NATIONAL ACCELERATOR LABORATORY

PERFORMANCE SPECIFICATION FOR POWER SUPPLIES FOR

BOOSTER GRADIENT MAGNET

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1. Introduction

The 200 GeV proton accelerator, which will be constructed near Batavia, Illinois, will include a Booster Synchrotron. The Booster contains 96 magnets located in a circular tunnel approximately 490 feet in diameter.

Magnet excitation will be obtained by using a distributed series-resonant circuit with dc biased sinusoidal excitation.

The circuit, as shown in Drawing #0323-EA-2201, consists of a total of 48 series-connected resonant cells, each resonant cell consists of a magnet with its series resonant capacitor tuned for 15 Hz and a choke with its parallel resonant capacitor, also tuned for 15 Hz. The chokes are combined into a transformer arrangement to allow equalizing currents to flow between the series connected resonant cells.

There will be a total of four (4) power supplies to provide the necessary dc biased sinusoidal current in the magnet system. These power supplies will be voltage programmed by a Buyer supplied analog voltage. The program will be such that the output current always flows in one direction. The output voltage will also be unidirectional.

The frequency of the sinusoidally variable component of the magnet current will be 15 Hz and problems associated with mechanical resonance have to be considered. The large energy storage capability of the magnet circuit requires a discharge path on power supply turn-off. Therefore, diodes across the output buses are required. These diodes shall not be fused.

This specification covers the four (4) power supplies.

2. General

2.1 The four (4) power supplies shall be designed to operate off Buyer's 13.8 kV, 3-phase, 60 Hz solidly grounded system.

2.2 The rms current rating of each power supply shall be 800 amperes for continuous operation at 40° C ambient room temperature.

2.3 The four (4) power supplies will be connected in series with the 48 cell resonant circuit as indicated on drawing #0323-EA-2201, with each power supply effectively powering a typical load of 12 resonant cells in series. Under normal operating conditions, all 4 power supplies will be controlled by Buyer's programmer.

The Seller shall provide one (1) gate drive rated to supply the gates of four (4) thyristor equipment simultaneously. The Buyer will provide and arrange coaxial connections to give simultaneous and identical control to the four (4) power supplies.

The first power supply shall include the main control amplifier.

2.4 The power supply output voltage and current wave shapes under normal full load conditions are shown on Drawing #0323-EA-2204. Each power supply shall be rated for 1200 volts maximum output voltage at 1300 amperes peak current.

2.5 Each power supply shall have its own power transformer, connected as specified in paragraph 6, Power Circuitry.

2.6 The power transformer shall be outdoor construction, oil-cooled, convection circulated, and free standing.

2.7 All transformer connections shall be made in terminal chambers so that no live parts are exposed. The field connections will be made by Buyer. Termination practices shall be recommended by Seller.

2.8 Each power transformer shall have a no-load manual tap changer.

2.9 Buyer will provide mounting pads for all outdoor equipment.

2.10 The transformer shall be contained in a boiler plate tank, naturally cooled by radiators. Fittings shall include conservator, silica-gel breather, Buchholtz relay, dial type thermometer, filler cap, thermometer pocket, earthing terminal, rating and diagram plates.

2.11 Each transformer shall be subjected to the following tests in accordance with USASI C57.12.90-1968 and C57.12.00-1968: resistance measurement; applied potential tests; excitation losses and impedance; ratio and regulation; temperature rise by means of short-circuit method; polarity and phase relation.

2.12 Connections between Buyer's switchgear and Seller's transformer will be in underground conduit provided by Buyer. Interconnecting cable will be provided by Buyer, ratings shall be recommended by Seller.

2.13 All rectifier and auxiliary equipment shall be outdoor type, housed in a separate walk-in compartment. This thyristor compartment shall be throat-connected to the transformer and output terminals shall be suitable for underground connections.

3. Thyristor Compartment

3.1 All parts requiring grounding shall be safety grounded to the ground bus in the cabinet.

3.2 A control transformer with 25% spare capacity shall be a part of each power supply and shall be used for all necessary control, interlock and auxiliary circuits. This transformer shall receive its power from the secondary of the main transformer ahead of the secondary contactors. The transformer shall be single phase, 60 Hz, either dry type or mounted in the oil of the main rectifier transformer tank. The control transformer secondary shall be 120-0-120 volts.

3.3 The following major devices shall be mounted inside the thyristor cabinet.

3.3.1 One (1) ac ammeter and switch for indicating the ac input current.

3.3.2 One (1) voltmeter for ac voltage (off the control transformer) with 150 volt coil, scale 0-15000 volts.

3.3.3 Control push buttons and indicating lights for the secondary contactors.

Note: The output of the control transformer will be used to indicate the primary voltage.

3.4 The thyristor cabinet shall also contain the following equipment.

3.4.1 All auxiliary transformers, as required for phase control or other functions.

3.4.2 Three (3) current transformers of suitable ratio and 5 A secondary.

3.4.3 Three (3) overcurrent relays for instantaneous and time overcurrent protection with self-contained test facilities, device No. 50/51. These relays shall be Westinghouse Type CO-8, or approved equal.

3.4.4 One (1) overcurrent ground relay with self-contained test facilities, device No. 50/51G. This relay shall be Westinghouse Type CO-9, or approved equal.

3.5 In the final installation, the power supplies will be grouped in pairs.

The outdoor equipment for two power supplies may be mounted adjacent, depending on Seller's recommendations.

4. Applicable Standards

The Seller shall assume full responsibility for the power supplies to conform to the best engineering and manufacturing practices. In all respects, except where specifically mentioned otherwise herein, equipment shall conform to and electrical tests shall be conducted in accordance with the latest applicable standards of:

American Society for Testing Materials
United States of America Standards Institute
Institute of Electrical and Electronics Engineers
Underwriter's Laboratories, Inc.

A certificate of compliance from these organizations is not required. Deviations from the standard recommendations may be made, subject to Buyer's approval.

5. Provided by the Buyer

The Buyer will unload, receive and mount the equipment, provide all external power and control cables and complete the installation and provide field testing.

6. Power Circuitry

6.1 The basic power circuitry shall be as shown on drawing #0323-EA-2205, Rev. A.

6.2 The power transformer shall have a delta primary with taps at 100% rated input voltage and at 2.5 and 5% above and below rated input voltage.

6.3 The transformer shall have two separate, identical zig-zag secondaries. The zig-zag connections shall be made so that the phase shift between the two secondaries is $30^{\circ} \pm 1/2^{\circ}$.

6.4 Each zig-zag secondary shall be connected to a separate 3-phase full wave SCR bridge.

6.5 The two 3-phase full wave SCR bridges shall be connected in series, so that a basic 12-phase output voltage ripple will result.

6.6 The power supply shall include diodes across the output buses as indicated on drawing #0320-EA-2205. These diodes shall be rated for continuous full load current.

6.7 The first power supply shall include the SCR control logic as follows.

a) One (1) main control amplifier

b) One (1) pulse amplifier

c) One (1) set of pulse transformers

d) All associated power supplies

The remaining three (3) power supplies shall each include the following.

a) One (1) pulse amplifier

b) One (1) set of pulse transformers

6.8 The timing of the SCR firing angle at maximum output shall not deviate by more than ± 1° and shall not deviate by more than ± 3° over the entire range of the setting from the control required.

6.9 The power supply programmer will be supplied by the Buyer.

6.10 The power supply output voltage shall be variable within the specified limits by means of Buyer's control signal. Buyer's programmer signal will be a dc biased 15 Hz sinusoidally varying signal, synchronized with the 60 Hz incoming line frequency. The input impedance as seen by Buyer's programmer shall be minimum 10 kΩ. The amplitude limits of Buyer's programmer output signal will be +10 volts and -0 volts. The power supply output voltage shall be in phase with the programmer signal.

6.11 The voltage and current ratings of the SCR cells shall be such that only one SCR is used per leg.

6.12 The catalog inverse voltage rating of the SCR cells employed shall be at least 2.0 times the maximum inverse voltage applied. The SCR cells shall also have a safety factor of at least 2.0 times the applied voltage on peak forward break-over voltage rating.

6.13 The SCR cells shall be protected against transient voltages larger than 75% of the catalog inverse and forward voltage ratings.

6.14 The SCR cells shall be mounted and cooled so that thermal ratings are not exceeded.

6.15 The power supply shall include all necessary control, interlock and indicating circuitry. This circuitry shall all be operated at 120 volt. The 120 volt power shall be derived from the control transformer.

6.16 The power supply shall be designed so that the capacitance to ground does not exceed .0025 μF.

6.17 Normal operation of the power supply will be with a 15 Hz signal superimposed on a dc signal. The power supply shall be designed so that no mechanical resonance will occur at 15 Hz continuous operation.

7. Protective Devices

7.1 Each power supply shall have the following protections.

7.1.1 Control power failure

7.1.2 SCR failure

7.1.3 Insufficient cooling

7.1.4 Door interlocks

7.1.5 Overcurrent

7.2 Each and every failure as specified under paragraph 7.1 shall be made to trip the contactors in the secondary and in addition trip a summation relay. The summation relay shall provide an alarm signal and a failure annunciation. A N/O and a N/C contact of the summation relay shall be available for Buyer's use.

7.3 Door interlocks shall have provisions for defeat with automatic reset on closing of doors.

7.4 Failure annunciator lights and an annunciator reset shall be part of the power supply.

7.5 Provisions shall be made for remote annunciation of failure and of power supply status.

7.6 The power supply shall have a complete set of protective and auxiliary devices.

8. Power Supply Control

The power supply will be controlled by means of Buyer's programmer. Buyer's programmer will have the following functions.

8.1 Provide a command signal to energize power supply.

8.2 Generate a dc biased 15 Hz signal to control the power supply output voltage.

9. Grounding

9.1 The power supply shall be designed for operating at 2,000 volts to ground.

9.2 All metallic frames, enclosures and supports of any equipment exposed to the operator will be safety grounded to Buyer's common building ground system (earth). This grounding shall not interfere with any functioning of the power supply equipment.

9.3 A ground pad shall be provided.

10. Metering

The power supply metering shall include:

10.1 An ac voltmeter indicating incoming ac line voltage. (see also paragraph 3.3)

10.2 An ac ammeter and ammeter switch for incoming ac line current.

10.3 A current transductor, isolated from the bus, to observe the output current wave form. This transductor will be used only for indicating purposes. No specific degree of accuracy is required.

10.4 An rms output voltmeter and ammeter.

11. Nameplates

Nameplates shall be installed to designate metering, operating, indicating and protective devices on the front doors and panels and on components inside the power supply.

12. Noise

The maximum tolerable noise level of the outdoor equipment is 85 db at a distance of 4 feet from the equipment.

13. Acceptance, Tests, and Inspection

13.1 Acceptance

The equipment will be accepted in two stages. The first stage of acceptance will be before shipment after Buyer has witnessed and approved factory tests. The second and final stage of acceptance will be after the equipment is completely installed and field tested.

13.2 Factory Tests

13.2.1 All components shall be subjected to the standard commercial tests in accordance with the applicable standards.

13.2.2 The Seller shall conduct performance tests on the assembled power supply to ensure that the equipment meets this specification, by the following means:

a) Tests may be carried out on a 50 Hz system.

b) A full voltage test shall be carried out on a reduced (approximately 200 kW) resistive load. Other tests shall be conducted as agreed between the Buyer and Seller, to prove the adequacy of design and workmanship.

13.2.3 The Seller shall install thermocouples or other temperature measuring devices inside the power supply at locations approved by the Buyer. A factory heat run by means of a short circuit test at reduced voltage with the SCR's fully conducting and carrying an equivalent continuous load shall be performed and may be witnessed by the Buyer's representative.

13.2.4 The Seller shall notify the Buyer at least five (5) calendar days in advance of any such performance tests in order that the Buyer's representative may be present when the tests are conducted.

13.2.5 The power supply shall be operated with a control signal of ¼ of the supply frequency. Audible noise and mechanical vibration shall be measured to insure compliance with the specifications.

13.2.6 The capacitance to ground shall be measured as follows.

a) Place jumpers across all SCR's.

b) Apply a sinusoidal signal generator between the power supply output bus and ground.

c) Measure the generator current at frequencies of 60 Hz to 1,000 Hz in steps of 100 Hz.

13.2.7 A high-pot test shall be applied between the power circuitry and the cabinet. The test shall consist of 60 Hz, 5,000 volts rms for one minute.

13.2.8 A 1,000 volt dc megger test shall be applied between the power circuitry and the cabinet, and the insulation resistance shall be measured. The insulation resistance shall be not less than 2 megaohm.

13.2.9 The Seller shall submit to the Buyer in triplicate a complete certified report with performance charts and test data covering each test within seven (7) calendar days after the tests have been completed.

13.3 <u>Field Tests</u>

13.3.1 For final acceptance the power supply will be tested after the installation.

13.3.2 These tests will be mainly performance tests of the assembled equipment under normal load conditions, heat runs and tests to check vibrations, audible noise, linearity and protective devices.

13.3.3 Should these tests prove the fact that the power supply does not comply with the design and workmanship required by this specification, then the Seller shall, at his own expense, make changes and/or additions and further tests required within a reasonable time to fully comply with the specification. The Seller shall not be responsible for any mal-operation of the equipment caused by Buyer's programmer, magnet system or other sources over which the Seller has no control.

13.4 Inspection

The Buyer, or his representative, shall at any time during the design, construction, assembling or testing of the power supply be allowed to visit the Seller's shops and offices for the purpose of inspecting the progress and witnessing the tests. The Seller shall provide pertinent information and all reasonable facilities and assistance for the safety and convenience of the Buyer's inspectors in the performance of their duties.

14. Seller's Drawings and Design Approval

14.1 The Seller shall submit within 90 calendar days after award of the contract for approval of the design four (4) certified copies of each of the following drawings to the Buyer.

14.1.1 Outline drawings of the power supply, including over-all dimensions, general arrangement, clearances required, weights and mounting.

14.1.2 Detailed drawings of terminal and connector arrangement with wire or bus sizes and types and an interconnection diagram. Drawings shall include information on power, control, and water connections.

14.1.3 Complete schematic and wiring diagrams.

14.2 The manufacturer shall be responsible for all changes made without approval of the Buyer.

15. Final Sets of Drawings and Manuals

15.1 On or before shipment of the power supply, the Seller shall furnish the Buyer with six (6) complete sets of prints and one (1) reproducible of each drawing as finally approved, corrected and built; these drawings shall include items listed under paragraph 14.1. The reproducibles shall be mylar or comparable quality and shall not exceed the size of 28 inches by 40 inches.

15.2 Any changes, after submittal of final drawings and before final acceptance of the equipment, have to be approved by the Buyer. A new replacement set of revisions to the affected drawings, reproducibles and parts lists shall be furnished by the Seller within 15 calendar days after approval of changes.

16. Packing and Shipment

16.1 The equipment shall be shipped as completely assembled as practical.

16.2 All equipment shall be suitably packed, crated rigidly braced and protected against weather, damage, or undue strain during shipment. Instruments, relays, regulators and other fragile parts shall be braced and protected individually.

16.3 The Seller shall be responsible for and make good any and all damage due to improper preparation and loading for shipment.

16.4 All shipping crates exceeding two hundred (200) pounds gross weight shall be prepared for shipment so that slings for handling by crane may be readily attached.

16.5 A packing list shall be prepared listing the contents of each box, crate, or bundle. Each box, crate, bundle, etc., shall be assigned an identification

number, which shall be clearly shown on each shipping piece. A copy of the packing list, the name of the carrier, the routing, the number of the car or truck, and the date of shipment shall be mailed to the Buyer promptly following the shipment.

16.6 The Seller shall notify the Buyer ten (10) days prior to any shipment being made.

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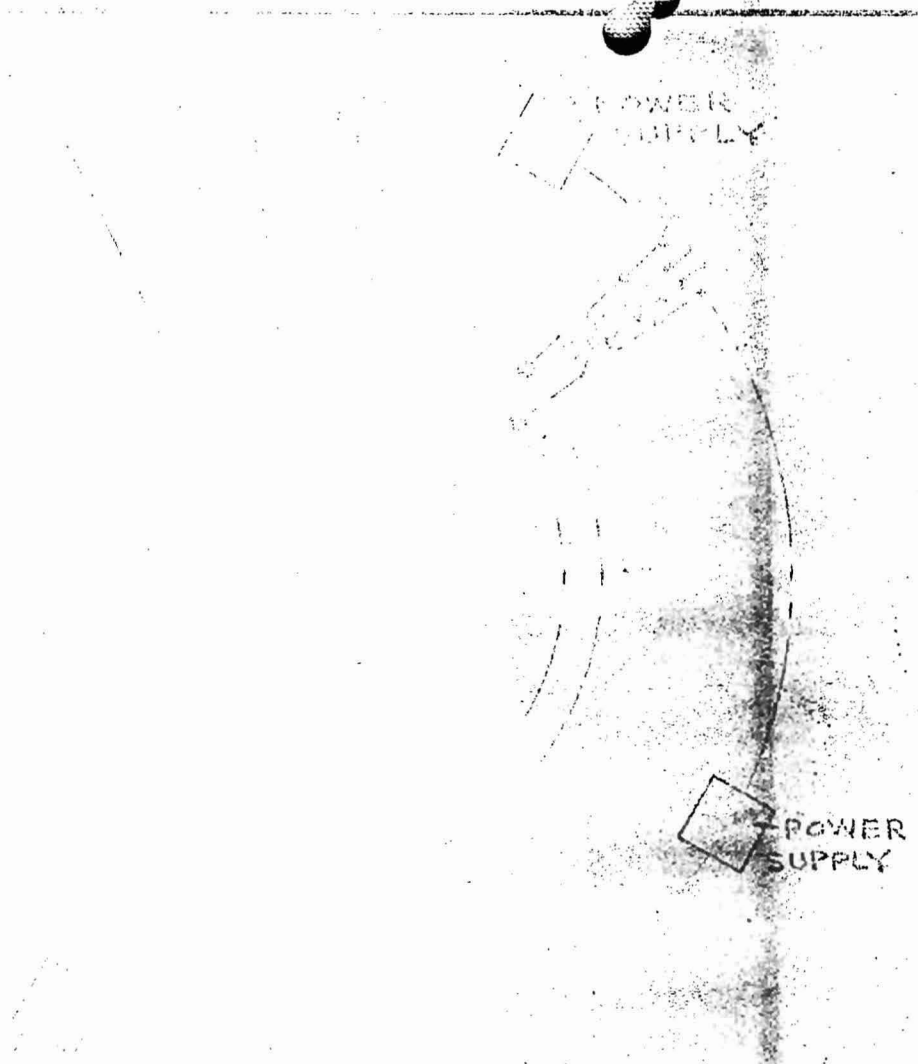

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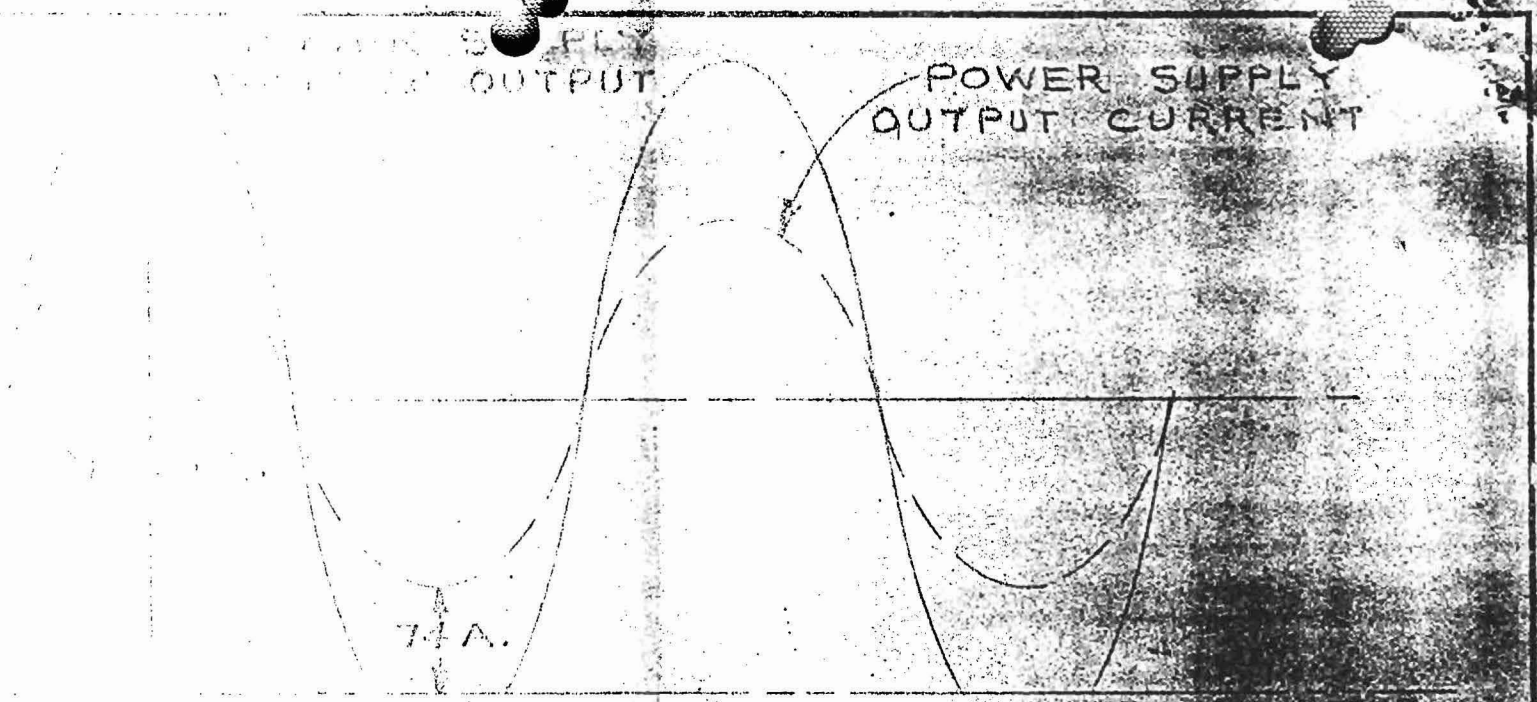
TITLE

BOOSTER SYNCHROTRON MAGNET CIRCUIT

SCALE	SHEET	DRAWING No.	REV.
~	OF	0323-EA-2201	

0323-EA-2201



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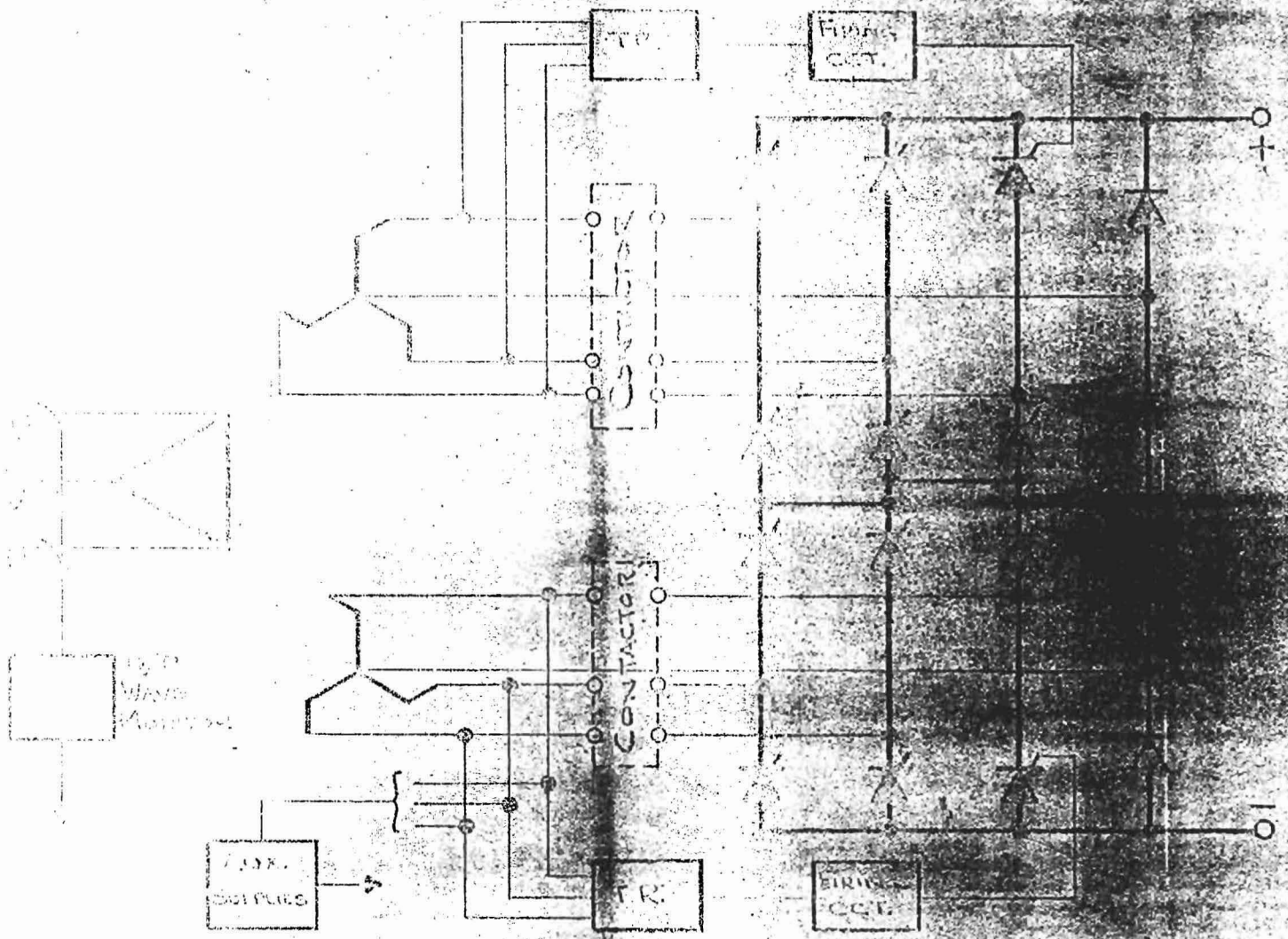
TITLE
POWER SUPPLY
OUTPUT VOLTAGE
& LOAD CURRENT

SCALE	SHEET	DRAWING No.	REV.
X	OF	0323-EA-2204	

0323-EA-2204



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SCALE | SHEET | DRAWING No. | REV.

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