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

October 1, 1978 - December 31, 1978

MASTER

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to

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by

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I. INTRODUCTION

The objective of this experimental research, initiated in December 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 viable. To perform the experiment, an existing facility at the Arnold Engineering Development Center 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 portion of the expended effort are the generator channel and 6 Tesla (T) cryogenically cooled magnet. The generator channel is now complete and the magnet is approximately 85 percent complete. Proof testing of various components has been performed to the extent possible and extensive testing of the plasma generator with its ancillary systems in particular has been completed.

During the period between October 1, 1978, and December 31, 1978, the assembly of the magnet continued with the installation of the force containment structure (FCS) and upper pole steel being completed. Final placement of the magnet was accomplished and initial testing of the magnet performance was started. In the course of this testing, an arc over occurred in the outlet end coolant tubes and the testing was terminated to effect remedial repairs. Prior to the arc over, three successful powered tests with a peak field strength slightly greater than 2 T were performed.

Fabrication of the components for the subsonic diffuser and alignment of the generator channel sections on the channel cart were also completed in this period.

II. TECHNICAL PROGRESS SUMMARY

Program status at the end of the quarter is indicated in Fig. 1. In the following, applicable comments concerning the progress of the subefforts during the quarter are presented.

1. Facility Development

The rails for the channel cart and diffuser were installed in the facility.

2. Flow Components

The major effort scheduled was the fabrication of the diffuser components which was completed. In addition, during the removal of the burner for the final magnet placement, the burner backplate was removed, inspected, found to be sound, and reinstalled.

3. Generator Systems

The five sections of the generator channel were previously assembled and placed in storage. During the past quarter, the sections were removed from storage, the rollers installed and the sections aligned, and bolted together on the channel cart. This was a trial assembly to minimize the alignment time required prior to installation in the magnet. The completed channel is shown in Fig. 2 as it appears mounted on the channel cart.

Installation of the instrumentation for the channel continued with sensor lines being installed from the junction boxes in the vicinity of the magnet to the data acquisition system in the control room. After the magnet had been placed in its final position, the installation of the patch panels for connecting the generator channel to the Faraday load bank was started and was approximately 50 percent complete at the end of the quarter.

4. Magnet Systems

The installation of the FCS and its associated instrumentation comprised of strain gages and thermocouples was completed. Initial checking revealed that the FCS is shorted circumferentially although numerous components had been anodized to prevent such an occurrence. From the initiation of the magnet design, it had been speculated that a circumferential short in any part of the magnet structure would act as a shorted single-turn winding of a transformer. As such, it would cause the field strength to lag the exciting current which in turn would increase the overall rise time, resistive heating of the coils, and as a result, lower the peak field strength produced. In addition, the circulatory current induced in the FCS would result in an additional force for which the structure was not designed to react. In particular, the force on the structure could be directed inward while the structure is designed to counteract outward directed coil forces only. No supportive analysis for this speculation was provided in the magnet design.

Calculations using a lumped parameter analysis have been made to ascertain the influence of the shorted FCS. Results of these calculations are shown in Figs. 3 and 4 for one particular case, the 6 T cold pulse. For this case, the coupling coefficient between the coil and the FCS was taken to be 0.8 and the resistance of the FCS taken to be 1×10^{-6} ohm. In Fig. 3, the peak field strength as a function of time is given. During the rise of current in the magnet coil, the induced current in the FCS is of the opposite sense which has two effects: first, the rate of current rise in the coil is faster and second, for a given current in the coils, the magnetic field is of lower strength than for no induced countercurrent. During the field rise, the field produced lags

the current as indicated in Fig. 3 and this lag, coupled with resistive heating, does reduce the field peak value slightly.

At the peak field point, the coil current is constant and the induced current in the FCS is zero. As the coil current drops, the induced current is in the same sense and tends to slow the decay of field after the peak, as well as when the power is terminated corresponding to 60 sec in Fig. 3.

A similar phenomena is manifested in the forces developed in the FCS, as shown in Fig. 4. The force in a current-carrying element in the presence of a magnetic field is the vector cross product of the current and the field. A simple measure of the force in the case of no-shorted FCS is then the product of the coil current and field strength at any time. This force measure is shown in Fig. 4, nondimensionalized with respect to the maximal value at the peak field-current point for the unshorted case. In the case of the shorted FCS, the coil forces along the horizontal runs will always be directed outward. However, the induced forces in the longitudinal tension members (LTM's) will be directed inward during the field rise and outward during the field decay in accordance with the directions of the induced countercurrent. The peak force is reduced due to the lower field and current as well. The resulting effects of a shorted FCS are not severe and of the order of the uncertainties in the design values themselves. An initial test of the magnet was made by powering the magnet coils with an arc welder which passed about 100 amp through the coil at 50 v potential. Leads connected to one of the transverse tension members (TTM's) indicated that a substantial circulatory current was present in the member during the transient power in the coil. However, the welder characteristics as well as the absence of the upper pole steel precluded any quantitative comparison with the design analysis.

The magnet assembly was moved outside the High Temperature Laboratory (HTL) for placement of the steel return frame. Figure 5 is a photograph showing the magnet outside prior to starting the steel placement. Mobile cranes were used to install the frame steel and Fig. 6 is a photograph of the final steel block installation. The magnet was subsequently moved back into the building and placed in its final position to within 0.060 in. perpendicular to the desired bore centerline and 0.562 in. longitudinally to the desired inlet position on this centerline.

The installation of the manifolding connections for the coil coolant tubes was started along with installation of the patch panel on top of the magnet. Welding of tie plates on the steel frame was also completed after the magnet had been placed.

5. Checkout and Operation

The bus bar installation was completed to the magnet and the power supply was checked out with a dummy load. The Hall probes were mounted on a PVC and fiberglass structure in the magnet bore, as shown in Fig. 7, and the magnet was temporarily connected to the power supply to perform the warm mode checkout. The first two powerings of the magnet were with an open-circuit voltage of 1,400 v, the lowest voltage setting available. The third test was conducted with an open-circuit voltage of 2,100 v and achieved a peak field strength of 2.26 T at 4,100 amp. For the fourth test, the open-circuit voltage was increased to 2,800 v and during the test, arc over on the lower coil coolant tubes occurred. The arc over occurred at a field strength of 2.32 T and 4,250 amp, conditions quite close to steady conditions achieved in the previous test. As a consequence of the arc over, the coil coolant tubes were damaged as shown in Fig. 8. No further coil damage, turn-to-turn for example, has been found.

III. TECHNICAL INVESTIGATION

Preliminary Magnet Data

To check out the magnet and obtain its operating characteristics, four powered runs were made in the uncooled or "warm" mode with the upper and lower coils series-connected. The first run was of 20-sec duration using Transformer Tap 1, which has the lowest power supply open-circuit voltage of 1,400 v. This was essentially a proof test and the duration was insufficient to reach the steady-state peak field. The second test was a repetition of this test for 50-sec duration with achievement of a steady peak field of 1.7 T at 2,800 amp. The third test was performed with Transformer Tap 17, which has an open-circuit voltage of 2,100 v. This test was of 47-sec duration and resulted in a steady peak field strength of 2.3 T at 3,900 amp. The fourth test was performed using Transformer Tap 33, which has the highest available open-circuit voltage of 2,800 v. This test was terminated after 15.5 sec due to an arc over. At the time of termination, the peak field value was 2.32 T at a current of 4,200 amp.

In addition to the power supply voltage and current measurements, the major instrumentation for the magnet tests was an array of twelve Hall probes to measure the field in the magnet bore. These probes are uniaxial and were mounted to sense only the vertical field component within the bore. The location of the probes during the tests is shown in Fig. 9 for reference. The probes were situated to roughly span the

interior area of the loaded portion of the generator channel and the first transverse row closest to the bore inlet was placed to coincide with the edge of the first pole piece.

Measured field strengths of three axial positions for the three power supply settings used are given in Figs. 10, 11, and 12 for transformer tap settings of 1, 17, and 33, respectively. In all cases, the resolution of the data appears good and no crossing of the curves is indicated. In Fig. 10, the fields measured with Probes H9 and H11 are nearly identical, suggesting that these probes are indeed near the peak of the axial field distribution. Also in Fig. 10, a reference line of the same terminal slope of the data has been extended back to the origin. The fact that the data dip below this reference line in the initial rise of the field is indicative of the field rise lagging the current rise and is explainable on the basis of the shorted FCS. This characteristic is manifested in Figs. 11 and 12 as well. In Fig. 11, the field variation between probe position H9 and H11 is more pronounced for the higher fields and currents, which may be suggestive that the axial location of the field peak value varies with the field or steel saturation characteristics. For comparison, the steady-state conditions for the Tap 1 test is shown on Fig. 11. Again, a lagging of the field rise for a given current rise is indicated by the data for the transient portion of Tap 17 operation falling below the steady-state operating point for Tap 1 operation. This may also be a manifestation of the shorted FCS. Finally, the available data for Tap 33 operation is given in Fig. 12 and exhibits the same qualitative characteristics previously discussed. However, the B-I characteristic curve previously used for design predictions is shown in Fig. 12 for comparison and the agreement is not very good. In particular, no sharp break corresponding to saturation of the steel has been observed during the tests. In Fig. 13, the comparison of the design and experimental curves is made on a more appropriate scale with the experimental curve extrapolated to higher current values using the theoretical slope which appears reasonable. The comparison in Fig. 13 suggests that ultimate peak performance of the magnet may be approximately 0.25 T below its design value but the evidence is quite inconclusive at this time.

In Fig. 14, the field transients measured at the location of the Hall probe H11 are given for the three transformer tap settings used. As expected, the rate of rise is fastest for the highest tap voltage. The experimental rate of rise is less than the pretest prediction made for Tap 33 only. For completeness, the transient current rise for the three power supply settings are given in Fig. 15.

In Fig. 16, the steady-state axial profile for the Tap 1 and Tap 17 tests are presented. Tap 33 results did not achieve a steady-state and are therefore not given. The distributions are qualitatively similar and exhibit some variation in the field peak near the inlet which may be indicative of the steel saturation. In addition, the results for off-axis probe locations indicate that the field in the bore is quite uniform transverse to the centerline.

IV. DISCUSSION

Work Planned for Next Quarter

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

1. Facility Development

No effort is scheduled.

2. Flow Components

Diffuser assembly will be completed.

3. Generator Systems

The generator channel will be assembled on the cart in the High Temperature Laboratory in preparation for installation of the magnet. Power instrumentation for the channel will be completed.

4. Magnet System

The arc-over damage will be assessed and necessary repairs implemented. The installation of the vapor barrier thermal liner and LN₂ manifold system will continue and is expected to be completed at the end of the next quarter.

5. Shakedown and Operation

No shakedown testing or operation of the major systems will be scheduled due to the delay incurred to repair the magnet. Component checking required during assembly (i.e., continuity, shorts, etc.) will proceed as required.

▽ SUBEFFORT COMPLETION

SOLID BAR INDICATES WORK ACCOMPLISHED
BROKEN BAR INDICATES SLIPPAGE AND RESCHEDULING OF ACTIVITIES

HPDE PROGRAM SCHEDULE

REVISÉD 7-7-78

Figure 2. Photograph of HPDE Generator Channel Installed on the Channel Cart

Figure 3. Calculated Influence of Shorted FCS on HPDE Magnet Performance during Cold Mode Pulsed Operation

Figure 4. Calculated Influences of Shorted FCS on HPDE Magnet Coil Forces during Cold Mode Pulsed Operation

Figure 5. Photograph of HPDE Magnet Assembly Outside of High Temperature Laboratory prior to Placement of Frame Steel

Figure 6. Photograph of Placement of Last Steel Frame Member on HPDE Magnet Assembly

Figure 7. Installation of Hall Field Probes for Measuring Magnetic Field Strength during Warm Mode Magnet Checkout

Figure 8. Photograph of Coolant Tube Damage Resulting from Arc Over during the Fourth Warm Magnet Test, View is Looking Down at Right Rear Saddle Region of Lower Coil.

Figure 9. Hall Probe Locations, Top View

Figure 10. Magnetic Field Strength Variation during Current Increase for Transformer Tap 1 Operation

Figure 11. Magnetic Field Strength Variation during Current Increase for Transformer Tap 17 Operation

Figure 12. Magnetic Field Strength Variation during Current Increase for Transformer Tap 33 Operation

Figure 13. Comparison of Design and Experimental B-I Characteristic Curves for the HPDE Magnet

Figure 14. Peak Magnetic Field Strength Variation with Time, Probe H-11

Figure 15. Magnet Current Variation with Time

Figure 16. Magnetic Field Strength Distribution along Magnet Bore