Kristina Phillips

Ren

MAE 598

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Project 2

Introduction

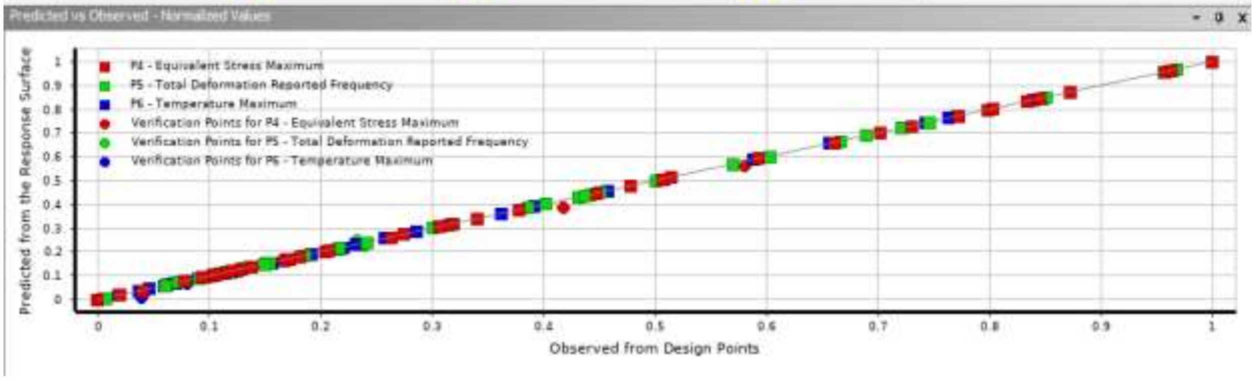
In this project, I focus on altering the size of a brake disk to maximize a few objectives. My design variables were the disk's outer diameter and disk's thickness. I chose these as my variables because through doing research on brake disks, these factors were how different brakes were distinguished. I also chose the disk's inner diameter as a design variable but during my research I found it was uncommon for the brake disk's inner diameter to be listed. My objectives are to minimize the brake disk's volume, minimize the max stress in the brake disk, and maximize the first natural frequency of the brake disk, and minimize the maximum temperature the brake disk is subjected to. In terms of constraints, the resonant frequency for a BMW 5 Series Sedan is 34 Hz, so it is ideal that at a minimum the first natural frequency is above this (1). For a standard road car, the highest temperature their brake disks should be able to handle is 130°C (2). The final constraint is for the stress in the brake disk which is limited by the factor of safety. The typical factor of safety in an automobile is 3, so the max stress occuring on the brake disk cannot be greater than 1/3 of the maximum stress for the material that the disk is made from (3). To make sure that the chance of failure is low, I am going to choose the max stress at the tensile ultimate stress because it is lower than the compressive one. The ultimate stress is 2.4e8 Pa so the max stress we can subject the brake pad to is 8e7 Pa.

Design of Experiments

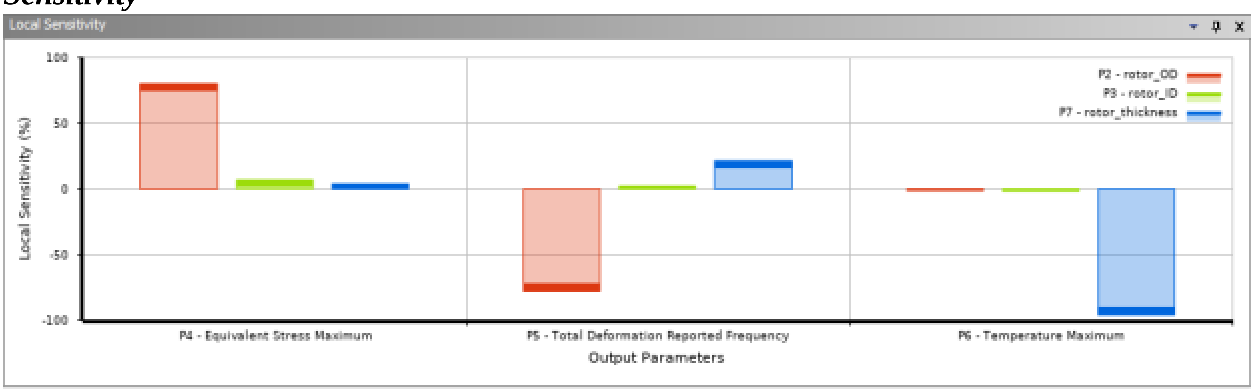
The Design of Experiments method chosen was Latin Hypercube Sampling. When setting up the experiment, the bounds placed were Rotor OD = [125,302], Rotor ID = [66,90], and Rotor thickness = [7.8,28.3] all in units of mm. The outer diameter and thickness bounds were chosen based off how data found online (4). There was no data found online for the inner diameter, so I used the bound that ANSYS had prepopulated for me. The first response surface method used was Kriging because the data is highly nonlinear based off the design of experiments run. When I started off, I did 8 verification points which amounted to about 1/4 of the sample. I couldn’t get a low enough error with this many verification points, so I took my previous verification points and turned them into refinement points while increasing my verification points in increments of 2. I iterated this until I got a low maximum and average error seen below.

Table of Schematic E3: Response Surface

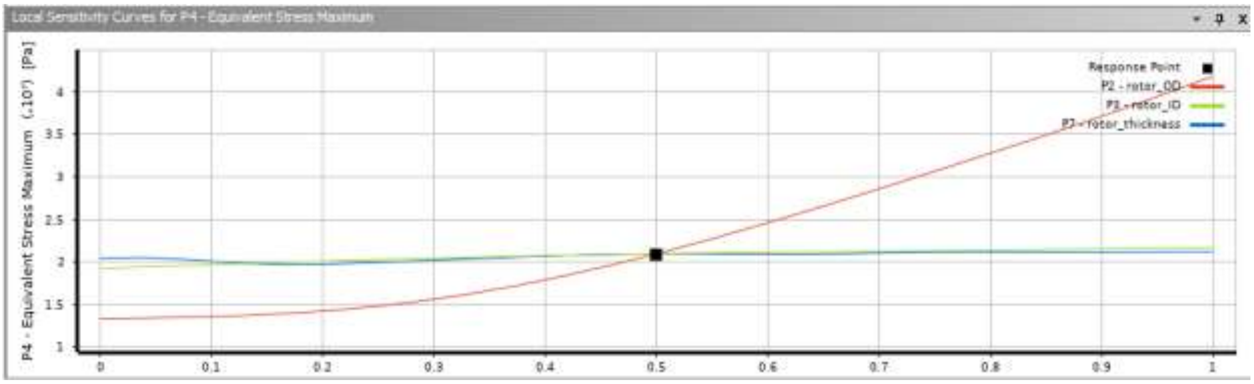
	A	B	C	D
1		P4 - Equivalent Stress Maximum	P5 - Total Deformation Reported Frequency	P6 - Temperature Maximum
5	Learning Points	0.073425	1.412E-05	3.495E-06
6	Verification Points	2.7939E+05	8.9933	2.5106
7	Relative Maximum Absolute Error (Best Value = 0%)			
8	Learning Points	0	0	0
9	Verification Points	8.6118	4.8971	8.8613
10	Relative Average Absolute Error (Best Value = 0%)			
11	Learning Points	0	0	0
12	Verification Points	0.93761	0.6178	0.85269



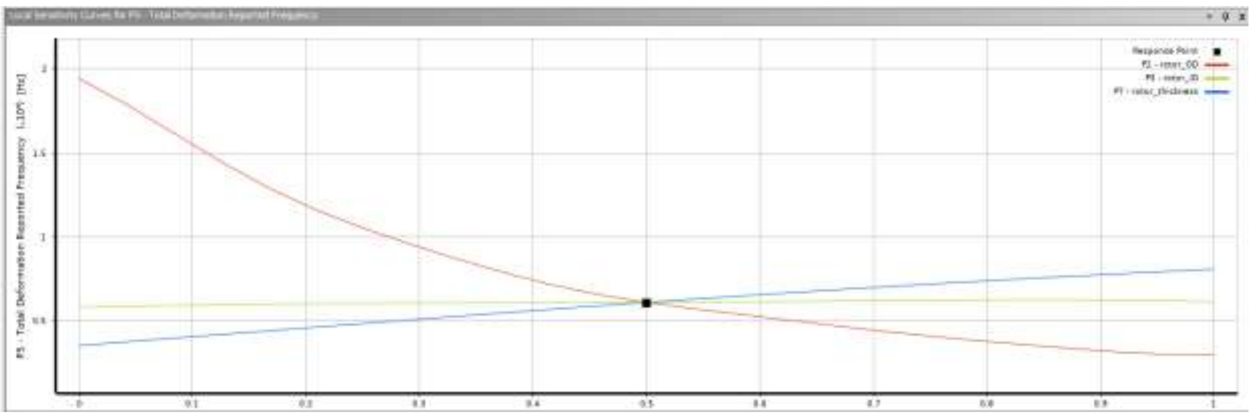
Sensitivity



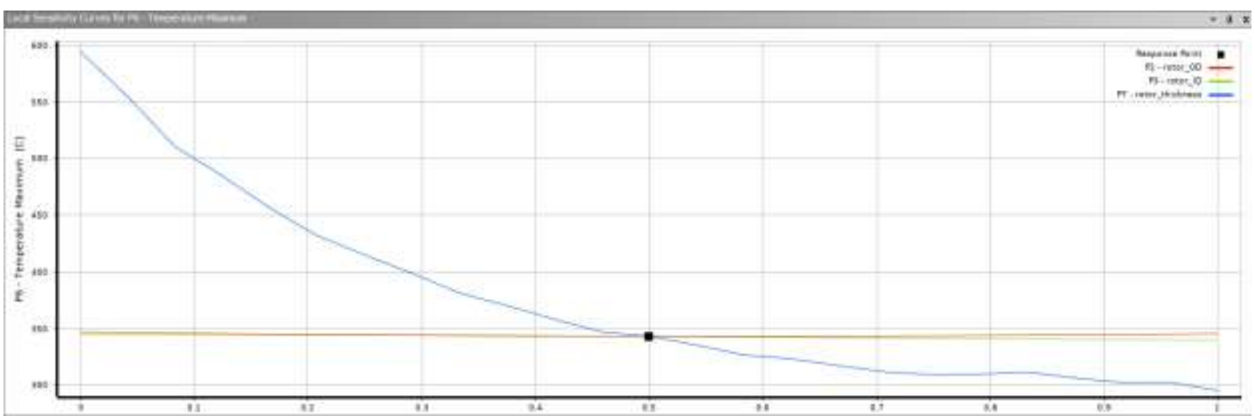
In my sensitivity analysis, I can see that the maximum stress and the first natural frequency are both significantly affected by the outer diameter of the rotor. The first natural frequency is also somewhat affected by the rotor thickness while the maximum temperature is significantly affected by the thickness.



Here it can be seen that an increasing rotor outer diameter will increase the maximum stress in the disk.



Here it is seen that increasing the rotor outer diameter will decrease the first natural frequency. Increasing the thickness is shown to slightly increase the first natural frequency.

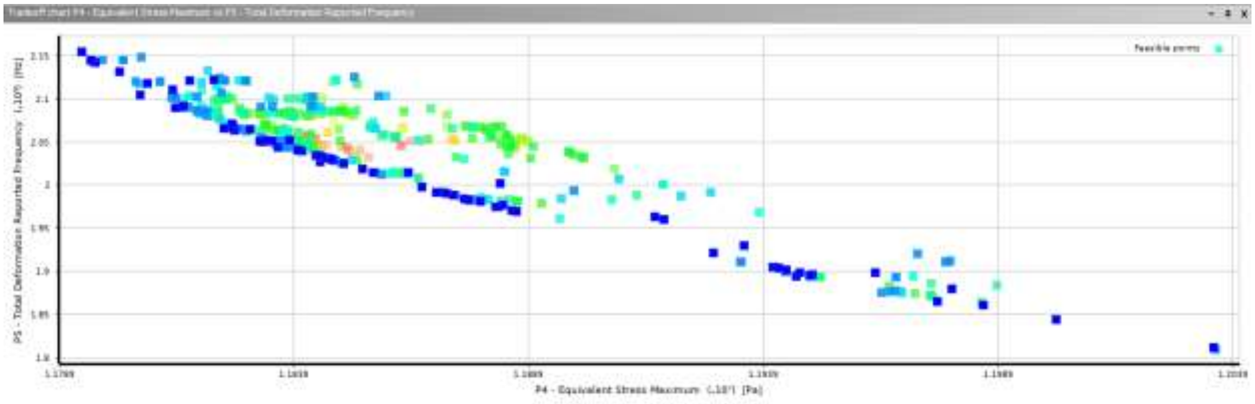


Increasing the thickness will exponentially decrease the maximum temperature the disk experiences.

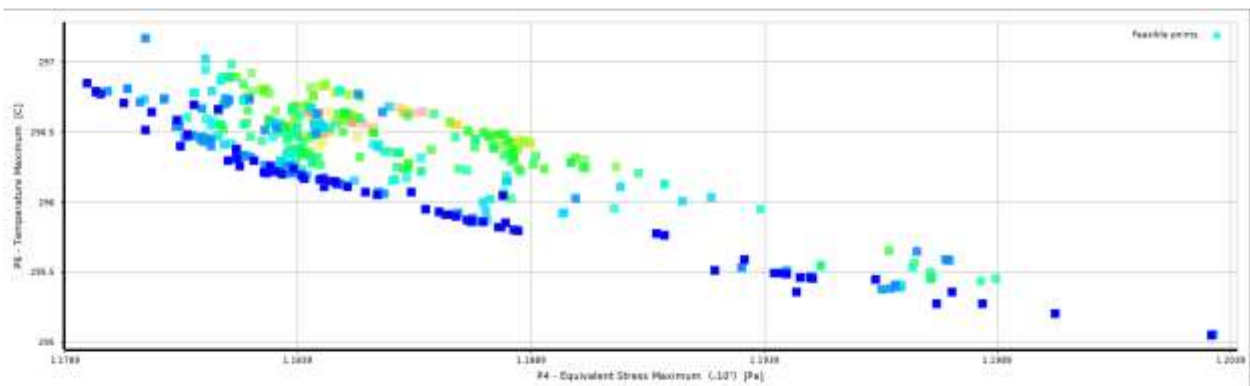
Optimization

For my optimization, in reviewing the criteria I had previously set, I realized that I would not be able to meet my temperature maximum as none of the values I got reached below 300. In addition, none of the first natural frequencies found were even below 200 Hz so I know this constraint would be met. Therefore, I chose to only set a constraint on what the maximum stress in my disk could be. I set it so that the maximum stress had to be lower that 2.4e8 Pa and then just minimized the maximum temperature and maximized the first natural frequency. With multiple objectives, I used the Multi-objective Genetic Algorithm (MOGA) to run my optimization.

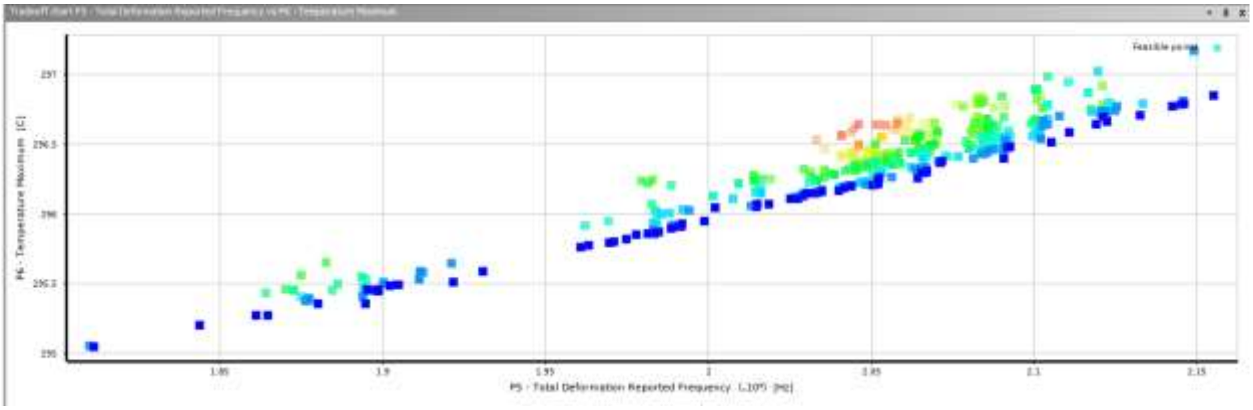
Pareto Frontier



From this pareto frontier it is seen that maximizing the equivalent stress will minimize the first natural frequency and vice versa.

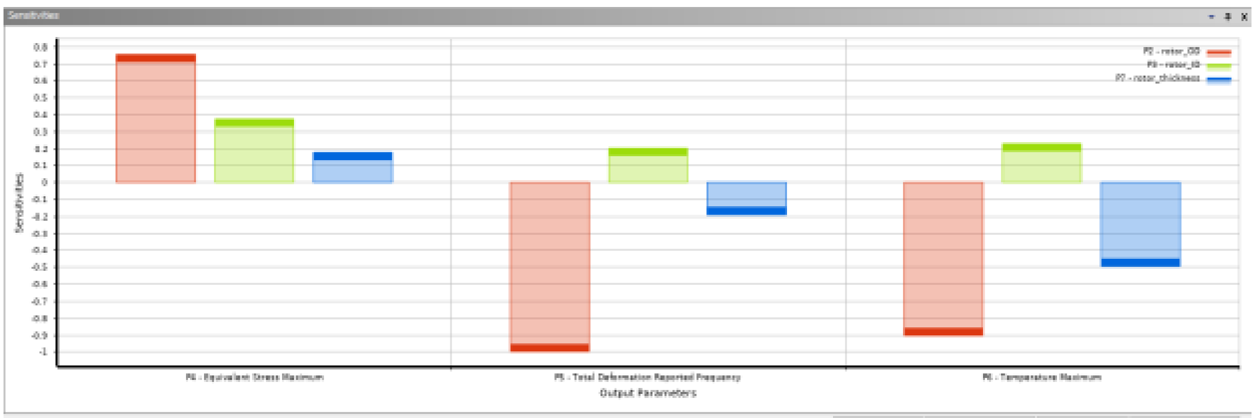


From this pareto frontier it can also be seen that maximizing the equivalent stress will minimize the maximum temperature.



From this pareto frontier, it shows that the first natural frequency increases as the temperature increases and vice versa.

In looking at my sensitivity analysis for optimization, it has changed significantly.



The equivalent stress maximum has similar sensitivities with rotor inner diameter starting to have a more significant effect. The same effect with the first natural frequency where it is most affected by the outer diameter. However, the maximum temperature is now significantly affected by the rotor's outer diameter where an increase in it will decrease the maximum temperature. It is interesting because the effects of an outer diameter change are more significant than the effects of the thickness which was the only prominent variable previously.

With these objectives and constraints, I came to the following design points:

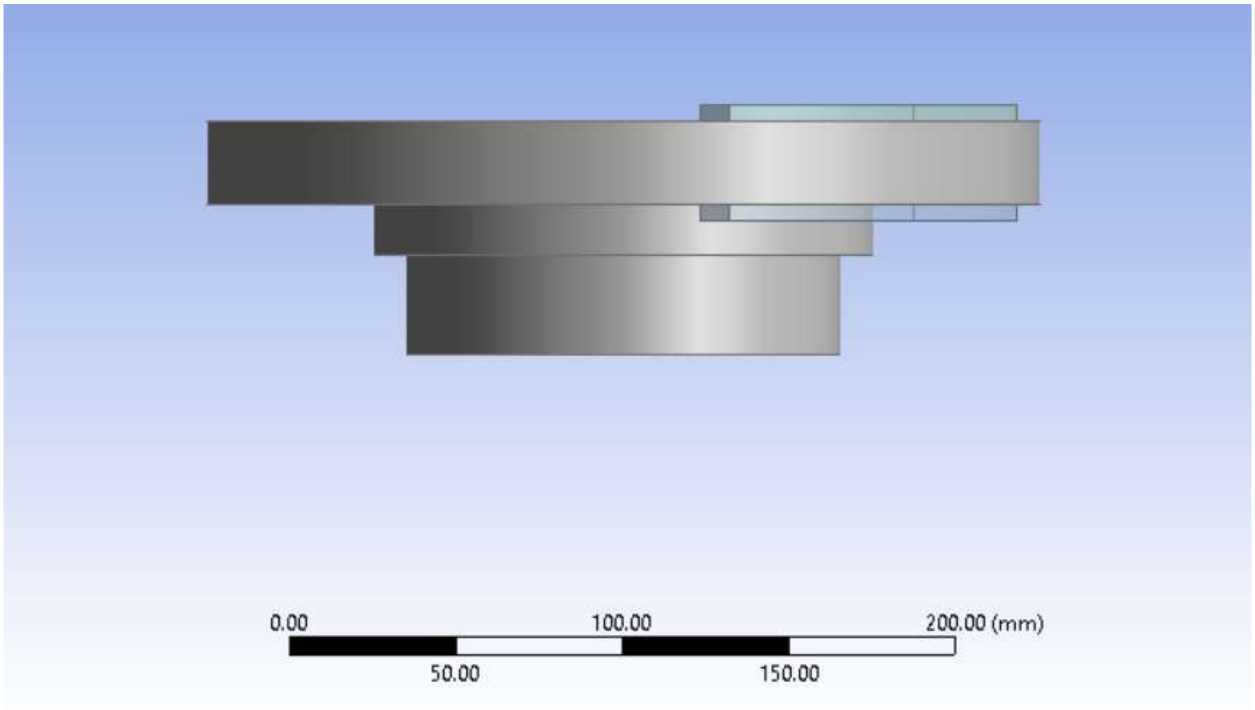
	A	B	C	D	E	F	G	H	I	J	K
1	Reference	Name	P2 - rotor_OD (mm)	P3 - rotor_ID (mm)	P7 - rotor_thickness (mm)	P4 - Equivalent Stress Maximum (Pa)		P5 - Total Deformation Reported Frequency (Hz)		P6 - Temperature Maximum (C)	
2						Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
3	○	Candidate Point 1	125.06	66.009	28.283	1.1799E+07?	-0.26%?	2135.1?	4.28%?	296.85?	0.18%?
4	○	Candidate Point 2	127.75	66.033	28.29	1.1806E+07?	-0.19%?	2105.2?	1.86%?	296.32?	0.07%?
5	●	Candidate Point 3	126.77	66.014	28.29	1.1824E+07?	0.00%	2066.3?	0.00%	296.2?	0.00%
*		New Custom Candidate Point	213.5	78	18.05						

Candidate point 1 aligns the most with my objectives/constraints because it has the smallest equivalent stress maximum, the largest first natural frequency, and the smallest temperature maximum.

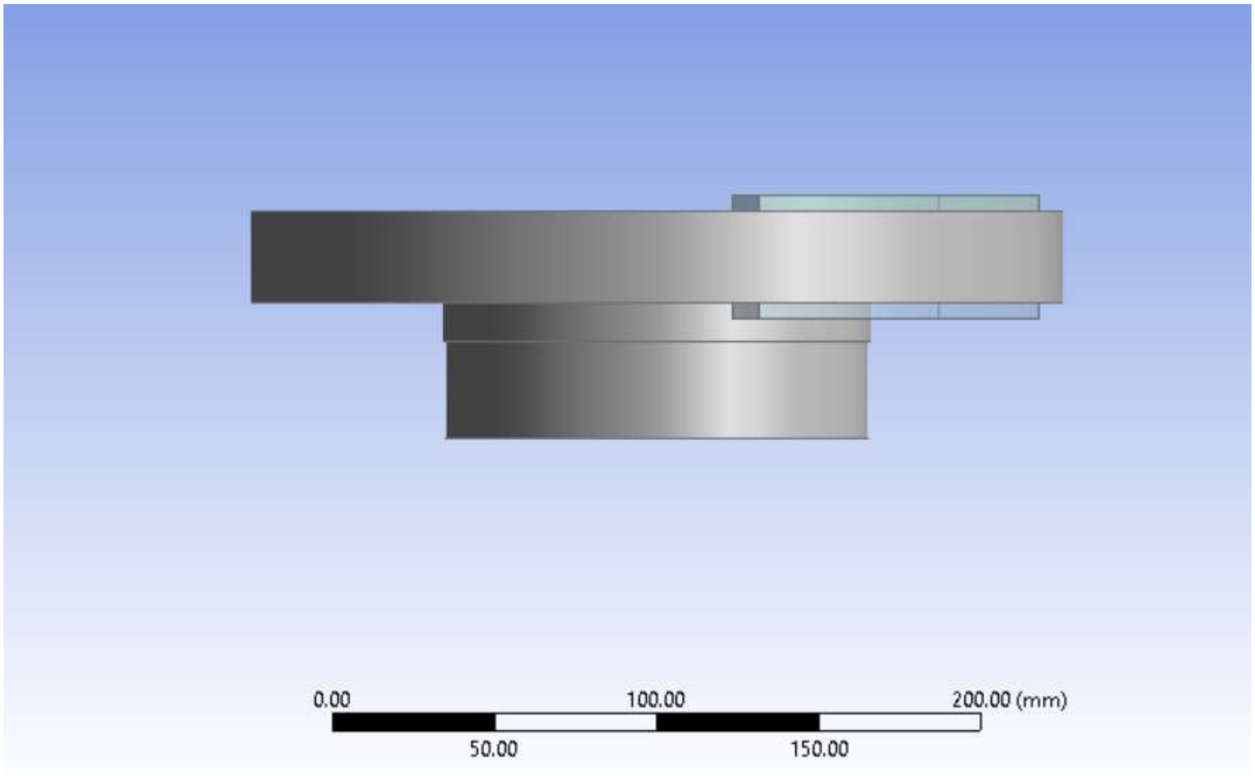
Verification

To verify this point, I will input these values into my geometry and run the static simulation, modal analysis, and transient thermal blocks.

Here is my previous geometry

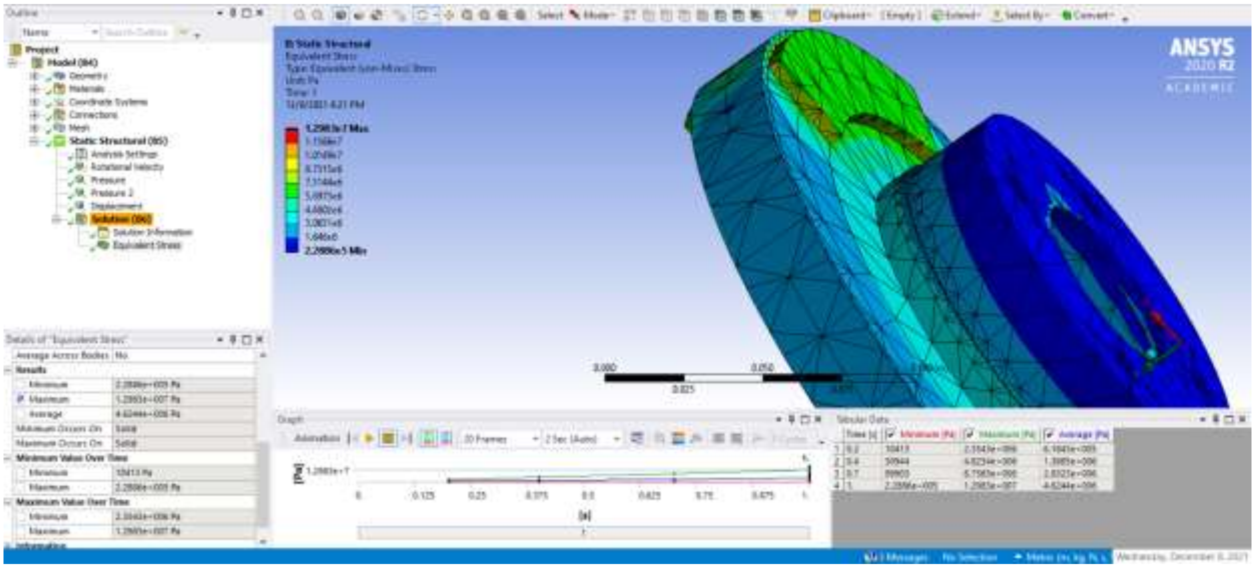


Here is my updated geometry

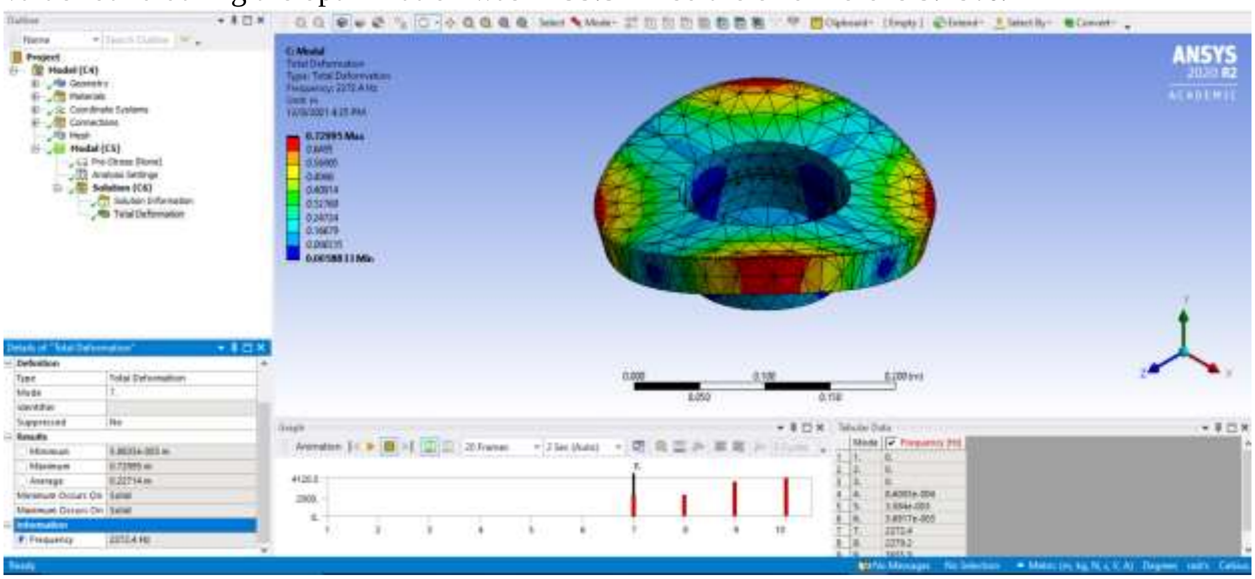


As can be seen from the two pictures the inner diameter is what changed the most significantly. I believe this is still reasonable, but it was the only variable where I didn't find a lot of information online about what the specific range for this was. The old volume of the disk was 9.667e-4 m^3 new v was 1.184 e-3 m^3 which only led to a volume increase of less than 1%. This seems odd since the pictures look significantly different, but this could be due to different scaling picture sizes.

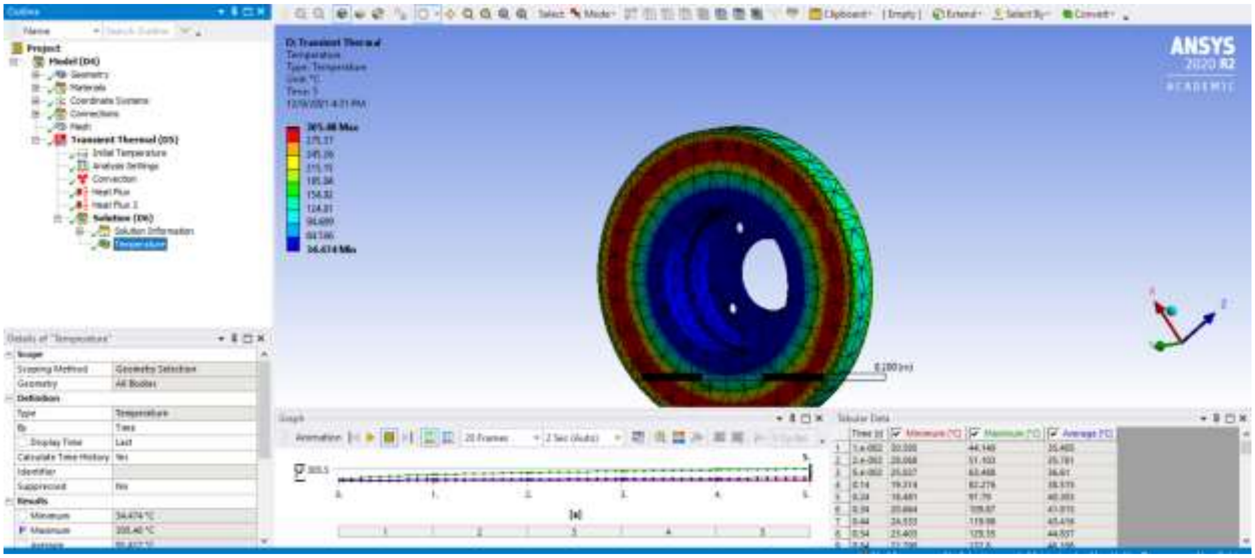
Here is the new static structural I received where the max stress was1.2983e7 Pa. The value calculated during the optimization was 1.1794e7 Pa so it has an error of 7.69%



Here are the results for the first natural frequency where the value found was 2272.4 Hz. The value found during the optimization was 2155.3 Hz so the error here is 5.29%.



Here the result for the maximum temperature was 305.48 while the value found during optimization was 296.85. This error difference for these 2 values is 2.87%



Overall looking at the data and comparing to what I found online, the maximum temperature and first natural frequency were significantly off from the constraints I set. The first natural frequency was in the 2000 range which I believe seems impossible. Also, the maximum temperature experienced when I tried to minimize it was still around 300°C which I think is insanely high and any parts subjected to this temperature would fail. Overall, though, I do not know a whole lot about brake plates and disks so I would further research into them to see if I could have found a better solution by setting different objectives/constraints or by changing the range which the variables are pulled from.

References

(1)https://audiojudgement.com/resonant-frequency-car/

(2)https://www.kwik-fit.com/blog/should-brake-discs-get-hot#:~:text=For%20standard%20road%20cars%2C%20you%20should%20expect%20your,cool%20back%20down%2C%20you%20could%20experience%20brake%20fade.

(3)https://whatispiping.com/factor-of-safety/

(4)http://www.blackdiamondperformance.com/pdf/disk_measurements_07_05.pdf