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Electric Machines and Power Electronics: Safety Precautions and Basic Equipment

--Manuscript Draft--

Manuscript Number:	10114
Full Title:	Electric Machines and Power Electronics: Safety Precautions and Basic Equipment
Article Type:	Manuscript
Section/Category:	Manuscript Submission
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Electrical Engineering Science Education Title: Electric Machines and Power Electronics: Safety Precautions and Basic Equipment

Overview

Electric machines and power electronics experiments involve electrical currents, voltages, power, and energy quantities that should be handled with extreme diligence and care. These may include three-phase AC voltage (208 V, 230 V, or 480 V), up to 250 V DC voltages, and currents that can reach 10 A. Electrocution occurs when an electrical path is established through a person's body with very low currents that can damage vital organs, such as a person's heart, and may cause immediate death. All experiments must be performed in the presence of personnel trained to handle electricity at these voltage and current levels. In case of emergency, evacuate the lab through any of the exits and dial 911.

Principles

The "Safety Precautions" procedural section covers the major guidelines and precautions intended to achieve a safe lab and operating environment for people performing experiments. These guidelines are by no means inclusive of all necessary precautions, and local electrical safety rules and regulations should be followed.

Experiments involving electric machines and power electronics typically use common equipment to supply power and to measure electrical quantities. However, circuits and apparatus being tested vary for different experiments. The "Basic Equipment" procedural section provides an overview of major equipment used for most electric machines and power electronics experiments. Specific equipment, circuits, and apparatus are introduced in each experiment as needed.

Procedure

1. Safety Precautions

1.1. Electric Power and Experimental Setup

1.1.1. Avoid loose wires, cables, and connections.

1.1.2. Assume any exposed metal is live with electricity, unless otherwise verified.

1.1.3. Familiarize oneself with all ON/OFF buttons on equipment, circuit breakers in the lab, and disconnect switches of a bench.

1.1.4. Only make changes to the experimental setup when the circuit power is turned off and all power sources read zero voltage and zero current, as applicable.

1.1.5. Use wires of suitable length for their appropriate applications. Long wires or connections can cause clutter on a bench, and very short wires or connections can be too tight and may be easily disconnected.

1.1.6. Separate higher power equipment and connections from lower power equipment, such as microcontrollers, to avoid both interference and electrical interconnections between sensitive electronic devices and higher power devices.

1.1.7. Make sure all DC power supplies, AC sources, and other power sources start from a zero voltage and zero current output or as directed in an experiment. Starting from a non-zero voltage is possible in certain applications where a voltage source should have a specific initial condition.

Commented [AM1]: What would the alternatives be?

1.1.8. Turn off all equipment before leaving the lab once an experiment concludes.

1.1.9. Do not allow a single user to perform an experiment alone. Make sure at least two users perform an experiment when operating more than 50 V DC and three-phase AC.

1.2. Work Environment

1.2.1. Familiarize oneself with the exits in the laboratory.

1.2.2. Avoid a cluttered work environment.

1.2.3. Have a pen, calculator, lab notebook, and experiment description prepared and ready.

1.2.4. Appropriately cool and label warm (due to heat dissipation) equipment.

1.3. Clothing and Personal Requirements

1.3.1. Remove jewelry, metal wrist watches, or other metal accessories while performing any experiment, as these can be dangerous in the vicinity of rotation machinery and electrical connections.

1.3.2. Do not wear loose apparel, shorts, or short skirts, as they expose skin to electrical connections and rotation machinery.

1.3.3. Do not wear hanging ~~non-metal~~ necklaces, glasses, ties, and other accessories, as users tend to get close to rotating machinery and electrical connections. Also, avoid hanging glasses around the neck, as these can be easily grabbed by rotating machinery.

Commented [AM2]: Any reason for non-metal here? Or do you mean any hanging accessories?

1.3.4. Tie long hair to the back of the head.

1.3.5. Wear safety goggles at all times during the experiment. Wear other personal protective equipment (PPE) as required by local safety rules and regulations. For example, common PPE includes fire-retardant coats, high-voltage insulating gloves

Commented [AM3]: What other safety equipment would we expect for electrical experiments?

(worn when handling live wires or cables), and earplugs (used when operating loud machinery).

2. Basic Equipment: Demonstration and Overview of Electronic and Measurement Equipment

2.1. Turn on the function generator (**Figure 1**). Function generators provide periodic AC signals of different shapes. These shapes are mainly sinusoidal, triangular, saw-tooth, and square.

2.1.1. Set up the function generator to produce a sinusoidal output of 10 V peak at a frequency of 400 Hz and zero DC offset.

~~2.1.1.~~2.1.2. Connect a BNC-to-alligator connector with the BNC tied to the function generator output port.

~~2.1.2.~~2.1.3. Adjust the frequency and peak, or peak-to-peak, of these signals, if desired.

~~2.1.3.~~2.1.4. On triangular and saw-tooth signals, adjust the slope and shape, if desired. Square waveforms have adjustable duty cycle, which is defined as the proportion of the period during which a square waveform is positive or “high” versus negative, zero, or “low”.

~~2.1.4.~~2.1.5. Note that certain function generators provide non-periodic noise and random signals but these are not commonly used in power electronics and electric machines applications.

2.1.6. Keep the function generator output off.

2.2. Turn on the DC power supply (**Figure 2**). Low power DC supplies operate in two main modes – either voltage sources or current sources.

2.2.1. Observe the voltage and current readings.

2.2.2. Set the DC power supply output voltage to 10V by adjusting the output voltage knob. Operating as a voltage source is the most common, where the supply provides low voltage DC, typically ranging between 0 and 36 V. In a current source operation, these supplies are “current limited” where their maximum current is set to the desired value, and their voltage is automatically adjusted to provide the desired maximum current. Current and voltage limits thus provide operational flexibility, as well as safety margins when operating a DC power supply.

2.2.3. Press the “Current” button to display the current limit and adjust the current knob to adjust the maximum current limit. Set the current limit of the supply to 1A.

Commented [AM4]: Please provide representative figures showing the basic equipment covered here. Label the components discussed in the text in each figure.

Commented [AM5]: You introduce each piece of equipment by stating what it is used for.

Revise each introductory statement to include what the instrument is/does/how it works.

~~2.2.3.~~2.2.4. Note that most single-output DC power supplies have three terminals labeled as +, –, and ground. In many applications, – and ground are tied to provide a more stable and reduced noise environment when providing an external circuit with power. However, certain cases require that – is floating from ground to isolate the electrical circuit or apparatus under test from the supply ground.

~~2.2.4.~~2.2.5. Keep the supply output off.

2.3. Turn on the oscilloscope (**Figure 3**). Oscilloscopes, or scopes, display voltage and current waveforms on a screen, which provides a wide range of essential measurements.

2.3.1. Connect a regular probe (**Figure 4**) to channel 1 and a differential probe to channel 2. Oscilloscope probes connect to the BNC connectors on the scope interface, and each channel displays a single waveform. Every scope comes with a variety of channels. The most common are two- and four-channel scopes, but newer scopes can have eight channels.

2.3.1.1. Remove any offset on channel 2.

2.3.2. Oscilloscope probes are used most often with electric machines and power electronics experiments. The main types of probes include the conventional grounded probe, the differential voltage probe (**Figure 5**), and the current probe (**Figure 6**).

2.3.2.1. Use conventional grounded probes when measuring voltage across two points in a circuit or apparatus, where one of the points is tied to earth ground. Typically, the grounded part of the scope is an alligator clip, and the other test lead is a hook that ties easily to circuits and electrical components.

2.3.2.2. Never use these probes with ungrounded connections, as a short circuit to ground will occur, causing risk to the user, sparks, and damage to the probes. Usually, these probes are rated to several hundred volts.

2.3.2.3. Use differential voltage probes to provide isolation between the earth ground and both test points, across which voltage is being measured. These probes are essential when neither of the points are grounded (e.g., when measuring across two of three phases in a three-phase voltage source). Such probes are more expensive and require manual or automatic offset adjustment before every use, as a form of basic calibration. They are less robust to noise due to the lack of grounding on the probe test leads. Their voltage ratings in educational labs typically reach 1000 V.

2.3.2.4. To measure current in a wire, place the wire in the window of the current probe and ensure that the wire is locked within the probe hole. Adjust the probe scaling (e.g., 100 mV/A) on the probe enclosure and note the scale. Current measurements are displayed as voltage measurements.

2.3.2.5. A wire carrying AC or DC current passes through the core, generating a magnetic field, which induces voltage on the wire winding wrapped around the core. This gives a voltage measurement proportional to the current in the wire, and current can be measured using this probe. These are typically even more expensive than differential voltage probes and can range up to 100 A in educational labs. Many educators and researchers replace them with sensing resistors that have very low but accurate resistance. Sensing resistors pass current proportional to the voltage across their terminals, and by Ohm's law, measuring the voltage while knowing the accurate resistance gives an accurate approximation of the current.

2.3.3. Connect the regular probe terminals to the alligator side of the function generator's output.

2.3.4. Turn on the function generator output.

2.3.5. Adjust the time axis scale by using the sec/div knob on the scope to zoom in and out of the displayed channel 1 waveform. Each scope may have a different approach to adjust the display, but all common scopes have two major divisions to set. On the x-axis (time-axis), divisions resemble a certain period of time and can vary from µs per division to several seconds per division.

~~2.3.3.~~2.3.6. Adjust the y-axis of channel 1 by using the channel 1 knob. Use the volts/div knob to adjust which divisions on the y-axis show volt readings. Each waveform has a unique y-axis scaling knob.

2.3.7. Press the "measure" feature button on the scope to measure the frequency and peak-to-peak of the displayed waveform on channel 1. This can also be used to find the measurements of the mean, root mean square (RMS), and period of a signal.

~~2.3.4.~~2.3.8. Press "math" " to use mathematical functions, such as addition, subtraction, or more advanced functions using more than one waveform displayed on the scope. For example, it is useful to show the product of instantaneous voltage and current in order to see instantaneous power.

~~2.3.5.~~2.3.9. Trigger manually by adjusting the "trigger" knob, or automatically by pressing "Set level to 50%". Select the scope channel from which all waveform displays are triggered. By using the appropriate trigger level, the jitter in the displayed waveforms is eliminated, so all waveforms look stationary and clean.

~~2.3.6.~~2.3.10. Press "cursor" to measure the distance between two points on either the time-axis or y-axis.

~~2.3.7.~~2.3.11. Press the “CH1”, “CH2”, or other channel buttons and select the appropriate digital filter to eliminate noise from the waveform display. Low-pass filter corner frequencies are preset and may differ in different scopes.

2.3.12. Adjust the function generator output until the desired amplitude and frequency are achieved.

2.3.13. Turn off the function generator and disconnect the scope probe.

~~2.3.8.~~2.3.14. Turn off the oscilloscope.

2.4. Turn on the multi-meter (**Figure 7**) and make sure that its terminations are in the voltage measurement connection position. Multi-meters, whether handheld or bench-top, measure the average value of a DC voltage or current, or the RMS value of an AC voltage or current. Carefully revise the connections to measure voltage or current before powering a circuit, as these connections are a common source of error when performing an experiment.

2.4.1. Turn on the DC power supply output with no banana wires placed at its output ports.

~~2.4.1.~~2.4.2. Use the multi-meter to measure across the two output ports (+ red and – black). To enhance the measurement resolution, manually adjust the signal range up to 10 V or 1000 V.

2.4.3. The multi-meter should read 10V.

~~2.4.2.~~2.4.4. Note that multi-meters include other measurement features, such as the resistance between two points and the direction of current flow (diode symbol), which is useful in debugging diodes and transistors.

2.5. Use digital power meters to measure average power. Digital power meters are similar to multi-meters but use concurrent voltage and current measurements to measure average power. Advanced meters can measure power factor, reactive power, and apparent power.

2.5.1. Connect two voltage leads across (in parallel with) the two points where voltage should be measured.

2.5.2. Connect two current leads in series with the wire or component.

2.5.3. The displayed power is the average of the instantaneous product of voltage and current.

2.6. Aside from the low power DC supply used in this procedure, there are other types of power supplies including a three-phase outlet (**Figure 8**), a three-phase variable autotransformer (**Figure 9**), and a higher power DC supply.

Commented [AM6]: What will we be filming for the power supply sections? Will you be demonstrating the equipment with any specific demo?

2.6.1. The three-phase outlet provides three-phase voltages, typically at 208V, 230V, or 408V in most electrical engineering laboratories. These voltages are equal in frequency and amplitude, and are 120° out phase from each other. Handling three-phase outlets requires special training and safety precautions.

Commented [AM7]: Introduce what a three phase outlet is and why use it

2.6.1.1. In the US, 208 V, 230 V, and 480 V are common three-phase voltage levels in an educational lab environment that deals with power electronics and electric machines.

2.6.2. The three-phase variable autotransformer (VARIAC) is an auto-transformer or isolated transformer that provides a variable three-phase AC source from the three-phase outlet.

Commented [AM8]: Is this a brand name? What is the generic term? Introduce what this is and why you'd use it.

2.6.2.1. Adjust the knob on the variac where the variac output can vary between 0% and 100% of the provided input voltage.

2.6.3. A higher power DC supply provides higher DC voltage. Most low power DC supplies can provide up to 36V and less than 10A. High power DC supplies can provide hundreds of volts and amps.

2.6.3.1. In an educational lab environment, a higher power DC supply provides DC voltage typically up to 400 V. They are common in power electronics applications, because they emulate large battery packs in electric and hybrid vehicles, rectified household voltage, and other scenarios. They are also common in DC electric machine applications and inverter-based AC machines.

Applications

Commented [AM9]: Please provide more discrete examples of applications. What real world and lab situations would you see these pieces of equipment?

Provide simple applications that are lab based that we could film with this video.

Safety is the most important practice in an electrical engineering laboratory. Electrical measurement and power equipment are common in many heavy industries (metal processing, pulp and paper, etc.), automotive, marine, aerospace, military, and others. Various brands and models of different equipment and tools described in the video may have different labels, buttons, and knobs, but the general concepts still apply.

In an educational laboratory environment, the safety details and equipment described above are commonly used in experiments related to AC/DC, DC/AC, DC/DC, and AC/AC power conversion, transformers, electric motors and generators, and basic electric motor drives.

Legend

Figure 1: A function generator.

Figure 2: A commonly used DC power supply.

Figure 3: An oscilloscope.

Figure 4: A regular conventional grounded probe.

Figure 5: A view of a differential probe.

Figure 6: A side-view of a current probe.

Figure 7: A multi-meter.

Figure 8: A three-phase outlet.

Figure 9: A top-view of a three-phase variable autotransformer (VARIAC).

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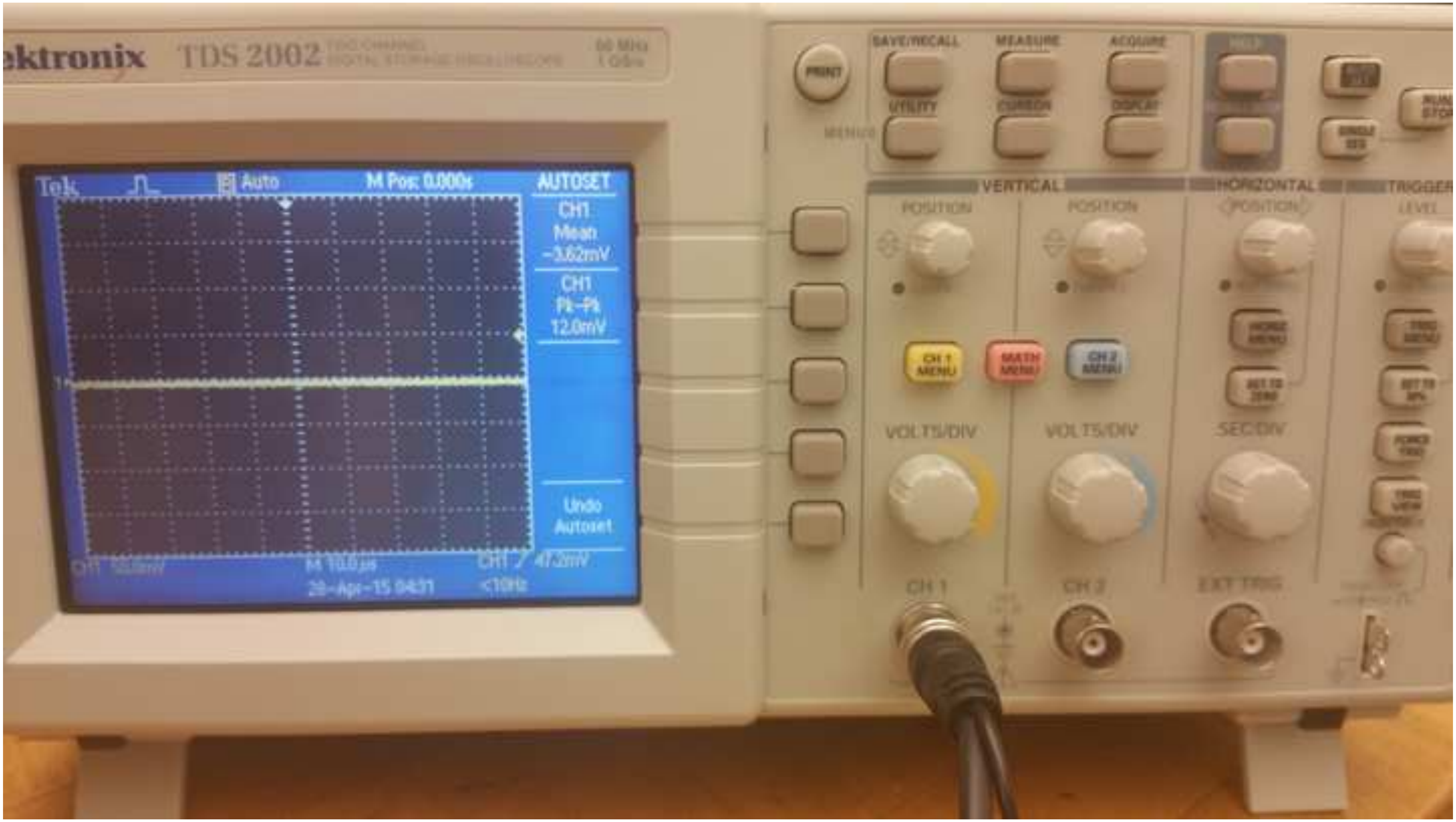

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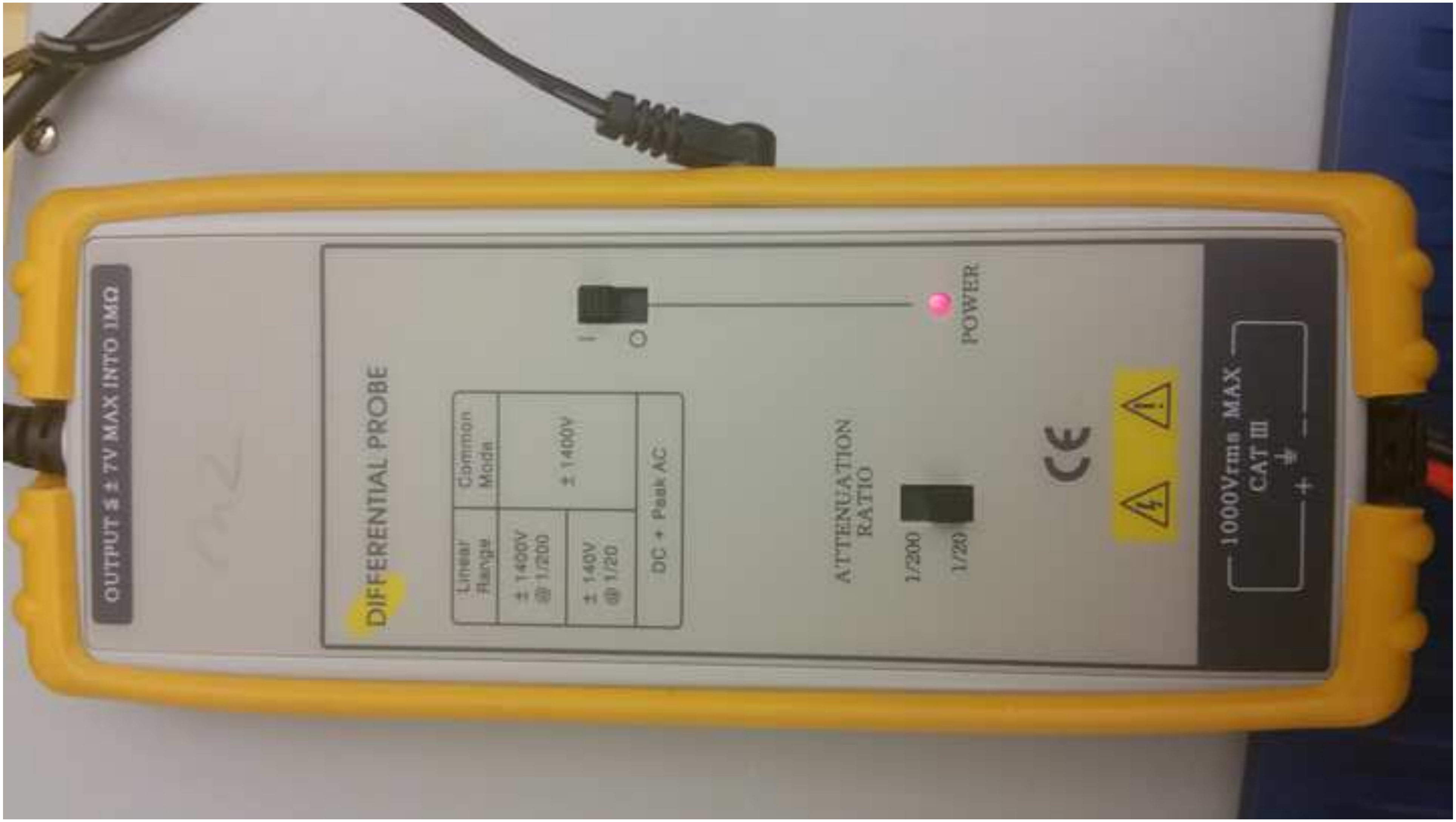

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