural frequency reduced from 2081 Hz to 1507.3 Hz. The maximum stress reduced from 1.4 Mpa to 1.1 Mpa, and the maximum temperature saw a smaller improvement of ~ 2C. The sensitivity analysis showed that the stress reduces with increasing rotor thickness, the temperature maximum was inversely related to all three design variables and the natural frequency is inversely related to the inner diameter of the rotor but the outer diameter had no significant impact on it. These results are summarized in Figure 9.

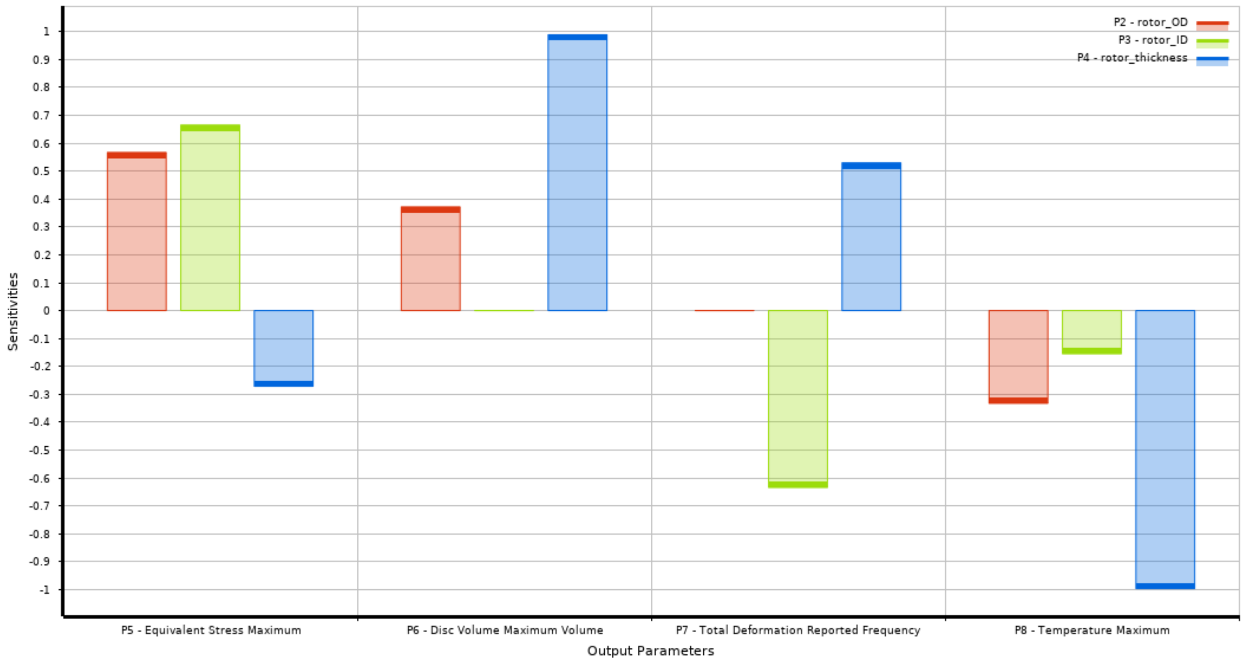

Figure 9: Sensitivity Analysis