MONTANA STATE UNIVERSITY

Department of Mechanical and Industrial Engineering

EMEC 405: Finite Element Analysis

Investigation of ANSYS Magnetostatic Engine

Final Report

By

Tanner Jergeson

Montana Marks

Walter Olson

For: Dr. Erick Johnson

Department of Mechanical Engineering, Montana State University, Bozeman, MT 59717

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Abstract

The Finite Element method is one of the most powerful tools available to engineers today. This method, when applied correctly, allows engineers to predict the behavior of material, structures, and other physical phenomena with a fair degree of certainty. However, it is necessary for the individual using the software to insure that the solutions they are obtaining are correct. The world of Computer Aided Engineering is very dynamic and new software is released frequently. This new software can sometimes mislead the user and give incorrect solutions. For this reason it is important for engineers to explore and validate any new software that might be used.

Introduction

For this project, the team will be exploring the function of the Magnetostatic block within ANSYS Workbench. The original premise of the project was to simulate a electromagnetic piston engine. By solving the system as a transient problem and simulating a piston oscillating within a cylinder, the team would try and solve for the forces exerted on the piston and the power output of the engine. However, due to the inability of creating a transient problem within the Magnetostatic block, the team decided to simplify the project objective. The new project objective would be to simulate an electromagnet and its effect on a steel cylinder. This new objective, although simple, would still prove to be a challenge for the team.

Procedure

Prior to obtaining an actual solution several unsuccessful attempts were made. With the first attempts, geometry was created within SolidWorks (Figure A1), exported as an .igs file and then imported to ANSYS Workbench for analysis. The first models consisted of geometry that was a coiled wire. However, it was determined shortly after, that building the coils into the geometry is unnecessary. The Magnetostatic project block inherently allows for the coil to be represented geometrically as a solid cylinder. This cylinder can then be defined within the solution setup as a coil having a specified number of turns, current direction, and current magnitude. It is also possible to specify whether the source conductor is stranded or solid. The current direction is established by creating a cylindrical coordinate system whose origin is located at the center of the coil cylinder.

The solution setup also involves specifying Magnetic Flux Parallel surfaces. This specification would prove to be a source of misunderstanding in the primary stages of the project. It was determined that in order to run the solution and generate a magnetic field, the geometry would require the creation of a cylinder of air surrounding the magnetic coil. The outer surfaces of the cylinder of air would be specified as the Magnetic Flux Parallels. However, through many bouts of trial and error it was also determined that no cylinders could intersect others. For this reason, the team would resort to creating the geometry within designmodeler. Within Design Modeler, the cylinder extrudes would be specified as a slice extrude command. This would insure that none of the cylinders created would intersect each other (Figure A2).

Through trial and error the following parameters were tested: cross-sectional area of coil, material properties, current, stranded or solid core, and location within the model. A tutorial was found online (shown in Appendix B) that provided an immense amount of help in the setup process.

Results

Through much trial and error, the team was able to induce a directional current within the coil cylinder using 10 amps and 1000 turns (Figure A4). This current and its direction can be seen in the Figure A5 vector plot. The current through the coil also induced a magnetic field within its surroundings. The magnetic field produced has the shape and direction that is as expected and can be seen in Figure A6. With the piston located within the magnetic field, there is a force vector that is applied to the piston. These force vectors with various mesh refinements can be seen in Figures A7 and A8.

In order to validate the results obtained from ANSYS, the equation shown below was used. This equation is derived from a combination of Maxwell's Equations[1]. The calculated value for the expected force on the piston is shown in Table 1.

$$F = (N \times i)^2 \frac{\mu A}{2g^2};\ [Newtons]$$

$$N = number\ of\ turns\ in\ the\ coil$$

$$i = current\ in\ amps$$

$$\mu = permeability\ constant\ for\ the\ core\ [H]$$

$$A = area\ of\ object\ being\ affected\ by\ magnetic\ force\ [m^2]$$

$$g = distance\ between\ electromagnet\ and\ object\ experiencing\ magnetic\ force\ [m]$$

As we can see from Table 1, the force vectors calculated with ANSYS are smaller than expected. When we compare these results with the ones obtained from the analytical solution we can see that the values do not agree. The reason for this discrepancy is unknown. Attempts at troubleshooting to determine the source of error were conducted. Various changes to the solver such as solution method, mesh refinement, current magnitude, and material properties were made in an attempt to determine the source of the error. However, these changes had little effect on the solution as a whole and the source of the error still remains unknown.

When comparing the values determined using the analytical solution to systems that are already in place, such as scrap yard crane magnets. This resemblance further condemns the solutions gathered from ANSYS.

Table 1:

Solution Method	Force on Steel Cylinder (lbf)
ANSYS	3.87e-5
Analytical	484.8

Conclusion

In conclusion, this project could be considered a success. The Magnetostatic block was used without any error but the validity of the results are questionable at best. This could have been due to a user error or it could be some sort of unknown discrepancy in the settings that was overlooked. Through much trial and error, this could not be fixed. However, a more advanced understanding of the Magnetostatic block was gained by the group members.

Appendix A:

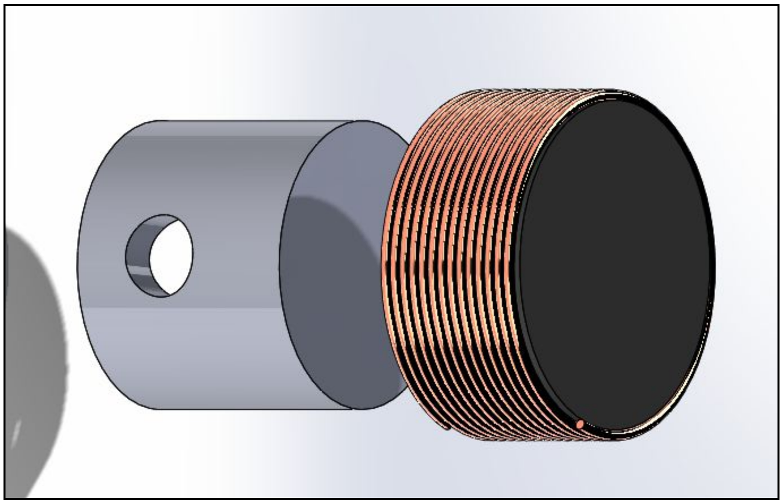

Figure A1: Geometry of the piston and electromagnet created in SolidWorks

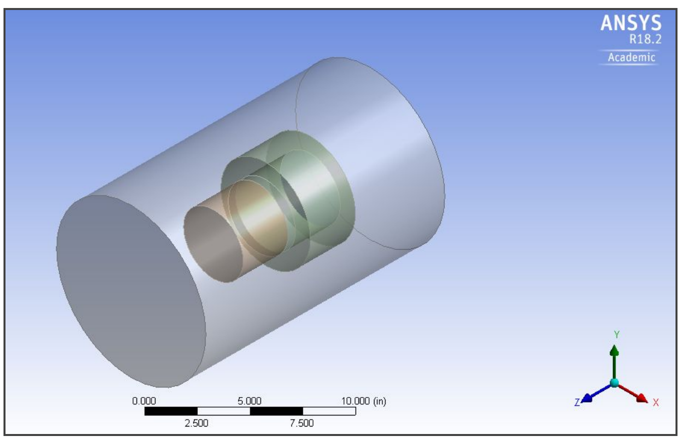

Figure A2: Simplified geometry created in Design Modeler showing the piston, core, coil, and air enclosure.

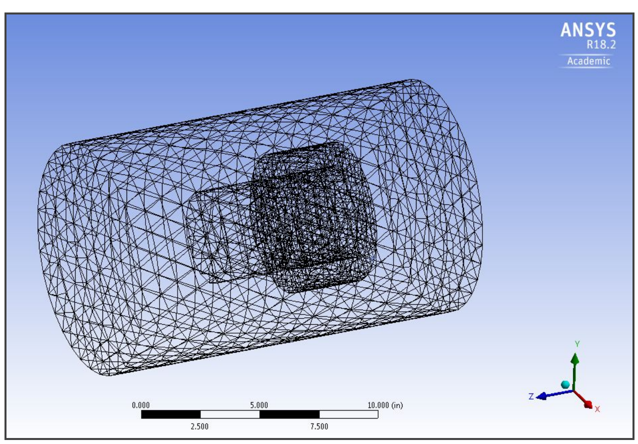

Figure A3: Representation of the mesh using a wireframe model.

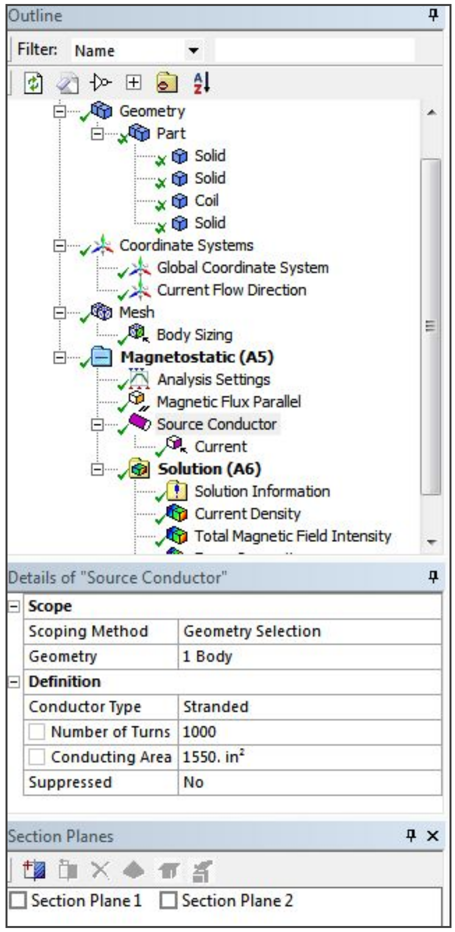

Figure A4: Screenshot showing the setup of the source conductor along with the various other components of the analysis settings.

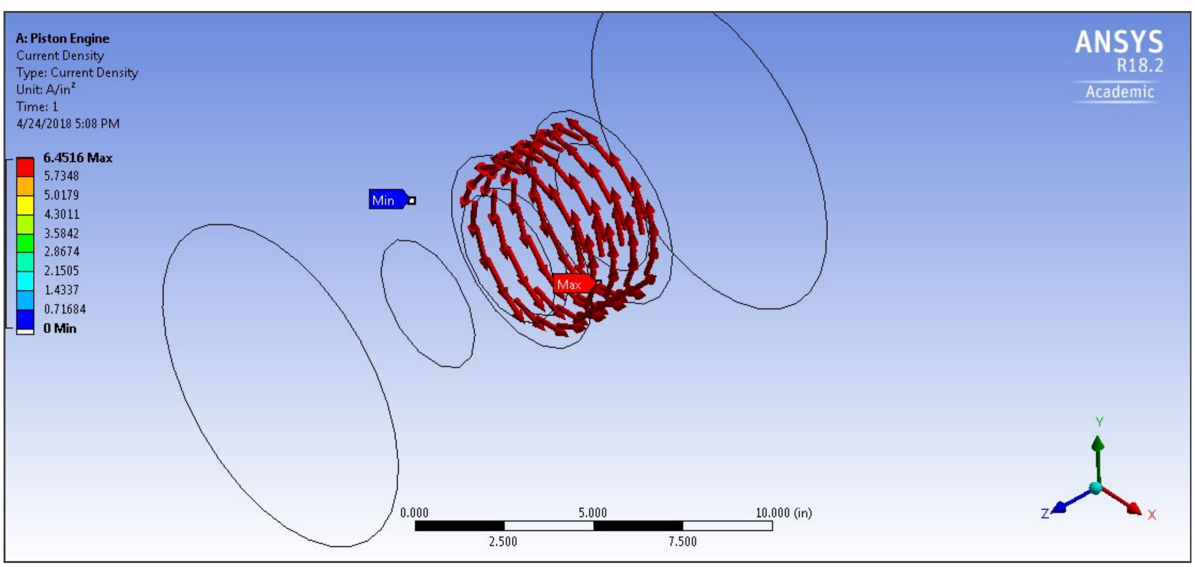

Figure A5: Vector plot of the current density [A/in^2] in the electromagnet coil.

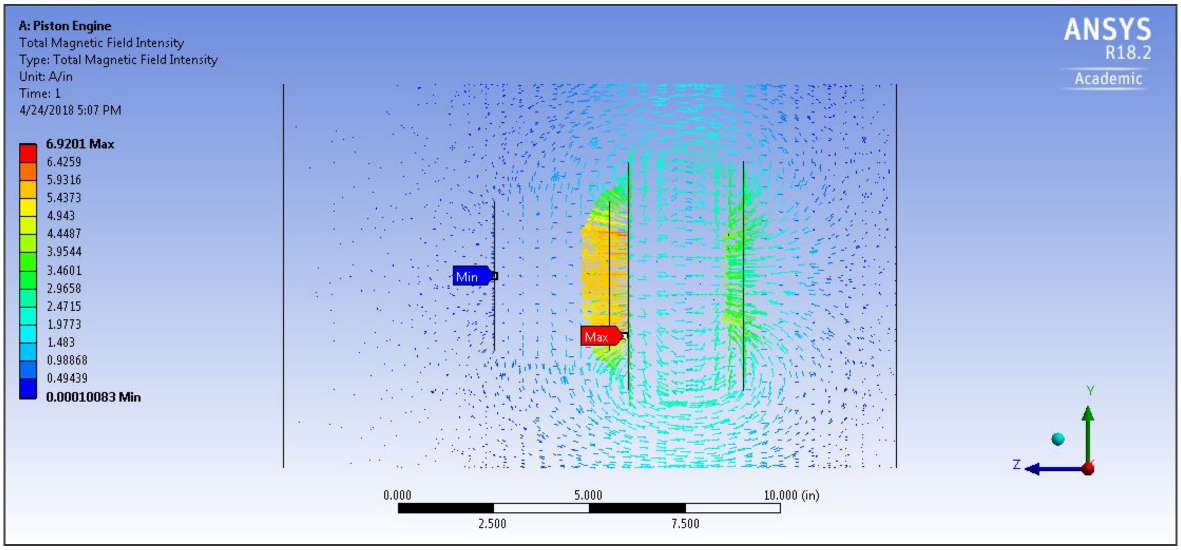

Figure A6: Vector plot of the magnetic field intensity [A/in] induced by the coil.

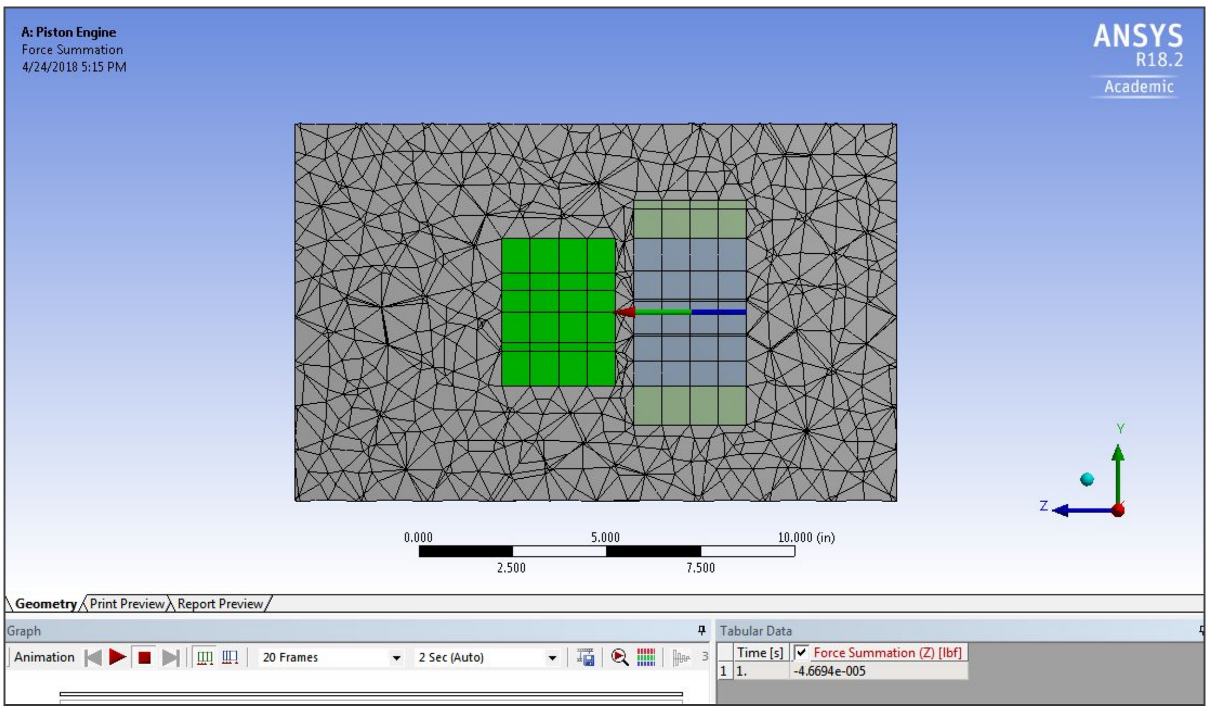

Figure A7: Screenshot of original, unrefined mesh with the force summation on the piston. The total force calculated by ANSYS was -4.6694e-005 lbf in the z-direction, meaning the piston is being pulled towards the electromagnet.

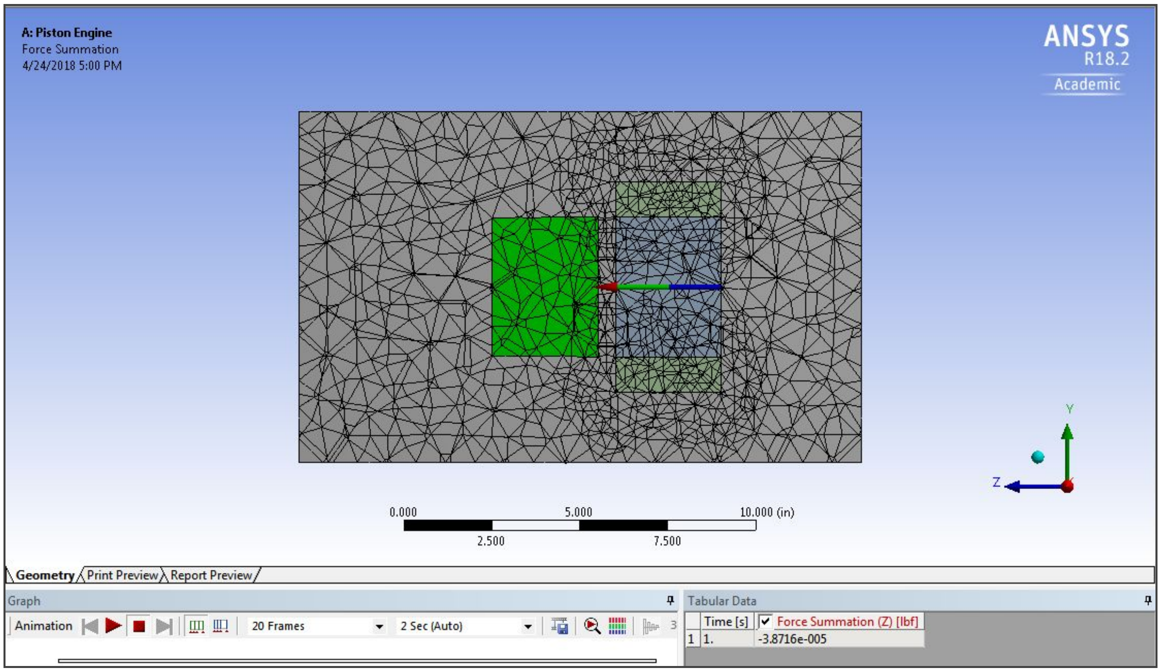

Figure A8: Screenshot of the refined mesh with the force summation on the piston. The total force calculated by ANSYS was -3.8716e-005 lbf in the z-direction, meaning the piston is being pulled towards the electromagnet.

Appendix B: Sources

1. Ulaby, F. T., & Ravaioli, U. (2015). *Fundamentals of applied electromagnetics*(7th ed.). Boston: Pearson.

http://oss.jishulink.com/caenet/forums/upload/2013/04/03/261/11723694506628.pdf