DEVELOPMENT OF A MAGNETIC GEAR ACOUSTIC OPTIMIZER

An Undergraduate Research Scholars Thesis

by

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This project did not require approval from the Texas A&M University Research Compliance & Biosafety office.

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ABSTRACT

Development of a Magnetic Gear Acoustic Optimizer

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Contactless magnetic gearboxes have been identified by NASA and others to be a potential key enabling technology necessary to realize future fully electric aircraft and spacecraft. These gears are significantly more efficient and reliable compared to mechanical gearboxes. Additionally, mechanical gearboxes are louder than magnetic gearboxes; however, the acoustic noise produced by magnetic gears is typically isolated to a few frequencies as opposed to a wide spectrum. Identifying and eliminating the sources of this noise would significantly improve the attractiveness of magnetic gears to companies.

Furthermore, developing and testing magnetic gears can be very time intensive. Magnetic gears typically fall into two broad categories: axial flux gears and radial flux gears. Designing either of these gear types can be tedious due to the relatively large number of components, especially since each gear model must be nearly identical when testing various parameters. In

addition to creating these models, simulating magnetic gears usually required importing force vectors to emulate the magnetic forces imposed upon the gear during various modes of operation. Individually adding upwards of one hundred force vectors is extremely inefficient. This research aims to create several automation scripts aimed at resolve these issues.

This research involves the development of a lightweight, modular data analysis tool designed to analyze the acoustics of magnetic gears. The tool will provide a quick analysis of acoustic data and output design optimization suggestions. These optimization suggestions will allow the user to determine how various parameters affect the acoustics that the magnets gear generates. Data used for these calculations will be stored within a local database that can be accessed by the user. The analysis tool also includes functionality for generating plots of the data being analyzed. While base data for this analysis tool will be provided, the tool is designed to use data provided for the user that is specific to the gear design they are testing since different designs could have significantly different input data.

Additionally, several companion automation scripts will be developed to allow for the rapid creation and testing of magnetic gear simulation models. These scripts will assist in generating simple magnetic gear models from user-provided parameters. The automation scripts are designed to run directly in 3D modeling software and provide a significant amount of flexibility in their designs. The resulting gear models can serve as a base for more complex gear designs or as a quick method to determine the feasibility of a design. The scripts will allow for the creation of both a radial flux and axial flux magnetic gear. Another significant benefit of these scripts is the consistency of the gear models which will help to test a large number of gear models that slightly vary input parameters.

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Contributors

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Special thanks goes to Bryton Praslicka, a graduate ECEN student who supported me throughout the course of this project.

Thanks also go to my friends, colleagues, faculty, and staff in the Electrical and Computer Engineering department for making my time at Texas A&M University a great experience.

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1. INTRODUCTION

This document is an introduction to the Magnetic Gear Acoustic Optimizer, a model used to predict the acoustic noise generated by the operation of a magnetic gear. The optimizer will allow engineers to both implement alterations to reduce acoustic noise for current magnetic gears and adjust new designs to include these alterations. In addition to the optimizer, this document covers the development of several automation scripts designed to rapidly design and test magnetic gear models. This project will be useful for both companies wishing to implement magnetic gears in their products—such as electric vehicles—and for researchers who are experimenting with different magnetic gear designs.

1.1 Background

Gearboxes help reduce the size, weight, and cost of systems that use electric motors. They can be found in a range of applications, from electric vehicles to onshore wind turbines. However, mechanical gearboxes rely on physical contact between gear teeth, making them noisy and prone to maintenance and eventual failure. A relatively new technology—contactless magnetic gearboxes—has been identified by NASA and others to be a potential key enabling technology necessary to realize future fully electric aircraft and spacecraft. Magnetic gears typically excel in high torque, low speed applications but can also operate in the same capacity as mechanical gears [1]. Unlike mechanical gears, magnetic gears significantly reduce the required maintenance and avoid many of the issues which derive from the meshing of physical gear teeth [2]. One of these issues is acoustic noise. Mechanical gearboxes are louder than magnetic gearboxes; however, the acoustic noise produced by magnetic gears is typically isolated to a few frequencies as opposed to a wide spectrum [3]. Identifying and eliminating the sources of this noise would significantly improve the attractiveness of magnetic gears to companies. One known source of this noise is vibrations that occur due the spinning of the magnetic gear and slight imperfections in the magnetic gear casing [4].

This research involves the design, creation, and testing of a model that can be used to predict the acoustic noise generated by a magnetic gear. This model will use data generated from the experimental testing of several prototype magnetic gears. The data from these tests and the analysis of these results in conjunction with the data model will help to identify the sources of noise in the magnetic gear designs. Identifying the sources of this noise will allow for the development of more efficient, quieter magnetic gears. Additionally, this research will focus on various ways to optimize the design process of magnetic gears, specifically in the virtual model design and creation. This will take the form of several related automation scripts designed to quickly design a gear model and prepare it for simulation testing. Reducing the time it takes to generate models and improving the design consistency of these models will allow for more precise testing of magnetic gears.

1.2 Overview

This project will focus on the analysis of acoustic data for magnetic gears and the incorporation of this data into a predictive model. Using previously collected data and the corresponding magnetic gear, an acoustic model will be created and integrated into a locally hosted web page. This model will generate estimations of acoustic levels based on various magnetic gear parameters. These parameters include values such as the speed of the gear, the torque, and any other parameters defined by the user. To ensure the accuracy of the model, the physical magnetic gear will be tested against the acoustics predicted by the model. After verifying the model, the maximum and minimum requirements for the magnetic gear can be inputted into the model in order to determine the minimally predicted acoustic noise. Further points of optimization for the magnetic gear will also be identified. These various optimizations can be reincorporated into the original design files of the magnetic gear; this will refine the simulated models and can be used to manufacture a more acoustically optimized gear.

This project will also focus on the development of several automation scripts to speed up the development of magnetic gear models. These scripts will be able to generate models for both radial flux and axial flux magnetic gear models. Two scripts will be created, one for each type of gear, and will use input provided by the user to generate a magnetic gear model with the corresponding parameters. Additionally, there will be a script to assist in the mechanical analysis of the gear designs This will be done by automating the addition of calculated force vectors onto various parts of the gear. Finally, there will be a script to automatically add new data into the acoustic model that is being developed in parallel. Together, these scripts will significantly reduce some of the repetitive and tedious processes involved in designing and testing the magnetic gear models.

The process of designing, creating, and testing a magnetic gear is extensive and certain parts of the process fall outside of the scope of this project. The concept and design of the magnetic gear being used to create the acoustic model has already been determined. Additionally, the individual components of the gear have already been manufactured; these components will need to be adjusted and minorly modified but otherwise are ready. Some magnetic gear acoustic data has already been collected for use in verifying the accuracy of the model being created. Additional data will be collected as needed.

2. METHODS

This project will focus on the analysis of acoustic data for the magnetic gear and the incorporation of this data into a predictive model. The data being used for the acoustic model will be a combination of new and old data that has been collected through the use of an acoustic chamber. The sound data has been further post-processed using Fourier decomposition analysis to determine the harmonic frequency spectrum and the power of each frequency. Additionally, this project will focus on streamlining and standardizing the process of magnetic gear model generation. This will be achieved through the creation of automation scripts that run within ANSYS 3D modeling and analysis tools. These scripts can be used separately but are designed to run sequentially. Furthermore, these scripts allow for adjustments and modifications to be made to the model in between scripts.

2.1 Project Scope

The objective of this project is to develop the Magnetic Gear Acoustic Optimizer and create several automation scripts for developing a magnetic gear simulation model. The optimizer should be capable of predicting changes to the acoustics of a given magnetic gear design and should be able to refine this prediction if provided with new data. The automation scripts should each run under one minute and produce a testable magnetic gear model. This project will use some example data to test functionality but will not provide a database of data to be used when running the model; this data will need to be provided by the user since each magnetic gear design will behave slightly different compared to all other designs.

The process of designing, creating, and testing a magnetic gear is extensive and certain parts of the process fall outside of the scope of this project. The concept and design of the magnetic gear being used to create the acoustic model has already been determined. Additionally, the individual components of the magnetic gear have already been manufactured.

2.2 Operational Description

The Magnetic Gear Acoustic Optimizer is intended to act as a tool used in the development process of magnetic gears. The optimizer is intended to work with other tools—both software and hardware based—in the design and fabrication sections of the magnetic gear development process. The model will provide feedback for current designs and guidance for design concepts. The automation scripts will primarily work within the magnetic gear modeling software (ANSYS) and facilitate the initial gear model creation. These scripts will also partially assist in the testing performed on the simulation model of the magnetic gear.

There are two main systems that will be developed over the course of this project: the acoustic model subsystem and the automation scripts subsystem. The acoustic model subsystem can be broken down into three main components: the graphical user interface, the acoustic model, and the database. The automation scripts consist of five major scripts: the radial flux base model designer, the axial flux base model designer, the orientation generator, the force adder, and the gear tester.

Both the radial flux base model designer and the axial flux base designer are intended to be run from an empty modeling environment in SpaceClaim; they serve as the first step in designing a magnetic gear. The orientation generator is only intended to be used for cycloidal magnetic gears and is designed to run immediately after the radial flux base model designer. This script also runs in SpaceClaim. The force adder can be run after any modeling script and is supposed to be run in ANSYS Mechanical. The gear tester script is integrated into the Magnetic Gear Acoustic Optimizer and is intended to be used when testing physical magnetic gears.

2.3 Modes of Operation

The primary mode of operation for the Magnetic Gear Acoustic Optimizer will be an interactable model which predicts the intensity of the acoustic noise for a given set of magnetic gear parameters. This model will also dynamically adjust to new data imported into the model by the user. The magnetic gear parameters typically used by the model will include the number of magnets, operating speed, and the gear housing thickness. This mode of operation is intended to be used in the initial design process of the magnetic gear but can also be used to verify collected data. Another possible use of this mode is to check if a set of parameters fall within the realm of possibility; this mode can verify if a given speed, torque, and other parameters generate an acoustic noise magnitude under the maximum allowable value.

The other mode for the Magnetic Gear Acoustic Optimizer will be mainly used for refining the model to account for new data. This mode would take a set of collected acoustical data and magnetic gear setup as input and add this new dataset to the data already used within the model. This mode would then update the model to reflect the new data. This configuration would be primarily used by researchers who are training the model for their specific magnetic gear setup.

The automation scripts only have one mode of operation which is used for developing a magnetic gear model. This mode would be used for developing a new magnetic gear model either from scratch or from an existing model provided by the user. In both cases, the scripts are functionally identical. This configuration would be primarily used by companies or researchers who are designing or developing a new magnetic gear model.

2.4 Applications

The Magnetic Gear Acoustic Optimizer is intended for two main groups: companies who would use magnetic gears in their products or researchers looking to optimize various use cases of magnetic gears. Companies would use this tool to determine some of the specifications of the magnetic gear or determine the feasibility of an existing design. Alternatively, researchers would use this model to help refine their simulation models, and they would also use their experimental data to refine the acoustic model to better suit the specific gears they are utilizing. In both of these cases the Magnetic Gear Acoustic Optimizer will be able to quickly estimate and report the predicted acoustic for the gear design being analyzed. This data will significantly increase the ease of designing magnetic gears.

In order to use Magnetic Gear Acoustic Optimizer, a basic understanding of how magnetic gears operate and how to interpret the acoustical data is required. Furthermore, to use some of the secondary functionality, a more thorough understanding of magnetic gears is likely required. These levels of understanding would be based on the user's knowledge of the magnet gear structure, the impact of the orientation/number of magnets, the influence of the magnetic field generated by the gear, and the various materials incorporated into the gear. Since it is unlikely that companies need access to the secondary features provided, this level of required knowledge is acceptable. In the case that they did need access to the secondary features, they would be able to refer to the support documentation.

The automation scripts are more geared towards researchers. These scripts require a moderate understanding of modeling software and how magnetic gears operate. Running the scripts with the desired input values is very simple and efficient. However, if the user wishes to apply secondary scripts (the orientation generator or the force adder) to a model that they have designed separately, then they would need a relatively deep understanding of how the modeling software works. While it is not recommended, the documentation for the automation scripts includes how to use the scripts in this manner. Companies with a good understanding of SpaceClaim and ANSYS would be able to use these scripts in the same capacity as mentioned above.

Support for the Magnetic Gear Acoustic Optimizer and the automation scrips will be provided as a combination of a user’s manual and code documentation. The user’s guide will contain information on both modes of usage for the optimizer and provide some basic troubleshooting information. The optimizer itself will also include some base data for an initial predictive model. All automation code that is created will include internal documentation as well as a basic breakdown within the user’s manual. The user’s manual will also include the requirements for running each script on a 3D model; with the correct model setup, it is possible to customize the gear model between running each script.

3. RESULTS

The Magnetic Gear Acoustic Optimizer will significantly increase the ease of magnetic gear testing and design. The system will process acoustic data and speed up the process of magnetic gear model creation. All computations and data will be stored locally for data security. The Magnetic Gear Acoustic Optimizer can be divided into two main subsystems: the acoustic model subsystem and the automation scripts subsystem. The two subsystems function independently in the magnetic gear creation process (Figure 1). Each subsystem has been tested and validated for general and edge cases. Since each subsystem has been validated and fulfills its proposed requirements, there is a clear path to integration for these subsystems into a single, complete system.

3.1 Acoustic Model Subsystem

The acoustic model subsystem is the primary system of the Magnetic Gear Acoustic Optimizer. This subsystem is responsible for the processing and manipulation of the acoustic data measured from the magnetic gears being tested. In addition to acoustic data, the acoustic model includes functionality to work with other magnetic gear data including efficiency and torque. This subsystem comprises of three smaller components: the acoustic model, the graphical user interface, and the database. All three of these components were programmed in Python. Each individual component of this subsystem and the complete subsystem were tested to validate the system's performance and reliability.

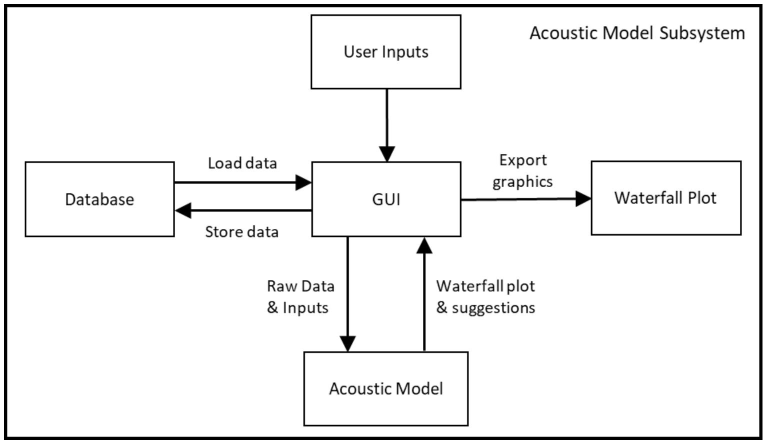


Figure 1: Acoustic Model Subsystem Block Diagram

3.1.1 Acoustic Model

The acoustic model is responsible for all the calculations performed by the acoustic model subsystem. This model generates graphs, creates suggestions, and manipulates data based on the raw data passed from the database and user inputs received via the GUI.

3.1.1.1 Operation

The acoustic model uses raw data and some user-specified parameters to generate graphics and suggested gear design alterations. These outputs are sent to the GUI to be displayed to the user. Several Python packages are used in this component including numpy, pandas, and matplotlib. Numpy is used for data calculations and is used to predict possible changes that would improve or worsen the acoustics generated by the magnetic gear with the given data. Pandas is a database management package and interprets the data passed from the database. Matplotlib is used to generate images based on the received data.

3.1.1.2 Validation

The acoustic model was validated by using a known data set. The output of the known data set was calculated manually and then compared to the output of the acoustic model. This was performed for all the different combinations of X, Y, and Z parameters. Additionally, the suggested alteration provided by the model is compared to the known response from changing than parameter. The graphs generated and the suggested alterations both matched their expected values.

3.1.2 Graphical User Interface (GUI)

The graphical user interface (GUI) is the main controlling hub for the subsystem. The GUI is responsible for accepting input from the user and generating the desired outputs. This component also passes data to and from the other two components.

3.1.2.1 Operation

The GUI is created using a Python package called Streamlit. Streamlit is used to format and run a local web page. This web page has three main tabs: the acoustic model page, the database page, and the gear tester assistant page. The acoustic model page is where the used can manipulate the data input to the acoustic model and view the resulting output. The database page is where the user can add data to the database or save the database to an Excel document. The final page—the gear tester assistant—falls under the automation scripts subsystem but was included in the GUI so that the new data could be easily imported to the acoustic model.

The acoustic model page is based around an image generated by the acoustic model component. Above the image is a download button that will allow the user to save the image depicted. Below the image are several settings that allow the user to manipulate the image and change the inputs to the acoustic model component. The expandable section labeled “View Orientation” contains two value sliders that change the orientation of the graph. Under this section, there are three drop-down menus that control the three parameters’ inputs to the acoustic model. The final component is a button that turns the scatterplot into a plot of the curve predicted by the acoustic model.

The database page starts with an expandable section that specifies the requirements for uploading new data as an Excel file. Below these instructions, there is a file upload field that prompts the user to upload a file. This field will only accept Excel (.xlsx) files.

When a file is uploaded, new GUI elements are created to allow for the management of this new data. A data-framer viewer of the new data is created. Additionally, two buttons are created; one button uploads the new data to the stored database and the second button exports the new data as an Excel file. If multiple Excel files are uploaded, each individual data set will be combined into a single data-frame.

The final section of the database page is the current data section. This section has a data-frame viewer of the current database. Under the data-frame viewer is a download button that will allow the user to download the current database as an Excel file.

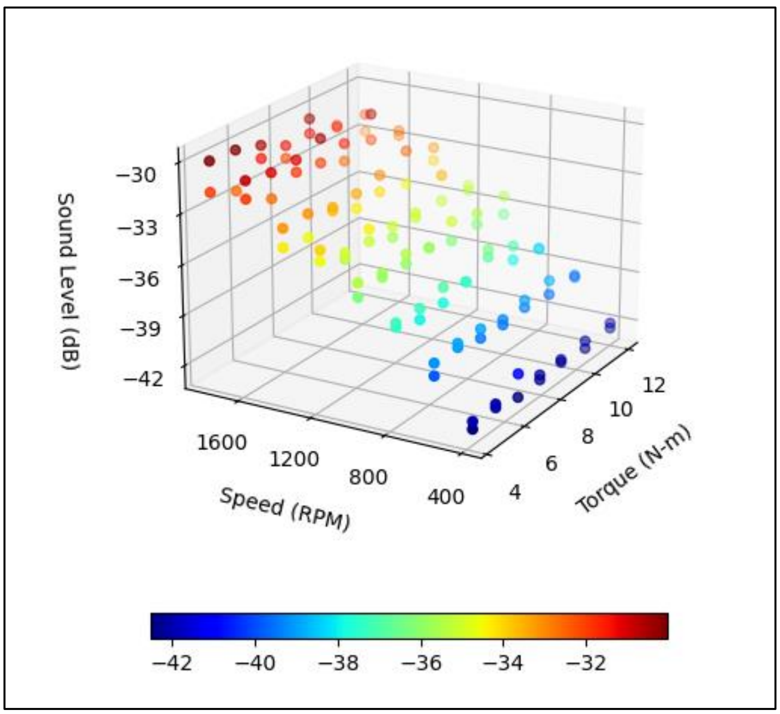


Figure 2: Example Output

3.1.2.2 Validation

The GUI was validated by sequentially testing each GUI element. These elements include value sliders, text fields, buttons, expandable sections, drop-down menus, file upload fields, file download buttons, and data-frame viewers. Each GUI element worked as expected. Additionally, the integration between the GUI, acoustic model, and database were all tested and verified to be functioning correctly.

3.1.3 Database

The database is responsible for storing data between program runs. This component interfaces with the GUI but can also be directly edited.

3.1.3.1 Operation

The database is saved as an Excel file with the parameter name as the top row. Column A holds an index value that is unique for each individual data set. New parameters would be added to the column that is immediately right of the right-most column, and new data sets would be added below the data set with the highest index. Additionally, this is very similar to the format for uploading large amounts of data into the database through the use of the GUI. The GUI has functionality to combine the current database with a database that is uploaded by the user. This is to allow for large amounts of data to be rapidly integrated into the acoustic model as opposed to entering each data point individually.

3.1.3.2 Validation

The database was validated by both manually updating the data in the database and adding data through the GUI. After changing the database, the values in the database data-frame viewer and the acoustic model graph were checked to see if they were successfully updated. The database worked as expected with the caveat that the GUI only displays these changes when the

GUI web page is refreshed. This refresh happens automatically when certain GUI elements are used. Furthermore, the functionality of uploading an Excel file to be added into the database was verified through the use of the GUI; an example dataset was uploaded and then manually verified to be imported in the correct style and formatting. The resulting acoustic model was also checked and found to be correct.

3.2 Automation Scripts Subsystem

The automation scripts subsystem consists of a series of programming scripts designed to speed up the process of creating magnetic gear models. These scripts were created to run sequentially and to build upon the output of the previous script. This subsystem involved four Python scripts: the base model designer, the orientation generator, the force adder, and the gear tester. Each individual component of this subsystem and the complete subsystem were tested to validate the system's performance and reliability.

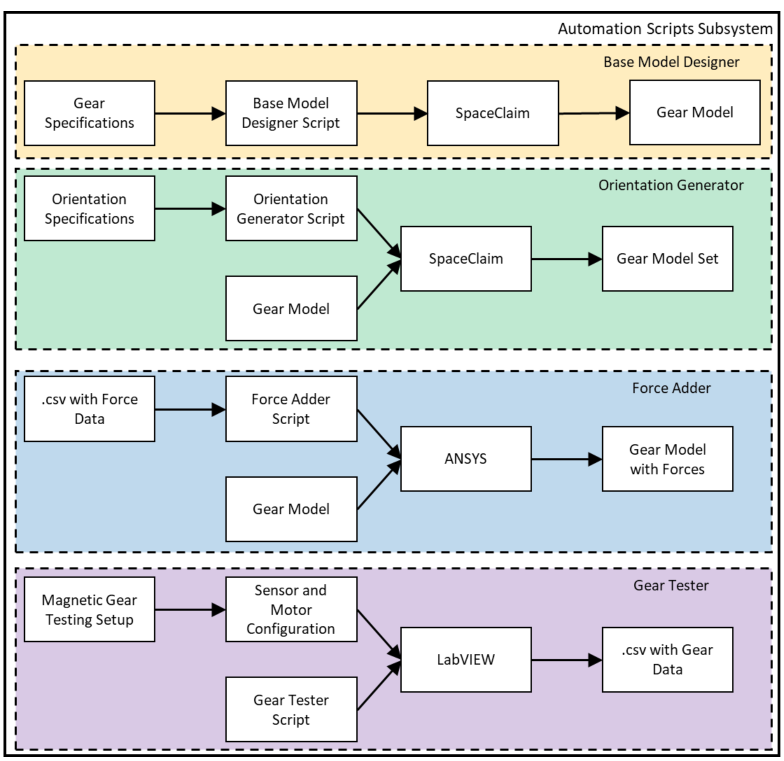


Figure 3: Block Diagram for Automation Scripts Subsystem

3.2.1 Radial Flux Base Model Designer

The base model designed is designed to be the first script to be executed when designing a new magnetic gear model. This script will take a set of gear parameters as input and output a SpaceClaim model that can then be used with the orientation generator and force adder. This is one out of two possible gear base model generators.

3.2.1.1 Operation

The radial flux base model designer takes gear radius, gear thickness, axle offset, axle number, magnets number, and magnet spacing as input. These parameters can be changed by the user; however, certain combinations of parameters will cause the program to not run correctly. Error handling has been added in order to prevent the program from executing if an invalid set of inputs are detected. The input parameters are used to generate an inner rotor, outer rotor, and axle set (Figure 8). The script is run directly in SpaceClaim through the integrated scripting editor.

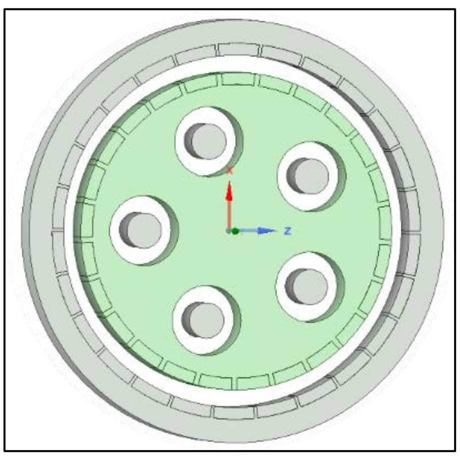


Figure 4: SpaceClaim Model Generated by Radial Flux Base Model Designer

3.2.1.2 Validation

The radial flux base model designer was validated by testing various input parameters and checking the output compared to a manually created model. The models were compared by checking the dimensions of each corresponding component and ensuring they were within 0.1% accuracy. The reason for this tolerance is due to rounding done by some of the functions used when calculating component dimensions. The script performed as expected and functioned correctly for a wide variety of different inputs. Additionally, the script ran in under sixty seconds and produced an identical output given the same input parameters.

3.2.2 Axial Flux Base Model Designer

This is an alternative base model designer created for generating axial flux magnetic gear models. This script is compatible with the force adder; however, this script is not intended to be used in conjunction with the orientation generator. Similar to the original model designer script, a set of gear parameters will be used as input in order to output a SpaceClaim model

3.2.2.1 Operation

The axial flux base model designer takes gear radius, rotor thicknesses, rotor spacing, rotor axle radii, number of magnets per rotor, magnet size, magnet spacing, and modulator parameters as input. These values can be changed by the user and are used to generate an inner rotor, outer rotor, and axle set (Figure 4). Error handling is also present as described in section 3.2.1.1. The script is run directly in SpaceClaim through the integrated scripting editor.

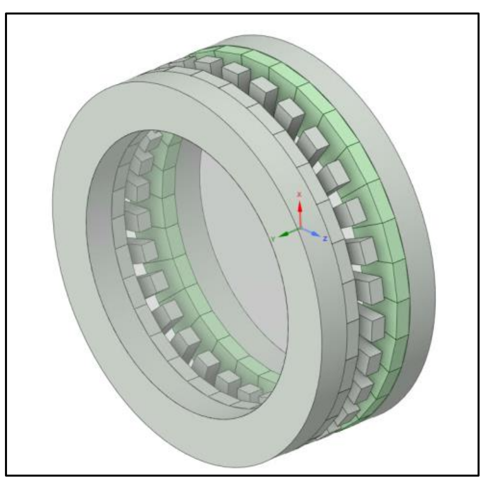


Figure 5: SpaceClaim Model Generated by Axial Flux Base Model Designer

3.2.2.2 Validation

The base model designer was validated by testing various input parameters and checking the output compared to a manually created model. The models were compared by checking the dimensions of each corresponding component and ensuring they were within 0.1% accuracy. The reason for this tolerance is due to rounding done by some of the functions used when calculating component dimensions. Additionally, the functionality for including no spacing between the rotor magnets was tested since this specific spacing in not required in an axial gear design. The script performed as expected and functioned correctly for a wide variety of different inputs. Furthermore, this script ran in under sixty seconds and produced an identical output given the same input parameters.

3.2.3 Orientation Generator

The orientation generator creates a file set of all desired orientations of a magnetic gear. This program is primarily for cycloidal magnetic gear models since these models need analysis done on multiple different orientations. This script is intended to be ran directly after the radial flux base model designer, specifically for cycloidal gear designs.

3.2.3.1 Operation

The orientation generator takes a file path, save name, number of saves, orientation angles, and gear radius as input parameters. These parameters can be changed by the user. The program outputs a file folder with all the saved models (Figure 9). If the file path specified by the user does not refer to an empty or non-existing folder, then the program will not execute and provide an error message to the user. This is to prevent the program from overwriting old data. The script is run directly in SpaceClaim through the integrated scripting editor.

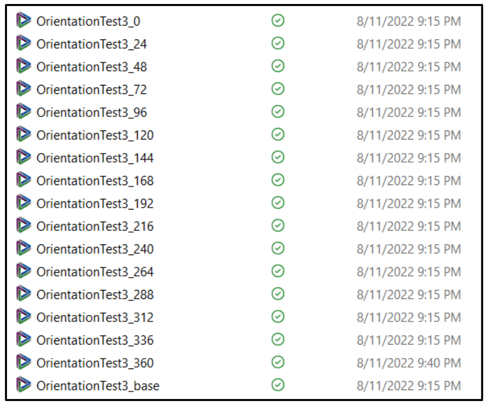


Figure 6: Orientation Generator Output

3.2.3.2 Validation

The orientation generator was validated by testing several models with various number or orientations and various angles. The resulting file set was individually checked to ensure that the models were saved correctly. Additionally, several tests were done with non-empty folders to ensure the program would not accidentally overwrite anything. The script worked as expected. The orientation generator's runtime depended on the number of gear variations being generated; however, the runtime was typically under sixty seconds. Additionally, the script produced the same output for a given set of inputs.

3.2.4 Force Adder

The force adder takes a list of force data and applies that data to a 3D model. The program is designed to work on either the inner rotor or the outer rotor. Other model components should be removed or suppressed for calculations to ensure that the script runs correctly.

3.2.4.1 Operation

The force adder uses an Excel file to add force vectors on to a magnetic gear model (Figure 5). To run this script, the magnetic gear model needs to have labels assigned to each outer magnet face so that the program can correctly assign the force vectors. These labels could be manually added into an existing model; however, both the radial and axial base model designers automatically add these labels into their respective gear model. This script can also be adapted to add forces onto different components by switching the labels being targeted.

The force adder takes a file path as input in order to read in the force vectors. This file path can point to either a text file or an Excel file. The script pulls the provided force vectors and assigns them to the relevant portion of the model. If the section of the model being edited has existing force vectors, the script will remove the older vectors and replace them with the new values.

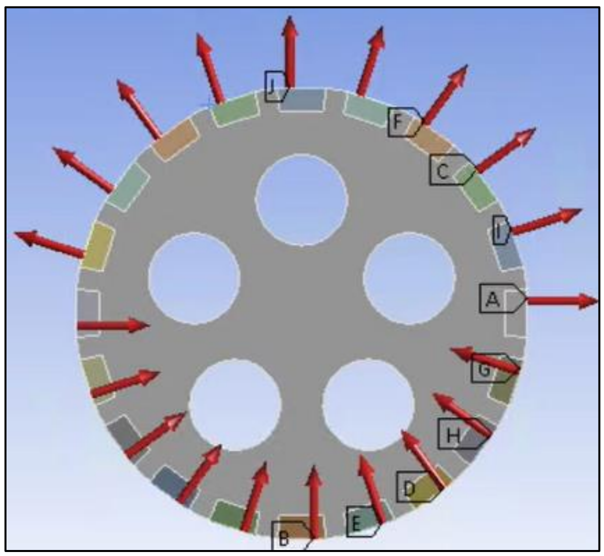


Figure 7: Force Adder Output

3.2.4.2 Validation

The force adder was validated by using several sets of force data with a corresponding magnetic gear model. The output of the script was checked against a magnetic gear model that had the forces added manually. The script worked as expected and the force vectors were identical to each other. The script ran in under thirty seconds and consistently added the correct forces to the correct sections of the gear model.

3.2.5 Gear Tester

The gear tester takes a single dataset as input and adds it to the database used by the acoustic model subsystem. The script is integrated into the GUI of the acoustic model subsystem and operates as a repeatable form.

3.2.5.1 Operation

The gear tester assistant takes inputs corresponding to the current parameters stored in the acoustic model subsystem's database (Figure 6). The corresponding dataset will be automatically added to the database. When a new dataset is added, the GUI will add a text output with the dataset below the form that added the new data. Additionally, a copy of the database viewer with the new dataset will be shown (Figure 7).

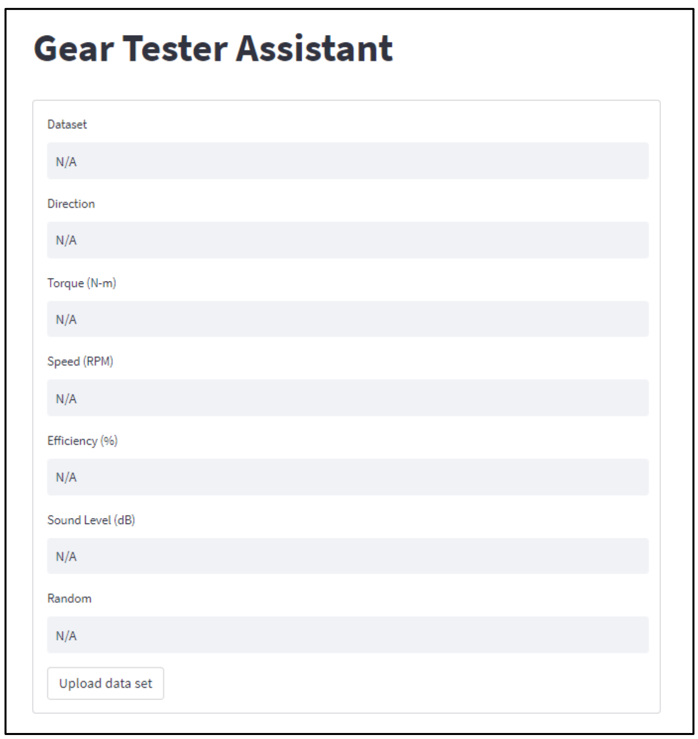
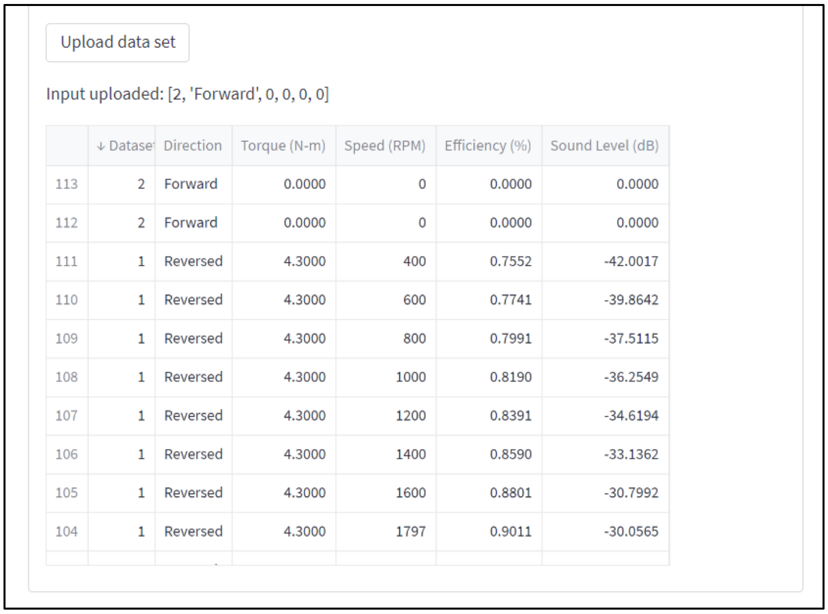


Figure 8: Gear Tester Assistant Page



Upload data set

Input uploaded: [2, 'Forward', 0, 0, 0, 0]

	↓ Dataset	Direction	Torque (N-m)	Speed (RPM)	Efficiency (%)	Sound Level (dB)
113	2	Forward	0.0000	0	0.0000	0.0000
112	2	Forward	0.0000	0	0.0000	0.0000
111	1	Reversed	4.3000	400	0.7552	-42.0017
110	1	Reversed	4.3000	600	0.7741	-39.8642
109	1	Reversed	4.3000	800	0.7991	-37.5115
108	1	Reversed	4.3000	1000	0.8190	-36.2549
107	1	Reversed	4.3000	1200	0.8391	-34.6194
106	1	Reversed	4.3000	1400	0.8590	-33.1362
105	1	Reversed	4.3000	1600	0.8801	-30.7992
104	1	Reversed	4.3000	1797	0.9011	-30.0565

Figure 9: Gear Tester with Added Data

3.2.5.2 Validation

The gear tester was validated by adding several new datasets and then ensuring that the data was accurately reflected in the acoustic model. Additionally, the new dataset was located in the Excel file that acts as the database to ensure it was added correctly. Overall, the script worked as expected.

4. CONCLUSION

The Magnetic Gear Acoustic Optimizer and supporting automation scripts will reduce both the time and money spent on magnetic gear design and development. They will provide a quick and relatively easy way of determining the impacts of different modifications on the acoustic noise generated by the magnetic gear. Furthermore, standardizing and streamlining the process of generating magnetic gear models will better facilitate the design of new magnetic gear model designs. This will allow companies and researchers to more efficiently alter existing magnetic gears or better design future gears to reduce the acoustic noise being generated. The adjustable nature of the acoustic optimizer will allow for the incorporation of new data which will result in more accurate measurements and enable new gear designs to be included. Additionally, this functionality allows for the acoustic optimize to adapt over time to newer designs; the model is future proof and will be usable for a relatively long time. The automation scripts for simulation model design will help to facilitate the design of magnetic gear simulation models and will significantly decrease the amount of time required to generate magnetic gear models.

4.1 Limitations

The two primary limitations of the Magnetic Gear Acoustic Optimizer are the lack of training data and the ease of use. Additionally, the model is only as good as the data it is being created with. Given that this project will only be collecting data from two magnetic gear designs and a lack of public acoustic data for magnetic gears, this model will only be able to provide a very rough prediction. Consequently, the model will be useful in what kind of adjustments to make but will lack the precision to give the precise adjustments. Additionally, this model will only be reliable for the type of magnetic gear that is used to generate the initial data. This can be compensated for by including data from different magnetic gear types; however, this falls outside the scope of this project. Ideally, a central, online database would be used to build up a repository of known acoustic data for magnetic gears; however, security concerns for the magnetic gear designs prevent this from being an option

Ease of use of the model is the other point of concern. Ideally, the model would be something that any company, researcher, or individual could use. However, there is a high likelihood that someone not familiar with magnetic gears would be unable to operate or correctly interpret the results of the model. Due to the nature of the acoustic data, it is difficult to perform the calculations necessary to identify the frequencies that generate the majority of the acoustic noise created by the magnetic gear.

Additionally, operation of the automation scripts for creating the magnetic gear models can be difficult to operate without substantial background knowledge. In the case of simply using the user defined parameters and leaving everything else unchanged, the script is easy to use. However, modifying the model between scripts or designing a model by hand to be used by these scripts will be significantly more challenging. The other significant limitation of the automation scripts is that they are designed only for SpaceClaim and or ANSYS software; if the user does not have this software, then these scripts would need to be recreated using their specific modeling software.

4.2 Impact

Given the widespread potential of magnetic gears, a consistent way to predict the acoustic noise generated by a magnetic gear would have a large impact. The Magnetic Gear Acoustic Optimizer will allow for magnetic gear designs to better fit any noise specifications and allow the user to design a gear that manipulates the generated noise in a way that does not affect the functionality of the gear. Having more control over the acoustic specifications would lead to the inclusion of magnet gears into more commercial products. Replacing mechanical gears with magnetic gears in vehicles would reduce the noise pollution that cars create which would reduce the necessity of highway noise barriers. With a better understanding of how much noise the magnetic gears generate, companies would be able to more optimally design machines with noise regulation. Magnet gears would also see more use in wind turbines, wave power, and similar forms of high-torque low-speed applications. Magnetic gears already outcompete mechanical gears in terms of efficiency and reliability. Reducing the acoustic noise generated by magnetic gears removes one of the few barriers preventing their widespread use. By reducing the acoustic noise of magnetic gears, their competitiveness against mechanical gearboxes will also significantly increase.

The use of automation scripts will also significantly improve the magnetic gear design process. Having an accurate and consistent way of generating magnetic gear models opens the door to further methods of automation. Pairing these scripts with an automation testing scripts will allow for researchers to meticulously test various magnetic gear designs quickly and reliably. These tests will allow for researchers to determine the optimal magnetic gear parameters for the specific applications they are working on. Due to the general nature of the automation scripts, they are not limited to acoustic noise testing but can also be used for determining the maximum torque, maximum speed, or other specifications.

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