NuMI Horn Production Power Supply Safety Analysis Report

Ken Bourkland
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Purpose: A power supply system has been built for the purpose of pulsing the NuMI focusing horns. This system will first be used in MI-8 for the continued testing of the prototype NuMI horns and, later, for operation in the NUMI beamline . Various field, temperature, vibration, and life tests will be carried out on the horns using this equipment. The charging source and capacitor bank, working together, can produce the pulse train as shown in Figure 1. It is capable of producing pulse widths of 2.6 ms or 5.2 ms and designed to operate continuously at a rep-rate of 1.9 seconds.

In the MI-8 test area, a dummy load is included in series with the horn to represent the electrical equivalent of the additional resistance and inductance of the full length stripline and second horn that are a part of the beamline installation.

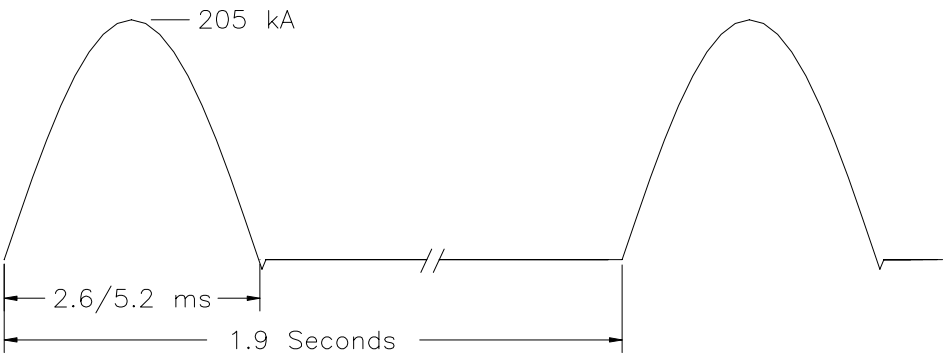

Figure 1. Output waveform from capacitor bank

Equipment: The circuit contains a capacitor bank that consists of 120 units of 7.5 mF, each rated at 670 working-volts. For safety, the capacitor bank is divided into twelve independent sections. The capacitors within each section can be connected in parallel for 75 mF, or in series-parallel for18.8 mF, to achieve the two different output pulse widths. Each of the twelve capacitor sections is isolated from the other sections and the charging source by diodes, and from each other and the load by SCRs. Three sections of capacitors, working together with their respective SCRs, drive one of the conductor pair of the output stripline. The other three stripline conductor pairs are driven in the same manner by their respective quadrants of the capacitor bank.

The capacitor bank output is connected to the dummy load and horn via an eight layer, four conductor pair, stripline. The dummy load is connected into the stripline, electrically in series between the capacitor bank and horn, to provide the equivalent resistance and inductance the system will encounter in beamline operation in order to achieve the proper pulse width and expected system loses. The capacitor bank is charged

by two 240kW PEI power supplies connected in series to provide up to 1,200 volts. The PEIs are standard units but have been up-dated to include later model regulation electronics, new water hoses, and provisions for a lock on the rear doors. A schematic of the equipment is shown in Figure 2.

The capacitor bank is constructed within a heavy duty enclosure equipped with multiple doors, all of which are secured with latches and key locks. The equipment is installed in the south end of the MI-8 service building. A floor plan of the equipment configuration is shown in Figure 3.

Hazards: Certain hazards inherent with high voltage, high current, and capacitive energy storage exist within this circuit. A list of each hazard and the mitigation steps for that hazard is as follows.

- Voltage: The PEI power supplies used to charge the capacitor bank are connected in series, one configured for 800 volts output and the second for 400 volts output. This configuration can provide from 0-1,200 volts at 300 Amps and will be operated to approximately 950 volts during horn testing. The PEI enclosures are fitted with door interlock switches on their respective rear doors. This interlock will turn off the supplies if either set of doors is opened. The rear doors will be locked during operation.

The PEI front doors are locked by the front panel disconnect switch mechanism when the disconnect is in the ON position. All internal bus associated with either 480 Vac or the DC output in each PEI is covered with protective insulated shields to prevent personnel exposure to energy that could originate from the second series connected PEI power supply. There will be no need to enter either PEI during start-up or shut-done of horn operations in MI-8.

The PEIs are isolated from the capacitor banks by diodes to prevent any energy stored in the capacitors from back-feeding into the PEI should there be a fault internal to the PEI. The isolation diodes are rated at $2{,}500V_{PIV}$.

All of the doors of the capacitor bank enclosure are fitted with interlock switches. These switches are connected into the PEI interlock chain to turn off the charging supply upon entry. All of the capacitor bank doors (24) are secured by Best® cylinder locks, all keyed alike and operated by a single key. This same key also operates the gates of the fenced-in area around the horn load and the locks securing the back doors of the PEIs. The key will be captured by the MI-8 control system and must be in place to permit operation.

The dummy load, mounted above the capacitor bank, rises to the capacitor bank voltage when the horn is pulsed. It is enclosed by fencing to prevent personnel access.

- Current: Each capacitor bank section is designed to provide up to 17 kA_{PK} to its respective SCR. The capacitor row buses have a tab for each respective capacitor bushing. The tabs are constructed of 1/16" x 1-1/2" copper, 0.094 in^2 cross-sectional

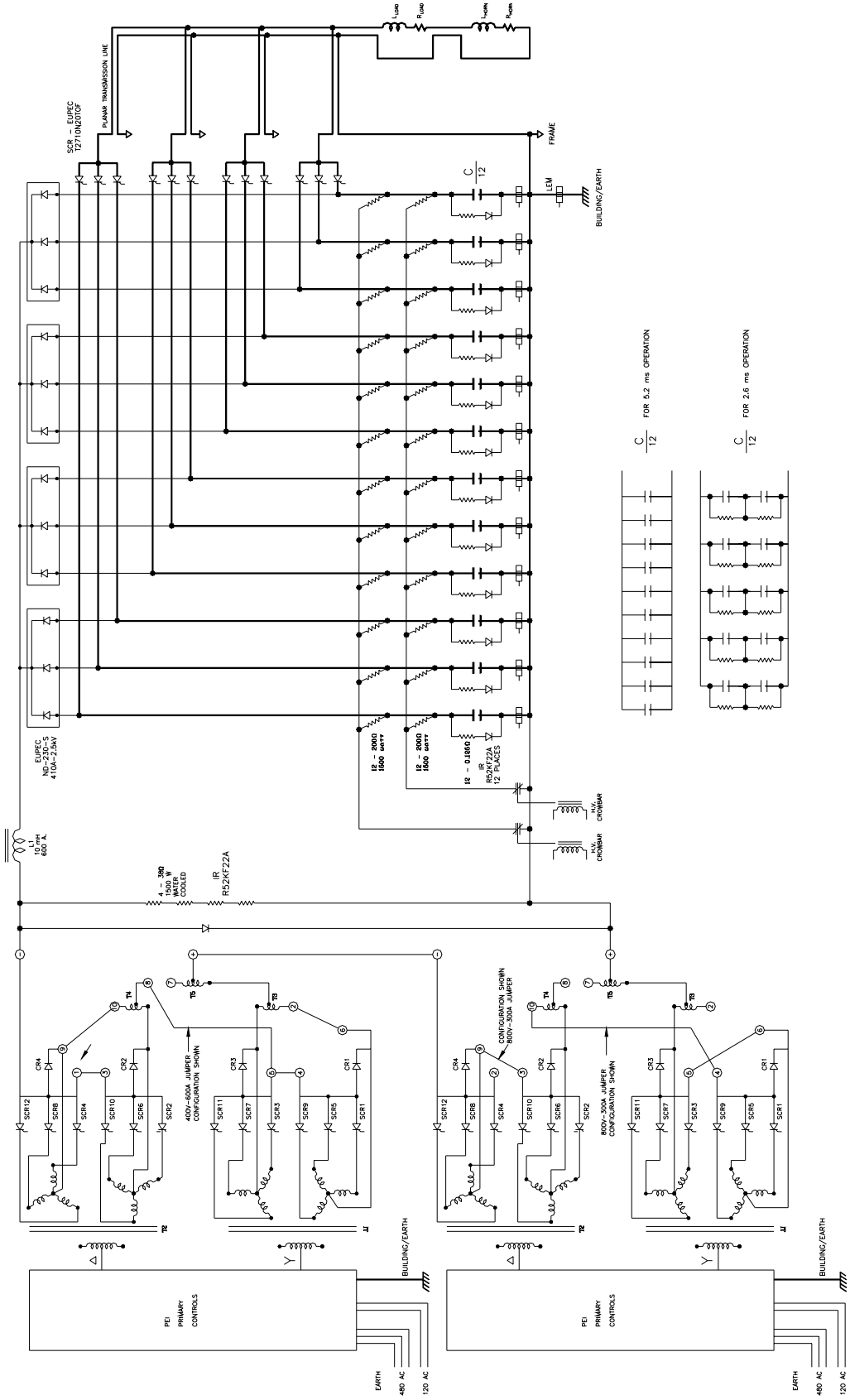

Figure 2. Schematic

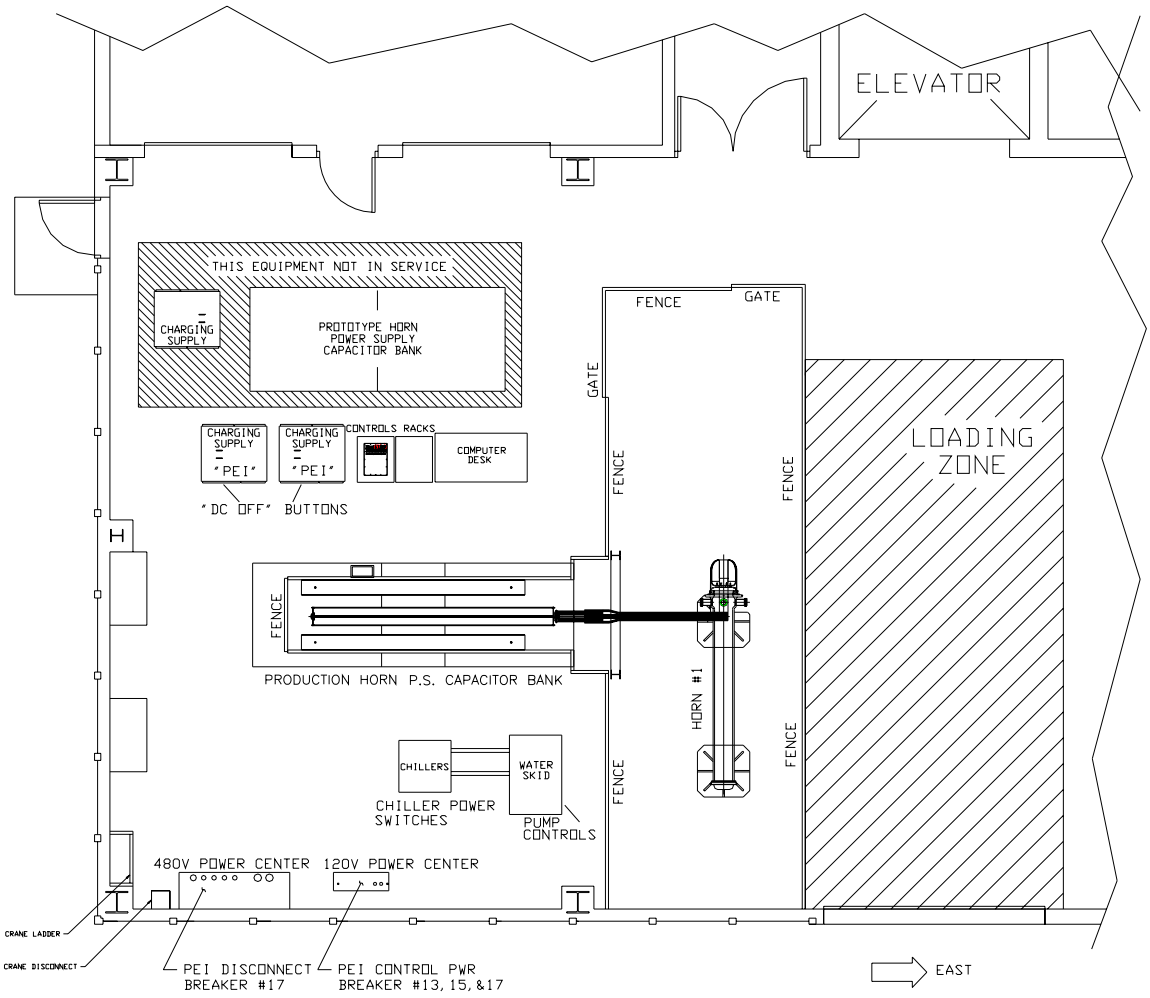

Figure 3. Layout of equipment in the MI-8 service building.

area, and operate up to a maximum of 65 A_{RMS}. The main bus material in each capacitor row is 1/4" x 4" copper, 1 in^2, and will operate up to a maximum of 605 A_{RMS}. The combined output of the three SCRs on each quadrant switch panel sums three capacitor sections to produce 51 kA_{PK}, 1,815 A_{RMS}. The bus material in each SCR switch panel, and the center bay stripline of the enclosure, is 1/4" x 12" copper, providing 3 in^2 cross-sectional area.

The stripline leading from the center bay of the enclosure, and external to the enclosure, is constructed of 3/8" x 12" 6101-T61 aluminum electrical bus alloy. Both materials can operate at 7250 A_{RMS} continuously.

Any access to high current connections requires LOTO procedures to be followed so that no hazard exists.

• Stored energy: The energy stored in each capacitor bank section is 11.4 kJ. Each diode providing capacitor section isolation from the PEIs is rated for 2.5 kV_{PIV} and 410 $A_{IF(AV)}$. The Eupec SCRs switching the output are rated for 2 kV V_{DRM} and V_{RRM}. The NWL capacitors are rated for a Hi-pot voltage of 1,340 volts terminal-to-terminal, 2 kV terminal-to-case, and a working voltage of 670 volts. The case construction withstand specification was for 25 kJ containment. Case material is 14 Ga. (0.075") steel.

Two high voltage, high current, Ross® shorting relays, with independent discharge resistors, are series connected across each of the capacitor sections for discharging the capacitors upon turn-off of the charging supplies. The relays close the resistors across the capacitor banks while in the de-energized state. The dual shorting scheme provides redundancy for additional electrical safety. The shorting relays are mounted such that gravity assist is accommodated for fail-safe operation, eliminating dependence upon springs for contact closure. Auxiliary contacts on the shorting relays are connected into the control interlock chain to withhold the "Enable" signal to the PEIs unless both shorting relays are energized.

Two resistive ground sticks are provided to discharge the twelve capacitor groups, one mounted on each side of the enclosure. Two hard-ground sticks are also provided, one on each side of the enclosure. Anchored grounding clip leads are provided to maintain capacitor grounding as needed.

• Capacitor over pressure: The NWL capacitors are of the segmented metalized foil design. The typical failure mode for this type construction is voltage punch through followed by self clearing of the metalization. This process, should it continue within a capacitor, will result in gradual loss of capacitance and build-up of pressure within the capacitor case. All of the capacitors are fitted with normally closed pressure switches. These switches, all connected in series, are a part of the controls interlock chain and will stop power supply operation should an over pressure condition occur.

• Induced voltage on Equipment During Faults to Ground:

The low side of the capacitor bank (+) and the enclosure are bonded together to form a single point ground within the enclosure. This common point is in turn connected to the external steel stripline support structure via two 900 mcm cables to provide a current return path to the capacitor bank in the event a fault should occur either at the horn or stripline. Ground fault current detection is provided by a LEM current monitor on these cables.

The PEI enclosures, the controls rack, and the stripline support structure steel are all bonded to the MI-8 building ground system grid via 500 mcm bare copper conductor.

• Acoustic: It is not anticipated that the sound levels will be high enough to be hazardous to building occupants but sound levels will be measured if so indicated. In the past, horn operations have been limited to nights and weekends to spare personnel the annoyance of day shift operations.

• Hazardous Materials: All of the NWL energy storage capacitors are of identical construction and are impregnated with Calchem® C-102, manufactured by Calgene Chemical, Inc. A MSDS sheet is on hand for this product. The product description states this material is rape seed oil (Canola oil) and does not contain any PCBs. The capacitors, while mounted on their sides to facilitate removal and replacement, are mounted with their pressure switch toward the top of the case to minimize leakage volume should a leak occur at the switch location. The enclosure design in the capacitor bank bays is such that it has an oil containment capacity of ~14 gallons. Each capacitor contains ~2.5 gallons of oil.

The SCR snubber capacitors are manufactured by GE and are marked "Non PCB." The impregnant, presumably oil, is unknown.

No other materials known to be hazardous exist within the equipment.

LOTO: Due to there being two sources of energy for the PEIs, and the potential for stored energy in the capacitors, a written LOTO procedure will be necessary. The LOTO procedure describes the steps to safely lock out energy sources and discharge stored energy.

480 V_{AC} power for the PEIs is supplied via a dedicated circuit breaker in power panel DHP-MI8-1, breaker #17. It is located in the southeast corner of MI-8.

The circuit breaker for the 120 V_{AC} control power in the PEIs is located in power panel PP-MI8-1A-5-A1, breaker #13.

The circuit breaker for the 120 V_{AC} power for the controls rack is located in power panel PP-MI8-1A-5-A1, Circuit Breaker #15. All 120 V_{AC} power in the rack is installed according to NEC.

The circuit breaker for the 120 V_{AC} power for the capacitor bank enclosure is located in power panel PP-MI8-1A-5-A1, Circuit Breaker #17. All 120 V_{AC} power in the capacitor bank enclosure is guarded by utility boxes and guards over terminal strips.

All breakers are fitted with a locking device for LOTO locks.

Warning Device: A flashing red warning light is installed atop the capacitor bank enclosure, on the end nearest the horn load. It will operate at any and all times either of the PEI charging supplies is in the "DC ON" mode.