AC 2007-625: RE-WIRING A POWER/MOTORS LABORATORY FOR IMPROVED STUDENT SAFETY

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Re-wiring a Power/Motors Laboratory
for Improved Student Safety

Abstract

For over 40 years, the Purdue University EET program has included a required course that, at various times, has covered transformers, motors, basic power system calculations, relay controls, and PLCs. In the laboratory, we have used Hampden equipment with banana-plug patch cords. Since the lab equipment was installed in 1985, one student was shocked (back in 1989) and on a number of occasions, hot leads have been removed by students, accidentally or deliberately without thought, which resulted in contact with grounded cabinets. Thus, for a number of years, our laboratory safety committee has asked the power instructors to come up with a safer means of connecting the experiments. After a couple false-starts, we finally arrived at a safer method of connecting equipment, although it required replacing every socket on every piece of equipment in the lab. This paper will describe the pitfalls that were encountered and the final results of the renovation in the hope that others can avoid some of the difficulties we encountered.

Re-wiring of the power benches and equipment

The Electrical Engineering Technology (EET) program at Purdue University was founded in 1965 and has traditionally included a required power course in the sophomore year. In 1985, the program moved into renovated laboratory space and the power lab received eight new Hampden[1] benches, one of which is shown in Figure 1. Each bench is equipped with single and three-phase induction motors, synchronous alternators, dc motors and generators, dc dynamometers, single-phase resistive load boxes, three-phase RLC load boxes, transmission line simulators, phase-shifting transformers, phase angle meters, and other equipment.

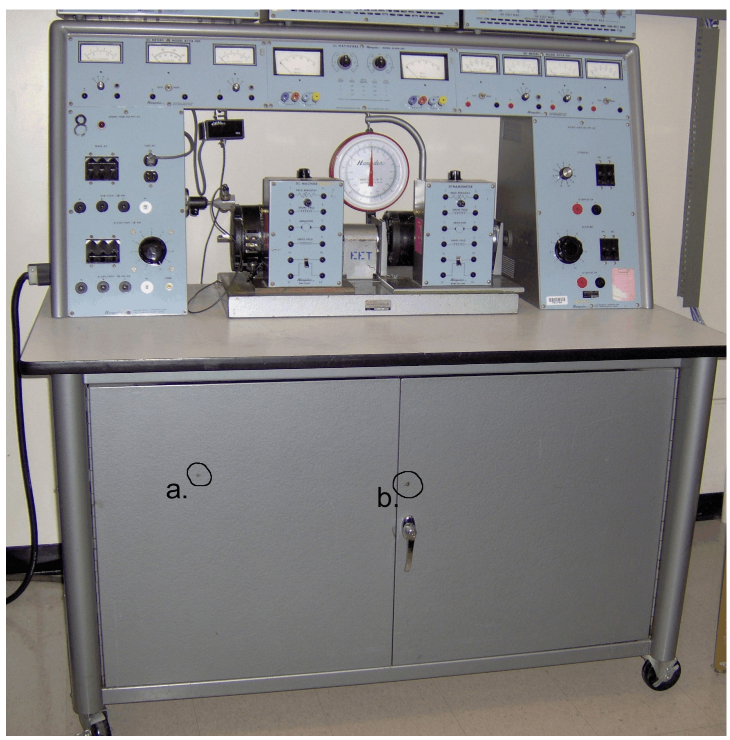

Figure 1: Power lab work bench

As originally constructed, connections were made to the bench and other devices using banana-plug leads, as shown in Figure 2. As can be observed in Figure 2, the power supplies had sockets that only accepted banana plugs, while the ground terminal had a screw-down terminal that allowed either banana plugs or spade lugs to be connected. The rotating machines generally had the screw-down terminals, while most of the load boxes had sockets that only accepted banana plugs. One problem with the banana plugs, which is evident in Figure 2, is that hot leads can be left unconnected. This, of course, represents a potential shock or arcing hazard.

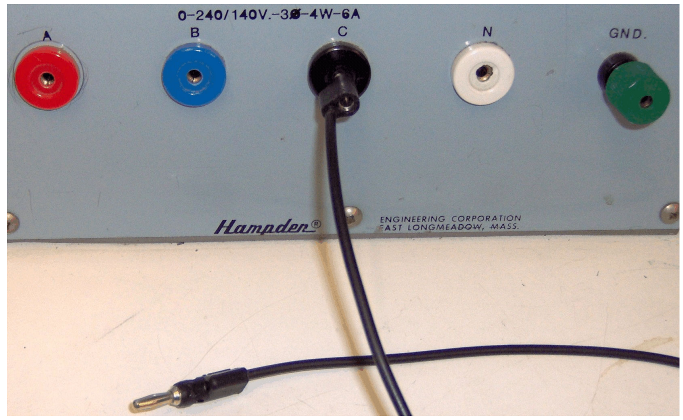

Figure 2: Bench power lead connections, as originally installed

Fortunately, there has only been one known shock incident and that occurred in 1989 before all of the authors, except Robertson, were on the faculty and staff. Part of this success is attributed to devoting the first laboratory session each semester to electrical safety. Using a presentation developed by author DeWitt, the students are shown both real and dramatized electrical accidents, and aspects of electrical hazards and safety are discussed in detail. Despite the emphasis on safety, however, there have been a number of arcing incidents (probably once every three semesters on average) during the years. In Figure 1, there are two circles marked "a" and "b," which resulted from energized leads contacting the grounded cabinet. Close-ups of these are shown in Figure 3.

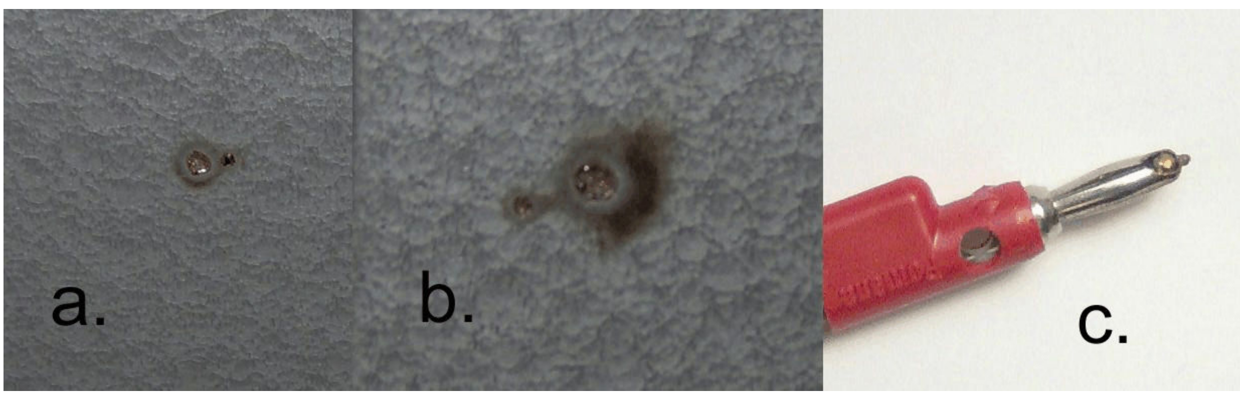

Figure 3: Results of arcing accidents. a.and b. Arc damage to power console. c. Arc damage to banana-plug lead.

Also shown in Figure 3, as part "c," is the damage to a banana plug resulting from an arc event. Obviously, when these events occur, it is rather scary to the students involved and they do present a burn hazard due to molten metal. Arcing events result either by accident or due to student carelessness.

Banana plugs are held in place by the friction created by springs on the side of the metal connector. Figure 4 shows a close-up of a banana plug in which one of the springs has broken off, due to metal fatigue resulting from numerous insertion/removal cycles. When that occurs, the holding strength of the plug is reduced and it is susceptible to being accidentally knocked out of the socket. To avoid this, the students are instructed to always check the leads at the start of lab and to verify they are in good repair. However most, if not all, of the arc events that have occurred in the lab were likely due to students not turning off the power prior to disconnecting all or part of the circuit. Author DeWitt on one occasion observed a student who removed a hot lead and then, realizing it was hot, stood there swinging it back and forth, unsure what to do. Before the student could decide what to do or the instructor could intervene, the hot lead made contact with the bench. Fortunately, no student has ever been injured, as the circuit breakers have always operated in sufficient time to prevent anything more than superficial scarring of the benches and a damaged lead. (Note: students are required to wear approved eye protection in lab.)

Despite the good safety record, we wanted to improve the safety of our laboratory equipment. Two challenges arose. First, what would improve the safety, and second, the sheer number of terminals and leads involved in any change. For several years, the head of our department safety committee proposed that we use spade-lug connectors with screw-down terminals. Intuitively, those of us who teach the introductory power course were opposed to such leads, but after continued pressure, we purchased several leads to investigate their usefulness in our lab.

Figure 4: Damaged banana plug

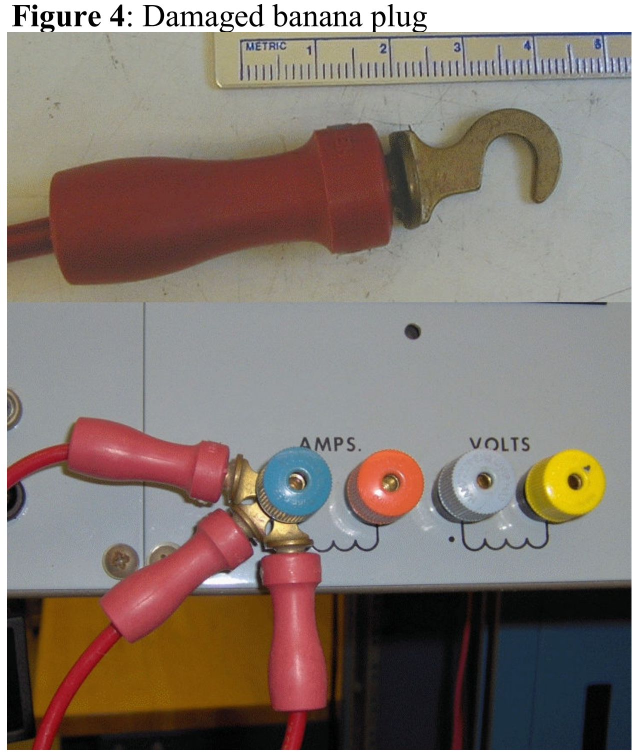

Figure 5: Top–spade lug. Bottom–multiple connections to a single terminal

The top portion of Figure 5, shows a close-up view of a spade-lug connector designed for use with our equipment. As is evident, they are relatively large. After examining them, we quickly ruled them out because many of the experiments require two, or more, connections to a single terminal. As shown in the bottom portion of Figure 5, multiple connections of the spade-lug connectors require quite a bit of room and leave bare metal exposed that presents a shock hazard to the students. These connectors could worsen the situation if a student disconnected a circuit prior to turning off the power.

With the emphasis on arc-flash prevention in industry, new products came to market and several years ago, we began looking at other alternatives. The first product that came to our attention was the safety banana plug. As shown in Figure 6a, the metallic portion of the banana jack is covered with a plastic sheath, which retracts, as shown in Figure 6b. Also as shown in Figure 6b, the tip of the plug is plastic so when the sheath is extended, there is no shock hazard. As we had done with the spade lugs, we purchased some samples to test in the lab.

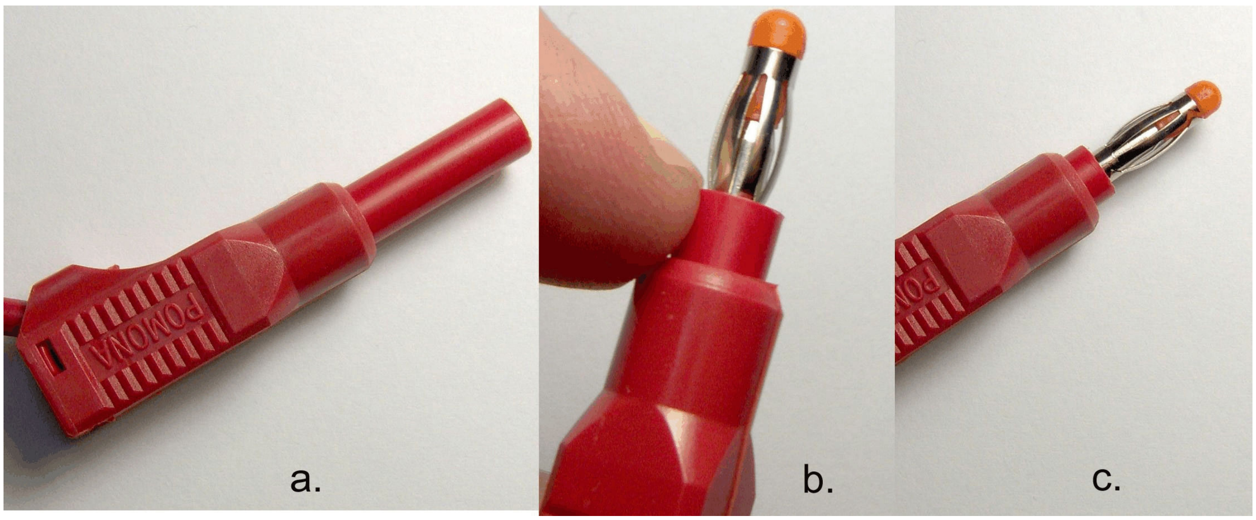

Figure 6: Safety banana plug. a. Sheath extended. b. Sheath being retracted. c. Sheath stuck in the open position.

These leads seemed at first to be an ideal solution, as they could be used with all of the existing sockets in the lab. In theory, there should be no shock hazard when a plug is removed from a socket. Unfortunately, that was not to be the case, as we quickly found a problem with the leads. The principle of operation of these leads is that a spring holds the sheath in the extended position and that inserting the plug into a socket causes the sheath to retract, compressing the spring. Removal of the plug from the socket should cause the sheath to extend back over the metallic portion of the plug. We found, however, that a significant portion of the leads we purchased would remain in the retracted position upon being removed from the socket. In some cases, the sheath would slowly cover the metallic connector over a period of a few seconds, while in others the sheath had to be wiggled out. Figure 6c shows the connector in the open position without anything holding it in place. As a result, we reluctantly decided that these would not be a feasible solution. With the failure of the retractable safety leads, we were left with fixed-sheath safety leads, as shown in Figure 7.

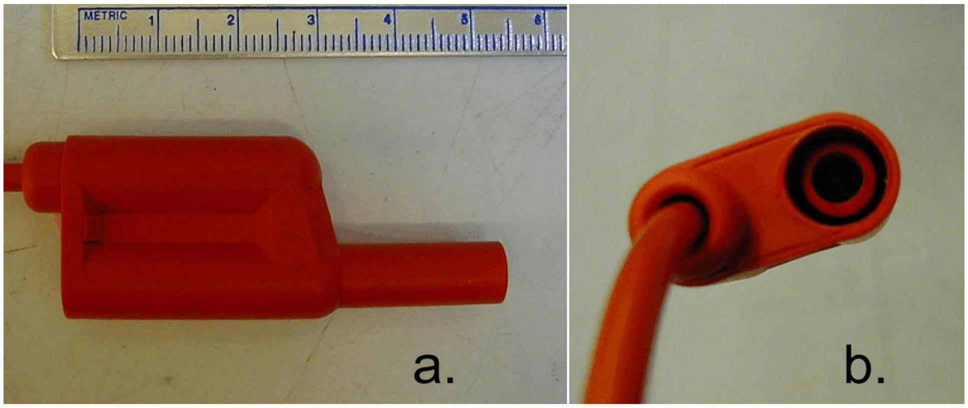

Figure 7: Fixed-sheath safety banana plugs. a. Side view of sheathed jack and b. end view of stackable receptacle.

Figure 7a shows a side view of the plug. The sheath over the banana jack is permanent, which means the receptacle must allow the sheath to enter as well as the jack. Figure 7b shows the end view of the plug with a stackable socket. From the picture it is apparent that the sheath slides into the outer ring, while the metal jack enters the inside circle. The primary advantage of this system is that, as long as the connectors are undamaged, it is impossible to have a live, loose connector.

Figure 8 shows a bench with the new sockets and a loose wire. Since the metal portion of the banana jack is surrounded by the plastic shield, no harm is done if the power is turned on with a wire left unconnected. Another advantage that we found during our evaluation is the connectors require more force for insertion and removal than a conventional banana jack, so it is extremely unlikely that a wire could fall out. The disadvantage of choosing these connectors, of course, was that every socket in the lab would have to be replaced, at a cost of several thousand dollars and many hours of labor. Despite the cost, it was decided that the project could be done during the summer of 2005 by author Brelage and the materials were ordered. Unfortunately, further problems were encountered.

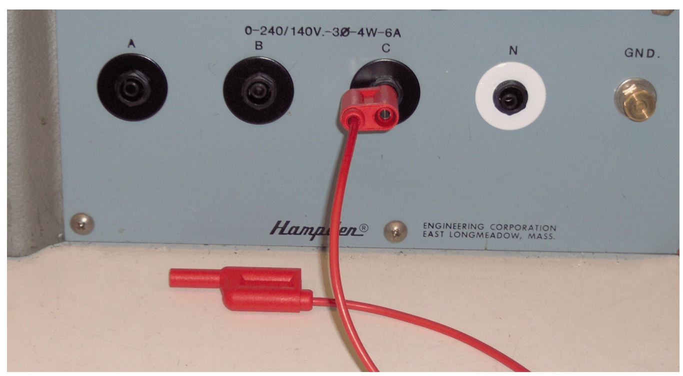

Figure 8: Power supply with new sockets and safety connectors.

Figure 9 shows the backside of three safety sockets. Connections are made to them by screwing nuts onto post connectors. It was found, however, that tightening down the nuts pulled the post connector loose from plastic portion of the socket. It quickly became evident that the brand of connectors we had purchased would not be feasible and an alternative would have to be found.

Fortunately, a supplier for the European market was found. Samples were ordered from them and found to yield acceptable results, as shown in Figure 9.

The change to a different brand resulted in delays so installation of the new sockets was not completed until the middle of the spring semester of 2006. Fortunately, the new sockets are backwards compatible and do accept conventional banana plugs. Thus, we were able to phase in the installation of the sockets during the school year and continue using the old leads. Once all of the sockets were changed out, we immediately went to the new leads, due to their enhanced safety.

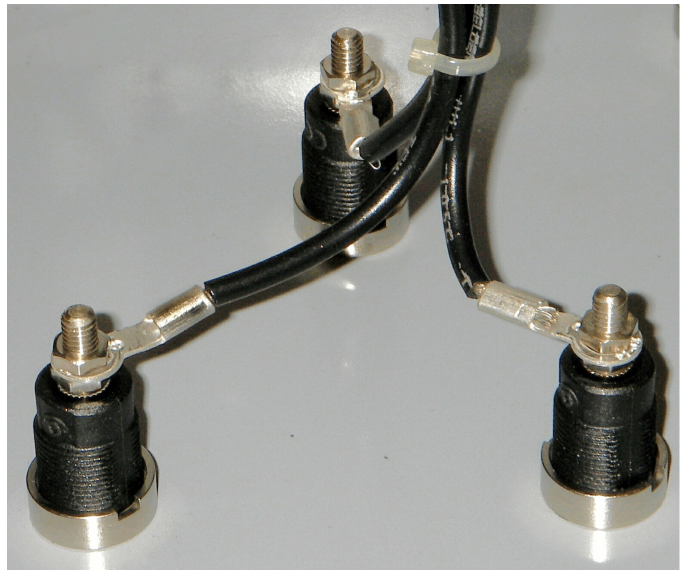

Figure 9: Back connections to safety sockets

Conclusion

We found during our investigation that not everything works as advertised. Thus, we definitely recommend that anyone planning to rewire their lab start with a test batch of materials to make sure they do the job. We were fortunate in that the manufacturer of the first batch of sockets we purchased took them back when the problem was shown to them.

By re-wiring the power benches and equipment, the safety of the laboratory has been improved. At the time of the writing of this paper, we have been using the safety leads for two semesters. During that time, there have been no arcing events or electrical shocks.

Unfortunately, the safety leads are not indestructible. Figure 10 shows a lead that was found to be broken, most likely by someone stepping on it. Thus, it is still necessary to instruct the students to check all of their leads before using them (it is also necessary to remind students not to leave leads lying on the floor).

Figure 10: Broken safety lead.

Acknowledgments

Authors Skvarenina, DeWitt, Robertson, and Kulatunga particularly wish to thank author Brelage for his outstanding work in changing out all of the sockets and working with the manufacturers to obtain workable equipment.

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References

1. Hampden Engineering. http://www.hampden.com