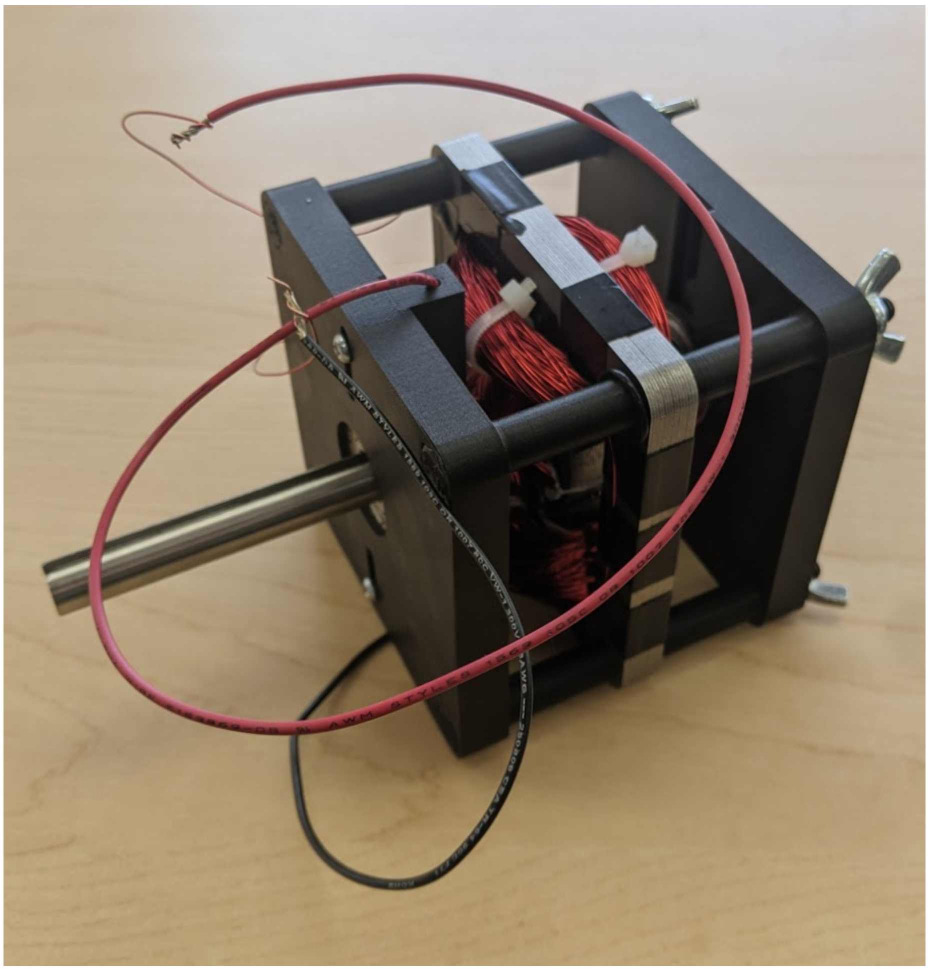
Compact Low Voltage Asynchronous Induction Motor Commissioned by Grainger Teaching Studio



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Department of Mechanical Engineering
University of Wisconsin - Madison
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Summary

With very few accessible hands-on experiences relating to power conversion being offered at the University of Wisconsin – Madison, our team has been tasked by the Grainger Teaching Studio with building asynchronous induction motor prototypes to be implemented as in-class projects. The broad objectives for this design are to have a spinning induction motor by early May 2021 and to have a detailed corresponding fabrication pamphlet so students can make their own as an in-class activity with minimal professor involvement. There are many stakeholders involved in the outcome of the project including the instructional staff, the client commissioning the project, and the students participating in the hands-on learning. Each group presents objectives that must be considered in the planning and undertaking of this project. Designs must be simple for the students in the classroom.

Extensive research into current designs of induction machines has been conducted and yielded a level of knowledge regarding the operations of induction machines. All of this is briefly summarized in the background section of this proposal. Asynchronous motors are known for their high efficiency in comparison to a traditional DC motor, and the students who enroll in this class will likely see the applications of AC motors throughout their professional careers. With many arguments in favor of proceeding with this project including enhanced hands-on learning, logistical ease for professors, and the potential for reducing carbon emissions, this project is well worth undertaking. A plan of attack has also been formulated with an adaptable timeline covered extensively in the plan of action section of this report.

Table of Contents

Introduction

Do you lack the confidence going into a professional engineer career solely because you do not understand how things are physically assembled and interact in the real world? This pivotal component is often left out in academic settings, leaving students on their own with little more than the textbook knowledge they have acquired. The Grainger Teaching Studio desires to provide students this opportunity through the fabrication and optimization of an asynchronous induction motor. Induction motors are one of the leading machines in electrical power consumption applications. The AC motors will be fabricated based off a current DC motor in the Grainger Lab. AC motors are known to have a much higher efficiency and are more commonly used in favor of DC motors in today's industry.

There are numerous ways induction motors can be fabricated, but they often must be modified to create a desired output, such as a torque or speed. The optimization process may require a change in the magnetic field generated, a material change, among many others. While the machines created for the client will be on a smaller scale than the industry, the key learning objectives from the course will certainly be applicable to larger induction machines students may see in the workplace. Software will be used to simulate the behavior of the machine and see how the motor performance is altered when parameters are changed. The prototypes will contain fabrication manuals to assist students as they begin their optimization process. A plan of action going forward has been put in place after defining these objectives.

Problem Statement

Engineering students graduate college with an abundance of technical knowledge, but they often lack the hands-on experience that may enhance their skillset in preparation for an increasingly competitive industry. The Grainger Teaching Studio aims to provide students within the Electrical and Computer Engineering department this opportunity through the fabrication an AC induction motor. A research study conducted at the University of Colorado at Boulder found that students who opted to take a hands-on structured engineering course in favor of an equivalent non-hands-on course had an average of a 19% higher gain in retention rates [1]. This high-level course would challenge students to optimize machine parameters, which include, but are not limited to, the number of poles, number of winding turns, or a desired torque. We intend to provide the lab with 3 to 5 prototypes for student reference that are inexpensive for classroom use. After speaking with the client, his main concern was the time commitment on behalf of the teaching staff. Simple designs and a detailed fabrication instruction manual will mitigate the hassle that many professors associate with hands-on projects. With variable parameters, the manual will also provide students the tools necessary to create their own optimized designs. The prototypes will allow students in this high-level course the opportunity to round out their college education and gain a competitive edge going into the industry.

Stakeholders

Unlike an industrial project where certain goals and parameters must be met, this project is revolved around education, requiring a multitude of stakeholders to buy into and embrace the project. To accomplish this, the thought process and needs of the primary stakeholders (professors, client, and students) have been outlined below with a corresponding list of specific tasks to ensure the accomplishment of the overarching goal of this project outlined in the problem statement above.

Professors

While the main end user will be the student, if the induction motor project is not versatile enough to be added to a professor’s curriculum, then how easy to use, make and understand for the student is meaningless. Therefore, in a prioritized list from most to least important below, a few key points are outlined to ensure that this project is viable enough for professors to incorporate into a class:

- Fabrication Instructional Manual
- Easily Configurable and Adaptable Parameters

The forefront objective in eliminating hassle for professors is having an easily accessible and robust fabrication manual. The manual is written with the intent of a professor of a class with no fabrication experience teaching the class. The fabrication manual will include no theory regarding the workings of windings, stators, cages, etc. Not only would this material be repetitive as the assembly will be required alongside course readings detailing the theory behind induction motors, but it would also limit the adaptability of the project, binding it to the depth of content covered. For example, if an ECE 377 level knowledge of magnetism and induction is assumed and written in the manual, the manual would be intimidating at best and all together discarded if the machine was desired to be used in an introduction to electrical engineering class.

The second item is easily configurable and adaptable parameters. As mentioned before, this project is meant to be useful and engaging regardless of what level of class it is used in. While a lower-level class may be satisfied with simply building the motor and watching it spin, a graduate class may desire more. Because of this, several parameters are left available for optimization incorporation opportunities. A few of these initial parameters in mind are altering the number of poles, windings, or wire gauge to exhibit how the manipulation of these parameters will lead to a change in the max torque output, start-up torque, efficiency, effect on cogging, etc. By writing detailed opportunities for optimization, a professor can easily change the difficulty of the project depending on the education level and time commitment of students in the class.

Client

The client for this project is Kyle Hanson, the WEMPEC Lab Manager at the University of Wisconsin – Madison. While he will not be directly impacted by the project as he is not the one who will be teaching or learning from the project, his reputation is on the line as he is the overseer of the project. All specifications and requirements he sets as objectives are of the upmost importance. A majority of the considerations for this stakeholder are taken up front during the planning and proposal portions of the design and therefore have already been set. The process of figuring out just what these objectives were required interpretation, clarification, and iteration. This process was documented in a design specification sheet as statements were taken from the client, interpreted by the team to come up with cold hard numbers, clarified to ensure quality, and finally thoroughly reassessed by both the client and the team multiple times in an iterative fashion to ensure that key objectives are the same before beginning prototyping. These specifications can be found in Table 1 below. It is important to note that all specifications outlined in this table are simply initial parameters and are open for further adaptation as the project goes on and the team encounters errors and opportunities that may shift the outcome objectives.

Table 1. Detailed design specifications derived from client needs.

Client Needs
Client Need Statement
The Grainger lab needs an induction machine design that can be easily manufactured so that students can take a class that provides hands on learning on induction machines.
Client Needs (in their words)
Needs a 3 phase AC induction motor that builds off of a previous project that involved a DC motor
Client is looking for an easy-to-build induction motor design that could be made by students
An instruction manual should accompany the design and be simple enough for average students with little hands-on experience
Motor should have 4 poles, operating at 1800 rpm
Single layer winding can be used for first design, but final design should utilize double layer winding
The design must be able to easily attach to an existing dino for torque testing and analysis
Design should be relatively inexpensive to produce
Spinning Prototype by end of semester
RFQ
Fabrication should be affordable for the student
Design should incorporate manufacturing techniques and materials found and provided by the Grainger Lab

Engineering Specifications					
Specification description	**Target**	**Unit**	**Test method**	**Rank**	**Met**
Materials					
Component materials stocked in the lab	All	-	Bill of materials with specified in-stock part, client evaluation	Nice	
1 48" x 10" metal sheet per motor	1	sheet	Solidworks metal surface area evaluation	Should	
Minimize fabrication costs	<100	$ ea.	Bill of materials with component costs, client evaluation	Should	
Specifications					
Coils/wiring should be identical, compatible with 3 phase AC supply, and assembled as designed	pass	-	Phase Resistance Test	Must	
Low torque to fit within dyno specs	<5	N*m	JMAG for pre-production / Dyno for post-production	Must	
Number of bars offset from number of slots	pass	-	Design Spec	Must	
Power specification	350	W	JMAG for pre-production / Dyno for post-production	Nice	
Wire Gauge	18-20	gauge	Design Spec	Should	
Squirrel Cage Rotor	pass	-	Client evaluation	Nice	
Overall Design					
Must fit on dyno c-face mounting bracket	pass	-	3D assembly modeling (pre-production) and trial testing (post-production)	Must	
4 poles	pass	-	Client Evaluation	Must	
Easy to manufacture with in-house equipment	pass	-	Client Evaluation	Must	
Skewed rotor to prevent cogging	pass	-	Client evaluation	Nice	
Operations & Deliverables					
Spinning prototype by end of semester	pass	-	Passes hi-pot and phase resistance tests, spins using specified voltage supply	Must	
Folder with all 3D models and manufacturing files	pass	-	Client Evaluation	Must	
Instruction Manual with optimization parameters and manufacturing techniques	pass	-	Client Evaluation	Must	

Students

At the end of the day, the students will be the main stakeholder interfacing with the induction motor. Despite them being the ones who will learn and realize the potential and complete the learning objectives that are desired from this project, by fulfilling the objectives to satisfy the client and professors involved, the students' needs will be met very easily with very little supplementary consideration. There is, however, one consideration of the upmost importance that is specifically related to the wellbeing of the student as they seek to navigate building their own induction motor from scratch. The aforementioned consideration is a simply and detailed fabrication process.

As mentioned in the professor stakeholder paragraph above, an instruction manual will be included to detail the fabrication process. Emphasis will be placed on considering the perspective of the students, this includes assuming that they have no manufacturing experience and need step by step instructions. Assuming that students inherently have common knowledge results in complex logic jumps and loses many students along the path to the end objective of the lab. This common issue in college level laboratory activities can be prevented by taking excessive notes during the prototyping stage that can be condensed and reviewed to craft the manual after a spinning prototype is finished. As this team is comprised of current undergraduate students, all have experience with poorly written lab instructions and will be using this past knowledge in conjunction with our faculty consultant, Kyle Hanson to prevent any potentially misleading directions.

Background on Induction Machine

Induction machines, also known as asynchronous machines, are one of the most widely used electrical motors in both domestic and industrial applications. In fact, about 50 percent of global power is consumed by electric machines and over 90 percent of industrial machines are induction motors [2]. One of the main reasons it is so widely used is due to its high efficiency, which can achieve as high as 97 percent [3]. The high efficiency combined with low maintenance and self-starting properties makes the induction machine one of the most popular choices within the industry.

An induction machine comprises of two main components, the stationary stator and a rotating rotor. An exploded view of a common industrial squirrel cage type induction machine is shown in Figure 1. The main frame, typically made from cast iron, is used to house and protect the stator and rotor from damage as well as protect the user while operating. While sometimes not necessary, fans are also added to the machine to prevent the stator coils from overheating.

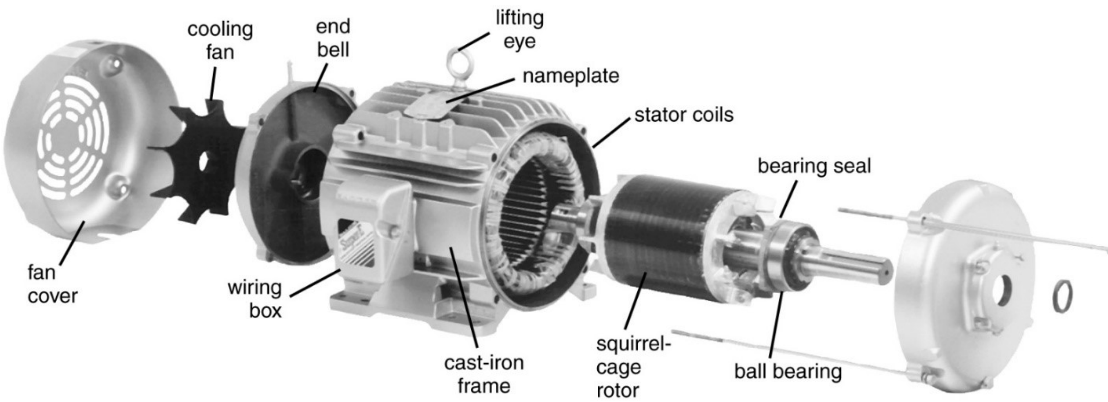

Figure 1. An exploded view of a squirrel-cage type induction motor. [5]

A cross-sectional view of the stator is shown in Figure 2 and is derived from the design software. The stator of an induction machine is typically composed of stator windings and iron laminations. The copper windings in the stator of an AC machines are typically wounded in a distributed fashion, meaning they are typically spread throughout the stator lamination [4]. Since an induction machine typically has three phases, the windings would have three individual input terminals. When the three-phase windings in the stator are connected to a three-phase power source, a rotating magnetic field is generated as the electromagnets interact. This rotating magnetic field induces a current in the rotor and generates torque in the rotor, creating a rotating motion. An example of a 4 pole, 12 slot machine motor and slot winding diagram are shown in Appendix A.

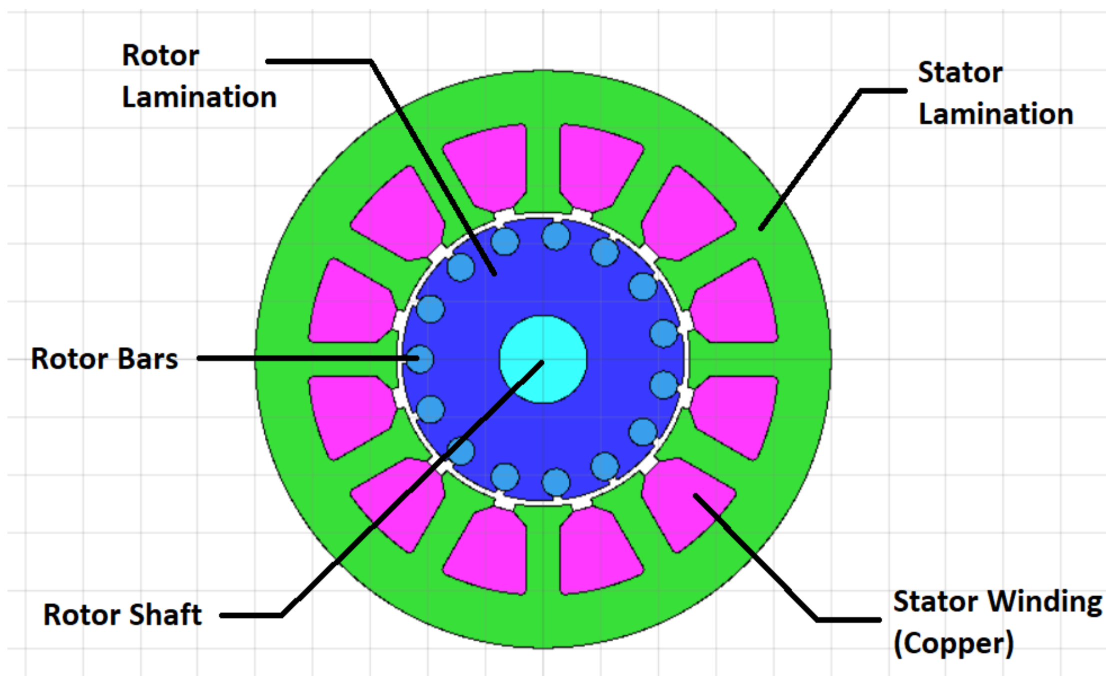

Figure 2. Cross-sectional view of a squirrel cage type induction machine stator and rotor.

One of the most common rotor designs for induction machine is the squirrel cage design. The construction of the squirrel cage rotor is shown in Figure 3.

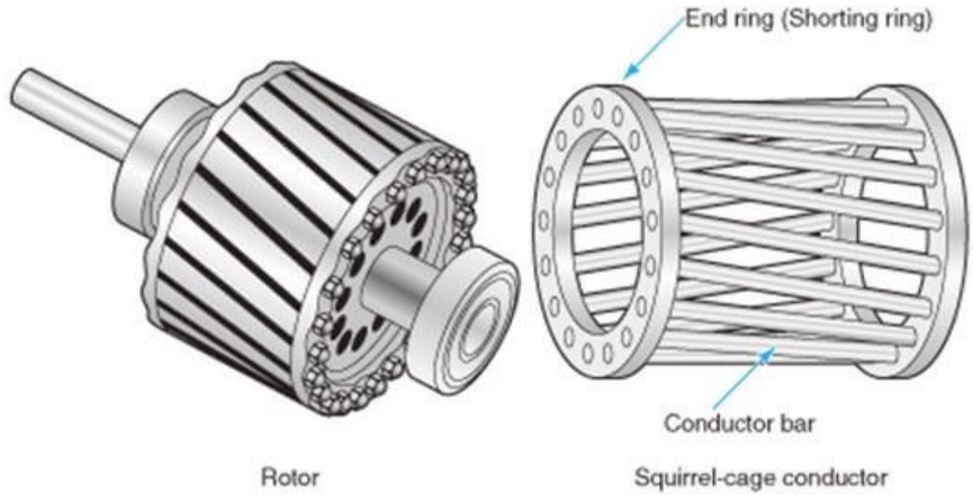

Figure 3. Construction of a squirrel-cage rotor [5].

The squirrel cage rotor design uses conducting bars (typically made from copper and/or aluminum) connected to a shorting ring on either end [4]. Within the cage, iron laminations are added to assist the flow of magnetic flux generated by the stator windings. A current is induced in the rotor bars when a rotating magnetic field is generated by the stator windings. The interactions between the induced current in the rotor and the rotating magnetic field in the stator allows the generation of torque in the squirrel cage rotor, creating a rotating motion. As seen above, the bars are skewed at an angle. This is to prevent cogging, which is a locking of the rotor upon startup that commonly occurs when there is an equal number of conductor bars and stator teeth [6]. Despite eliminating this, the motor may experience cogging in the form of running rough. The skew can help mitigate these adverse effects if properly implemented. For the scope of this project, skewing is ranked as a “nice to have” feature in later iterations but will not be included in the initial prototype.

Similar Solutions

The Grainger Prototype Lab had previously designed several brushed DC machines for classroom purposes. An example design is shown in Figure 4. This design was provided by our client and is currently being used in classes such as ECE 601 to provide students with hands-on experience.

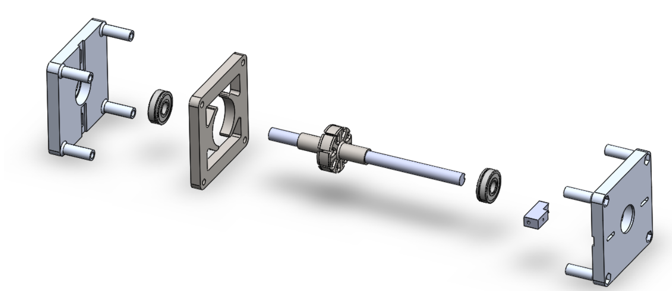

Figure 4. An exploded view of a brushed DC machine design that utilizes 3D printed end plate.

This design provides a reference and a good starting point for the AC motor. The existence of the DC motor does not hinder the need for an AC motor because the two solutions are fundamentally different. Certain components, manufacturing techniques, and materials associated with the existing DC motor will be incorporated into the new design. The footprint of the AC motor will be relatively similar to that of the DC motor, and both will have to have the same dynamometer fixture compatibility for testing. There will be parallels in the design of new endplates, laminations, and axial components. The coil windings, stator, and rotor will reflect the fundamental differences between DC and AC motors, but the aforementioned similarities in auxiliary components will be very helpful in allowing the group to divert more resources towards the more complex components.

One can find similar induction motors in a plethora of different industries; however, these motors are normally suited for a specific application and are generally difficult to inspect and modify. They often have permanent or semi-permanent housings and are built using manufacturing techniques that cannot be rivaled for this project. Figure 1 illustrates how when fully assembled, industrial motors create a very robust, compact envelope that would have to be rigorously disassembled and likely redesigned for any other parameters to be used. Since students will be changing motor parameters, the “skeleton” of the design should not be very specialized, and the assembly should intuitively represent the factors and relationships that students will be studying. Similar solutions found in industry serve as design examples to reference for these reasons, but not as applicable solutions to the problem at hand. Because of this, though standards and patents were researched, none were found to be applicable for the general size and power output that this motor will feature, so everything will be designed from scratch.

Apart from the motor design itself, there are many similar instruction manuals to that which will be included alongside the AC motor. Every industrial induction motor has an instruction manual of some capacity, but these manuals are often specific to the design and use at hand. Looking into fabrication manuals for similar individual components (e.g. laser cut part manual) as well as assembly instructions for entire motors will help the team write a comprehensive, robust, manual that translates well to what the students will likely encounter in industry.

Additional Arguments

Throughout the Problem Statement and Stakeholders sections of this report, many reasons for the necessity of this project have been presented including increased learning through a hands-on activity, easy adaptability for use in multiple different courses, and allowing a professor to implement a hands-on activity with virtually no added time requirements on their behalf. Two additional arguments in favor of this project have been outlined in the paragraphs below. These supplementary arguments address both logistical and environmental impact.

The first additional argument pertains to the logistical feasibility of assigning the assembly of an AC motor as a project. It can be argued that buying a kit already in production would be the easiest option to satisfy all the previous requirements and learning objectives outlined. The problem is that there are very few kits for building your own AC induction motor on the market that seek to teach the lessons that will be taught with the design outlined by this proposal. The closest example is a kit by EngineDIY [7]. While the price of this kit is currently $94.99, which is $5.01 below the estimated cost of the proposed motor, this coils in this kit do not need to be wound and it features no stator. A kit like that from EngineDIY is not satisfactory because the overall objective of this project is to give students insight into how industrial induction motors work. After extensive research, no kits were found to hit this requirement. Building the proposed induction motor and writing the corresponding fabrication manual is the most logistically efficient and feasible option.

The second additional argument is related to environmental impact. Electric motors are easily run off renewable energy resources and are important to the future of power manufacturing. For example, motors in cars have quickly pivoted from running on gas to running on electric. If all cars were to become electric, carbon emissions would decrease by as much as 12% [8]. Since the Toyota Prius, the world's first mass produced electric vehicle, was released just over 20 years ago in 2000, the world has seen its first fully electric cars and is quickly approaching this future without gas stations. This push for electric drivetrains has created a massive market for people with hands-on experience with electric motors. Giving this hands-on experience may not only help educate but also inspire the next generation of electric drivetrain engineers leading the charge for a better environment for our future.

Plan of Action

The team has implemented a plan of action going forward after speaking with the client and completing preliminary research. The overarching goal for this semester is to have a spinning prototype the team can present to the Grainger Teaching Studio. The client has emphasized that this may take several attempts before a successful prototype is reached. The designs are planned to be prototyped early and often to account for this. Beyond this semester, the client requests that 3-5 functional prototypes be created for classroom use. As more prototypes are introduced, it is expected that the succeeding designs will be more robust while still being easy for students to fabricate.

The design specification as seen in Table 1 is actively being adapted to ensure the entire scope of the project is covered. This live document may change through the year, but it will serve as a reference both to the team as well as for the client. The team plans to begin prototyping the first induction motor after the design specification is clearly defined. Testing is anticipated to begin in the last week of March. Regardless of the outcome, the team will continue to redesign and optimize. Detailed notes will also be kept on each run. This will be beneficial in ensuring all known data is accounted for in potential optimization runs. A Gantt chart will be used to track the team's overall progress as well as keep the client up to date on progress made. Measurability is a critical component to goal tracking, so a calendar along the top has been added to set specific dates. A current revision of the Gantt chart can be seen in Table 2.

Table 2. Team Gantt chart (updated 03/01/21).

Week	1	2	3	4	5	6	6	7	8	9	10	11	12	13	14
	Jan	Feb				Mar						Apr			
Task	29	5	11	19	23	2	5	12	19	26	2	9	16	23	29
Project Proposal						O									
All members read guidlines		X													
All members find 3 sources & write summary of stakeholder's needs		X													
Determine Applicable Standards			X												
Client Need Statement			X												
Problem Statement			X												
Determine Approximate Dimensions			X												
Presentation				X											
Peer Review					X										
Project Proposal						X									
Proof Of Concept										O					
Descision Matrix Generated															
Product Architecture Generated															
Finalize Intail Design															
Begin Prototyping															
Final Working Prototype In Hand															
Midyear Review														O	
X = Completed Tasks, O = Milestone Deadlines															

Conclusions

The team intends to provide the Grainger Teaching Studio at the UW-Madison campus with 3-5 AC induction motor prototypes. The protypes will be used in a classroom atmosphere, and the future students will be challenged to fabricate and optimize the provided prototypes. Detailed instruction manuals will be provided in conjunction with the prototypes to decrease the effort on behalf of the instructors. Previous DC induction motors fabricated in the lab will serve as a reference in the project, especially as the team is first getting started. Communication with the client and research completed have been pivotal early on, and the team has created a plan of action containing the current milestones to be reached in the next few months and beyond to ensure all objectives are accounted for.

Appendix A:
Motor and slot diagram of a 4 Pole – 12 Slot Induction machine

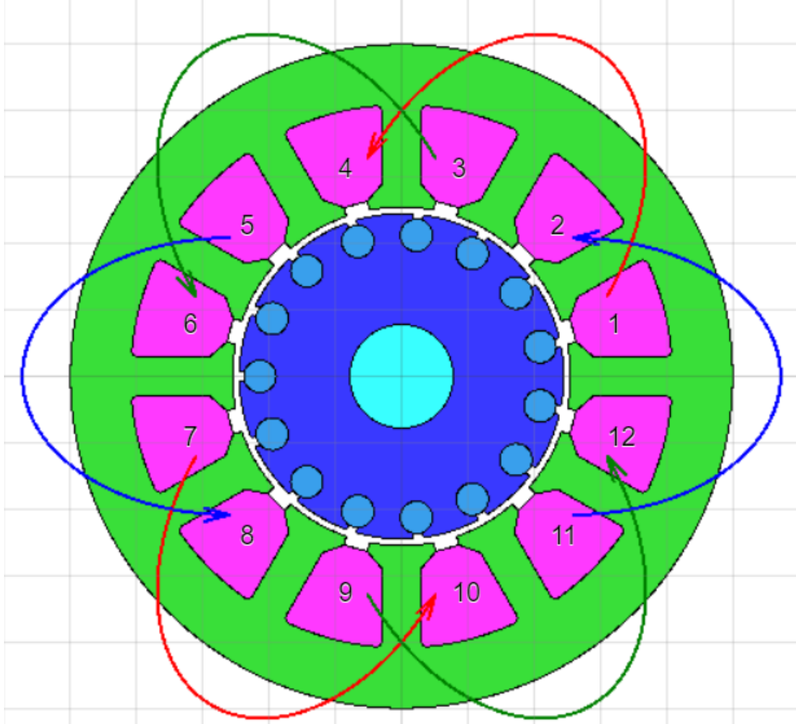

Figure A-1. Motor diagram of a 4 Pole – 12 Slot induction machine

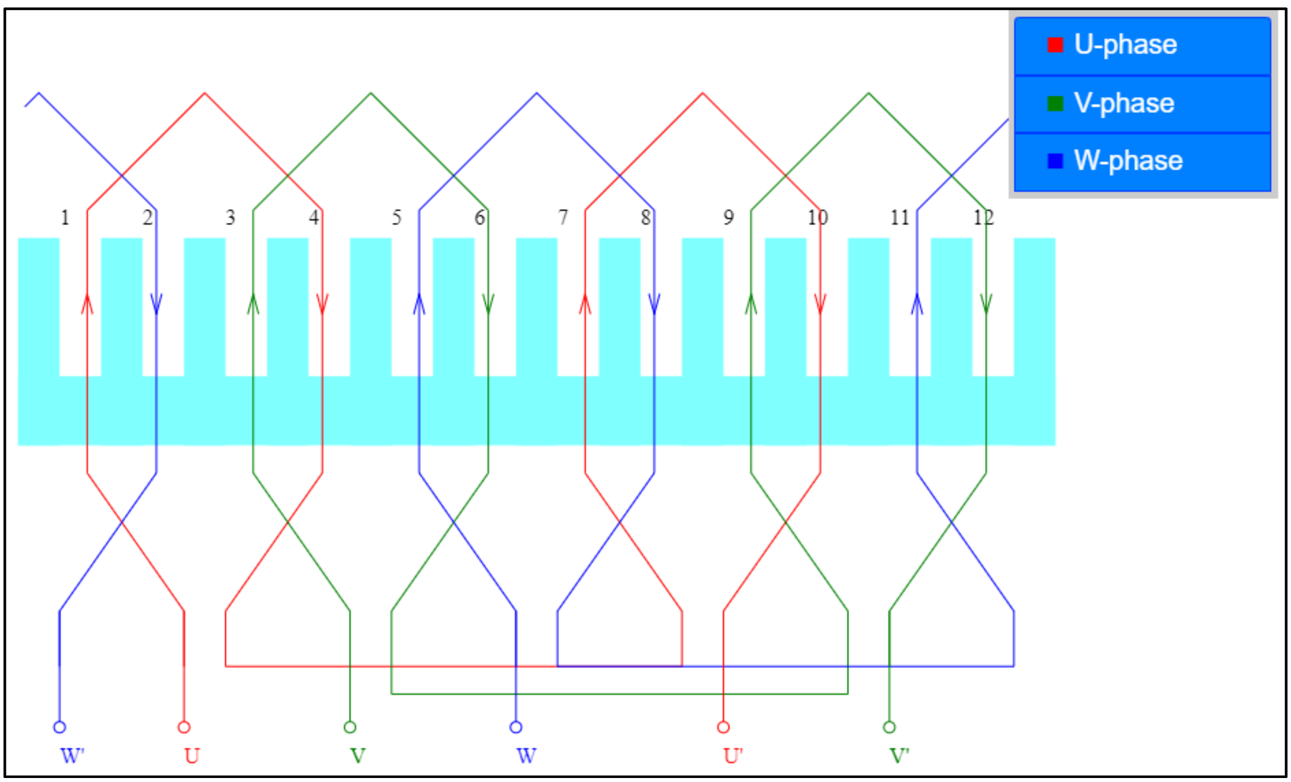

Figure A-2. Slot diagram of a 4 Pole – 12 Slot induction machine.

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Project Proposal Report Rubric

Faculty Consultant Signature:	Grade:
Team Name:	

Instructions

1) Mark the box for each item in the rubric, 2) add positive and/or constructive comments, and 3) provide a letter grade.

Technical Communication

	Strongly Disagree	Disagree	Agree	Strongly Agree	Comments
structure					
The document organization is logical, mapped for the reader, and enhances the readability.					
style					
The writing style is efficient, clear, precise, and lends credibility to the authors.					
mechanics					
Document is proofread and readable. References are cited. Graphics and equations effectively communicate relevant information.					

Content

	Strongly Disagree	Disagree	Agree	Strongly Agree	Comments
problem statement					
Clear need of client/stakeholders identified.					
Need remains open-ended and concepts for solutions are not discussed.					
Need is succinctly and memorably communicated.					
client and stakeholders					
Primary clients/stakeholder are clearly defined.					
Initial client/stakeholder interactions clearly support the identified need.					
Plan for client/stakeholder interaction communicated clearly.					

research					
Excellent research that convincingly answers "What has been done to solve this (or a similar) problem before?"					
Research is varied and includes patents, standards, and journal articles.					
Market potential clearly demonstrated (if applicable).					
Detailed understanding of competitors and their products (if applicable).					
additional arguments					
Additional arguments provide strong support that need exists.					
Social, political, environmental, etc., impacts considered.					
objectives and plan					
Major project deliverables (i.e. objectives) identified and their impact clearly communicated					
Success or failure of deliverables is easily measurable/quantifiable.					
Deliverables are reasonably scoped given the project resources.					
Reasonable plan of action communicated clearly.					