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Development of Ultra Efficient Electric Motors

Quarterly Report for the Period
July-September 1999

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TITLE

Development of Ultra Efficient Electric Motors

PROGRAM DESCRIPTION

There are four major tasks included in this project:

- 1) Design, build and test a 1000 horsepower synchronous motor with high temperature superconducting (HTS) coils operating in the 25 to 40 K temperature range
- 2) Design, build and test a 5000 horsepower synchronous motor with HTS coils operating in the 25 to 40 K temperature range
- 3) Develop and integrate closed-cycle cryogenic refrigeration systems with both motors
- 4) Develop the HTS wire and coil technology required for both motor demonstrations.

The goal of the 1000 hp motor demonstration is to build an HTS motor which is comparable in size and efficiency to a conventional motor of the same rating. The goal of the 5000 hp motor demonstration is to build an HTS motor which is half the active volume and has half the losses of a conventional motor of the same rating, and to demonstrate continuous operation of the 5000 horsepower motor at a beta test site. The project represents a vital step in the development of HTS motors for commercial applications.

PROGRESS

- ☐ Completed rotor structural integration.
- ☐ Completed thermal performance evaluation of high-pressure cryogenic transfer coupling at 1800 rpm.
- ☐ Completed preparation for installation of stator form-wound coils.

1000 Horsepower HTS Motor Development

Rotor Development: Rotor assembly continues with a major milestone reached in the bonding of the composite torque tubes. Upon the completion of the bonding process, the rotor has been integrated into a single structural element. The bearing seats on the shaft extensions and the outer surface of the main structure were final machined at the same setting to meet their concentricity requirement. Currently the rotor cryostat is ready to accept the HTS field winding coils, while the delivery of the two replacement HTS coils from American Superconductor Corporation is expected to take place early next quarter.

The flux shield has been completed and is supported by rounding rings to prevent any undesirable deformation prior to rotor installation/integration. The vacuum jacket of the rotor cryostat has also been completed. A fixture for holding the vacuum jacket during dynamic balancing was fabricated and used to balance the vacuum jacket. Balancing weights were successfully bonded to the inner surface of the vacuum jacket. The cold mass of the rotor cryostat will be trim balanced once all HTS coils are mounted and then a final trim balance will occur after the outer vacuum jacket is attached to close off the rotor cryostat.

Stator Development: The stator core final machining was completed and the G-10 laminations were stacked, inserted, and then bonded inside the laminated stator back-iron structure. The G-10 stack consists of twenty-three pieces of 1" thick G-10 laminations. Individual G-10 laminations were stacked and bonded in substructures prior to the stator final assembly. Winding slots were water-jet cut in these G-10 pieces to accommodate the stator coils. The stator structure was shipped to the Reliance Washington Service Center in Pennsylvania (RWP) in August for the installation of stator coils. The final step of the stator fabrication will be a vacuum pressure impregnation (VPI) process of the stator assembly once all coils are in place. The hydraulic resistance of each cooling tube embedded in the stator coils has been characterized. The cooling circuit in the frame was helium-leak checked prior to the installation of the stator coils. Currently, the coil installation is near completion. The VPI process is expected to take place in next quarter.

Brushless Exciter Development: The winding design has been finalized, and the mechanical drawings for both the stator and the rotor have been completed. Some of the component drawings have been released for production. The control circuitry has been bread-boarded and initial testing completed. The final layout for the control circuit board has yet to be completed. A slip ring assembly will be used for initial testing of the motor.

Transfer Coupling Development: The high-pressure cryogenic transfer coupling has been tested at cryogenic temperatures while rotating at its operating speed of 1800 rpm. The testing was conducted to simulate the actual application scenario by connecting a helium refrigerator (PSI Model 1420) to a rotor cryostat test rig which was comparable in size to the 5000 HP HTS motor. Available instrumentation does not allow isolation of thermal performance of each component connected, such as the vacuum-jacketed transfer lines, the transfer coupling, and the rotor cryostat. Therefore, the cryogenic static and dynamic loads from this transfer coupling can only be estimated at around 10 W and 20 W, respectively. Future plan includes high-pressure, stand-alone testing of this transfer coupling once the baseline refrigeration system becomes available. The transfer coupling will be mounted on a specially designed test rig and connected to the refrigerator. A U-shaped, vacuum-jacketed jumper tubing will be used to interconnect the supply and return streams, which eliminates the need for a load device such as a rotor cryostat. This stand-alone testing will reduce the uncertainty in heat leak measurement and therefore will allow a more accurate estimate on the transfer coupling's thermal performance.

1000 Horsepower HTS Motor Testing Facility

Preparation for the testing of the 1000 hp HTS motor continues. A final layout for the test area has been generated. Renovation of the facility area continues, including providing power sources for auxiliary equipment, in order to accommodate the motor testing. A skid for the coldbox of the baseline refrigeration system and a supporting fixture for the transfer coupling and vacuum jacketed helium supply and return lines have been designed. The skid is to make up the elevation differential between the motor shaft and the vacuum-jacketed helium supply and return lines. It is equipped with a sliding mechanism on the top, which allows the coldbox to travel up to six inches parallel to the motor shaft for the engagement of the bayonets.

5000 Horsepower HTS Motor Development

The performance of the rotor electrical shields was further analyzed under fault conditions. The losses by non-symmetrical short-circuit were calculated. The coil designs for one-layer and two-layer stator windings were compared.

Further analyses and design refinements were completed in preparation for creating the mechanical layout of the system. Based on preliminary analysis, it appears that sleeve bearings may be required for the first time in HTS motor development history to support the rotor. The overall motor dimension has been estimated, which defines a working envelope for the motor system. A report describing the electrical design analyses was also completed.

Problem Areas

- Contamination due to the flux used for braze joints of the field winding current leads caused electric shorting, which was immediately detected and rectified.
- A water cooling tube in a stator coil was damaged. A splice was used to extend the tube for the VPI process. The tube extension beyond the splice will be trimmed off after the VPI process, and therefore should not cause any problem during the subsequent plumbing work of the stator cooling system.

Subcontractor Work Status

- The subcontractor work performed by American Superconductor Corporation on cryogenic refrigeration system and HTS wire and coil development is summarized in a separate report (see attached).

FUTURE PLAN

Next Quarter

- Complete mounting of HTS field winding coils.

- Complete dynamic balancing of rotor cryostat.
- Complete installation of stator winding.
- Ready baseline refrigeration system for preliminary testing.
- Complete conceptual mechanical design of the 5,000 HP motor.

SPENDING

The actual total program outlay, in comparison with the projected spending, through the end of May, 1999, is graphically presented in Figure 1. Spending data through the end of September, 1999, was not available at this time.

Figure 1. DoE SPI Phase 2 spending (actual vs. projected)

DEVELOPMENT OF ULTRA-EFFICIENT ELECTRIC MOTORS PHASE II

Quarterly Report Summary (July - September '99)

Department of Energy Superconductivity Partnership Initiative DE-FC36-93CH10580

American Superconductor Corporation

1000 HP FULL COILSET DEVELOPMENT

The final two full coilsets (nos. 1862 and 1863) were completed and shipped to Rockwell during this quarter. These coils both had very low power dissipation characteristics. As a next step, these coils along with two other sets—1440 and 1442—will be installed into the 1000 HP rotor. The goal is to complete the assembly of the motor and begin preliminary testing by the end of this calendar year.

5000 HP COIL DEVELOPMENT

In an effort to qualify the insulation for the 5000 hp motor, the rotor body testing continued during the reporting period. For these rotor body tests, the coils are potted into an aluminum casing, which simulates the effect of the coil being potted to the rotor. Previously, the Kapton-based insulation system was the baseline choice; however, after repeated cycling, it became clear that this insulation was contributing to I_c degradation. Therefore, a decision was made to switch to glass-wrapped wire. Preliminary tests showed promise as the first glass-wrapped coil survived 20 thermal cycles with an overall retention of ~98%. More of these coils are being fabricated to accumulate more data.

Also, work has progressed on our ability to wind conical coils. Several trials have been performed using "practice" wire to establish the proper tensioning and method of potting for these coils, and a full-size conical coil has been wound, as shown in Fig. 1. The next step is to develop and fabricate some potting and winding fixtures that will allow us to make the prototype coils with good wire.

Figure 1 – Full-size conical coil.

CRYOGENIC SYSTEMS

Introduction: The cryogenic systems task is focused on the development of refrigeration system options that are technically and economically attractive for the motor application. The selected goals of the refrigeration system for the 1000 HP motor includes the capability to provide 27 watts of cooling at or below the selected winding operating temperature and additional 33 watts above the winding temperature.

1000 HP Refrigeration System: Testing of the refrigerator for the 1000 HP system has been completed. It was shipped to Rockwell at the end of September. A photograph of the refrigeration unit for the 1000-hp

system is shown in Fig. 2.

Figure 2 – 1000-hp refrigeration system.

5000 HP refrigeration System: We have been working with Rockwell in the design of a viable refrigeration system for cooling the rotor. A flowing system is required because the system will need a set of two cryocoolers, and because of the geometry of the rotor supports. There are currently two options, a fan circulation loop with helium gas and a neon thermosiphon. We have chosen the A20 fan from Stirling Technologies for the helium circulation loop option. This fan A helium loop will offer the most flexibility in the design of the rotor cooling and will require less input power for the cryocoolers. We have purchased one of these fans for testing purposes and expect it to be delivered at the end of October. The fan has a limited working head and the cooling loop will need to be designed carefully to accommodate this limit. At this time Rockwell's coaxial feed through design is the major limiting factor. Rockwell is currently looking into its design to see if it can be modified for less pressure drop. Until the fan design is proven out the neon thermosiphon is the option of choice. We have worked out test plans and have material on order and should be testing a thermosiphon loop by the middle of October.