STANFORD UNIVERSITY

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PRELIMINARY REPORT FOR BEAM SWITCHYARD DC MAGNET POWER SUPPLY SYSTEM

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BEAM SWITCHYARD

D.C. MAGNET POWER SUPPLY SYSTEM

PRELIMINARY REPORT

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BEAM SWITCHYARD
D-C MAGNET POWER SUPPLIES
PRELIMINARY REPORT

1.0 SCOPE

This technical note was prepared to describe the basis for selection of the proper d-c power supplies for the Beam Switchyard Magnets. This report will indicate the power supply systems that I prefer; the Appendix will show other related information.

The design criteria will be given along with a standard set of transient environmental conditions that within which the power supplies must operate. It is to be hoped that this report will stimulate enough discussion so that there will be no question as to the ultimate requirement of the power supplies.

This note will be restricted to the D-C Quadrupole and Bending Magnet Systems; the pulsed magnet power supplies and low power Steering Magnet power supplies will be described elsewhere by I. Lutz.

2.0 DESIGN CRITERIA OF THE MAGNET POWER SUPPLIES

The Beam Switchyard will use several different classes of magnets [1) 2)] See Table I for required values for a 25 BEV beam.

The Magnet Power Supply Systems shall be designed with the following considerations:

1. The nominal value of Beam Switchyard magnet currents for 25 BEV and the designed accuracies of regulation are given in Table I.

BEAM SWITCHYARD
MAGNET CURRENT
KVA AND INPUT

MAGNET SYSTEM	NUMBER OF MAGNETS	MAGNET RESISTANCE (OHMS)	MAGNET L/R (SEC)	25 BEV CURRENT (AMPERES)	DESIGNED CURRENT REGULATION	REQUIRED MAXIMUM CURRENT △	LOAD VOLTAGE REQUIRED *	MAXIMUM KW TO LOADS	MAXIMUM KVA DEMAND
1. "A" 3° Bending	8 + 1	9 x 0.095	1.8	765	± 0.005%	805 4)	701	590 x	690
2. "A" 8 CM Q 10	1	0.074	.5	452	± 0.10	497 1A)	43	22.	33
3. "A" 8 CM Q 11	1	0.074	.5	473	± 0.10	520 1A)	45	24.	34
4. "A" 8 CM Q 13	1	0.074	.5	474	± 0.10	520 1A)	48	25	37
5. "A" 8 CM Q 14	1	0.074	.5	445	± 0.10	490 1A)	45	22	30
6. "A" 18 CM Q 12	1	0.136	0.4	315	± 0.10	345 1B)	52	18	23
7. "B" 3° Bending	4 + 1	5 x 0.095	1.8	765	± 0.02	805 5)	390	337	390
8. "B" 8 CM Q 30	1	0.074	.5	472	± 0.10	520 1A)	45	24	35
9. "B" 8 CM Q 31	1	0.074	.5	500	± 0.10	550 1A)	47	26	37
10 "B" 8 CM Q 33	1	.085	.5	805	± 0.10	805 7)	77	62	85
11 "B" 8 CM Q 34	1	..085	.5	805	± 0.10	805 7)	77	62	85
12 "B" 18 CM Q 32	1	0.136	0.4	283	± 0.10	312 1B)	47	16	21
13 EMERGENCY	2	2 x 0.091	1.7	330	± 0.05	347 1B)	75	26	46
14 A Dump 3°	4	0.140	1.4	1000	± 0.25	1050 6)	610	640	640
								1,894 KW	2,346 KVA
									- 81% - P.F.

x Includes transistor regulator losses
△ 25 BEV + 5% for Bending Magnets
25 BEV + 10% for Quadrupoles
* Includes D-C feeder voltage losses
1A) 55^V at 550 A Dual Output
1B) 85^V at 350 A Dual Output (No. 1 reconnected)
3) 105^V at 805 A These units can be reconnected to 80^V at 1,050 A for use in the Dump Circuits
4) 2 of 300 KVA Units + 1 of (3) + 1 series transistor bank
5) 1 of 300 KVA Unit + 1 of (3) + 1 series transistor bank
6) 3 of 300 KVA Units + 1 of (3)
7) 105^V at 805 A gives ~ 95°C exit water

TABLE I

2. Regulation Accuracy

Energy range	Regulation at set value
25 BEV to 10 BEV	As specified in Table I
10 BEV to 2.5 BEV	Equivalent to ± 1 MEV
2.5 BEV to 0	Reduced regulation

3. Range of Current Control: The bending magnet currents shall be controllable from 0% to 105% of the 25 BEV current. The quadrupole shall be controlled from 0% to 110% of the 25 BEV current.

4. Fineness of Control: There shall be a set of controls that allow the current to be adjusted to the accuracy of the designed regulation. There should be some degree of correlation between dial numbers and current, although not to the accuracy of regulation.

   There shall be a way of reading the regulated current corresponding to the required accuracy.

5. Magnetic Field Monitoring: An NMR or other equivalent device will be supplied to read magnetic field in the "A" and "B" Bending reference magnets.

6. Ground Current Leakage: Provisions shall be made to read any electrical leakage to ground that could upset the accuracy of magnetic field vs. current. There shall be an alarm if this ground current is excessive.

7. Similarity of Components: Consideration shall be given to the use of similar power packages from one system to another. Then, in case of equipment failure, emergency operation may be obtained by exchanging equipment.

8. Taps for Higher Currents: If possible, there shall be taps available that will give the existing units a higher current and lower voltage rating. We then only have to change taps and add more power supplies to analyze beams of energies above 25 BEV.

9. Bending Magnet Groups: Each of the bending magnet groups, A, B, Dump and Emergency, shall have their magnets in series so that one control will set the current for all magnets in the group.

10. Ganged Controls: The possibility of ganged current controls shall be considered in the planning of the control system.

11. "A" Bending Magnet Trimming: Separate steering magnets located after the main bending magnet will be used to make up for minor variations in steering.

12. Line Voltage Steps: The magnet current regulators shall have sufficient frequency response and range to correct for those line voltage steps that are most likely to occur. Extra money should not be put into wide range amplifiers if this extra wide range would not be used for days at a time. The present design allows for the following voltage changes of the power supply input:

Slow changes	5% (480 V to 456 V)
Step changes	± 2 ½%
Line Voltage unbalance	1%

13. Water Cooling for Power Supplies: The water cooling system for the magnet power supplies should be an isolated system. The power supplies should not use the same water as the BSY magnets because the water may become slightly radioactive.

2.1 Design Criteria for Data Assembly Building Equipment Temperatures

1. Control Room - Air conditioned
   Supply air 22° to 27°C (72° to 80°F) at 50% maximum humidity. Supply air may be ducted to a few critical components. Other equipment in the racks should be operational from 20° to 40°C.

2. Power Supply Room - Ventilated and space heaters.
   Ambient air temperature range 22° to 45°C, 20° variation in one day. Temperatures within racks or power supplies may be 20°C above ambient air temperatures... this depends upon specific design. Design for a Low of 15°C to allow for variations in the room.

   Humidity: 50% (maximum) at 45°C
   80% (maximum) at 25°C

   Barometric Pressure: 28-31 inches of mercury

3. Low Conductivity Water for Equipment
   a. Supply line pressure 80 to 100 PSI gauge
   b. Return line pressure less than 20 PSI
   c. Resistivity greater than 5×10^5 ohm cm
   d. Supply line temperature 10° to 40°C

3.0 ENVIRONMENTAL CONDITIONS

The power supplies are subjected to the same general environmental conditions because they are all connected to the same 12 KV AC lines, connected to the same general water cooling system, and they are located within the same building.

3.1 12 KV AC Power

The 12 KV AC power to be fed to the Beam Switchyard will be regulated with a stepping regulator, 0.46 percent per step. The voltage to the BSY sub-station should normally be within a band of ± 5/8%.

According to Kent Wilson of Plant Engineering, the 220 KV line that supplies the 12 KV distribution system is expected to have slow seasonal voltage changes of ± 4-3/4% and possible daily changes of ± 2 to 2 1/2%. These variations are expected to be regulated out with the step regulator. The regulator will have a response time of 3 seconds and a full range response of ± 7·1/2% in 15 seconds.

Circular chart recordings have been taken of the 12 KV line voltage at Monte Vista sub-station. This voltage is derived from the same 220 KV system that will eventually feed the SLAC project. These charts show that ± 2% step changes might be expected 6 to 10 times every day. During a storm one can expect larger short duration changes.

On Friday, November 8, 1963, an oscilloscope was used to view the output of an unfiltered 3 ϕ bridge rectifier connected to the potential transformers on the 12 KV system at the Monte Vista sub-station. There were very few voltage disturbances and no major line switchings during this period. There were many minor variations noted in the range of ± 1/4%. The voltage held constant to within 1/4% for several minute periods.

There were several times when one-phase voltage seemed to drop 1/4% for a few seconds, then it would return to normal. To be on the safe side, I believe one should expect 1/2% to 1% line unbalance feeding a typical rectifier system. This type of line unbalance will introduce a 120 cps ripple in the rectifier output. The transformers and variable voltage units within the power supply may introduce an additional 1% 60 cps line unbalance.

A 12 KV voltage change of about 0.4% can be expected when one of the 1,750 KV variable voltage substations feeding two accelerator sectors is turned off.

A change of 0.9% will occur on the 12 KV when 5,000 KVA in the end station is turned off. The BSY and the end stations may be fed from different 12 KV systems during the first year of operation.

I believe that a design based upon ± 2% line step with an added margin of ± ½% should be an acceptable design criteria for the BSY power supplies.

3.2 Water Cooling

The cooling water system for the BSY magnets and power supplies is divided into two systems. The reference magnets located in the Data Assembly Building are part of the main BSY magnet water system. The d-c power supplies will be fed from a separate cooling system thus minimizing any hazard associated with water that may be slightly radioactive.

Table 2 gives some of the main features of this system:

TABLE 2

Feature	Magnet Cooling System	Power Supply Cooling
Resistivity - Ohms - Cm *	5×10^5	5×10^5
Supply Line Pressure	150 psi	80 to 100 psi
Return Line Pressure	0-5 psi	0 to 20 psi
Supply Temperature Range	$10^\circ C$ to $40^\circ C$	$10^\circ C$ to $40^\circ C$
Temperature rise through magnet		
Bending 3°	$20^\circ C$	
Dump	$35^\circ C$	
Quadrupoles	$20^\circ C$	
Field Lens	$15^\circ C$	

* Water resistivity decreases about 1% per $1^\circ C$ temperature rise.

The total power supply losses depend upon the type of regulation system used in each power supply. The presently estimated total power supply losses will be about 250 KW. The power supply water cooling system is estimated to cost about $ 10,000. This is $ 40 per KW and does not include the water tower costs of about $ 6.50 per KW cooled.

Each 16 KW of losses to be water-cooled requires about 1 KVA of water pumps.

3.3 Ambient Air Temperature - Power Supply Room

General area space heaters are being provided in the Data Assembly Building. On hot days it can be expected that the ambient air around a power supply will vary with the outside air. See 2.1.

The power supplies must maintain their stability over an ambient temperature range from 15°C to 45°C, although variations may be only 20° in one day.

I intend to use water-cooling for both the power supplies and regulators because water-cooled solid-state diodes, transistors and silicon-controlled-rectifiers will operate with a higher reliability than air-cooled units.

Power transistor circuits would probably not be practical if one depended upon air cooling for a large bank of units.

4.0 ACCURACY, STABILITY, AND REPEATABILITY

The accuracy, stability and repeatability of a regulation system are somewhat interrelated, although it is possible to have high stability and repeatability without knowing the absolute calibration of the current or magnetic field of a magnet.

4.1 Current Measurement

Two sets of precision current air-cooled shunts with 100 MV output have been ordered with a specified calibration of 0.04 percent. When these shunts are received, one set will be given a National Bureau of Standards (NBS) calibration.[5] The NBS will certify resistors of this range to 0.005 percent and the resistance will be given to 0.001 percent. Later calibrations after long aging may be certified to 0.002 percent.

The NBS certified shunts will be maintained as a precision reference for the calibration of other shunts used in the BSY. The NBS certification will provide a means of accurate rechecks in the case that our precision reference shunts are ever damaged.

The NBS normally calibrates resistors of this type in oil at 25 $\pm$ 0.05°C. Shunt-type manganin can be expected to be within $\pm$ 0.005 percent over the temperature ranges of 20°C to 30°C or 30°C to 60°C. Any current measuring shunts that will be used in the power supplies will probably be water-cooled shunts that have a voltage drop of two volts at rated current. These higher power shunts may not have a stability better than 0.005 percent unless well aged and temperature regulated. The temperature difference between the two ends of a volt shunt must be held within 6° for manganin or 0.2°C for constantin, otherwise there will be an error of 0.001 percent because of thermal EMFS. Evenohm may be used for shunt material....it is within $\pm$ 0.015 over the temperature range from 10°C to 40°C but can be compensated to be within $\pm$ 0.005% over this same temperature.

The four core transductor is another method of measuring large currents to a fair degree of accuracy. This device is relatively new.[6)] Daytron Inc. believes that their Model No. TCR-1000A current sensor is stable to ± 0.01 percent; Magnetics Inc. claim that they will have a unit certified to ± 0.005 percent. The inherent voltage ripple out of the Daytron transductor is about ± 0.07%; this must be filtered out which requires a filter with a cut off frequency of about 30 cps. There are two large advantages to a tranductor; first, the voltage output can be 10 or 20 volts with only a few watts dissipation; secondly, the transductor gives a voltage output that is isolated from the D-C current being monitored. This isolation is very useful when dealing with precision regulators of high power devices. A detailed calibration check has yet to be done on the Daytron unit. Even if the transductor is not useful for the bending magnets, I am sure that it should be used on the quadrupole power supplies. The unit from Daytron Inc. is expected to have a band-width from D-C to above 10 KC(not including the filter to reduce ripple voltage.)

4.2 Magnetic Field Measurements

While one can use rather simple methods for 0.1 percent D-C stability, it requires considerably more effort to be sure of the 0.01 percent or better required for the bending magnets.

The best absolute precision that can be measured when using a Varian Nuclear Fluxmeter F-8 and an External Frequency Counter is 0.0038 percent at 1 kilogauss and 0.0004 percent at 10 kilogauss. The internal oscillator FX-81 of the fluxmeter F-8 becomes the critical part in limiting field stability when the fluxmeter is used in a regulating system. The specifications for the Varian FX-81 crystal oscillator gives a ± 0.01 percent frequency accuracy with a ± 0.5°C temperature change. This then is the limit of accuracy for a closed loop system using NMR unless higher stability oscillators are used.

The NMR field measuring fluxmeter is a narrow range system and if some perturbance shifts the field more than 0.3 gauss, it must be brought manually back into range. This type of system is permissible in a laboratory system but I believe that it would be too critical for normal accelerator operations. On the other hand, the Hall probe (up to now only a ± 1 percent device) would be more acceptable than NMR because of its wider range of control. Recently, Varian has claimed 1 part in 10^5 for their Fieldial, but it is not on the market yet. Spectromagnetics believes that their Fieldial System will be good to 1 part in 10^5 ; it is temperature compensated.

The original plans for ultimate calibration and stability of the bending magnets called for an identical or reference magnet to be installed in series with each group of A and B bending magnets in the BSY. These reference magnets are to be installed in the Data Assembly Building where field measurements can be made without deterioration from nuclear radiation. The magnetic field of the reference magnet will be used for regulation if it is shown that the current vs. field does not have the required stability of ± 0.01%.

At this point, we should investigate the possible sources of error in the relationship between the magnetic field and magnet current.

Those modes of operation that may affect the stable relationship between current and magnetic field and magnet current are:

1. Temperature of the magnets as it might change the volume of the gap or the B-H relationship of the iron. A note from J. Cobb to H.A. Weidner dated April 10, 1964 shows that it is better to regulate on current than on magnetic field. The integral of Bdl is independent of magnet temperature changes if the current is held constant; this is true if the beam passes through the magnet.
2. Hysteresis loop between current and field
   a. Small loops when adjusting to a given value
   b. Large loops from off to on and reversing

3. Hysteresis loops in individual magnets in a group because of local trimming or adjustments for special experiments or adjustments. The magnetic test program will indicate whether hysteresis loops are a problem.

4.3 Reference Voltage

The stability of the reference voltage is as critical as the current signal in regard to overall system stability (drift) and repeatability (knob setting vs. actual current).

Saturated Standard cells in a temperature controlled air bath can be certified by the National Bureau of Standards (5) to about 0.001 percent when held to a few hundredths of a degree C. When in an oil bath and held to within a few thousandths of a degree, they can be certified to an accuracy of 0.0002 percent or better. These Saturated Standard cells are not practical to use in a regulation system. The unsaturated cell is normally considered as a working standard of EMF. The NBS will certify them to an accuracy of 0.01 percent and they should not be used in systems of higher accuracy.

Zener diode circuits, where the diodes are carefully matched and temperature regulated, may be used in systems certified for a stability of ± 0.001 percent for a year. These precision zener reference systems may have a temperature stability of ± 0.0002 percent (2 ppm) per $^{\circ}$C. (Calibrations Standards Corporation Series 200 Instruments).

A major part of the standard reference voltage is the stability of the voltage divider that is used to provide a variable voltage reference. The circuit used should maintain constant current and temperature through all parts of the divider independent of the set voltage output. A stability of 5 ppm/$^{\circ}$C should be attainable with extreme care.

5.0 "A" BENDING MAGNET SYSTEM STABILITY

The operating temperature range of the bending magnets will cause a $0.38 \times 40^{\circ}C = 15$ percent change in magnet resistance. It requires an overall system loop gain of 3,000 to hold the current deviation to 0.005 percent during the time that the temperature of the water system

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The $\pm 2\frac{1}{2}$ percent step line voltage changes require a loop gain of 400 to hold the current to 0.005 percent. This amount of gain will require that careful consideration be given to the regulation system.

The 3° bending magnets are reported to have a 1.8 second $^{L}/R$ time-constant. Care must be taken in applying the $^{L}/R$ time-constant to magnets that are not laminated when considering the transfer function in the regulation system: Data from Cambridge (CEAL-TM-127) indicates that the 360 cps current in an unlaminated magnet may be 10 times the a-c current for the same magnet with 0.014" laminations. This low a-c impedance of a solid core magnet is because of effective shorted turns creating eddy currents and the reduction of effective L because of the limited skin depth in the solid iron.

Data from UCLRL Berkeley (UCID-1972) shows a factor of 3 reduction in magnetic field ripple relative to the current ripple at 360 cps (approximately 1/2 inch laminations). Eddy currents are providing this additional shielding. A rough measurement made on a small unlaminated magnet (0.8 sec. time constant, 4-1/2 pole diam, 1 inch gap) showed a 0.4% field change in 5×10^{-3} sec for a 100% voltage change.

I would expect a 0.005% field variation for the bending magnet within 5.5×10^{-3} seconds after a 2.5% Line Voltage change. This assumes a linear extrapolation of the test data $(5 \times 10^{-3}) \times \frac{.005}{14} \times \frac{100}{2.5} \times \frac{1.8}{18} = 5.5 \times 10^{-3}$ seconds; a regulator must respond in less time than this.

Data to be taken during the magnetic measurements of the prototype magnets in July will be used to develop a suitable transfer function for the final regulation system. In the meantime, I will develop an approximate simplified circuit of the magnet for preliminary stability checks. I will assume a 1 KC response is required for the fast regulator until I can show that this is not correct.

The minimum noise level that one should work to at the summing point of an amplifier is about 20μ volts. If 20μ volts is 0.001 percent of the shunt voltage then the shunt reference voltage should be at least 2 volts. The regulation system must be stable with 0.01 percent regulation at 40 percent output and 0.04 percent regulation at 10 percent output.

Good amplifiers can have a common mode rejection of 120 db; if the amplifier noise level is 10×10^{-6} volts then the shunt system must be less than 10. volts a-c or d-c off ground. We probably should use amplifiers with 140 db of rejection, and try to work to 10μ volts noise levels at the amplifier input. The voltage to ground of the shunt should be held to 1 volt, if possible. The transductor when used for current measurement can give an output of 20 volts; if the stability of the transductor can be shown to be good enough it should be used to obtain a higher signal voltage and minimize the amplifier voltage to ground.

The voltage to ground of shunt system is relevant because the whole magnet system is tied to ground through a resistor at one point only. The ground resistor allows any ground current leakage to be measured and at the same time limits any fault currents to ground. Voltages on this resistor can be from insulation leakage, leakage through water cooling hoses, and transformer capacitances to ground.

It is more economical to break-up the total regulation loop into two parts:

1. Slow loop with 1 percent or less dead zone. Possibly a motor driven powerstat with a loop gain of 10 or 15. The best approach may be an SCR regulated power supply for the slow loop. Its loop gain can then be high enough to make the fast loop an easier problem.

2. A fast series loop with an a-c loop gain of 400 or 500 and 1 KC frequency response will take care of the line voltage steps. The d-c gain of this loop must be about 100 to 200 depending upon the characteristics of the slow loop.

5.1 "A" Bending Magnet Power System Possibilities

There are a total of 8-3° magnets used for spectrum analysis in the "A" beam. These magnets identified as B-10, 11, 12, 13, 14, 15, 16 and 17 are in two groups of 4 magnets each. The magnets B-14, 15, 16 and 17 are downstream about 200 feet from the first group.

Since the eight bending magnets comprise one bending system, it is believed that they should all be in series so that there will not be a possibility of an accumulative error in reading the current to several magnets. When all of the magnets are connected in series, it is possible to add one more "duplicate" magnet as a reference magnet. If all of the magnets are identical then field measurements taken on the reference magnet B100 located in the Data Assembly Building should be indicative of the field in the rest of the magnets in series in the BSY. We will have to wait for measurements on the magnets to see how identical they are. It is my hope that it can be shown that only current measurements need to be made after the magnets have been degaussed originally.

For the present, I will assume only a current regulation system but with provisions made to connect in a field measuring device if required.

There will then be 9 magnets in series; this will require a maximum voltage around the loop of 733 volts allowing a small margin for line losses and regulator losses.

The design of the magnets does not allow for long leakage paths in the water cooling connections, therefore, the 733 volts should not be one large power supply.

The Voltage to ground can be considerably reduced by breaking up the total voltage into two dual power supplies and one series regulator to take care of the fast line voltage steps. See Figures 1 and 2. The system in Figure 2 costs about $ 5,000 more than Figure 1. I prefer the system of Figure 2 because of the lower voltages to ground and because it gives more flexibility for future magnet connections when desired for special experiments.

A load resistor could be connected between points A-B or between C-D to trim the current in one group of magnets with respect to the other group. A trim current of 1 percent may be desired if the magnets are not identical. It would be better to use separate small range steering magnets rather than trim the current in the main circuit.

Step Voltage Changes

(a) An examination of the power supply system shown in Figure 2 will reveal that a line voltage change will show up on all magnets immediately because the power supplies and magnets are grouped alternately. On the other hand, there will be a delay before a correction inserted at one spot at the fast regulator (as in Figure 2) can reach magnet B-14. This delay is caused by the inductances and distributed capacitance of the series system.

See Figure 2A for a simplified picture of this problem. The equivalent circuit of a magnet is shown; the time constant of this magnet will vary with frequency because both eddy current losses and the inductance are a function of the applied frequency. The data taken during the magnetic measurements on the prototype will determine the correct transfer function for these magnets.

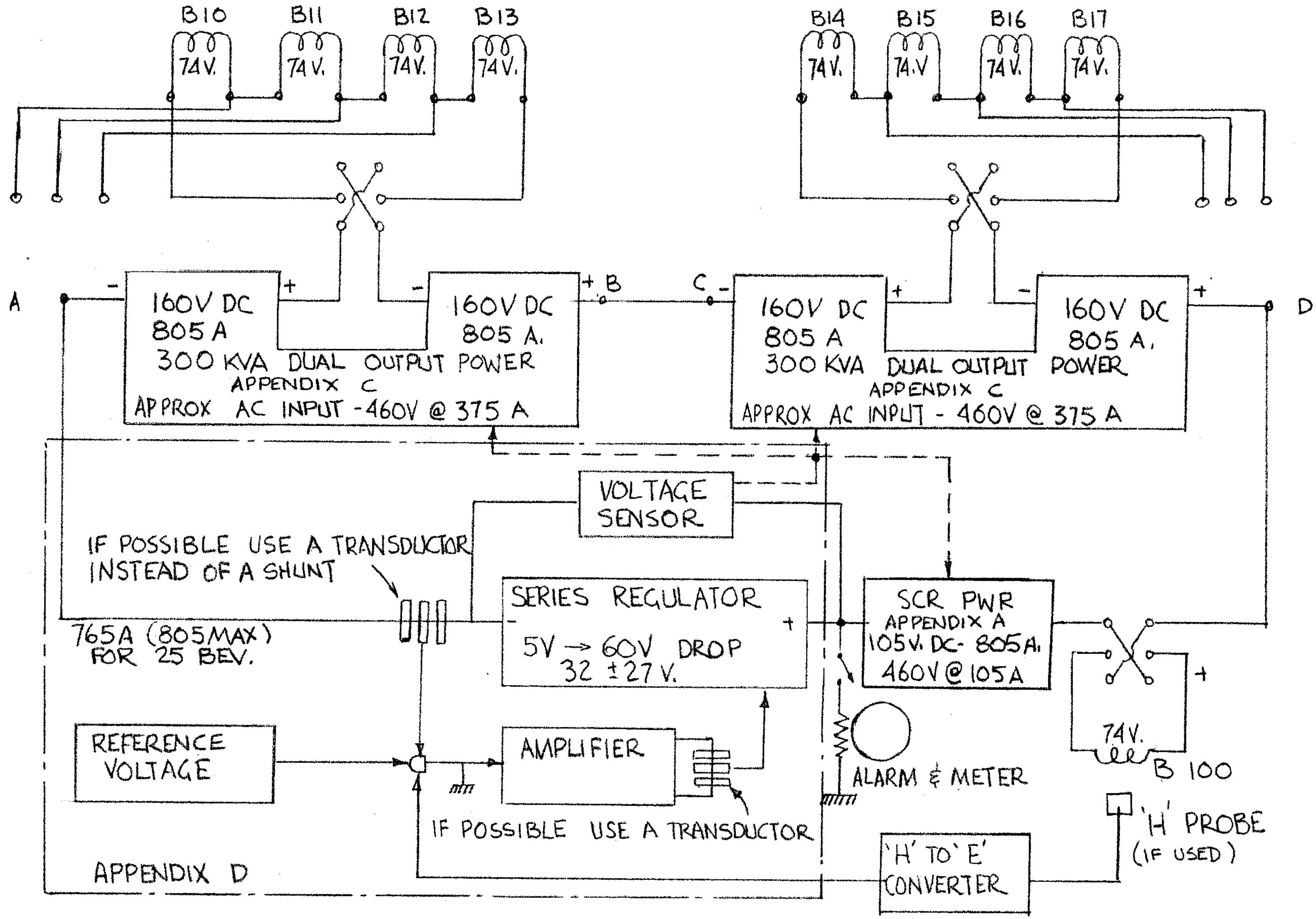
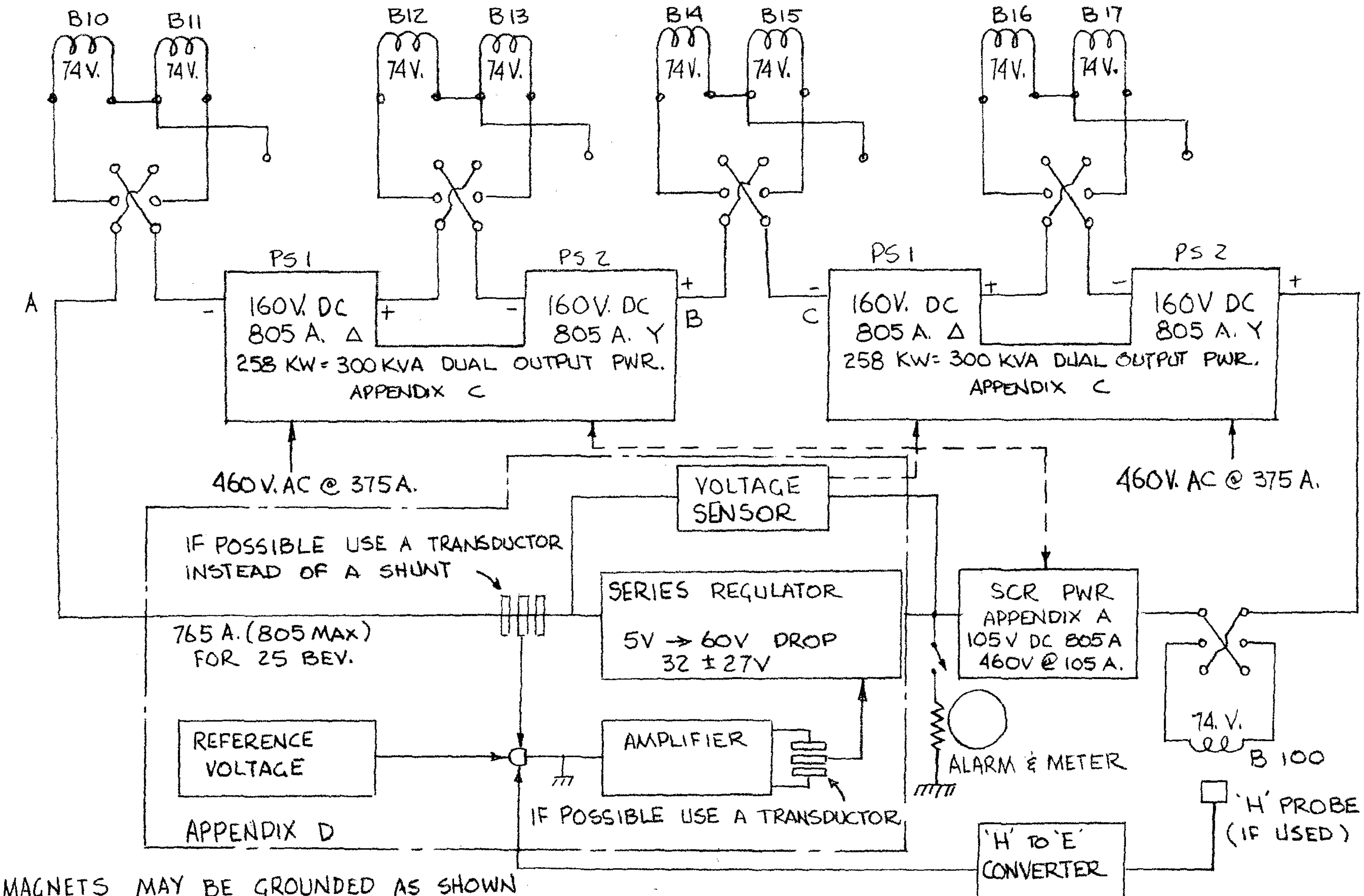


FIGURE 1 'A' BENDING MAGNET DC POWER SYSTEM - GROUPS OF FOUR MAGNETS.



MAGNETS MAY BE GROUNDED AS SHOWN
WHEN TRANSDUCTORS ARE USED FOR ISOLATION OF THE REFERENCE & AMPLIFIER

FIGURE 2 - 'A' BENDING MAGNET DC POWER SYSTEM - GROUPS OF TWO MAGNETS -

There are two possible ways to compensate for the distributed capacitance.

1. Add low leakage capacitors across each magnet that are large compared to the distributed capacitance but small compared to the power supply filters (10 to 100 MFD) might do the job.

2. Break-up the fast regulator section into two or more sections and place them distributed around the loop instead of as a single unit. I prefer the added capacitors as the best correction to this transient problem.

Leakage Currents

(b) Any leakage currents to ground or terminal to terminal in the series circuit of the bending magnets can be bothersome if they are of a value near the regulation requirements of the system. The leakage current should be proportional to the voltage impressed on the system; therefore, a check at full power should be sufficient. The leakage currents to ground can come from four main sources.

1. Power supply leakage and capacitive ground circuits.
2. Leakage in the cable from the power supply to the magnets.
3. Leakage through the dielectric of the magnet.
4. Leakage through the water used to cool the magnets and the power supplies.

The first three can be minimized by normal design considerations.

The fourth (water leakage) should be carefully considered. The main consideration will be given to the parallel paths of cooling water to the magnets. There are twelve ceramic water cooling pipes distributed along the magnet; each of these tubes are 3/8" ID by approximately 8" long. The resistance of each water column is 2.8×10^6 ohms for water resistivity of 1×10^5 ohm cm. If all of these tubes had 200 volts across then the current would be $(200 \div 2.8 \times 10^6)\ 9 \times 12 \approx 8 \times 10^{-3}$ amp.

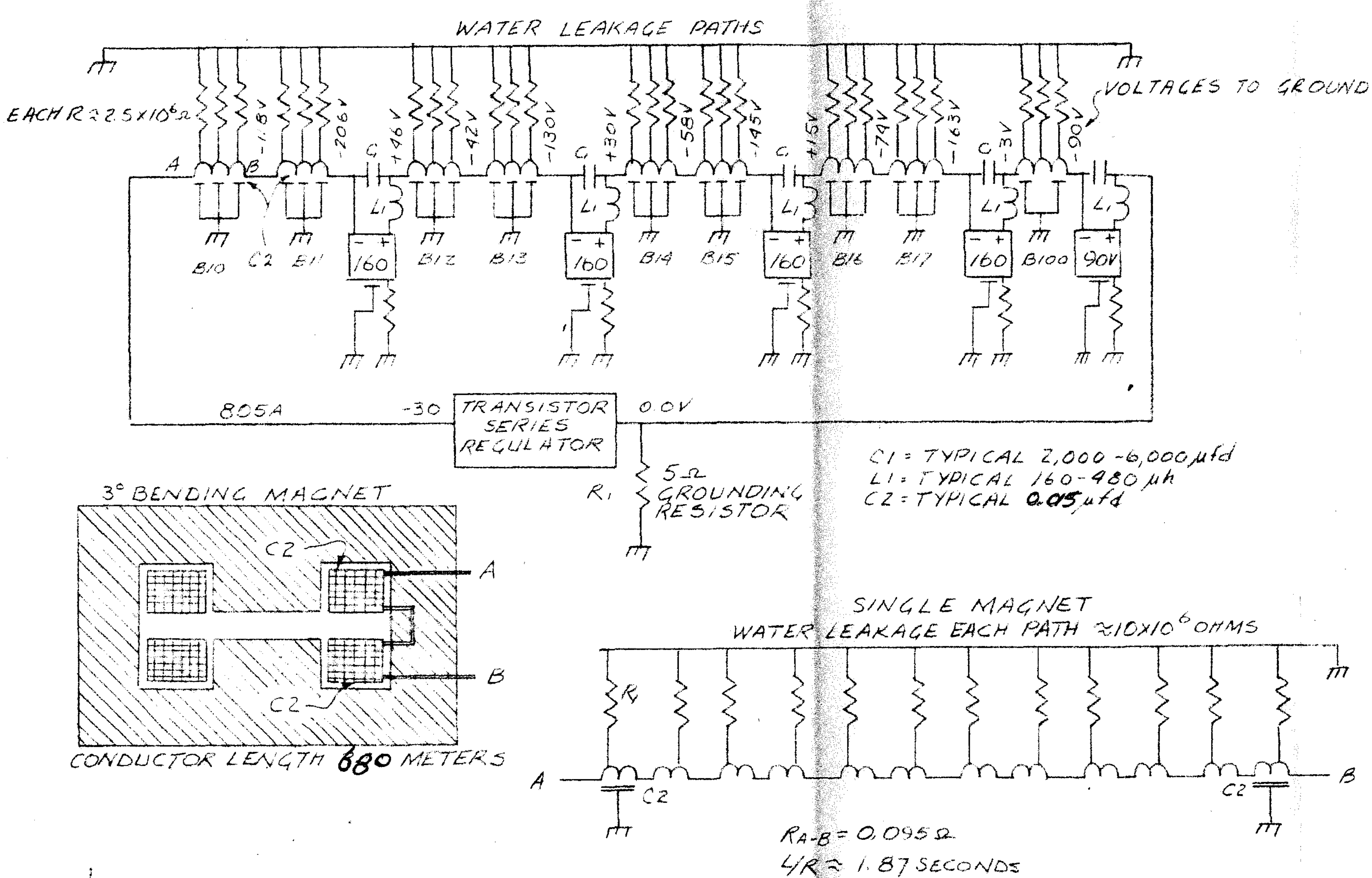


FIGURE 2A - 'A' BENDING MAGNET DC POWER SYSTEM - LEAKAGE TO GROUND

This value is well below 10^{-4} x 756 amps (the rated 25 BEV current) or 75 x 10^{-3}; actually, there will never be a time when all of the magnets are biased 200 volts in the same polarity from ground. See Figure 2A for typical voltages to ground. Consideration is being given to a guard system in the water circuit that could be biased if the leakage through the water becomes a problem.

5.2 Type of Regulating Unit

The series regulating unit may be any one of several types.

a. Series transistor bank is probably preferred. (See Appendix D)

b. A 400 cps 3 phase MG source could be used for a narrow range fast response SCR controlled d-c power source. This would probably eliminate the need for a series transistor bank but it may be marginal in frequency response. See Figure 6.

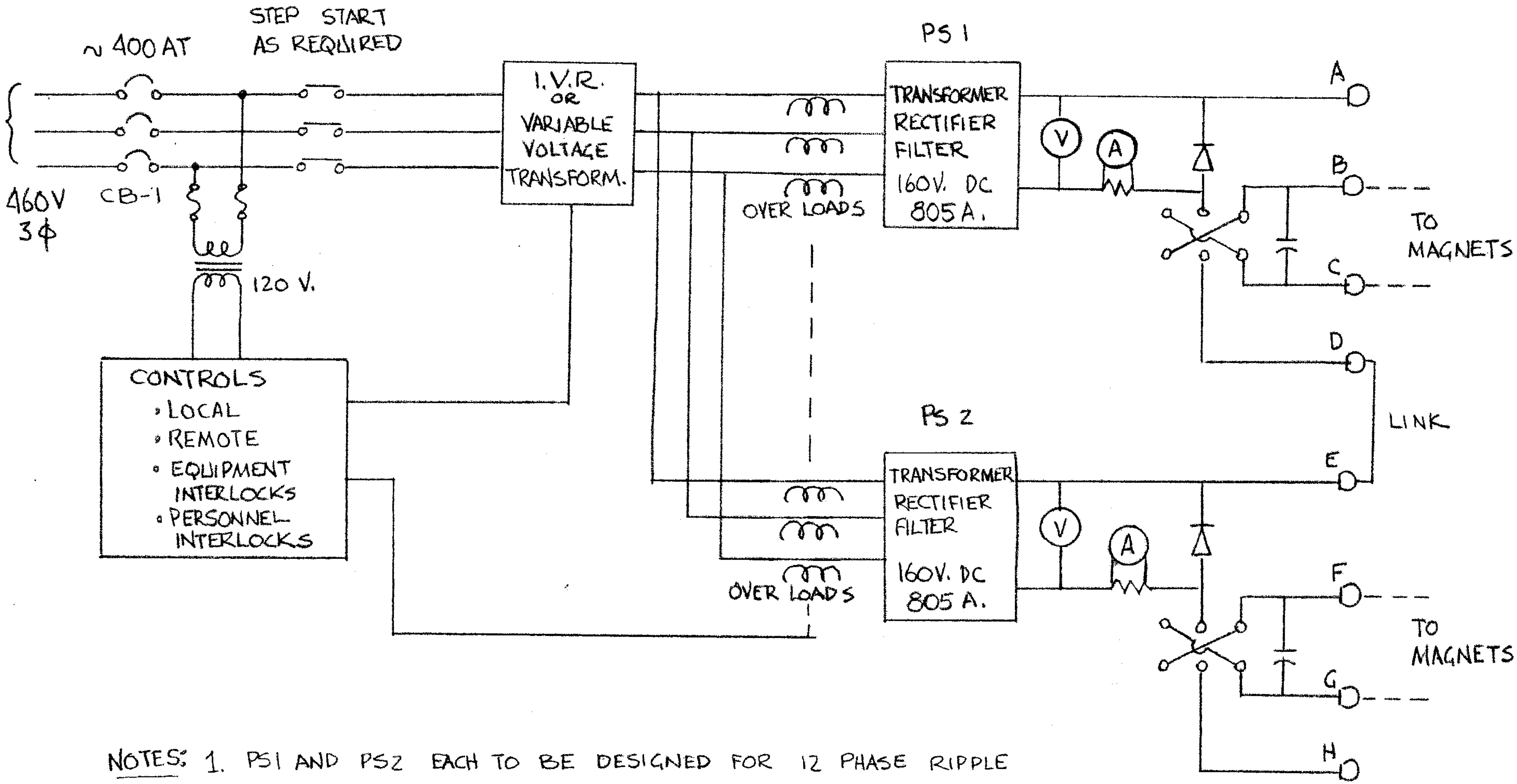
c. High frequency chopper; not developed far enough to use.

d. Quinten Kerns; high voltage transformation to series impedance. US PAT 2,579,235. This system would be too expensive at this power level.

5.3 Series Regulating Element

Some consideration should be made to decide whether this unit should be all lossy or if there should be a power supply with it to make up for its internal voltage drop.

5.3.1 An all lossy regulation system would require that the power loss be made up in the other power supplies. I believe that if an SCR controlled rectifier were used as the additional power source then it could act as an emergency regulator of lower precision if the transistor section were in trouble. The characteristics of an SCR supply might allow a narrower range fast section than would be allowed without an SCR section. See Figure 3.



NOTES: 1. PS1 AND PS2 EACH TO BE DESIGNED FOR 12 PHASE RIPPLE
EACH TO HAVE A DUAL RATING OF 160 VOLTS - 805 AMPS
122 VOLTS - 1050 AMPS

2. SEE APPENDIX C

FIGURE 3. - 258 KW DC POWER SUPPLY - DUAL 129 KW UNIT.

PS1 + PS2 must each deliver 160 V at 805 amp or a total of 258 KW output. The most economical variable voltage unit in this power range is the H-C series powerstat. The H-C powerstat ratings jump from 187 KVA to 332 KVA in one step. If the A beam series regulator unit did not contain a power supply, the dual power supplies would require a higher rating and would not be within the ratings of the H-C powerstat. A variable transformer such as those made by Glenn Pacific may also be used; their KVA ratings do not have a large jump in this range.

A series transistor regulator should be a complete self contained system ordered and tested as a separate device. This unit could be built by companies in the critical control field and the rest of the power supplies could be constructed by many other reliable companies. We would take the ultimate responsibility for the complete system. Figure 2 would describe this system.

5.4 Other Features Required

1. Alarm to indicate above threshold current flowing in ground resistor R1. Turn off in case this becomes excessive.
2. Output from series regulator to drive slo-syn motors. Possibility of two-speed for slewing rapidly.
3. Some system of adjustable by-pass for ± 0 to 1% current by-pass around magnets B-14, 15, 16, 17. This trim system would be eliminated if separate steering magnets were used.
4. Remote control of reference voltage with setability to 0.005%.
5. System protected so that it can be turned on or off at full power without damage from transients. It is better to run the primary control to zero and start out easy when turned on.

6. Range of regulated current control from 250 amps to 805 amps with 0.005% or 1 MEV Regulation, whichever is larger over the full range. The current will be controllable down to approximately zero current.

7. Provision must be incorporated to reverse the magnets manually; reversing to be done at zero current.

8. Provisions should be made so that the magnets may be degaussed using the existing power supplies.

9. Provision must be made for remote controlling of the units.

10. The individual power supplies PS-1, PS-2 should have enough filtering to keep the peak-to-peak ripple voltage less than 1%.

5.5 <u>Variable Voltage Substation vs. Individual Powerstats Located in Power Supplies</u>

An earlier proposal suggested that it might be more economical to use a 12 KV to low voltage, variable voltage substation instead of individual powerstats. A cost comparison is given here for the "A" bending magnet power supply system. Only those costs involved in the choice will be shown.

Variable Voltage

1,000 KVA,12 KV to 0-600 V	$ 37,040
600 volt feed line and bus duct.	5,530
Controls	2,000
	$ 44,570

Individual Powerstats

1,000 KVA,12 KV to 480 transformer.	$ 12,000
480 volt feed line and bus duct.	7,360
2 332 KVA powerstats + 1 of 94 KVA.	19,800
Controls	5,000
	$ 44,160

This comparison shows that the two systems cost about the same.

(a) The second system uses more standard components and would be easier to put back into service in the advent of a major component failure.

(b) The components of the second system are more useful on other jobs in case a major modification of the BSY is made.

(c) The variable voltage unit located within the power supply makes the unit more attractive as a packaged item and makes the power supply easier to test.

For these reasons, I have now settled on the system shown in Figure 2 with individual powerstats as the best for our purposes.

5.6 Provisions for Increased Current

At some later date it may be required to accelerate higher energy electrons through the "A" system. The current required in the present "A" Bending magnets for 30 BEV is 1050 amp; this could be obtained by changing the transformer taps on the power supplies for a higher current and then adding a power supply to increase the available voltage. The present "A" magnet system bending 3° per magnet will not be able to handle a 40 BEV beam; additional magnets would have to be added in this line-up.

6.0 "B" BEAM 3° BENDING MAGNETS SYSTEM

The "B" beam has an expected energy resolution of 0.3% which is three times that for the "A" beam.

The current regulation required for the "B" system has been stated as ± .02%. (Initially only ± 0.05% is required). An accuracy of 0.02% requires the precision and frequency response of a series transistor section as to be used in the "A" bending system. See Figure 4. The initial accuracy of ± 0.05% might be accomplished with

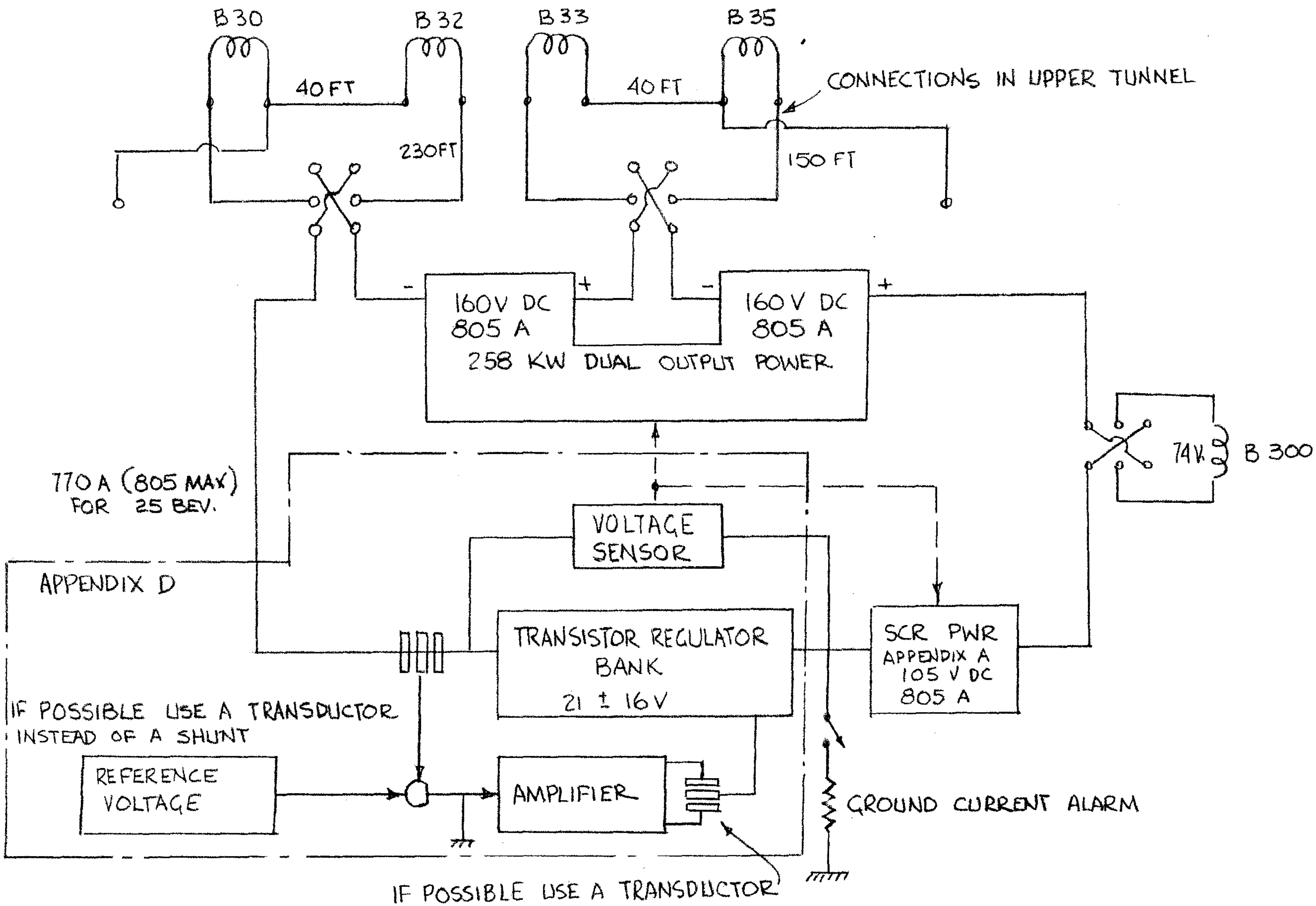


FIGURE 4 - 'B' BENDING MAGNET DC POWER SYSTEM

the straight SCR Power supplies, but in this case, it is probably better to build in ± 0.02% at the start.

There are four magnets in the spectrum analyzer for the "B" beam. The four magnets are identical to those in the "A" system and will require 765 amps for 25 BEV or 920 amps for 28 BEV. At some later date two additional magnets could be added; it would then require 850 amps to bend a 40 BEV beam 2° per magnet.

6.1 "B" Regulator Section

The regulator section may be any one of several basic types similar to the "A" bending system. See Section 5.2.

The system as shown in Figure 4 has the voltage available to go to 805 amps with 5 magnets (4 bending + 1 reference).

7.0 8 CM QUADRUPOLES POWER SUPPLIES (SEE APPENDIX B FOR SPECIFICATION)

There are eight quadrupoles to be energized... four of these units are on the "A" side and four are on the "B" side. Each quad requires a nominal value of 40 V at 500 amps with a regulation and stability of 0.1%. The power supplies to be supplied will be rated for 55 volts and 550 amps thus providing some over-ranging of the current.

These quadrupoles operate in pairs, but it may be required to adjust the current of one as much as 15% different than the other. The range of ± 0.1% regulated current must extend from 45 amps to full current; the current control must be able to reduce the average output current to zero.

7.1 Regulation System

The types of regulation systems that could be used for the quadrupole power supply regulator are as follows:

a) Series transistors with power supply. This is probably more expensive than required.

b) SCR controlled rectifier as shown in Figure 5

c) SCR's used in a high frequency chopper mode

d) Standard variable voltage rectifier plus a fast narrow range SCR control on line voltage. Note possible use of 400 cps 3 phase for a higher frequency response.

e) SCR's or transistors used in a switching mode in combination with a digital system of variable resistance.

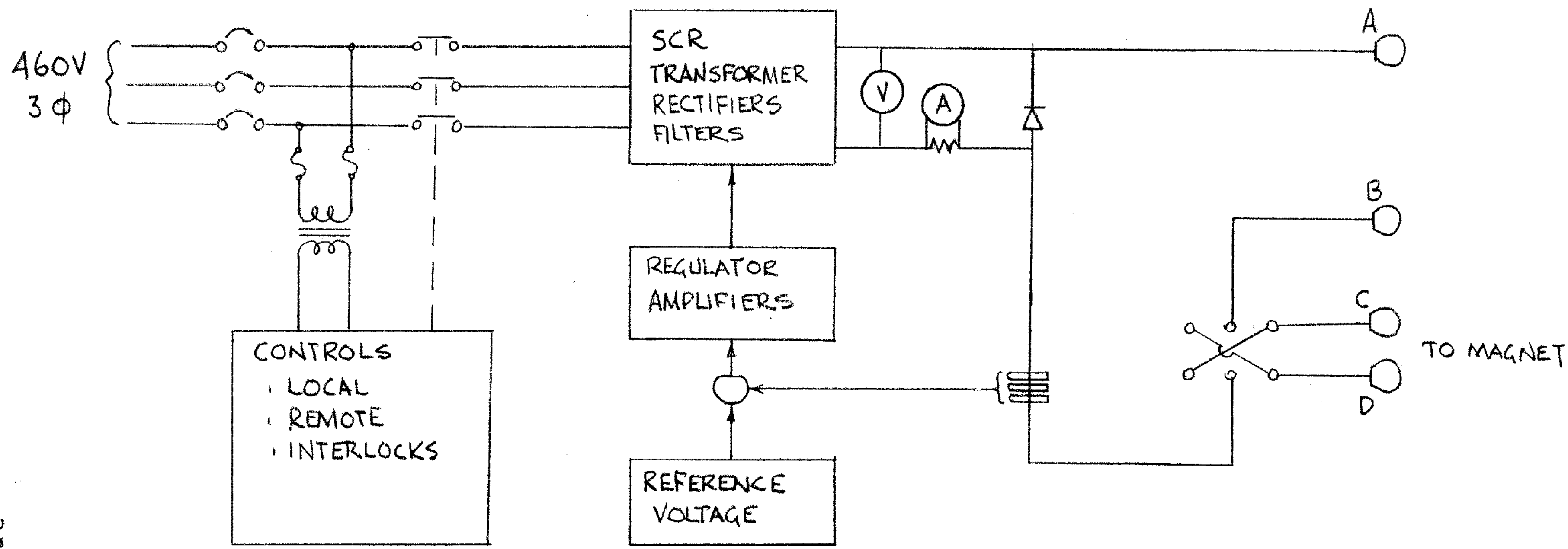
See Figures 5 or 6. The final system will be chosen on the basis of overall costs and reliability.

7.2 Ripple Voltage on the Magnet

An SCR power supply produces a large percentage of ripple voltage that must be filtered out. The amount of filtering required is dependent upon the magnetic structure, leakage reactance of the magnet being energized, and frequency of the ripple. I feel that we should await the final ripple measurements on the prototype quadrupole before specifying the allowed ripple voltage. I expect that a 5% peak to peak voltage ripple will be within tolerance.

7.3 Power Supply System Design

The two quadrupoles that form a doublet could be connected in series and operated from a single power source. The required current trimming between the two quadrupoles would then be done by some separate unit. The combination of these two types of regulators is more complex and less versatile than to build two individual but identical units to feed the quads separately. Some savings may be



NOTES: 1. THE SCRS COULD BE EITHER ON THE AC OR DC SIDE OF THE TRANSFORMER

2. SEE APPENDIX A FOR SPECIFICATIONS

3. THE 460V INPUT COULD BE AT 400 CPS TO IMPROVE THE FREQUENCY RESPONSE

FIGURE 5. - 84.5 KW SCR CURRENT REGULATED DC POWER SUPPLY
60 CPS INPUT

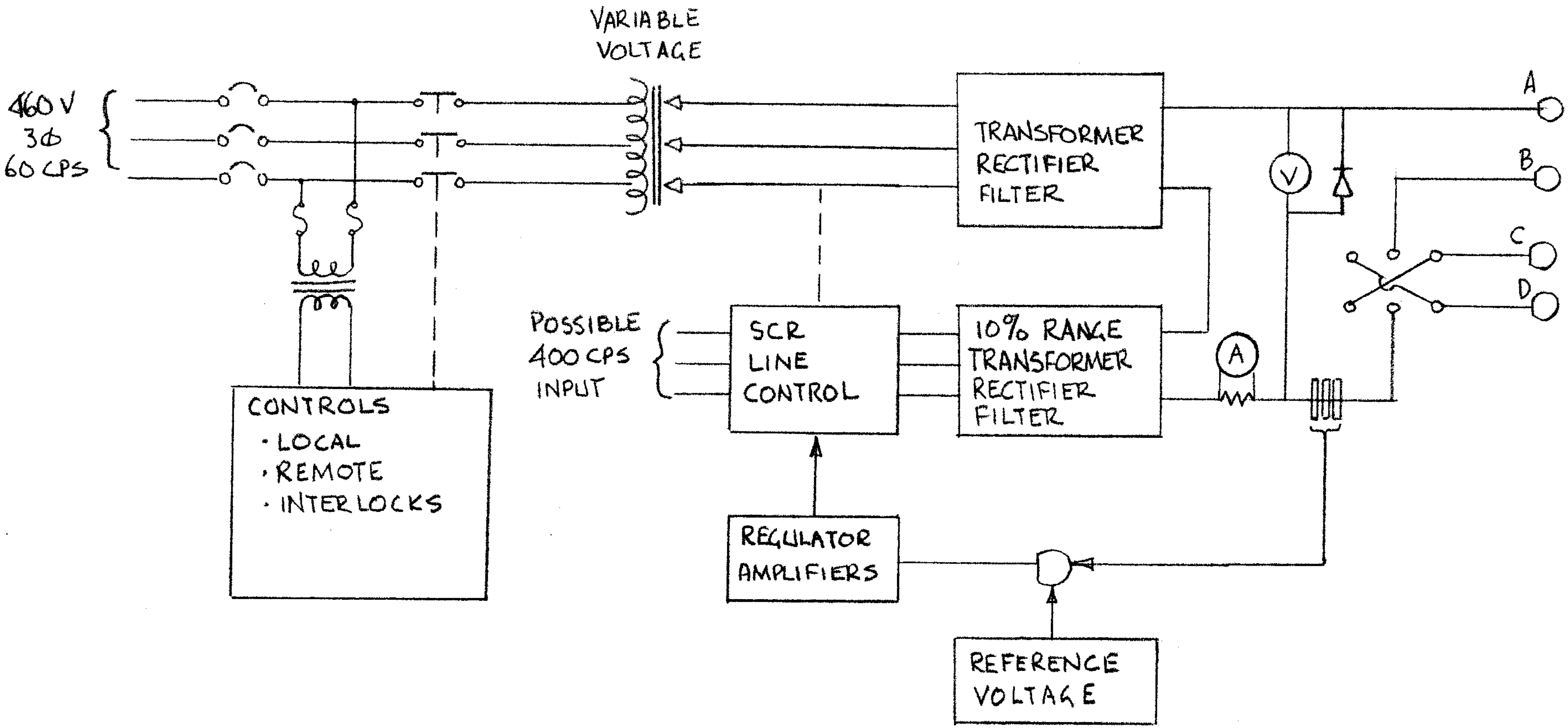


FIGURE 6. 84.5 KW SCR CURRENT REGULATED DC POWER SUPPLY
400 CPS SUPPLY FOR NARROW RANGE

made by combining two of the regulated power supplies in one power package. This is planned.. See Figure 7.

An additional economy could be made by making the series connection between quadrupoles in the BSY. This would require only a small lead from the midpoint to the Data Assembly Building. I feel that the common impedance so introduced by this lead would cause additional regulation problems and would not be worth the $ 1,000 saving per pair of quadrupoles. A check will be made to evaluate more accurately the problems that this common impedance may introduce.

7.4 8 CM Quads High Power

Quadrupoles Q-33 and Q-34 will require a maximum of 805 amps at 77 volts. This power would be handled best with the 105 V 805 amp SCR regulated package that is part of the "A" and "B" bending and the dump magnet circuits. See Figures 5 or 6, or Appendix A.

8.0 18 CM Quadrupole Power Supplies

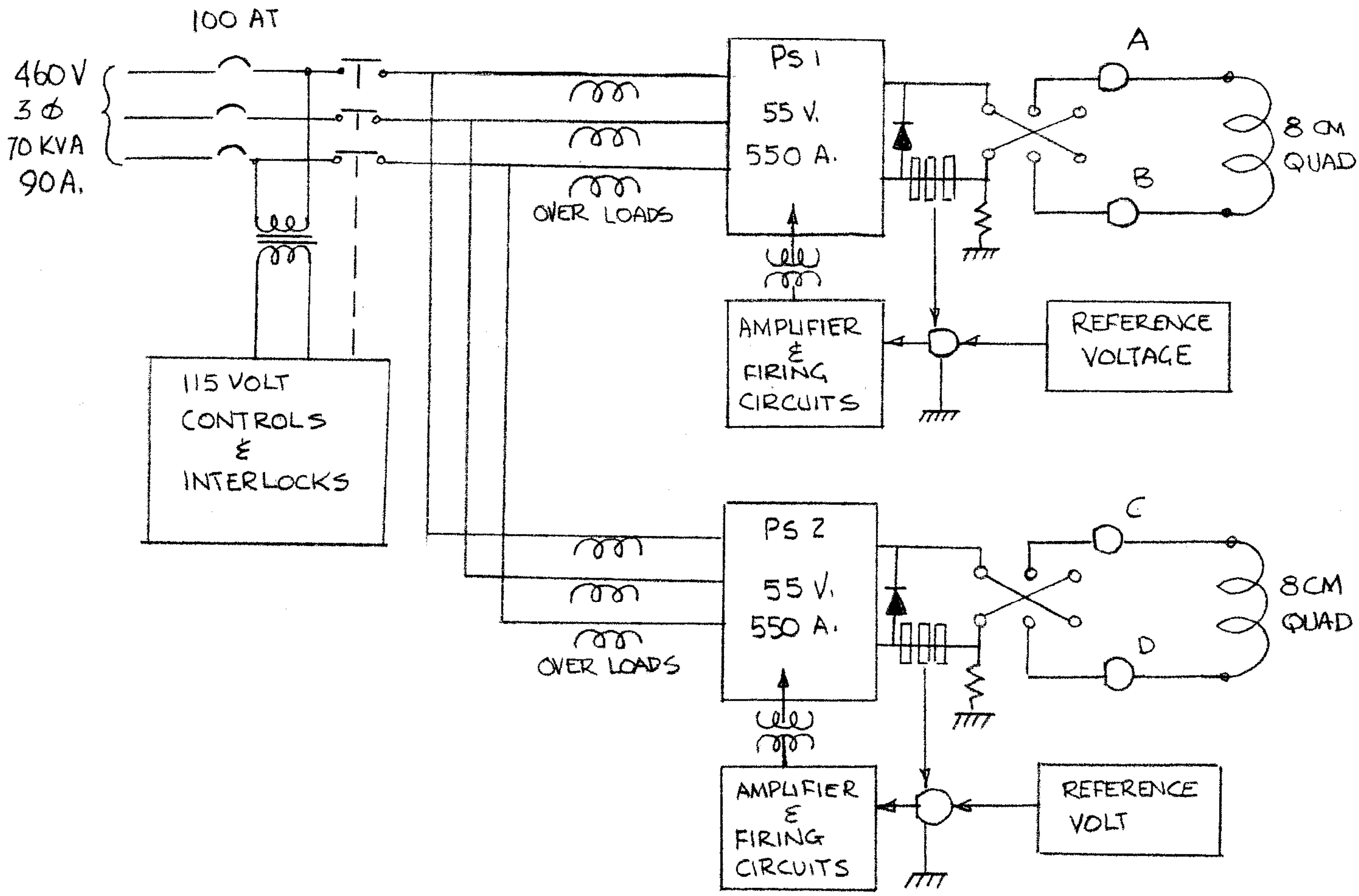
There is one of these quadrupoles or field lenses installed in each beam lineup.

The magnet requires 52 volts at 315 amps. I would favor the same system as will be used for the 8 cm quads with slightly different ratings to fit the requirement. A slight shift of the taps on the transformer would allow the dual unit of Figure 7 to operate for this requirement.

9.0 DC Emergency Magnet Power Supplies

These two magnets in series require 60 volts and 330 amps regulated to 0.1%.

You will notice a similarity in ratings between these magnets and the 18 cm quads. I would propose that these be identical units, then for most normal operations when the pulsed bending magnets are used, this



NOTES: 1. EACH POWER SUPPLY HAS TAPS OR RECONNECTION FOR DUAL RATING 55 V - 550 A, 80 V - 350 A.

2. PS 1 & PS 2 POSSIBILITIES:

A. - HARMONIC TRAPS
VARIABLE VOLTAGE TRANSFORMER
RECTIFIER TRANSFORMERS
RECTIFIERS
FILTERS
NARROW RANGE SCR RECTIFIER

B. - HARMONIC TRAPS
VARIABLE VOLTAGE TRANSFORMER
RECTIFIER TRANSFORMERS
RECTIFIERS - SCR'S - PHASE CONTROLLED
FILTERS

C. - HARMONIC TRAPS
RECTIFIER TRANSFORMERS
RECTIFIERS - SCR'S - PHASE CONTROLLED
FILTERS
THE SCR'S COULD BE PLACED ON THE AC SIDE OF THE TRANSFORMERS FOR PRIMARY CONTROL.
(SIMPLEST SYSTEM - PROBABLY MOST ECONOMICAL)

3. SEE APPENDIX 'B' FOR SPECIFICATIONS -

FIGURE 7 - 60 KW SCR REGULATED POWER SUPPLY
DUAL 30 KW

unit is a spare for both the 18 cm quadrupole and for most of the 8 cm Quadrupole Power Supplies.

10.0 A COMMON POWER SUPPLY SYSTEM FOR QUADRUPOLES

The high frequency chopper mode type of power supply (see 6.1 a) might be economically used in a system as shown in Figure 8. Such a system as this is in operation at UCLRL Livermore and a different type of the chopper system is being developed by Westinghouse. The main advantage of this system is to be had when a single large power supply can be used to feed currents to several similar loads.

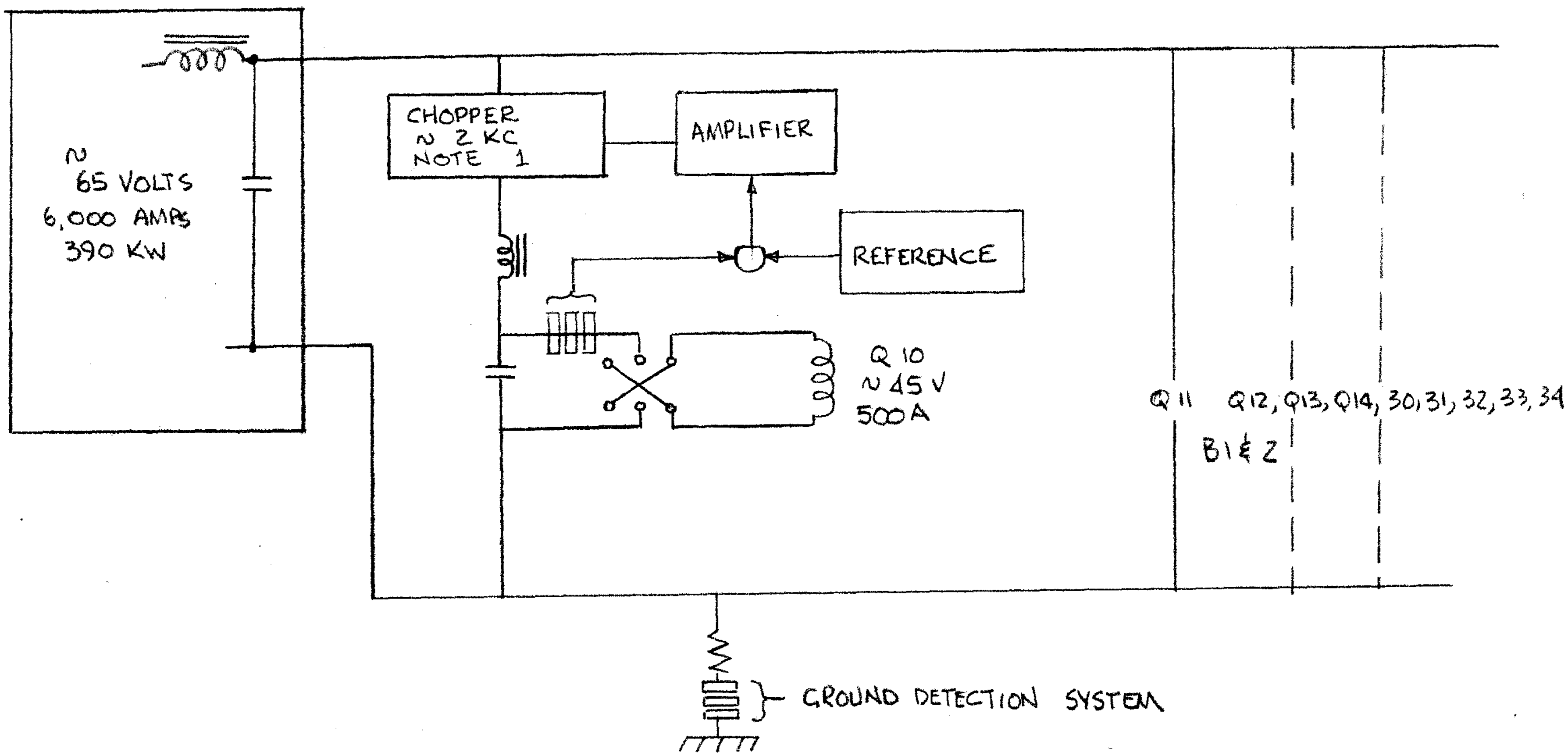
In principle, it would be possible to put all of the quadrupoles and emergency magnets on this type of common source power supply.

It is of further interest to note that the total power as shown in Figure 8 for all of the quadrupoles and emergency magnets is about the same power level as the common type unit planned in Figure 1, 2, 3, 4 and 9. This type of system would be putting a lot of eggs in one basket, but it might pay off if all of the large power supplies could be identical.

The savings in the cost of the one large unit relative to many small units is about $ 28,000 of which a large part would have to go back into the 12 chopper assemblies. I am not sure that there is a net savings but I will check the system more accurately for a better estimate even though I don't like this system.

11.0 3° BEAM DUMP MAGNETS

There are four of these magnets to be powered. Each magnet will require 140 volts at $\pm$ 1,000 amps. These magnets require only $\pm$ 1/4% regulation of current; I intend to use three of the basic rectifier units of Figure 3 and one 105 V 805 A SCR power supply with taps change to 80 V at 1050 A. See Figure 9. The design of the SCR System Regulator



NOTES: 1. CHOPPER MAY BE:
a. CONSTANT FREQUENCY VARIABLE PULSE WIDTH (W)
b. CONSTANT PULSE WIDTH VARIABLE FREQUENCY (LRL)
c. COMBINATION (a & b)

FIGURE 8 - COMMON SOURCE POWER SUPPLY.

will be based upon one of the systems as described in Section 6.1. It will probably be some modification of the power supply shown in Figure 5 or 6, and it should give a regulation better than ± 1/4%. The choice of blocks shown in Figure 9 will allow bending of a beam up to about 28 BEV.

12.0 POWER SUPPLY ELECTRICAL NOISE

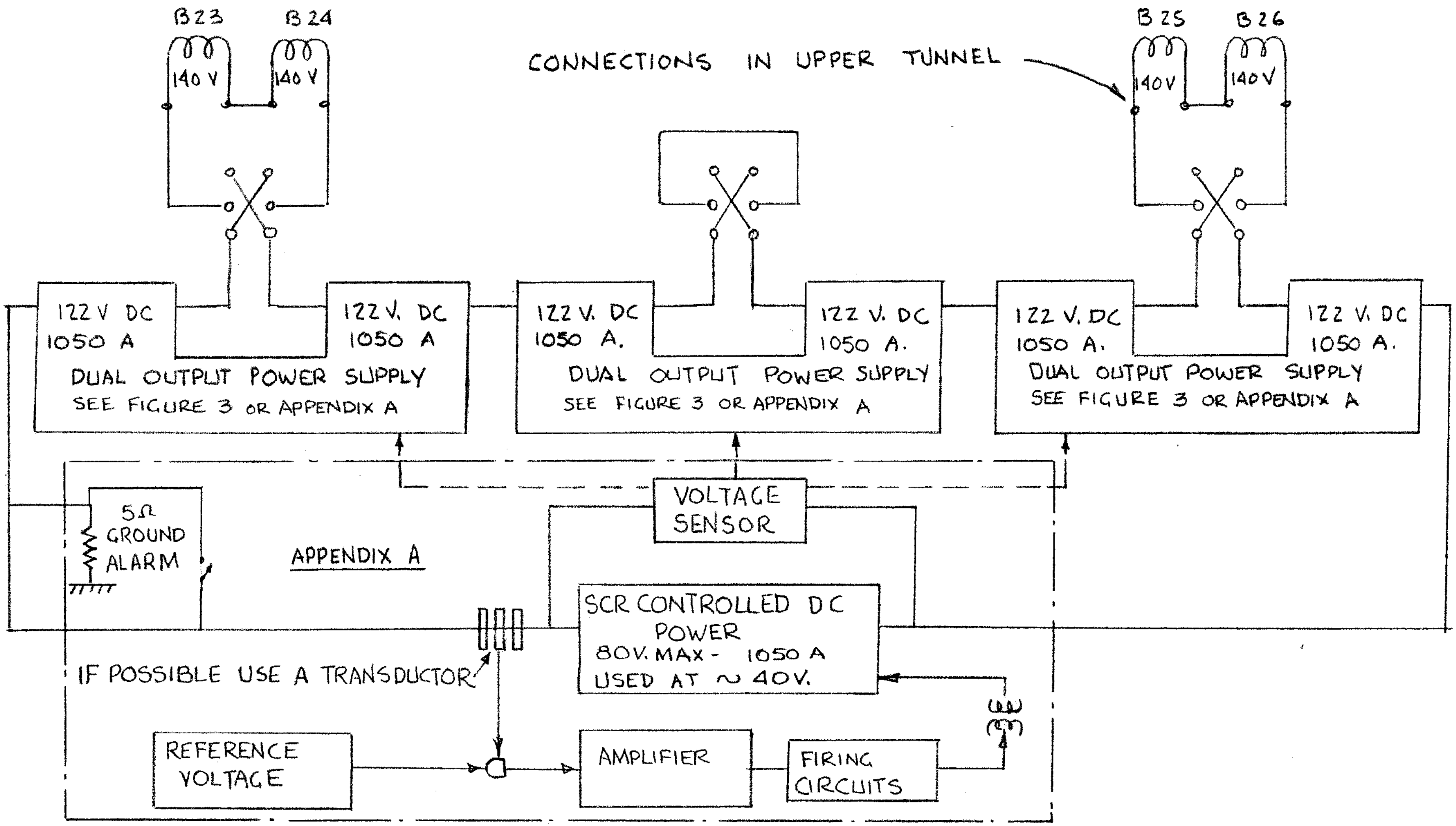
Considerations must be given to minimizing the radiated RF noise that might be generated by the SCR FIRING CIRCUITS and associated power transients. This type of noise (10 KC to 10 Megacycle) will be held to low levels by the following steps:

a) Care in the layout of the power supply major components and wiring.
b) Application of transient suppression circuits to keep RF in local circuits.
c) Shielded transformers
d) Design of d-c filter to also aid in not radiating noise
e) Application of harmonic suppression in combination with power factor correction.
f) Remote controls will generally be with the use of 24 or 48 V d-c with proper isolation.
g) Good cabinet doors

The cost of these noise suppression steps will be small compared with the purchase of a different type of power supply that does not use SCR's such as a series transistor system.

13.0 POWER SUPPLY CONTROLS

The controls of a power supply can be divided into two major divisions, d-c and a-c power.



THIS SYSTEM USES THE SAME BLOCKS AS IS PLANNED FOR THE 'A' & 'B' BENDING SYSTEM EXCEPT FOR THE TRANSISTOR REGULATOR.

FIGURE 9 - DUMP MAGNET DC POWER SUPPLY

13.1 D-C Magnet Current Controls

The adjusting of the regulated d-c current into a given magnet will probably be done by varying the reference voltage into the regulator.

The reference voltage may originate in the power supply and be remotely controlled with either a remoted potentiometer or a remote motor drive. The reference voltage could originate in the BSY Control Room and be sent to the power supplies. The final decision as to the preferred system will be made at a later date. Provisions to accurately read the various magnet currents must be made so that the operator can easily read and adjust to the precision required. The precision current monitoring will be done with units separate from the power supply regulation system and will be mounted on the magnet leads not in the power supplies. I. Lutz suggested this split in monitoring devices and it seems the best way to maintain a magnet calibration independent of the power supply connected to it.

13.2 A-C Controls and Interlocks

The a-c controls must be an integrated system encompassing all of the personnel and equipment interlocks as required.

Many of the signal levels to be monitored in the Data Assembly Building Control Room will be at the threshold of noise, therefore, it is desirable to keep all signals and controls to the control room as noise-free as possible.

Some of the power supplies will use power devices such as Silcon controlled rectifiers. These can be a source of noise frequencies up to a few megacycles. The electrical noise bursts generated by an SCR power supply may be in a synchronism with the normal accelerator beam pulses, therefore, we must be sure that disturbing electrical noise does not leave the power supplies in question.

It should be easy to affect good electrical noise isolation between the power supply circuits and the remote controls if the remote controlling is done using 48 volts d-c and telephone pairs and relays. The additional cost of the conversion to low voltage d-c remote controls will be made up by the lack of additional noise suppression that otherwise may be required.

Figure 10 shows a typical conversion panel that might be used. It is my aim that a standard conversion panel be designed that can be used on various power supplies. It is my feeling that this same type of conversion could be used when remoting the controls of a power supply from an experimental area to the Counting Control Room. Care must be taken to make the remote controls fail-safe for both equipment and personnel.

The power supply remote controls will be plugged into a special SLAC panel on each power supply. The use of plugs at this point allows an easy change-over of controls to a stand-by power supply in case of an emergency.

The control cables will be routed at right angles to the a-c power and will terminate in a control cross-connect at the north end of the trench leading to the control room. Most of the various system interlocking will be set-up in this cross-connect. The cables for the control of reference voltage will go directly to the control room.

Some system of Key interlocks will be used to insure that a power supply is off before work can be performed on theD-C power cable termination boxes or magnet disconnecting plugs. This safety feature is very important because of the great separation between the various loads and the power supplies; the need for this safety feature is enhanced further by the requirement of disconnecting plugs on the magnets.

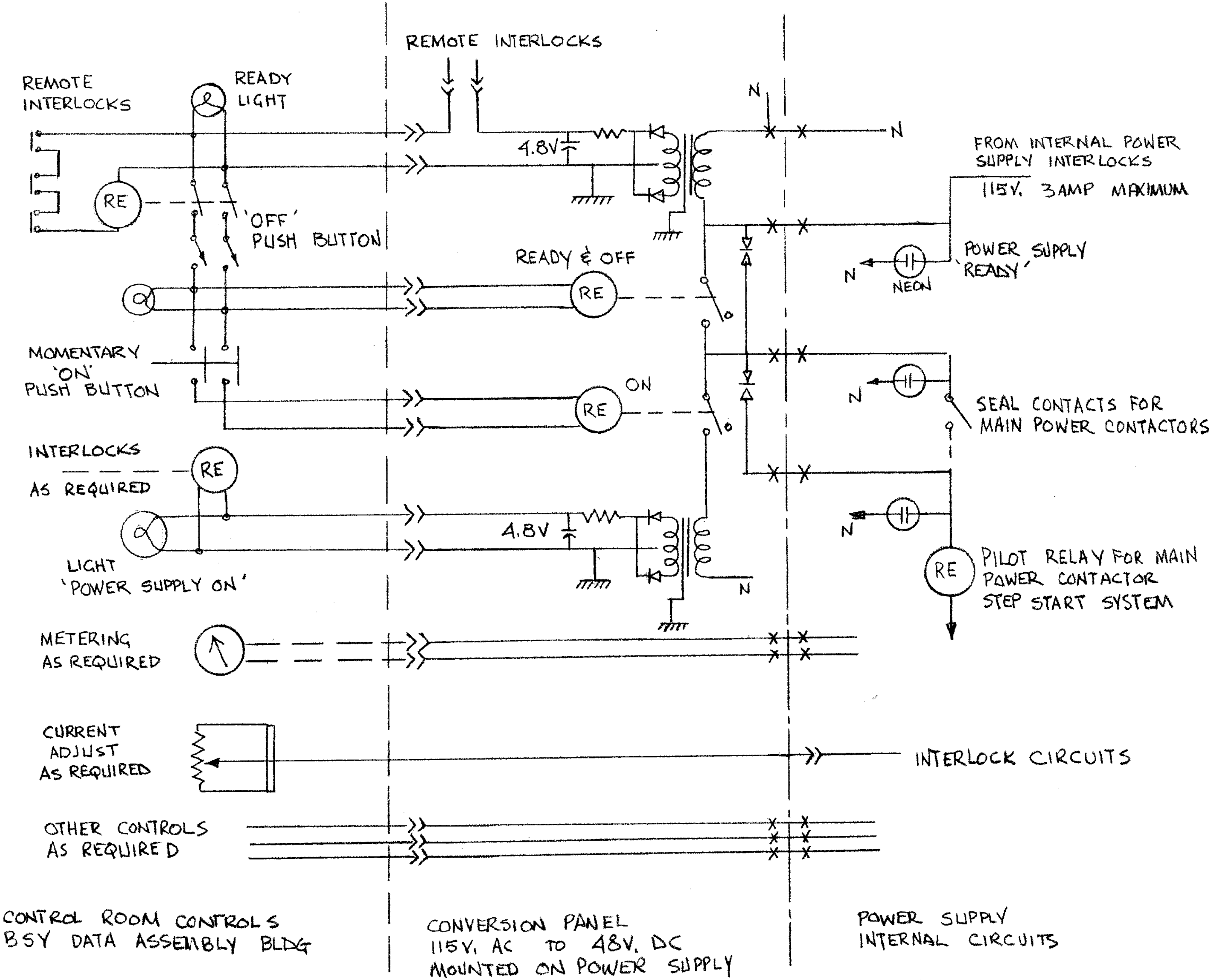


FIGURE 10- TYPICAL POWER SUPPLY CONTROL CONVERSION SYSTEM

14.0 POWER FACTOR CORRECTIONS

The general project requirement is to hold the power factor above 90% SCR power supplies generally run in a phased back condition even when operating at nearly full rating. This phasing back to about 80% power factor is required so that an SCR controlled rectifier can have some reasonable voltage gain left when operating as a regulator. Of course, any operation at a further reduced voltage will make the power factor more lagging.

The present analysis of the loads shown 1,800 KVA of maximum rating of power supply for normal rectification type supplies and about 550 KVA of load that might end up being all SCR type power supplies. If the SCR's are phased back to 70% power factor this will also reduce the power by 70% and would require about 200 KVA of capacitors for correction to 90%. If I install these capacitors in the individual power supplies they can be made part of a general harmonic correction system; total costs might be $ 4,000 for this system. A small amount of power factor correction in the power supplies in combination with the high power factor loads in the water pumping system should result in a 90% power factor for the BSY power.

15.0 DATA ASSEMBLY BUILDING POWER SUPPLY LAYOUT

15.1 A-C Power

Figure 11 shows a preliminary layout of the power supplies in the building. It is our present intention to run the a-c power in gutters or ducts just under the beams of the building. The a-c power will run lengthwise of the building and drop down to the power supply.

The 84.5 KW and 60 KW SCR power supplies may be fed individually from the main power panel. The impedance of individual lines will hold the available short circuit (SC) current at the power supplies to less than 15,000 amps asymetrical, otherwise the power supply main breakers would have to be increased to 25,000 amp SC rating. Equipment rated for 15,000 amp SC is smaller and more economical than designs that take 25,000 amp SC.

An attempt will be made to design the power feed to the Dual 129 KW power supplies to be less than 400 amp and 15,000 SC. Further studies must be made to be sure that it is possible.

We had considered overhead bus ducts and plug-in breakers or switches but this type of installation would raise the available short circuit current and would give rise to electrical interference if care is not taken.

15.2 D-C Power

The d-c power cables will be routed overhead from the power supplies to the north wall of the building and then to the appropriate location in the Beam Switchyard.

We have considered the possibility of making an intermediate connection in the D-C cables at the wall of the building. A terminal at this point would increase the cost of the power distribution system, but would make a better division point for the different electrical contractors that might be working on the installation of the power supplies. A definite terminal point at the wall would be a good place to install any special current monitors or other circuits that may be required.

There is also the possibility of installing the magnet reversing switches at this point. Personally, I prefer the reversing switches to be in the power supplies, and thus leave the building walls as clear as possible for future devices.

Reversing switches are required in the magnet leads because provisions must be made to guide either positrons or electrons through the Beam Switchyard. The time required to change from accelerating electrons to positrons in the accelerator proper may be 15 minutes or longer. The present plans call for being able to reverse the current in all magnets of the Beam Switchyard within 30 minutes with provisions so that this time may be shortened to 15 minutes or less at some future date. The time period mentioned includes turning off, reversing, and resetting to a new value.

The routing and physical arrangement of the d-c power cables to the Beam Switchyard will be carefully controlled to minimize any stray field interference with the beam optics. The beam drift paths between the various magnets and monitoring equipment will require magnetic shielding to lower the earths magnetic field by a factor of ten in these areas. The existence of this magnetic shielding makes the problem of stray magnetic fields from d-c power cables less critical; we will not be in trouble by using only moderate care in routing of the d-c power and in a few cases twisting the cables.

Standard cables (possibly polyethylene) will be used from the Data Assembly Building into the upper housing of the switchyard. At that point, we will convert to a radiation resistant method. The high humidity and possible presence of a nitric acid atmosphere may make it desirable to use busses mounted on ceramic insulators in the lower area where the radiation exposure is high. We are designing on the basis of 10^{13} ergs per gram of radiation dosage accumulated over a 10 year life.

The magnets will be connected to the ends of the busses with quick disconnect plugs and interlocks arranged for handling with manipulators from behind appropriate shielding. Cars carrying the shielding and manipulators will travel on tracks over the magnets.

15.3 Floor Plan

The floor plan arrangement (see Figure 11) has a minimum aisle width of 36". The power supplies will be laid out so that all of the major components of each unit can be replaced without shifting the power supply out of position. See also Figure 12.

The height of the power supplies will be kept to a maximum of seven feet or seven feet six. The power supplies will have a depth of 30 inches and will be 7 or 8 feet long as required. The power supplies will be designed for movement with an air pad. The air pad should provide an easy way to move the 30 inch wide power supplies down a 36" wide aisle.

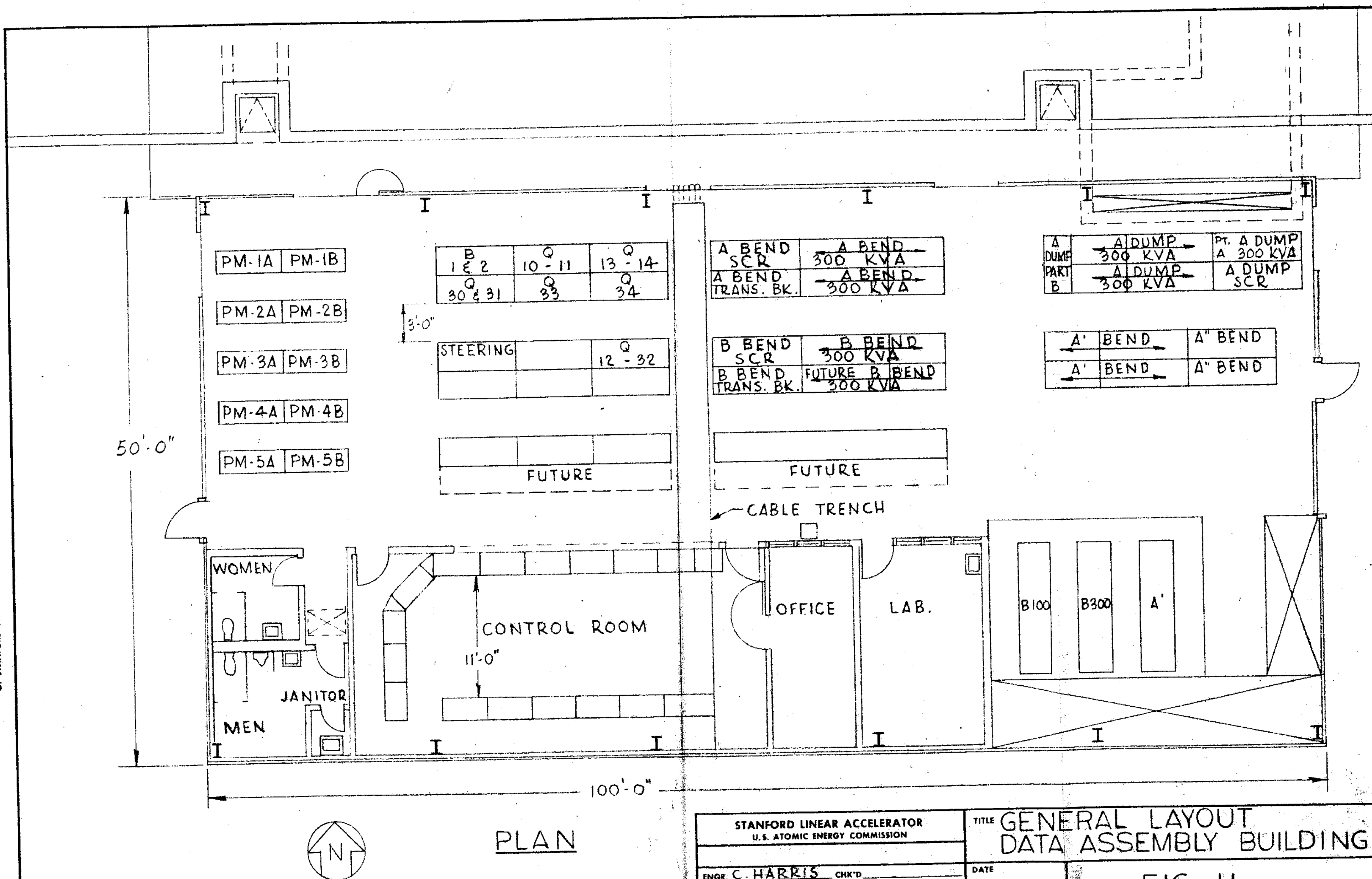
We will group equipment of a given beam line up and identify them adequately in order to minimize errors when manually operating the reversing switches.

The reference magnets will also be movable with air pads so they can be shifted to a position covered by a portable crane.

I believe that there is room in the present building for the power supplies associated with the A' beam and for those that may be used in the gamma beam.

All of the available space in the building will be used up when the A' beam, gamma beam and the B beam pulser supplies have been added.

One of the features of an overhead power distribution system as planned for this building is the possibility of re-arrangement of the power supplies without considerations for a network of trenches or in floor conduits. We will modify the floor plan as we develop the final power supply systems, and thus should end up with the best for our case.



PLAN

STANFORD LINEAR ACCELERATOR
U.S. ATOMIC ENERGY COMMISSION

TITLE GENERAL LAYOUT DATA ASSEMBLY BUILDING

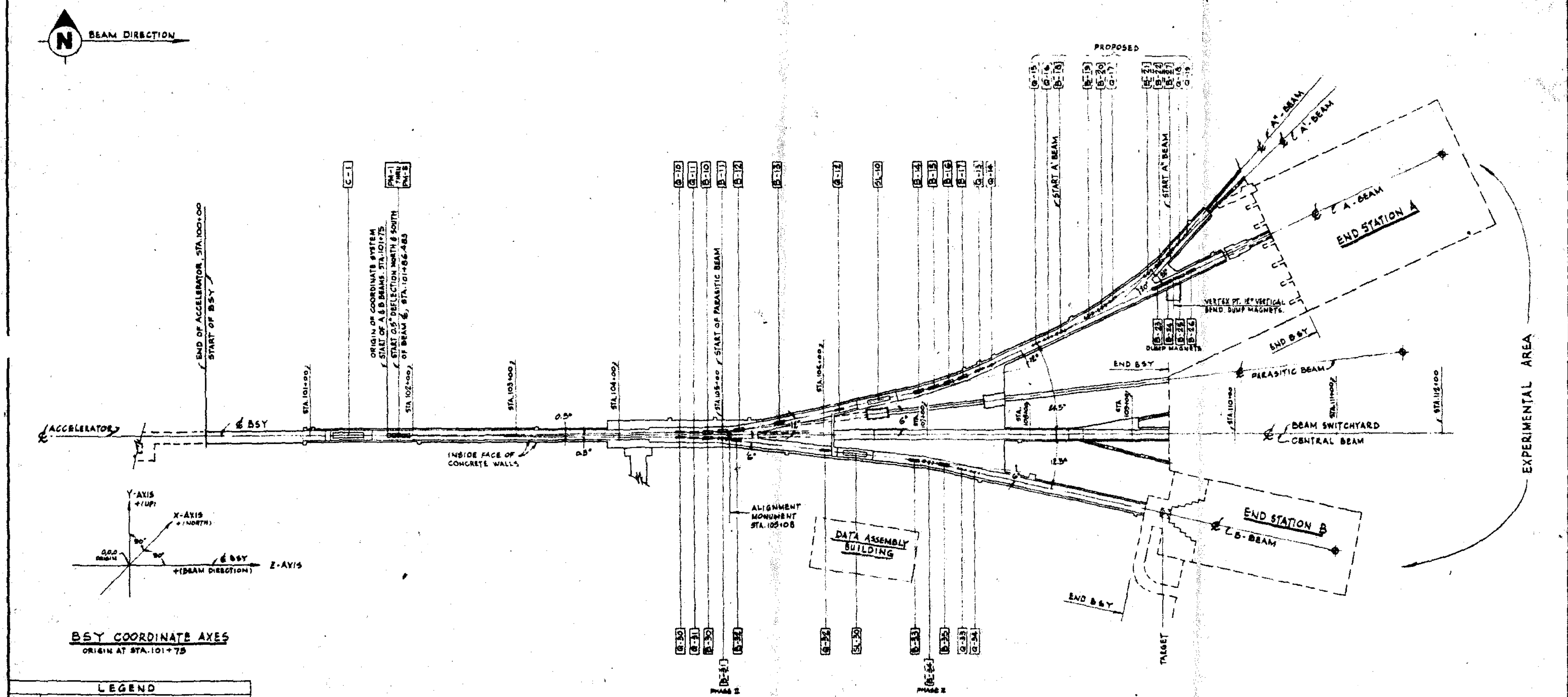
ENGR. C. HARRIS CHK'D

DFTS. M. WALLACE APPV'D

DATE

SCALE 1/8" = 1'-0"

FIG. 11



BSY COORDINATE AXES
ORIGIN AT STA.101+75

PLAN
SCALE - 1" = 40'-0"

LEGEND	
SYMBOL	DESCRIPTION
B	D.C. BENDING MAGNET
BSY	BEAM SWITCHYARD
C	COLLIMATOR
PM	PULSE MAGNET
Q	QUADRUPOLE
SL	ENERGY DEFINING SLIT
⊕	GRAVITY VECTOR

NOTES

1. PHASE II IS THE PROPOSED SECOND STAGE DEVELOPMENT OF B-BEAM

STANFORD LINEAR ACCELERATOR CENTER
U.S. ATOMIC ENERGY COMMISSION
STANFORD UNIVERSITY STANFORD, CALIFORNIA

J. ANTON
D. JEONG

BEAM TRANSPORT SYSTEMS
BEAM SWITCHYARD

FIG 12

TR 863 - 248 R0

15.5 Water Cooling

All of the power supplies will have water lines running to them. The present plans call for these lines to run overhead and drop down to each unit. I presume that most of the water lines will originate at the west end of the building and be brought out the length of the building to each unit. In most cases a common supply and return line could feed water to several power supplies. Each of the power supplies should have its individual supply and return line; none of the power supplies are to have the water lines in series.

16.0 SUMMARY

What has been presented here in brief are the general considerations being given to the D-C Power System for the BSY.

An attempt has been made to minimize the number of styles of power supplies to be ordered. I believe that I have found logical standard blocks that puts us in a good position regarding emergency repairs in case of a serious failure during operations. The building plan is compact, but the final system should be easy to service and modify as future plans may dictate.

Appendix A, B, C and D are preliminary specifications for the various major power supplies.

The present plan calls for the purchase of the following units:

a) Five 84.5 KW SCR controlled rectifiers. Part of Figure 2,4 and 9. Appendix A. "A" and "B" beam and Dump and Q-33 and Q-34

b) Five of 60 KW SCR regulated dual 30 KW output power supplies Figure 7.
Appendix B. Slightly modified for the field lenses.

c) Six basic 258 KW units with dual output of 129 KW each.
   Appendix C.

d) Two 48 KW transistor regulators.
   Part of Figures 2 and 4, "A" beam and "B" beam.
   Appendix D.

Appendix F shows the tentative time schedule for the procurement of the various power supplies.

Appendix G gives some of the reasons why I prefer static rectifiers over rotating motor generator sets.

1. H. Brechna - TN-64-44- "Magnet for the Beam Switchyard"

2. H.R.Ross - "Summary of Major Water Cooling Loads, D-C Power Requirements and Equipment Weights for the Beam Switchyard" November 20, 1963

3. J.K.Cobb, D.R.Jensen, J.J.Murra - TN-63-100 - "Magnetic Measurements and Calibration of Magnetic Measuring Devices" December 1963

4. D.A.G.Neet - TN-63-21- "A Beam Energy Spectrum Analyser for the Two-Mile Accelerator"

5. National Bureau of Standards - Report 6795, TK 7870 N28, "Facilities and Services of the Electronic Calibration Center" August 18, 1961

6. A.A.Windsor - IEEE CP-63-249 - "A D-C Transformer with Low Noise and High Frequency Response"

STANFORD UNIVERSITY

STANFORD LINEAR ACCELERATOR CENTER

TECHNICAL SPECIFICATION PS-900-503-RI

FOR

84.5 KW SILICON-CONTROLLED RECTIFIER REGULATED POWER SUPPLY FOR ELECTRO-MAGNETS

Research Division
Stanford Linear Accelerator Center

Issue Date: June 26, 1964

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84.5 KW SILICON-CONTROLLED RECTIFIER

REGULATED POWER SUPPLY FOR ELECTRO-MAGNETS

PS-900-503-R1

TECHNICAL SPECIFICATION

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TECHNICAL SPECIFICATION FOR A 84.5 KW POWER SUPPLY FOR ELECTRO-MAGNETS

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1.0 SCOPE

1.1 This document specifies minimum requirements for the design and manufacture of a 84.5 KW 80/105 DC Volt current regulated power supply to be used to energize electro-magnets having different L/R time constants and different resistances.

1.2 The current regulated power supply shall be a complete unit with all necessary components wired and ready for operation as herein specified.

1.3 Reliability of operation shall be considered of prime importance in the design and manufacture of the equipment. All practical means shall be employed to assure quality and maximum realiability consistent with state of the art.

2.0 APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids shall form a part of this specification to the extent specified herein. If a listed document, other than those published by the University, is superseded, the Subcontractor shall bring the matter to the attention of the University without delay.

2.1.1 University Documents

SLAC QC-034-100-01-R3 - Quality Control Workmanship Standard

2.1.2 Other Documents

a. MIL-STD-16C - Electrical and Electronic Reference Designations
b. Federal Communications Commission Rules and Regulations, part 18
c. NEMA Standard IC-1-2.68 Enclosures - Non-ventilated Types
d. NEMA Standard IC-1-2.69 Enclosures - Ventilated Types

2.2 The Subcontractor shall bring to the attention of the University any conflict which should occur between this document and those listed in paragraph 2.1 and 3.1 before starting production of the equipment. The University will decide which document has precedence.

3.0 REQUIREMENTS

3.1 General

3.1.1 Specifications and Standards - Subcontractor specifications and standards used during manufacturing shall be compatible with documents listed under paragraph 2.1 and National Electric Codes (wiring and grounding), AWS (welding) ASTM (materials) ASA (screw threads).

3.1.2 Component Ratings - All components within the power supply shall be used within the components manufacturer's recommended ratings for high reliability during a 10 year expected life. All components shall be adequately protected against overloads of transient voltage or current. (See 3.6 for reliability)

3.1.3 Identification and Marking - Equipment, assemblies and parts shall be marked for identification. Subcontractor shall attach a nameplate to major assemblies with the following data:

a. Part name (84.5 KW SCR Regulated Power Supply for Electro-Magnets)
b. Manufacturer's part number
c. Manufacturer's name or trademark
d. Manufacturer's serial number
e. SLAC specification number PS-900-503-R1
f. Weight of assembled power supply
g. Year of manufacture
h. Input power requirements
i. Power supply output ratings

3.1.4 Parts Reference Designations - Parts reference designations and chassis markings shall comply to numbering method specified in MIL-STD-16C. Marking process shall be in accordance with SLAC QC-034-100-01.

3.2 Performance

Unit shall meet the following performance characteristics:

3.2.1 Output Voltage Range: 0 to $\pm$ 80 Volts or 0 to $\pm$ 105 Volts (Taps or reconnection of the transformer windings shall be used to obtain the choice of voltage ratings. A reversing switch, manually controlled shall provide the choice of the polarity of the output.)

3.2.1 (continued)

Regulation Accuracy:

100 Amps to full current rating:	± 0.1%
20 Amps to 100 Amps current range:	± 100 Milliamps

3.2.2 The range of characteristics for the electro-magnet that will be used as a load at the University are as follows:

a. Resistance:	0.05 to 0.2 Ohms
b. Load time constant:	0.2 second to 2 seconds for frequencies less than 1.0 cps

c. The pole tips are not laminated (See 3.2.5)

3.2.3 The current regulation system shall maintain a set DC average load current constant to the specified regulation accuracy (sec. 3.2.1). A selector switch and/or potentiometer may be used to adjust the feedback compensation for different loads. This specified regulation shall apply to any combination of the following conditions after an initial 2 hour warm-up period of the regulator amplifiers and reference circuits; the warm-up time does not apply to the main DC power circuits.

a. Step line voltage change:	± 2-1/2% (maximum)
b. Slowly varying (3 seconds) between successive maximum and minimum input AC voltage:	± 5% (437 to 483 Volts AC)
c. Slowly varying load resistance:	16% due to heating or cooling of the electromagnet, 1% per minute (maximum)
d. Ambient temperature:	Range of 15°C to 45°C (5° per hour max.
e. Input cooling water temperature:	Range of 10°C to 40°C (10° per hour ma
f. Output voltage range:	Controlled 0 to ± 80 Volts or 0 to ± 105 Volts. Regulated voltage range 5% to 90% of maximum voltage.

g. For any step voltage changes introduced by any internal equipment of the power supply.

3.2.3 (continued)

h. Resolution: The current control shall be sensitive enough to set the regulated current to within 100 milliamps.

i. Shunt (or other device) used for regulation shall have a stability consistent with 3.2.1.

3.2.4 The power supply output shall be able to withstand accidental short circuits or shorts to ground at any output voltage without damage to the regulation system, power rectifiers or other components. The main circuit breaker may trip, the AC or DC overloads may trip off the main power contactor, but fuses shall not blow under these conditions.

3.2.5 Current Ripple - The variations in current fed to an electromagnet as specified in 3.2.2 shall not exceed the following peak to peak values:

Frequency	Maximum Variation, Percent of Set Value
0 to 30 cps	±0.05%
30 cps and higher	±0.1%

NOTE: The 360 cps current ripple in the magnet will be about 10 times higher for this unlaminated magnet core than would be calculated on the basis on a laminated core structure and the magnet time constants in 3.2.2.b.

3.2.6 Application

The regulated power supply described in these specifications will be used in several different modes of operation. The load time constants in each of the following cases will be per 3.2.2.b. (See 3.2.5 also)

a. It will be used by itself feeding regulated power to a single load at a maximum of 80 Volts, 805 Amps. It must have a dynamic range sufficient to take care of ± 2-1/2% step voltage, ±5% slow voltage change and 16% load resistance change.

b. It will be used in series with other induction voltage regulator (IVR), or variac type controlled power supplies supplying a total power of 610 Volts at 1,100 Amps. In this mode it will act as the fast section of a slow and fast loop regulation system. It must have a dynamic range sufficient to correct for the ±2-1/2% step of the total voltage or ±15 Volts.

3.2.6 b. (Continued)

In this mode the power supply will be phased back to about 40 volts output. The IVR slow loop system will correct for the wide range variations. Overall regulation required is $\pm 0.1\%$.

c. It will be used in series with other induction voltage regulator or variac type controlled power supplies supplying a total power of 701 Volts and 805 Amps. In this mode it will act as a medium response-time loop of a 3 loop regulation system. The other loops will be the slow induction voltage regulator control and a fast series transistor system. The higher frequency response available with the series transistor bank is required for an ultimate regulation of $\pm 0.005\%$.

3.3 <u>Electrical Design</u>

The power supply shall meet the following requirements: See Figure 1.

3.3.1 <u>AC Power</u>

a. Input AC Power: 460 Volts $\pm 5\%$, 60 CPS, 3 phase, one percent unbalanced line to line for either 3-wire grounded wye or an ungrounded system. The imput voltage will randomly vary over the range indicated; transformer taps are not to be used to compensate for this variation.

b. Circuit Breaker CB1: The breaker shall be capable of interrupting 15,000 Amperes short circuit asymmetrical at 460 Volts. The line side of this breaker may be considered the input of the power supply. Provision shall be made for an easy route for the primary power out the top of the power supply. See Figure 2.

c. A "Kirk-Type" key interlock shall be connected to the main circuit breaker. It shall be impossible to remove the key unless the breaker is in the OFF position. Each power supply shall have a lock with a different combination. Three keys shall be furnished for each power supply.

d. The RMS current rating of the main circuit breaker in paragraph 3.3.1.b shall be less than 125% of the normal full load current of the power supply. The breaker rating shall apply at maximum expected ambient temperatures at the breaker. The in-rush current shall not trip the

3.3.1 (continued)

primary breaker during any turn on cycle. Step start circuits are required. The peak in-rush current during the step start function shall be less than 4 times normal full load current.

e. The power supply shall be designed so that it can be turned off or on at any combination of current or voltage without damage to the components.

f. The layout and design of the power supply shall include provisions to minimize the high frequency (above 1 K.C.) transients generated by the silicon-controlled-rectifiers from being transmitted on the input power lines, the DC output lines, or radiated out through the cabinet. Maximum radiated electrical noise permitted is

g. Rectifier Transformer: Transformer must be double shielded, one shield surrounding the primary winding and one shield surrounding the secondary winding. The primary shield shall be grounded; the secondary shield should be made available and insulated for 600 Volts DC. Provision shall be made to tie this shield to the high side of the grounding resistor of section 3.3.2.d.

h. Power Factor Correction: About 18 KVA of power factor correction with protection circuits shall be added at the input to the power supply. This can also aid in electrical noise suppression. See Figure 1.

i. Over-current protection: AC over-current protection shall not be accomplished with fuses. Protection may consist of thermal or magnetic relays. DC overload shall be easily adjustable by means of a meter indicator control located on the front panel. (Weston Model 1075 or equal)

j. The SCR voltage control system may be located in the AC side of the plate transformer instead of the DC side, providing that all necessary precuations are taken.

k. Wire and busses operating at greater than 300 Volts DC or RMS shall be kept separate from lower voltage circuits. In no case shall they appear on the same terminal strip, or on the same terminal board with lower voltage terminals.

3.3.2 DC Rectifier Circuits

a. The rectifier circuit shall use SCR's, Westinghouse Type 221F or University approved mechanical and electrical equal. Any multiplicity of components, such as diodes, SCR's or transistors shall be designed for easy replacement without breaking any water circuits.

b. A double bridge or half wave circuit that has 720 CPS or higher ripple frequency, shall be used in this controlled rectifier. The higher frequency ripple will permit a smaller filter and consequently a shorter response time through the power supply. (See Section 6.2)

c. Isolation - DC power circuits and connected circuitry of the power supply shall be insulated from ground for 600 Volts so that two or more of the power supplies may be operated in series.

d. Power Supply Grounding - Provisions shall be made to ground either the positive or the negative DC terminal of the power supply through a resistance of 5 Ohms with a knife switch. A ground current detecting system shall be connected to read the current through the 5 Ohms grounding resistor. The ground current detection system shall be adjusted to trip out the power supply on a ground alarm if the AC or DC current in the resistor exceeds 20 Milliamperes. This system should lock out the controls and require a manual reset function before turning on. In case of a ground fault, this circuit must trip out before the ground current resistor or other circuitry is damaged.

e. Reversing Switch - Manually operated reversing switch (not links) shall be connected between DC power source and the output terminals. The switch shall be accessible behind an interlocked door so that it cannot be operated unless the power supply is turned off. Surge protection should be added for the case when the switch is operated with two Amps flowing in the inductive load. The output terminals of the power supply shall be identified "A", "B", "C", and "D" (see section 3.3.3.f Metering). There shall be space available for the addition of a motor drive on this reversing switch.

f. Free wheeling diodes or reverse diodes shall be connected across the power supply output terminals before the reversing switch.

3.3.2 (continued)

The inverse voltage rating of these diodes shall be a minimum of 300 Volts. The diode assembly shall be rated for full load DC current; they may be watercooled.

g. DC Output - Provision shall be made so that the DC output leads may be easily connected and routed out the top of the power supply. The DC leads should be well separated from the 460 Volts AC leads. See Figure 2.

h. Fast-acting fuses (Amp Trap form 101 or University approved equal) shall be used in series with each SCR.

i. The DC short circuit current shall be limited to 16,000 Amps maximum for 50×10^{-3} seconds maximum. This includes peak discharge from any filter capacitances. The main AC contactor shall open by this time.

3.3.3 <u>Control Circuits and Interlocks</u>

a. Control Power: 115 Volts AC control power shall be derived from a step-down transformer connected with fuses to the load side of the input AC circuit breaker. One side of the control power shall be grounded at the control transformer; this point shall be easily accessible. The steady state and surge current in the interlock chain shall be held to less than 3 Amp AC; auxiliary contacts and pilot relays shall be used to control functions drawing more than 3 Amps. See Figure 1.

b. Controls: A panel or panels shall be mounted on the front face of the power supply and shall contain at least the following controls:

DC Power Supply Off/On
DC Output Current Adjustment

c. Wires and busses operating at greater than 300 Volts DC or RMS shall be kept separate from lower voltage circuits. In no case shall they appear on the same terminal strip or terminal board with lower current terminals.

d. The power supply shall have an interlock that requires the SCR firing circuits to be firing for zero voltage output before the power supply can be turned on. This firing circuit start control shall be returned to normal regulation within 250 Milliseconds after the step start function.

e. All critical components in the regulation system such as bias supplies, whose loss could cause regulator or power supply damage shall be interlocked to open the main contactor in case of fault or overload. The interlocks shall be arranged in a series interlock with a neon indicator light for each interlock. Provision shall be made for the insertion of an external interlock. The water interlocks, door interlocks and external interlocks, in that order, shall be last in the chain before the off/on control buttons.

f. Reversing Switch Interlocks: There shall be indicator lights showing the position of the reversing switch, with provisions for remote indication. A provision shall be made that insures that the reversing switch is not partially engaged.

g. The power SCR;s shall be controlled (triggered) through pulse transformers; this provision and the use of a transductor for current monitoring allows the regulation amplifiers and reference voltage to be isolated from the high power DC circuits.

h. A spare 12" high x 12" deep x 19" wide panel space shall be provided for use by the University. This space shall be located above the power supply interlock lights as shown in Figure 2.

i. Two terminal strips TS1 and TS2 shall be provided just below the space in 3.3.3.h. These terminal strips shall be 24 point and 12 point Gen-Pro 440 series terminal strips or equal for remote controlling the power supplies. The control functions shall be wired to the terminal strip as in Figure 1.

3.3.4 Regulation System

a. The regulator, reference voltage and firing circuit generator shall be rack and panel mounted and be available on one of the doors of the power supply. Plug-in printed circuits are preferred for ease of maintenance and replacement.

b. The overall DC loop gain of the regulation system shall be adjustable over a range from 25 to at least 3,000 over the regulated output voltage range of the power supply. (See applications 3.2.6 a and b)

3.3.4 Regulation System (continued)

c. The phase angle firing control circuits and amplifiers for the regulator circuits shall have no less than a zero to 2 KC frequency response. This shall be measured from the DC power supply current measuring device through the amplifiers to the input of a firing circuit similar to that shown in Figure 3. Saturable reactor or magamp firing is not permitted.

d. The phase angle firing control circuits or amplifiers shall contain limiting circuits that will maintain firing signals for zero current or for maximum current output of the power supply depending upon which limit the regulator system is demanding.

e. Reference and Current Monitoring: The precision reference voltage and the voltage from the current monitor used for regulation shall be available on the front panel of the power supply for precision monitoring and calibration. PG1 and PG5 of Figure 1.

f. The current regulated power supply shall have an input plug that allows the insertion of an external voltage into the summing point of the reference voltage and current signal. The regulation system shall use a summing type junction for mixing the reference voltage and the voltage from the current measuring transductor. The reference voltage polarity shall be positive grounded. The regulator amplifiers and reference system shall have a one point ground that is easily accessible to allow checking of the amplifier grounding with a 1,000 Volt megger. This ground point may be lifted when operating in the voltage regulation mode (see 3.3.4g(2)).

g. The current regulated power supply shall have adequate provisions so that when this unit is connected in series with other power supplies it can have its voltage programmed from an external source by any of the following methods:

(1) When acting as a unit in series with one or more external power supplies and a transistor regulator, this power supply shall be able to function in a voltage regulation mode. In the voltage regulation mode the DC output voltage shall track as a function of a command DC voltage inserted in the place of the

3.3.4 (continued)

internal regulator reference voltage. The input DC voltage may have one side grounded or it may be isolated from ground and range from 0 to 20 Volts DC; the 0 to 20 Volts DC input shall force the power supply to cover its full operating range.

The frequence response of the voltage tracking system shall be 10 CPS minimum. The accuracy of tracking shall be ± 2 Volts. output.

(2) Provisions shall be made so that the voltage output of this power supply may be controlled with 2 sets of relay contacts; one for a raise function and a second for a lower function. In this relay control mode the time for 0-100% voltage change may be 45 seconds maximum. The combination of this section and the contacts in section 3.3.4j shall provide a system that can set the output voltage to within ± 1/2 Volts of a desired value over the range of 10% to 90% Voltage; there shall be no hunting or continued oscillation of the relays at the balance point.

h. Two male plugs (PG2 and PG3) shall be located below the space in 3.3.3h. These plugs shall allow a remote potentiometer to be used on the reference voltage for current regulation control. The remote potentiometer may be 75 feet from the power supply. The wiring to the plug shall be as shown in Figure 1.

i. A transductor (Daytron Incorporated current sensor, or a Magnetics Incorporated current sensor, or University approved equal) with a 10 or 20 Volts output shall be used as the current sensing element for the current regulator input.

j. Two sets of relay contacts shall be provided in this power supply to control a motor drive on an external power supply as a function of the voltage output of this power supply. Adjustable voltage sensing circuits are to be provided in this power supply; the range of adjustment of these relays shall be from 10% to 90% of the DC output of this power supply. The DC voltage level control of these relays shall be independent but shall not overlap.

3.3.5 Metering

a. The metering used on this power supply shall be 4-1/2" case (± 2% accuracy) meters similar to the Weston 1900 series, Core type suspension and/or taut-band suspension preferred.

b. Local Metering

(1) Voltmeter 125-0-125 Volts shall be mounted to read the output voltage of the power supply. Meter shall read positive when the negative voltage output of the power supply is grounded and the terminal marked "A" output is positive polarity.

(2) An ammeter to read 0 to 1200 Amps shall be connected to the 100 MV shunt to read current. This meter shall be a contact making meter (Weston Model 1075 or equal) with an adjustable pointer for setting an over-current trip.

(3) Ground current meter 100-0-100 Milliamperes AC or DC. This could be a contact making meter with an adjustable pointer for the ground current alarm. It must be protected for high surge currents as limited by the grounding resistor with 250 Volts applied across it.

c. Current metering remote: There shall be a 100 MV, 1,200 A, 1/4% accuracy switch board shunt provided for local and remote current metering. The shunt output shall be wired through a resistor capacitive filter to the terminal strip above the spare panel of 3.3.3.h. See Figure 1 for wiring.

3.3.6 Miscellaneous Provisions

a. Ripple Voltage Detector: There shall be a circuit connected to the circuits of the power supply that will open a set of contacts if the peak to peak voltage ripple exceeds 2% of the set power supply voltage for a period which is adjustable from 10 seconds to 60 seconds. This circuit shall function from 5% to full voltage output.

b. Large filter capacitors shall have a discharge circuit connected to their terminals. The time constant of the discharge system sould be less than 15 seconds.

3.3.6 (continued)

c. Component Mounting: Any multiplicity of components such as diodes and transistors shall be designed for easy replacement and without breaking any water circuit.

3.3.7 Fire Hazard: Design of equipment shall be such that assemblies and components therein shall not create a fire hazard during either service usage or storage. Materials such as the following should be used whenever possible:

a. Track resistant "glastic".
b. Grade FR canvass bakelite (Spaulding C-832 or equal)
c. NEMA grades FR-1 and FR-2 paper phenolic
d. NEMA grade FR-3 paper epoxy
e. NEMA grade FR-4 and FR-5 glass epoxy
f. Vinyl chloride acetate or Plexiglass 5009B

3.4 Mechanical Design: The power supply shall meet the following requirements:

a. Cabinet Construction: Power supply shall be enclosed in a metal cabinet designed for floor mounting and free standing. Mechanical construction shall consist of an angle iron basic frame which shall sit upon "I" beam skids. The cabinet shall be equipped for fork lift handling of the complete unit, including weight of any coolant. These power supplies will be moved into place on special air-pad moving dollies. Figure 2 shows how the cabinet must be designed to accommodate these dollies.

b. The cabinet shall be "drip tight", "ventilated" as defined in NEMA standards, Section IC 1-2.68 and IC 1-2.69. Hinged panels or doors shall be provided for those areas requiring service access. Large panels which are fastened with bolts or screws shall have alignment studs to make easy replacement possible; a minimum number of fasteners shall be used. Quick operating fasteners are preferred. Light weight metals are preferred for large panels.

c. Cabling to components on hinged panels or doors shall be done by making long twisted loops in the cable along the hinge, so that repeated opening of doors shall not damage wires or insulation.

3.4 (continued)

Stranded wire shall be used in such cables.

d. Resistors of 50 Watt size or larger shall be mounted with machine screws and supported. Solder shall not be used in making connection to these resistors.

e. No bolted or screwed electrical connection shall depend upon an insulating material (ceramic, phenolic or other) to maintain contact pressure.

f. Lugs for large size conductors (No. 8 AWG and larger) shall be both crimped and soldered.

g. Figure 2 shows an approximate layout of the power supply. This rough layout is to be followed unless a specific deviation has been granted by the University. Note maximum dimensions.

h. The cabinet and layout of parts shall be so designed that all major or minor parts can be replaced from the front of the power supply without access to the rear of ends of the power supply.

i. When the local line circuit breaker is turned off there shall be no voltages exposed in the cabinet. The line terminals of the circuit breaker shall be covered.

j. When the main circuit breaker is turned on and the normal access doors are open, there shall be no exposed voltages greater than 300 Volts DC or RMS. The main control contactors shall be in separate enclosures.

k. When the power supply doors and panels are in place, there shall be no holes in the cabinet large enough to permit a small mouse to enter.

3.4.1 Ventilation and Water Cooling

a. Ventilation and cooling shall be designed for indoor units with an ambient air temperature range of 15°C to 45°C. Forced air cooling of components is acceptable provided filtering is used on the intake air. The filters shall be located such that they may easily be removed for cleaning. Filters shall be dry-type. Air-flow interlocks shall be provided wherever forced air cooling is used.

3.4.1 (continued)

b. De-mineralized water with a minimum resistivity of 10^5 Ohms cm will be supplied from the University water system for cooling. The supply line water temperature will vary from 10°C to 40°C. Normal supply pressure may vary from 80 PSI to 100 PSI gauge. The return line pressure may be as high as 20 PSI. Design for 150 PSI piping and a 225 PSI gauge hydrostatic test. The power supply should be designed for less than 50 PSI drop through the power supply.

c. The entire water system shall be constructed of copper, brass, bronze or 18-8 stainless, (No. 316 or No. 304), except that insulating connections shall be made with Weatherhead H9 rubber hose or equal. No plastic tubing allowed. Hose bibbs or fittings subject to corrosion or electrolysis shall be made of No. 304 stainless.

d. Layout of the water system, particularly insulating hose connections, should be designed (if possible) so as to avoid spraying electrical components in the case of a water leak.

e. An all-bronze Y strainer with No. 10 mesh brass or monel strainer, Bailey No. 100 with 3/64 inch perforations or equal, shall be used in the supply line. This is to be located and adequately supported such that it can be readily accessible and cleaned without dripping water on components.

f. A Hayes Shureflow water flow interlock or equal shall be connected with unions in the return line of each parallel water path. They shall be located within the outline of the cabinet such that they are readily available for servicing or checking through a door without removing any panels, or dripping water on components. Flow switches in combination with temperature alarms may be used to protect several parallel paths.

g. When short hoses are used to make insulated water jumpers, no hose shall be less than 6 inches long and they shall be looped for easy replacement. The hose, when dry, shall measure greater than 100 Megohms per inch when checked at a voltage gradient of 500 Volts per inch.

3.4.2 Noise Level: The audible noise level 6 feet from the cabinet shall be less than 72 DB above 0.0002 dynes per sq. centimeter. The ambient noise level at the time of measurement shall not be above 62 DB.

3.5 Environmental Conditions: Unit shall operate under the following conditions:

3.5.1 Temperature: Equipment shall operate within the requirements specified herein over an ambient temperature range of 15°C to 45°C.

3.5.2 Humidity: Without degradation of performance, the equipment shall withstand relative humidities up to 80% including the effects of condensation due to temperature change.

3.5.3 Shock and Vibration: Without degradation of performance the equipment shall withstand normal shocks and vibrations during shipment and handling.

3.6 Reliability: Operating life (design objective shall be 87,000 hours (ten years) of continuous duty. Choice and rating of components shall be consistent with high reliability. The University reserves the right to approve all schematics, circuit diagrams and parts layouts before and during construction. This review of prints by the University does not remove the responsibility for the design from the Subcontractor.

4.0 TEST PROVISIONS

4.1 Standards and Calibration: All subcontractor measuring and control equipment used during testing shall bear evidence stating the last date of calibration, next calibration date, and the laboratory that performed the calibration. Calibrating laboratory must be able to furnish certified records upon request stating that their standards are traceable to the National Bureau of Standards. Certification is not required for equipment standards not yet established by the National Bureau of Standards.

4.2 Procedure and Conditions: Test equipment and the procedures required for testing shall be approved prior to initiation of the test program.

4.2.1 Test procedures shall contain, as a minimum, the following:

a. List of test equipment intended for use.

b. Detailed sequence of performance tests based on Section 3.0 including sequence of steps for each test to be performed.

c. Laboratory conditions that will prevail during testing.

d. Accumulative operating time check.

e. Provisions for inspection.

4.2.2 Test Conditions: Tests shall be performed under the humidity that prevails at the test location provided the relative humidity is not in excess of 90%. The power supply shall be completed unit with all panels in place for the following sequence of tests.

4.2.3 Tests: Equipment testing shall be in accordance with University approved test plan and subcontractor shall demonstrate in his shop with either simulated or actual loads that the power supply will perform as herein specified. The tests to be performed shall include the following:

a. Each power supply shall be tested separately.

b. The power supply shall have a resistance greater than 250,000 Ohms at 500 Volts DC with the grounding knife switch open and water flowing in the cooling circuits, measured from power supply terminals to ground.

c. At least one power supply of the group shall be run at full power to demonstrate that the power supply will function at the maximum temperatures as specified in 3.2.3. This test is to run until the temperatures within the power supply levels off but in no case for less than 4 hours; this test may take 8 to 12 hours. Component temperatures shall at no time during the test be greater than those recommended by the component manufacturer. All other power supplies shall be run at full power for at least 2 hours.

d. The complete water system shall be subjected to a static hydraulic test of 250 PSI gauge for one minute; no leaks shall be apparent.

e. Regulation stability shall be checked during 4.2.3.c.

f. The regulation tests and heat run at the factory may be made using a resistive load. The peak to peak current ripple into the resistive load shall be less than $\pm$ 0.5%. It is preferred to make the tests with a magnet as a load.

4.2.3 (continued)

g. The load resistance shall be varied to show that the power supply meets the requirement of 3.2.3.

h. The line voltage shall be monitored during the tests to check the stability of the power supply with respect to line voltage steps. The line voltage steps may have to be artifically generated to demonstrate the adequacy of the regulation system if the AC power system used to supply power for the tests does not show 2-1/2% line voltage steps.

i. The power supply terminals shall be shorted while the power supply is operating at full power. This test is to demonstrate the adequacy of the overload protection system. Repeat this short circuit test as required.

j. The ungrounded lead of the power supply shall be shorted to ground while the power supply is operating at full power. This test is to demonstrate the adequacy of the ground protection interlocks. Repeat test as required.

k. DC circuits of the power supply shall withstand 2500 Volts DC for one minute without damage.

l. At the conclusion of the test programs there shall be no evidence of water leakage or other evidence that could lead to an early power supply failure or shortening of expected life.

m. The University inspector has the option to require any tests to be repeated if deficiencies during a test have had to be corrected.

4.3 <u>Test Records</u>: All subcontractor test records shall show the following data:

a. Pertinent test data.

b. Equipment used.

c. Test procedures used and conditions.

d. Block diagrams of all test setups used.

e. Irregularities observed during testing.

f. Recorded total elapsed time of each test and increments between each sequential test step.

5.0 PREPARATION FOR DELIVERY

5.1 Preservation and Packaging: All equipment shall be adequately protected against damage during shipping by common carrier.

5.2 Marking for Shipment: All exterior shipping containers shall be adequately and properly marked for identification. All packages shall include the following minimum markings:

a. Addressee

b. Shipper

c. University purchase order number and/or subcontract number

d. Special markings, warnings, or tags in accordance with ICC Regulations.

6.0 NOTES

6.1 Three instruction books with appropriate schematic diagrams and parts lists of all electrical components or sub-assemblies shall be furnished at the time of delivery of the power supply.

6.2 Consideration shall be given to a single bridge or half wave circuits that give 360 CPS or higher ripple frequency. A cost comparison should be given for the case of 360 CPS and 720 CPS frequency ripple. The final specification will specify which ripple frequency to design for in Section 3.3.2b.

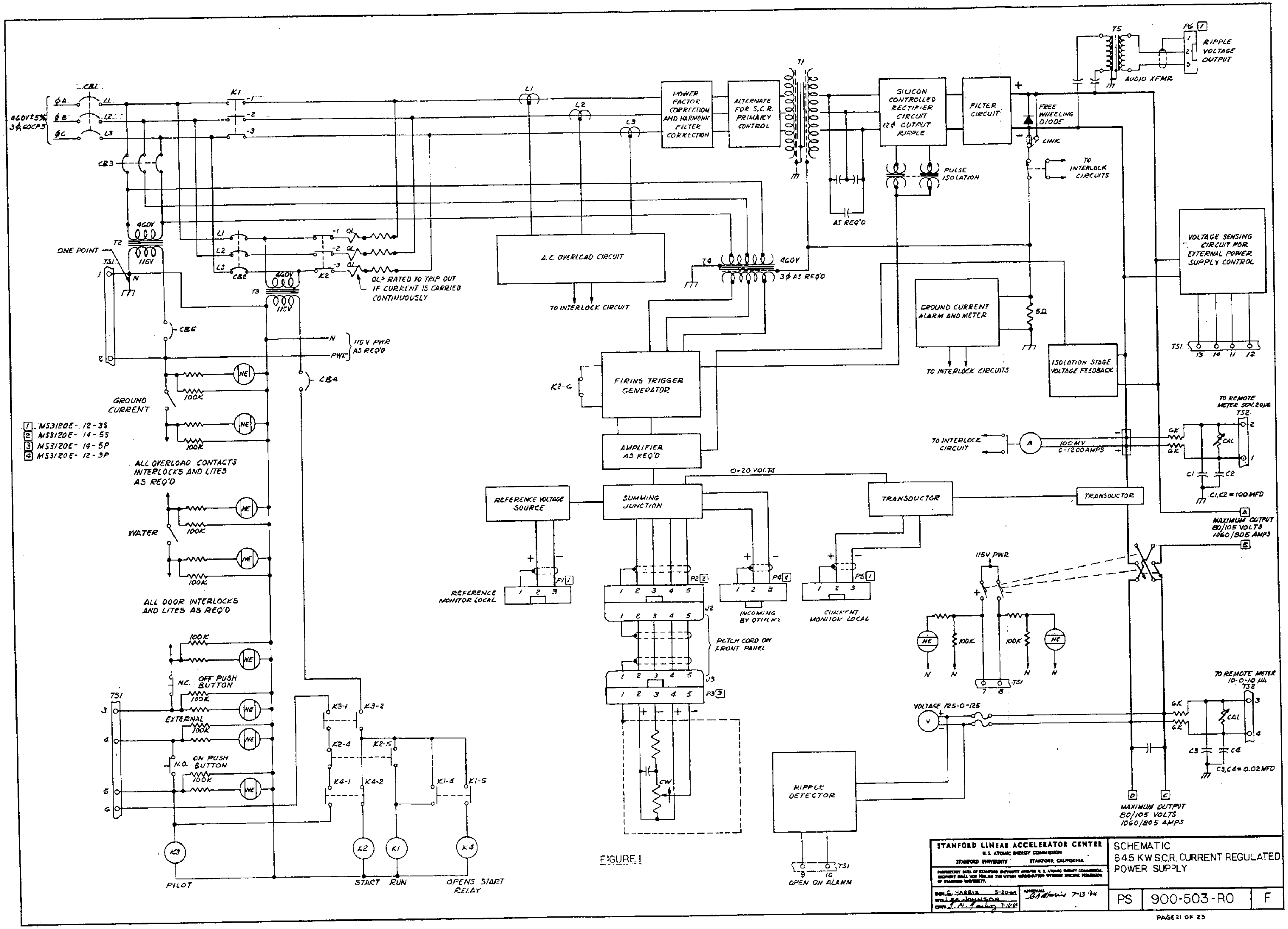

460V±5% 3φ, 60CPS
φA
φB
φC
CB1
L1
L2
L3
K1
CB3
460V
T2
115V
ONE POINT
TS1
N
L1
L2
L3
CB2
460V
T3
115V
K2
OL
OL'S RATED TO TRIP OUT IF CURRENT IS CARRIED CONTINUOUSLY
CB5
N
PWR
115V PWR AS REQ'D
CB4
GROUND CURRENT
100K
NE
1 MS3120E- 12-3S
2 MS3120E- 14-5S
3 MS3120E- 14-5P
4 MS3120E- 12-3P
ALL OVERLOAD CONTACTS INTERLOCKS AND LITES AS REQ'D
WATER
ALL DOOR INTERLOCKS AND LITES AS REQ'D
N.C. OFF PUSH BUTTON
EXTERNAL
N.O. ON PUSH BUTTON
K3-1
K3-2
K2-4
K2-5
K4-1
K4-2
K1-4
K1-5
K3
PILOT
K2
START
K1
RUN
K4
OPENS START RELAY
L1
L2
L3
POWER FACTOR CORRECTION AND HARMONIC FILTER CORRECTION
ALTERNATE FOR S.C.R. PRIMARY CONTROL
T1
SILICON CONTROLLED RECTIFIER CIRCUIT 12φ OUTPUT RIPPLE
FILTER CIRCUIT
FREE WHEELING DIODE
LINK
TO INTERLOCK CIRCUITS
PULSE ISOLATION
AS REQ'D
T5
AUDIO XFMR
P6 1
RIPPLE VOLTAGE OUTPUT
A.C. OVERLOAD CIRCUIT
TO INTERLOCK CIRCUIT
T4
460V
3φ AS REQ'D
GROUND CURRENT ALARM AND METER
5Ω
TO INTERLOCK CIRCUITS
VOLTAGE SENSING CIRCUIT FOR EXTERNAL POWER SUPPLY CONTROL
TS1 13 14 11 12
ISOLATION STAGE VOLTAGE FEEDBACK
K2-6
FIRING TRIGGER GENERATOR
AMPLIFIER AS REQ'D
TO INTERLOCK CIRCUIT
A
100MV 0-1200 AMPS
TO REMOTE METER 50V, 20μA
TS2
6K
CAL
C1
C2
C1,C2 = 100MFD
0-20 VOLTS
REFERENCE VOLTAGE SOURCE
SUMMING JUNCTION
TRANSDUCTOR
TRANSDUCTOR
A
MAXIMUM OUTPUT 80/105 VOLTS 1060/805 AMPS
B
P1 1
REFERENCE MONITOR LOCAL
P2 2
J2
P4 4
INCOMING BY OTHERS
P5 1
CURRENT MONITOR LOCAL
115V PWR
PATCH CORD ON FRONT PANEL
J3
P3 3
CW
TS1
7 8
VOLTAGE 125-0-125
V
TO REMOTE METER 10-0-10 μA
TS2
C3
C4
C3,C4 = 0.02MFD
RIPPLE DETECTOR
TS1
9 10
OPEN ON ALARM
D
C
MAXIMUM OUTPUT 80/105 VOLTS 1060/805 AMPS
STANFORD LINEAR ACCELERATOR CENTER
U.S. ATOMIC ENERGY COMMISSION
STANFORD UNIVERSITY STANFORD, CALIFORNIA
C. HARRIS 5-20-64
SCHEMATIC
84.5 KW S.C.R. CURRENT REGULATED POWER SUPPLY
PS
900-503-R0
F

FIGURE 1

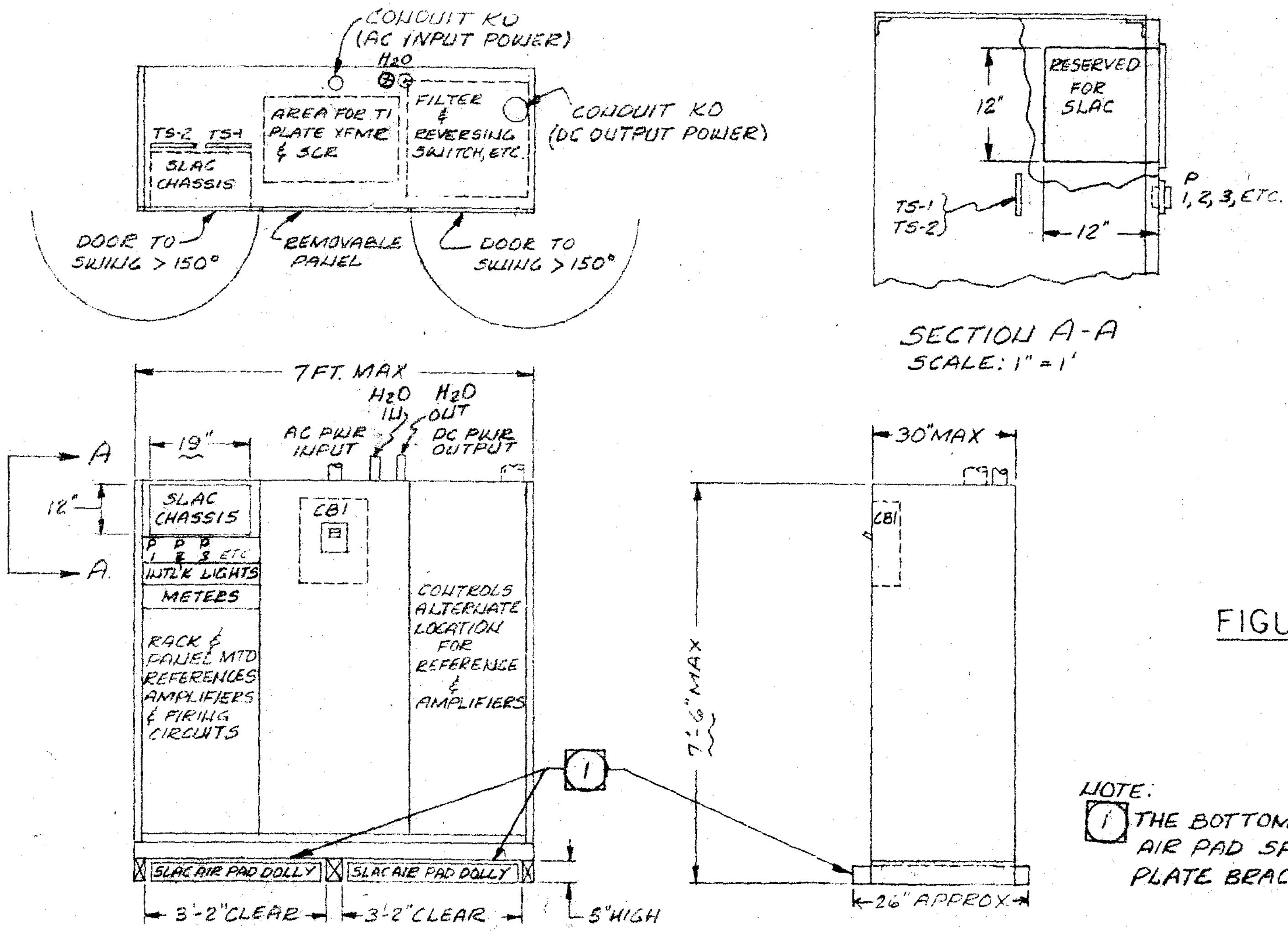
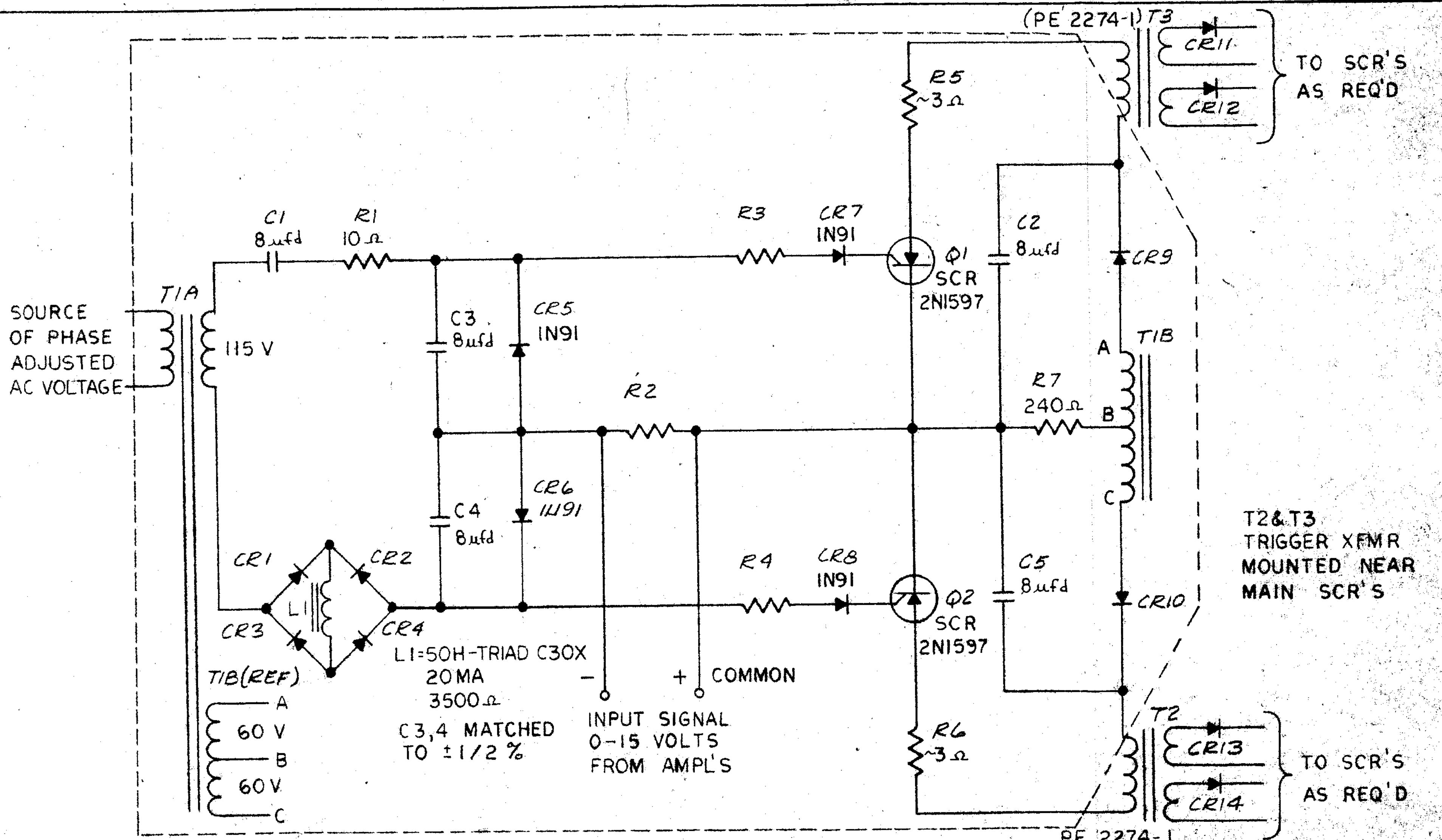


FIGURE 2

NOTE:
(1) THE BOTTOM OF THE CABINET OVER THE AIR PAD SPACE SHALL BE A SMOOTH PLATE BRACED TO TAKE UNIFORM LOADING.

STANFORD LINEAR ACCELERATOR U. S. ATOMIC ENERGY COMMISSION	TITLE CURRENT REGULATED POWER SUPPLY 84.5KW SCR
ENGR. C. HARRIS CHK'D [signature] DFTS. D. SPANOS APPV'D [signature]	DATE 5-15-64 SCALE 1/2" = 1' — PS-900-503-R0 B



NOTE: THIS CIRCUIT IS USED AT LAWRENCE RADIATION LABORATORY

FIGURE 3

STANFORD LINEAR ACCELERATOR U.S. ATOMIC ENERGY COMMISSION	TITLE TYPICAL SCR PHASE CONTROLLED FIRING CIRCUIT	
ENGR. C. HARRIS CHK'D [signature] DFTS G. BASHORE APPV'D [signature]	DATE MAY 15, 1964 SCALE NONE	PS-900-503-RO B

STANFORD UNIVERSITY

STANFORD LINEAR ACCELERATOR CENTER

TECHNICAL SPECIFICATION PS-900-505-RO

FOR

60 KW SILICON-CONTROLLED RECTIFIER
(DUAL 30 KW)
REGULATED POWER SUPPLY FOR ELECTRO-MAGNETS

Research Division
Stanford Linear Accelerator Center

Issue Date: June 26, 1964

B

60 KW SILICON-CONTROLLED RECTIFIER

(DUAL 30 KW)

REGULATED POWER SUPPLY FOR ELECTRO-MAGNETS

PS-900-505-RO

Technical Specification

Submitted C A Harris ________ Heavy Electronics

Reviewed E J Brown ________ Systems Engineering

[redacted]ed ________ Research Division

Research Division
Stanford Linear Accelerator Center
Stanford University
Stanford, California

June 26, 1964

TECHNICAL SPECIFICATION
FOR A
60 KW SILICON-CONTROLLED RECTIFIER POWER SUPPLY FOR ELECTRO-MAGNETS

1.0 SCOPE

1.1 This document specifies minimum requirements for the design and manufacture of a current regulated power supply with two independent outputs of 30 KW each. These power supplies will be used to energize magnets having different L/R time constants and different resistances.

1.2 The current regulated power supply shall be a complete unit with all necessary components wired and ready for operation as herein specified.

1.3 Reliability of operation shall be considered of prime importance in the design and manufacture of the equipment. All practical means shall be employed to assure quality and maximum reliability consistent with state of the art.

2.0 APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids shall form a part of this specification to the extent specified herein. If a listed document, other than those published by the University, is superseded, the Subcontractor shall bring the matter to the attention of the University without delay.

2.1.1 University Documents

SLAC QC-034-100-01-R3 Quality Control Workmanship Standard

2.1.2 Other Documents

a. MIL-STD-16C Electrical and Electronic Reference Designations

b. Federal Communications Commission Rules and Regulations, Part 18

c. NEMA Standard IC 1-2.68 Enclosures - Non-ventilated Types

d. NEMA Standard IC 1-2.69 Enclosures - Ventilated Types

2.2 The Subcontractor shall bring to the attention of the University any conflict which should occur between this document and those listed in paragraph 2.1 and 3.1 before starting production of the equipment. The University will decide which document has precedence.

3.0 REQUIREMENTS

3.1 <u>General</u>

3.1.1 Specifications and Standards: Subcontractor specifications and standards used during manufacturing shall be compatible with documents listed under paragraph 2.1 and National Electric Codes (wiring and grounding), AWS (welding), ASTM (materials) and ASA (screw threads).

3.1.2 Component Ratings: All components within the power supply shall be used within the component manufacturer's recommended ratings for a 10 year expected life. All components shall be adequately protected against overloads of transient voltage or current. (See paragraph 3.6 for reliability.)

3.1.3 Identification and Marking - Equipment, assemblies and parts shall be marked for identification. Subcontractor shall attach a nameplate to major assemblies with the following data:

a. Part name (Dual 30 KW SCR Regulated Power Supply for Electro-Magnets)
b. Manufacturer's part number
c. Manufacturer's name or trademark
d. Manufacturer's serial number
e. SLAC specification number PS-900-505-R0
f. Weight of assembled power supply
g. Year of manufacturer
h. Input power requirements
i. Power supply output ratings

3.1.4 Parts Reference Designations: Parts reference designations and chassis markings shall comply to numbering method specified in MIL-STD-16C. Marking process shall be in accordance with SLAC QC-034-100-01.

3.2 <u>Performance</u>

Unit shall meet the following performance characteristics:

3.2.1 <u>Dual Output Voltage</u>:

Each Section: 0 to ± 55 volts or 0 to ± 85 volts

(Taps or reconnection to the transformer windings shall be used to obtain the choice of voltage ratings. A reversing switch, manually controlled, provides the choice of the polarity of the output voltage.)

<u>Dual Output Current</u>:

Each Section: 0 to ± 550 amps or 0 to ± 350 amps

Regulation accuracy;

each section: 100 Amps to full current: ±0.1%

10 Amps to 100 Amps: ±100 Milliamps.

3.2.2 The range of characteristics for the electro-magnet that will be used as a load at the University are as follows:

a. Resistance — 0.05 to 0.2 Ohms

b. Load time constant — 0.2 second to 2 seconds for frequencies less than 1.0 cps

c. The magnet yoke and tips are not laminated, See 3.2.5

3.2.3 The current regulation system shall maintain a set DC average load current constant to the specified regulation accuracy, (sec. 3.2.1) A selector switch may be used to adjust the feedback compensation for different loads. This specified regulation shall apply to any combination of the following conditions after an initial 2 hour warm-up period of the regulator amplifiers and reference circuits; the warm-up time does not apply to the main DC power circuits.

a. Step line voltage change: — ±2-1/2% (maximum)

b. Slowly varying (3 seconds) between successive maximum and minimum input AC voltage: — ±5%

c. Slowly varying load resistance: — ±16% due to heating or cooling of the electromagnet 1% per minute (maximum)

d. Ambient temperature: — Range of 15°C to 45°C (5° per hr. max.)

e. Input cooling water temperature: — Range of 10°C to 40°C (10° per hr. max.

f. Dual output voltage range, each section (see 3.2.1):

controlled voltage range: — 0 to 55 Volts or 0 to 85 Volts

regulated voltage range: — 5% to 90% of maximum voltage

g. For any step voltage changes introduced by any internal equipment of the power supply

h. Resolution: The current control shall be sensitive enough to set the regulated current to within 100 milliamps

i. Shunt (or other device) used for regulation shall have a stability consistent with 3.2.1.

3.2.4 The power supply output shall be able to withstand accidental short circuits on the output or shorts to ground at any output voltage without damage to the regulation system, power rectifiers or other major components. The main circuit breaker or the AC or DC overload shall trip under these conditions, but fuses shall not blow.

3.2.5 Current Ripple - The variations in current fed to an electromagnet as specified in 3.2.2 shall not exceed the following peak to peak values:

Frequency	Maximum Variation, Percent of Set Value
0 to 30 cps	±0.05%
30 cps and higher	±0.1%

NOTE: The current ripple in the magnet will be about 10 times higher for this unlaminated magnet than would be calculated on the basis of a laminated magnet yoke and the load time constants in 3.2.2.b.

3.2.6 Application:

This power supply will be used to supply power to magnets in one of the following ways:

a. To feed power to independent loads with separate controls.

b. Reconnected so that both sections in series may be used to feed one load with a single control.

3.3 Electrical Design

The electrical design of the power supply shall comply with the following minimum requirements. See Figure 1.

3.3.1 A-C Power

a. Input AC Power: 460 Volts ±5%, 60 cps, 3 phase, one percent unbalanced line to line for either 3-wire grounded wye or an ungrounded system. The input voltage will randomly vary over the voltage range indicated; transformer taps are not to be used to compensate for this variation.

b. Circuit Breaker: Capable of interrupting 15,000 Amperes short circuit asymmetrical at 460 Volts. The line side of this breaker may be considered the input of the power supply. Provision shall be made for an easy route for the primary power out the top of the power supply

c. A "Kirk type" key interlock shall be connected to the main circuit breaker. It shall be impossible to remove the key unless the breaker is turned off. Each power supply will have a lock with a different combination. Three keys shall be furnished for each power supply.

d. The RMS current rating of the main circuit breaker in paragraph 3.3.1b shall be less than 125% of the normal full load current of the power supply. The breaker rating shall apply at maximum expected ambient temperatures at the breaker. The in-rush current shall not trip the breaker during any turn on cycle. Step start circuits in the AC input power system are required; if the SCR's are on the transformer primary the firing circuits shall be used with the step start mode. The peak in-rush current during the step start function shall be held to 4 times the full load current.

e. The power supply shall be designed so that it can be turned on or off at any combination of current or voltage without damage to the components.

f. The layout and design of the power supply shall include provisions to minimize the high frequency (above 1 K.C.) transients generated by the silicon-controlled-rectifiers from being transmitted on the input power lines, the DC output lines, or radiated out through the cabinet.

g. Rectifier Transformer: Transformers must be double shielded, one shield surrounding the primary winding and one shield surrounding the secondary winding. The primary shields shall be grounded; the secondary shields should be made available and insulated for 600 volts DC. Provision shall be made to tie this shield to the high side of the grounding resistor of section 3.3.2.c.

h. Power factor correction: About 16 KVA of power factor correction with protection circuits shall be added at the input to the power supply. This can also aid in electrical noise suppression.

i. Over current protection: AC overcurrent protection shall not be accomplished with fuses. Protection may consist of thermal or magnetic relays. DC overload shall be easily adjustable by means of a meter indicator control located on the front panel.

j. The SCR voltage control system may be located in the AC side of the plate transformer instead of the DC side, providing that all necessary precautions are taken.

k. Wires and busses operating at greater than 300 volts DC or RMS shall be kept separate from lower voltage circuits. In no case shall they appear on the same terminal strip on the same terminal board with lower voltage terminals.

3.3.2 <u>D-C Power</u>

a. Component Mounting: Any multiplicity of components such as diodes and transistors shall be designed for easy replacement and without breaking any water circuit.

b. Reversing Switch: Each section of the power supply shall have a reversing switch, manually controlled. The reversing switch (not links) shall be connected between DC power sources and the output terminals. The switch shall be accessible behind an interlocked door so that it cannot be operated unless the power supply is turned off. Surge protection should be added for the case when the switch is operated with two amps flowing in the inductive load. The output terminals of the power supply shall be identified "A", "B", "C" and "D", (See section 3.3.5, metering, and Figure 1). There shall be space available for the addition of a motor drive on this reversing switch.

c. Power Supply Grounding: Provisions shall be made to ground the negative or the positive DC terminal of each of the power supplies through a resistance of 5 ohms with a knife switch. A ground current detecting system shall be connected to read the current through the 5 ohm grounding resistor; the ground detection system shall be adjusted to trip out the power supply on a ground alarm if the AC or DC current in the resistor exceeds 20 milliamperes. This system should lock out the controls and require a manual reset function before turning on. In case of a ground fault, this circuit must trip out before the ground current resistor or other circuitry is damaged.

3.3.2 (continued)

d. Isolation - DC power circuits and connected circuitry of the power supply shall be insulated from ground for 600 volts so that two or more of the power supplies may be run in series.

e. DC Output - Provision shall be made so that the DC output leads may be easily connected and routed out the top of the power supply. The DC leads should be well separated from the 460 volt AC leads.

f. Free wheeling diodes or reverse diodes shall be connected across the power supply output terminals before the reversing switch. The inverse voltage rating of these diodes shall be a minimum of 300 volts. The diode assembly shall be rated for full load DC current; they may be water cooled.

g. The power supply should be designed so that it can be turned off at any combination of current or voltage without damage to the components.

h. Large filter capacitors shall have a discharge circuit connected to their terminals. The time constant of the discharge system should be less than 15 seconds.

i. Ripple Frequency: A bridge circuit or half wave circuit that gives a ripple frequency of 360 cps or higher shall be used.

j. The SCR voltage control system may be on the AC side of the plate transformers instead of on the DC side providing all necessary precautions are taken.

k. The DC short circuit current shall be limited to 16,000 amperes maximum for 50×10^{-3} seconds maximum. This includes peak discharge from any filter capacitances. The main AC contactor shall open by this time.

3.3.3 <u>Regulation</u>

a. Reference and Current Monitoring: The precision reference voltage and the voltage from the current monitor used for regulation shall be available on the front panel of the power supply for precision monitoring and calibration. (See Figure 1)

b. The current regulated power supply shall have an input plug that allows the insertion of a 0-10 volt signal into the summing point of the reference voltage and current signal.

3.3.3 (continued)

c. The power supply shall have an interlock that requires the SCR firing circuits to be firing for zero voltage output or that they be off before the power supply can be turned on. This firing circuit start control shall be returned to normal regulation within 250 milliseconds after the step start function.

d. A female plug (PG-2 and 7) shall be located below the space in 3.3.6a. This plug and a conveniently located remote local switch shall allow a remote potentiometer to be used on the reference voltage for current regulation control. The remote potentiometer may be 75 feet from the power supply. The wiring to the plug shall be as shown in Figure I. A local potentiometer shall be provided on the power supply.

e. The available DC loop gain of the regulation systems shall be at least 2,000 over the regulated output voltage range of the power supply. Appropriate means shall be provided on the front panel of the power supply for a continuous adjustment of the loop gain over the range of 25 to maximum gain.

f. A transducer (Daytron Incorporated current sensor, Magnetics Incorporated current sensor or University approved equal) with a 10 or 20 volt output shall be used as the current sensing element for the current regulator input.

g. The power SCR's shall be controlled (triggered) through pulse transformers; this provision and the use of a transductor for current monitoring allows the regulation amplifiers and reference voltage to be isolated from the high power DC circuits.

h. The regulator reference voltage and firing circuit generator shall be rack and panel mounted and be available on one of the doors of the power supply. Plug-in printed circuits are preferred for ease of maintenance and replacement.

i. The regulation system shall use a summing type function for mixing the reference voltage and the voltage from the current measuring transductor. The reference voltage polarity shall be positive grounded. The regulator amplifier and reference system shall have a one point ground that is easily accessible to allow checking of the

3.3.3i (continued)

amplifier grounding with a 1,000 volt megger. This ground point may be lifted and grounded elsewhere as required.

j. The phase angle firing control circuits or amplifiers shall contain limiting circuits that will maintain firing signals for zero voltage or maximum voltage output depending upon which limit the regulator system is demanding.

3.4 Controls and Interlocks

a. Controls: A panel or panels shall be mounted on the frong face of the power supply and shall contain at least the following controls:

DC Power Supply Off/ON

DC Output Current Adjustment

b. All critical components in the regulation system, such as bias supplies whose loss could cause regulator or power supply damage, shall be interlocked to open the main contactor in case of a fault or overload. The interlocks shall be arranged in a series interlock with a neon indicator light for each interlock. The water interlocks, door interlocks and external interlocks, in that order, shall be last in the chain before the off-on control buttons.

c. Control Power: The 115 volt AC control power shall be derived from a step-down transformer connected with fuses to the load side of the input AC circuit breaker. One side of the control power shall be grounded at the control transformer; this point shall be accessible. The steady state and surge current in the interlock chain shall be less than three amperes AC.

d. Two terminal strips shall be provided just below the spare space in 3.3.6a. These terminal strips shall be Gen-Pro 440 series, carry the required terminals for remote controlling the power supplies. The control functions shall be wired to the terminal strips as in Figure 1.

e. Reversing Switch Interlocks: There shall be indicator lights showing the position of the reversing switch with provision for remote indication provided. A provision shall be made that insures that the reversing switch is not partially engaged when the supply is turned on.

3.3.5 Metering

a. Metering similar to the Weston 1900 series (± 2% full scale accuracy). Core type taut bands or equivalent magnetically shielded meters shall be used for indication in each section of the power supply.

DC Output Voltage	(Weston Model 1941T)
DC Output Current	(Weston Model 1075)
AC-DC Ground Current	(Weston Model 1075)

b. Local Metering: A (4-1/2") - 2% meter - 100-0-100 volts shall be mounted to read the output voltage of the power supply. Meter shall read positive when the negative voltage output of the power supply is grounded and the terminal marked "A" output is positive polarity, Weston 1941T or equal.

c. Current Metering Remote: There shall be a 100 M.V., 600 ampere, 1/4% accuracy switch board shunt provided for local and remote current metering. The shunt output shall be wired through a resistor capacitive filter to the terminal strip above the spare panel of 3.3.6a. (See Figure 1 for wiring.)

3.3.6 Miscellaneous Provisions

a. A spare 12" high X 12" deep X 19" wide panel space shall be provided for use by the University. This space shall be located above the power supply interlock lights as shown in Figure 2.

b. Ripple Voltage Detector: There shall be a circuit connected to the DC output of the power supply that will open a set of contacts if the peak-to-peak ripple voltage exceeds two percent of the set power supply voltage for a period which is adjustable from ten seconds to 60 seconds. This circuit shall function from 5% to full voltage output.

3.3.7 Fire Hazard

Design of equipment shall be such that assemblies and components therein shall not create a fire hazard during either service usage or storage.

3.4 Mechanical Design

The power supply shall meet the following requirements:

a. Cabinet Construction: Power supply shall be enclosed in a metal cabinet designed for floor mounting and free standing. Mechanical construction shall consist of an angle iron basic frame which shall sit upon "I" beam skids. The cabinet shall be equipped for fork lift handling of the complete unit, including weight of any coolant. These power supplies will be moved into place on special air-pad moving dollies. Figure 2 shows how the cabinet must be designed to accommodate these dollies.

b. The cabinet shall be "drip-tight", "ventilated", as defined in NEMA standards, section IC 1-2.68 and IC 1-2.69. Hinged panels or doors shall be provided for those areas requiring service access. Large panels which are fastened with bolts or screws shall have alignment studs to make easy replacement possible; a minimum number of fasteners shall be used. Quick operating fasteners are preferred. Light weight metals are preferred for large panels.

c. Cabling to components in hinged panels or doors shall be done by making long twisted loops in the cable along the hinge so that repeated opening of doors shall not damage wires or insulation. Stranded wire shall be used in such cables.

d. Resistors of 50 watt size or larger shall be mounted with machine screws and supported. Solder shall not be used in making connections to these resistors.

e. No bolted or screwed electrical connection shall depend upon an insulating material (ceramic, phenolic or other) to maintain contact pressure.

f. Lugs for large size conductors (No. 8 AWG and larger) shall be both crimped and soldered.

g. Figure 2 shows an approximate layout of the power supply. This rough layout is to be followed unless a specific deviation has been granted by the University. Note maximum dimensions.

h. The cabinet and layout of parts shall be so designed that all major or minor parts can be replaced from the front of the power supply without access to the rear or ends of the power supply.

3.4 (continued)

i. When the local line circuit breaker is turned off, there shall be no voltages exposed in the cabinet. The line terminals of the circuit breaker shall be covered.

j. When the main circuit breaker is turned on and the normal access doors are open, there shall be no exposed voltages greater than 300 volts DC or RMS. The main control contactors shall be in a separate enclosure.

k. When the power supply doors and panels are in place there shall be no holes in the cabinet large enough to permit a small mouse to enter.

3.4.1 <u>Ventilation and Water Cooling</u>

a. Ventilation and cooling shall be designed for indoor units with an ambient air temperature range of 15°C to 45°C. Forced air cooling of components is acceptable provided filtering is used on the intake air. The filters shall be located such that they may easily be removed for cleaning. Filters shall be dry-type. Air flow interlocks shall be provided wherever forced air cooling is used. Ventilation shall be through front panels only.

b. De-mineralized water with a minimum resistivity of 10^5 ohm cm will be supplied from the University water system for cooling. The supply line water temperature will vary from 10°C to 40°C. Normal supply pressure may vary from 80 psi to 100 psi gauge test. The power supply should be designed fro less than 50 psi drop through the power supply.

c. The entire water system shall be constructed of copper, brass, bronze or 18-8 stainless (No. 316 or No. 304), except that insulating connections shall be made with Weatherhead H9 rubber hose or equal. No plastic tubing will be allowed. Hose bibbs or fittings subject to corrosion or electrolysis shall be made of No. 304 stainless.

d. Layout of the water system, particularly insulating hose connections, should be designed (if possible) so as to avoid spraying electrical components in the case of a water leak.

3.4.1 (continued)

e. An all bronze Y strainer with No. 10 mesh brass or monel strainer, Bailey No. 100 with 3/64 inch perforations or equal shall be used in the supply line. This is to be located and adequately supported such that it can be readily accessible and cleaned without dripping water on components.

f. A Hayes Shureflow water flow interlock or equal shall be connected with unions in the return line of each parallel water path. They shall be available for servicing or checking through a door without removing any panels and without dripping water on components. Flow switches in combination with temperature alarms may be used to protect several parallel paths.

g. When short hoses are used to make insulated water jumpers, no hose shall be less than six inches long and shall be looped for easy replacement. The hose, when dry, shall measure greater than 100 megohms per inch when checked at a voltage gradient of 500 volts per inch.

3.4.2 Noise Level

The audible noise level six feet from the cabinet shall be less than 72 db above 0.0002 dynes per square centimeter. The ambient noise level at the time of measurement shall not be above 62 db.

3.5 Environmental Conditions

Unit shall operate under the following conditions:

a. Temperature: Equipment shall operate within the requirements specified herein over an ambient temperature range of 15°C to 40°C.

b. Humidity: Without degradation of performance, the equipment shall withstand relative humidities up to 80 percent including the effects of condensation due to temperature change.

c. Shock and Vibration: Without degradation of performance the equipment shall withstand normal shocks and vibrations during shipment and handling.

3.6 Reliability

Operating life (design objective): 87,000 hours (ten years) of continuous duty. Choice and rating of components shall be consistent with high reliability. The University reserves the right to approve all schematics, circuit diagrams and parts layouts before and during construction. This review of prints by the University does not remove the responsibility for the design from the Subcontractor.

4.0 TEST PROVISIONS

4.1 Standards and Calibration - All Subcontractor measuring and control equipment used during testing shall bear evidence stating the last date of calibration, next calibration date and the laboratory that performed the calibration. Calibrating laboratory must be able to furnish certified records upon request stating that their standards are traceable to the National Bureau of Standards. Certification is not required for equipment standards not yet established by the National Bureau of Standards.

4.2 Procedure and Conditions - Test equipment and procedures required for testing shall be approved prior to initiation of the test program.

4.2.1 Test procedures shall contain, as a minimum, the following:

a. List of test equipment intended for use.
b. Detailed sequence of performance tests based on section 3.0, including sequence of steps for each test to be performed.
c. Laboratory conditions that will prevail during testing.
d. Accumulative operating time check
e. Provisions for inspection.

4.2.2 Tests shall be performed under the humidity is not in excess of 90%. The power supply shall be a completed unit with all panels in place for the following sequence of tests.

4.2.3 Tests: Equipment testing shall be in accordance with University approved test plan and shall demonstrate in his shop with either simulated or actual loads that the power supply will perform as herein specified. The tests to be performed shall include the following:

a. Each power supply shall be tested separately.

4.2.3 (continued)

b. The power supply shall have a resistance greater than 250,000 ohms at 500 volts DC with the grounding knife switch open and water flowing in the cooling circuits measured from power supply terminals to ground.

c. One power supply shall be run at full power to demonstrate that the power supply will function at the temperatures as specified in 3.2.3. This test is to run until the temperatures within the power supply level off, but in no case for less than four hours. Component temperatures shall at no time during the test be greater than those recommended by the component manufacturer. All units shall be run at least two hours.

d. Regulation stability shall be checked during 4.2.3c.

e. The regulation tests and heat run at the factory may be made using a resistive load. The peak-to-peak current ripple into the resistive load shall be less than $\pm$ 0.2%. It is preferred to make the tests with a magnet as a load.

f. The load resistance shall be varied to show that the power supply meets the requirement of 3.2.3.

g. The line voltage shall be monitored during the tests to check the stability of the power supply with respect to line voltage steps. The line voltage steps may have to be artifically generated to demonstrate the adequacy of the regulation system if the AC power system used to supply power for the tests does not show 2-1/2% line voltage steps.

h. The power supply terminals shall be shorted while the power supply is operating at full power. This test is to demonstrate the adequacy of the overload protection system. Repeat this short circuit test as required.

i. The ungrounded lead of the power supply shall be shorted to ground while the power supply is operating at full power. This test is to demonstrate the adequacy of the ground protection interlocks. Repeat test as required.

4.2.3 (continued)

j. At the conclusion of the test programs there shall be no evidence of water leakage or other evidence that could lead to an early power supply failure or shortening of expected life.

k. The University inspector has the option to require any tests to be repeated if deficiencies during a test have had to be corrected.

4.3 Test Records

All Subcontractor test records shall show the following data:

a. Pertinent test data
b. Equipment used
c. Test proceudres used and conditions
d. Block diagrams of all test setups used
e. Irregularities observed during testing
f. Recorded total elapsed time of each test and increments between each sequential test step.

5.0 PREPARATION FOR DELIVERY

5.1 Preservation and Packaging: All equipment shall be adequately protected against damage during shipping by common carrier.

5.2 Marking for Shipment: All exterior shipping containers shall be adequately and properly marked for identification. All packages shall include the following minimum markings:

a. Addressee
b. Shipper
c. University purchase order number and/or subcontract number
d. Special markings, warnings or tags in accordance with ICC regulations.

6.0 NOTES

Three instruction books with appropriate schematic diagrams and parts lists of all electrical components of sub-assemblies shall be furnished at the time of delivery of the power supply.

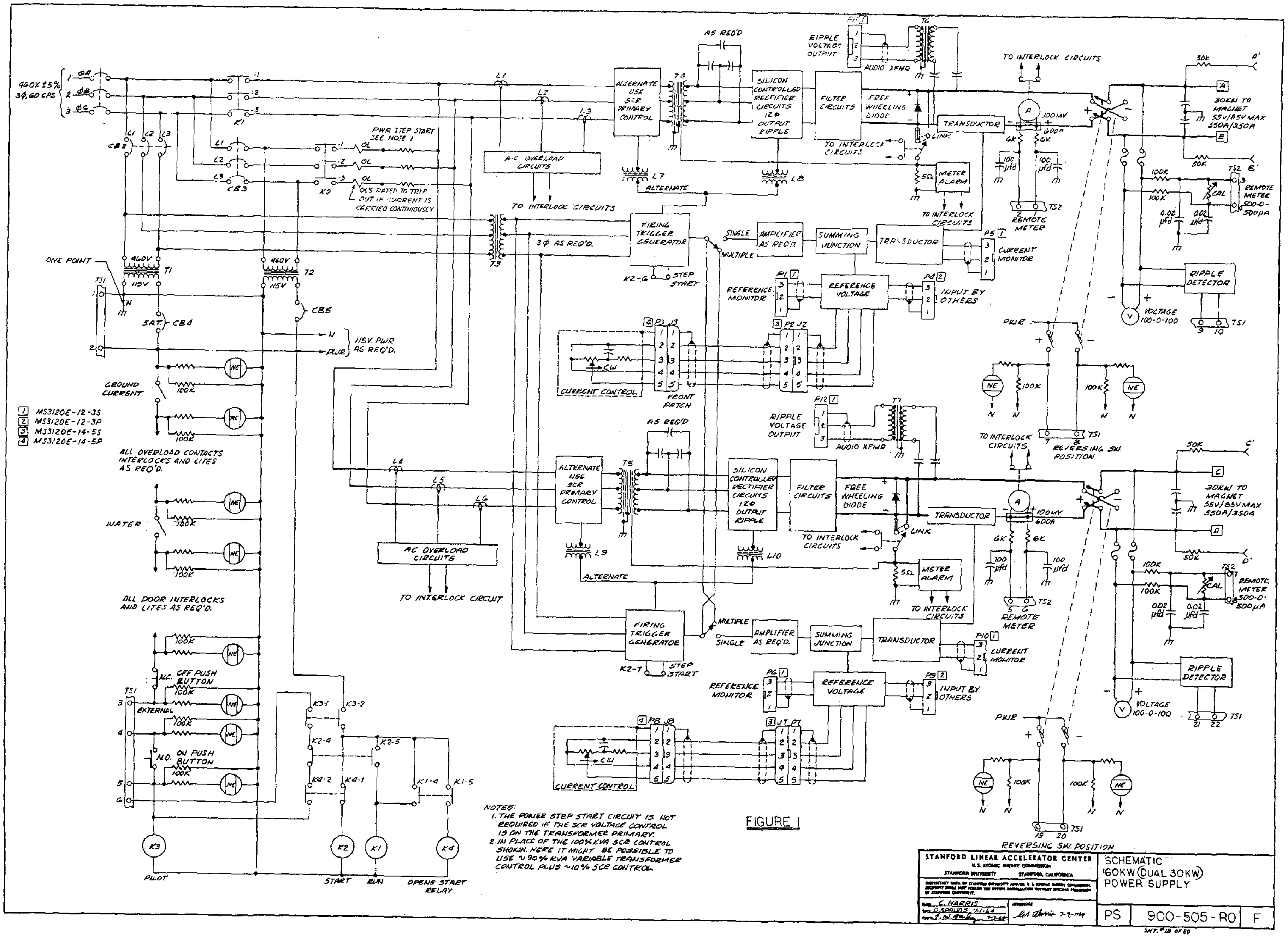

460V ±5%
3Ø, 60 CPS
ØA
ØB
ØC
K1
CB2
CB3
K2
L1
L2
L3
OL
PWR STEP START SEE NOTE 1
OL'S RATED TO TRIP OUT IF CURRENT IS CARRIED CONTINUOUSLY
AC OVERLOAD CIRCUITS
TO INTERLOCK CIRCUITS
ALTERNATE USE SCR PRIMARY CONTROL
AS REQ'D
T4
SILICON CONTROLLED RECTIFIER CIRCUITS 12Ø OUTPUT RIPPLE
FILTER CIRCUITS
FREE WHEELING DIODE
RIPPLE VOLTAGE OUTPUT
AUDIO XFMR
T6
TO INTERLOCK CIRCUITS
TRANSDUCTOR
LINK
100MV
600A
6K
100 µfd
METER ALARM
REMOTE METER
TS2
50K
A'
A
B
B'
30KW TO MAGNET 55V/85V MAX 550A/350A
100K
CAL
REMOTE METER 500-0-500µA
0.02 µfd
L7
L8
ALTERNATE
T3
3Ø AS REQ'D.
FIRING TRIGGER GENERATOR
K2-6
STEP START
SINGLE
MULTIPLE
AMPLIFIER AS REQ'D
SUMMING JUNCTION
CURRENT MONITOR
P5
RIPPLE DETECTOR
VOLTAGE 100-0-100
TS1
ONE POINT
460V
115V
T1
T2
CB4
CB5
5RT
115V. PWR AS REQ'D.
PWR
N
REFERENCE MONITOR
REFERENCE VOLTAGE
INPUT BY OTHERS
P1
P4
P3 J3
P2 J2
FRONT PATCH
CURRENT CONTROL
CW
GROUND CURRENT
NE
1 MS3120E-12-3S
2 MS3120E-12-3P
3 MS3120E-14-5S
4 MS3120E-14-5P
ALL OVERLOAD CONTACTS INTERLOCKS AND LITES AS REQ'D.
WATER
ALL DOOR INTERLOCKS AND LITES AS REQ'D.
PWR
REVERSING SW. POSITION
P12
T7
L4
L5
L6
T5
L9
L10
C'
C
D
D'
TO INTERLOCK CIRCUIT
K2-7
P6
P9
P10
P8 J8
J7 P7
EXTERNAL
N.C. OFF PUSH BUTTON
N.O. ON PUSH BUTTON
K3-1
K3-2
K2-4
K2-5
K4-2
K4-1
K1-4
K1-5
K3
K2
K1
K4
PILOT
START
RUN
OPENS START RELAY
NOTES:
1. THE POWER STEP START CIRCUIT IS NOT REQUIRED IF THE SCR VOLTAGE CONTROL IS ON THE TRANSFORMER PRIMARY.
2. IN PLACE OF THE 100% KVA SCR CONTROL SHOWN, HERE IT MIGHT BE POSSIBLE TO USE ~90% KVA VARIABLE TRANSFORMER CONTROL PLUS ~10% SCR CONTROL.
STANFORD LINEAR ACCELERATOR CENTER
U.S. ATOMIC ENERGY COMMISSION
STANFORD UNIVERSITY STANFORD, CALIFORNIA
C. HARRIS
SCHEMATIC
160KW (DUAL 30KW) POWER SUPPLY
PS
900-505-R0
F
SHT. #18 OF 20

FIGURE 1

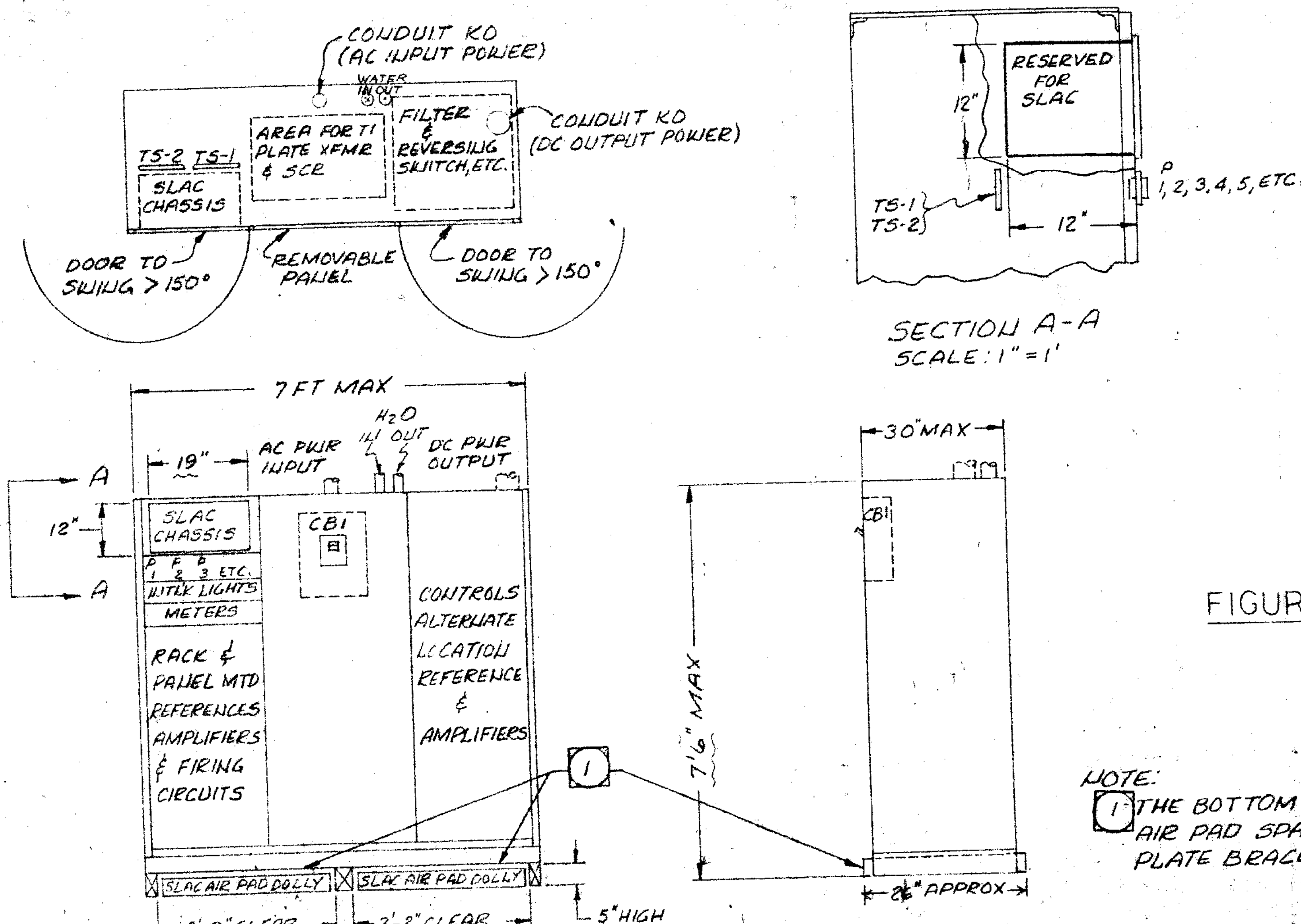
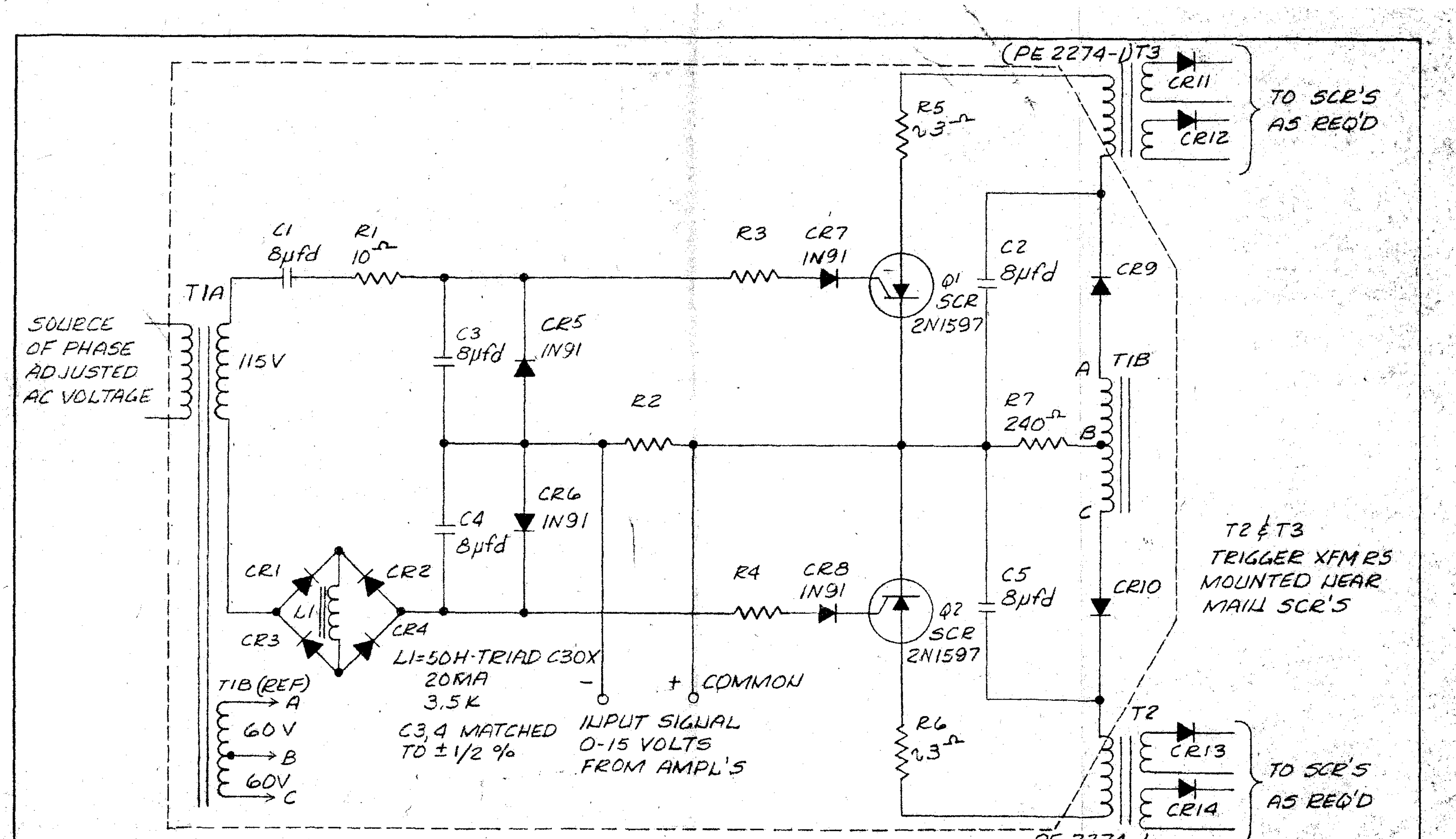


FIGURE 2

NOTE:
(1) THE BOTTOM OF THE CABINET OVER THE AIR PAD SPACE SHALL BE A SMOOTH PLATE BRACED TO TAKE UNIFORM LOADING.

STANFORD LINEAR ACCELERATOR U.S. ATOMIC ENERGY COMMISSION	TITLE CURRENT REGULATED POWER SUPPLY DUAL 30KW SCR		
ENGR. C. HARRIS CHK'D [signature]	DATE 5-15-64	PS-900-505 - RO	B
DFTS. D. SPALLOS APPV'D [signature]	SCALE 1/2" = 1'		



NOTE: THIS CIRCUIT IS USED AT LAWRENCE RADIATION LABORATORY.

FIGURE 3

STANFORD LINEAR ACCELERATOR
U. S. ATOMIC ENERGY COMMISSION

TITLE TYPICAL SCR PHASE CONTROLLED FIRING CIRCUIT

ENGR. C HARRIS CHK'D [illegible]
DFTS. D SPANOS APPV'D [illegible]
DATE 6/24/64
SCALE NONE
PS 900-505-R0 B

STANFORD UNIVERSITY

STANFORD LINEAR ACCELERATOR CENTER

TECHNICAL SPECIFICATION PS-900-506-RO

FOR

260 KW DC POWER SUPPLY FOR ELECTRO-MAGNETS
(DUAL 130 KW)

Research Division
Stanford Linear Accelerator Center

Issue Date: June 26, 1964

260 KW

DC POWER SUPPLY FOR ELECTRO-MAGNETS

DUAL 130 KW

PS-900-506-R0

TECHNICAL SPECIFICATION

Submitted *G. A. [signature]* Heavy Electronics

Reviewed *E. J. Brown* Systems Engineering

Approved ____________________ Research Division

Research Division
Stanford Linear Accelerator Center
Stanford University
Stanford, California

Issue Date: June 26, 1964

TECHNICAL SPECIFICATION FOR A 260 KW POWER SUPPLY FOR ELECTRO-MAGNETS

PS-900-506-RO

1.0 SCOPE

1.1 This document specifies minimum requirements for the design and manufacture of a Daul 130 KW power supply to be used to energize electro-magnets having different L/R time constants and different resistances,

1.2 The power supply shall be a complete unit with all necessary components wired and ready for operation as herein specified.

1.3 Reliability of operation shall be considered of prime importance in the design and manufacture of the equipment. All practical means shall be employed to assure quality and maximum reliability consistent with state of the art.

2.0 APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids shall form a part of this specification to the extent specified herein. If a listed document, other than those published by the University, is superseded, the Subcontractor shall bring the matter to the attention of the University without delay.

2.1.1 University Documents

SLAC QC-034-100-01-R3 - Quality Control Workmanship Standard

2.1.2 Other Documents

a. MIL-STD-16C - Electrical and Electronic Reference Designations
b. Federal Communications Commission Rules and Regulations, part 18
c. NEMA Standards, IC 1-2.68 Enclosures Non-Ventilated Types
d. NEMA Standard IC 1-2.69 Enclosures Ventilated Types

2.2 The subcontractor shall bring to the attention of the University any conflict which should occur between this document and those listed in paragraph 2.1 and 3.1 before starting production of the equipment. The University will decide which document has precedence.

3.0 REQUIREMENTS

3.1 <u>General</u>

3.1 (continued)

3.1.1 Specifications and Standards - Subcontractor specifications and standards used during manufacturing shall be compatible with documents listed under paragraph 2.1 and National Electric Codes, (wiring & grounding) AWS (welding), ASTM (materials), ASA (screw threads).

3.1.2 Component Ratings - All components within the power supply shall be used within the component manufacturer's recommended ratings for high reliability during a 10 year expected life. All components shall be adequately protected against overloads of transient voltage or current. (See paragraph 3.6 for reliability)

3.1.3 Identification and Marking - Equipment, assemblies and parts shall be marked for identification. Subcontractor shall attach a nameplate to major assemblies with the following data:

a. Part name (260 KW DC Power Supply for Electro-magnets)
b. Manufacturer's part number
c. Manufacturer's name or trademark
d. Manufacturer's serial number
e. SLAC specification number PS-900-506-R0
f. Weight of assembled power supply
g. Year of manufacture
h. Input power requirements
i. Power supply output ratings

3.1.4 Parts Reference Designations - Parts reference designations and chassis markings shall comply to numbering method specified in MIL-STD-16C. Marking process shall be in accordance with SLAC QC-034-100-01.

3.2 Performance

Unit shall meet the following performance characteristics:

3.2.1 Dual Output Voltage:

each section: 0 to ± 122 Volts or 0 to ± 160 Volts

(The rectifier transformer shall have taps or be reconnected to give a choice in output power ratings of each section of this dual output power supply. A manually controlled reversing switch will be used to give

3.2.1 (continued)

a choice in the polarity of the output of each section.)

Dual Output Current:

each section: 0 to 1,050 Amps or 0 to 805 Amps.

3.2.2 The range of characteristics for the electro-magnet that will be used as a load at the University are as follows:

a. Resistance 0.05 to 0.2 Ohms

b. Load time constant: 0.2 second to 2 seconds for frequencies less than 1.0 CPS

c. The pole tips are not laminated (See section 3.2.5)

3.2.3 The power supply shall have one variable voltage unit or group of units that control both DC outputs simultaneously. The power supply shall operate under any combination of the following conditions:

a. Step line voltage change: $\pm$ 2-1/2% (maximum)

b. Slowly varying (3 seconds) between successive maximum and minimum input AC voltage: 460 Volts $\pm$5%

c. Ambient temperature: Range of 15°C to 45°C (5° per hour max.)

d. Input cooling water temperature: Range of 10°C to 40°C (10° per hour max.)

e. Dual output voltage range: (See 3.2.1) Controlled 0 to 122 Volts or 0 to 160 Volts

f. For any step voltage changes introduced by any internal equipment of the power supply.

g. Resolution: The voltage control system shall be sensitive enough to set the output voltage to within 1/2 Volt.

h. Voltage control speed: The motor drive used to control the output voltage shall run from 0 to full output voltage within 45 seconds maximum.

i. Shunt accuracy: The nominal accuracy of the shunt or other device used for current monitoring shall be $\pm$1/4%.

3.2.4 The power supply output shall be able to withstand accidental short circuits or shorts to ground at any output voltage without damage to the regulation system, power rectifiers or other major components. The main circuit breaker ot the AC and DC overloads may trip the main contactor under these conditions. The Amp trap fuses may blow under a short circuit condition.

3.2.5 Voltage Ripple - The variations in voltage fed to an electromagnet or resistive load as specified in 3.2.2 shall not exceed the following peak to peak values:

Frequency	Maximum Variation, Percent of Set Value
0 to 30 CPS	± 0.5%
30 CPS and higher	± 1%

NOTE: The current ripple in the magnet will be about 10 times higher for this unlaminated magnet than would be calculated on the basis of a laminated core structure and the load time constants in 3.2.3.b.

3.2.6 Application

The regulated power supply described in these specifications will be used in several different modes of operation. The load time constants in each of the following cases will be per 3.2.2.b.

a. It will be used by itself feeding power to a single load within the ratings of the power supply.

b. One or more of these units will be used in series with other SCR Current regulator controlled power supplies supplying a total power of 610 Volts at 1,050 Amps.
In this mode it will act as the slow section of a slow and fast loop regulation system. The IVR slow loop system will correct for the wide range variations.

c. One or more of these units will be used in series with other SCR controlled power supplies supplying a total power of 701 Volts at 805 Amps. In this mode it will act as the slow loop of a 3 loop regulation system. The other loops will be a SCR current regulator control and a fast series transistor system. The higher frequency

3.2.6 (continued)

response available with the series transistor bank is required for an ultimate regulation of ±0.005%.

3.3 Electrical Design

The power supply electrical design shall meet the following minimum requirements. See Figure 1.

3.3.1 AC Power

a. Input AC Power: 460 Volts ± 5%, 60 CPS, 3 phase, one percent unbalanced line to line for either 3-wire grounded wye or an ungrounded system. The input voltage will randomly vary over the voltage range indicated; transformer taps are not to be used to compensate for this variation.

b. Circuit Breaker: Capable of interrupting 15,000 Amperes short circuit asymmetrical at 460 Volts. The line side of this breaker may be considered the intput of the power supply. Provision shall be made for any easy route for the primary power out the top of the power supply.

c. The input circuit breaker shall be equipped with a Kirk-type lock which will permit the key to be removed only when the breaker is off. The lock for each power supply shall have a different combination. Three keys shall accompany each power supply.

d. The RMS current rating of the main circuit breaker in paragraph 3.3.1.b. shall be less than 125% of the normal full load current of the power supply. The in-rush current shall not trip the breaker during any turn on cycle. The peak in-rush current shall not be more than 4 times the normal full load current. Step start currents may be required (See Figure 1).

e. Rectifier Transformer: Transformer must be double shielded, one shield surrounding the primary winding and one shield surrounding the secondary winding. The primary shield shall be grounded; the secondary shield should be made available and insulated for 600 Volts DC. Provision shall be made to tie this shield any output lead of

3.3.1 (continued)

the power supply. The insulation from secondary to primary shield shall withstand a 2200 Volt RMS test and subsequent 1200 Volt DC tests applied many times during the 10 year life of the power supply.

f. The power supply shall be deisgned so that it can be turned off at any combination of current or voltage without damage to the components.

g. Wires and busses operating at greater than 300 Volts DC or RMS shall be kept separate from lower voltage circuits. In no case shall they appear on the same terminal trip or terminal board with lower current terminals.

h. This power supply may be split into two packages: one frame to carry the voltage variable unit, and a second unit to contain the plate transformer, contactors, rectifiers, filters, reversing switches and controls.

i. The AC variable voltage unit shall allow the DC output of one section to be set within $\pm$ 2 Volts.

3.3.2 DC Power

a. Insolation - DC circuits of the power supply shall be insulated from ground for 600 Volts so that two or more of the power supplies may be run in series.

b. Component Mounting - Any multiplicity of components such as diodes shall be designed for easy replacement and without breaking any water circuit.

c. Reversing Switches - Manually operated reversing switches shall be connected between the DC power sources and the output terminals. The switches shall be accessible behind an interlocked door so that they cannot be operated unless the power supply is turned off. Surge protection should be added for the case when the switch is operated with two Amps flowing in the inductive load. The output terminals of the power supply shall be identified "A" to "H". (See Figure 1). There shall be space available to add a motor to this manually operated switch.

3.3.2 (continued)

d. Over-current protection: AC over-current protection shall not be accomplished with fuses. Protection may consist of thermal of magnetic relays. DC overload shall be easily adjustable by means of a meter indicator control (Weston Model 1075 or equal) located on the front panel.

e. Free wheeling diodes or reverse diodes shall be connected across the power supply output terminals after the filter and before the reversing switches. The inverse voltage rating of these diodes shall be a minimum of 700 Volts. The diode assembly shall be rated for full load DC current; they may be water-cooled.

f. Large filter capacitors shall have a discharge circuit connected to their terminals. The time constant of the discharge system should be less than 15 seconds.

g. The layout and design of the power supply shall include provisions to minimize the high frequency (above 1.K.C.) transients generated by the silicon rectifiers and transmitted on the input power lines, the DC output lines, or radiated out through the cabinet. Maximum radiated electrical noise permitted is Volts per meter. (See).

h. The two rectifier systems shall each be designed for 12 Ø ripple with a 15° phase shifting system located between them; or each of two rectifier systems may be designed for 24 Ø ripple.

i. Eight jacks (cannon co-axial connectors 83-1SP or equal) for monitoring voltages shall be mounted on the front panel; these shall be identified "A" to "H" and connected with 50 K resistors as shown on Figure 1.

j. Fast acting fuses (Amp Trap form 101, or University approved equal) shall be used in series with each SCR.

k. The DC short circuit current shall be limited to 16,000 Amps maximum for 50×10^{-3} seconds maximum. This includes peak discharge from any filter capacitors. The main AC contactor shall open by this time.

3.3.3 <u>Controls and Interlocks</u>

a. Controls: A panel or panels shall be mounted on the front face of the power supply and shall contain at least the following controls:

DC Power Supply Off/On
DC Output Voltage Adjustment

3.3.3 (continued)

b. All auxilary voltages in the power supply whose loss could cause power supply damage shall be arranged in a series interlock chain with a neon indicator light for each interlock. The water interlocks, door interlocks and external interlocks, in that order, shall be last in the chain before the off/on control buttons. See Figure 1.

c. Control Power - The 115 Volts AC control power shall be derived from a step-down transformer connected with fuses to the load side of the input AC circuit breaker. One side of the control power shall be grounded at the control transformer; this point shall be accessible. The steady state and surge current in the interlock chain shall be less than 3 Amp AC.

d. Terminal strips TS1 and TS2 shall be provided just below the spare space in 3.3.3.c. These terminal strips shall be Gen Pro 440 series or University approved equal and shall carry the required terminals for remote controlling the power supplies. The control functions shall be wired to the terminal strip as in Figure 1.

e. A spare 12" high x 12" deep x 19" wide panel space shall be provided for use by the University. This space shall be located above the power supply interlock lights as shown in Figure 2.

f. A male plug PG-1 shall be located below the space in 3.3.3.e. This plug and a conveniently located remote local switch shall allow an external voltage to be applied for servo voltage control...see 3.2.6, b and c. The wiring to the plug shall be as shown in Figure 1.

g. The reversing switches shall have indicator light circuits to indicate the polarity of the switch. Provisions shall be made to insure that the switches are in the same polarity and fully engaged before the power supply can be turned on.

h. Remote Voltage Control, Servo: In the series mode of operation, the power supply voltage shall be able to be controlled by a signal of 0 to 20 Volts fed in as a reference voltage of a servo system. The output voltage of the power supply shall track this input voltage signal over the full range of the power supply. The accuracy of tracking shall be 5 Volts measured on the output of one section

3.3.3 (continued)

of the power supply. These control circuits shall be isolated from ground so that the input reference voltage may be grounded elsewhere.

i. Remote Voltage Control, Realys: The DC output voltage of this power supply shall be capable of being controlled by means of relay contacts (rated at 10 Amps 115 Volts AC) located external to this power supply.

3.3.4 Metering

a. Meters used on this power supply shall be 4-1/2 inch case size with a full scale accuracy of ± 2% full scale. Taut band suspension core type magnets or equivalent magnetically shielded meters shall be used in each section of this power supply (See Figure 1)

b. Local Metering -

(1) A Voltmeter (200-0-200 Volts) shall be mounted to read the output voltage of each section of the power supply. Meter shall read positive when negative voltage output of the power supply is grounded and the terminal marked "A" or "F" output terminal is positive polarity. Weston Model 1900 or equal.

(2) An Ammeter (0 to 1200 Amps) shall be connected to the 100 MV shunt to read current of each section. This meter shall be a contact making meter with an adjustable pointer for setting an overcurrent trip. Weston Model 1075 or equal.

c. Remote Current Monitoring - There shall be a 100 MV, 1,200 A, 1/4% accuracy switchboard shunt provided for local and remote current metering. The shunt output shall be wired through a resistor capacitive filter to terminal strip below the spare panel of 3.3.3.e. See Figure 1 for wiring.

3.3.5 Fire Hazard - Design of equipment shall be such that assemblies and components therein shall not create a fire hazard during either service usage or storage. Materials such as the following should be used whenever possible.

a. Crack resistant "glastic"

3.3.5 (continued)

b. Grade FT canvass bakelite (spaulding C-832 or equal)

c. NEMA frades FR-1 and FR-2 paper phenolic

d. NEMA grade FR-3 paper epoxy

e. NEMA grade FR-4 and FR-5 glass epoxy

f. Vinyl chloride acetate or Plexiglass 5009B.

3.4 Mechanical Design - The power supply shall meet the following requirements:

a. Cabinet Construction - Power supply shall be enclosed in a metal cabinet designed for floor mounting and free standing. Mechanical construction shall consist of an angle iron basic frame which shall sit upon "I" beam skids. The cabinet shall be equipped for fork lift handling of the complete unit, including weight of any coolant. These power supplies will be moved into place on special air-pad moving dollies. Figure 2 shows how the cabinet must be designed to accommodate these dollies.

b. The cabinet shall be "drip-tight", "ventilated" as defined in NEMA standards, Section IC 1-2.68 and IC 1-2.69. Hinged panels or doors shall be provided for those areas requiring service access. Large panels which are fastened with bolts or screws shall have alignment studs to make easy replacement possible; a minimum number of fasteners shall be used. Quick operating fasteners are preferred. Light wieght metals are preferred for large panels.

c. Cabling to components in hinged panels or doors shall be done by making long twisted loops in the cable along the hinge, so that repeated opening of doors shall not damage wires or insulation. Stranded wire shall be used in such cables.

d. Resistors of 50 watt size or larger shall be mounted with machine screws and supported. Solder shall not be used in making connection to these resistors.

e. No bolted or screwed electrical connection shall depend upon an insulating material (ceramic, phenolic, or other) to maintain contact pressure.

3.4 (continued)

f. Lugs for large size conductors (No. 8 AWG and larger) shall be both crimped and soldered.

g. Figure 2 shows an approximate layout, of the power supply. This rough layout is to be followed unless a specific deviation has been granted by the University. Note that two frames are permitted.

h. The cabinet and layout of parts shall be so designed that all major or minor parts can be replaced from the front of the power supply without access to the rear or ends of the power supply.

i. When the local line circuit breaker is turned off, there shall be no voltages exposed in the cabinet. The line terminals of the circuit breaker shall be covered.

j. When the main circuit breaker is turned on and the normal access doors are open there shall be no exposed voltages greater than 300 Volts DC or RMS. The main control contactors shall be in a separate enclosure within the main power supply frame.

k. When the power supply doors and panels are in place, there shall be no holes in the cabinet large enough to permit a small mouse to enter.

3.4.1 <u>Ventilation and Water Cooling</u>

a. Ventilation and cooling shall be designed for indoor units with an ambient air temperature range of 15^{o} to 45^{o}C. Forced air cooling of components is acceptable provided filtering is used on the intake air. The filters shall be located such that they may easily be removed for cleaning. Filters shall be dry-type. Air flow interlocks shall be provided wherever forced air cooling is used.

b. De-mineralized water with a minimum resistivity of 10^5 Ohms CM will be supplied from the University water system for cooling. The supply line water temperature will vary from 10^{o}C to 40^{o}C. Normal supply pressure may vary from 80 PSI to 100 PSI gauge test; the design shall be based upon 150 PSI and a 225 PSI hydrostatic test. The power supply should be designed for less than 50 PSI drop through the power supply.

c. The entire water system shall be constructed of copper, brass, bronze or 18-8 stainless (No. 316 or No. 304) except that insulating connections shall be made with Weatherhead H9 rubber hose or equal. No plastic tubing allowed. Hose bibbs or fittings subject to corrosion or electrolysis shall be made of No. 304 stainless.

3.4.1 (continued)

d. Layout of the water system, particularly insulating hose connections, should be designed (if possible) as as to avoid spraying electrical components in the case of a water leak.

e. An all bronze Y strainer with 10 mesh brass or monel strainers, Bailey No. 100 with 3/64 inch perforations or equal, shall be used in the supply line. This is to be located and adequately supported such that it can be readily accessible and cleaned without dripping water on components.

f. A Hayes Shureflow water flow interlock or equal shall be connected with unions in the return line of each parallel water path. They shall be located within the outline of the cabinet such that they are readily available for servicing or checking through a door without removing any panels, or dripping water on components. Flow switches in combination with temperature alarms may be used to protect several parallel paths.

g. When short hoses are used to make insulated water jumpers, no hose shall be less than 6 inches long and they shall be looped for easy replacement. The hose, when dry, shall measure greater than 100 megohms per inch when checked at a voltage gradient of 500 Volts per inch.

3.4.2 Noise Level - The audible noise level 6 feet from the cabinet shall be less than 72 db above 0.0002 bynes per sq. centimeter. The ambient noise level at the time of measurement shall not be above 62 db.

3.5 Environmental Conditions - Unit shall operate under the following conditions:

3.5.1 Temperature - Equipment shall operate within the requirements specified herein over an ambient temperature range of 15° to $45^{\circ}C$.

3.5.2 Humidity - Without degradation of performance, the equipment shall withstand relative humidities up to 80 percent including the effects of condensation due to temperature change.

3.5.3 Shock and Vibration - Without degradation of performance the equipment shall withstand normal shocks and vibrations during shipment and handling.

3.6 Reliability - Operating life (design objective): 87,000 hours (ten years) of continuous duty. Choice and rating of components shall be consistent with high reliability. The University reserves the right ot approve all schematics, circuit diagrams and parts layouts before & during construction. begins. This review of prints by the University does not remove the responsibility for the design from the Subcontractor.

4.0 TEST PROVISIONS

4.1 Standards and Calibration - All Subcontractor measuring and control equipment used during testing shall bear evidence stating the last date of calibration, next calibration date, and the laboratory that performed the calibration. Calibrating laboratory must be able to furnish certified records upon request stating that their standards are traceable to the National Bureau of Standards. Certification is not required for equipment standards not yet established by the National Bureau of Standards.

4.2 Procedure and Conditions - Test equipment and procedures required for testing shall be approved by the University prior to initiation of the test program.

4.2.1 Test procedures shall contain, as a minimum, the following:

a. List of test equipment intended for use.
b. Detailed sequence of performance tests based on Section 3.0 including sequence of steps for each test to be performed.
c. Laboratory conditions that will prevail during testing.
d. Accumulative operating time check
e. Provisions for inspection

4.2.2 Test Conditions - Tests shall be performed under the humidity that prevails at the test location provided the relative humidity is not in excess of 90%. The power supply shall be a completed unit with all panels in place for the following sequence of tests:

4.2.3 Tests - Equipment testing shall be in accordance with University approved test plan and shall demonstrate in his shop with either simulated or actual loads that the power supply will perform as herein specified. The tests to be performed shall include the following:

a. Each power supply shall be tested separately except for the heat run. The heat run shall be conducted on the first unit; subsequent heat runs will be conducted at the option of the University inspector.

b. The power supply shall have a resistance greater than 250,000 Ohms at 500 Volts DC with the grounding knife switch open and water flowing in the cooling circuits, measured from power supply terminals to ground.

c. The first power supply shall be run at full power to demonstrate that the power supply will function at the maximum temperatures as specified in 3.2.3. This test is to run until the temperatures within the power supply levels off but in no case for less than 4 hours. The test may require 8 or 12 hours. Component temperatures shall at no time during the test be greater than those recommended by the component manufacturer. All doors and panels shall be closed during the test. All units shall be run at least 2 hours.

d. Servo voltage control shall be checked during the tests of section 4.2.3.c.

e. The tests and heat run at the factory may be made using a resistive load. The peak to peak current ripple into the resistive load shall be less than $\pm$ 0.2%. It is preferred to make the tests with a magnet as a load.

f. It shall be demonstrated that the power supply meets the requirements of 3.2.3.

g. The line voltage shall be monitored during the tests to check the stability of the power supply with respect to line voltage steps. The line voltage steps may have to be artifically generated to demonstrate the adequacy of the regulation system if the AC power system used to supply power for the tests does not show a 2½% line voltage step.

4.2.3 (continued)

h. The power supply terminals shall be shorted while the power supply is operating at full power. This test is to demonstrate the adequacy of the overload protection system. Repeat this short circuit test as required.

i. The ungrounded lead of the power supply shall be shorted to ground while the power supply is operating at full power. This test is to demonstrate the adequacy of the ground protection interlocks. Repeat test as required.

j. At the conclusion of the test programs there shall be no evidence of water leakage or other evidence that could lead to an early power supply failure or shortening of the expected life.

k. The University inspector has the option to require any tests to be repeated if deficiencies durig a test have had to be corrected.

4.3 Test Records - All Subcontractor test records shall show the following data:

a. Pertinent test data
b. Equipment used
c. Test procedures used and conditions
d. Block diagrams of all test setups used
e. Irregularities observed during testing
f. Recorded total elapsed time of each test and increments between each sequential test step.

5.0 PREPARATION FOR DELIVERY

5.1 Preservation and Packaging - All equipment shall be adequately protected against damage during shipping by common carrier.

5.2 Marking for Shipment - All exterior shipping containers shall be adequately and properly marked for identification. All packages shall include the following minimum markings:

a. Addressee
b. Shipper
c. University pruchase order number and/or subcontract number
d. Special markings, warnings, or tags in accordance with ICC regulations.

6.0 NOTES

Three instruction books with appropriate schematic diagrams and parts lists of all electrical components or sub-assemblies shall be furnished at the time of delivery of the power supply.

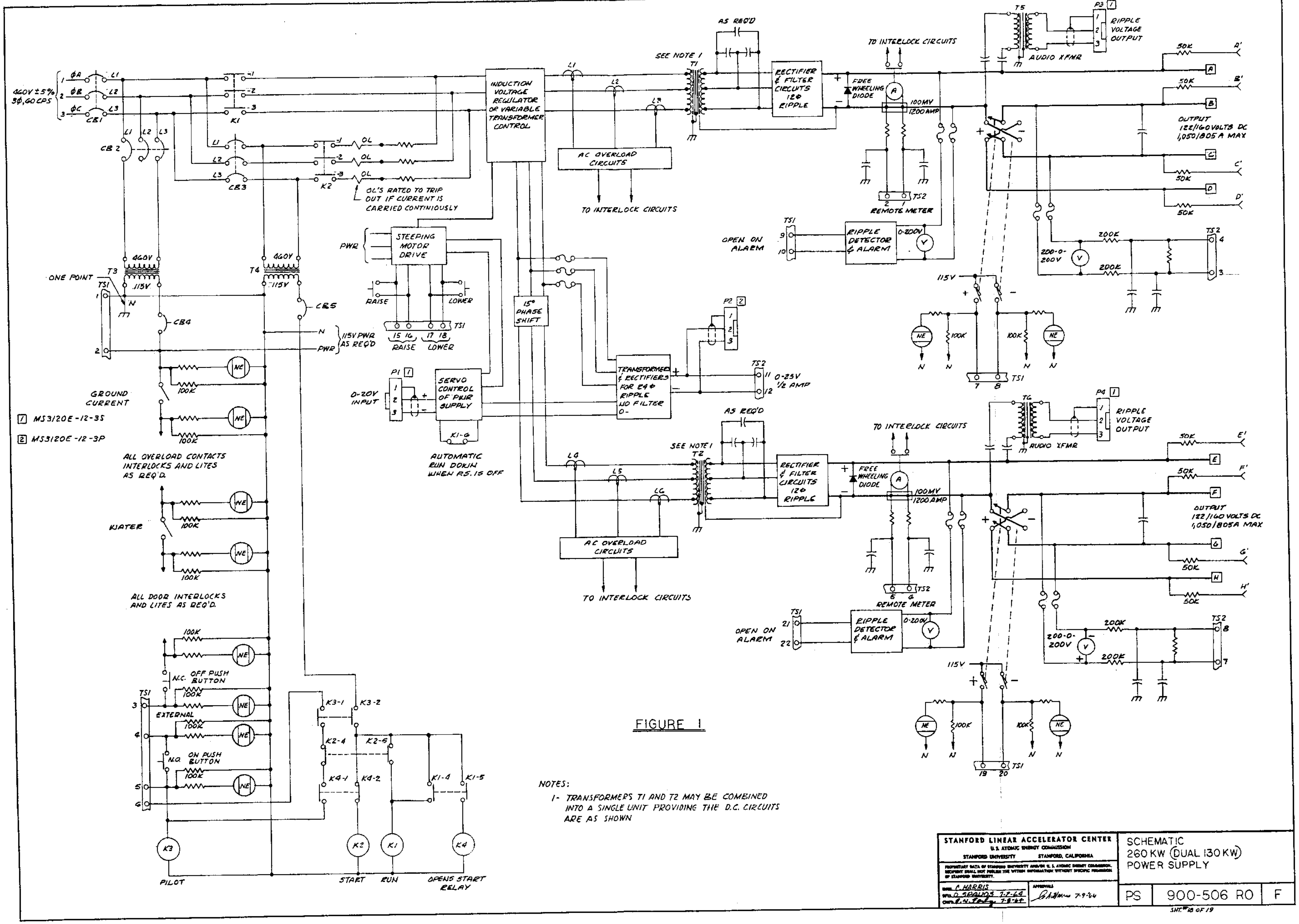


FIGURE 1

NOTES:

1- TRANSFORMERS T1 AND T2 MAY BE COMBINED INTO A SINGLE UNIT PROVIDING THE D.C. CIRCUITS ARE AS SHOWN

STANFORD LINEAR ACCELERATOR CENTER
U.S. ATOMIC ENERGY COMMISSION
STANFORD UNIVERSITY STANFORD, CALIFORNIA

SCHEMATIC
260 KW (DUAL 130 KW)
POWER SUPPLY

A. HARRIS
D. SPAULDS 7-7-64
7-9-64

PS 900-506 R0 F

SHT. 18 OF 19

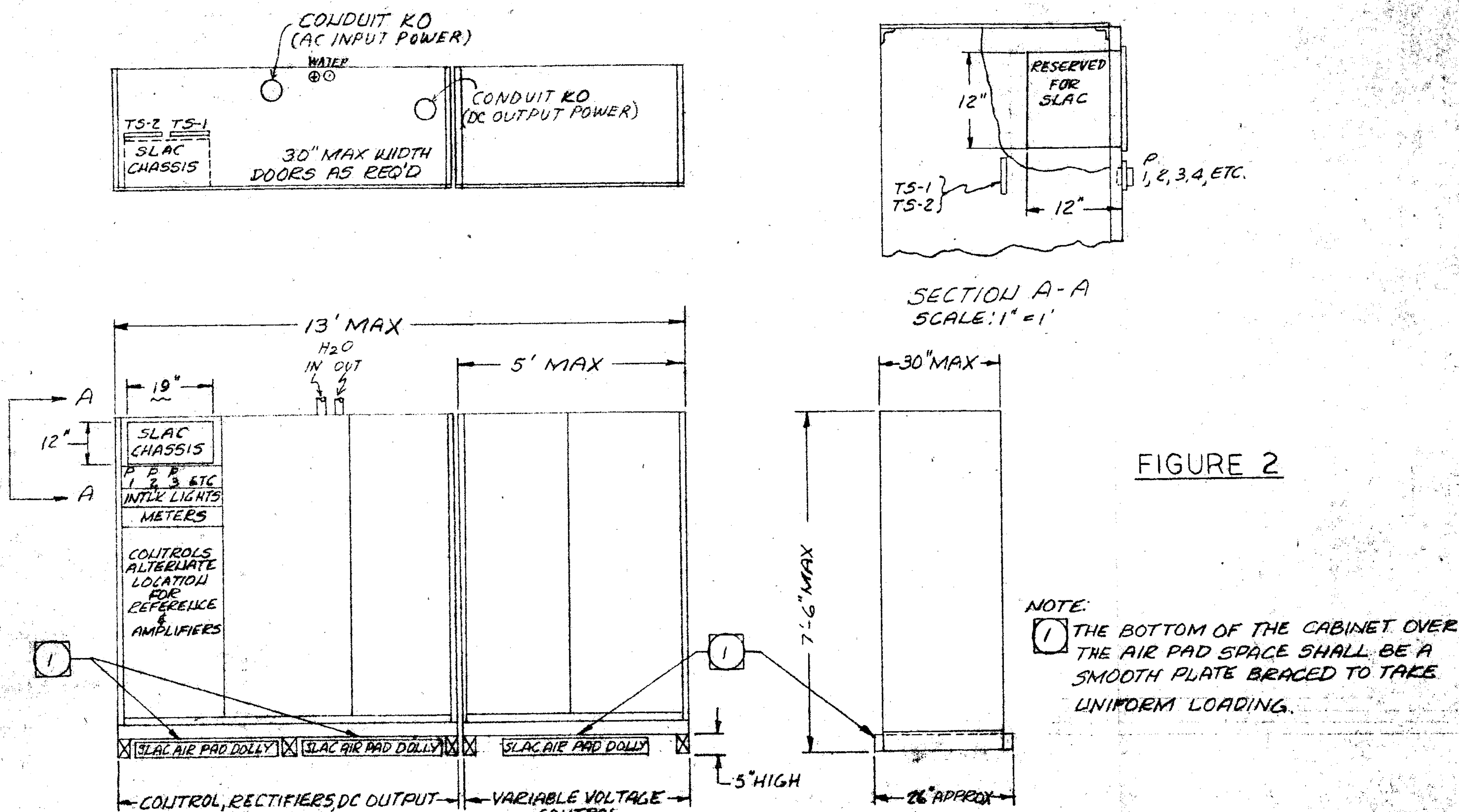


FIGURE 2

NOTE:
(1) THE BOTTOM OF THE CABINET OVER THE AIR PAD SPACE SHALL BE A SMOOTH PLATE BRACED TO TAKE UNIFORM LOADING.

STANFORD LINEAR ACCELERATOR U.S. ATOMIC ENERGY COMMISSION	TITLE CURRENT REGULATED POWER SUPPLY DUAL 129KW
ENGR. C HARRIS CHK'D [signature]	DATE 6-25-64 PS-900-506-RO B
DFTS. D. SPALIOS APPV'D [signature]	SCALE 1/2" = 1"

STANFORD UNIVERSITY

STANFORD LINEAR ACCELERATOR CENTER

TECHNICAL SPECIFICATION PS-900-504-R0

FOR

48 KW SERIES TRANSISTOR CURRENT REGULATOR FOR ELECTRO-MAGNETS

Research Division
Stanford Linear Accelerator Center

Issue Date: June 26, 1964

48 KW SERIES TRANSISTOR

CURRENT REGULATOR FOR ELECTRO-MAGNETS

PS-900-504-R0

TECHNICAL SPECIFICATION

Submitted ____________ Heavy Electronics

Reviewed ____________ Systems Engineering

Approved ____________ Research Division

Research Division
Stanford Linear Accelerator Center
Stanford University
Stanford, California

Issue Date: June 26, 1964

TECHNICAL SPECIFICATION FOR A 48 KW SERIES TRANSISTOR

CURRENT REGULATOR FOR ELECTRO-MAGNETS

PS-900-504-RO

1.0 SCOPE

1.1 This document specifies the minimum requirements for the design and manufacture of a 48 KW, 805 Amp Series-Pass Transistor, Regulator and Amplifier. This unit, connected in series with an external electro-magnet & controlled DC Voltage Power Supply shall regulate the current to an electro-magnet as specified in 3.0.

1.2 The transistor regulator shall be a complete unit with all necessary components wired and ready for operation as herein specified.

1.3 Reliability of operation shall be considered of prime importance in the design and manufacture of the equipment. All possible means shall be employed to assure quality and maximum reliability consistent with the state of the art.

2.0 APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids shall form a part of this specification to the extent specified herein. If a listed document, other than those published by the University, is superseded, the Subcontractor shall bring the matter to the attention of the University without delay.

2.1.1 University Documents

SLAC QC-034-100-01-R3 - Quality Control Workmanship Standard

2.1.2 Other Documents

a. MIL-STD-16C - Electrical and Electronic Reference Designations

b. Federal Communications Commission Rules and Regulations, part 8

c. NEMA Standard, IC 1-2.68 Enclosures - Non-Ventilated Types

d. NEMA Standard, IC 1-2.69 Enclosures - Ventilated Types

2.2 The subcontractor shall bring to the attention of the University any conflict which should occur between this document and those listed in paragraph 2.1 and 3.1 before starting production of the equipment. The University will decide which document has precedence.

3.0 REQUIREMENTS

3.1 General

3.1.1 Specifications and Standards - Subcontractor specifications and standards used during manufacturing shall be compatible with documents listed under paragraph 2.1 and National Electrical code,(wiring and grounding), AWS (welding), ASTM (materials), ASA (screw threads).

3.1.2 Materials, Parts and Processes - All parts and materials shall be new and compatible with design and performance requirements of this specification and documents listed under paragraph 2.1. No process used shall damage parts or materials, or restrict functional operation of the equipment specified herein. Parts having same manufacturer's part number shall be functionally and dimensionally interchangeable.

3.1.3 Protective Coating - Components with exposed surfaces subject to climatic and environmental conditions likely to cause deterioration during service usage shall be protected with a corrosion-resistant film.

3.1.4 Component Ratings - All components within the Regulator shall be used within the component manufacturer's recommended rating for high reliability during a 10 year expected life. All components shall be adequately protected against overloads of transient voltage or current. (See paragraph 3.6 for reliability).

3.1.5 Finish - Unless otherwise specified, cabinet enclosures, front panels and other exterior surfaces (other than components) shall be finished in accordance with SLAC QC-034-100-01. Components may be standard manufacturer's colors.

3.1.6 Identification and Marking - Equipment, assemblies and parts shall be marked for identification. Subcontractor shall attach a nameplate to major assemblies with the following data:

a. Part name (48 KW Series Transistor Current Regulator for Electro-magnets)
b. Manufacturer's part number
c. Manufacturer's name or trademark
d. Manufacturer's serial number
e. Weight of assembled regulator
f. Year of manufacture

3.1.6 (Continued)

g. Input power requirements

h. Regulator output ratings

i. SLAC Specification number PS-900-504-R0

3.1.7 Parts Reference Designations - Parts reference designations and chassis markings shall comply to the numbering method specified in MIL-STD-16C. Marking process shall be in accordance with SLAC QC-034-100-01.

3.2 Performance - Unit shall meet the following requirements:

3.2.1 Regulation System - A multiple loop system shall be used for regulation and shall consist of:

a. A fast response series transistor section with current and voltage feedback, as required for stable operation in this specification.

b. A slow-response system using an external power supply as connected by the University. (See Section 6.0 for the power supply characteristics).

3.2.2 Regulator Power Range

a.	Series Voltage drop:	5 to 60 Volts DC
b.	Output current range:	0 to 805 Amps
c.	Maximum power Dissipation:	Zener Diode clamped for protection

3.2.3 The range of characteristics for the electro-magnet that will be used as a load at the University are as follows:

a.	Resistance:	0.05 to 0.2 Ohms (see 3.2.1)
b.	Load time constant:	0.2 seconds to 2 seconds when measured at frequencies less than 0.1 CPS

c. The pole tips are not laminated (see 3.2.7).

3.2.4 This current regulation system (when used with a separate DC power supply which is not a part of this specification) shall maintain a set DC average current in the load constant to within $\pm 0.005\%$ for load currents from 250 to 805 Amps and to within ± 12.5 Milliamps for currents less than 250 Amps. This specified regulation shall apply for 1 week at a time to any combination of the following conditions after an initial 2 hour warm-up period of the regulator amplifiers and reference circuits; the warm-up time does not apply to the main DC power circuits.

3.2.4 (continued)

a. Step line voltage change: $\pm$2-1/2% (maximum)

b. Step DC input voltage change: $\pm$2-1/2% (maximum)

c. Slowly varying (3 seconds between successive maximum and minimum) input AC or DC voltage: $\pm$5%

d. Slowly varying load resistance: 16% due to heating of the electro-magnet (1% per minute maximum)

e. Ambient temperature: 15°C to 45°C

f. Input cooling water temperature: 10°C to 40°C (for transistor cooling)

g. Output voltage range: 0 to 100% power supply rating

h. For any step voltage changes introduced by any internal equipment of the unit.

i. Resolution: The current control shall be sensitive enough to set the regulated current to within the regulation accuracy over the range of current specified. Coarse and fine controls may be used.

3.2.5 The transistor regulator output shall be able to withstand an accidental overload of 2000 Amps for 0.20 seconds at any initial output voltage without damage to the regulation system or other components.

3.2.6 Overload Protection - Adjustable DC overcurrent interlocks shall be provided.

3.2.7 Current Ripple - The variations in current fed to an electro-magnet as specified in 3.2.3 shall not exceed the following peak to peak values: (See section 6.2 also).

Frequency	Maximum Current Variation (Percent of Set Value)
0 to 30 cps:	$\pm$0.005%
30 cps and higher:	$\pm$0.01%

NOTE: The current ripple in the magnet will be about 10 times higher for this unlaminated magnet than would be calculated on the basis of a laminated magnetic structure and the load time constants in 3.2.3b.

3.2.8 Application

The series transistor regulator described in these specifications will be used in several different modes of operation. The load time constants in each of the following cases will be per 3.2.3b.

3.2.8 (Continued)

a. It will be used with an induction voltage regulator (IVR) controlled DC power supply to energize a single load at a maximum of 80 Volts, 805 Amps DC. It must have a dynamic range sufficient to take care of ±2-1/2% step voltage, (in this mode the center voltage of the dead band might be set to 8 or 10 Volts).

b. It will be used in series with other induction voltage regulator controlled DC power supplies supplying a total power of 425 Volts at 805 Amps DC. In this mode it will act as the fast section of a slow and fast loop regulation system. It must have a dynamic range sufficient to correct for the ±2-1/2% step of the total voltage or ±11 Volts. In this mode the center voltage of the dead band might be set to 17 Volts. The IVR slow loop system would correct for the wide range variations.

c. It will be used in series with other induction voltage regulator controlled DC power supplies supplying a total power of 701 Volts at 805 Amps DC. In this mode it will act as the fast loop of a 2 loop regulation system. The other loop will be a slow induction voltage regulator control of most of the DC power. The higher frequency response available with the series transistor bank is required for an ultimate regulation of ±0.005%.

3.3 Electrical Design - The transistor power-regulation system shall be water cooled and shall meet the following requirements:

3.3.1 Input AC Power: 115 Volts ±5% AC 60 CPS single phase for the regulator control powe

3.3.2 Regulator

a. DC Output and Input Terminals - Two terminals shall be provided for DC power connection with easy access and remote from the control wiring. See Figure 1.

b. Input Current Regulation - The current regulator shall provide an input for a Varian Model F-8 Nuclear Fluxmeter (±10 Volts 20 K Ohm Output impedance).

c. Reference Voltage and Shunt Voltage Monitoring - The reference voltage and regulating shunt or transductor voltage shall be available on the front panel of the regulator for stability monitoring.

3.3.2 (Continued)

d. Voltage Feedback - The front panel shall contain two plugs that will accept DC voltages to be used as stabilization feedback signals. Signal levels 0 $\pm$1 Volt with 1,000 Ohm internal impedance will be provided. This signal source will be insulated from ground.

e. The regulator system should be designed so that the power supply can be turned ON or OFF at any combination of current or voltage without damage to the components. 115 Volt AC control power will be provided from the external controls when the power supplies are turned on. This control power should be used to bias the series transistor bank to minimum voltage drop when the external power supply is turned off.

f. Each power transistor shall have an indicator that identifies the transistor in case of failure. The indicator shall be visible from outside of the cabinet. A light and alarm point for remote monitoring shall be used to alert the operator that a transitor failure has occurred.

g. Free Wheeling Diode rating - 1,000 Amps continuous duty; 300 Volts minimum inverse voltage rating.

h. Regulator Grounding - The regulation system amplifier reference voltage, etc., shall have provision for a single point ground if a transductor. current monitoring system is used. The use of a shunt for the current monitor necessitates that all of the amplifiers reference, etc., be insulated from ground for 600 Volts. (See 3.3.2j)

i. The regulator DC power system shall have a resistance to ground greater than 250,000 Ohms at 1200 Volts DC with the grounding knife switch open and water flowing in the cooling circuits.

j. Isolation - DC circuits of the regulator shall be insulated from ground for 600 Volts. They should withstand a high potential test of 1200 Volts DC repeatedly applied in the field.

3.3.3 <u>Controls and Interlocks</u>

a. A control panel shall be located on the front face of the Regulator. This panel shall contain the critical control function of the regulator; i.e., current control. Provisions shall be made for remote control from a distance of 50 feet.

3.3.3 (continued)

b. Relays contacts shall be made available for the automatic voltage control of the external power supply. Voltage sensing circuits for the relays are to be provided in the regulator (see Figure 1). The voltage level sensing circuits shall provide for up/down relay closures that can be set independently (but without overlap) over the voltage range of six volts to 50 volts. The controls shall have adequate delays and adjustments to automatically re-center the operating range of the transistor regulator when there has been a drift to near one end of its operating range. The relay closure sensing circuit shall provide a relay closure or opening within 16 milliseconds after the series transistor voltage drop exceeds the given set dead band of control.

c. Interlocks: A 115 volt series interlock chain shall be provided with interlock lights. The interlock chain shall terminate in a relay; the relay contacts shall be available for interlocking an external power supply. Interlocks shall include, but not be limited to, the following:

(1) Doors

(2) Water flow switches

(3) Temperature

(4) Overcurrent

3.3.4 <u>Metering</u> (± 2% full scale accuracy)

The following meters shall be provided:

a. DC driver voltage

b. DC driver current

c. DC series regulator voltage (Weston Model 1900 or equal)

d. DC current through regulator (contact making adjustable pointer Weston Model 1075 or equal)

3.3.5 <u>Miscellaneous Provisions</u>

a. Component Mounting - Any multiplicity of components, such as diodes and power transistors, shall be designed for easy replacement without breaking any water circuit.

3.3.5 (continued)

b. Capacitor Discharge Circuits - Any large capacitors shall be provided with a bleeder having a discharge time constant of 15 seconds maximum.

c. Fire Hazard - Design of equipment shall be such that assemblies and components therein shall not create a fire hazard during either service usage or storage. Materials such as the following should be used whenever possible:

(1) Track resistant "Glastic".

(2) Grade FR canvas bakelite (Spaulding C-832 or equal)

(3) NEMA Grades FR-1 and FR-2 paper phenolic

(4) NEMA Grade FR-3 paper epoxy

(5) NEMA Grade FR-4 and FR-5 glass epoxy

(6) Vinyl chloride acetate or Plexiglass 5009B.

3.4 Mechanical Design

The unit shall meet the following requirements:

3.4.1 Cabinet Construction: Unit shall be enclosed in a metal cabinet designed for floor mounting and free standing. Mechanical construction shall consist of an angle iron basic frame which shall sit upon I beam skids. The cabinet shall be equipped for both crane and fork lift handling of the complete unit. No eye bolts shall be used for lifting; however, bolted ears are permitted. Maximum height is 90 inches.

a. The cabinet shall be "drip-tight" and "ventilated" as defined in NEMA standards IC 1-2.68 and IC 1-2.69. Hinged panels or doors shall be provided for those areas requiring service access. Large panels which are fastened with bolts or screws shall have alignment studs to make easy replacement possible. Quick operating fasteners are preferred. Light weight metals are preferred for large panels.

b. Standard EIA relay rack and panel construction shall be used where possible.

c. A blank panel 10-1/4" high shall be provided. The bottom of this panel should be at least 4 feet above the floor level.

3.4.2 Cabling to components in hinged panels or doors shall be done by making long twisted loops in the cable along the hinge, so that repeated opening of doors shall not damage wires or insulation. Stranded wire shall be used in such cables.

3.4.3 Resistors of 50 watt size or larger shall be mounted with machine screws and supported. Solder shall not be used in making connection to these resistors.

3.4.4 No bolted or screwed electrical connection shall depend upon an insulating material (ceramic, phenolic or other) to maintain contact pressure.

3.4.5 Lugs for large size conductors (No. 8 AWG and larger) shall be both crimped and soldered.

3.4.6 When the doors are closed and the panels are in place, there shall be no openings in the cabinet large enough to permit a small mouse to enter.

3.4.7 Ventilation and Water Cooling

a. Ventilation and cooling shall be designed for indoor units with an ambient air temperature range of 15°C to 45°C. Forced air cooling of components is acceptable provided filtering is used on the intake air. The filters shall be located such that they may be easily removed for cleaning. Filters shall be dry-type. Air-flow interlocks shall be provided wherever forced air cooling is used.

b. Cooling water requirements - Demineralized water with a minimum resistivity of 10^5 ohm cm will be supplied from the University water system for cooling of the transistors in the power circuit.

(1)	Supply line water temperature:	10°C to 40°C
(2)	Normal supply pressure:	80 to 125 psig
(3)	Return line pressure:	20 psig (maximum)
(4)	Design pressure:	150 psig
(5)	Static pressure test thru Unit:	225 psig
(6)	Pressure drop:	50 psi (maximum)

c. Construction - Water system shall be constructed of copper, brass, bronze or 18-8 stainless (No. 316 or No. 304), except that insulation connections shall be made with Weatherhead H9 rubber hose or equal. Plastic tubing shall not be used. All metal fittings subject to electrolysis or corrosion shall be made of No. 304 stainless steel.

3.4.7 (continued)

d. Water System Layout - Insulating hose connections should be designed so as to avoid spraying electrical components in the case of water leak.

e. Strainer - An all bronze "Y" strainer with 10-mesh brass or monel screen, Bailey No. 100 with 3/64 inch perforations or equal, shall be used and shall meet the following requirements:

(1) Located in supply line

(2) Easily accessible from outside for cleaning

(3) Adequately supported

f. Water Interlock Switches - Hayes Shureflow water flow interlock or equal meeting the following requirements:

(1) Connected with unions in the return line of each parallel water path.

(2) Located within the outline of the cabinet.

(3) Readily available for servicing or checking through a door without removing any panels or dripping water on components.

(4) Flow switches in combination with temperature alarms may be used to protect several parallel paths.

g. When short hoses are used to make insulated water jumpers, no hose shall be less than six inches long and shall be looped for easy replacement. The hoses, when dry, shall measure greater than 100 megohms per inch when checked at a voltage gradient of 500 volts per inch.

3.5 <u>Environmental Conditions</u>

Unit shall operate under the following conditions:

3.5.1 Temperature - Equipment shall operate within the requirements specified herein over an ambient temperature range of 15°C to +45°C.

3.5.2 Humidity - Without degradation of performance, the equipment shall withstand relative humidities up to 80 percent including the effects of condensation due to temperature change.

3.5.3 Shock and Vibration - Without degradation of performance, the equipment shall withstand normal shocks and vibrations during shipment and handling.

3.6 Reliability

Operating life (design objective): 87,000 hours (ten years) of continuous duty. Choice and rating of components shall be consistent with high reliability. The University reserves the right to approve all schematics, circuit diagrams and part layouts before & during construction. This review of these prints by the University does not remove the responsibility for the design from the Subcontractor.

4.0 TEST PROVISIONS

4.1 Standards and Calibration

All Subcontractor measuring and control equipment used during testing shall bear evidence stating the date of calibration, next calibration date and the laboratory that performed the calibration. Calibrating laboratories must be able to furnish certified records upon request stating that their standards are traceable to the National Bureau of Standards. Certification is not required for equipment standards not yet established by the National Bureau of Standards.

4.2 Procedure and Conditions

Test equipment and procedures required for testing shall be approved prior to initiation of test program.

4.2.1 Test procedures shall contain, as a minimum, the following:

a. List of test equipment intended for use.
b. Detailed sequence of performance tests based on Section 3.0 including sequence of steps for each test to be performed.
c. Laboratory conditions that will prevail during testing.
d. Accumulative operating time check.
e. Provisions for inspection of workmanship.

4.2.2 Test Conditions - Tests shall be performed under the humidity that prevails at the test location provided that relative humidity is not in excess of 90 percent, and temperatures not exceeding those indicated in 3.2.4.

4.2.3 Tests - Equipment testing shall be in accordance with University test plan and the Subcontractor shall demonstrate with either simulated or actual loads that the regulator will perform as herein specified. The final equipment testing may be performed at the University by the Subcontractor if the Subcontractor cannot provide a power supply of sufficient rating. The tests to be performed shall include the following:

a. Each regulator shall be tested separately.

b, The regulator DC power system shall have a resistance to ground greater than 250,000 ohms at 1200 volts DC with the grounding knife switch open and water flowing in the cooling circuits, The regulator DC system is to be given a high voltage test to ground, without water, with 1200 volts DC; record the resistance reading. No insulation failure should be noted.

c, Each regulator shall be run at full power to demonstrate that the regulator will function at the maximum temperatures as specified in 3.2.4. This test is to run until the temperatures within the regulator levels off, but in no case for less than four hours. Component temperatures shall at no time during the test be greater than those recommended by the component manufacturer.

d. Regulation stability shall be checked during 4.2.3(c). The input water temperature shall be controlled over the full range of expected temperatures during the stability checking.

e. The regulation tests and heat run at the factory may be made using a resistive load. The peak to peak current ripple into the resistive load shall be less than $\pm$ 0.01% for all frequencies. It is preferred to make the tests with a magnet as a load.

f. The load resistance and variable voltage control shall be varied to show that the regulator meets the requirement of 3.2.4.

g. The line voltage shall be monitored during the tests to check the stability of the regulator with respect to line voltage steps. The line voltage steps may be artifically generated to demonstrate the adequacy of the regulation system.

4.2.3 (continued)

h. The regulator system shall be tested for a 2000 amp overload for 0.20 seconds. (See Section 3.2.5) Repeat this overload test as required.

i. At the conclusion of the test programs there shall be no evidence of water leakage or other evidence that could lead to an early power supply failure or shortening of expected life.

4.3 Test Records

All Subcontractor test records shall show the following data:

a. Pertinent test data
b. Equipment used
c. Test procedures used and conditions
d. Block diagrams of all test setups used
e. Irregularities observed during testing
f. Recorded total elapsed time of each test and increments between each sequential test step

5.0 PREPARATION FOR DELIVERY

5.1 Preservation and Packaging

All equipment shall be adequately protected against damage during shipping by common carrier.

5.2 Marking for Shipment

All exterior shipping containers shall be adequately and properly marked for identification. All packages shall include the following minimum markings:

a. Addressee
b. Shipper
c. University purchase order number and/or subcontract number
d. Special markings, warnings or tags in accordance with ICC regulations.
e. Description of contents.

6.0 NOTES

6.1 Three instruction books with appropriate schematic diagrams and parts lists of all electrical components or sub-assemblies shall be furnished at the time of delivery of the regulator.

6.2 External DC Power Supplies

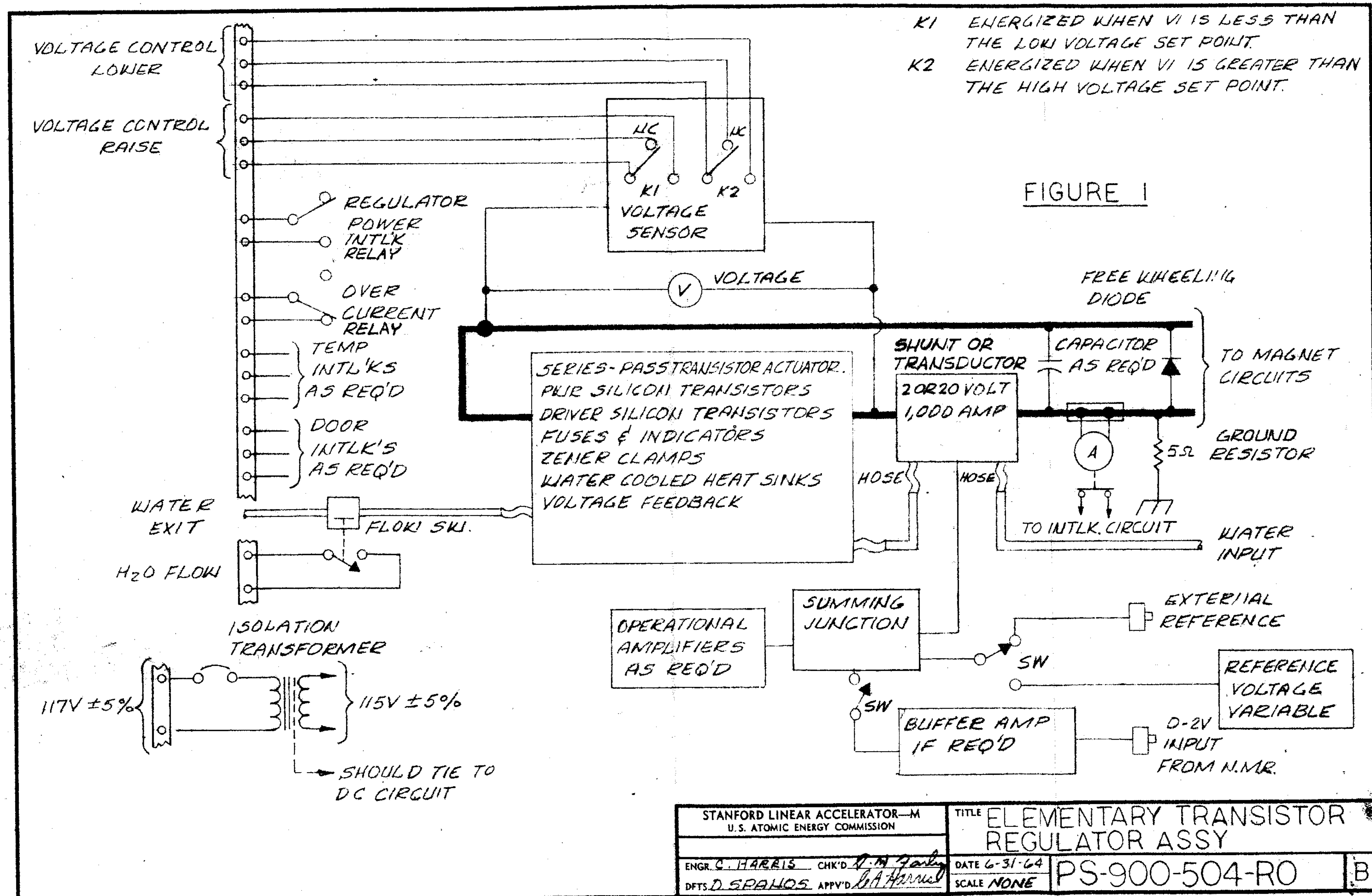
The specifications for the typical power supplies that the University may use with this series transistor regulator are enclosed for information. These are:

Dual 130 KW output DC power supply

85 KW SCR regulated power supply

These power supplies may have a one percent peak to peak voltage ripple. Figures 3, 4 and 5 show how these units may be connected to form a complete system as described under 3.2.1 applications. The LC filter on the output if these power supplies might be as large as 200 μ henries and 500,000 MFD. The DC short circuit current may be as high as 16,000 Amps for 50×10^{-3} sec before the main AC contactor is opened.

6.3 During the preliminary investigations for possible vendors for this regulator system, it is possible to consider the stable reference voltage system as a separate item to be furnished by the University. The University would like to know the added cost if this reference voltage is supplied with the regulator.



K1 ENERGIZED WHEN V1 IS LESS THAN THE LOW VOLTAGE SET POINT.
K2 ENERGIZED WHEN V1 IS GREATER THAN THE HIGH VOLTAGE SET POINT.
FIGURE 1
VOLTAGE CONTROL LOWER
VOLTAGE CONTROL RAISE
NC
NC
K1
K2
VOLTAGE SENSOR
REGULATOR POWER INTLK RELAY
OVER CURRENT RELAY
TEMP INTL'KS AS REQ'D
DOOR INTLK'S AS REQ'D
VOLTAGE
FREE WHEELING DIODE
SHUNT OR TRANSDUCTOR
2 OR 20 VOLT 1,000 AMP
CAPACITOR AS REQ'D
TO MAGNET CIRCUITS
SERIES-PASS TRANSISTOR ACTUATOR.
PWR SILICON TRANSISTORS
DRIVER SILICON TRANSISTORS
FUSES & INDICATORS
ZENER CLAMPS
WATER COOLED HEAT SINKS
VOLTAGE FEEDBACK
5Ω GROUND RESISTOR
HOSE
HOSE
TO INTLK. CIRCUIT
WATER EXIT
FLOW SW.
WATER INPUT
H2O FLOW
OPERATIONAL AMPLIFIERS AS REQ'D
SUMMING JUNCTION
EXTERNAL REFERENCE
SW
SW
REFERENCE VOLTAGE VARIABLE
BUFFER AMP IF REQ'D
0-2V INPUT FROM N.M.R.
ISOLATION TRANSFORMER
117V ±5%
115V ±5%
SHOULD TIE TO DC CIRCUIT
STANFORD LINEAR ACCELERATOR—M
U. S. ATOMIC ENERGY COMMISSION
TITLE ELEMENTARY TRANSISTOR REGULATOR ASSY
ENGR. C. HARRIS
CHK'D
DFTS. D. SPAHOS
APPV'D
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SCALE NONE
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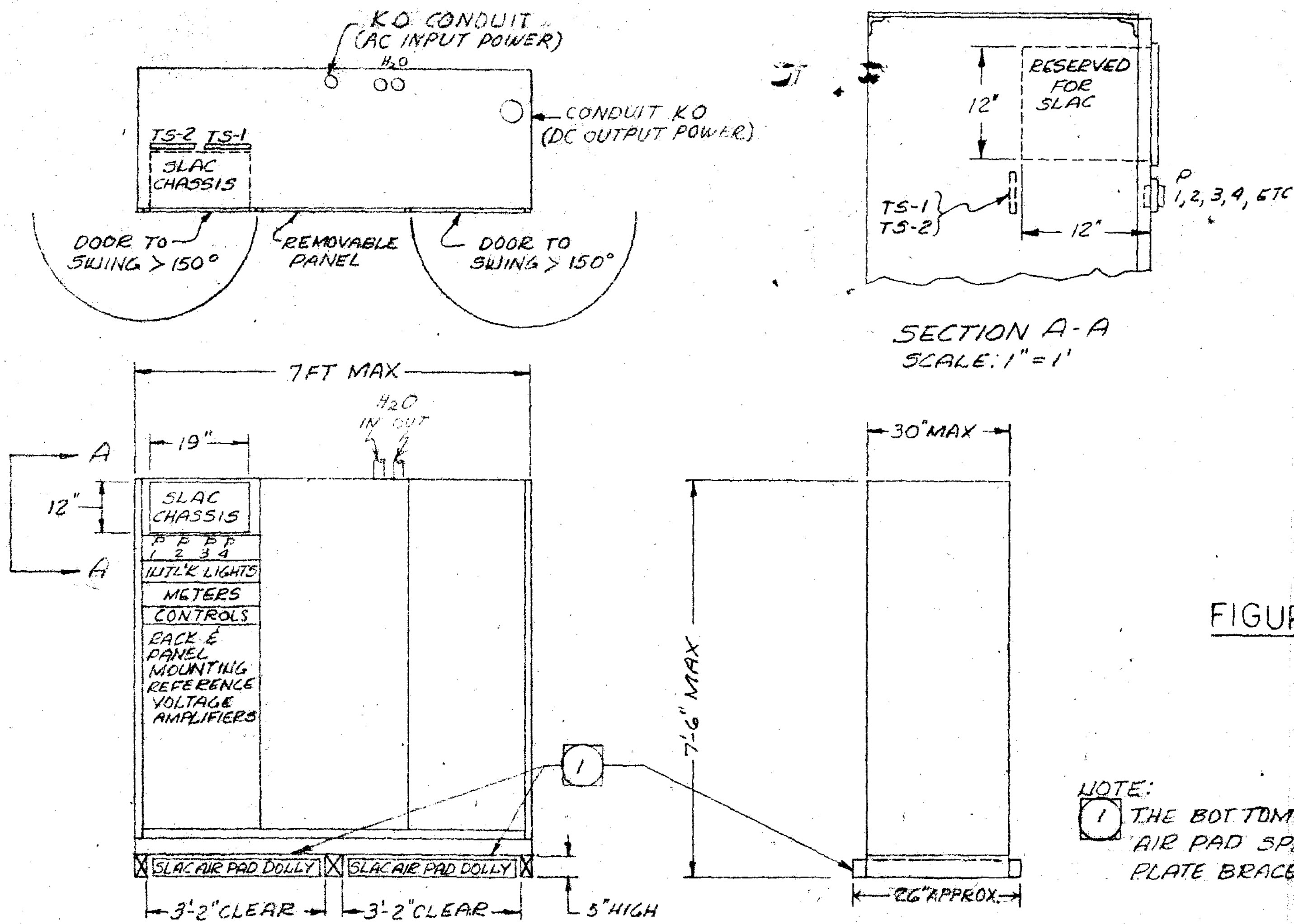

FIGURE 2

NOTE:
(1) THE BOTTOM OF THE CABINET OVER THE AIR PAD SPACE SHALL BE A SMOOTH PLATE BRACED TO TAKE UNIFORM LOADING.

STANFORD LINEAR ACCELERATOR U. S. ATOMIC ENERGY COMMISSION	TITLE TRANSISTOR REGULATOR
ENGR. C HARRIS CHK'D G. M. Gaaby	DATE 6-24-64
DFTS. D SPALLOS APPV'D C.A. Harris	SCALE 1/2" = 1'
PS-900-504-R0	B

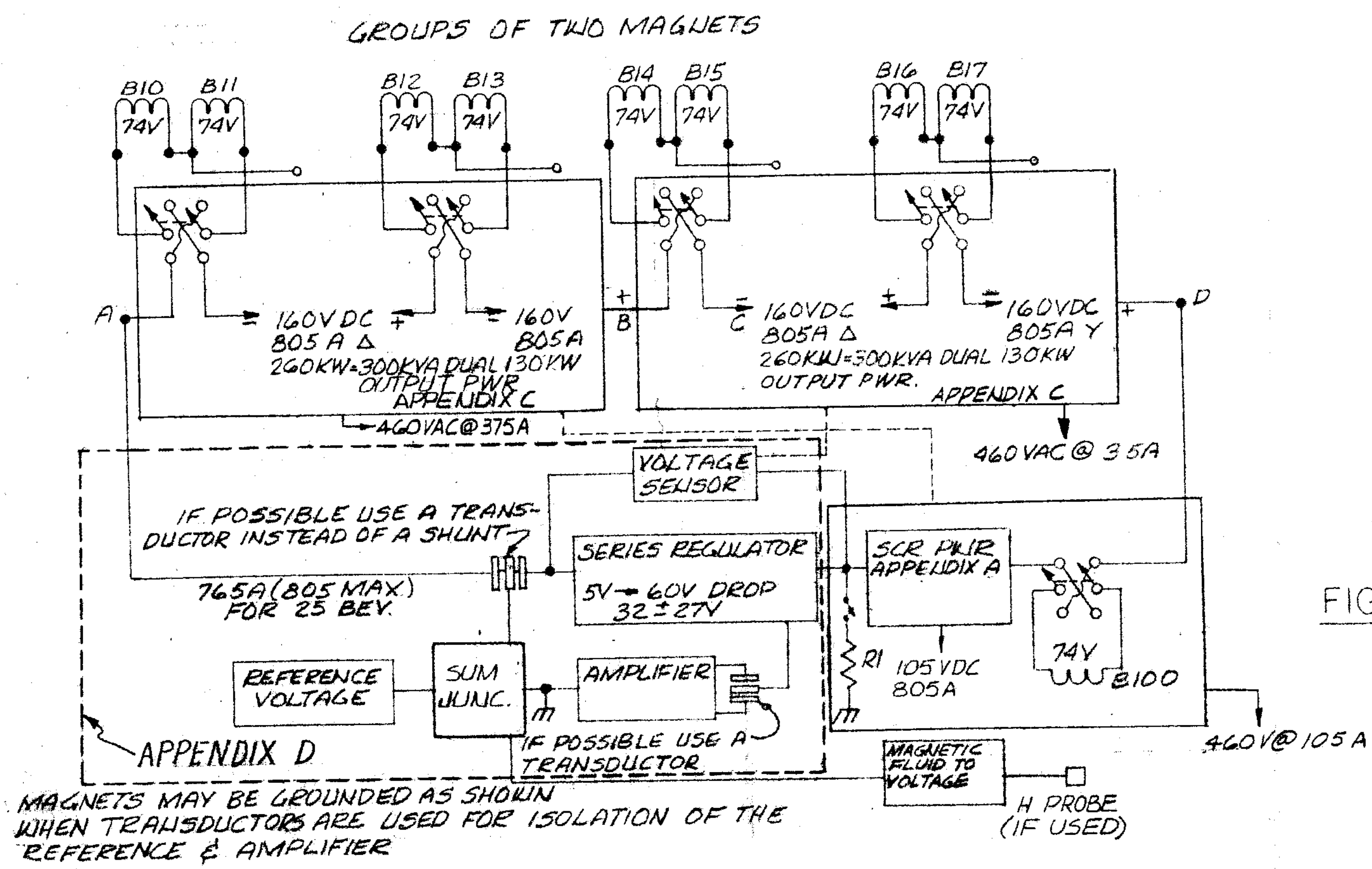

FIGURE 3

STANFORD LINEAR ACCELERATOR—M U. S. ATOMIC ENERGY COMMISSION	TITLE 'A' BEAM BENDING MAGNET DC POWER SYSTEM	
ENGR. C. HARRIS CHK'D D. W. Fauley DFTS. D. SPANOS APPV'D [signature]	DATE 6-26-64 SCALE NONE PS-900-504-R0	B

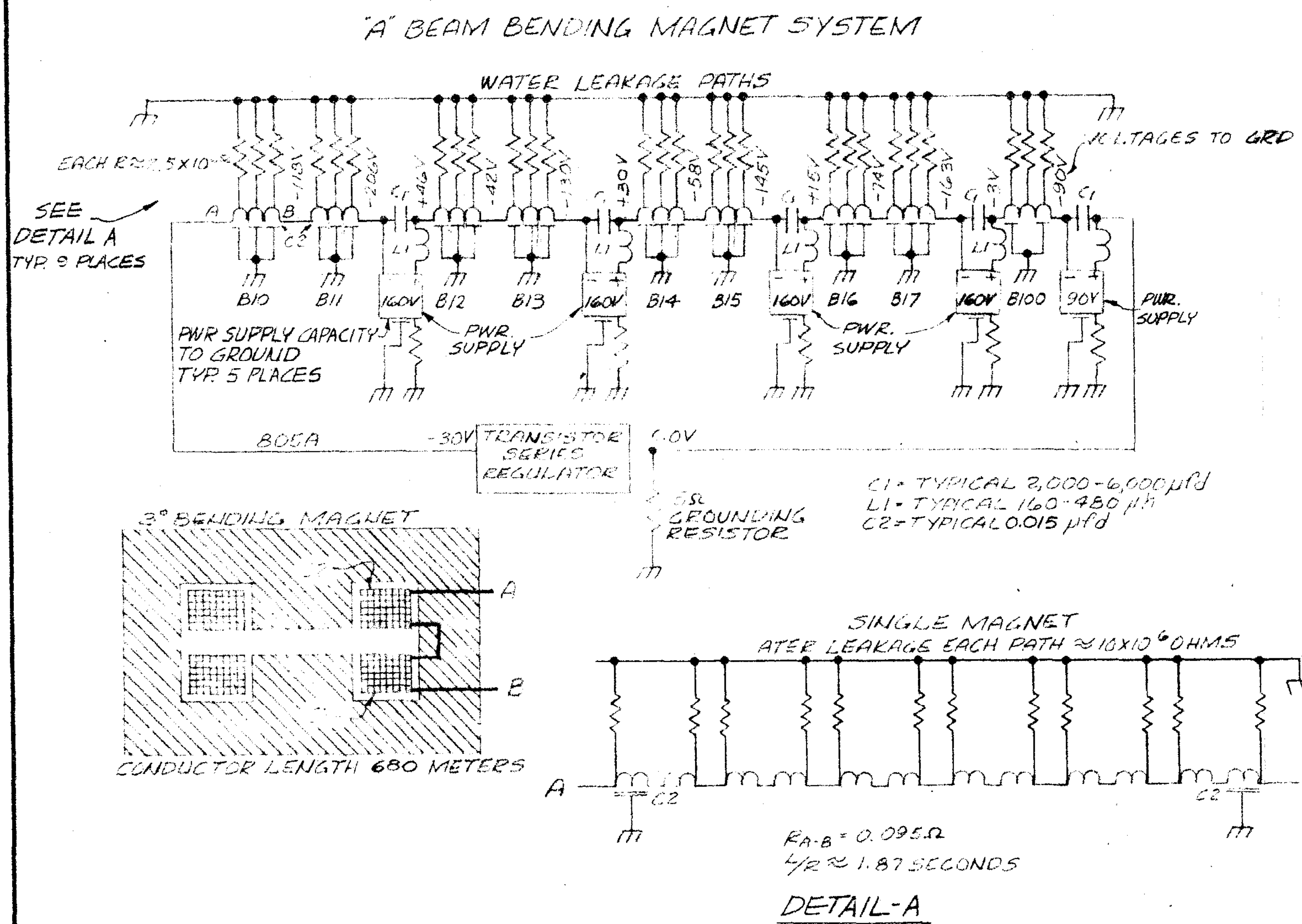

FIGURE 4

STANFORD LINEAR ACCELERATOR—M U.S. ATOMIC ENERGY COMMISSION	TITLE 'A' BEAM BENDING MAGNET SYSTEM
ENGR. C. HARRIS CHK'D	DATE 6-24-64
DFTS. D. SPALLOS APPV'D	SCALE NONE
	PS-900-504-R0 B

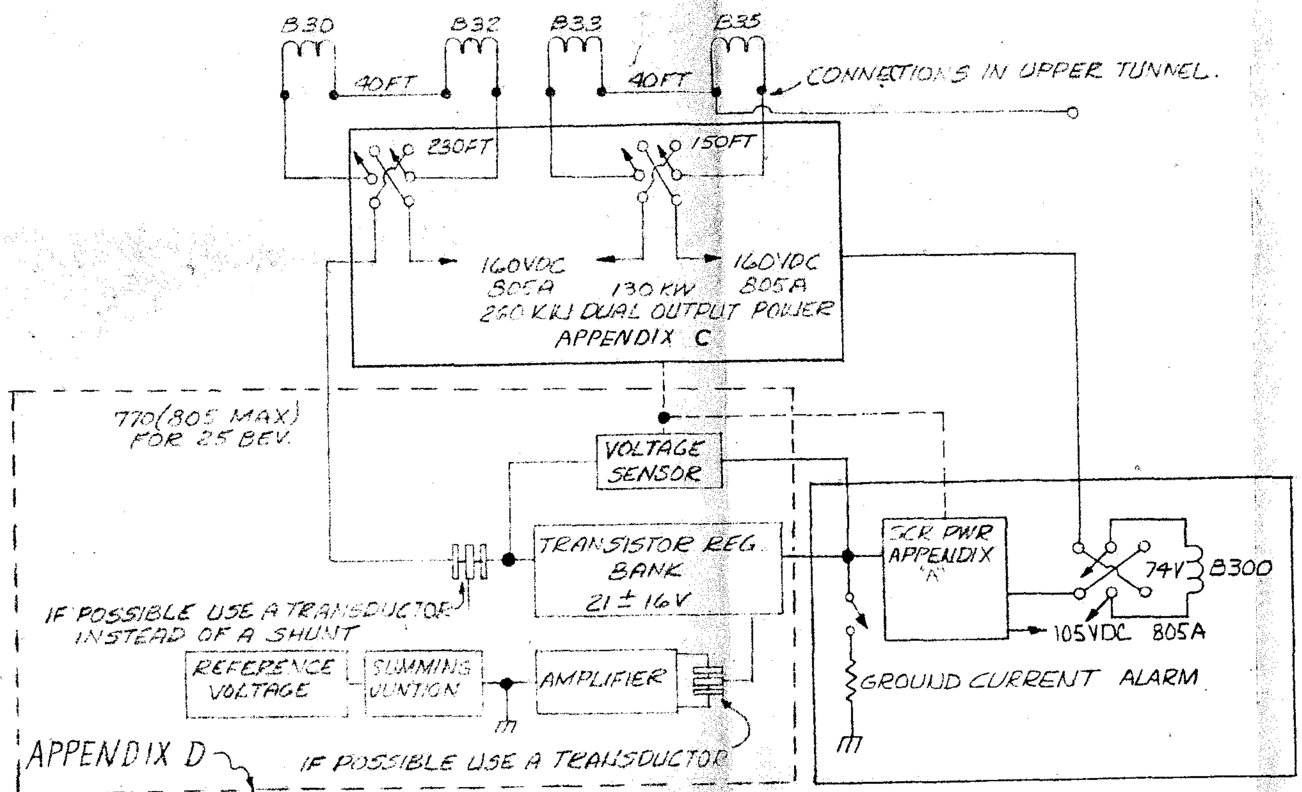

FIGURE 5

STANFORD LINEAR ACCELERATOR—M U.S. ATOMIC ENERGY COMMISSION	TITLE 'B' BEAM MAGNET DC POWER SYSTEM	
ENGR. C. HARRIS CHK'D [illegible] DFTS D. SPALLOS APPV'D [illegible]	DATE 6-25-64 SCALE NONE	PS-900-504-RO — B

STANFORD LINEAR ACCELERATOR CENTER
Quality Control Workmanship Standards
QC-034-100-01-R3
August 20, 1963

1.0 SCOPE

1.1 This document describes the minimum requirements of the University for the manufacture and assembly of mechanical, electrical and electronic equipment. It is not intended to be complete or to limit the quality of materials and workmanship offered.

1.2 This standard shall apply to the fabrication of equipment by contractors or the University from engineering designs furnished by the University or the contractor. The University may furnish the following design information with the purchase order or subcontract.

a. The equipment performance specification.
b. The schematic circuit diagram.
c. Parts list.
d. Drawings.

1.3 Where discrepancies occur between this standard and the specifications and drawings listed above, the above listed items shall take precedence in the order shown.

a. In cases where the purchase order states that the subcontractor is also responsible for design and/or development of the units ordered, fabrication practices recommended by the subcontractor may be followed in lieu of those required in some sections of this standard. However, the fabrication practices to be substituted must be approved by the authorized University representative, and the high quality of construction established by this standard remains a requirement of the order.

2.0 APPLICABLE DOCUMENTS

2.1 The applicable provisions of the latest issue of the following documents shall form a part of this document. If a listed document other than those published by the University is superseded, the matter shall be brought to the attention of the University by the subcontractor without delay.

a. Federal Specification TT-P-636, Primary Coating, Synthetic
b. Federal Specification TT-P-664, Primary Coating, Synthetic, Rust Inhibiting
c. Federal Specification TT-E-529
d. Federal Standard 595, Colors

3.0 GENERAL

3.1 *Quality of Material and Workmanship*

a. *Quality Level*—The quality of material and workmanship shall comply with the best standards obtainable for high-quality custom equipment fabricators. All equipment shall be manufactured and completed in a thoroughly neat and workmanlike manner.
b. *Parts*—The manufacturer shall use only new, high-quality parts of current manufacture and ready availability, and shall advise the University of the discontinuance (by the part manufacturer) of any part listed in an order.
c. *Substitutions*—All substitutions, including "or equal," must be approved by the designated University representative.
   (1) "Or equal" substitutions must be of equal quality in every respect, and must not affect the original design or assembly.
   (2) In cases where any substitutions (including "or equal") are made without specific written approval of the designated University representative, if the University chooses to accept the items, the manufacturer will be responsible for all changes necessary to meet the operational requirements of the completed equipment, even though operational specifications may not be included in the purchase order.

3.2 *Workmanship*

a. The equipment, including all parts and accessories, shall be constructed and finished in a thoroughly workmanlike manner. Particular attention shall be paid to neatness and thoroughness of soldering, wiring, mating of parts and assemblies, plating, painting, machine-screw assemblies, welding and brazing, and freedom of parts from burrs, sharp edges and corners.

3.3 *Interchangeability*

a. Mechanical and electrical interchangeability shall exist between like assemblies, subassemblies and their replaceable parts, regardless of manufacturer or supplier. Interchangeability, for the purpose of this paragraph, shall not mean identity. Interchangeability shall mean substitution of like assemblies, subassemblies and replaceable parts. The substitution shall be accomplished without physical or electrical modification of any part of the equipment or assemblies, including cabling, wiring and mounting. Substitution shall be accomplished without resorting to selection. Design tolerances shall be sufficiently broad to accommodate various sizes and characteristics of any article, such as tubes, resistors or other parts having limiting dimensions and characteristics set forth in the specifications for the particular item when required by the purchase order or subcontract.

4.0 REQUIREMENTS

4.1 *Mechanical Design*—The design of the equipment shall provide maximum convenience and safety to personnel in installing, operating and maintaining the equipment. Suitable protection shall prevent contact by personnel with moving mechanical parts such as gears, fans and belts, when the equipment is complete and in the operating position. Sharp projections on cabinets, doors and similar parts shall be avoided.

a. *Dimensions and Tolerances*—All dimensions and dimension tolerances shall be given on the drawings.
   (1) If tolerances are not given on the drawings, these tolerances shall apply:
      Sheet metal
         $\pm 1/32$ inch to lengths of 1 foot
         $\pm 1/16$ inch to lengths from 1 foot to 4 feet
         $\pm 1/8$ inch to lengths from 4 feet to 12 feet
      Machined parts
         ± 0.005 inch to lengths of 6 inches
         ± 0.010 inch to lengths of 6 inches to 24 inches
         ± 0.020 inch to lengths in excess of 24 inches
   (2) Measurements of repeating tolerances, such as a series of equally spaced holes in a straight line, shall not show additive error tolerances. When dimensions and tolerances affect the interchangeability, operation or performance of the equipment, they shall be held or limited accordingly.
   (3) Machining, drilling and forming shall be done with the use of accurate templates, jigs or gauges. Boxes, cases, shields and compartment walls shall be made by casting, drawing or bending and welding; except when ease of servicing of equipment requires that a removal panel construction be used, or when the applied stresses dictate the use of a strong alloy which does not provide a good weld for such parts, bolting may be used.

4.2 *Fabrication and Assembly*

a. *General Fabrication*—Holes may be either punched or drilled. All burrs and sharp points to be removed. Tool marks and fabrication blemishes must be kept to a minimum. Finishes below 64 RMS shall have no tool marks or fabrication blemishes.
b. *Forming*—Formed edges are to be free of stress lines and cracks. All sharp sheared edges shall be rounded. All formed edges shall have minimum bend radii equal to two times the thickness of the metal unless otherwise specified.

main bare shall be caustic dipped or alodyned. Where brightwork is specified for parts fabricated from carbon steels, finish shall be cadmium plate. Machined or welded stainless steel parts shall be cleaned and passivated with nitric acid–dichromate mixture. Parts fabricated from copper to copper alloys shall be bright dipped. All piping shall be clean and ends plugged until installation.

f. *Mounted Hardware and Tapped Holes*—Tapped holes of parts to be painted shall be chased following painting. Tapped holes of parts to be plated shall be plugged prior to plating. Hinges, catches, screws, nuts shall be removed and remounted after completion of finish process. If breaks of film occur on either the hardware or surrounding mounting area, touch-up paint shall be applied per paragraph 4.3d.

g. *Covers and Shielding*—Brass and copper covers and shields shall be bright dipped. Aluminum covers and shields shall be caustic etch or alodyne finish.

4.4 *Marking—Front Panels*

a. *Life Expectancy*—All markings shall be of such quality as to last the expected service life of the equipment.

b. *Marking Procedure*—Front panels shall be silk screened or engraved as detailed on the drawing. Rear face of panels shall be rubber stamped. All characters shall be sans-serif capital Gothic type. Unless otherwise specified, rubber stamping shall be performed with ink per Federal Specification TT-E-529. Use black paint on light background and light paint on dark background. No varnish shall be used on engraving or silk screening. All engraving, rubber stamping, and/or silk screening shall be in location as shown on drawings.

(1) The name of the chassis unit, as given on the drawing, shall be placed on the front panels as follows:

(2) Panels 8¾ inches high or less, the name shall be ½ inch down from top of panel to top of letters, unless otherwise specified.

(3) Panels larger than 8¾ inches, place 1 to 3 inches down for best appearance.

(4) Center the title horizontally, unless components interfere. Move left or right if necessary, but consider neatness in all cases.

(5) Letters shall be 5⁄32 inch high with maximum line width of 1⁄32 inch, using Gothic-type lettering.

4.5 *Marking—Chassis*

a. *Procedure*—All major components shall be marked at the most readable point on the chassis, with neat, legible letters ⅜ inch or less, by means of stencils, stamping, engraving, silk screen or rubber stamps. The Western Electric No. 2315R stamp is acceptable. Examples of major components are tubes, transformers, chokes, large resistors, can-type capacitors and terminal strips. Component marking shall be as given on the schematic diagram.

(1) Black ink shall be used on light background, and white ink on dark background, and shall be covered with a coat of clear lacquer.

(2) Plugs mounted on the rear panel shall be marked on the chassis exterior with name (if any) above the plug and the number below it.

(3) Plugs, switches, posts and fuses mounted on front panels shall have their names and/or rating stenciled or silk screened on the front of the panel, and their letter or number designations (such as P_1, S_1) stenciled on rear (inside) of the panel. Marking on inside of chassis shall be located for maximum readability.

(4) The type of designation of each tube and the appropriate reference designation shall be marked adjacent to the tube socket on the tube side of the chassis or supporting structure for identification of the particular tube. The reference designation used to identify the tube socket and type designation of the tube shall be marked on the reverse side of the chassis adjacent to the socket. If available space does not permit such marking of tube-type designations, then reference designation for tubes and sockets shall be placed where it is visible when viewing either the tubes or the bottoms of the tube sockets.

(5) Stenciling on the panels which shows above the chassis mounting plates shall read right side up when the chassis is in normal position. Stenciling on the panels which shows below the chassis plates shall read right side up when the chassis is upside down.

(6) Electron tubes are marked with "V" number on top and bottom of chassis. The tube type is shown on the top only.

(7) Keyways of miniature tube sockets shall be indicated on top of the chassis plate by an adjacent stenciled line approximately 5⁄32 inch wide and ½ inch long.

(8) Multichannel circuits within the same chassis shall be stenciled to read left-to-right from the front and right-to-left from the rear.

(9) The current rating of each circuit breaker shall be stenciled on the back of the breaker (if space permits) or on the panel, so as to be easily read after chassis assembly.

(10) Stencil all first and last contacts of each terminal strip, and every fifth contact in between (Western Electric strips, every tenth between).

4.6 *Welding*

a. *General*—Welding shall be in accordance with requirement specified on weldment drawings. When specified, all class "A" welding shall be performed by qualified class "A" welders, certified by an approved testing laboratory. Certified welders shall submit certification upon request. All surfaces to be welded shall be clean of rust, dirt, scale and similar contaminated coatings. All welds shall be free of cracks, excessive porosity, burned areas, undercutting, and shall have adequate penetration. Tensile strength requirements, as specified, shall be met.

(1) All jigs and fixtures used shall be capable of minimizing warping or misalignment of joined metals. Electrodes used in arc welding shall produce a weld having chemical and physical properties similar to those of the parent metal. All weakening of welded parts (a short distance from the weld) due to annealing as a result of the welding process shall not reduce the strength below design requirements. Where stresses occur from welding, welded parts shall be stress relieved. All welds shall be clean of scale, weld splatter and oxide by abrasive cleaning. When spot or seam welding is specified, number of welds shall be sufficient to provide adequate strength. Anti-splatter compound shall be used in inert-gas welding processes.

4.7 *Electrical Design*—Provision shall be made to prevent personnel from accidental contact with voltages in excess of 30 volts while operating equipment(s). Means shall be provided so that power may be removed while installing or interchanging equipment(s), components or parts. This requirement shall also be met when tubes or fuses are being changed. In addition, this requirement requires protection to personnel from capacitor discharges. The main power ON-OFF switch shall remove *all* power from the complete equipment.

4.8 *Wire, Cable, Cords and Connectors*

a. *Types and Sizes*—For all chassis wiring except filament circuits, hookup wire shall be no smaller than No. 20 AWG, unless otherwise specified. Smaller wire may be used on solid-state circuitry, such as printed board, etc. Select wire sizes so that the following ratings are not exceeded:

Wire Size AWG	Current Amperes
8	30
10	20
12	15
14	10
16	7
18	5
20	4

NOTE: This table has been derated to satisfy close spacing and temperature problems of electronic chassis.

(1) For filament supply circuits only, hookup wire sizes shall be selected so that the minimum current for a given run does not exceed the appropriate value in the table below. This table applies only to filament wiring within a chassis and is based on (1) a drop of 0.076 volts, or 1.2% on a 6.3-volt circuit, and (2) the filament loads are practically all lumped at the far end of the line:

the number of leads terminating at any one terminal to three. The attachment of these leads shall be effected in a manner to permit unsoldering without damage to any part. Wires shall be connected to the tie points with a one-turn wrap. Except where stray circuit capacity or other deleterious effects may be introduced or when it is impractical due to space considerations, a short wire end (approximately 1/16 inch) shall be left.

g. *Grounding*—All chassis grounding shall be done with lugs.

h. *Filament Leads*—Unless otherwise required, AC filament leads need not be twisted.

k. *Interconnections*—All interconnections are to be made as short as possible (except AC and filament leads). Special care shall be taken with leads in high-impedance circuits to avoid excessive capacitance to ground and to preserve minimum inductance in the leads.

m. *Potentiometers*—Potentiometers shall be wired so that "CW" designates the clockwise rotation of the potentiometer, when viewed from the shaft side.

(1) Grounding points and use of shielded wire shall be only as shown on the drawings or production models.

4.10 *Mounting Small Components*

a. *Capacitors*—All capacitors shall be securely mounted and stress relieved. They shall be mounted by means of wire leads; except those capacitors whose weight does not exceed 5 grams may be secured by leads only, provided that the total length of leads from the capacitor to the terminals, lugs or tube socket pins shall not exceed 1 inch unless other mechanical support for the body of the capacitor is provided.

(1) Electrolytic capacitors shall be spaced away from heat-radiating surfaces wherever possible if mounting details are not furnished.

b. *Resistors*—Resistors shall be securely mounted and stress relieved in such a manner as to allow for expansion with temperature changes. They shall not be mounted by means of wire leads unless other mechanical support is provided for the body of the resistor, except that the unit resistors whose weight does not exceed 5 grams may be secured by only their leads if the total length of both leads from the resistor to the terminals to which the resistor is secured does not exceed 1.0 inch. In no case shall wire leads be less than 1/4 inch.

c. *High Voltage*—Circuits over 1,000 volts shall be wired with a minimum of 1 inch clearance to ground and to adjacent components for each 10,000 volts.

4.11 *Soldering*

a. *General*—Soldering shall be so performed that both a good electrical and a mechanical connection are assured, and that no damage is caused to adjacent parts. All joints shall be mechanically secure, and shall be clean before the application of solder.

(1) Only resin, resin alcohol or equivalent plastic mixtures shall be used as flux, and then only when absolutely necessary.

(2) Each conductor or lug shall be tinned prior to making the mechanical connection. The conductors and/or lugs are to be heated after making the mechanical connection and prior to applying the connection solder to ensure the free flow of solder over the surface of the joint.

(3) All parts of a soldered joint are to be held motionless until the solder solidifies. There shall be no evidence of "cold joints." Sufficient heat shall be applied so that solder flows freely and completely over the joint. The soldered connections shall be free from excess solder and flux, such as drippings and joints. Generally, only the amount of solder and flux necessary to solder the joint shall be applied. Solder will be Alpha, Tri-core Rosin 60/40—.062-inch wire, Alpha Metals, Inc., or equivalent.

(4) Soldering techniques used for connection of crystal diodes, precision resistors and similar temperature-sensitive elements shall prevent excessive heating in the circuit element without affecting the quality of the solder joint.

(5) Unless specifically approved, no assembly shall depend solely on soft solder for mechanical strength, except for variable capacitor plates and sections and other relatively light parts that are of accepted commercial design and that have, by actual use, proved to be generally suitable for use in electronic equipment. All solder connections shall be cleaned completely of flux, using alcohol or equivalent solvent.

(6) All connections to pins of multi-pin plugs shall be made by first tinning the conductor, then inserting it into the pin, keeping the outside of the pin free of solder. The pin and the bare conductor shall be covered with sleeving. When a conductor is assembled to a cable, clamps shall be used where appropriate to relieve the soldered connections of any stress. Where necessary, rigid inserts shall be used to adapt the clamp to the cable, with the shield braid, if any, between the insert and the clamp. Cup-type connectors shall not have more than one wire per cup unless specifically authorized.

5.0 INSPECTION AND SPECIAL TOOLS

5.1 *General*—Inspection shall be performed to the requirements of the procurement specification and these standards.

5.2 *Manufacturer's Inspection—Mechanical*

a. *Neatness*—Particular attention shall be paid to neatness and thoroughness of all mechanical assembly. All units shall be cleaned completely. This includes removal of spattered solder, flux, metal chips and other foreign material. Screw heads and nuts that are deformed shall be replaced.

5.3 *Manufacturer's Inspection—Electrical*—The manufacturer shall inspect each outgoing equipment(s). Errors in wiring or assembly shall be corrected. Also, manufacturer shall connect the equipment(s) to the proper primary voltage(s) (when applicable), and then check for shorts, arc-covers and correct operation. Acceptance tests shall be performed when specified.

5.4 *Special Tools*—The manufacturer shall include in the shipment any special tools needed in installation, calibration or maintenance of the equipment.

SUGGESTIONS FOR IMPROVEMENT

The University desires to obtain high-quality equipment at the lowest cost without sacrificing reliability. The best possible relations with subcontractors and manufacturers are important. Subcontractor's constructive suggestions for better ways and means of attaining this goal are welcome and will be given immediate consideration.

BSY MAGNET POWER SUPPLIES

SCHEDULE FOR PROCUREMENT

POWER SUPPLY	Number to be Purchased	Final Review Completed	Out for Proposal or Bid	Award Contract	Received Power Supplies
84.5 KW SCR Regulated Appendix A PS-900-503-R2	5	Sept. 1, 1964	Sept 14, 1964	Nov. 16, 1964	April 15, 1965
60 KW (Dual 30 KW) Appendix B PS-900-505-R1	5	Sept. 1, 1964	Sept. 14, 1964	Nov. 16, 1964	June 25, 1965
260 KW (Dual 130 KW) Appendix C PS-900-506-R1	6	Sept. 1, 1964	Sept. 14, 1964	Nov. 23, 1964	July 30, 1965
48 KW Transistor Regulator Appendix D PS-900-504-R1	2	Sept. 1, 1964	Sept. 14, 1964	Nov. 23, 1964	June 25, 1965
Conversion panels for Control	20	Dec. 20, 1964	Jan. 30, 1965	March 30, 1965	May 30, 1965

APPENDIX

G

STATIC RECTIFIERS VRS. MOTOR GENERATORS

Readers of this report will undoubtedly wonder why I seemed to have ignored the possible use of MG sets for these applications.

There is no question in my mind that MG sets could be used. They can be regulated to 0.1% with ease, and they are somewhat free of line voltage disturbances that will plague the engineer planning an SCR regulated power supply.

Regulation systems requiring ± 0.01% stability or better may require a fast narrow range system in series with the main current (such as a series transistor bank). The series regulator may be required to compensate for once per revolution variations in generator output voltage. Highly regulated systems using MG sets, even with synchronous motors, can have regulation stability problems associated with the natural torsional vibration frequency of the motor-generator masses. These problems are particularly important if there are pulsed loads on the same a-c power system that can produce a voltage change or phase change and that have a repetition frequency close to the natural frequency of the MG set combination.

Space

MG sets will normally require a larger floor space than rectifiers. Some of this is because MG sets tend to be low and long. Rectifiers on the other hand can be can be constructed in most any configuration that is best suited to a power supply building layout.

More floor space is required around the outside of an MG set than a rectifier to allow for the required maintenance inevitably required.

Noise

Buildings with many MG sets are always noisy. This can lead to difficult communications when servicing units next to others in operation. A high noise level is not desirable when an accelerator control room is near by as in the case of the Beam Switchyard Data Assembly Building.

Foundations

The larger MG sets may require special foundations to hold the sets level and rigid; without heavy foundations an MG set might roll over if a short circuit occurred on the d-c system.

Short-Circuit Possibilities

There is always a possibility of a short circuit in a magnet power system. A rectifier system can be designed to protect itself in case of such a fault. The commutator of a d-c generator may flash-over in the event of high short circuit currents. A flash-over would require considerable maintenance before putting the set back into operation.

Naturally, all care will be taken to minimize the possibility of a short circuit. Some obvious ways are to keep opposite polarity leads separated by a ground plane wherever possible. These d-c power systems are grounded through a high impedance and monitored for ground faults. A ground fault will turn off the power system before a line to line fault develops.

The "A" bending magnets, the "B" bending magnets and the Dump Magnets consist of a series group of magnets and power supplies alternated to give a minimum voltage to ground. This type of connection minimizes the possibility of a fault resulting in hazardously high short circuit currents.

Line Harmonics

Obviously MG sets produce a minimum of harmonic distortion on the a-c power lines.

Harmonics and low power factor can be of serious consequence in the use of rectifiers. The system I am proposing uses a minimum of SCR phased back units, therefore, we should be in a good position on power factor. The harmonics will be kept low by using multi-phase rectifiers.

Service and Reliability

MG sets have been successfully operated for many years but they have always been blessed with a continual maintenance program. High maintenance is required because of winding deterioration, brush life, commutator wear, and bearing problems.

Brush life can become a serious problem on MG sets for this type of application. Care must be taken to ensure that the machine is not run for long periods at zero or low current because this tends to eliminate the natural lubrication between the brushes and the commutator with a consequent shortening of brush life.

I believe that silicon rectifier power supplies, SCR or otherwise, will operate for longer trouble-free periods and with less skilled personnel tending them. Persons trained in d-c power supply and regulator amplifiers are also valuable for servicing the other electronic equipment that makes up the rest of the accelerator controls; those persons associated with maintaining large motor generators are not usually of this caliber.

Voltage Control

I must admit that it is more economical to control the voltage output of an MG set over large ranges than is possible with rectifiers.

Whenever a large rectifier is considered there will always be an economic factor tending to make a smaller range of continous voltage control desirable. The wider the range of continuous control the higher the cost.

Reversing

The polarity of an MG set may be easily reversed by electronic control on the generator field.

Reversing switches must be used on rectifiers; this increases the cost and brings the output leads near each other which can be a concern regarding short circuits.

Safety

MG sets are less safe than rectifiers because of the ever presence of a large rotating mass that is a hazard to work around.

Also, when an MG set is turned off there is considerable time delay before the voltage on the system is absolutely zero. MG sets do coast for several minutes unless some form of dynamic braking is used. Dynamic brakes may be a hazard in the case of turning off on a fault because power may be poured into the fault from the dynamic brake circuits.

High Frequency Control

There is one combination of MG set that does look desirable for certain applications.

Instead of using a motor and a d-c generator we could have the motor drive a 400 cps 3 ϕ alternator; the use of a silicon controlled rectifier coupled to the a-c output would be attractive to provide a system with a higher frequency response and better line isolation than is possible with SCR on a 60 cps power line.

In this way, the motor gives line isolation, the SCR gives frequency response and probably eliminates the use of a transistor regulator. Unfortunately this is probably economical only up to about 100 KVA, but is a possibility if a 3 ϕ SCR rectifier at 60 cps proves to be too slow for some of the applications required of the unit described in Appendix A.

The problem of noise is increased with a 400 cps alternator, and we would have the other maintenance problems of an MG set. The cost of this solution is less than using a transistor bank if the 3 ϕ 60 cps SCR's are too slow for the Dump circuits. We should know within a few weeks which direction to take.

Conclusions

After all is said and considered, I believe that SCR controlled rectifiers and standard IVR controlled rectifiers when used in proper proportions will produce a d-c power system more economically and with better reliability than is possible with MG sets.