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MHD HIGH PERFORMANCE DEMONSTRATION EXPERIMENT
INTERAGENCY AGREEMENT NO. ET-78-I-01-2895
QUARTERLY PROGRESS REPORT

January 1, 1979 - March 31, 1979

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MASTER

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I. INTRODUCTION

The objective of this experimental research started in late 1973, is to demonstrate the attainment of MHD performance on a sufficiently large scale to verify that the projected efficiency of the commercial MHD concept is attainable. To perform the experiment, an existing facility at the Arnold Engineering Development Center (USAF) was refurbished and the new systems required for performing the experiment have been designed and built. In particular, the largest systems which have required the greatest expenditure of resources are the generator channel and the 6 Tesla (T) cryogenically cooled magnet. The generator fabrication is complete and the five sections are being connected and pressure tested on the channel cart. The magnet is approximately 98 percent complete, lacking only the outlet end thermal enclosure, manifolding hookup, and permanent attachment of the power leads.

During the period between January 1, 1979, and March 31, 1979, considerable effort was devoted to the magnet assembly to permit progress concurrent with repairs necessitated by arc damage which occurred at the end of the previous quarter. An air conditioning system to control moisture condensation in the magnet bore, or on or within the generator channel when it is installed, was designed and is being procured. Final assembly of the subsonic diffuser was started.

II. TECHNICAL PROGRESS SUMMARY

Program status at the close of the current quarter is indicated in Fig. 1. In the following, comments applicable to the progress of the subefforts are presented.

1. Facility Development

No effort was scheduled nor performed during the quarter.

2. Flow Components

The major effort scheduled was the assembly of the subsonic diffuser. A photograph of the diffuser assembly showing the progress is shown in Fig. 2.

3. Generator Systems

The five sections of the generator channel were previously aligned on the channel cart. The channel and its cart were transported to

the High Temperature Laboratory (HTL) for installation of instrumentation sensors and pressure testing in preparation for installation in the magnet bore. For this testing, after the sensor hardware has been installed, the sections are connected sequentially and pressure tested after each section is added. In its design operating condition, the pressure distribution decreases along the length of the channel. To pressure check the channel, the inlet section is tested to the inlet design pressure. As each subsequent section is added, the assembly is pressure tested to the design value at the inlet of the added section. While each channel section was individually pressure tested after its fabrication, these latest tests have revealed leaks of two forms: in the section longitudinal seals and in the flange gasket. The former are thought to be consequential to the handling and movement and are relatively easily eliminated. The latter leaks, however, have proved to be more troublesome.

At the flanges, the copper pegs and electrodes extend beyond the flange sealing plane such that a 0.060-in. gap results on the inside of the channel while the gasket itself is 0.180-in. thick. Tolerances, primarily on the insulating pegs, are such that when the insulating mica is installed in the flange area an interference results which prevents the necessary gasket compression to produce an adequate seal. To correct the situation, it has been necessary to relieve the copper overhang by machining with a portable mill. The alternatives are to use a thinner mica insulator or a thicker gasket. The former would reduce the breakdown potential across the pegwall while the latter is impractical due to the unavailability of gasket material in nonstandard thicknesses. The machining approach has resulted in an acceptable fix and the first three channel sections have passed the required pressure tests.

4. Magnet Systems

The damage incurred at the end of the previous quarter was confined to the coolant tubes, eight of which required replacement all the way to the water blocks. A method of drilling and tapping the water blocks, which are quite inaccessible because of their location inside the coil buildup, was perfected. The replacement tubes were fitted with a threaded bushing and installed without further difficulty. Bench tests of the scheme to implement the repairs indicated that these mechanical joints should be leak-free up to the coil design value of 400 psi. In addition, electrical insulation was added to these coolant tubes and the penetrations through the structure sideplates on all locations. A photograph of the damaged tube after the repairs had been implemented is given in Fig. 3. The photograph also shows the installation of the lower coil power leads with the insulating standoffs installed.

Installation of the coolant tube manifolding on the magnet was completed and Fig. 4 is a photograph of the completed lower left inlet end tube manifolds before the vapor barrier was installed. Because of the concurrent repairs on the outlet end, the inlet end manifold installation proceeded at a faster rate and by the close of the quarter the vapor barrier on the inlet end was installed.

During the quarter, the installation of the bore insulation in the magnet was also completed. The insulation is comprised of styrofoam with a liner fabricated from NEMA G-10 fiberglass panels. A photograph of liner end structure at the inlet end of the magnet is given in Fig. 5. The G-10 panels are glued to the underlying styrofoam and this was facilitated by using large inner tubes placed in the bore and inflated to serve as an expanding mantle until the glue had set.

5. Checkout and Operation

No checkout was scheduled; however, as a consequence of the arc-over the magnet power supply was checked out and is reported in the Technical Investigations section.

III. TECHNICAL INVESTIGATIONS

1. System Checkout

Several meetings were held with DOE personnel and their designated representatives during the quarter regarding the arc-over in the magnet and the resumption of testing. In particular, two meetings were held regarding the philosophy for implementing the test program. It was concluded that the testing should proceed not to achieve the performance goals as quickly as possible, but rather to progress to these goals in steps of incremental stress on the hardware - particularly the magnet. In this regard, the possibility of supersonic channel operation in the Faraday and two-terminal modes should not be discounted.

To implement these conclusions, a test plan for the remainder of the fiscal year has been formulated and is given in Table 1. It is expected that the magnet assembly will be at a convenient state to redo the warm mode checkout in the early part of April. Three tests, duplicating the pulses performed last December, will be performed. Around the first of May, the magnet assembly should be complete at which time cooldown of the coils to 160°K will be

attempted. When this cooldown is satisfactorily completed, the magnet will be pulsed up to three times to fields of 3.0, 3.5, and 4.0 T, respectively. This should be completed before the end of May and following the pulses, the magnet will be allowed to warm up to room temperature. The generator channel will be installed and the hot flow train completed in the first half of June. The burner will be checked out in the latter half of June with at least two unseeded firings to cure the channel refractory. During the last burner firing, the magnet will be pulsed to check the operation of the fuel valve in the presence of the magnetic field.

During July, the initial power producing runs will be made with the magnet pulsed at room temperature at field strengths of 1.7, 2.2, and 2.8 T. The channel will be configured in the Faraday mode with the loading appropriate for the 4-T operation. It is expected that the channel will operate supersonically and produce approximately 20 MW electrical at the peak field. The purpose of these tests will be to check out the power circuitry (load bank and instrumentation) and produce power with an orderly progression in the power production parameter $\sigma u^2 \beta^2$. If necessary, time has been allotted at the end of these power production runs to perform a conductivity check. The last half of August and all of September will be devoted to additional power production testing with increasing magnetic field strengths up to 4 T. For these tests the magnet will be cooled to achieve the higher field. While the peak field during these tests will be up to 4 T, no attempt will be made to optimize the performance of 4 T at this time. Rather, these tests will be to demonstrate the orderly progressive increase in $\sigma u^2 \beta^2$ and the 4-T performance demonstration will be performed in the first quarter of FY80.

2. Magnet Bore Purge System

During the Fall of 1978, engineering evaluations of alternate concepts for the HPDE magnet thermal liner were initiated since the vacuum box approach appeared to be unreliable. Based on this engineering work, it was evident that the interior surface of the thermal liner would be significantly colder than ambient temperature regardless of the actual concept chosen. Moisture would collect on the surface and freeze in place or drip onto the MHD channel depending on the strength of free convection currents circulating in the very small annular space between the liner and channel.

The study revealed that a 2-in. thick styrofoam liner would provide insulation equivalent to the best which could be expected from the vacuum box. The reliability of the styrofoam liner appeared to be far superior to any alternative.

To prevent condensation in the bore region, the annulus could be charged with a sealed-in dry gas or a forced convective flow of dehumidified gas could be used. In the former, the internal surface of the liner would drop into the 20°F to 30°F range. The free convective currents of this cold dry gas would also cool the channel to within a few degrees of this same temperature and the condensation problem would move to the channel bore. Obviously, this could present an even more severe electrical problem considering the nature of the MgO refractory. In the second case, the internal surface temperature is maintained at a value closer to ambient and condensation is prevented by using dehumidified air (a small penalty in heat transfer to the magnet is paid, however).

The criteria for this dehumidified gas purge are:

- a. Minimize the heat input to the magnet
- b. Minimize the cooling to the channel
- c. Possess reliability required for nearly continuous operation

The flow rate and inlet temperature of the purge were chosen to maintain the inner liner surface within 10°F of the ambient temperature, to chill the purge air, and hence the exterior of the channel, no more than 15°F, and to be condensate-free at the exit of the bore. Solution of the equations for a range of parameters, as depicted in Fig. 6, indicates that purge flow rates in the range of 1 lbm/sec, or less, are sufficient if a purge air temperature drop of 10°F to 15°F is accepted. The purge air, therefore, should be dehumidified to a dew point of between 50°F and 60°F.

A standard commercial unit was chosen which meets the requirements specified above. The unit is similar to a home heating/cooling unit and involves a centrifugal blower, a heat exchanger to cool and dehumidify the air, and a resistance heater to elevate the air temperature to near ambient. The cooling system is a split unit with the compressor mounted outside of the HTL Building. Figure 7 is a schematic of the purge air conditioning system indicating the wet and dry bulb air temperatures between the system units.

3. MHD Power Supply Checkout

On March 30, 1979, open-circuit and short-circuit tests were conducted on the MHD power supply systems. These tests were designed to verify the following:

- a. Operation of the transformer tap changer.

- b. Total current delivered by the power supply as a function of transformer tap setting.
- c. Current balance from the two halves of the power supply.
- d. Open circuit voltage as a function of transformer tap.
- e. Safety interlocks
- f. Calibration check of the current transducers

The MHD power supply feeder circuit is shown in Fig. 8. Circuit Breaker 2E1 is the primary control of power. This relay is interlocked with the data system for power supply output current overload, with the rectifier cooling water flow, and with the magnet coil ground detection system.

Figure 9 shows a schematic of the power supply and magnet system. The current transducers were to be checked against the shunt meter readings. This portion of the test was postponed and the transducers were compared with each other and with theoretical data. The voltage transducer supplied a signal to a control room voltmeter and a galvanometer oscillograph recorder. The two voltage towers supplied a voltage reading for the data system.

Maximum current available from the power supply is controlled by the inductance selected (primary side of the regulating transformer, Fig. 8). Variations from minimum to maximum output current are controlled by the regulating transformer. The schematics for one phase of the regulating or tap changing transformer are shown in Fig. 10,

The turns ratio of the transformer is changed by increasing or decreasing the number of active turns in one winding with respect to the other. In this case the number of low side windings (designated $N_1, N_2, N_3 \dots$) is changed. The designations $N_1, N_2, N_3 \dots$ are referred to as taps.

Figure 10. Regulating Transformer

So that the turns ratio can be changed without interfering with the load, a means for shunting the load current during switching is provided through an auxiliary winding. This auxiliary winding also serves as a bridging or preventive transformer designed to limit the circulating current when two adjacent taps are bridged.

In Figure 10 with A on Tap 0 and B on Tap 1, the variable part of the primary has N_1 turns. If A is moved to Tap 1 while B is still on Tap 1, no change occurs. Now let B move to Tap 2. During the switching time, no change occurs since A is still on Tap 0. When B reaches Tap 2 and A is on Tap 1, the effective turn is now N_2 . If A is now lifted from Tap 1 the effective turns become N_3 . Thus a continuous change of taps occurs without interrupting the load. For this experiment reactance Tap 8 (2.28 reactance) was selected. This tap would theoretically allow a short circuit current of 18,000 amps to flow at voltage Tap 1 (1,400 v). The data system safety kill was set at 16,000 amps, 8,000 amps from either half of the power supply.

The open-circuit test results are tabulated in Table 2. This table compares the voltage reading of the transducers with the voltage towers and the measured values with the theoretical values. The voltage towers and transducers agree within approximately 3 percent. This is reasonable since the transducer readings were taken from an oscillograph trace. The absolute values agree within approximately 12 percent with theoretical values for all tap settings.

The short circuit test results are tabulated in Table 3. The two rectifiers show a balance within 5 percent and an agreement with theoretical values within 2.5 percent. These are considered satisfactory results.

The three safety interlocks have been checked out and are operational.

IV. DISCUSSION

WORK PLANNED FOR NEXT QUARTER

The following work on the major subefforts is planned for the next quarter.

1. Facility Development

No effort is scheduled.

2. Flow Components

The diffuser assembly will be completed and the diffuser will be installed in the flow train. The burner will be reinstalled.

3. Generator Systems

The generator channel assembly and pressure testing will be completed allowing placement of the channel in the magnet bore after the cooldown check of the magnet has been completed. Sensitivity studies of off-design channel operation will be completed.

4. Magnet Systems

Assembly operations on the magnet will be completed including the installation of the LN₂ system and the bore purge system.

5. Shakedown and Operation

Retesting of the magnet at room temperature to check the repairs and modifications incorporated will be completed. Initial, partial cooldown and cold mode testing of the magnet will be performed. Burner operation in the presence of magnetic field will be verified and the refractory in the channel will be cured. No power producing tests are anticipated in the next quarter.

Table 1
HPDE Test Schedule FY79

	Mar	Apr	May	Jun	Jul	Aug	Sept
1. WARM MAGNET CHECK	3/0*						
2. COLD MAGNET CHECK	1 to 3/0						
3. SYSTEM CHECKOUT	1/2						
4. 20 MW POWER PRODUCTION GOAL	3/3						
5. POWER PRODUCTION UP TO 4 TESLA	3/3						

*Magnet Pulses/Burner Firings

Table 2
Rectifier 4A and 4B
Open Circuit Test
Inductance Tap 8

<u>Transformer Tap Setting</u>	<u>Voltage from Towers</u>	<u>Voltage from Transducers</u>	<u>Voltage Design</u>
1	1,600	1,640	1,400
2	1,640	1,685	1,450
3	1,706	1,770	1,500
4	1,741	1,810	1,540
5	1,810	1,850	1,590
6	1,845	1,895	1,620
7	1,912	1,935	1,660
8	1,942	1,980	1,710
9	2,010	2,060	1,760
10	2,040	2,105	1,800
11	2,120	2,145	1,845
12	2,146	2,190	1,890
13	2,115	2,270	1,940
14	2,245	2,315	1,980
15	2,320	2,360	2,020
16	2,340	2,400	2,060
17	2,415	2,440	2,100
18	2,440	2,570	2,150
19	2,450	2,610	2,190
20	2,515	2,690	2,240
21	2,540	2,735	2,280
22	2,625	2,780	2,320
23	2,638	2,820	2,360
24	2,720	2,900	2,410
25	2,740	2,925	2,450
26	2,820	2,980	2,500
27	2,835	3,030	2,540
28	2,915	3,070	2,590
29	2,935	3,115	2,630
30	3,015	3,200	2,680
31	3,025	3,220	2,720
32	3,110	3,260	2,780
33	3,190 → 3,206	3,280	2,920

Table 3
Rectifier 4A and 4B
Short Circuit Test
Inductance Tap 8

Transformer Tap Setting	Current Data System			Current Design
	4A	4B	Total	
15	6,912	6,900	13,812	13,800
16	6,700	6,700	13,400	13,550
17	6,600	6,600	13,200	13,300
18	6,500	6,400	12,900	13,050
19	6,400	6,450	12,850	12,850
20	6,400	6,400	12,800	12,600
21	6,200	6,200	12,400	12,450
22	6,100	6,000	12,100	12,200
23	6,000	5,800	11,800	11,950
24	5,800	5,600	11,400	11,700
25	5,600	5,600	11,200	11,550
26	5,300	5,300	10,600	11,300
27	5,300	5,400	10,700	11,150
28	5,200	5,200	10,400	11,000
29	5,150	5,120	10,270	10,800
30	5,120	5,050	10,170	10,650
31	5,070	5,050	10,120	10,450
32	5,050	5,000	10,050	10,300
33	5,020	4,980	10,000	10,150

△ SUBEFFORT BEGINNING

▽ SUBEFFORT COMPLETION

SOLID BAR INDICATES WORK ACCOMPLISHED

BROKEN BAR INDICATES SLIPPAGE AND RESCHEDULING OF ACTIVITIES

HPDE PROGRAM SCHEDULE

REVISED 7-7-78

Figure 1. High Performance Demonstration Experiment Program Schedule

Figure 2. Photograph of Diffuser Assembly Prior to Installation of Sidewalls

Figure 3. Photograph of Lower Exit Coolant Tubes after completion of Repairs and Installation of Power Lead Standoffs

Figure 4. Photograph of Completed Coolant Tube and Manifold Installation on Inlet End of the Magnet Prior to Vapor Barrier Installation

Figure 5. Photograph of Insulating Bore Liner at the Inlet End of the Magnet

Figure 6. Bore Purge Cooling Air Requirements

Figure 7. Schematic of HPDE Magnet Bore Purge System

MHD MAGNET POWER SUPPLY FEEDER CIRCUIT

Figure 8. MHD Magnet Power Supply Feeder Circuit

MHD MAGNET, POWER SUPPLY, AND EQUIPMENT

Figure 9. MHD Magnet Power Supply and Equipment