BorgWarner Turbo Systems

Turbocharger Impeller Frequency Study

Western Carolina University

School of Engineering + Technology

Original Objectives

- Develop and validate a modal analysis methodology for turbo charger impellers.
- Identify sources of errors such as modelling or measurement limitations.
- Investigate the impact of current manufacturing processes such as machining, mold casting and balance cuts.
- Develop strategies to quantify and/or mitigate the impact of the inherent limitations and real-world challenges.

Requirements

Req#	Requirement	Description	Verification	Requirement Type	Met/Unmet
1	Repeatable	The yield process will be able to be repeated by others with the desired predictions	Demonstration	Performance	Met
2	Reproducible	Standard deviation of results must be within 5% of each other	Demonstration	Performance	Unmet
3	Straightforward	The derived instructions will be easy to follow and perform	Demonstration	Performance	Met

Concepts

Develop an accurate test method to measure the natural frequencies and mode shapes in the provided impeller assembly. The results of these measurements will become the benchmark modal parameters by which the FEA model will be compared to. The FEA model will be developed on ANSYS using the provided CAD model. From this point, the team will develop hypothesis for why the analytical model is incorrect.

FEA Approach:

Explore potential errors in the FEA modeling such as meshing errors, material properties, damping, ect.

Material Approach:

Explore how the manufacturing process may impact the natural frequencies and modal parameters. Specifically, examine each stage in the manufacturing process, including wax mold machining, material being used for casting, The casting process, shaft welding, fine tuning/balance cuts. Perform modal analysis on an impeller from each stage of the manufacturing process. This approach assumes that the FEA is unlikely to be wrong. In addition, acquire good and bad specimens for material testing (hardness testing, acid etching to analyze grain structure)

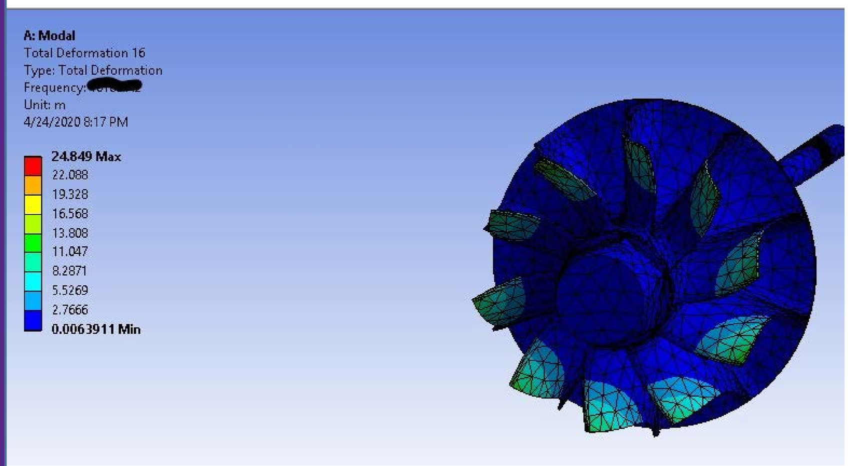
Problem Statement

Develop a methodology for predicting the natural frequencies and mode shapes of turbocharger impellers (turbine). Validate the methodology against experiments.

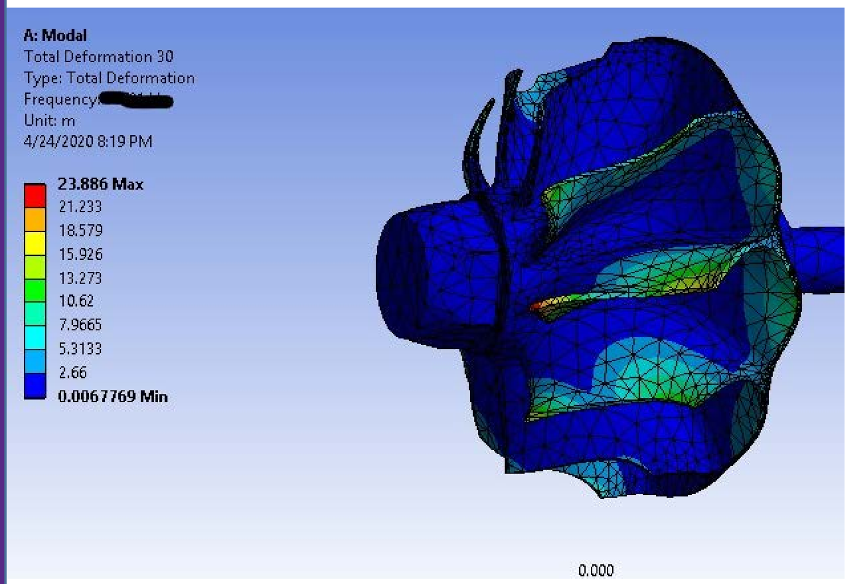
Final Design/Results *

- Through laser vibrometry, the team was able to obtain modal frequencies for a turbine impeller for a turbo charger.
- Finite element were developed to predict the modal frequencies for the first 3 mode shapes.
- Through material testing and FEA simulation, the team was able to predict the frequencies for the first 2 mode shapes within 5%.
- Further testing through Ansys and through laser vibrometry will be required to more accurately predict the modal frequencies.
- Borg Warner has been provided methods that will allow them to complete any further analysis needed.

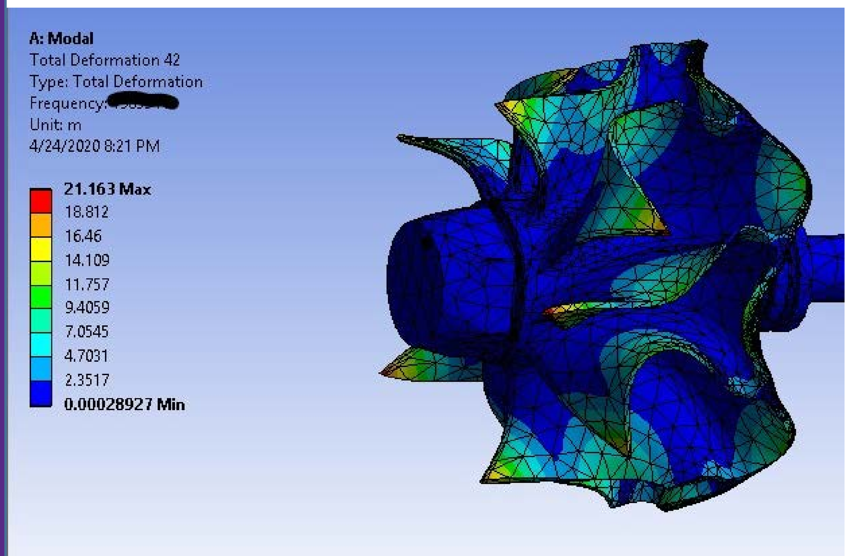
1st Mode Shape



2nd Mode Shape



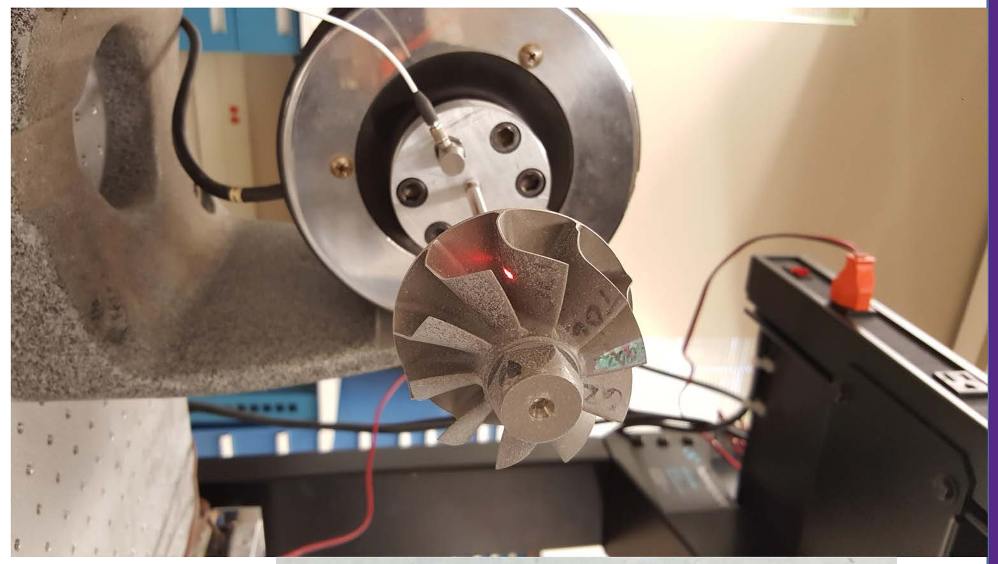
3rd Mode Shape



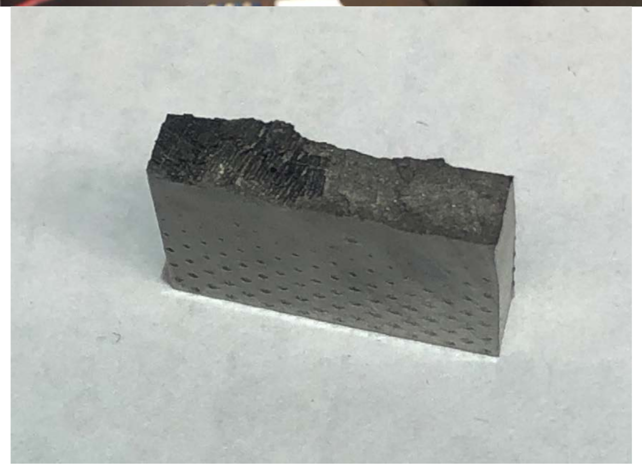
- In order to complete this project, laser vibrometry was used.
- The polytec laser vibrometer in the Rapid Center was used to perform all scans of the turbine wheel
- The turbine wheel was fixed to the electrodynamic shaker on the vibrometer using a custom designed and machined fixture

- Laser vibrometer setup

- Turbine wheel fixed to shaker with accelerometer



- Casting defect in a material sample



* On March 16, 2020 classes and labs were closed to students due to the COVID-19 Pandemic. Without access to fabrication and testing equipment, Objectives and Deliverables were modified accordingly.

Modified Objectives*

Due to COVID-19 some of our objectives had to be modified or outright disregarded. Any of the original objectives involving the compressor wheels has been disregarded due to lack of access to fabrication equipment and very limited access to test equipment. The following are unrelated to the compressor wheels:

- Tensile test material specimens. Without access to labs, we will be unable to use the tensile tester.
- Acid etch material specimens. Lack of time, and unable to access the labs makes this test uncompletable.

COVID-19 had a significant impact on how our team operated. Being restricted to only digital communication largely complicated testing of the turbine wheel. The computer that had the Ansys licence on it was remotely accessible, however the fashion in which we had remote access made it largely unusable. Our project revolved around special lab equipment and without direct access to that equipment, it made it difficult or even impossible to complete several of our initial deliverables. In an effort to continue to project, we arranged for our faculty mentor Dr. Jeff Bevan to carry out vibrometer testing under our instruction. This was successful, but it didn't get us much further.

Summary

Through vibrometer testing, we found that the individual blades on the turbine wheel had a variation of 10% for the first mode shape. For the second mode shape, the variation between the different blades came to be over 13%. With such a large range in frequency mode shape, and the fact that one of the inconel samples had a defect, we came to the conclusion that the blades are non-isotropic. We theorize that this is caused during the manufacturing process. It could be a flow issue within the investment casting or it could be non-uniform cooling/annealing of the parts.

Team & Acknowledgements

- Logan Hedrick: B.S. Engineering, Mechanical
- Danielle Tesoriero: B.S. Engineering, Mechanical
- Sawyer Strand: B.S. Engineering, Mechanical
- Andrew Merrill: B.S. Engineering Technology
- Logan Sluder: B.S. Engineering Technology
- Paul Troxler: Senior Staff Engineer at BorgWarner Turbo Systems, Sponsor POC
- Dr. Jeff Bevan: Faculty Mentor