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ACCELERATOR DEVELOPMENT FOR THE NRL FREE ELECTRON LASER PROGRAM

FINAL REPORT
PSI-FR-121

JUNE 1988

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This work describes work performed on the linear induction accelerator (LIA) at the Naval Reserve Laboratory in support of the Free Electron Laser Program. Included in the report are descriptions of the final assembly and operation of the LIA, installation and testing of a new accelerating gap in the five core stage of the accelerator to operate at 150 kV, and the moving of and modifications of the charging and firing controls for remote operation of the accelerator.

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1.0 INTRODUCTION

This final report describes work done under contract #N00014-81-C-2434 from July, 1981 to August 1986, in support of the Free Electron Laser (FEL) experiment at the Naval Research Laboratory. Aside from general technical support activities to the FEL program, the work included specific tasks related to the National Bureau of Standards Linear Induction Accelerator (NBS/LIA) which was moved from NBS to NRL. These tasks involved the final assembly of the NBS/LIA, its initial operation, and its routine operation as an electron beam source for the FEL experiment. Additional elements of the contract included the installation and test of a new accelerating gap, moving the charging and firing controls into the control area outside the shielded experimental area, modifying the electron beam source, modifying the output of the accelerator to suit the various FEL configurations, and the monitoring of the electron beam. A brief description of the accelerator is given followed by the description of the work performed.

The NBS/LIA is a three stage single shot pulsed electron beam accelerator. It was originally developed by NBS to demonstrate the use of commercially available mild steel for the ferromagnetic core of the induction module. The accelerator uses radial core stacks which permit more uniform saturation of the steel core, thereby decreasing the quantity of core steel required. These features needed to be demonstrated for the economical design of a high-current, high-energy (>30MeV), long-pulse (2 microsecond) accelerator. The prototype accelerator was able to transport and accelerate an 800 ampere beam to a final energy of 800 keV. Unfortunately, the usefulness of the accelerator was severely limited by a short cathode emission life. This led to the eventual development at NRL of a cold or plasma cathode in place of the original tungsten dispenser cathode. This change proved to be a fundamental one and, while providing the required current reliably, it required a new electron optical configuration for beam transport.

The first accelerating stage is the electron diode which injects a 400-500 keV, 1 kA electron beam through an anode screen of knitted tungsten wire (25.4 um) into the transport vacuum system. The diode is housed in an Astron ceramic insulator stack. The voltage profile across the diode gap is shaped by focussing electrodes (often referred to as "buckets"). The existing diode design had been referred to as the high gradient design since it provides net focussing of the electron beam in the diode region. This entire assembly is on loan from Lawrence Livermore National Laboratory.

The second and third accelerating stages are separate accelerating gaps in the vacuum chamber driven inductively by a set of four radially stacked cores in the second stage and a set of five radially stacked cores in the third stage. Both of the accelerating gaps and their associated cores and high voltage modulators are housed in a common oil tank with the entire assembly referred to as the induction module.

There are six separate "gaps" in the induction accelerator. Four of the gaps are spark gaps which breakdown in normal operation and two of the gaps are insulating breaks in the accelerator vacuum wall. It is across these insulating breaks that the accelerating voltage is applied to the electron beam and any breakdown in these gaps appears as an undesired load.

The first gap energized is the master trigger spark gap which provides synchronized high voltage trigger pulse to all three accelerating stages. In particular this trigger pulse is applied to the trigger electrode of the high voltage spark gap switch of each accelerating stage. The high voltage spark gap switches couple the high voltage energy store and pulse forming network (or modulator) to the load. It is the normal function of these spark gaps to break down (close) and failure to do so is a fault in the operation. The final gaps are the insulating breaks across which the inductive voltage is applied to accelerate the electron beam. The normal function of the accelerating gaps (individually referred to as the four core gap and five core gap after the respective radial core stacks) is to transfer the stored energy to accelerate the electron beam without breaking down.

The electric optical configuration consists of simple magnetic coils and solenoids. It is the positions and strength of these coils which determine how a given injected electron beam will be transported. A versitile beam envelope code developed by Al Mondelli of Science Applications, Inc. was used extensively to guide the experimental adjustment of the transport system. This code has the advantage of being very fast and having a simple interactive input structure to allow quick comparison of the effect adjusting the existing transport system. There were significant differences between the calculated envelopes and the behavior of the actual electron beam. Some of this can be traced to an incomplete knowledge of the initial beam parameters and to the inability of the envelope equations to model the focussing effect of the anode screen.

2.0 OPERATION

The NBS/LIA has been operating at NRL since August, 1981. Pulse Sciences, Inc. personnel were involved with the accelerator starting with the assembly and layout of the accelerator and continuing through to the present routine operation of the accelerator as an electron beam source for the FEL experiment. Some major milestones in the operating history are noted below, followed by a description of the operation of the machine in its present configuration.

Final Mechanical Assembly - June 1981
Initial Electron Beam Extracted - September 1981
Cold Cathode Installed - February 1982
Five Core Gap Insulator Replaced - August 1982
Accelerator Control Moved to Control Area - August 1982
Focussing Coil Added to Five Core Gap - Decmeber 1982

The NBA/LIA operates in a single shot mode. FEL experiments have been carried out using a variety of wigglers with or without a uniform solenoidal field superimposed on the wiggler field. Anywhere between thirty and fifty shots can be fired per day depending on the type of experiments being run. The electron beam is typically run at preset voltages which have been found experimentally to optimize the transported current. It is possible to adjust the beam energy between approximately 500 keV and 700 keV by either turning off the five core accelerating gap for the low voltage or increasing the diode and four core accelerating gap charging voltages to 70 keV (instead of the typical 65 keV) for the higher voltage.

3.0 COLD CATHODE

From August 1981 until January 1982 the electron diode used a thermionic dispenser cathode as the electron source. The long heating cycle and continuous cathode poisoning exacerbated by frequent opening of the vacuum system led to the development of a cold cathode emitter based on a design used at the Sandia National Laboratories in electron beam pumped laser studies. This new cathode allowed changes in the experimental configuration with no effect on the current emitted from the cathode. The quality or emittance of the electron beam did change. The emittance of the beam generated by the cold cathode was higher than that of the dispenser and required stronger focussing forces. The dispenser cathode required several days of heating to reactivate the cathode after every opening of the vacuum chamber to atmospheric pressure required for experimental changes. The peak current emitted never was as high after a reactivation as before exposure to room pressure, even using a continuous argon flow into the diode. The new emitting surface consisted of carbon fiber bundles 1 cm high, resembling an artist's paintbrush spaced on a 1 cm x 1 cm grid. The surface of the bundles was nominally the same surface as the planar surface of the dispenser cathode but was much more irregular. Single fibers cold be seen rising as much as 3 mm above the nominal cathode surface.

4.0 FIVE CORE CAP INSTALLATION

The installation of the new ceramic insulator required the removal of the old insulator from the gap housing, the modifications and reassembly of the gap housing, and finally the placement of the gap assembly in the accelerator.

The removal of the old insulator required breaking the Torr-Seal bond between the ceramic insulator (alumina) and the gap housing (stainless steel). Varian Associates, Santa Clara, CA suggested two methods of breaking down the Torr-Seal. The first is a high temperature bake at or above 500 C unitl the epoxy crumbles. Adequate ventilation is required because toxic gases are released during the chemical breakdown of the Torr-Seal. The second method is to use a chemical solvent. Varian recommends D-Solv 292 from Ram Chemicals, Gardena, CA or either of two products from Oakite Products, Inc., New York, NY. These are an immersion solution, Stripper SA, or a brush-on paste, Vis Strip. These solvents are combinations of organic solvents (e.g. methylene chloride) and acids. Adequate ventilation is again required as well as protective clothing (rubber apron or coveralls, gloves, face shield) and a proper respirator. Polyethylene or stainless steel containers are recommended since mild or galvanized steel is subject to rapid oxidation by the solvents.

Stripper SA was chosen for several reasons. The thermal breadown technique was not used because the bonded insulator is subject to cracking from the thermal stresses and no suitable oven was accessible at NRL. The stripper SA was selected because it would allow complete coverage of the bonds and require the least personal exposure to the solvent. Stripper SA had previously been used in the paint shop at NRL.

A simple stainless steel pan (29" OD 10" H) was fabricated to allow the immersion of both epoxy joints simultaneously with a minimal amount of the solvent and the 1/2" of water which acts as a vapor seal above the Stripper SA. This seal is required or else the solvent will evaporate away before it can dissolve the epoxy. Immersion for five days was sufficient to weaken the epoxy to allow final separation using gentle prying with hand tools. The stainless parts were scraped free of residual epoxy and then cleaned in a pickling solution available at the NRL plating shop. Before installation the capture grooves had to be enlarged to fit the smaller inner diameter of the new insulator. The inner diameter of the groove was reduced to 15.125" from 15.625". This smaller diameter interfered with the diagnostic ports used by Haimson Associates during the original microwave testing and which had previously been plugged and welded at NBS. The plugs were welded completely around on the outside. Although this procedure can cause virtual vacuum leaks, no change in the attainable base pressure of the accelerator has been noticed. The gap housing parts were given final rinses with freon followed by methanol before reassembly.

The assembly method used by NBS for bonding the ceramic gap insulator to the stainless steel housing was by cementing the pieces together using Torr-Seal, a low vapor pressure epoxy made by Varian Associates, instead of using permanent brazing techniques. The use of epoxy was faster, less expensive and could be applied in the laboratory. To save time both epoxy joints were made a the same time. This procedure should not be used in the future. Any excess epoxy on the upper joint flows down the side of the insulator forming an irregular dielectric boundary (drips) which may enhance breakdown instead of forming the desired smooth fillet. The description below is for the cementing of each joint one at a time, the preferred technique.

The high voltage side of the gap housing (the flat stainless steel plate) is first cemented to the insulator. A 3/8" bead of Torr-Seal is applied to the groove in the stainless stell using a modified plastic glue syringe with an enlarged 1/4" opening. The insulator is them placed on the epoxy bead and weighed down with three evenly spaced lead bricks (25 pounds each) resting on a plate placed over the free edge of the insulator. This weight is enough to cause the epoxy to flow forming a fillet on the inner and outer diameters of the insulator and a thin (0.020" - 0.050") epoxy layer between the steel and the insulator face. The fillet adds little to the mechanical strength of the epoxy bond but guarantees that the epoxy bond covers the entire insulator edge. That the fillet adds little strength was demonstrated when an early attempt to repair vacuum leaks in a still apparently mechanically sound joint by adding epoxy to the fillet proved futile. The second epoxy joint is made the following day. A similar epoxy bead is laid down in the groove of the ground electrode and this time an aluminum alignment fixture is used to maintain the spacing and concentricity of the high voltage electrode with respect to the ground electrode. This fixture centers both vacuum flanges on a common axis and maintains the plane of both flanges perpendicular to this common axis. By allowing for 0.080" of epoxy in the two bonds (nominally 0.040" thickness for each bond) the high voltage side of the gap housing is fixed in relation to the ground electrode independent of the epoxy bonds or the exact orientation of the insulator. The spacing of the insulator above the ground electrode should be checked before putting the epoxy in the groove. The epoxy should be allowed to cure for at least twenty-four hours.

The next step was to leak check the gap assembly. This was done using two lucite end plates with greased flat rubber gaskets for vacuum seals. One of the end plates had a pumping port connecting the gap assembly to a Varian portable leak detector which was also used to evacuate the gap assembly. Preliminary leak checking was done by flowing helium gas from a nozzle over the epoxy joints. If no leaks were found a plastic sheet was taped between the lip of the ground electrode and the high voltage electrode. This then formed a "bag" which was filled with helium to allow a constant source of slightly pressurized helium to seek out any potential leaks. A successful leak check at this point usually indicates a good epoxy bond and reliable operation once installed on the accelerator.

The installation of the gap assembly requires one special part: an indium coated copper gasket for the modified Varian flange on the high voltage electrode. The indium is perferably plated on, which was done by the NRL plating shop, but can also be spread on using a soldering iron. The plating gives a thinner, more uniform layer. The indium should be at least 0.005" thick. Four alignment pins about 4" long are placed into the blind taped holes of the core beam tube. A single nylon strap is used to lift both the gap assembly and the gap housing clamp ring. Two C-clamps secure the clamp ring to the gap housing and simultaneously enclose the nylon sling to prevent the gap housing from falling out of the sling. The oil tank O-ring is held in place by simple brass clips. Five clips were used. Before the gap assembly begins to slide over the alignment pins the copper gasket is put in place. This gasket usually falls out of position before the gap housing is in place but remains strapped by the alignment pins. Once the flange is close to being in place, several bolts are put in the tank clamp ring to secure the gap assembly and roughly position the housing. The copper gasket is pushed into position using a thinned tongue depressor. It is useful to have several tongue depressors prepared to check that the gasket is properly seated. Once properly seated, the compression on the flange from the core beam tube bellows will keep the gasket in place. The bolts used to tighten the flange are sprayed with a fresh coat of Micro-Moly, a dry molybdenum disulphide lubricant available in the NRL chemical storeroom. The modified flange design has half the recommended number of bolts and these are tightened beyond usual limits before the gasket is properly seated. Many successive rounds of gentle tighting up on the flanges are recommended. A gap uniform to within 0.003" and less than 0.018" between the flanges indicates a properly seated gasket, with 0.015" being a typical final spacing.

The next step is to align the outer vacuum flange with the beam axis. This is done using crossed strings on the flange and the alignment targets in the core beam tube. Adjustment is by using the four screws in the side of the clamp ring. The clamp ring is then tightened down the rest of the accelerator vacuum chamber reassembled. A final vacuum check should be performed before pumping the oil back into the tank. In our case this was simply pumping the accelerator down and checking the pressure to be sure a satisfactory base pressure was achieved.

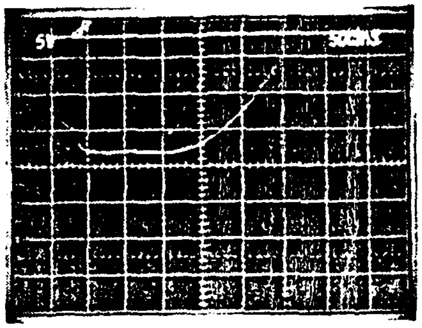
5. FIVE CORE TEST

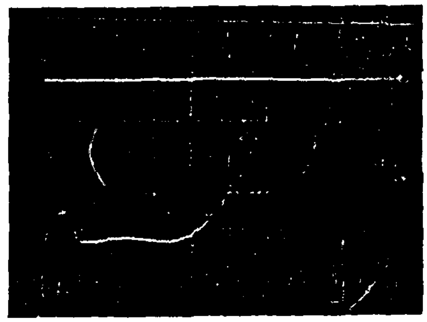
Once installed, the testing of the accelerating gap required in situ vacuum testing, cleaning of the five core high voltage gap, calibration of the voltage monitor and, finally, conditioning of the gap until the accelerating gap would hold off 150 kV for the entire pulse.

The entire accelerator was reassembled with the required beam diagnostic but the oil was not pumped into the module tank. The vacuum system was then pumped out and reached the required pressure of 1×10^{-5} Torr within twenty-four hours. Since the initial evacuation, the insulator and accelerator gap assembly have been cycled from atmospheric pressure to less than 1×10^{-5} Torr routinely. It was found, however, that the replacement insulator required pressure of 2×10^{-6} Torr or less to meet the voltage hold off requirement. This more stringent requirement was also satisfied.

Calibration of the voltage monitor was made by comparing the voltage on the high voltage end plate measured with a Tektronix 40 kV high voltage probe to the recorded voltage on the capacitive voltage monitor. This required charging the modulator to considerably less than normal operating voltage (less than 20 kV charge for calibration compared to greater than 60 kV charge for acceleration) to keep within the operating limits of the Tektronix probe. Triggering of the high voltage sparkgas was then accomplished by dropping the gas pressure in the spark gap, thereby lowering the self-breakdown voltage below the voltage across the gap. Using this method, modulator voltages of 5 kV could be triggered. Initially the voltage was measured on the primary side of the stacked cores, but comparison of the voltage monitored at several positions showed large inductive effects on the waveform. For routine checking of the voltage calibration, the primary side will give reasonable calibrations if the voltage is measured within several inches of the high voltage plane of the core stack on the copper strap from the spark gap. The most reliable method of measuring the accelerating voltage was to add a 1/4" copper tube extension to the high voltage probe and measure the votlage on the high voltage electrode directly. The derived voltage calibration was 1.90 kV/V (See Figure 1a).

The next step was the testing of the accelerating gap at the specified level of 150 kV. The voltage holdoff capability of this gap is limited by the magnitude and shape of the electric field at the "triple point" junction of the vacuum, ceramic insulator, and metal electrode. This leads to the flashover of the insulator, causing an arc which acts as the load for the modulator instead of the voltage being applied to the accelerating gap with the electron beam acting asthe load. Previous experience at NBS has shown that the accelerating gaps behave like a conventional microwave tube and allow a gradual improvement in voltage hold-off through conditioning. This is not the case for high power short pulse insulators where any breakdown across an insulator damages the surface and lowers the voltage hold-off for succeeding pulses. A voltage level of 150 kV was achieved after several days of conditioning (See Figure 1b). Further experience indicates that the breakdown voltage is sensitive to the residual gas in the system. Once a voltage level has been achieved, daily conditioning of the gap is required for the first week of operation. Conditioning and becomes less important the longer the vacuum is maintained. Every time the vacuum system is opened a new conditioning sequence is required once the accelerator is reevacuated.





Tektronix 1000:1 HV probe	Five core HV probe with 10 ft of cable
Vert. sens. : 5V/div.	2V/div.
Hor. sens. : 500ns/div.	500ns/div.
$(3.25\ \text{div})\left(5\ \frac{\text{V}}{\text{div}}\right)\left(1\ \frac{\text{kV}}{\text{V}}\right) = 16.3\ \text{kV}$	$(4.3\ \text{div})\left(2\ \frac{\text{V}}{\text{div}}\right) = 8.6\ \text{V}$

Five core probe sensitivity 16.3 kV/8.6 V=1.9 kV/V

Fig. 1a) Calibration of five core voltage monitor against a Tektronix 1000:1 HV probe (model P6015)

Vert. sens. : 20 V/div.
Hor. sens. : 500 ns/div.

$$(3.95\ \text{div})\left(20\ \frac{\text{V}}{\text{div}}\right)\left(1.9\ \frac{\text{kV}}{\text{V}}\right) = 150\text{kV}$$

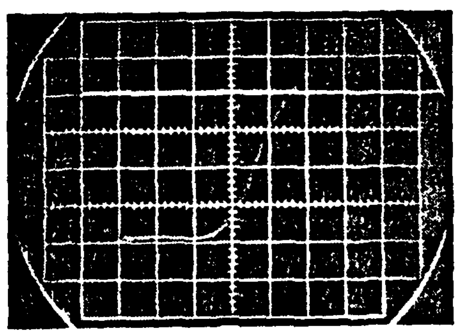


Fig 1b) Voltage across five core gap with the modulator charged to 75 kV

Reliable arc-free operation typically requires a base pressure of less than 2×10^{-6} Torr maintained for at least 24 hours. The vacuum cycle time of the accelerator is speeded up by backfilling the system with dry nitrogen gas instead of venting to room air.

The above activities completed the testing of the five core accelerating gap. The gap has operated routinely since its initial test in August 1981.

6. REMOVE CHARGING AND TRIGGERING

The contract required the moving of the charging and triggering (or firing) controls of the LIA into the control area (called staging area "A" on blueprints of the cyclotron building). Before implementing the move, a definition of the required control operations desired by the experimentalists was first obtained. The above move was completed in August 1982 when routine operation of the LIA resumed for FEL experimentation.

The required control capability decided on by the NRL staff was ability to trigger the LIA appropriately synchronized with the charging and triggering of the uniform field capacitor bank and the wiggler capacitor bank for a series of multiple shots at fixed accelerator parameters. A premium was placed on getting the LIA operating again quickly after it was decided to install the new insulator and move the controls.

The control relocation evolved into the following four elements. First was the relocation of the entire injector core reset charging supply. Second was the installation of remote meters for all five of the Universal Voltronics Corp. (UVC) charging supplies. Third was the separation of the "HV and TRIGGER CONTROL" panel from the relay rack chassis and its installation in the remote control relay rack. The final element was the construction of a remote control with monitoring the first focussing coil magnet power supply. This supply energizes an air-cooled solenoid limited to intermittent operation, instead of the continuous operation of the water cooled solenoids or the two beam tube solenoids immersed in the oil of the module tank.

The injector reset power supply is a 10 kV Hippotronics supply which was added at NBS but never modified for automatic cycling by the control circuit. The four and five core reset supplies have appropriate current limiting resistance installed in the module tank and the power supply control wiring has been modified to defeat the ZERO SET interlock, allowing the supply to be preset to a convenient level (usually 10 kV to decrease the time to reach the 9 kV charge required for reset). The injector reset supply was operated manually. The operator uses the voltage control to limit the current and then lowers the voltage control to zero before firing to stop a large current surge as the supply tries to recharge the injector reset capacitors. The Hippotronics supply was moved to the control area and mounted in the rack keeping the manual operation. The high voltage was routed through the existing cyclotron signal cables using one of the RG/9 cables fitted with type HN coaxial connectors. A new cable was required to go from the control area upstairs to the patch panel in the old cyclotron counting room. It was found that the choice of HN plug is critical, there being several different styles available. The difference is in the insulation length between the center pin and the ground braid along the center conductor insulator. One type of connector (Amphenol PN# 17900, MIL# UG-59D/U) has a length of 5/16 inches and will hold off the 10 kV for a limited amount of time if carefully constructed. There are two designs with an insulation length exceeding 1/2 inch (one requiring the tapering of the cable insulator using a "pencil sharpener", the second not requiring any cable modification) which are capable of holding off the intermittent application of 10 kV for sustained periods of time. There is one such connector on the accelerator which has been in use for 10 years. The Amphenol part numbers of the better connectors are PN# 82-804 (MIL# UG-59B/U) and PN# 82-83 (MIL# UG-59A//U). The PN# 82-83 requires the tapering of the insulator. There was only one good connector available for the initial installation of the power supply. The second HN connector was initially a PN# 17900, but has been replaced by a PN# 82-804 plug. This change involved no wiring changes which affect the control schematics.

Secondly, each of the five UVC supplies was equipped with a remove meter panel located in the control area. The remote meter panels were purchased from UVC. The required modifications were made to the power supplies and the changes noted on the schematic (see Figure 2). It is pointed out on the schematics and emphasized here that either the wire pairs in the UVC power supply should be shorted or the remote meters installed before the power supplies are energized. This is because the UVC metering circuit completes the high voltage current path and, if the remote meters are disconnected and the two jumpers in the power supply not shorted, the high voltage side of the meter circuit in the main chassis may rise to the full high voltage output of the power supply. However, meters will not rise to dangerous levels of high voltage because of the protection circuits (principally the spark plugs on the top of the oil drums), but will not indicate the power supply voltage or current properly.

The third element was required in order to control the charging and firing of the machine. It was decided that the best way to accomplish this task was to separate the front panel of the "HV and TRIGGER CONTROL" panel from its chassis and to relocate the front panel in the control area. This involved making extension wires for nearly every wire on the front panel of the chassis. These wires were then patched through to the control area using the old cyclotron cable panels. Six shielded six-conductor cables were used. A detailed list of the wires used is given in Table 1. This table indicates the number given to the six extension cablels and the wire color, the number and color of the chassis wire to which the extension is attached and ther cyclotron cable panel identification. The r and b in front of the PATCH PANEL LABEL denotes red and black respectively of a banana jack pair. Table 2 repeats the chassis wire number and

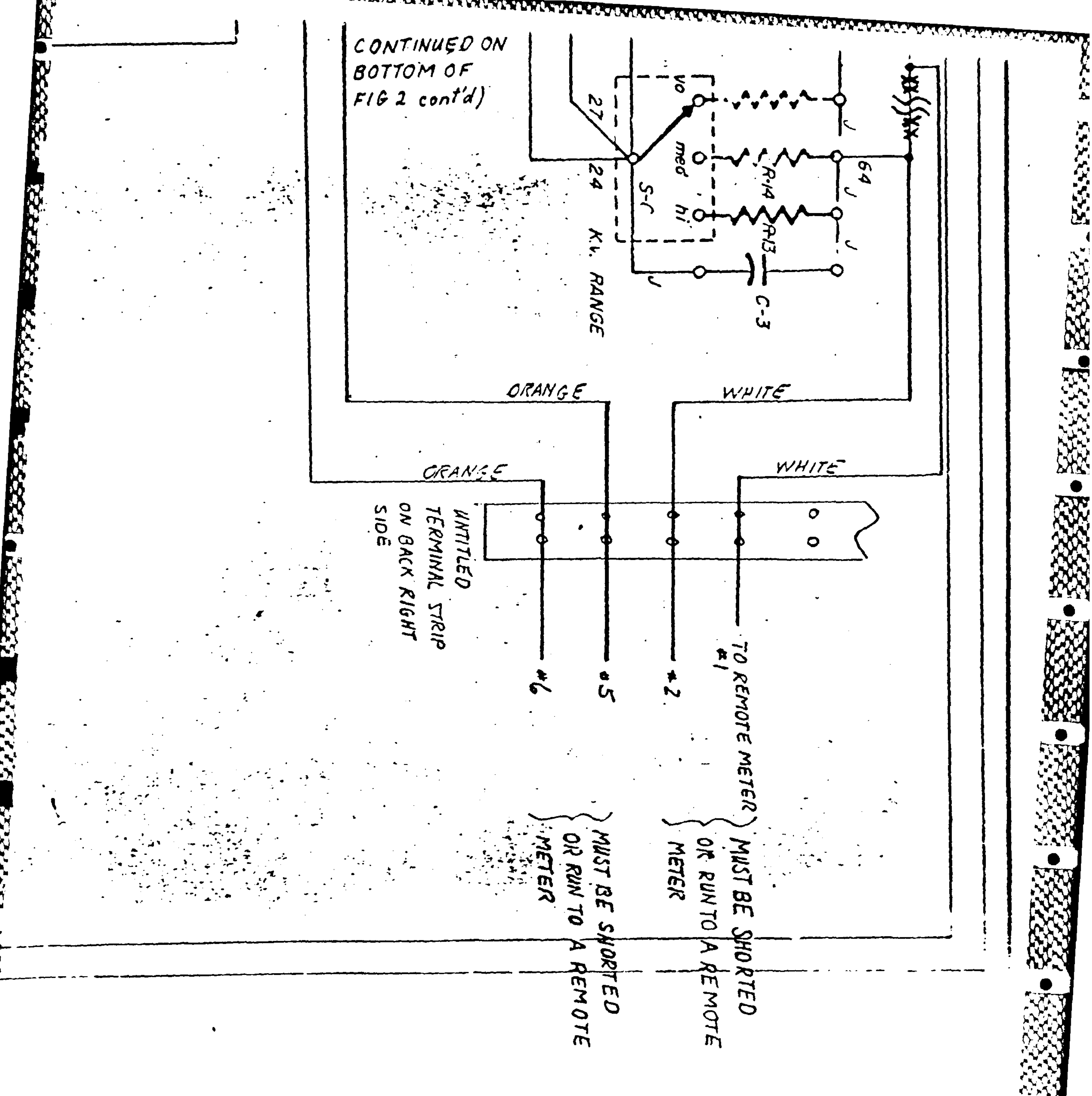


Fig 2) Schematic changes for remote meter of the UVC high voltage power supplies.

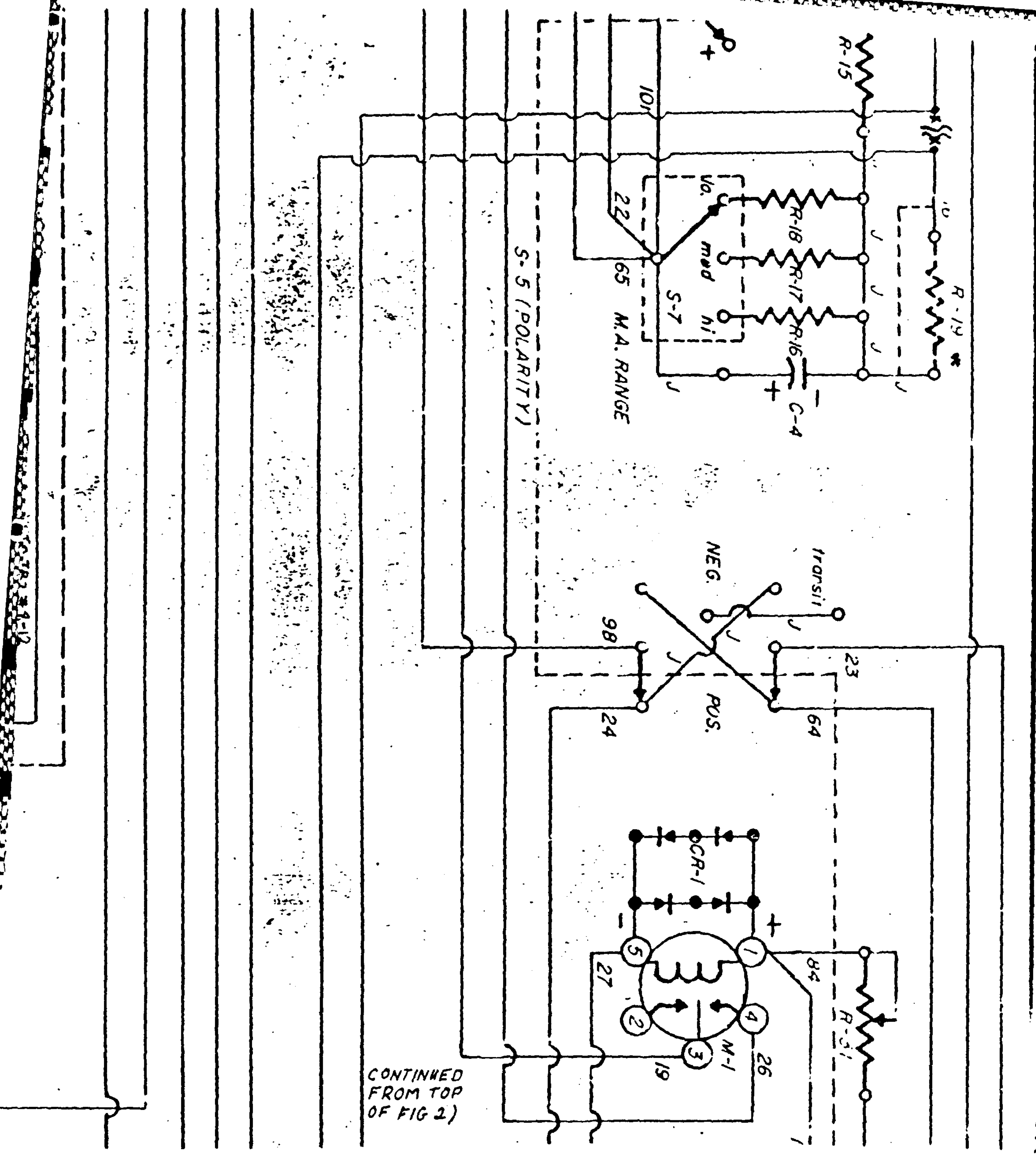


Fig 2 cont'd) Schematic changes for remote meter of the UVC high voltage power supplies.

CABLE #	PATCH PANEL LABEL	CABLE COLOR	CHASSIS WIRE #	CHASSIS WIRE COLOR
1	r37	red	1	green
	b38	brown	2	purple
	r39	yellow	3	brown
	b40	orange	4	blue
	r41	blue	5	brown
	b42	green	6	white
2	r43	red	37	orange
	b44	brown	34	green
	r45	yellow	35	white
	b46	brown	7	purple
	r47	blue	8	blue
	b48	green	11	green
3	r49	red	10	red
	b50	brown	9	purple
	r51	yellow	32	green
	b52	orange	29	blue
	r53	blue	13	red
	b54	green	33	blue
4	r55	red	23	black
	b56	brown	25	orange
	r57	yellow	12	brown
	b58	orange	31	orange
	r59	blue	27	blue
	b60	green	26	purple
5	r61	red	17	green
	b62	brown	14	brown
	r63	yellow	15	white
	b64	orange	30	orange
	r65	blue	16	red
	b66	green	20	red
6	r67	red	19	white
	b68	brown	18	black

TABLE 1

CHASSIS WIRE #	COLOR	DESCRIPTION OF WIRE PURPOSE (viewing the back of the panel)
1	green (3)	CONTROL ON switch terminal
2	purple	CONTROL ON switch terminal
3	brown (long)	HIGH VOLTAGE TRIGGER switch (bottom right)
4	blue	HIGH VOLTAGE TRIGGER switch (top right)
5	brown (short)	HIGH VOLTAGE TRIGGER switch (middle left)
6	white	HIGH VOLTAGE TRIGGER switch (top left)
7	purple	HIGH VOLTAGE CHARGE switch
8	blue	HIGH VOLTAGE CHARGE switch
9	purple	RESET TRIGGER switch (bottom left)
10	red	RESET TRIGGER switch (middle left)
11	green (2)	RESET TRIGGER switch (top left)
12	brown	RESET CHARGE switch
13	red (2)	RESET CHARGE switch and chassis wire # 28 (red)
14	brown	OFF AUTO SEQUENCE switch (switch terminal #1)
15	white (2)	OFF AUTO SEQUENCE switch (switch terminal #2)
16	2500 ohm	wire # 16 ties to one end of a 2500 ohm resistor with the other end to the OFF AUTO SEQUENCE switch terminal #4
17	green (2)	OFF AUTO SEQUENCE switch (switch terminal #5)
18	black	ON AUTO SEQUENCE switch (switch terminal #3)
19	white	ON AUTO SEQUENCE switch (switch terminal #6)
20	2500 ohm	wire # 20 ties to one end of a 2500 ohm resistor with the other end to the ON AUTO SEQUENCE switch terminal #4

TABLE 2

CHASSIS WIRE #	COLOR	DESCRIPTION OF WIRE PURPOSE (viewing the back of the panel)
21	black	NUMBER OF RESET CHARGES counter
22	black	NUMBER OF HIGH VOLTAGE CHARGES counter
23	black	reset CHARGE light
24	grey	reset CHARGE light
26	purple	reset gap pressure ON light
27	blue	RESET GAP PRESSURE switch (bottom left)
28	red	RESET GAP PRESSURE switch (bottom middle) and chassis wire # 13 (red)
29	blue	reset trigger FIRED light
30	orange	reset gap pressure OFF light
31	orange	ALL HIGH VOLTAGE ON switch
32	green	ALL HIGH VOLTAGE ON switch
33	blue	high voltage CHARGE light
34	green	high voltage trigger FIRED light
35	white	ALL HIGH VOLTAGE OFF switch
36	green	CONTROL ON indicator light
37	orange	CONTROL ON indicator light

TABLE 2 cont'd

color and gives a brief description of where each wire in the chassis goes to on the front panel. This method of extending the controls, although tedious, has worked reliably. Again no changes in the control schematics were made.

The last control change needed to operate the LIA from the control area was the circuit to operate the #1 focus coil magnet supply from the control area instead of manually operating the power supply from the front panel. The Hewlett-Packard Model 6259B power supplies have several available modes of remote control. The mode chosen was the resistance programming mode of the output voltage. A remote variable resistor was used to adjust the output voltage. The level of voltage which could be driven by the remote control was more voltage than was necessary to drive the desired coil current. The power supply would then increase the current in the coil until the current limit set using the front panel current controls of the power supply. A resistive shunt was added to the coil wiring to provide a remote measure of the coil current, and allows the operator to be sure that the focus coil was operating properly. Since the coil can only be operated intermittently, a time-delay relay was included in the power supply remote control so that the current turns off after a sixty-second delay in case the operator fails to lower the controlling resistance after the shot. In this case the indicating neon light remains lighted, although the current meter indicates no current in the coil. The circuit diagram for the power supply control is included as Figure 3.

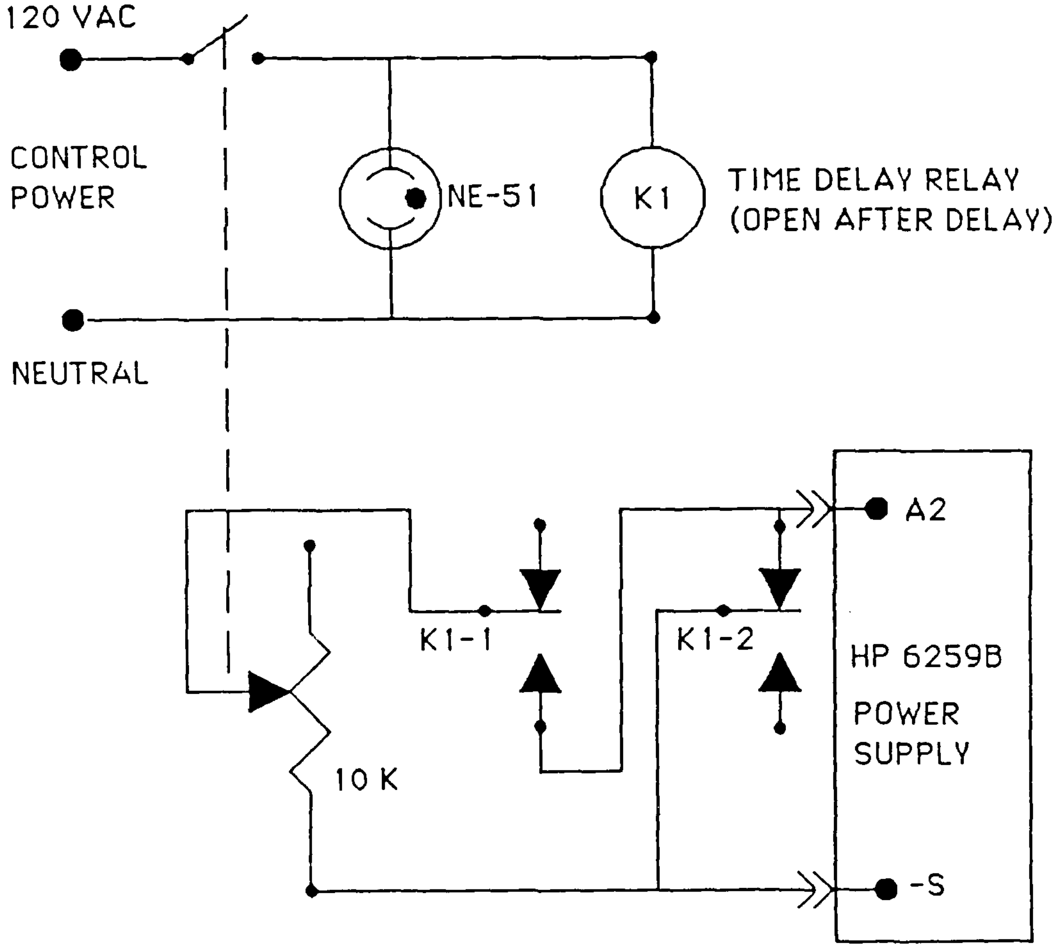


Fig. 3 Schematic of remote control for power supply to focus coil # 1.