FINAL REPORT

for

1.7 MEGAJOULE PROTOTYPE BANK TESTING

LAWERENCE LIVERMORE NATIONAL LABORATORY
SUBCONTRACT B137125

Prepared by

American Control Engineering
7636 Miramar Road, Suite 1200
San Diego, California 92126

MASTER

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1. INTRODUCTION

American Control Engineering is pleased to submit to LLNL this Final Report describing the final assembly and preliminary testing of the 1.7 megajoule prototype capacitor bank that is located at our facility. The purpose of this test program was to evaluate and characterize the performance of this capacitor bank. These tests were necessary in order to proceed with the design of a final building block module that is to be used to create a reliable and cost effective multi-hundred megajoule energy storage system. The period of performance covered by this contract is from January 1, 1991 through August 31, 1992.

American Control Engineering has provided all of the necessary facilities, personnel and materials that were required to perform this testing effort (except for the existing capacitor bank, the LLNL provided flashlamp assembly and E-size ignitron switch tube). An overall view of the assembled capacitor bank system as it appeared at the completion of this subcontract is shown in Figure 1.

The initial statement-of-work for the testing and characterization of the capacitor bank was as follows:

1. Measure all of the principal electrical parameters for the 1.7 megajoule prototype capacitor bank at low voltage (about 200 volts) before proceeding to high voltage testing. This low voltage testing is to include measurement of both normal and fault current and voltage waveforms, starting with the smallest building block grouping (consisting of six 3 Kj capacitors) and proceeding systematically through to the capacitor bank load. Measurements will be made for one branch (of approximately 70 capacitors), then for the entire bank (with 9 branches totaling approximately 564 capacitors) and then for the capacitor bank with output switch, coaxial transmission line and load elements added in turn.

2. Assemble and attach each of the major subsystem elements to the capacitor bank as they are required for low voltage testing including the ignition output switch structure, coaxial transmission line and load assembly.

3. Make comparison of the test results collected through low voltage testing with those forecasted by the computer mode. Evaluate and resolve any discrepancies between the two results until the computer model achieves reasonable agreement with the actual measured test results.

FIGURE 1. 1.7 MEGAJOULE CAPACITOR BANK SYSTEM (OVERALL VIEW).

4. Integrate the HV charging system and safety dump assembly with the capacitor bank and test the system to the planned operating voltage level (about 20 kilovolts).

5. Conduct tests to evaluate the main design criteria of the prototype capacitor bank including the current carrying ability of bolted connections, the effectiveness of using resistors for damping and fault isolation of the energy storage capacitors and the viability of the low cost pultruded fiberglass force bracing concept employed throughout the prototype capacitor bank.

6. Measure both normal operating currents and fault currents (at high voltage) for individual capacitors as well as at various points along the collector busswork subsystem.

7. Install and conduct limited testing with LLNL supplies flashlamp assemblies in order to secure preliminary current sharing and flashlamp triggering data.

8. Adapt and conduct limited testing of the LLNL designed and supplied E-size ignitron output switch.

9. Make a bill of materials with estimated production quantity cost estimates for the final proposed baseline capacitor bank design including the capacitors, capacitor support structure, output switch, coaxial transmission line and flashlamp distribution panel.

10. Prepare a final report summarizing the test results.

Reporting of progress was accomplished both verbally (by visits and telephone contact) and by memorandum and brief letter reports along with various supporting sketches, drawings and data. It was understood that there would be a wide variety of information exchanged from time to time between Technical contact of the University and American Control Engineering. These data were exchanged directly between the technical parties concerned and formal reporting and distribution was not required in these instances. This Final Report incorporates a reference list of major drawings and documents in the Appendix of this report.

2. INTEGRATION OF THE MAIN SYSTEM COMPONENTS

The first few months of the subcontract were spent integrating all of the major subsystem components of the capacitor bank. This effort is summarized in the letter report dated September 16, 1991. A copy of this report is included in the Appendix of this Final Report. The next ten figures show the construction details of the completed capacitor bank system.

Figure 2 is a close-up of the parallel plate collector/distribution assembly. Flashlamps were connected to this distribution panel for testing. Figure 3 shows the preliminary load resistor assembly and the parallel plate transmission line/inductor that connects the capacitor bank to the load. Figure 4 is a close-up of a section of the capacitor bank showing how the capacitors are grouped and how each group is protected by a fault current limiting resistor assembly. As shown by the photograph, the resistor assembly is connected between the capacitor group and the collector busswork (force braced channels). Figure 5 is a head on view that shows clearly the geometry of the capacitors, the fault current limiting resistor and the branch collector busswork. Figure 6 is another photo which shows details about how the six 3 kilojoule capacitors are bussed together as a group. Figure 7 is a view that shows the D-size ignitron switch assembly and how it is connected to the collector busswork and to the coaxial transmission line. Figure 8 shows the safety dump resistor board assembly which is made up of a large number of series/parallel connected wire wound resistors. Figure 9 is a close-up of the outer flange connection of the coaxial transmission line. The Indium gasket material can be seen extruding from under the connecting flange. A pattern of 8 fiberglass force bracing bolts surrounds the coaxial termination. Figure 10 shows how the inner connector of the coaxial transmission line is terminated onto the parallel plate transmission line. The busswork that connects between the coaxial transmission line and the load also is used to provide the waveshaping inductance. This force braced transmission line/inductor is shown as Figure 11. Finally, a typical section of bolted connection is shown in Figure 12. These clearly defined bolted connection sections were useful in determining the amount of current that can be carries per unit length of connection. Additional force bracing is also provided wherever the capacitor bank output is concentrated into a narrow path.

FIGURE 2. PARALLEL PLATE COLLECTOR/DISTRIBUTION ASSEMBLY.

FIGURE 3. LOAD RESISTOR ASSEMBLY (PRELIMINARY).

FIGURE 4. SECTION OF CAPACITOR BANK (ANGLE VIEW).

FIGURE 5. SECTION OF CAPACITOR BANK (HEAD ON VIEW).

FIGURE 6. SIX CAPACITOR GROUP.

FIGURE 7. D-SIZE IGNITRON OUTPUT SWITCH ASSEMBLY.

FIGURE 8. SAFETY DUMP RESISTOR ASSEMBLY.

FIGURE 9. COAXIAL TRANSMISSION LINE (OUTER FLANGE).

FIGURE 10. COAXIAL TRANSMISSION LINE INNER CONDUCTOR CONNECTION.

FIGURE 11. FORCE BRACED TRANSMISSION LINE/INDUCTOR.

FIGURE 12. TYPICAL BOLTED CONNECTION TEST SECTION.

3. TEST RESULTS

A wide range of preliminary performance tests were performed on the capacitor bank. The details of these tests are reported in the fourteen letter reports that were submitted to LLNL between September 26, 1991 and August 31, 1992. Two important results were achieved. First, the measured performance of the completed capacitor bank matched very well with the computer based circuit model. Second, it was determined that flashlamps connected in parallel across the capacitor bank show very good current sharing and triggering characteristics.

4. TASKS TO BE PERFORMED

At the end of this subcontract, a number of additional useful and important tasks were identified and prioritized. These tasks are outlined in the letter report of November 30, 1992 which is included in the Appendix of this report. It is suggested that this list can be used as a basis for additional future testing and development activities utilizing this capacitor bank testbed.

5. SUMMARY

In summary, the capacitor bank was completely assembled and was integrated with a load resistor, charging power supply and operating controls. The electrical performance was characterized and compared to a computer model of the capacitor bank. Parallel flashlamps were tested with the capacitor bank and were found to share current and trigger well. A drawing package was prepared and provided to LLNL that illustrated the next generation capacitor bank design. Cost estimates for the modular bank design were prepared and provided to LLNL for integration into the overall cost documentation.

6. APPENDIX

The letter reports that were submitted to LLNL along with their attached data and illustrations are included in the Appendix of this Final Report. A list of major drawings that have been provided to LLNL is also included.

The following letter reports are included in this APPENDIX:

DATE	REFERENCE NO.
1. September 16, 1991	10917A01
2. September 26, 1991	10926A01
3. October 17, 1991	11017A01
4. October 21, 1991	11021A01
5. November 5, 1991	11105A01
6. November 11, 1991	11111A01
7. November 18, 1991	11118A01
8. November 27, 1991	11127A01
9. May 12, 1992	20512A01
10. July 8, 1992	20708A01
11. July 16, 1992	20716A01
12. July 29, 1992	20729A01
13. August 12, 1992	20812A01
14. August 31, 1992	20831A01
15. November 30, 1992	21130A03

The following is a list of the principal drawings that were produced or revised during this subcontract. Copies were provided to LLNL.

DESCRIPTION	DWG NO.
1. Bank, side view	41040
2. Bank, top view	41041
3. Bank, rear view	41042
4. Busswork to capacitor detail	41043
5. 2.1 MJ capacitor bank	41044
6. Energy storage capacitor	41045
7. Coaxial transmission line	41048
8. Busswork insulator assembly	41072
9. Load collector plate	41091
10. Dual "E" size ignitron assy	41092

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

September 16, 1991
Ref: 10917A01

Lawrence Livermore National Laboratory
P.O. Box 5012
Livermore, CA 94550

Attn: Mr. Doug Larson, L-487

Subject: Current Bank Testing Status

Dear Doug,

Here is a brief status report summarizing our telephone conversation of last week.

The current bank testing status is as follows:

- o The parallel plate transmission line to ignitron switch adaptor busswork has been fabricated and installed.
- o The output switch assembly has been installed and temporarily modified to use only one D-Size ignitron tube.
- o The coaxial transmission line has been supported and installed.
- o The coaxial transmission line termination and flashlamp distribution assembly has been installed.
- o The waveshaping inductor (force braced channels) has been installed and interconnected to the distribution assembly.
- o The capacitor bank safety dump resistor panel has been installed and connected to the capacitor bank.
- o Current limiting resistors have been installed at each of the nine capacitor branches in order to discharge the capacitor winding to case capacitance.
- o A temporary low voltage test load assembly has been fabricated and installed.
- o Various low voltage waveforms have been collected at charging voltages up to one kilovolt. Good agreement has been achieved with the computer circuit model.

The principle tasks that remain to be completed before bank testing at higher voltage can begin are:

Item	Task Description
1.	Modify the inductor (channels) to accept the redesigned bank load resistor assembly.
2.	Complete fabrication of the redesigned load assembly and integrate it with the modified inductor.
3.	Put the high voltage charging power supply subsystem into operation.
4.	Fabricate a system operation control panel and integrate the safety and interlock provisions.
5.	Start collecting system waveforms up to 10 kilovolts.

The near term target schedule is as follows:

Item	Description	Completion Date
1.	Inductor modification	September 20
2.	Load fabrication	October 3
3.	Integrate the HV supply	October 15
4.	Fabricate controls	October 15
5.	Start HV operation	October 21

As soon as the last few physical details of the bank are complete, we will provide you with a complete set of as built photographs of the completed bank and its subsystem components. We will also provide you with copies of the latest data waveforms that were collected at low charging voltage levels.

We should be collecting some interesting data soon.

Best Regards,

Bob Anderson

RLA:km

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

September 26, 1991

Ref: 10926A01

Lawrence Livermore National Laboratories

P.O. Box 5012

Livermore, CA 94550

Attn: Mr. Doug Larson, L-487

Subject: Bank Testing Status Update

Dear Doug,

Here is a brief report to update you on the Bank status.

- (1) We have completed the inductor modifications (Item 1 in our letter of September 16) and have reinstalled the inductor channels.
- (2) We are about half finished with the fabrication of the redesign load and should have it in place by about the October 3 estimated completion date.
- (3) We have not received the four 10 foot long Reynolds cables that you thought that you could get from stock. Are they available or should we get connectors from Reynolds and fabricate cables?
- (4) We also need a set of schematics for the HV power supply so that we can understand how to interface our system control panel with the supplies interlock and STOP CHARGE (dump) features.
- (5) I'm enclosing the data that we collected for the bank at low voltage using a mercury relay as the output switch.
 - o Photo 2 shows the output current at 1,000 Amps per division through a 35 milliohm load resistor. The charging voltage was 500 volts and the output current was 7,000 Amps.
 - o Photo 3 shows the current peak to be at about 180 microseconds.

o Photo 4 is the voltage measurement across the 35 milliohm load resistance and is about 250 volts.

These parameters look about right as a starting point for operating the bank at high voltage.

(6) We'll get some photos for you in a couple weeks when the mechanical part of the bank is finished.

I hope that everything is going well for you at the Lab.

Best Regards,

A handwritten signature in black ink, appearing to read 'Bob', enclosed within a circular flourish.

Bob Anderson

RLA/km

enclosures

CAPACITOR BANK TESTING

OSCILLOSCOPE TRACE LOG SHEET

DATE 7/25/91 PHOTO BY _____ SUBJECT _____ PAGE 1 OF 6

PHOTO NO. _____ SCOPE _____
 CAMERA _____ LENS _____
 GRAB EXP f _____ SEC
 TRACE EXP f _____ SEC
 SWEEP 200μs SEC/CM
 SINGLE ☒ REPETITIVE ☐
 TRIG SOURCE _____

COMMENTS _____
8"X25" INDUCTOR PLATES
PLATE SEPERATION = 4"
BANK V = 250V
(SWITCH MERCURY CONTACTOR)

CHAN	PLUG-IN	FUNCTION	PROBE	VERT/CM	DATA POINT
1		<u>CURRENT</u>		<u>1000A/cm</u>	<u>35mΩ RESISTOR LOAD</u>
2					
3					
4

PHOTO NO. 2 SCOPE _____
 CAMERA _____ LENS _____
 GRAB EXP f _____ SEC
 TRACE EXP f _____ SEC
 SWEEP 200μs SEC/CM
 SINGLE ☒ REPETITIVE ☐
 TRIG SOURCE _____

COMMENTS _____

BANK V = 500V

CHAN	PLUG-IN	FUNCTION	PROBE	VERT/CM	DATA POINT
1		<u>CURRENT</u>		<u>1000A/cm</u>	<u>35mΩ RESISTOR LOAD</u>
2					
3					
4					

CAPACITOR BANK TESTING

OSCILLOSCOPE TRACE LOG SHEET

DATE 7/25/91 PHOTO BY _____ SUBJECT _____ PAGE 2 OF 6

PHOTO NO. 3 SCOPE _____
 CAMERA _____ LENS _____
 GRAD EXP f _____ SEC
 TRACE EXP f _____ SEC
 SWEEP 50us SEC/CM
 SINGLE ☒ REPETITIVE ☐
 TRIG SOURCE _____

COMMENTS _____
8"X25' INDUCTOR PLATES
PLATE SEPERATION = 4"
BANK V = 500V.
(SWITCH MERCURY CONTACTOR)

CHAN	PLUG-IN	FUNCTION	PROBE	VERT/CM
1	_____	<u>CURRENT</u>	_____	<u>100A/cm</u>
2	_____	_____	_____	_____
3	_____	_____	_____	_____
4	_____	_____	_____	_____

DATA POINT _____
35m-2 RESISTOR LOAD

PHOTO NO. 4 SCOPE _____
 CAMERA _____ LENS _____
 GRAD EXP f _____ SEC
 TRACE EXP f _____ SEC
 SWEEP 200us SEC/CM
 SINGLE ☒ REPETITIVE ☐
 TRIG SOURCE _____

COMMENTS _____

CHAN	PLUG-IN	FUNCTION	PROBE	VERT/CM
1	_____	<u>VOLTAGE</u>	<u>A-B</u>	<u>100V/cm</u>
2	_____	_____	_____	_____
3	_____	_____	_____	_____
4	_____	_____	_____	_____

DATA POINT _____
35m-2 RESISTOR LOAD

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

October 17, 1991
Ref: 11017A01

Lawrence Livermore National Laboratories
P.O. Box 5012
Livermore, CA 94550

Attn: Mr. Doug Larson, L-487

Subject: Bank Testing Status Update

Dear Doug,

Here is another brief report to update you on the Bank status.

(1) The redesigned load fabrication is completed. However, we are mounting it onto a support base with wheels so that it can more easily be moved from point to point along the length of the inductor. This should be accomplished by next week.

(2) The LLNL provided power supply has been checked out by Garth Monday and it works fine. He did a very outstanding job getting it running. Please thank him again for us.

(3) We have completed and wired of the system controller panel, integrated it with the HVPS and checked out the operation.

(4) Because there has been some oil leakage from a few of the capacitors, we are hipotting the bank capacitors (in groups of 6) to 20 Kilovolts. As soon as this is completed we will start collecting bank data at high voltage.

(5) Due to hipotting the capacitors we will miss the forecasted start of HV operation date of October 21, but only by a few days.

Thanks again for your help in getting the power supply running.

Regards,

Bob Anderson

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

October 21, 1991

Ref: 11021A01

Lawrence Livermore National Laboratory
P.O. Box 5012
Livermore, CA 94550

Attn: Mr. Doug Larsen, L-487

Subject: Current Bank Testing Status

Dear Doug,

Here is a brief report summarizing current bank testing status as compared to the original statement-of-work. In effect, the bank is now physically complete and all of the activities required before high voltage testing can begin are essentially finished. The following is the task status, detailed by statement-of-work item:

SOW Item 1:

Measure all of the principal electrical parameters for the 1.7 megajoule prototype capacitor bank at a low voltage (about 200 volts) before proceeding to high voltage testing. This low voltage testing is to include measurement of both normal and fault current and voltage waveforms, starting with the smallest building block grouping (comprised of six 3Kj capacitors) and proceeding systematically through to the capacitor bank load. Measurements will be made for one branch (of approximately 70 capacitors), then for the entire bank (with 9 branches totalling approximately 564 capacitors) and then for the capacitor bank with output switch, coaxial transmission line and load elements added in turn.

Status summary:

Low voltage waveform measurements have been made at various points of the capacitor bank circuit. A total of over 80 waveforms have been collected and compared to the computer circuit model.

Three types of switch elements were used including large area SCR's, air spark gaps and mercury contactors. The waveforms measured at low voltages generally agree with those forecasted by the computer model. Since there is an effect on the low voltage waveform due to switch element characteristics such as current rise-time, voltage drop, "drop-out" at reversal, etc., small differences do exist. However, we will wait until we are operating the bank at the 10 KV charging level (using a size D ignitron) before we attempt any adjustment (if required) to the computer model.

In addition, we have air-arc'd a six capacitor section of the bank at high voltage in order to get a more accurate idea about self-breakdown air-arc fault resistance at high voltage and current levels. Again, the waveforms generally agree with those forecasted by the computer model.

SOW Item 2:

Assemble and attach each of the major subsystems elements to the capacitor bank as they are required for low voltage testing including the ignition output switch structure, coaxial transmission line and load assembly.

Status Summary:

The capacitor bank assembly is completed except for attachment of the re-designed load resistor. This load structure and roll-around support cart should be available next week. At that point, we will take "as-built" photos and provide you with a set of prints.

SOW Item 3:

Make a comparison of the test results collected through low voltage testing with those forecasted by the computer model. Evaluate and resolve any discrepancies between the two results until the computer model achieves reasonable agreement with the actual measured test results.

Status Summary:

See SOW Item 1 for details.

SOW Item 4:

Integrate the HV charging system and safety dump assembly with the capacitor bank and test the system to the planned operating voltage level (about 20 kilovolts).

Status Summary:

The HV power supply, charging system and safety dump have been completed, integrated and tested. We are using the HV supply this week to hi-pot all of the bank capacitors (in blocks of 6). We expect to achieve operation at the 10KV level within a few days after the load assembly (see item 2 above) is integrated to the bank.

SOW Item 5:

5. Conduct tests to evaluate the main design criteria of prototype capacitor bank including the current carrying ability of bolted connections, the effectiveness of using resistors for damping and fault isolation of the energy storage capacitor and the viability of the low cost pulltruded fiberglass force bracing concepts employed throughout the prototype capacitor bank.

Status:

Work will start on this and the remaining statement-of-work tasks the beginning of next week.

The cost to date totals a little under 50% and is consistent with our budget estimate for the portion of the activities that have been completed.

Regards,

A handwritten signature in black ink, appearing to read 'Bob Anderson', written in a cursive style.

Bob Anderson

RLA/km

copy: Mr. G. D. Klein, L-650

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

November 5, 1991

Ref: 11105A01

Lawrence Livermore National Laboratory
P.O. Box 5012
Livermore, CA 94550

Attn: Mr. Doug Larsen, L-487

Subject: Current Bank Testing Status for October

Dear Doug,

Here is a brief report summarizing current bank testing status through the end of October.

o We have completed hipot testing of all of the capacitors to 15 kilovolts for 5 minutes. The capacitors were tested in groups of six. One capacitor failed. The damping resistors (which were disconnected to allow hipot testing) have been reconnected. This completes all of the remaining bank preparation effort.

o For increased bank operational safety we have also:

- (1) Installed a video camera and monitor.
- (2) Insulated the current probes from bank fault ground buss voltages.
- (3) Preloaded the bank with a fixed discharge resistor bank in the event that the safety dump malfunctions and does not close.
- (4) Improved the connection of the system to the earth ground using 6 inch wide strapping.

o We have installed a 35 milliohm resistor (configured like a dumping resistor) across the capacitor bank output. A number of preliminary tests will be accomplished with this temporary load before connection of the final forced braced load element. We expect to observe the following on the temporary load:

- (1) The bank output waveshape at high voltage using the size D ignitron switch.
- (2) The mechanical motion of the unbraced section of resistance element due to the current caused forces.
- (3) The precise peak temperature rise of the load element due to energy deposition. There are two items of particular interest.

- (a) The heat rise should confirm accurately the energy that is being deposited into load (compared to the amount of energy that has been stored in the capacitors).
- (b) This test should also confirm the load element temperature rise that is to be expected in the final force braced load cell assembly.

o We also plan to do some preliminary experiments with respect to the current carrying ability of bolted connections and the effect of mass dumping versus force bracing on various system elements.

o We are now ready to start to attach the flashlamp assembly and trigger components to the bank as soon as they are received from LLNL. We will then be able to collect some current sharing and triggering performance data.

We'll FAX the initial data to you as it becomes available.

Regards,

Bob Anderson

RLA/km

copy: Mr. G. D. Klein, L-650

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

November 11, 1991
Ref: 11111A01

Lawrence Livermore National Laboratory
P.O. Box 5012
Livermore, CA 94550

Attn: Mr. Doug Larsen, L-487

Subject: Capacitor Bank Current Waveform Data

Dear Doug,

As of Friday November 8, we have operated the capacitor bank at charging levels up to 7 kilovolts. We plan to increase the operating level up to 10 KV by the end of this week (ending November 15). The output current waveform shape has been observed and compared to the computer generated output (using the model that was set up in Microcap III by Bill Gagnon). Figure 1 shows the bank output circuit values used as 4 microhenries (for coaxial transmission line plus aluminum channel inductor) and 35 milliohms for the load resistance. Figure 2 shows the "shape" match that is achieved. The scope trace is from the bank charged to the 7 kilovolt level. The computer output waveform (solid line with "steps") has been superimposed and fits very well within the boundary of the trace width.

We will report on the force data that we are collecting next week after the first set of preliminary experiments is finished.

Regards,

Bob Anderson

RLA/km

copy: Mr. G. D. Klein, L-650

Figure 1. Computer Circuit Schematic.

Figure 2. Computer and Measured Current Waveshapes.

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7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

November 18, 1991
Ref: 11118A01

Lawrence Livermore National Laboratory
P.O. Box 5012
Livermore, CA 94550

Attn: Doug Larsen, L-487

Subject: Capacitor Bank Current Waveform Data at 10kV Charging.

Dear Doug,

As of Friday November 15, we have operated the capacitor bank at charging levels up to 10 kilovolts. Figure 1 shows the waveform at this charge voltage level. This represents about 170 kiloamps of peak current through the 35 milliohm load resistor and is about as high as we should go with the D-size ignitron tube that is now installed in the switch assembly.

We plan to do a few tests on the damping resistor and then we will be ready to start integrating the flash lamps into the system.

I'll get a set of photos of the bank off to you next week.

Regards,

Bob Anderson

RLA/km

Enclosures

Figure 1. Current Waveform at 10kV Charging.

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7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

November 27, 1991
Ref: 11127A01

Lawrence Livermore National Laboratory
P.O. Box 5012
Livermore, CA 94550

Attn: Doug Larson, L-487

Subject: Capacitor Bank Photographs.

Dear Doug,

Here is a set of 12 photos showing the overall and detailed construction of the capacitor bank. I'll give you a call next week and we can discuss any questions that you might have.

We have also finished testing the damping resistor sample and I'll report the results to you at that time.

I hope that you are having a happy holiday.

Regards,

Bob Anderson

RLA/km

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Copy: Mr. G. D. Klein, L-650 (photo #1 only)

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

May 12, 1992
Ref: 20512A01

Lawrence Livermore National Laboratories
P.O. Box 5012
Livermore, CA 94550

Attn: Mr. Doug Larson, L-487

Subject: Bank Testing Status Update

Dear Doug,

Here is brief report to update you on the bank status. We have recently been able to get back to work on the bank and I believe that we now have all of the tasks under way that we discussed during your visit. The following are the principle activities and their status.

1. Design and fabricate adaptor for integration of the E-size ignitron to the present switch structure.

A method of attaching the E-size ignitron to the present switch structure has been designed. The adaptor components are being machined and fabricated now and should be available for assembly and wiring by the end of next week.

2. Make a new bank load element.

A new mass damped load element support structure has been designed. The design provides for much lower impulse pressure on the support structure, lower operating temperature for the stainless steel load element and allows for simpler load resistance value changes. The materials are being ordered this week. It will take about two weeks to complete the load after the materials are received.

3. Locate the flashlamp housing assembly near the distribution panel.

The flashlamp housing has been located on a stand near the distribution panel and is ready for flashlamp installation. The trigger pulser cable termination and fault isolation network has also been mounted on the stand (see item 4 below).

4. Design and assemble a pulse generator and fault isolation network to drive the reflectors for flashlamp triggering.

The preliminary circuit for triggering the flashlamps by pulsing the reflectors is shown in Figure 1. Resistor R_1 keeps the reflector at ground potential while capacitors C_1 & C_2 isolate the reflector from the pulser in the event of a flashlamp to reflector flashover. Resistor R_3 terminates the cable in order to get clean, reproducible and fast rise-time pulses. For the first tests, a capacitor discharge thyatron pulser will be used as shown. The pulser amplitude can be varied from low output levels up to about 15 kilovolts output.

When these four items are completed we should be able to start collecting the various flashlamp data that is of interest to you.

Regards,

A handwritten signature in cursive script that reads "Bob".

Bob Anderson

RLA:km
Enclosures
cc: Mr. Bill Gagnon

Figure 1. Trigger pulser and fault network circuit.

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

July 8, 1992
Ref: 20708A01

Lawrence Livermore National Laboratories
P.O. Box 5012
Livermore, CA 94550

Attn: Mr. Doug Larson, L-487

Subject: Capacitor Bank Testing Status Update

Dear Doug,

This is to bring you up to date on the current capacitor bank rework and testing status. The following are the principle activities and their status.

1. Design and fabricate adaptor for integration of the E-size ignitron to the present switch structure.

The E-size ignitron that you supplied has been installed into the ignitron switch assembly. Photos of this assembly are shown in Figures 1 and 2. Using the LLNL krytron ignitor pulser, the ignitor current waveform (160 Amps peak) is shown in Figure 3.

2. Make a new bank load element.

The new mass damped load element support structure has been fabricated and installed in the capacitor bank load area. Details of the load are shown in the photos Figures 4 and 5. The load resistor element consists of a 42 foot long length of 304 stainless steel sheet that is 12 inches wide and 0.035 inches thick. The resistance of this element is approximately the same as the one previously used, i.e. 34 milliohms. The element is folded back on itself with a spacing of about 1/4 inch (for low inductance). The insulation is provided by an 0.062 thick sheet of polyethylene that is thermally isolated between two sheets of masonite. The resistor element weighs about 62.5 pounds.

3. Locates the flashlamp housing assembly near the distribution panel.

The flashlamp housing has been located on a stand near the distribution panel and is ready for flashlamp installation. The trigger pulser cable termination and fault isolation network has also been mounted on the stand as reported to you previously.

4. Design and assemble a pulse generator and fault isolation network to drive the reflectors for flashlamp triggering.

The preliminary flashlamp trigger generator (thyatron) described previously has been checked out. Figures 6 and 7 shows the output voltage waveshape at the reflector for 1,200 volt peak output. The voltage rise-time applied to the reflector is about 10 nanoseconds (see Figure 6) and the decay time constant is about 60 microseconds (see Figure 7). This particular pulser can cover the voltage range up to about 3 kilovolts and should provide a good starting point. Because of the coulomb limitation of the thyatron, the decay constant will have to be shortened in order to reach higher pulse voltages (up the to 15kV level).

Rich is on vacation through the week ending July 17. We will turn on the bank to test the E-size ignitron and load element the week following his return and should be ready to install some flashlamps soon after that.

I hope that you had an enjoyable 4th of July holiday.

Regards,

Bob Anderson

RLA/km
enclosures
cc: Mr. Bill Gagnon

FIGURE 1. E-SIZE IGNITRON ASSEMBLY

FIGURE 2. E-SIZE IGNITRON (CLOSE-UP)

FIGURE 3. IGNITOR CURRENT WAVEFORM

FIGURE 4. LOAD ELEMENT ASSEMBLY

FIGURE 5. LOAD TRANSITION (CLOSE-UP)

FIGURE 6. REFLECTOR TRIGGER PULSE RISE-TIME

FIGURE 7. REFLECTOR TRIGGER PULSE FALL-TIME

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

July 16, 1992
Ref: 20716A01

Lawrence Livermore National Laboratories
P.O. Box 5012
Livermore, CA 94550

Attn: Mr. Doug Larson, L-487

Subject: Capacitor Bank Testing Status Update, Subcontract B137125.

Dear Doug,

Here are the scope traces for the bank output when it is charged at 10kV. The voltage peak across the load resistance is 5.8 kilovolts (Figure 1) and the current is 165KA (Figure 2). This calculates to 35 milliohms for the resistor (which measures 34.25 milliohms when measured with a 1 Amp dc current flowing). The current peak is at 189.5 microseconds (Figure 3).

As we discussed yesterday, we should be getting some preliminary flashlamp test data early next week and I'll FAX it up to you then.

Regards,

Bob Anderson

RLA:km
enclosures
cc: Mr. G. Klein, L-650

FIGURE 1 . VOLTAGE ACROSS LOAD RESISTOR

FIGURE 2. CURRENT THROUGH LOAD RESISTOR

FIGURE 3. TIME TO CURRENT PEAK

FIGURE 4. FLASHLAMP TEST CIRCUIT

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

July 29, 1992

Ref: 20729A01

Lawrence Livermore National Laboratories
P.O. Box 5012
Livermore, CA 94550

Attn: Mr. Doug Larson, L-487

Subject: Flashlamp Testing Update, Subcontract B137125

Dear Doug,

We have just completed a series of five flashlamp tests. The main purpose of these tests was to determine the order of magnitude of current sharing that might be expected among flashlamps that are sourced by a single large capacitor bank.

For the first test, six 14 microfarad capacitors were connected in parallel and then connected to a single flashlamp through a 300 microhenry inductor. This first test circuit is shown in Figure 1-1. A Pearson Model 310 current transformer was used to measure the lamp current.

The bank of six 14 microfarad capacitors was charged slowly until the flashlamp pre-fire level was reached. Three different lamps were checked and the pre-fire levels were found to be between 7.5 and 8.0 kilovolts. Therefore, a maximum operating voltage of 7 kilovolts was chosen for these first tests.

Next, various trigger voltages were applied to the reflector (without any DC voltage across the lamps). Below 5 kilovolts pulse, only the ends of the lamps flashed when triggered. Above 10 kilovolts, the entire length of the lamp contained a glow discharge and there were some streamers that extended from end to end along the inside of the glass surface. Therefore, a reflector trigger level of 13 kilovolts was chosen for initial testing (this being the resulting voltage when the trigger generator thyatron capacitor store was charged to 15 kilovolts). The waveshape rise-time of this trigger pulse is shown in Figure 2, and the overall pulse shape is shown in Figure 3. The ringing at the beginning of the pulse is caused by the reflector capacitance to ground and the lead wire inductance that connects the pulser to the reflector.

Next, the six capacitors were charged to various voltages and the reflector was pulsed to the 13 kilovolt level. The lamp did not fire reliably below about 4.5 kilovolts. Therefore, we decided that these preliminary tests would be conducted at dc charging voltages between 5 and 7 kilovolts. The flashlamp current waveshapes for this first test at 5kV and at 7 kV charging are shown in Figures 4 and 5.

For the second test, two independent flashlamps circuits similar to the first were set up with the two flashlamps mounted in the same reflector segment and pulsed with a common trigger pulse. This circuit is shown in Figure 1-2. At 7 kilovolts dc on the storage capacitors the current waveshape for each of the flashlamps is shown in Figure 6. Although the currents seem different by more than 10 percent, later re-calibrated of the two current transformer/attenuator sets (and elimination of the "ground bounce" effects) show a current difference between lamps to actually be only about 5 percent.

For the third test, the two sets of six 14 microfarad capacitors were bussed together as shown schematically in Figure 1-3. These 12 capacitors then fed the flashlamps through two separate inductor branches. The results were essentially the same as the previous test and shows that the use of a common capacitor energy storage source did not materially effect the division of current between the two flashlamps. The current traces are shown in Figure 7.

For the fourth test, the two inductors were also bussed in parallel, as illustrated in Figure 1-4, thereby paralleling the two flashlamps without the benefit of any separate "ballasting" inductance. The two flashlamp currents, shown in Figure 8, are virtually the same as those in the previous test. This test shows that this particular lamp type both triggers and shares current very well even when bussed tightly in parallel.

Finally, an additional 300 microfarad inductor was added in parallel with the previous two inductors, as shown in Figure 1-5, in order to shorten the current rise-time from trigger to the current peak. Additionally, the diagnostics ground was improved to eliminate the "ground bounce" in the measurement and the two current measurements were carefully re-calibrated. The final current measurements, shown in Figure 9, show a current difference between the two parallel bussed lamps to be less than 5 percent. The voltage across the lamps is shown in Figure 10 and is about 4.2 kilovolts at I peak or about 60% of the charging voltage. This test configuration matches very closely the voltage, current and waveshape that was measured at the test-bed capacitor bank load resistor (as reported to you last week).

In summary, we believe that these preliminary test are very encouraging and show that (as far as triggering and current sharing are concerned), large numbers of flashlamps can be successfully fed from a single large capacitor bank. Naturally, many issues remain to be worked including the optimum triggering waveshape and timing, ignitron firing reliability, lamp aging effects, fault protection, etc.

Next, we plan to connect some flashlamp to the bank in order to confirm these preliminary findings.

Regards,

Bob Anderson

RLA:km
enclosures
cc: Mr. G. Klein, L-650
Mr. B. Gagnon

FIGURE 1-1

FIGURE 1-2

FIGURE 1-3

FIGURE 1-4

FIGURE 1-5

FIGURE 2. TRIGGER PULSE RISE-TIME AT REFLECTOR.

FIGURE 3. TRIGGER PULSE FALL-TIME AT REFLECTOR.

FIGURE 4. SINGLE CIRCUIT, 5kV CHARGING.

FIGURE 5. SINGLE CIRCUIT, 7kV CHARGING.

FIGURE 6. CURRENTS FOR TWO FLASHLAMPS AT 7kV CHARGING.

FIGURE 7. CURRENTS FOR TWO FLASHLAMPS SOURCED BY A COMMON CAPACITOR.

FIGURE 8. CURRENTS FOR TWO FLASHLAMPS BUSSED IN PARALLEL.

FIGURE 9. CURRENT WAVEFORMS OF TWO FLASHLAMPS IN FINAL TEST CIRCUIT.

FIGURE 10. VOLTAGE ACROSS FLASHLAMP AT CURRENT PEAK.

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

August 12, 1992

Ref: 20812A01

Lawrence Livermore National Laboratories
P.O. Box 5012
Livermore, CA 94550

Attn: Doug Larson, L-487

Subject: Another Flashlamp Testing Update, Subcontract B137125.

Dear Doug,

We have just collected some additional flashlamp trigger and current sharing data using the full capacitor bank with two flashlamps connected across the bank. The two reflector triggered flashlamps were attached at the distribution panel as shown in the schematic sketch (Figure 1).

With the capacitor bank charged to 10 kilovolts, the peak current through each of the two flashlamps is within a few percent as shown in Figure 2. Figure 3 shows the current from one of the flashlamps along with the current through the 35 milliohm bank load resistor. The current through the load resistor is trace A while the flashlamp current is trace B. Although the time to current peak is similar, the flashlamp shows a significant lag before starting to draw significant current.

To help sort out the reasons for this lamp behavior, we are setting up to run the bank with only flashlamps as the load. For this test, we will disconnect all but one branch of the bank since we'd like to start out with only 6 to 8 flashlamps mounted into one amplifier segment and triggered by the same reflector pulse.

We should have this data with in a week or so. This test should be representative of flashlamp behavior when multiple reflector triggered flashlamp (but not pre-ionized) are sourced from a common tightly bussed capacitor source.

Regards,

Bob Anderson

RLA:km
enclosures
cc: Mr. G. Klein, L-650
Mr. B. Gagnon

FIGURE 1. FLASHLAMP TEST CIRCUIT.

FIGURE 2. CURRENT THROUGH TWO FLASHLAMPS.

FIGURE 3. CURRENT FOR BANK LOAD (A)
AND ONE FLASHLAMP (B).

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

August 31, 1992
Ref: 20831A01

Lawrence Livermore National Laboratory
P.O. Box 5012
Livermore, CA 94550

Attn: Doug Larson, L-487

Subject: Flashlamp Testing Update, Subcontract B137125.

Dear Doug,

We have finished collecting some data using flashlamps as the only load on the capacitor bank.

To run this test, we disconnected all but one of the bank capacitor branches. We also disconnected the 35 milliohm load resistor so that the flashlamps would be the only load across the bank. Next, we connected 6 flashlamps to the distribution plate assembly as shown by the simplified schematic, Figure 1. The reflector (common to all six lamps) was pulsed as before. All six lamps "glowed" uniformly for their full length when triggered. The reflector trigger pulse was timed to be simultaneous with the pulse to the ignitron trigger chassis. The bank was then charged and fired at voltages of 7,8,9 and 10 kilovolts. The resulting current traces for two of the six flashlamps are shown in Figures 2,3,4 and 5. As before, the current sharing appears to be very good and the flashlamp that has the higher current at 7 kilovolts has similarly higher current at each higher voltage level. It is also noticeable that at 7kv, the lamp current takes longer before it starts to rise than when the bank is charged to 10kv (and therefore the time from the trigger point to the current peak is longer). There is not enough data at this time to know for certain if this related to the ignitron, trigger method or flashlamp.

Before we proceed to collect more data, we are modifying the reflector trigger circuit so that it will automatically be fired if the ignitron switch should

prefire. This will help to insure that no single lamp will take all of the bank current should this type of fault occur. We can then explore a wider range of charging voltages, i.e. maybe from 5kv to 12kv as well as increased amounts of stored energy in the bank (by adding branches).

Regards,

Bob Anderson

RLA:km
enclosures
cc: Mr. G. Klein, L-650
 Mr. B. Gagnon

FIGURE 1. TEST CIRCUIT, SIMPLIFIED

FIGURE 2. 7 KILOVOLTS BANK CHARGING VOLTAGE

FIGURE 3. 8 KILOVOLTS BANK CHARGING VOLTAGE

FIGURE 4. 9 KILOVOLTS BANK CHARGING VOLTAGE

FIGURE 5. 10 KILOVOLTS BANK CHARGING VOLTAGE

AMERICAN CONTROL ENGINEERING INCORPORATED

7636 Miramar Road, Suite 1200 • San Diego, California 92126 • (619) 693-9477

November 30, 1992

Ref: 21130A03

Lawrence Livermore National Laboratory
P. O. Box 5012
Livermore, CA 94550

Attn: Doug Larson, L-487

Subj: Proposed Capacitor Bank Testing Activity.

Dear Doug,

Since the present contract extension and funding is about to run out, we would like to know how you would like to proceed with the bank development and testing effort.

As a suggestion, we have prepared an outline that proposes a list of tasks that we believe should be performed in order to wrap up the ongoing capacitor bank development program. Please look the list over and add, delete, expand or emphasize as you believe appropriate.

I have divided the tasks into three main categories as listed below. Some of the tasks fit into more than one category but are generally as shown.

- (1) TASKS TO BE PERFORMED ON THE EXISTING CAPACITOR BANK THAT WOULD BE USEFUL.
- (2) TASKS THAT SIGNIFICANTLY ADVANCE THE PROGRAM BY PROVIDING NEW, IMPORTANT AND NEEDED INFORMATION.
- (3) TASKS THAT PUT THE PROGRAM INTO FAST FORWARD, BUT AT A VERY MINIMAL COST.

With respect to the last category, I believe that there is enough information available to build a low cost first cut capacitor bank module. Further, I think that we can do it now with the reasonable expectation that the resulting bank configuration will be very representative of the final design.

To keep the costs down, we've worked out a way to cast the capacitor support modules here using a low cost molding process. This will give us first hand experience in the fabrication process and we can easily work out any fabrication or design problems as they come up.

This approach should provide the following major benefits:

1. Answers to any remaining questions about this bank configuration, i.e. a safe, compact, reliable, cost effective energy module feeding large numbers of parallel flashlamps.

2. Construction and layout would be very "representative" of the final design so that no major extrapolations or leaps in visualization would be needed for the next step.

3. Provide a full energy level, compact, safe and convenient advance test-bed module for further component development and life testing.

4. Provide a much better basis for the preparation of accurate manufacturing cost estimates applicable to the final bank design.

Even with limited funding, I'd be in favor of leaping past most of the remaining "supporting" tests (they can be done later if and as required) and spend whatever dollars are available on the fabrication of a best guess bank module package. Although we haven't costed out every activity listed in detail, it appears that most of the list could be accomplished with a funding level in the order of \$15K per month over a time span of 12 to 18 months.

I hope that you had a pleasant and enjoyable Thanksgiving holiday and I am looking forward to receiving your comments.

Regards,

Bob Anderson

Enclosure

NOVEMBER 30, 1992
R. ANDERSON

PRELIMINARY CAPACITOR BANK TASK OUTLINE

1. TASKS TO BE PERFORMED ON THE EXISTING CAPACITOR BANK

TEST LLNL CARBIDE DUMP RESISTOR ASSEMBLY

CONNECT TO BANK

TEST

ADD A SECOND E-SIZE IGNITRON TO THE BANK

DESIGN ADAPTOR SECTION

BASED ON BASE-LINE CONCEPT DESIGN

FABRICATE

ASSEMBLE (NEED ANOTHER LLNL PULSER)

TEST

REPAIR HV CHARGING SUPPLY

ADD FORCE BRACE STICKS TO THE DAMPING RESISTORS

LIST AND CONSIDER ALTERNATE FLASHLAMP TRIGGER METHODS/OPTIONS

BETTER OR MORE COST EFFECTIVE THAN REFLECTOR TRIGGERING

DO A LITERATURE SEARCH

EVALUATE REFLECTOR TRIGGERING AND ESTABLISH BASE-LINE DESIGN

DETERMINE SENSITIVITY TO

FLASHLAMP TYPE, DESIGN AND GEOMETRY

LAYOUT OF HOOKUP LEADS TO THE LAMPS

FLASHLAMP TO REFLECTOR GEOMETRY

AMPLITUDE OF THE TRIGGER PULSE

PULSE SHAPE

TRIGGER PULSE RISE-TIME

PULSE LENGTH

RC DECAY, SQUARE-WAVE, OSCILLATORY
TRIGGER PULSE POLARITY
TYPE OF FAULT ISOLATION SCHEMES USED
TIMING OF REFLECTOR PULSE TO THE MAIN PULSE
FREQUENCY AND VOLTAGE REVERSAL
DETERMINE LAMP FIRING VOLTAGE RANGE
FOR DIFFERENT TRIGGER WAVEFORMS
FOR DIFFERENT REFLECTOR GEOMETRIES
DURING LAMP LIFE-TIME
DETERMINE INTER-RELATIONSHIP WITH PRE-IONIZATION CIRCUIT
DESIGN BASE-LINE TRIGGER CIRCUIT
SIMPLEST POSSIBLE
MOST RELIABLE
MINIMUM COST
FABRICATE AND LIFE-TEST BASELINE FLASHLAMP TRIGGER CIRCUIT
PRE-IONIZATION CIRCUIT
DETERMINE IF NEEDED
DETERMINE THE REQUIREMENTS
DESIGN A BASELINE CIRCUIT
FABRICATE AND ASSEMBLE
TEST AND EVALUATE
COORDINATE WITH REFLECTOR TRIGGERING TASK
ADDITIONAL TEST OF THE EXISTING CAPACITOR BANK FOR:
BUSSWORK FORCES
CURRENT DENSITY OF BOLTED CONNECTIONS
FAULTS (ELECTRICAL AND MECHANICAL)
TO 20 KILOVOLTS

2. TASKS THAT SIGNIFICANTLY ADVANCE THE PROGRAM BY
PROVIDING NEW, IMPORTANT AND NEEDED INFORMATION

DESIGN AND CAST A TYPICAL SINGLE CAPACITOR ENCLOSURE

DESIGN

FABRICATE MOLD

CAST AND DE-MOLD

REVISE AS REQUIRED

CAST QUANTITY FOR A MODULE STACK

WORK ON DAMPING RESISTOR DESIGN

REVIEW RESISTOR VRS FUSE APPROACHES

REVIEW TYPES OF FUSES THAT ARE AVAILABLE

COMPARE WITH RESISTOR ISOLATION APPROACH

EFFECTIVENESS OF RESISTOR IN CONTROLLING FAULT CURRENTS

WHEN A SINGLE CAPACITOR FAILS

WHEN BANK (BUSS OR ANOTHER CAPACITOR) FAILS

ELECTRICAL EFFICIENCY IN NORMAL OPERATION

ENERGY LOSSES VRS RESISTIVITY & INDUCTANCE REQUIRED

RELIABLE AND FAIL SAFE DESIGN

LOW INDUCTANCE

COMPACT

COST EFFECTIVE (LOW COST)

PREPARE A BASE-LINE CONCEPT FAULT ISOLATION RESISTOR DESIGN

DESIGN

FABRICATE

TEST AND EVALUATE

PFN/BALLASTING INDUCTOR

DETERMINE BASELINE VALUES

DETERMINE OPTIMUM LOCATION OF INDUCTORS

EVALUATION OF COST EFFECTIVE DESIGNS

FABRICATE SAMPLE(S)

TEST

DESIGN TRANSMISSION LINE COMPONENTS

REVIEW LOW COST ALUMINUM TUBE TRANSMISSION LINE DESIGN

CONSIDER AND EVALUATE TRANSMISSION LINE OPTIONS

LOW COST END TERMINATION

MIDDLE SECTION SUPPORT ELEMENT

TURNING JOINT(S)

3. TASKS THAT PUT THE PROGRAM IN FAST FORWARD... AT MINIMAL COST

FABRICATE A FIRST CUT BASELINE LOOK-ALIKE CAPACITOR BANK MODULE

MAKE CAST SUPPORT STRUCTURE FOR SEVERAL CAPACITOR STACKS

USE SPARE 50KJ CAPACITORS AT LLNL

FABRICATE SUPPORTING BANK HARDWARE AND COMPONENTS

PARALLEL PLATE COLLECTOR BUSSWORK

DAMPING RESISTORS (COULD USE FUSES INITIALLY)

FABRICATE BEST GUESS DOUBLE E-SIZE IGNITRON SWITCH MODULE

ATTACH NEW BANK ASSEMBLY TO EXISTING COMPONENTS:

TRANSMISSION LINE

LOAD

FLASHLAMP DISTRIBUTION AND TEST PANEL

UPDATE EXISTING PAPER DESIGN OF THE BUILDING BLOCK MODULES

RE-DEFINE WHAT EACH BASE-LINE MODULE IS

PREPARE A WRITTEN DESCRIPTION

PREPARE SPECIFICATIONS

REDESIGN AS REQUIRED

RE-DRAW DRAWING PACKAGE

TOP ASSEMBLY OF SYSTEM

TOP ASSEMBLY OF SUB-SYSTEM ELEMENTS INCLUDING:

SINGLE CAPACITOR MODULE

CAPACITOR STACK

CAPACITOR MODULE GROUP

OUTPUT SWITCH

TRANSMISSION LINE

OTHER

FULL AND COMPLETE CAPACITOR BANK SYSTEM TESTING

FAULT MODES

FORCES

IGNITRON SWITCH

SAFETY DUMP

PILC

FLASHLAMP TRIGGERING

POWER TRANSMISSION

PREPARE UPDATED COST ESTIMATES BASED ON:

NEW BANK MODULE PROTOTYPE