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MAE 598 Design Optimization
Project 2 Report

Optimization Setup and Objectives

In this design optimization problem, we seek to optimize the geometry of a brake disc and brake pads with the objectives of minimizing volume, maximum stress in the disc, first natural frequency of the disc, and the maximum temperature in the disc.

To find this optimal design, we designate three brake disc dimensions as our input variables by parameterizing them in ANSYS Design Modeler: rotor thickness t, rotor outer diameter r_{OD}, and rotor inner diameter r_{ID}. These are given a feasible range according to the following:

$$22.5\ mm \leq t \leq 27.5\ mm$$

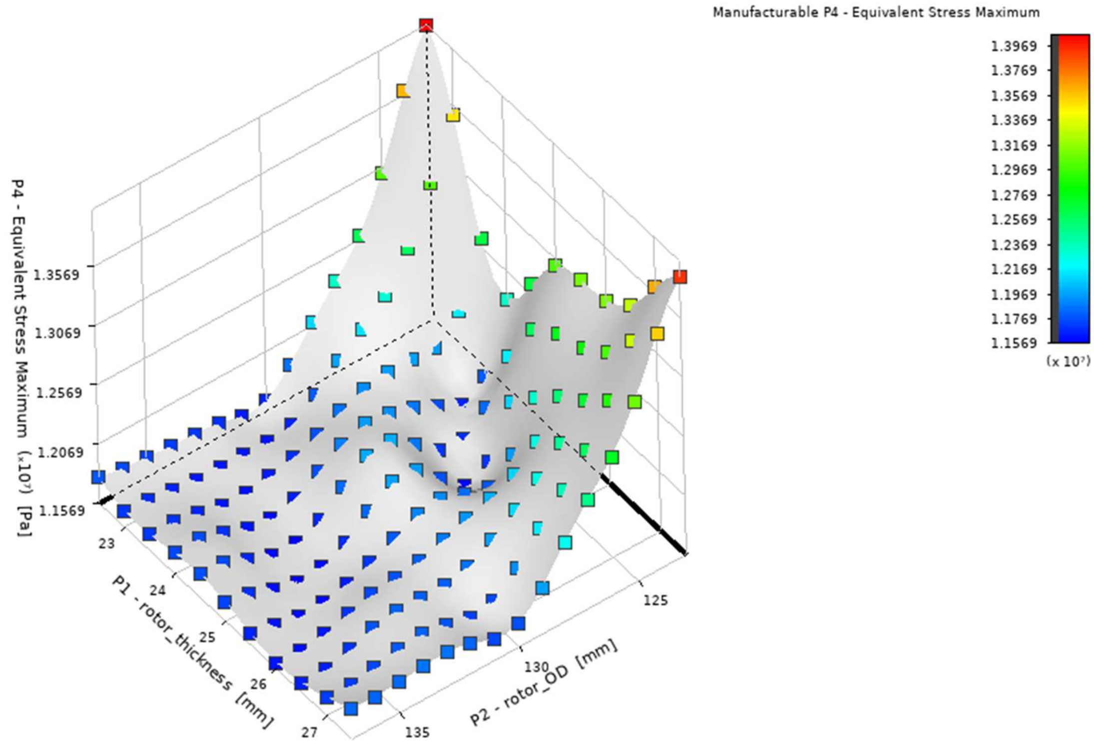
$$123\ mm \leq r_{OD} \leq 137.5\ mm$$

$$67.5\ mm \leq\ r_{ID} \leq 82.5\ mm$$

Our design search allows for manufacturable values incremented by 0.5 mm (e.g. 22.5, 23, 23.5… for feasible values of t).

Response Surface and Sensitivity

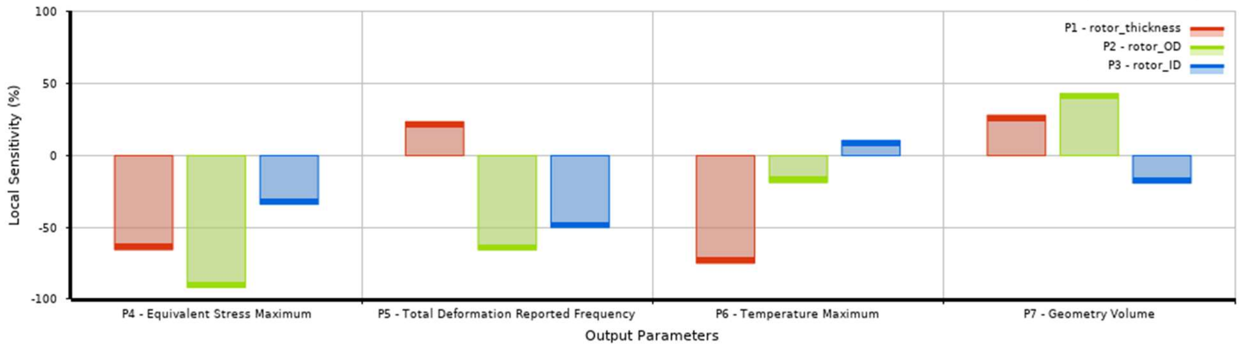
The response surface for this problem was generated with the Kriging method found in ANSYS, as we trust the results from the finite element solver in ANSYS, and the objectives may be highly nonlinear. A sample response surface showing the interaction between rotor thickness and r_{OD} and their effect on the maximum equivalent stress is shown below:



One should note that testing the accuracy of the response surface can be done by generating various verification points. However, since optimization is a goal, we do not have to overly refine the response surface. Thus, at this point the project was ready for the optimization process.

Sensitivity

One interesting feature provided by the ANSYS response surface tool is the ability to view the sensitivity of each parameter in the form of a partial derivative. For instance, in the figure below, we can observe that both the maximum stress and the geometry volume are most sensitive to changes in r_{OD}. On the other hand, changes in r_{ID} has the smallest effect on the maximum stress, maximum temperature, and geometry volume.



Optimization Process

We utilized ANSYS Workbench and its parameter optimization module in order to locate a solution within the feasible space. The algorithm of choice was Multi-Objective Genetic Algorithm (MOGA) because of its ability to seek a Pareto frontier with multiple objectives.

Table of Schematic E2: Optimization		
	A	B
1	⊟ Optimization Study	
2	Minimize P4	Goal, Minimize P4 (Default importance)
3	Minimize P5	Goal, Minimize P5 (Default importance)
4	Minimize P6	Goal, Minimize P6 (Default importance)
5	Minimize P7	Goal, Minimize P7 (Default importance)
6	⊟ Optimization Method	
7	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.
8	Configuration	Generate 12 samples initially, 4 samples per iteration and find 3 candidates in a maximum of 10 iterations.
9	Status	Converged after 24 evaluations.

Summary of the Optimization Procedure

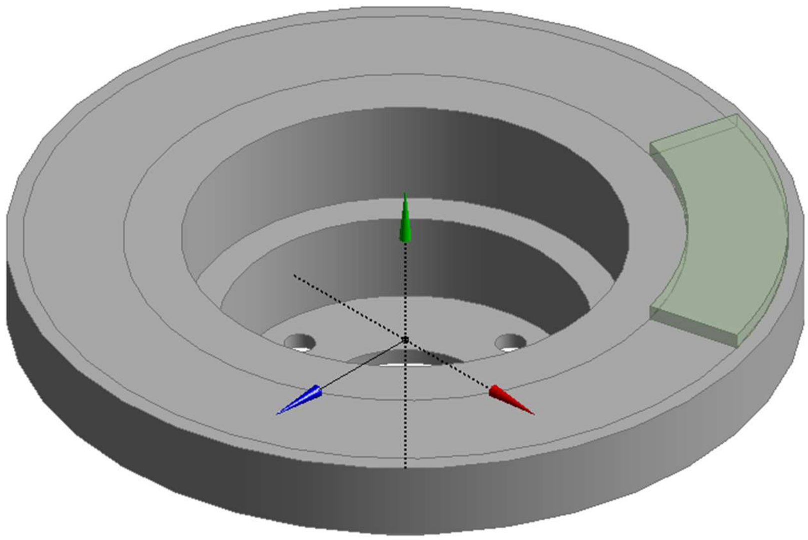
Final Optimized Design

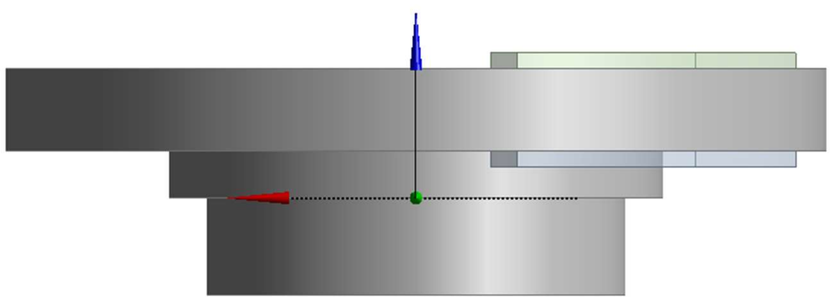
Performing this optimization procedure yielded three candidate points, two of which were the same. The results are shown below:

Name	P1 - rotor_thickn... (mm)	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P4 - Equivalent Stress Maximum (Pa)		P5 - Total Deformation Reported Frequency (Hz)		P6 - Temperature Maximum (C)		P7 - Geometry Volume (m^3)	
				Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
Candidate Point 1	25.5	127.5	76.5	1.2184E+07	3.08%	2014.9	-2.99%	310.48	0.41%	0.0010855	-2.31%
Candidate Point 2	25.5	127.5	76.5	1.2184E+07	3.08%	2014.9	-2.99%	310.48	0.41%	0.0010855	-2.31%
Candidate Point 3	25.5	127.5	73.5	1.182E+07	0.00%	2076.9	0.00%	309.21	0.00%	0.0011112	0.00%

In short, Candidate Point 3 provides a lower maximum stress by 3%, but higher deformation and volume. Its maximum temperature is very near to those of Points 1 and 2. Thus, because it only excels in providing lower stress, we chose Candidate Point 1 as the design of choice. However, one should note that prioritizing the equivalent stress as the output parameter would change this choice.

The final design, then, has a rotor thickness of 25.5 mm, a rotor outer diameter of 127.5 mm, and a rotor inner diameter of 76.5 mm.





Design Performance

Given the initial constraints on the input variables, this optimal design produces a maximum equivalent stress of 12.18 MPa, a total deformation frequency of 2014.9 Hz, a maximum temperature of 310.48° C, and an overall volume of $1.08\times 10^{-3}\ m^3$.