Semi-Linear Induction Motor

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Abstract

A Linear Induction Motor (LIM) is a specific type of alternating current (AC), multiple-phase machine that provides force and movement in a linear direction. Numerous applications of LIM's can be found in industry today, one of the most interesting being high speed magnetic levitation railway systems. The fundamental goal of this project is to determine the reasons for the limited functionality of the previous team's SLIM design. The current SLIM is using a rotor that was used for a magnetic levitation senior project. It is suspected that the problem with the existing rotor is that it has no ferromagnetic material beneath the conducting bars to increase the flux density in the air gap between the stator and the rotor. Therefore, a new rotor will be designed with a better magnetic circuit for this application. The SLIM will be thoroughly tested with the new rotor to quantify the improvement in functionality. If time permits, a microcontroller interface to provide operator input will be used in conjunction with a speed sensor and a Variable Frequency Drive (VFD) to provide simple open-loop control of the of the rotor speed.

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I. Introduction

A. Project Background

A linear induction motor (LIM) is a specific type of alternating current (AC) machine designed to produce motion in a straight line. A LIM operates under the same principles as its AC rotary motor counterpart, typically powered by a three-phase voltage source with a force that is produced by a moving magnetic field. The main difference between a typical rotary motor and a LIM is the way the magnetic field is produced. Inside of an AC rotary motor the magnetic field produced travels in a continuous rotary motion. A LIM can be imagined as an AC rotary motor cut down the center and the stator and rotor spread out along a flat line. The induced magnetic field now moves linearly across the flat motor face instead of rotating. A semi-linear induction motor is similar to the linear induction motor with the exception that the stator is not completely flat. The force created by the SLIM magnetic field can be used to drive large diameter rotors.

B. Project Statement

The initial project goal is to understand reasons for the limited functionality of the 2016 Semi-Linear Induction Motor design. The current SLIM uses a rotor that was used for a magnetic levitation senior project completed several years ago. It is suspected that the fundamental problem with the current rotor is that it has no ferromagnetic material to increase the flux density in the air gap. Therefore, the primary project goal is to design, construct, and test a new rotor that will provide a better magnetic circuit to increase the developed rotor torque. The SLIM will be thoroughly tested and modified until reasonable functionality is attained. The SLIM will use the stator that was developed by the 2016 team. All functional requirements will also be met.

II. Prior Work

The goals of the 2016 LIM project team included designing and building a SLIM that can be mounted under a 45.72cm diameter wheel used in a previous senior project to induce wheel rotation. The main focus of the project was to design and implement a SLIM that could eventually be used to power and control a magnetic levitation system for future senior design projects. Their objectives included inexpensive materials, electrically efficient, controllable, safe, constructible, and reliable. The 2016 LIM team developed the design equations needed for their stator design, and had the stator constructed with steel laminations. Additionally, the team wound coils that had four layers with 235 turns each, and placed a coil on each of the twelve stator teeth. The coils were then secured with cloth tape and zip ties. Furthermore, the project team designed a base to mount the rotor, and wired the coils in a three-phase wye configuration. The 2016 LIM team did not have the time to conduct extensive testing or implement necessary modifications which resulted in very limited available rotational torque. Therefore, the LIM was only able to spin the rotor very slowly.

III. Standards and Patents Applicable to the Project

- G. A. Francis. “Linear induction motor construction.” U.S. Patent 3155851 A, Nov. 3, 1964.
- T. Fellows, E.Laithwaite. “Secondary member for single-Sided linear induction motor.” U.S. Patent 3824414 A, Mar.13, 1973.
- N. B. John. “Linear induction motor.” U.S. Patent 3628072 A, Jun. 17, 1970.

IV. Subsystem Level Functional Requirements

A. Functional Requirements: Subsystem Level

A three-phase, 208[Vrms] AC source powers the Lenze AC Tech (model MH250B) Variable Frequency Drive (VFD). The VFD will vary the frequency and voltage provided to the stator coils to produce a moving magnetic field along the length of the stator. The moving magnetic field will induce a force along the periphery of the rotor, thereby generating a torque about the axis of rotation.

As indicated in the Project Statement section above, the primary project goal is to design, construct, and test a new rotor that will provide a better magnetic circuit to increase the developed rotor torque. However, if time permits the VFD user input parameters will be transmitted to the Atmega 128A motor monitor and controller via the user keypad, and displayed via the system’s liquid crystal display (LCD). The rotor rotation will be measured with a speed sensor that generates pulses via a photo-interrupter. The speed data will be sent to a microcontroller and converted from pulses/second to rotations/minute and displayed on the LCD. Although the VFD factory default setting is to operate over a frequency range of 0 – 60[Hz], the frequency range can be modified via the “Base Freq” parameter available in the Lenze AC Tech programming menu to a maximum of 360[Hz]. The 2016 LIM project team designed the stator to operate at 120[Hz], but never altered the “Base Freq” parameter to implement the change. Independent of the frequency range selected, the VFD provides the option to use a 0 – 10 [V] input signal to adjust the output frequency over the frequency range selected. Ultimately, the 0 – 10 [V] input signal will correspond to the 0 – 120[Hz] frequency range to be used for this project iteration. The VFD also provides a 0-10 V output signal proportional to the operating frequency. The VFD input and output signals will then be converted as required using analog to digital (A/D) and digital to analog (D/A) converters by the motor controller to monitor system operation and provide open-loop speed control.

1. LCD Subsystem

- Display
  - Desired rotor speed
  - VFD output frequency
  - Rotor speed

2. Tachometer Subsystem

- Main Components
  - Photo-interrupter
  - Transparent disk with opaque sections
- External Interrupt
  - Counts pulses
  - Four pulses per rotation
  - Updates data every 250 ms
- RPM
  - Read speed sensor data
  - Convert pulses to revolutions per minute [RPM]
  - Display speed on LCD

3. Subsystem to Monitor and Control the Variable Frequency Drive (VFD)

- 0-10 V signal correlates to 0-120 Hz
- A/D Converter
  - Onboard the Atmega128
  - 250 ms interrupt
  - Resolution is 0-5 V
- D/A Converter
  - External IC Chips
  - Provides 0-10 V input signal to VFD to control output frequency

B. Subsystem Block Diagram

As indicated above, if the rotor re-design is completed and the SLIM has reached reasonable functionality, the Atmega128A motor monitor and controller will be implemented. Figure 1 below provides a block diagram to illustrate the various subsystems included in the SLIM system.

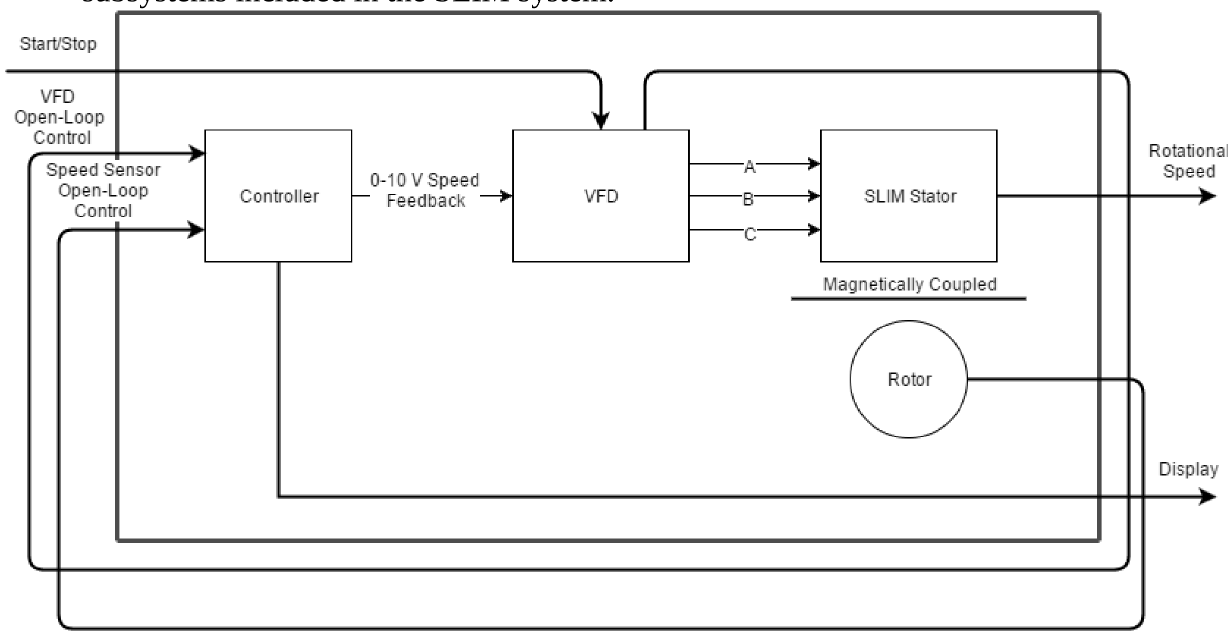


Fig. 1 Subsystem block diagram illustrating various subsystems and connections.

C. Engineering Efforts

The initial goal was to troubleshoot the previous SLIM project team's design, and thoroughly test the SLIM in an attempt to determine the reasons for its poor performance. Significant effort was dedicated to analyzing the previous team's design equations to uncover possible errors, but found no serious problems with the design. The only uncertainty remaining regarding the previous team's design is whether the applied three-phase voltages were intended to be connected in a WYE or DELTA configuration. After thoroughly reviewing the previous team's design equations, experiments were undertaken to uncover possible errors in the experimental SLIM apparatus. A compass was used to confirm that the stator coils were connected in the proper sequence and polarities. In addition, the coil phases and magnetic polarities were labelled using a pen and cloth tape.

After the coils were labelled, a DC current of 1.5 [A] was applied to each coil. The voltage required to attain the 1.5 [A] for each coil was measured to verify there were no short-circuits embedded in the coil windings and that no significant differences existed between the coil resistances. Fortunately, no short-circuits were discovered, and the required applied voltages were nearly identical for all coils.

The next step was to analyze the magnetic polarities associated with the current through each set of phase coils. As each set of phase coils was energized, a compass was used to obtain an approximate mapping of the magnetic field each phase was producing. The mapping indicated the various coils associated with each phase appeared to be connected correctly.

The previous project team had the system configured as a WYE connection. Since some uncertainty still exists as to whether the system was originally designed to operate in a WYE or DELTA configuration, the stator was wired in a DELTA configuration. The DELTA configuration resulted in larger phase currents than was measured with the WYE connection, but the developed rotor torque was still minimal. The project advisor recommended that the team should try increasing the VFD frequency to about 40[Hz], and it became obvious that the rotor was finally beginning to rotate without external assistance. To verify that the apparent effect was real, the rotor was pushed in the opposite direction by hand with the VFD frequency set at 40[Hz], and it was obvious a torque was present in the direction opposite to the pushing torque. To ensure the team had not missed some subtle issue associated with the three phase connection, the coils were reconfigured in every possible DELTA combination. The final configuration tested appeared to generate the largest apparent torque based on the apparent speed of the rotor with the VFD frequency set at 40[Hz], so the connection was left in that configuration (although no reason for the torque increase could be identified). The current was triple that of the rated coil current during the test, so it is suspected that a WYE configuration will probably be used in the final design to ensure that the coils are not destroyed. However, it is also theoretically possible that the redesigned rotor may increase the inductance of the combined stator and rotor magnetic circuit, so the effective coil impedance may increase significantly. If that is ultimately found to be the case, a three-phase DELTA connection may be practical as the final load configuration. In addition, smaller currents may be sufficient to generate the torque required to turn the rotor at the desired speed and load.

D. Parts List

The parts list shown in Table I is preliminary and will be finalized upon the completion of the new rotor design. However, as indicated the list will include (at a minimum) a rotor shaft, bearings, hub with keyway, manufactured sheet steel laminations, copper or aluminum bars, various bolts, screws, and nuts. No information is available relative to costs because the process of designing a new rotor is in its early stages.

E. Division of Labor

The project is divided into debugging, testing, rotor redesign, purchasing, and construction phases. All tasks are shown in Table II and will be completed by both team members.

Table I: Parts List

Component	Method of Procuring	Cost if Applicable
Rotor shaft	Purchasing	N/A
Bearings	Purchasing	N/A
Hub with Keyway	Purchasing	N/A
Manufactured sheet steel laminations	Purchasing	N/A
Copper or aluminum bars	Purchasing	N/A
Various bolts, screws, and nuts	Purchasing	N/A

Table II: Division of Labor

Tasks	Group Members
Review and Analyze Design Equations	Edgar and Jacob
Determine Coil Orientation	Edgar and Jacob
Test for Short-circuits	Edgar and Jacob
Map the Magnetic Field	Edgar and Jacob
Configure and Test Delta Connection	Edgar and Jacob
Research and Design New Rotor	Edgar and Jacob

V. Project Timeline

The SLIM project for the fall semester was divided into review and analysis of design equations, determination of coil orientation, test for short-circuits, mapping of the magnetic field, configuration and testing of a delta connection, and researching and designing a new rotor. The time spent on reviewing and analyzing the previous team's design equations was from November 3rd to November 8th. The time from November 10th to November 15th was used to determine the correct coil orientations. November 15th to November 17th was dedicated to testing the SLIM to determine if any coil short-circuits were present, to map the stator magnetic field, and confirm the delta connection was correct. Between November 22nd to December 9th the project team researched and planned the design of the new rotor.

As indicated in the proposed schedule for the spring semester shown in figure 3, tasks will include designing and constructing the new rotor, mounting and testing the new rotor, thoroughly testing the system and making improvements. As previously stated, if time permits the team will connect the Atmega128 to the SLIM system, create a program to read data from the tachometer, and create a program to output information to the LCD. The design and construction of the new rotor will take place from January 27th to February 7th. The mounting and testing of the new rotor will be from February 9th to February 21st. Again, if time permits the connection of the Atmega128 to the SLIM system and program generation to read data from the tachometer and output information to the LCD is scheduled for February 22nd to March 6th. Finally, the work on the final report and final presentation will be from April 4th to May 2nd. (See figure 3 in Appendix A for a detailed listing of the spring 2017 schedule.)

Figure 2: Fall Schedule

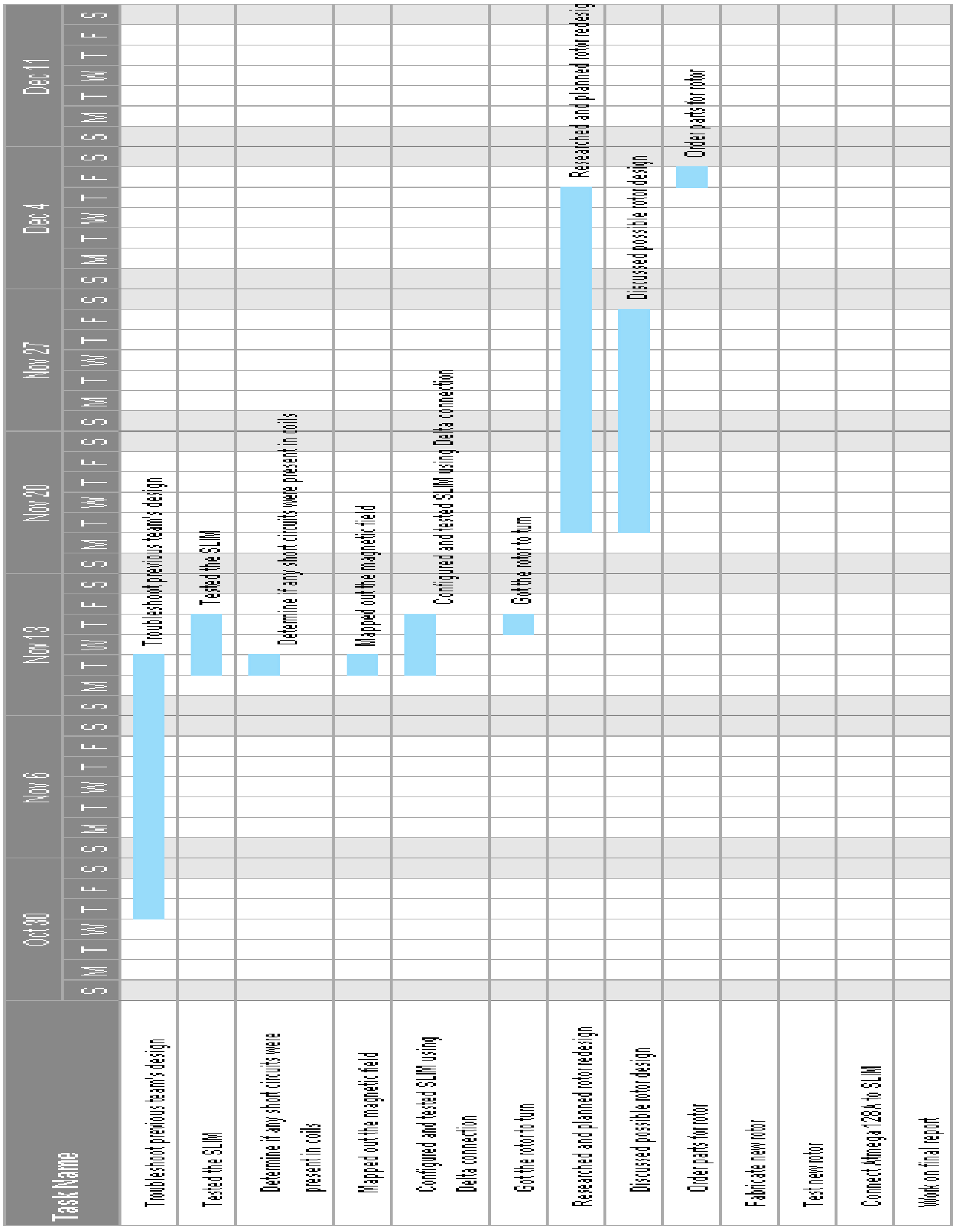
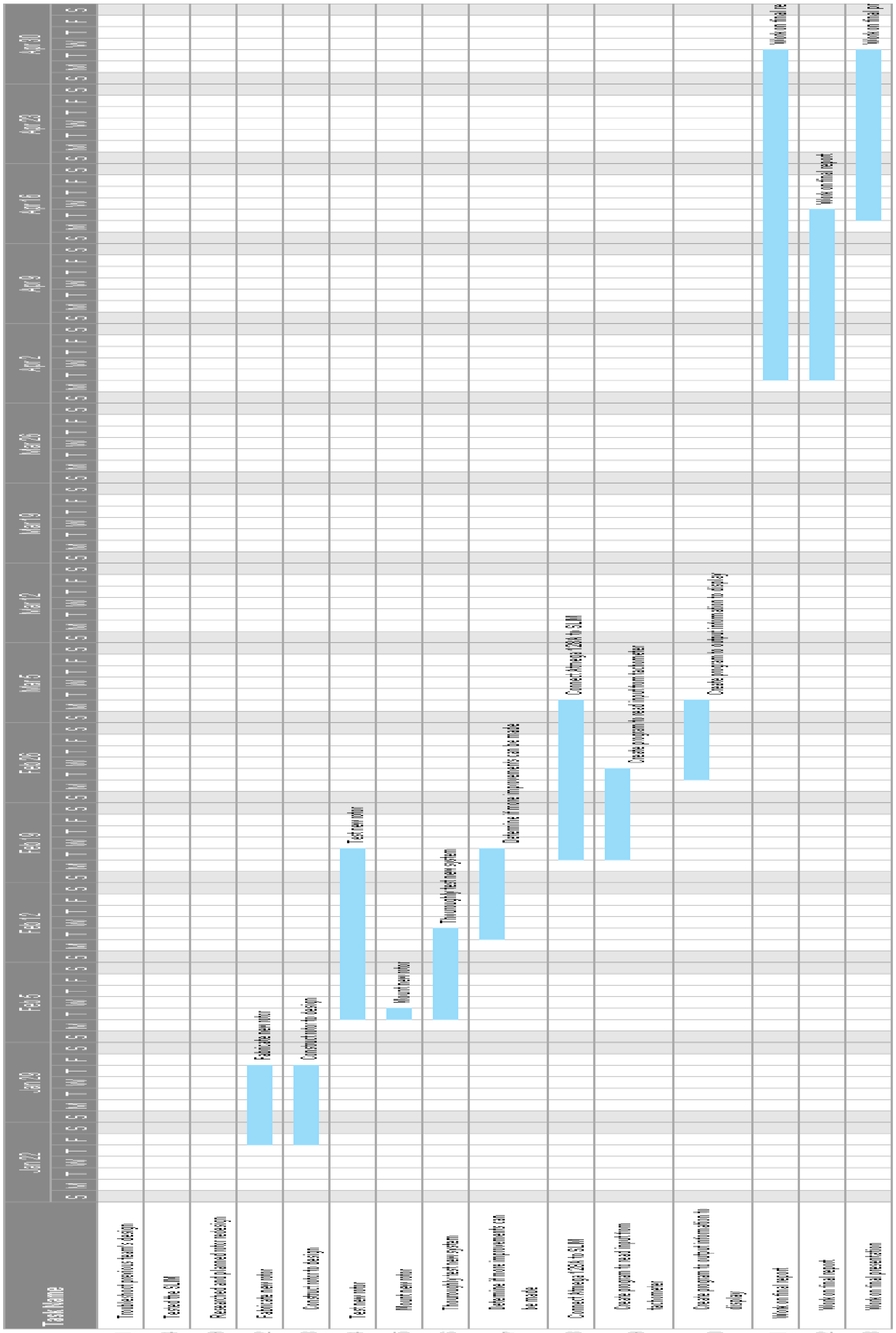


Figure 3: Spring Schedule



VI. Conclusion: Future Directions

Multiple improvements can be made to the current SLIM system to obtain greater efficiency. The main improvements deal with updating the semi-linear track (or rotor). Currently the copper track associated with the semi-linear track has no steel backing, and therefore the magnetic flux density in the air gap between the stator and the rotor is significantly reduced from the levels assumed in the original design of the machine Based on reports from previous senior capstone projects that used the current rotor indicate it can only operate up to about 1,100 rpm without significant vibration. Therefore, the new rotor must be designed to be as light as possible with the ability to be dynamically balanced for higher speed applications. The previous SLIM team designed the stator coils to be easily removed from the stator core so the coils could be redesigned to obtain higher power output if deemed necessary in the future. The next iteration of the SLIM system as a senior project could focus on combining the SLIM with a magnetic levitation system.

VII. References

1. Subsystem Block Diagram. [Drawing]
2. Linear Induction Motor: 2016 Senior Design Project Team of Tyler Berchtold, Mason Biernat, and Tim Zastawny
3. Steven Gutschlag, Project Advisor

VIII. Appendix A

Figures

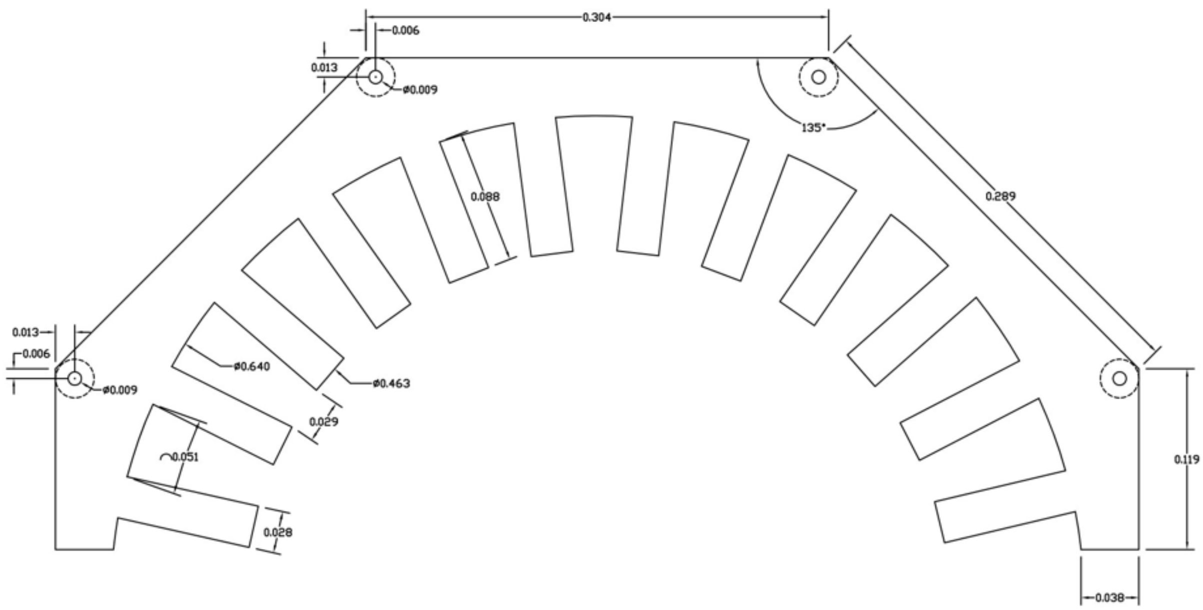


Fig. 2 Stator design developed from previous project team

A.

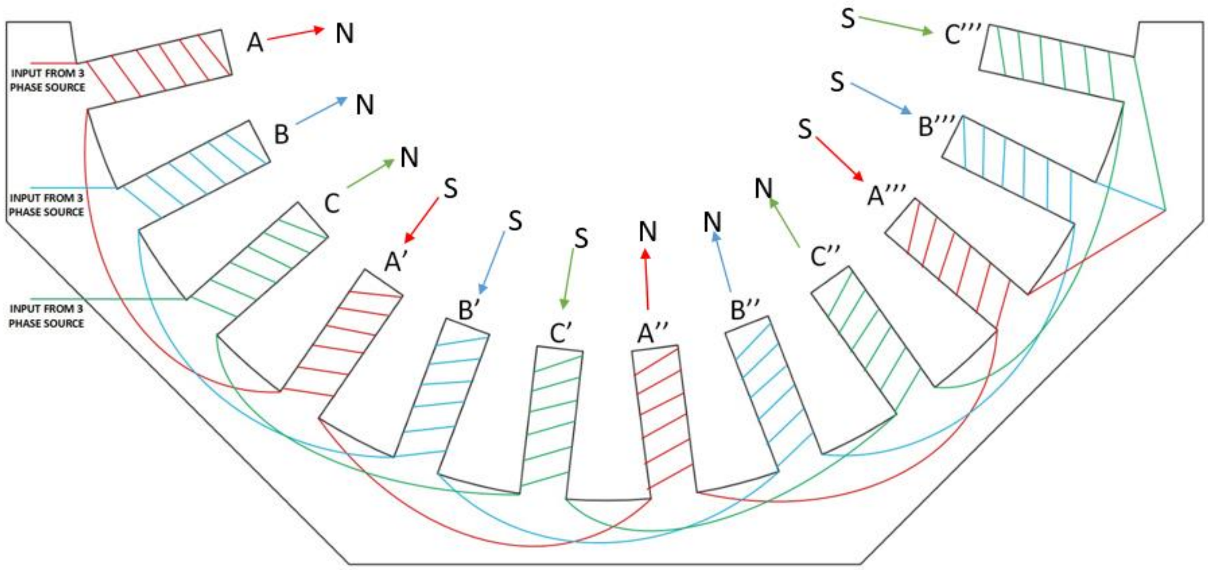


Fig. 3 Illustration of the stator wiring

Citations used for Figures in Appendix A

[1] Stator Design. [Diagram]. Retrieved from 2016 LIM Senior Electrical Engineering Project Final Report.
[2] Stator Wiring Diagram. [Diagram]. Retrieved from 2016 LIM Senior Electrical Engineering Project Final Report.