UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

AD-A211 320

1b. RESTRICTIVE MARKINGS

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release; distribution is unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
AFATL-TP-89-14

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
Electromagn. Launcher Tech
Anal & Strategic Defense Div

6b. OFFICE SYMBOL *(If applicable)*
AFATL/SAH

7a. NAME OF MONITORING ORGANIZATION
Analysis and Strategic Defense Division
Electromagnetic Launcher Technology Branch

6c. ADDRESS *(City, State, and ZIP Code)*
Air Force Armament Laboratory
Eglin AFB, FL 32542-5434

7b. ADDRESS *(City, State, and ZIP Code)*
Air Force Armament Laboratory
Eglin AFB, FL 32542-5434

8a. NAME OF FUNDING/SPONSORING ORGANIZATION
Analysis & Strategic Defense Division

8b. OFFICE SYMBOL *(If applicable)*
AFATL/SAH

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
In-House

8c. ADDRESS *(City, State, and ZIP Code)*
Air Force Armament Laboratory
Eglin AFB, FL 32542-5434

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.
63222C	K433	00	01

11. TITLE *(Include Security Classification)*
Final Design and Commissioning Test Results for the Hypervelocity Launcher Research Complex Battery Power Supply

12. PERSONAL AUTHOR(S)
James B. Cornette, John D. Sterrett, (AFATL/SA), Jack R. Lippert, Robert W. Williams (CSA)

13a. TYPE OF REPORT
Final

13b. TIME COVERED
FROM Sep 87 TO Sep 88

14. DATE OF REPORT *(Year, Month, Day)*
August 1989

15. PAGE COUNT
11

16. SUPPLEMENTARY NOTATION
This paper was not edited nor published by AFATL/DOIR

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Post Power
Batteries
Electromagnetic Launchers

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*
The preliminary design of the battery power supply (BPS) was reported to the 6th IEEE Pulsed Power conference [1]. In 1987, the final design was completed, assembled, and sequentially verified during approximately 1,750 operational verification tests. These experiments consisted of single string verifications at 1,000 aperes to a system discharge of 2,150,000 amperes. Final system design is very similar to the preliminary design previously presented. System fabrication is complete and at the present time consists of 858, 16 battery series strings resulting in 13,728 operational batteries. The final switching design has evolved into several levels of redundancy at varying current levels. These include 36 pneumatic, 100,000 ampere switches that control 24, 16 battery strings in parallel. These switches are used for the primary make and break of system current to charge the inductor. There are also 18 pneumatic crowbar switches at the 24 string level that are to short the inductor from the BPS prior to system opening. At the string level there are 2,000 ampere DC contactors that are used as a secondary current break and to pre-set the BPS in the (over)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
James Brion Cornette

22b. TELEPHONE *(Include Area Code)*
(904) 883-0316

22c. OFFICE SYMBOL
AFATL/SAH

DD Form 1473, JUN 86 — *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

3. DISTRIBUTION/AVAILABILITY OF REPORT (CONCLUDED)

appropriate parallel/series configuration prior to a discharche sequence. Explosively driven opening and closing switches are also employed at the interface junction to any Hypervelocity launcher test article. These switches allow the inductor to charge prior to Hypervelocity firings, are then opened for the event, and then explosively closed again to allow the inductively stored energy remaining to be dissipated in the busswork and pneumatic ciruits. Detailed descriptions and operations of these switching sequences are discussed further in the switching section along with descriptions and operational data of the final hardware tested. Control system philosopy, capability, and operation during the commis ioning tests are also discussed in detail.

Accession For
By
Distribution/
Availability Codes
Avail and/or
Dist Special
A-1

FINAL DESIGN AND COMMISSIONING TEST RESULTS FOR THE HYPERVELOCITY LAUNCHER RESEARCH COMPLEX BATTERY POWER SUPPLY

J.B. Cornette
J.D. Sterrett
Air Force Armament Laboratory (AFATL/SAH)
Eglin Air Force Base, Florida 32542
and
J.R. Lippert
R.W. Williams
Computer Science and Applications Inc.
Fort Walton Beach, Florida 32548

CLEARED
FOR OPEN PUBLICATION
MAY 31 1989 20
DIRECTORATE FOR FREEDOM OF INFORMATION
AND SECURITY REVIEW (OASD-PA)
DEPARTMENT OF DEFENSE

ABSTRACT

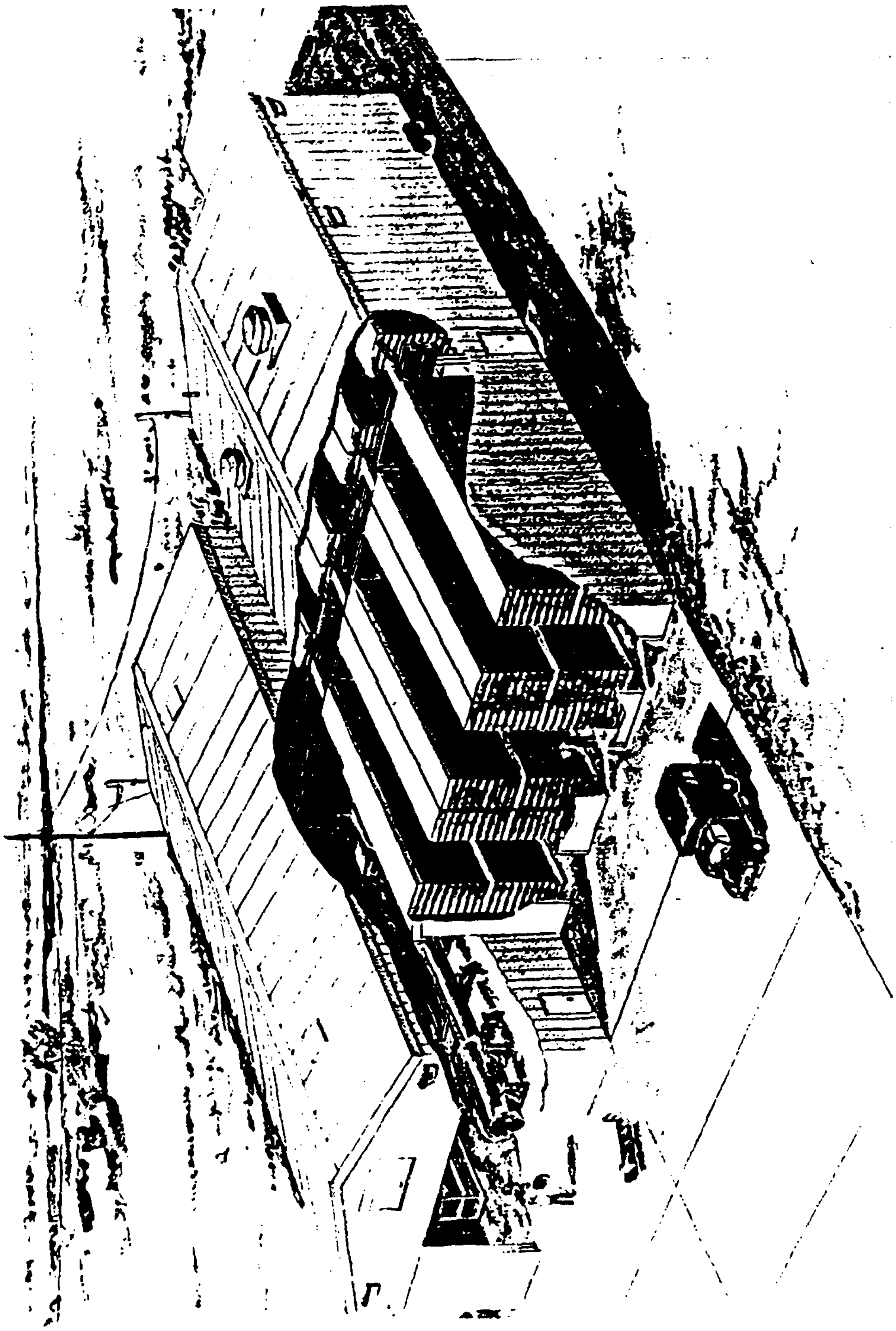
The preliminary design of the battery power supply (BPS) was reported to the 6th IEEE Pulsed Power conference [1]. In 1987, the final design was completed, assembled, and sequentially verified during approximately 1750 operational verification tests. These experiments consisted of single string verifications at 1000 amperes to a system discharge of 2,150,000 amperes. Final system design is very similar to the preliminary design previously presented. System fabrication is complete and at the present time consists of 858, 16 battery series strings resulting in 13,728 operational batteries. The final switching design has evolved into several levels of redundancy at varying current levels. These include 36 pneumatic, 100,000 ampere switches that control 24, 16 battery strings in parallel. These switches are used for the primary make and break of system current to charge the inductor. There are also 18 pneumatic crowbar switches at the 24 string level that are used to short the inductor from the BPS prior to system opening. At the string level there are 2000 ampere DC contactors that are used as a secondary current break and to pre-set the BPS in the appropriate parallel/series configuration prior to a discharge sequence. Explosively driven opening and closing switches are also employed at the interface junction to any Hypervelocity launcher test article. These switches allow the inductor to charge prior to Hypervelocity firings, are then opened for the event, and then explosively closed again to allow the inductively stored energy remaining to be dissipated in the busswork and pneumatic crowbar circuits. Detailed descriptions and operations of these switching sequences are discussed further in the switching section along with descriptions and operational data of the final hardware tested. Control system philosophy, capability, and operation during the commissioning tests are also discussed in detail. A BPS system artist's conception drawing is shown as the facility has been built in figure 1.

Recd 13 Jun 89
0 820
PA

This is a
SAF/PAS document
89-0825
Call 73222/78932
for pickup or
return to 5D227

89 8 14 172

89-116 891925
MSD/PA



SYSTEM OVERVIEW

The BPS is a modular design that requires a wide range of operational flexibility due to the multiple point load conditions. The basic building block for the current output is the battery string, consisting of two trays of eight batteries each connected in series. Configuration contactors allow the trays to be connected either in parallel (120V) or series (204V). Each string is individually controlled via the engagement of string select contactors. These contactors have also successfully demonstrated the capability of interrupting the full string current, in the event of the primary switch failure. Twenty-four strings are routed to a pneumatic actuated butt-contact switch performing the make/break function. Defined as a "GANG", the total D.C. current can be as much as 100,000 amps. An ARC tolerant contact of Copper-Tungsten Elkonite was used in the design as a replaceable low cost insert since the opening arcs result in substantial ablation. Most of the inserts had a dozen cycles of between 40-85 thousand amps each and were still usable at the completion of the baselining/commissioning program. Six "GANGS" are merged into a discrete bus run to the load and is called a "MODULE". Six "MODULES" are installed with their respective busses configured in a field compensated manner, commoned just before the "load" located in the adjacent test-bay building. This results in 858 output current strings for a total available of 13,728 batteries.

Since the batteries are a near constant voltage source, the resultant current is determined by the net effective resistance in the circuit. Peak power is obtained only at a very narrow operating regime.

Although the peak power output for single batteries is approximately 1800 amps, short duration pulses (2-3 seconds) at current levels of 2200 amps per battery have been demonstrated without adverse impact.

At low total system output, the relatively few strings on line would result in excessive current per battery. This abstract is overcome by a stainless steel "limiting resistor" attached to each string and a contact to "bypass" the resistor when desired. The 5 second pulse design requirement has been demonstrated with a worst case of temperature rise of 70 degrees C in these resistors; well below any thermal limitations.

The control system was designed with the capability to independently control 12 Modules of Strings. Implemented under this contract was a system control for 858 strings (6 Modules). The approach selected was to use a distributed control system, which involves multiple Prolog System 2 controllers at each of the battery Modules and a master Prolog System 2 controller located in the HPG Facility screen room. A "simplified" block diagram for the incorporated concept is shown in Figure 2. Module controllers are used to perform such tasks as "charging" and "diagnostics" independently of other controllers. Configuration of Strings for a "discharge" sequence are also performed by the Module controllers. During a "discharge" sequence, the Module controllers are tied together and required to perform in concert with the Master controller.

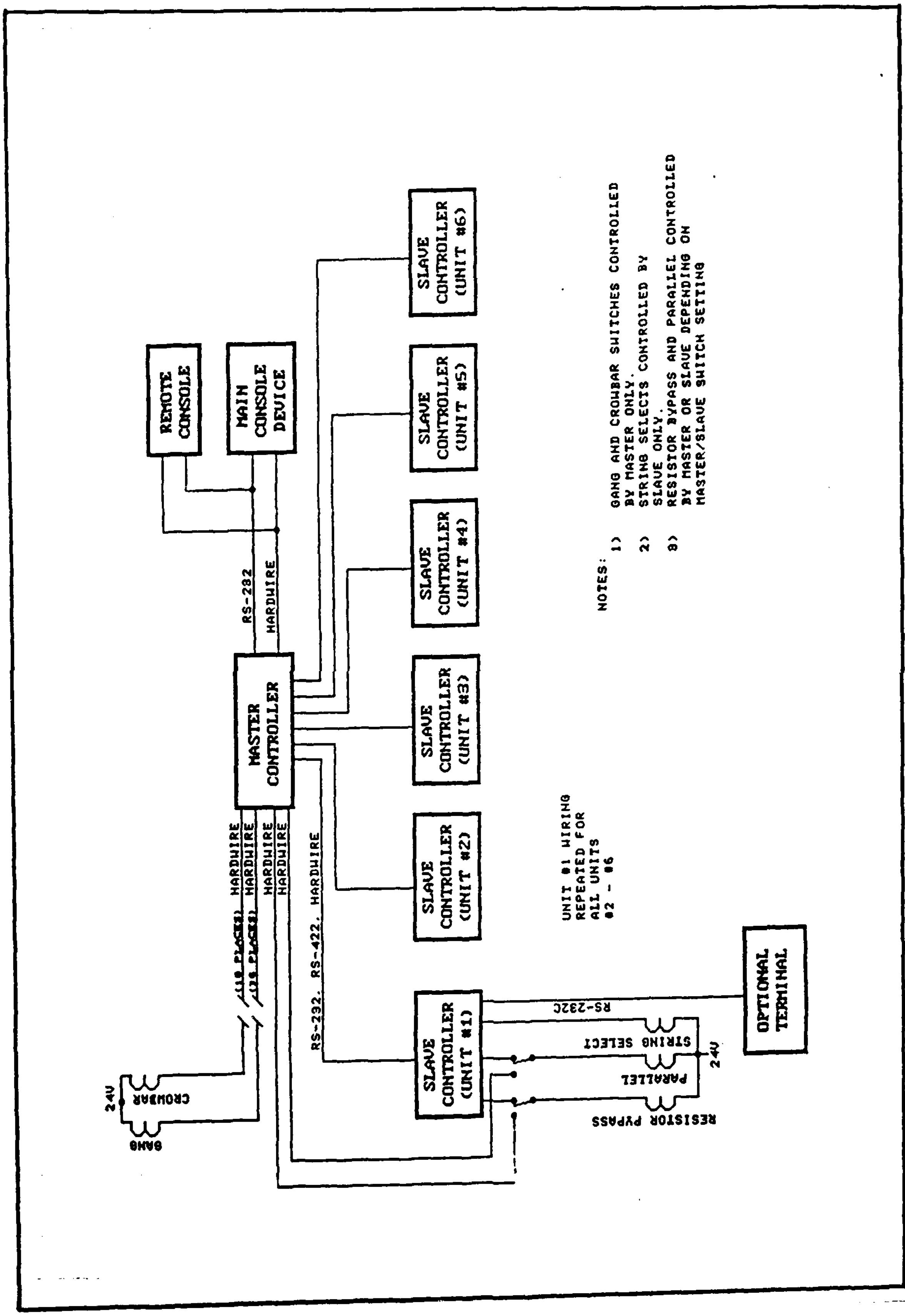


FIGURE 2. SIMPLIFIED CONTROL DIAGRAM

The ability to ABORT any test sequence has been incorporated to ensure a safe BPS system. During a "charging" or "discharging" operation, both voltage and current are continuously monitored in a multiplexed fashion from each string resulting in a simultaneous control and data acquisition (SCADA) type system. If a controller senses a value outside of the user defined limits of operation, the system will be shut down or aborted in an orderly sequence. The capability to "close" and "open" contactors and pneumatic switches at selected times has also been incorporated.

BPS COMMISSIONING PROGRAM

After the finalization of the BPS design, an energetic commissioning test program was undertaken in parallel with the assembly of the six modules. This program was used to formulate assembly procedures, verify and finalize control system operation, verify system electrical integrity, and demonstrate the critical electrical and mechanical design parameters of the overall system. Although the above stated components/parameters of the system were under direct scrutiny during the commissioning program, they represent only a fraction of the overall system knowledge obtained.

SCHEDULE SYNOPSIS

During the seven month commissioning program, several types of experiments were conducted. Of these, the first to be completed on any assembled module involved control system diagnostic programs that measure the open circuit voltages of each string individually in the series and parallel mode and is then printed for the operator to review the state of charge status of the batteries. The next step involved discharging the battery strings one at a time at approximately 1000 amps through a diagnostic load for 0.1 to 1.0 seconds to again verify the operational status of each string to include the resistor bypass and string select contactors. After successful completion of these two diagnostic routines, system current discharges through one turn of the inductor began at the multiple string level, proceeded to the multiple gang level, and culminated in the multiple module level. Demonstrated current levels range from 1000 amps, in the diagnostic load experiments, to 2,150,000 amps conducted for 3 seconds in a full system discharge on 27 September 1988.

The following chart shows the commissioning experiments completed from 3 March 88 to 27 September 88. The experimental acronyms, dates, and demonstrated current levels are listed in numerical acronym order. These experiments are not necessarily in julian order due to the assembly of modules in parallel with this experimental effort and the reverification of certain experiments.

BPS
COMMISSIONING EXPERIMENT SCHEDULE

ACRONYM	DATE COMPLETED	CURRENT OUTPUT
B-0A	3-11 MARCH 88	1KA
B-0B	11-25 MARCH 88	1KA
B-1	30 MARCH 88	8KA
B-2	4 APRIL 88	6KA
B-3	30 MARCH 88	45KA
B-4	1 APRIL 88	90KA
B-5	7 APRIL 88	90KA
B-6	5 APRIL 88	90KA
B-7	14 APRIL 88	90KA
B-8	20 APRIL 88	175KA
B-9	26 APRIL 88	240KA
B-10	29 APRIL 88	240KA
B-0C	11-16 MAY 88	1KA
B-0D	18 MAY-3 JUNE 88	1KA
B-11	24 JUNE 88	180KA
B-12	29 JUNE 88	320KA
B-13	6 JULY 88	470KA
B-14	13 JULY 88	850KA
B-15	15 AUG 88	1.0MA
B-16	30 JUNE 88	320KA
B-0E	25-29 JULY 88	1KA
B-0F	15-19 JULY 88	1KA
B-17	OMITTED	
B-18	3 AUG 88	130KA
B-19	23 AUG 88	1.2MA
B-20	26 AUG 88	1.5MA
B-20A		1.5MA
B-21	OMITTED	
B-22	2 SEPT 88	1.5MA
B-23	23 SEPT 88	250KA
B-24	27 SEPT 88	2.15MA

This baselining test series was to confirm component and system design parameters while carefully increasing the system performance envelope (and consequently system stress). The performance target was 2.0MA storing 16MJ of magnetic energy in the inductor. This value was exceeded using about two-thirds of the installed system.

Examples of the various types of experiments, including pre-shot simulations, pulse durations, transient analysis, example data plots, and lessons learned will be discussed in the following sections.

DIAGNOSTIC LOAD EXPERIMENTS

Sequential discharge of every battery string of the BPS into a discrete load resistor confirmed its connection integrity and proper operation of all the contactors. Approximately 900-1200 amps are extracted on two successive one second pulses. This test is also a routine maintenance tool to assess the string health.

MULTIPLE STRING EXPERIMENTS

Up to 24 strings were simultaneously discharged through the "GANG" switch to correlate the main BPS system performance with that of the prototype system of a slightly different installation configuration. This was also the first time the system pneumatic crowbars across the bus-inductor network could be meaningfully tested. No anomolies or problems were noted.

MULTIPLE GANG EXPERIMENTS

The integration into a system really begins with the multiple "GANG" tests. Significant variances in the actuation times of the large pneumatic switches demanded an individual control timing matrix to the operational data base control program. Disparities of hundreds of milliseconds are compensated for by pre-discharge firing of the "GANG" switches, storing the delays in a matrix and compensating for these delays in the control system trigger signals during the actual shot. The real limit to simultaneous switch operation is the shot-to-shot repeatability of the pneumatic chain of events.

The mechanical jitter limit for any given "GANG" switch/crowbar is approximately a +/- 10ms window. System wide this results in about a 40ms jitter from first to last switch. This difference is sufficient to excite transients particularly in the opening procedure when the storage inductor is charged and the source impedance changes. When the high current "by-pass" mode is used, these transients result in a notable current surge in the later "GANGS" to open, exacerbating arc ablation of those switches.

MULTIPLE MODULE EXPERIMENTS

When multiple Modules are discharged increasing system output current to significant levels (1.0 to 2.0 Megaamperes), the prevalent electromagnetic fields and their associated forces are of concern. Additionally, the high current "bypass" mode could only be attempted if 3 or more Modules were on line to prevent a battery overcurrent situation. An example of such a 3 Module bypass test is shown in figure 3 where the simulation predicts a current profile up to 1.46 MA and figure 4 showing the test data current profile up to 1.48MA. Other tests demonstrated still more significant milestones including:

(a) 130MW of power produce for 5 seconds
(b) 2.15MA through the single turn inductor
(c) Storing over 18.5MJ of magnetic energy in the storage inductor exceeding design requirements by 15 percent while using less than 70 percent of the installed system.

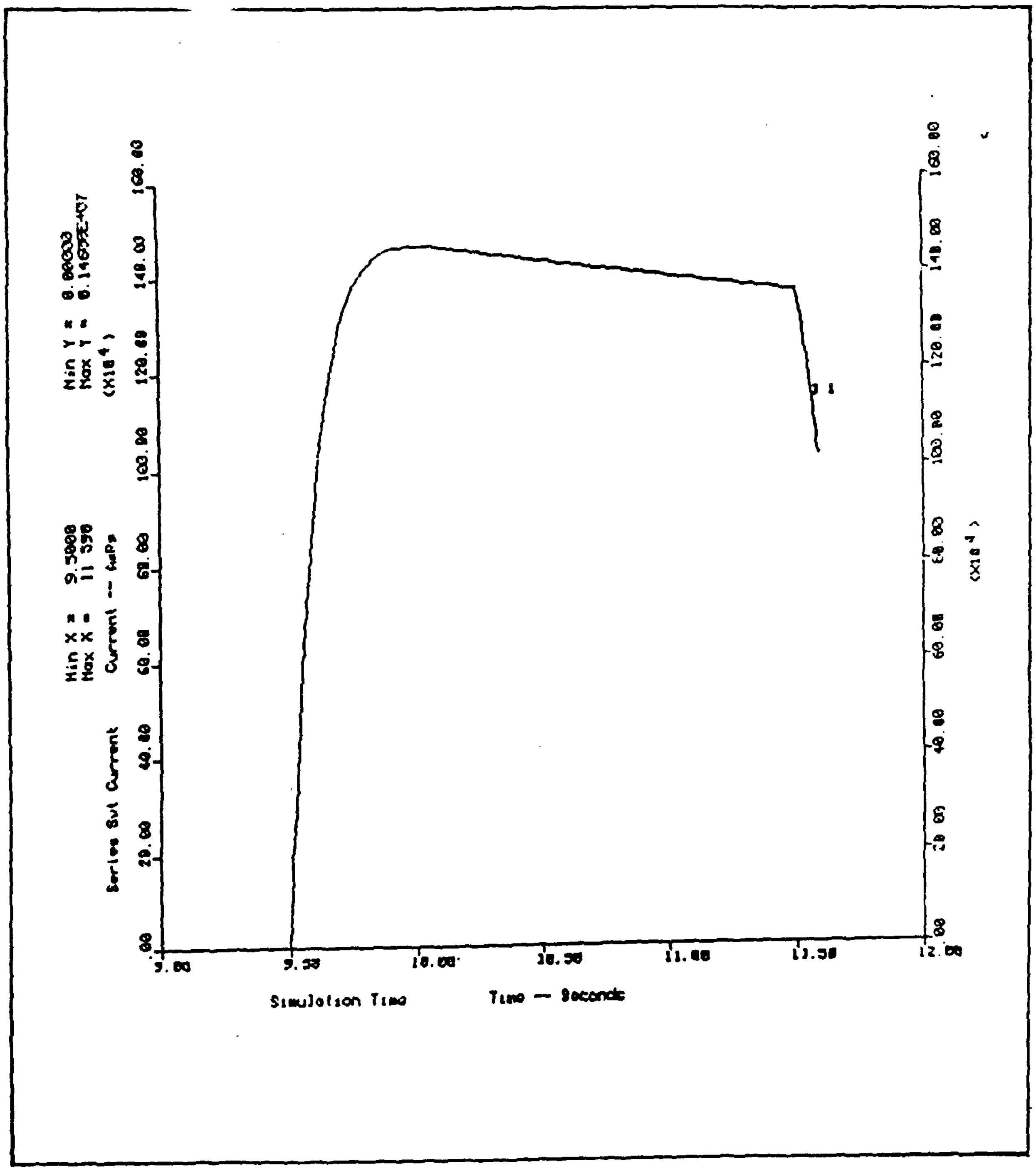


FIGURE 3. PRE-TEST TOTAL CURRENT SIMULATION FOR TEST B-22

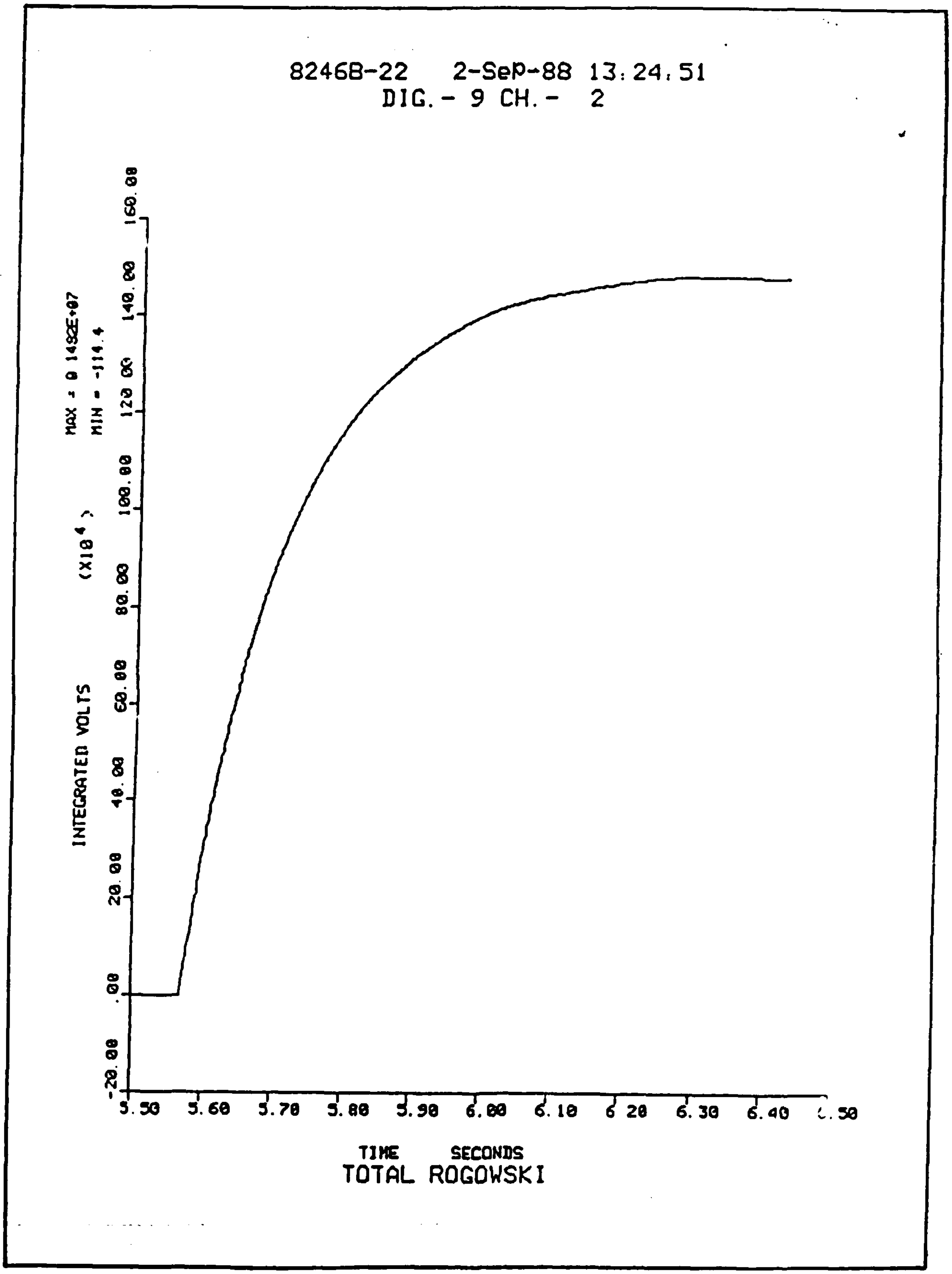


FIGURE 4. TOTAL SYSTEM CURRENT FOR TEST B-22

Attention to field compensation and the proper placement and orientation of the BPS components have shown them to be unaffected by the relatively large magnetic fields. However, the fields from the solenoid inductor in the test bay present an additional obstacle to test equipment and subsystems installed there. These fields will remain a factor, in the near term, until the completion of a non-conducting inductor building adjacent to the BPS test bay by early 1990.

SYSTEM STATUS/FUTURE PLANS

Presently an EMG switch/gun system as well as long conduction time explosives switches are being integrated into the BPS facility test bay. The intent is to perform EMG demonstration testing using the single turn inductor coil, while a new building is constructed to house the 4-turn storage inductor. This new building will contain the massive fields and forces associated with the 2.5 MA, 200 MJ capable storage inductor. In order to reach this power level with the increased resistance of a bus run, the BPS will be increased from its original 6 Modules to 10 containing a total of 22,880 batteries. The fact that the system performance obtained thus far exceeds initial design levels, allows the reduction from the originally anticipated 12 Modules required to 10 Modules for this application.

[1] J. D. Sterrett, J. R. Lippert, M. R. Palmer, N. E. Johnson, and M. C. Altstatt, "Design of a Battery Power Supply for the Electromagnetic Gun Research Facility," presented at the 6th IEEE Pulsed Power Conference, Washington D. C., June 29 - July 1, 1987.