HOMEWORK 5-Q3

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The aim of this project is to enhance the design of a gray cast iron brake disk featuring brake pads constructed from structural steel while preserving its structural, modal, and thermal integrity. Three geometric dimension parameters—inner radius, outer radius, and thickness—serve as the design variables for the brake disk. To ensure safety, the design is subjected to evaluations in scenarios involving maximum stress under static loading, frequency of free vibration, and maximum temperature. The primary constraints are imposed by geometry, emphasizing the need to avoid dimensions that are excessively large or small. The overarching goal of the design is to minimize strain, increase vibration frequency, and maintain a lower temperature. The analysis and optimization are conducted using the software ANSYS R21.

The input for ANSYS Workbench is the brake file (.agdb), which is subsequently employed by various analysis modules. Three distinct modules serve specific analysis purposes:

1. Static mechanical analysis

2. Modal analysis

3. Transient thermal analysis.

The model setup topology is illustrated in Figure 1, depicting the generation of part geometry from input parameters. The geometry and material properties of the part are common to all three modules. The brake pads are assigned structural steel, while the main body is assigned grey cast iron.

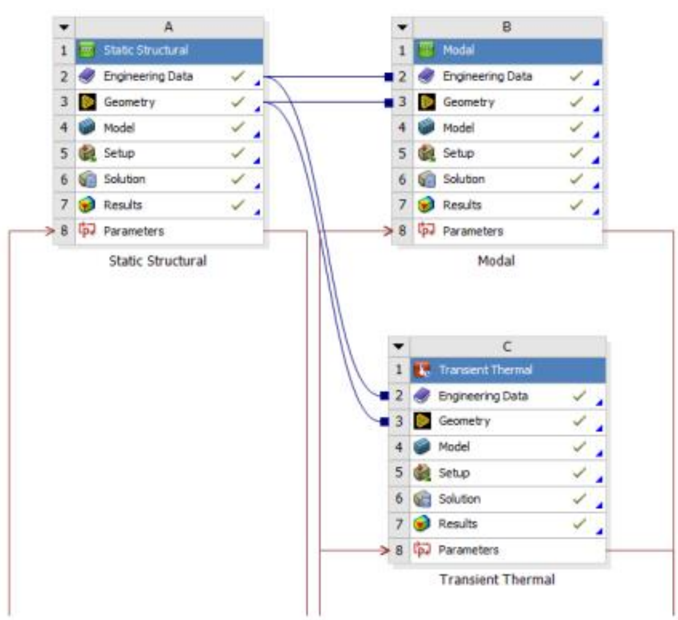

Fig 1. Structure of Design optimization workbench

Static Mechanical Analysis:

The examination involves utilizing the static structural module for analysis purposes. Employing the Patch conforming algorithm, the mesh is executed using the 'tetrahedron' method. Specifically, the inner face of the brake pad undergoes meshing with a 3mm element size. The primary brake disk body is designated to rotate around the y-axis at a speed of 250 rad/s. Frictional contact is established between the main body and the two pads. The pads are constrained in the x and z directions, and external pressures of 10.5 MPa are applied to the outer faces of the pads. The mechanical model setup is depicted in Figure 2. The output values comprise the maximum Von Mises stress and the volume of the main body.

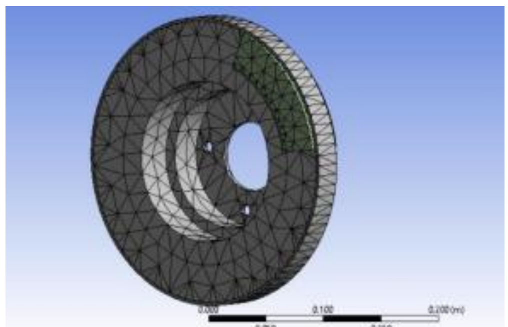

Figure 2. Tetrahedron Mesh in ANSYS

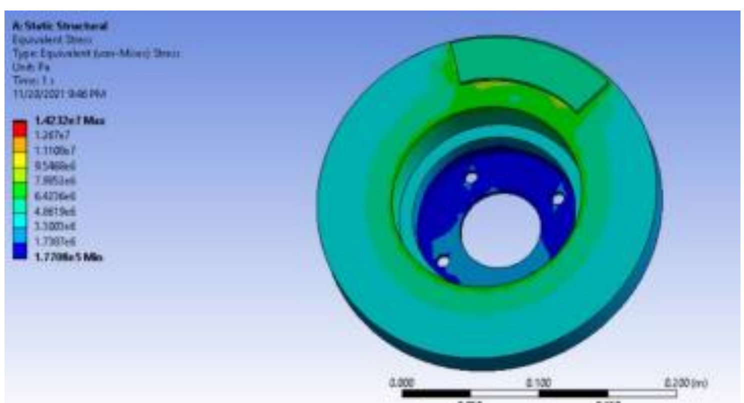

Figure 3. Von mises stress

Modal Analysis:

The modal analysis involves utilizing the modal module. While maintaining the same geometry and material assignments as the static structural analysis, the analysis excludes the two brake pads, which are suppressed. Since the objective is to solve for the free vibration response, no boundary conditions are applied to the part. The analysis aims to find up to 10 modes, with the 7th vibration mode selected for deformation calculation, as the first six modes correspond to rigid-body vibrations. The frequency of the mode is extracted as the output for modal analysis.

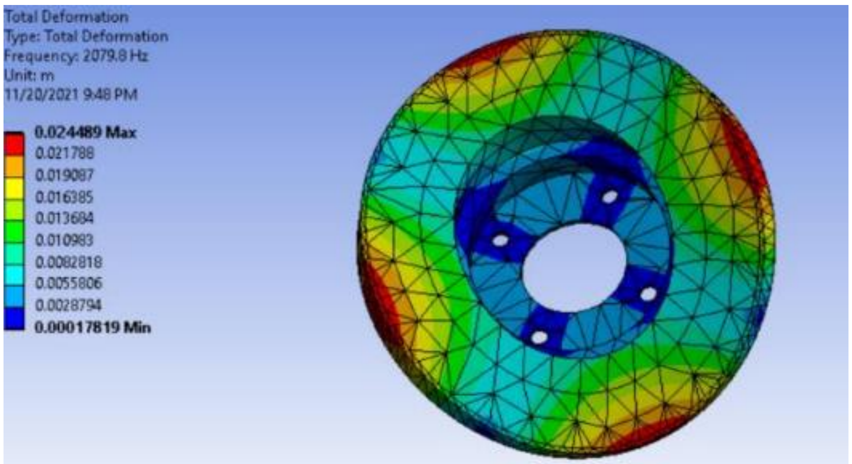

Figure 4. Deformation of the 7th vibration mode

Thermal Analysis:

For the transient thermal analysis, the thermal module is employed. Like the static structural analysis, the geometry and material assignments remain consistent, but the two brake pads are excluded from the simulation. Convection boundary conditions are applied to all faces of the geometry with a factor set at 5 W/m^2. A heat flux of 1500 kW/m^2 is applied to the surface of the main body in contact with the pads. The maximum temperature is extracted as the output value.

Initial Design Performance:

The input parameters for the initial design are set as follows:

1. Inner diameter = 75 mm

2. Outer diameter = 125 mm

3. Thickness = 25 mm

The volume of the initial design is determined. Following the static structural analysis, the Von Mises stress distribution is depicted in Figure 3. The maximum Von Mises stress for the initial design is recorded at 14.2 MPa.

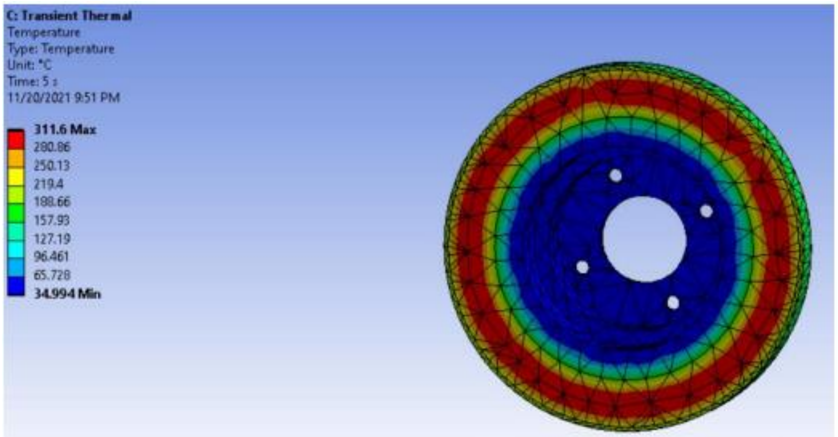

Figure 5. Temperature Distribution on the disk brake

Response Surface:

A response surface is a mathematical model that represents the relationship between input variables (design parameters) and the corresponding output responses. In this context, the design variables are considered dimensional parameters, implying that they are continuous rather than discrete. To expedite computations and analyses, a Latin Hypercube Sampling method is utilized to generate 10 design points, ensuring a representative distribution across the design space.

The next step involves employing neural networks to create a predictive model that captures the complex relationship between the input parameters and the desired responses. Neural networks are particularly adept at learning and approximating intricate patterns in data, making them suitable for modeling complex systems.

To assess the accuracy and reliability of the developed response surface, five verification points are selected. These points serve as a validation set, allowing for the evaluation of how well the response surface generalizes to new, unseen data points. The overall approach of using response surfaces, Latin Hypercube Sampling, and neural networks contributes to an efficient and effective exploration of the design space while managing computational resources.

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	Latin Hypercube Sampling Design
8	Samples Type	User-Defined Samples
9	Random Generator Seed	0
10	Number of Samples	10
11	Design Point Report	
12	Report Image	None

Figure 6. DOE setup

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 - Total Deformation Reported Frequency (Hz)	P5 - Temperature Maximum (C)	P6 - Equivalent Stress Maximum (MPa)
2	1	24.7	128.58	72	2058.9	312.43	15.153
3	2	26.5	123.18	86.4	1794.6	309.52	21.228
4	3	22.3	133.98	84	1686.8	320.22	15.904
5	4	25.9	131.28	69.6	2026.3	311.71	15.43
6	5	22.9	129.93	74.4	1955.2	317.17	15.291
7	6	27.7	132.63	76.8	1936.9	309.14	15.7
8	7	25.3	135.33	81.6	1770.1	311.46	16.047
9	8	27.1	127.23	79.2	1968.5	306.08	15.135
10	9	24.1	125.88	88.8	1655.2	309.99	14.383
11	10	23.5	124.53	67.2	2142.6	313.93	14.428

Figure 7. DOE design points

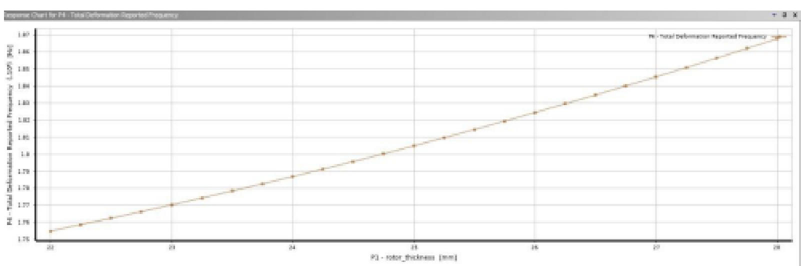

Figure 8. Response Surface

Optimization and Final Design Performance:

The primary goal of this project was to optimize the existing brake pad, aiming to minimize volume, stress, and temperature while maximizing frequency. A comparison with the design proposed by Professor Yi Ren indicates improved stress relief and slightly reduced temperature in this case. The final design, derived from engineering parameters and response surfaces, suggests that increasing thickness leads to a slight temperature reduction and a marginal shift in frequency. Modifying the lower and upper bounds also significantly influences this optimization project.

Due to the presence of multiple objectives, the Multi-objective Genetic Algorithm (MOGA) is employed to identify the optimal design candidates. As outlined earlier, the optimization aims to minimize volume, stress, and temperature, while maximizing frequency. Equal importance is assigned to each response. The resulting optimal design candidates exhibit enhanced stress relief, higher frequency, and improved temperature control compared to the initial design, despite a modest reduction in volume.

Optimization Study			
Seek P4 = 0 Hz	Goal, Seek P4 = 0 Hz (Default Importance)		
Seek P6 = 0 MPa	Goal, Seek P6 = 0 MPa (Default Importance)		
Optimization Method			
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.		
Configuration	Generate 3000 samples initially, 600 samples per iteration and find 3 candidates in a maximum of 20 iterations.		
Status	Converged after 5584 evaluations.		
Candidate Points			
	Candidate Point 1	Candidate Point 2	Candidate Point 3
P1 - rotor_thickness (mm)	22.073	22.049	22.187
P2 - rotor_OD (mm)	135.58	134.78	133.67
P3 - rotor_ID (mm)	78.883	78.353	78.942
P4 - Total Deformation Reported Frequency (Hz)	1751.6	1773.5	1786.5
P6 - Equivalent Stress Maximum (MPa)	15.548	15.106	14.691

Figure 9. Optimum Designs from ANSYS

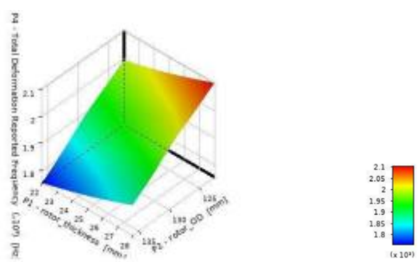

Figure 10. Response surface of deformation

Hence, we achieved the optimal design within the specified limitations and hardware constraints.