

# **Electrical Safety and the Conflict with a Motors Course**

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## **Abstract**

As a professor responsible for teaching the Electrical Engineering Technology courses and developing curriculum for the EET program, it has become evident that there exists a conflict between laboratory experiences traditionally taught and the ArcFlash requirements of NFPA 70E. This paper discusses the development of lab experiences that abide by the limitations of the NFPA requirements while continuing the principles of labs used prior to the implementation of this standard.

The discussion will include the argument as to why the need exists to re-visit labs using over 50 VAC equipment and how to effectively convey principles of working with higher voltage while effectively unable to have these voltages available in the teaching lab.

Lab experiences in the newly developed less-than 50 V environment will be examined. The discussion will also include lab experiences that can be accomplished in a simulated mode. While the lab experiences of real motors and other devices is favored, it is expected that there will be fewer schools embracing labs employing electrical equipment including motors since the Arcflash rules have been codified. This course or any course using voltage over 50 VAC should take a hard second look at the reasons for change while not giving up on real lab experiences.

## **Introduction**

Coursework many times is developed out of a tragedy and this is one. The tragedy was the death of a fellow professor in the EET program – Dr. Ahmad Farhoud. His sickness and eventual passing was the cause of much concern for the program and the entire department as others shifted over to “help out” with the courses for Ahmad.

## **Course Development**

One of the courses he had taught was the motors course – EET 4350 or “Electric Power Systems”. This course is taught twice each year – in Fall semester during the days and in Spring during the evenings. The course is a 4 hour course with 3 hours of lecture and a 1 credit two-

hour lab. The course had been taught in the same format for at least 20 years with Ahmad inheriting the course from a prior EET professor about 14 years ago at the time of that professor's retirement.

The Electric Power Systems or Motors course was taught by a part-time instructor during the year of Ahmad's illness. While this instructor was experienced in the subject material, it was determined that the course needed a full-time professor with teaching experience in the subject to take responsibility for the course and possibly take the course on as a regular teaching assignment.

A first attempt to find a 'fix' was to discuss the course with two professors from the Electrical Engineering Department who would be potential teachers since they were both recently retired. Their interest was genuine. But, ultimately both declined to take on the task. They both, however, recommended a change to a new text – Principles of Electric Machines and Power Electronics by P. C. Sen (Wiley). The prior text was Rotating Electric Machinery and Transformers by Richardson and Caisse (Prentice Hall). The text was changed. Although the recommendation came from two EE professors and the course would be taught to EET majors, the book was only somewhat accepted by the students. Problem sets tended to be difficult.

With no other teacher available, the EET professor was the choice to teach the course starting Fall 2013. He had not taught the course before. He had taken the EE Motors course as an undergraduate successfully as an EE student. The lab for that course was a one-hour course separate from the class-room course and he had been 'excused' from taking it (the result of a sympathetic advisor). He did have 15 years of industrial experience before coming to the university and had kept active in the intervening years with motor technology. He was not, however, prepared to teach the course and the start of the fall semester was less than a week away.

After a year (two semesters) of teaching the course, the book was deemed too difficult and a change was made. The text chosen was Electric Machines – Principles, Applications, and Control Schematics by Dino Zorbas. The text was used in Fall 2014 with better results than previously. The text has both exercises scattered in the text as well as problems at the end of the chapter. A combination of the both exercise and end-of-chapter problems seems to be an acceptable expectation for most EET students.

The course is being taught in Spring 2015 via a part-time instructor. Results from his class are still incomplete.

## **Lab Development**

In Fall 2013, the instructor had tried to track down the labs for the course. These labs were reportedly at a bookstore on campus so he took a walk over to the bookstore to pick up a set. On the way back, he stopped at the Safety Building to discuss the safety of the laboratory since he had some interest in the possibility that the arc-flash rules were not being enforced. The safety personnel were in their offices that day and questions posed concerning the safety of the laboratory equipment was met with a resounding 'no way'. The labs taught in the existing

format with voltages in excess of 50 VAC were not going to happen. Excerpts from NFPA 70E 2013 are included in Appendix 1.

The lab equipment under consideration was the Hamden equipment. It was old but efficient. The labs were printed and ready to go. But if anyone tried to use them and a student get hurt, both the university and the instructor would be liable.

The next step was to regroup and begin to write labs from scratch with equipment less than 50 volts. The result was to provide the lab experiences with low-voltage equipment as well as some simulation labs if they could be developed. The decision was made at that time to write new labs.

After making the decision to change, there was still some curiosity as to the validity of the decision to change the labs. A number of fellow practicing electrical engineers were queried and all agreed that the Hamden equipment was not safe with regard to the present arc-flash rules. The question was also posed to the electrical community on the Mike Holt internet forum. The answer was basically the same. The need to be safe was paramount even though the arc-flash rules were for industry and not educational institutions. Results from this internet forum may be viewed in Appendix 2.

The question was also posed to a number of fellow professors. No one at the University of Toledo would discuss the question directly, a disappointing but not unexpected occurrence. However, at a forum of heads of departments (sitting at a dinner table during a recruiting visit), several opinions were voiced and none disagreed that the decision to abandon the Hamdan equipment and stay at less-than 50 volt labs was a mistake. Their comment was that most schools had abandoned the lab component of the course entirely. This was a course that EET programs should not be willing to do since EET is a hands-on curriculum and the desire for hands-on labs has been a distinctive of the program. Other comments were that their school had abandoned the hardware and moved to a simulation-only lab experience only with computer output. This also was not an acceptable course of action since there was little hands-on experience with only computer simulations.

## **Results**

At the present, the course has been taught three times and is in the early stage of a fourth semester. Results are acceptable. The student can be expected to accomplish labs that are hands-on with equipment at less than 50 volts. Results from these labs, while not as impressive, are real and the principles are generally the same as those experienced with the older Hamden equipment. Appendix 3 shows the components of the labs from lab 4 to lab 8. The equipment is laid out with some equipment mounted to a board.

A list of lab experiences follows:

- 1 Wire a motor starter with push button control but do not demonstrate in a powered mode

- 2 Use AutoCAD Electrical to generate parts of an electrical one-line and three-line drawing.
- 3 Measurement of Transformer measuring both ideal and non-ideal parameters
- 4 Measurements with solenoids (two weeks)
- 5 Measurements with DC motors (three weeks)
- 6 Control of a Servo Motor
- 7 Control of a Stepper Motor

These labs are still in the process of development but have been well accepted in their present state. They can be found at the following website:

[www.cset.sp.utoledo.edu/~wevans](http://www.cset.sp.utoledo.edu/~wevans)

then sign-in with: wevans

and password: Myeet12

The labs follow the text usually by about a week or two and generally complement the text. The first two labs were introduced to make sure the student knew the steps in wiring a traditional motor starter without hooking it to power as well as the drawings that show the motor – the one-line and the three-line drawings. It was explained that the one-line drawing serves as the drawing of record if an OSHA official inspects the facility. The fault currents should be placed on the one-line at various points to show the distribution of fault current in the facility. The course did not attempt to derive the fault currents for a facility. A third lab did, however, review the report from a sample plant showing the fault currents at various points in the sample plant. The requirement for this lab was a 150 word paper reviewing the original report. The student should know of such reports and their importance in the modern facility concerned with electrical safety, specifically NFPA 70E and the arc-flash rules.

While using the Sen text, it was noticed that the text has changed from the second edition to the third edition.

The chapters are as follows:

1. Magnetic Circuits
2. Transformers
3. Electromechanical Energy Conversion
4. DC Machines
5. Induction (Asynchronous) Machines
6. Synchronous Machines
7. Single-Phase Motors
8. Special Machines
9. Transients and Dynamics
10. Power Semiconductor Converters
11. Wind Energy Systems

In the Fall 2013 (and again in Spring 2014) semester, chapters 1-5 were discussed. Chapter 6 was skipped. Chapters 7 and 8 concluded the course. The course had two tests, one after chapter

3 and the other at Finals week over the entire course. Several quizzes were given to keep students up-to-speed. Students were not allowed to use their book but were allowed one 8 x 11 sheet with anything they wanted on it per test. The quizzes and tests became an adventure in how much each student could fit onto these sheets. The problem sets at the end of each chapter were used for test questions and any problem assigned was a possible problem for the quiz or test. The course became a one of problem analysis and organization of information onto a single sheet.

In Fall 2014 and Spring 2015, the Zorbas text was used. The chapters are as follows:

1. Basic Electromagnetic Concepts
2. Transformers
3. Three-Phase Induction Machines
4. Single-Phase Motors
5. Synchronous Machines
6. DC Machines
7. Control Schematics
8. Electrical Safety and Reduction in Energy Consumption

Chapter 1 was extensive and was used to review ac sinusoidal principles missing in many students' background. This chapter was the main chapter used for the mid-term test. Other chapters studied were Ch. 2, 3, 4, and 6. These chapters formed the basis of the second half of the semester. Again, several quizzes were given to keep students up-to-speed. The students were allowed again one 8 x 11 sheet with anything they wanted on it per test. This procedure seems to work.

## **Discussion with Students**

The students who took the course in the year between the changes that have been outlined here and the end of Ahmad's active tenure had many comments that helped to shape the present course. One student encouraged the use of safety equipment in the lab using the Hamden equipment. This led to the effort to stop by the safety building which was really a request for use of safety equipment including glasses. This comment was timely in that even the students knew that there were problems with their exposure to 230 VAC in an open environment even though the university had tended to ignore the problem.

Subsequent discussions with the students taking the course in Fall - 2013 encouraged the use of the labs presently in place. The inclusion of the second and third labs actually aided in understanding the arc-flash rules and the need to deal with the newer standards of NFPA 70E.

The labs are presently being reviewed to provide a better over-all experience while maintaining integrity of the lab experiences. There are some complaints pertaining to the degree of difficulty of some of the labs in which students are unable to adequately complete the labs in a timely

manner. The lab equipment provided was bought in Fall 2013 and used by students in that semester. Equipment is being evaluated to upgrade and fix the items needing replacement.

What happened to the Hamden Lab? The EE classes continue to use it. Teaching assistants are assigned to teach the labs and students continue to learn on this equipment. And the effort to find labs that are purely simulation labs has not been adequately explored. Perhaps there is some merit in looking for labs that could be simulated. To date, this has not been accomplished.

The spring semester of year two has been interesting in a number of ways. The instructor for the past three semesters was needed elsewhere so a part-time instructor was sought. This instructor was a former student who had taken the course and now worked in industry. The department also provided a TA for help in the lab. The full-time instructor now had the responsibility to help the new instructor in preparation of the course material plus aid the TA with lab experiments. This arrangement was necessary due to the shortage of full-time instructors in the department.

The part-time instructor has done quite well with the lecture portion. His inclusion of several videos showing many aspects of electro-magnetic phenomena was helpful to the students. He even found a video of the internal workings of the motor overloads as they tripped in an over-current situation. The use of videos in this course will be continued and enhanced as the course moves forward.

The TA has been very helpful in identifying difficult or poorly written labs and has volunteered to re-write some of the lab assignments. His aid in helping to suggest changes in the labs has been very beneficial. Student comments from the fall semester were mostly complementary with few suggestions for upgrades. Students usually see the need to understand motors and electro-magnetic concepts although they many times complain about the content.

The program also received commitment for some VFD motor controllers from a reliable vendor recently. The use of small 3-phase VFD motors and motor controls is a plus going forward since the current and voltage can be displayed in the display window of the drives. Use of an oscilloscope may also provide useful if the arc-flash concerns can be met. Going forward, the course will continue to provide the less-than-50 volt labs but carefully move to include state-of-the-art motor controls with protection for the student.

## **Summary**

The Motors course needed to be changed but the manner in which the change came about was not expected or desired. The sickness and passing of one of the best professors in EET was not planned nor was the ensuing division of his courses among other faculty a planned occurrence. Events unfolded, however, and courses were ultimately re-assigned. The Motors course was one of these courses. The attempt by this author to examine this course led to a number of changes. First, the book was changed. Then the labs were changed.

This may be considered by some as ‘just soldiering on’. However, there needs to be an evaluation as to how any course is taught based on the changes of the profession. This is a

responsibility of the professor. The needed changes were implemented even while there has been continuing effort to evaluate whether the decision to abandon the Hamden equipment was correct. The professor should give primary consideration to how best to give students experiences similar to those of prior years but that are considered safe by today's standards.

Hopefully, there will be discussions about the merits of the changes of the Motors course as they pertain to other universities and the need for true hands-on lab experiences coupled with the theoretical concepts they demonstrate. Nothing would have pleased Ahmad more.

## Bibliography

- 1 Principles of Electric Machines and Power Electronics by P. C. Sen (Wiley).
- 2 Electrical Safety, the NFPA and PLC Safety, ASEE 2013 Atlanta National Convention, William T. Evans, PhD, PE
- 3 Electric Machines – Principles, Applications, and Control Schematics by Dino Zorbas (Cengage)

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## Appendix 1

### NFPA 70E

(A) Covered. This standard addresses electrical safety-related work practices for employee workplaces that are necessary for the practical safeguarding of employees relative to the hazards associated with electrical energy during activities such as the installation, inspection, operation, maintenance, and demolition of electric conductors, electric equipment, signaling and communications conductors and equipment, and raceways. This standard also includes safety work practices for employees performing other work activities that can expose them to electrical hazards as well as safe work practices for the following:

- (1) installation of conductors and equipment that connect to the supply of electricity
- (2) installations used by the electric utility, such as office buildings, , warehouses, garages, machine shops, and recreational building that are not an integral part of a generating plant, substation, or control center

### Article 130 Work Involving Electrical Hazards

#### (A) Energized Work

- (1) **Greater Hazard.** Energized work shall be permitted where the employer can demonstrate that de-energizing introduces additional hazards or increased risk.
- (2) **Infeasibility.** Energized work shall be permitted where the employer can demonstrate that the task to be performed is infeasible in a de-energized state due to equipment design or operational limitations.
- (3) **Less Than 50 Volts.** Energized electrical conductors and circuit parts that operate at less than 50 volts shall not be required to be de-energized where the capacity of the source and any overcurrent protection between the energy source and the worker are considered and it is determined that there will be no increased exposure to electrical burns or to explosion due to electric arcs.

## Appendix 2

Question posed on Mike Holt Blog:

I am a professor of Engineering Technology at the University of Toledo. Does NFPA 70E apply to educational labs? In other words, do students have to be protected in a motors lab from the same arc flash rules found in industry. We have labs with exposed 230 VAC and I have refused to teach with this equipment.

My course has been re-structured using less than 50 VAC which is really difficult since we can't do much with ac motors.

### Response 1 (moderator):

Have you read the Purpose (90.1) and Scope (90.2) of 70E? You are an employee of the school; are the students employees while in the lab?

Technically, the rules only apply to you; however, any avoidable accidents that would have been prevented by observing 70E could still expose the school to liability. Talk to the school's legal counsel. We aren't attorney's.

### Response 2

I agree with Mr. Alexander.(response 1)

In any case, exposing your students to 70E is good training for them.

### Response 3:

#### **It's the amps**

The energy from an accident can be controlled by providing resistance/reactance in the circuit. Get an EE buddy to help you figure out what you need for 120/240V to prevent arc flash. [Arc flash is actually pretty hard to get for 120/240 with small enough available amps]

If you are worried about electrocutions, follow 70E, PPE for measurements; lockout for wiring.

-- OR --

treat students like apprentices -- expendable

### Response 4:

The simplest solution is to change the exposed conductors to non-exposed, protected. Keep in mind non-exposed or protected is not the equivalent of not visible... meaning clear, see-through barriers can provide arc flash protection. Not so much on the visible flash if an arc were to occur, but depending on configuration, could significantly reduce the potential for an arc to occur.

Also, as mentioned are using means to control the amount of available incident energy.

#### Moderator:

There is no question that hazards in the lab can be mitigated; however, the OP asked if the students were covered by NFPA 70E. Unless there is an employer/employee relationship, neither NFPA 70E nor FedOSHA speaks to the issue.

In a few States (California is one of them, I don't know about Ohio) the State OSHA covers more than employees in certain cases. Under civil liabilities, since there are known hazards (the professor knows about 70E) it's likely a tort attorney would have no problem suing someone.

As I mentioned though, we aren't attorneys so no one here is qualified to say much more than 70E applies to employees.

#### Response 5:

If there are upper level students who are working as lab or teaching assistants, then whether or not they are employees for any particular purpose which distinguishes treatment of employees will be a very good question for those same lawyers.

Back when I was in school whether a student who got a scholarship or stipend for that kind of work was an employee depended on whether it was billed as part of his required learning experience or just a job for compensation.

#### Response 6 :

My earlier post is not in disagreement. ANSI/NFPA 70E (and similar electrical safety documents\*) are about mitigating hazards when work on or manipulation of electrical equipment is being performed by workers (employees)... and nothing about mitigating hazards to others that may do the same in a non-employee status. We can say plenty about that without getting into the legalities, the first of which is...

\* FWIW, I've been working in the nuclear power industry for the past few years. Everyone I've talked to says utility generating plant workers are not covered by NFPA 70E, the same as NFPA 70 doesn't apply to utility power plant installations. However, being the nuclear industry is documentation driven, each utility I'm aware of has a documented electrical safety program. I have two 50+ page documents sitting off to the side of my computer as I type this reply on the very subject, and each includes other (...pages upon pages of...) documentation by reference.

#### Response 7:

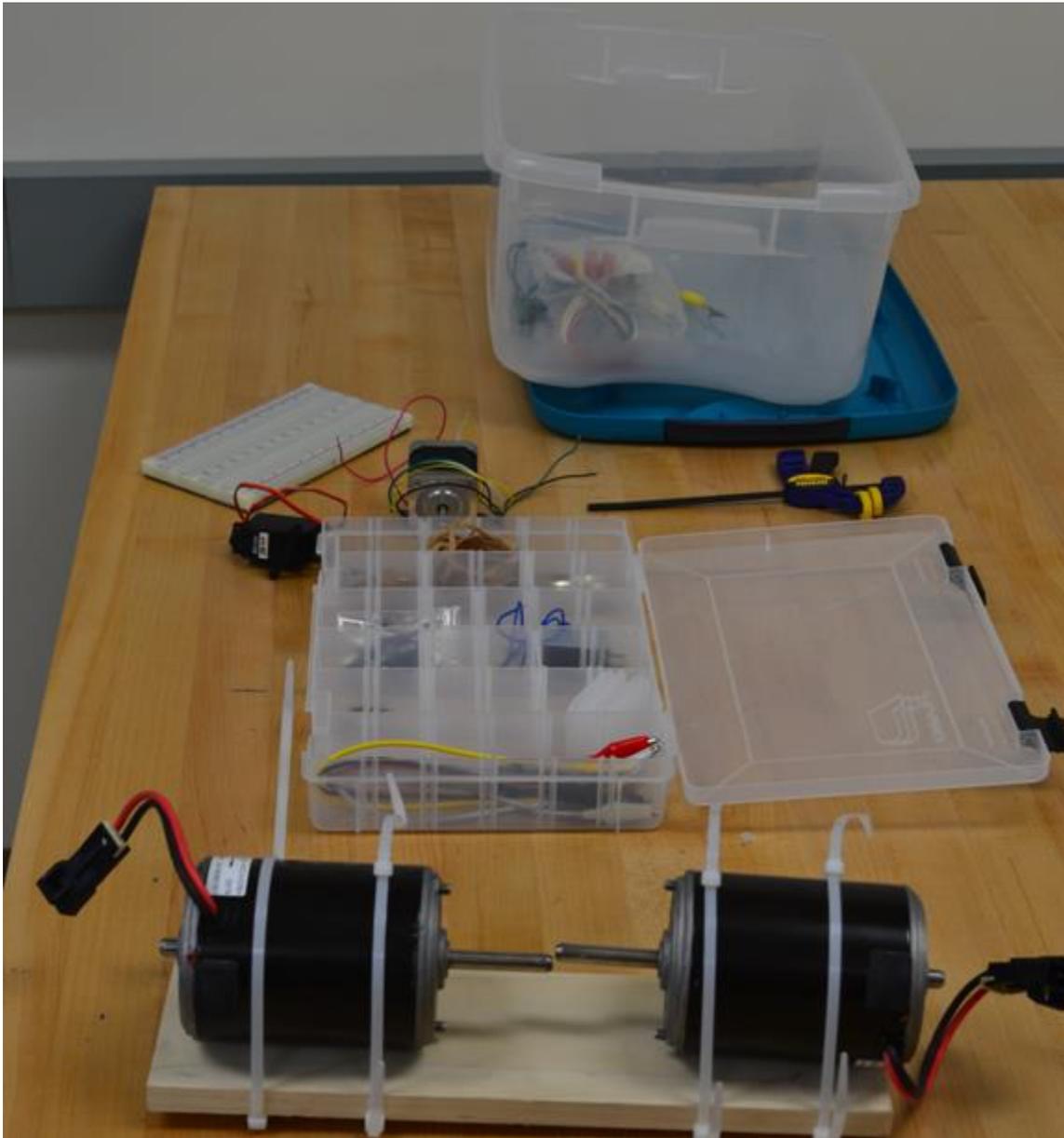
Just thinking out loud so take it for what it is worth.

There AC 3-phase motors under 50 volts, many of them. Some go up to 10 HP. You just have to think outside the box. Think Golf Carts, Neighborhood Electric Vehicles, Fork Lifts, and Radio Controlled Airplanes. See if that gives you any ideas.

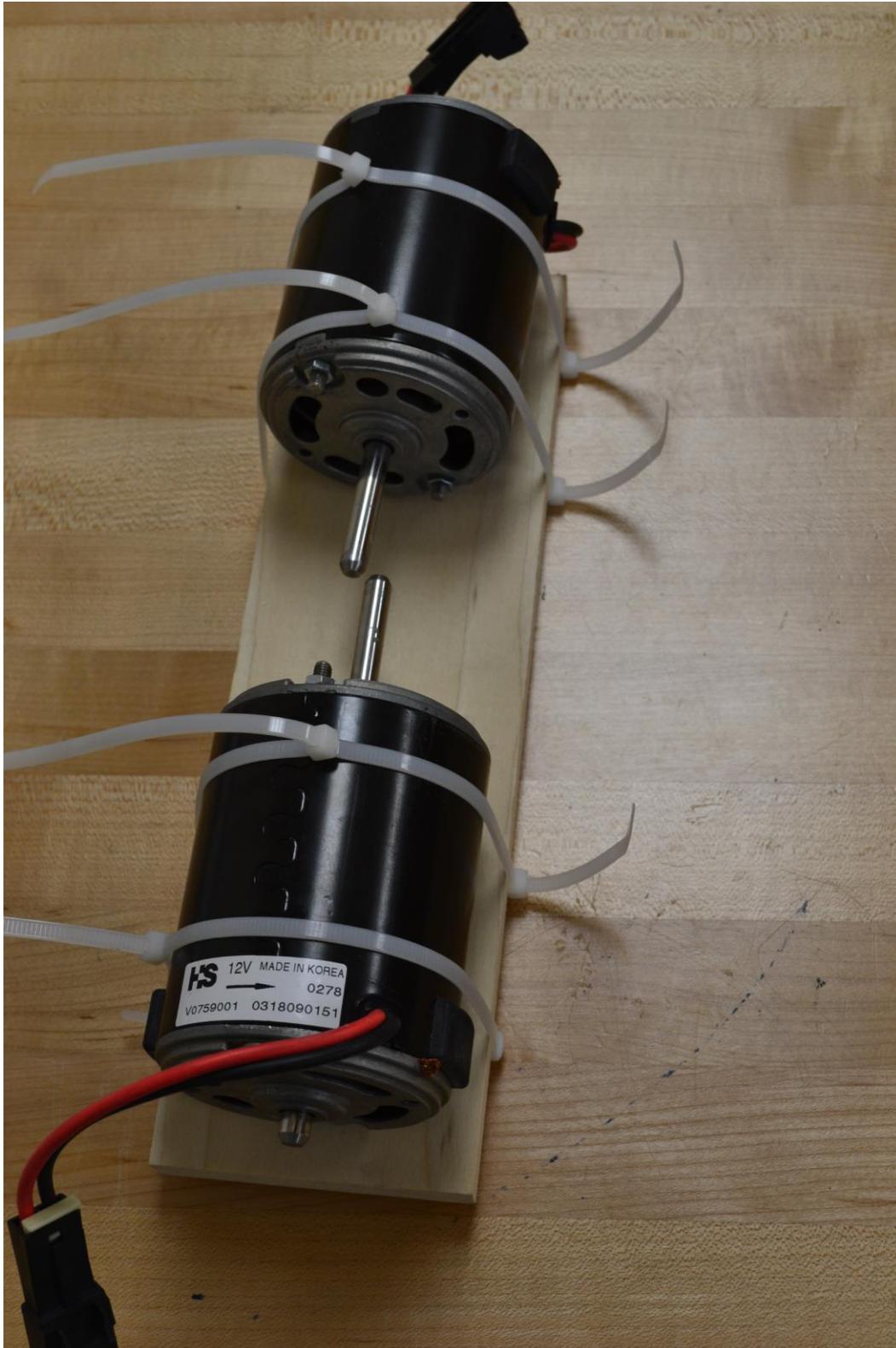
#### Response 8:

In a highly legalistic way no one is covered by NFPA70E. It is a program many employers choose to adopt to meet OSHA requirements to have an ES program in place. There is no general requirement at all that the ES program include any part of NFPA70E.

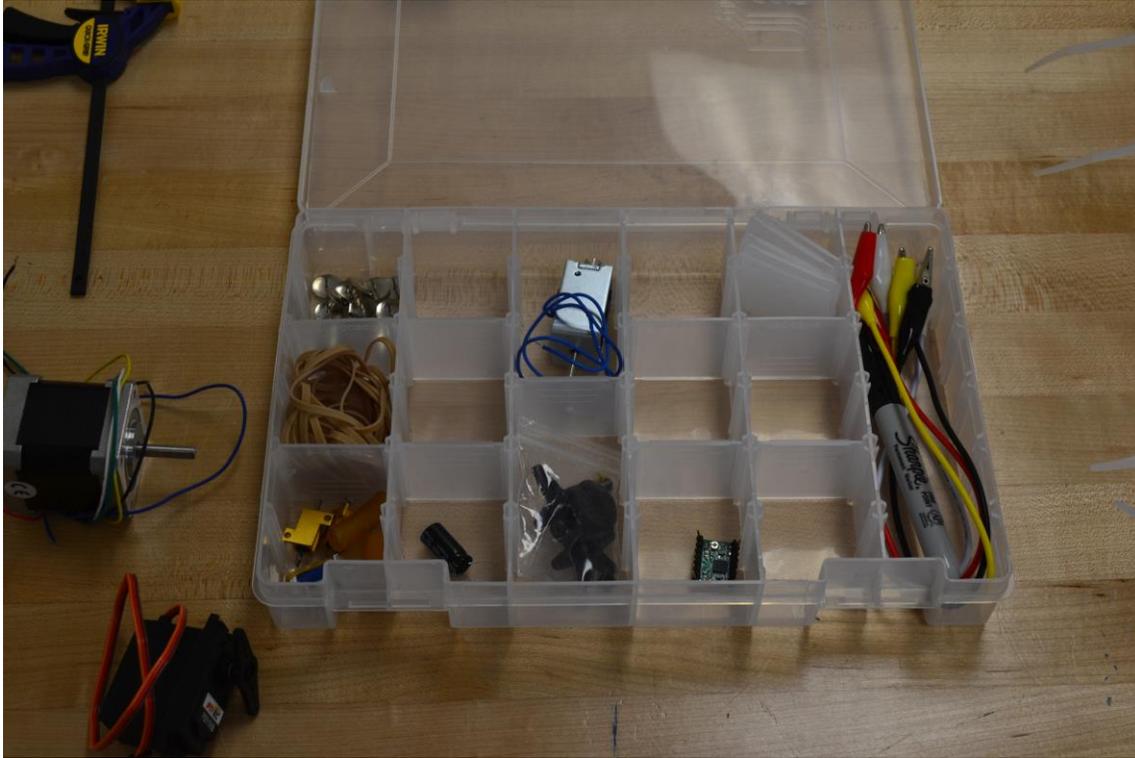
### Appendix 3 – Equipment used in Present Labs



Pictured above is a storage tub with the equipment for one lab station laid out for inspection. In the foreground is the mounting for two dc motors. Behind the motors is an organizer with smaller components. Finally is seen the breadboard, servo, stepper and locking mechanism for the motors.



Pictured here are the two motors mounted to a board. The boards were bought from Home Depot and used for mounting of equipment. Here can be seen the need for coupling between the motors. We used surgical tubing and duct tape. The combination worked quite well.



Pictured above is the organizer with various components from the labs in it. We used alligator clips for many connections. Pictured below is the transformer. We did not plug the transformer into the wall but used it with a variac for input voltage.





Pictured above are the elderly variacs used in the lab. We had them from years ago and used them again as needed. Pictured below are the dc power supplies used. We needed at least 6 A of 12 V power to run some of the motor experiments and these were the only ones capable of 6 or higher Amps.

