MHD Integrated Topping Cycle Project

Twentieth Quarterly Technical Progress Report

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EXECUTIVE SUMMARY

This twentieth quarterly technical progress report of the MHD Integrated Topping Cycle Project presents the accomplishments during the period May 1, 1992 to July 31, 1992. A summary of the work completed during this reporting period is presented in this Executive Summary.

SYSTEMS ENGINEERING (SECTION 3)

Interface verification for the combustor and channel was completed.

The O&M manuals for the channel and current consolidation hardware were delivered to the CDIF.

The overall integrated schedule for MSE, TRW, TDS, and Westinghouse was reviewed.

COMBUSTION SUBSYSTEM DESIGN AND FABRICATION (SECTION 4)

The manufacturing, assembly, and checkout of all combustor contingency and spare hardware was completed.

The water electrical isolators, which were fabricated and tested last quarter, were shipped to the CDIF this quarter.

PROTOTYPICAL CHANNEL SUBSYSTEM DESIGN AND FABRICATION (SECTION 5)

A successful nozzle proof test was concluded during this reporting period. The purpose of the test was to evaluate the adequacy of the nozzle structure and to evaluate sealing of the sidewall-to-electrode wall joints, water tubes, and stud and wire penetrations at operating pressure.

Design modifications to the spare channel inlet frame were made in order to incorporate the capability for iron oxide injection. These changes were based on tests performed in the CDIF 1A1 channel which compared the effect of different cathode wall iron oxide injection locations. Results indicated that injection through the side port may be more effective in spreading iron oxide, particularly should one of the two ports become clogged. Design confirmation testing of a pneumatically driven ram to clear a plugged iron oxide injector tip was performed.

The manufacture of spare and replacement parts for the 1A4 channel and diffuser was begun.

CURRENT CONSOLIDATION SUBSYSTEM DESIGN AND FABRICATION (SECTION 6)

During this quarter, the construction of the cathode power cabinets and associated control system was completed. The cabinets will undergo a test program similar to that conducted on the anode equipment before being shipped to the CDIF, where the cathode system will be installed along with the anode system in late October.

CDIF TESTING (SECTION 7)

During this reporting period, the hot-fire checkout test series was completed for the prototypical combustion subsystem. The Low Pressure Cooling System (LPCS) was used to cool the panels in the combustor and precombustor. Electrical isolators were installed in the piping between the LPCS and combustor. Seven hot-fire tests were performed in the Combustor Checkout Test Series accumulating 16.8 thermal hours. Overall, the test series demonstrated the adequacy of the overall cooling of the combustion subsystem and provided an initial evaluation of the combustor performance in terms of heat losses and slagging characteristics.

Several major facility activities were accomplished this quarter:

- 1) New iron oxide pumps and lines were installed. The iron oxide system was tested (100 hours on each pump) and is ready to support the design verification test series.
- 2) The initial on-line checkout of the coal feed system modifications was performed during this quarter as part of the combustor hot-fire checkout test series.
- 3) Seed system modifications, including replacement of the silo rotary feeder, installation of a new filter receiver on the silo, and converting the fly ash bin to a dust collector, were completed and successfully tested prior to the combustor hot-fire checkout tests.
- 4) All of the electrical wiring (used for the 1A1 channel) between the channel and HVR has been removed and will be replaced prior to power train DVT. The instrumentation (i.e. panel meters) have also been replaced.
- 5) The 1A4 prototypical channel and diffuser were shipped to the TDS Butte Field Office where they were subjected to numerous pneumatic pressure and hydraulic checks. The channel was then delivered to the CDIF and installed into place.

TTIRC (SECTION 8)

The draft seventh and eighth semi-annual status reports were distributed to the DOE for review.

SCHEDULE

The overall schedule for the ITC project is shown on the following pages.

MHD ITC Project
Revised Schedule

MHD ITC Project

Revised Schedule (Continued)

1. INTRODUCTION

The Magnetohydrodynamics (MHD) Integrated Topping Cycle (ITC) Project represents the culmination of the proof-of-concept (POC) development stage in the U.S. Department of Energy (DOE) program to advance MHD technology to early commercial development stage utility power applications. The project is a joint effort, combining the skills of three topping cycle component developers: TRW, TDS, and Westinghouse. TRW, the prime contractor and system integrator, is responsible for the 50 thermal megawatt (50 MW_t) slagging coal combustion subsystem. TDS is responsible for the MHD channel subsystem (nozzle, channel, diffuser, and power conditioning circuits), and Westinghouse is responsible for the current consolidation subsystem.

The ITC Project will advance the state-of-the-art in MHD power systems with the design, construction, and integrated testing of 50 MW_t power train components which are prototypical of the equipment that will be used in an early commercial scale MHD utility retrofit. Long duration testing of the integrated power train at the Component Development and Integration Facility (CDIF) in Butte, Montana will be performed, so that by the early 1990's, an engineering data base on the reliability, availability, maintainability and performance of the system will be available to allow scaleup of the prototypical designs to the next development level.

Ten tasks comprise the ITC Project.

Task 1 - Systems Engineering Studies

Task 2 - 50 MW_t Combustor Design, Fabrication, and Shipment

Task 3 - 50 MW_t Channel Design, Fabrication, and Shipment

Task 4 - Diffuser Design, Fabrication, and Shipment

Task 5 - Power Conditioning Design, Fabrication, and Shipment

Task 6 - Test Engineering Activities at the CDIF

Task 7 - Hardware Repair/Replacement

Task 8 - MHD Technology Transfer/Integration

Task 9 - Quality Assurance

Task 10 - Integrated Project Management

This Twentieth Quarterly Technical Progress Report covers the period May 1, 1992 to July 31, 1992. The report is organized into sections which roughly follow the above task structure. The first section is this introduction. Section 2 contains a concise description of the contract tasks to be performed and their objectives. Section 3 summarizes the systems engineering activities in Subtask 1.1. Sections 4 through 7 summarize progress on the combustion subsystem (Task 2), channel subsystem (Tasks 3 and 4), and current consolidation subsystem (Task 5) for this reporting period, and discuss testing at the CDIF (Subtasks 1.2 and 6.3). Activities of the Technology Transfer, Integration and Review Committee (TTIRC) are reported in Section 8. Planned activities during the next reporting period are summarized in Section 9. Section 10 is a brief summary of the work performed during the quarter, and Section 11 is the distribution list for this report.

2. PROJECT DESCRIPTION

The overall objective of the project is to design and construct prototypical hardware for an integrated MHD topping cycle, and conduct long duration proof-of-concept tests of the integrated system at the U.S. DOE Component Development and Integration Facility (CDIF) in Butte, Montana. The results of the long duration tests will augment the existing engineering design data base on MHD power train reliability, availability, maintainability, and performance, and will serve as a basis for scaling up the topping cycle design to the next level of development, an early commercial scale power plant retrofit.

The components of the MHD power train to be designed, fabricated, and tested include:

- A slagging coal combustor with a rated capacity of 50 MW thermal input, capable of operation with an Eastern (Illinois No. 6) or Western (Montana Rosebud) coal,
- A segmented supersonic nozzle,
- A supersonic MHD channel capable of generating at least 1.5 MW of electrical power,
- A segmented supersonic diffuser section to interface the channel with existing facility quench and exhaust systems,
- A complete set of current control circuits for local diagonal current control along the channel, and
- A set of current consolidation circuits to interface the channel with the existing facility inverter.

Specific objectives of the ten contract tasks are shown in Table 2-1. The overall approach to meeting these objectives is to: 1) utilize the design and operational experience gained from workhorse hardware to design and construct prototypical hardware, 2) conduct design verification tests on the prototypical hardware, and 3) integrate and operate the components for 1000 hours as a complete power train at the CDIF. At the current stage of the project, the technical approach is focusing on item (2) above. Initial checkout testing of the combustion subsystem, including the LPCS, was successfully completed. The prototypical channel and diffuser were delivered to the CDIF and installation was initiated. Systems engineering disciplines are ensuring compatibility of each of the prototypical subsystems with the overall topping cycle system as well as with the CDIF where they eventually will be integrated. Finally, the TTIRC is disseminating information on the POC program and airing the major integration issues involved in retrofitting an existing power plant so as to permit utilities, the potential future users of the technology, to assume an active role in the U.S. MHD program.

TABLE 2-1. MHD ITC TASK OBJECTIVES

SYSTEMS ENGINEERING STUDIES (TASK 1)	Perform power train/facility integration activities to ensure compatibility of topping cycle components with the existing test bay at the CDIF
PROTOTYPICAL 50 MW _t COMBUSTOR DESIGN, FABRICATION, AND SHIPMENT (TASK 2)	<p>Define system level requirements and specifications for the integrated topping cycle power train</p> <p>Provide test planning and performance data analysis support for CDIF power train testing</p> <p>Design, fabricate and deliver to the CDIF a prototypical coal-fired combustor for the integrated topping cycle power train</p> <p>Conduct testing in support of the prototypical design effort or to evaluate the risks and benefits of proceeding to the development of an early commercial scale retrofit MHD power plant</p>
PROTOTYPICAL 50 MW _t CHANNEL (TASK 3)	<p>Design, fabricate and deliver to the CDIF a prototypical MHD channel (including the inlet nozzle and diagonal current controls) for the integrated topping cycle power train</p> <p>Conduct testing in support of the prototypical design effort or to evaluate the risks and benefits of proceeding to the development of an early commercial scale retrofit MHD power plant</p>
DIFFUSER (TASK 4)	Design, fabricate and deliver to the CDIF a diffuser section for the integrated topping cycle power train
POWER CONDITIONING AND INVERTER (TASK 5)	Design, fabricate and deliver to the CDIF current consolidation circuits for the prototypical channel
TEST ENGINEERING ACTIVITIES AT THE CDIF (TASK 6)	Provide to CDIF personnel technical direction and guidance for the installation, checkout and testing of CDIF MHD power train components and appropriate auxiliary equipment
HARDWARE REPAIR/REPLACEMENT (TASK 7)	Provide for the repair or replacement of power train components that show excessive wear, are damaged, or fail as a result of operations and testing at the CDIF
CHARTER AND PARTICIPATE IN AN MHD TECHNOLOGY TRANSFER, INTEGRATION AND REVIEW COMMITTEE (TASK 8)	<p>Organize, charter and co-chair a committee that will permit potential users of MHD technology in the private sector to assume an active role in the MHD Program</p> <p>Review and integrate POC program schedules and integration issues and provide for technology transfer to potential future users</p>
QUALITY ASSURANCE (TASK 9)	Prepare and implement a plan to assure that prototypical power train components are manufactured per the approved design
INTEGRATED PROJECT MANAGEMENT (TASK 10)	Provide for overall technical, programmatic and subcontract management for the project

3. SYSTEMS ENGINEERING (TASK 1)

Systems engineering activities related to the power train integration and testing at the CDIF are discussed in this section. These activities comprise Subtask 1.1 of the ITC Project.

A principle objective of the systems engineering task is to focus the program's technical effort so that the subsystems designed and built for the topping cycle not only perform well by themselves, but also perform well when interconnected and integrated into the 50 MW_t power train at the CDIF. The integrated topping cycle system must be prototypical, and it must be designed to operate at conditions which closely approximate the operating state of a 250 MW_t retrofit power plant.

To attain these objectives, systems engineering studies are being performed on specific issues as they arise, and systems engineering documentation is being developed and maintained current to provide a consistent basis for the design, fabrication and testing of the prototypical power train. The status of the systems engineering documentation for the project is reported below.

3.1 SYSTEM/SUBSYSTEM DOCUMENTATION

Requirements, technical criteria, specifications and interfaces for the power train hardware are being documented to insure that Statement of Work requirements are met and that the subsystems designed and built for the power train are compatible with each other and with the test facility at the CDIF.

3.1.1 Interface Documentation

Interface verification, i.e., comparison of the actual hardware interfaces with the documentation, was completed this quarter for the combustion subsystem and the channel. The diffuser interface verification will be completed next quarter. The interface document will then be updated to reflect the minor differences that have occurred during construction and installation.

3.1.2 Deliverable Documentation

The O&M documentation required to be delivered with the channel and current consolidation hardware was completed this quarter. The channel O&M manual was delivered to MSE prior to delivery of the channel to the site from the TDS field office in Butte. A preliminary version of the current consolidation O&M manual was delivered about two weeks after the anode hardware was delivered. This was acceptable to MSE since the current consolidation will not be installed until late next quarter at the earliest. A final version will be delivered with the cathode consolidation cabinets in early September.

3.1.3 Integrated Schedule Review

During this quarter, a detailed look was taken at the schedules for all of the parties involved in the POC testing: 1) MSE, to understand the facility modifications and available test time; 2) TRW, to look at the LPCS piping installation and upcoming test series; 3) TDS, to look at the channel delivery and installation schedule; and 4) Westinghouse, for the current consolidation manufacturing and delivery schedule. The testing requested by the component developers was also included in the schedule review. These schedules were integrated to assess the status of the entire program. The main focus this quarter was the completion of the combustor checkout tests and the installation of the channel.

The schedule issues will continue to be addressed in the coming months to ensure that these schedules do not impact the baseline scheduled start of the duration testing. The bi-weekly telecons between TRW and MSE are continuing to allow continual conversation between the component developers and MSE to ensure that all issues are addressed as they surface, to provide the maximum amount of time to prepare work-arounds, and to ensure that these issues do not become problems which could jeopardize the schedule.

4. COMBUSTION SUBSYSTEM DESIGN AND FABRICATION (TASK 2)

Task 2 combustion subsystem design support engineering and prototypical design activities are discussed in this section. Three subtasks comprise Task 2 of the ITC project: Subtask 2.1, prototypical combustor design; Subtask 2.2, prototypical combustor fabrication and assembly; and Subtask 2.3, prototypical combustor shipment.

During this quarterly reporting period, the efforts were concentrated on Subtasks 2.2 and 2.3 as related to spare and contingency hardware and the water electrical isolators.

Subtask 2.1 was originally comprised of five elements:

- Subtask 2.1.1, Design confirmation testing at TRW. This subtask has been completed and the results have been reported.
- Subtask 2.1.2, Wall construction evaluations. Also completed and the results reported.
- Subtask 2.1.3, Design of prototypical combustor. Also completed and the results reported.
- Subtask 2.1.4, Low pressure oxidant second stage testing and design. This subtask was deleted from the program.
- Subtask 2.1.5, 20 MW_t combustor/channel characterization. Also completed and the results reported.

Subtask 2.2 includes the following elements:

- Subtask 2.2.1, Component fabrication and assembly. Completed this reporting period.
- Subtask 2.2.2, Hot fire DVT testing at TRW. This subtask was deleted from the program.

Subtask 2.3 includes prototypical combustor and LPCS shipment.

Section 4.1 titled Combustion Subsystem Design Activities includes elements of Subtask 2.1.3. Section 4.2 titled Combustion Subsystem Manufacturing includes elements of Subtask 2.2.1. Section 4.3 titled Combustor Shipment includes Subtask 2.3.

4.1 COMBUSTION SUBSYSTEM DESIGN ACTIVITIES (SUBTASK 2.1.3)

The activities in this subtask were completed during the last quarter. No additional activity will occur.

4.2 COMBUSTION SUBSYSTEM MANUFACTURING (SUBTASK 2.2.1)

During this quarter, the manufacturing, assembly, and checkout of all combustor contingency and spare hardware was completed. With the final manufacturing and assembly of this hardware, this subtask was completed.

4.3 COMBUSTOR SHIPMENT (SUBTASK 2.3)

The water electrical isolators were shipped to the CDIF this quarter. The spare and contingency hardware completed under subtask 2.2.1 will be shipped to the CDIF next quarter.

5. PROTOTYPICAL CHANNEL SUBSYSTEM DESIGN AND FABRICATION (TASK 3)

A successful nozzle proof test was concluded during this reporting period. The purpose of the test was to evaluate the adequacy of the nozzle structure and to evaluate sealing of the sidewall-to-electrode wall joints, water tubes, and stud and wire penetrations at operating pressure. Details of the nozzle proof test are reported in Section 5.1.

Work was also performed on the design modifications to the spare channel inlet frame in order to incorporate the capability for iron oxide injection. These changes were predicated by tests performed in the CDIF 1A1 channel which were performed to compare the effect of different iron oxide injection locations for the cathode wall. Results indicated that injection through the side port may be more effective in spreading iron oxide, particularly should one of the two ports become clogged. Design Confirmation testing of a "slag breaker" was also performed before formal engineering changes were initiated. Details of this work are reported in Section 5.2.

Following the completion of channel fabrication, attention turned during this quarter to the manufacture of spare and replacement parts for the prototypical generator. Reported in Section 5.3 are the spare fabrication plan, the schedule and the status of fabrication at the end of this reporting period.

5.1 1A4 NOZZLE PROOF TEST

5.1.1 Purpose of the Nozzle Proof Test

The intent of the proof test was to verify the structural rigidity and rupture resistance of the integral nozzle. While four-wall generator box construction has proven satisfactory for supersonic channel fabrication, this construction is a new concept in the (high pressure) subsonic nozzle. During nozzle proof testing, two additional features were examined. The first was the integrity of the electrode wall-to-sidewall corner joint which forms the surface providing the gas-side seal. Another goal was to check the element water tube-to-G11 penetration seal.

5.1.2 Description of the Nozzle Proof Test Rig

A leak/proof test was completed to evaluate the adequacy of the nozzle structure (i.e., glued fiberglass joints, fiberglass wall sections and bolting arrangements) to withstand operating stresses and to evaluate sealing of the sidewall-to-electrode wall joints, water tubes, stud and wire penetrations at operating pressure.

The nozzle test section was a full scale model of the actual nozzle section of the 1A4 channel. The test section consisted of a four-wall G11 box with the ends of the test section sealed using end plates and tie rods. Figure 5-1 is a photograph of the assembled test section. In general, the fabrication and assembly processes utilized for the test section were similar to those utilized on the 1A4 channel nozzle section. Specifically, the following items were similar: 1) fabrication of the G11 box, 2) procedures for installing the channel electrode/sidewall elements, and 3) the electrode-to-sidewall corner joint sealing. The areas that differed from actual 1A4 channel nozzle construction were: 1) only two of the G11 walls (one sidewall and one electrode wall) were drilled with holes for installation of channel elements, and 2) bolts were utilized to simulate cooling tube penetrations through the G11 walls where actual elements were not installed. There were approximately 150 sidewall tube penetrations, 6 wire penetrations and 15 stud penetrations in the test section walls. Sidewall and electrode bars were installed with RTV 159 utilizing the same techniques that were employed to put the elements in the 1A4 channel, including boron nitride spacers.

Dial indicators were attached to the tie rods to measure deformation of the plastic sidewalls during the pressure check. Measurements were made in the center of the high pressure section of the nozzle.

Preliminary "snoop" tests (conducted to identify gross leaks and fitting leaks) used air at no more than 6 psig. For safety reasons, however, the rigidity, structural and leak tests were conducted with pressurized water which was heated to more closely simulate actual channel conditions.

Figure 5-1. 1A4 Nozzle Proof Test Rig

Several builds of the nozzle test rig were made. For presentation purposes, all but the last two tests are considered preliminary. Thus, in the sections to follow, Test 2 refers to the last nozzle proof test and Test 1 refers to the trial immediately preceding Test 2.

5.1.3 Test Plan

The purpose of the nozzle pressure test was two-fold:

- 1) Verify that the nozzle construction is adequate for gas containment at nominal power train pressure and temperature operating conditions. In particular, verify that there are not any leaks at the corner seals and the coolant tube/stud penetrations through the G11 on the simulated nozzle assembly.
- 2) Verify that the nozzle structure can withstand proof pressure conditions (per ASME code criteria) without structural failure.

In order to meet these objectives, a simulated nozzle leak/proof test procedure was developed. The test pressure and temperature conditions were selected to be consistent with ASME Boiler and Pressure Vessel code criteria. Specifically, the ASME code specified that proof pressure tests shall be performed at 1.5 times the maximum allowable working pressure multiplied by the ratio of the material yield stress at the test temperature to the yield stress at the operating temperature:

$$P_{\text{test}} = P_{\text{operating}} \times \frac{\text{Yield Stress @ } T_{\text{test}}}{\text{Yield Stress @ } T_{\text{operating}}} \times 1.5$$

In the case of the 1A4 nozzle assembly, the bulk average operating temperature of the G11 is 180°F and the operating pressure is 75 psig nominal (88 psig maximum). The test setup at TDS was limited to a maximum temperature of 125°F and, therefore, the test pressure was increased to account for the difference in material properties at the test temperature and the actual operating temperature. A summary of the test temperatures and pressures is presented in Table 5-1.

TABLE 5-1. NOZZLE PROOF TEST CONDITIONS

Step No.	Temperature (°F)	Pressure (psig)	Comments
1	70	6	Leak test with air.
2	125	0	Fill test assembly with water and bring to operating temperature.
3	125	35	Simulate 1A4 operating conditions (press, temp) of the supersonic region of the nozzle assembly (downstream of throat).
4	125	75	Simulate 1A4 operating conditions (press, temp) of the subsonic region of the nozzle assembly.
5	125	125	Proof pressure test conditions based on nominal 1A4 operation pressure.
6	125	140	Proof pressure test conditions based on maximum 1A4 operating pressure.
7	125	0	Determine if there is any permanent deflection.

5.1.4 Initial Nozzle Proof Test Results (Test 1)

The electrode and sidewall bar elements had been installed in a previous build of the box. RTV 159 was used to seal all of the wall joints. A proof test was conducted on the assembly and leaks were noted at five of the tube penetrations. It also appeared that there was some leakage at the anode wall-to-sidewall seal, but when the test section was disassembled, it was noted that water had leaked around the end seal (which does not exist in the actual channel assembly), into the RTV filled cavity between the anode wall and the sidewall, and out through a pinhole in the anode wall/sidewall RTV. The primary corner joint seal remained intact at all times.

Following this test, the following changes were made to the test assembly:

- 1) Two-part RTV 88 was utilized to seal the sidewall-to-anode wall joint. RTV 159 was retained on the sidewall-to-cathode wall joint. (Note: RTV 159 was utilized on all joint interfaces on the 1A4 channel.)
- 2) Self-leveling RTV 116 was utilized to backfill all of the tube/stud penetrations in the G11. This was consistent with the procedure utilized on the 1A4 channel.
- 3) Jumper hoses and clamps were installed on the tubes in order to more closely simulate the 1A4 channel.
- 4) A modification was made in the placement of four bolts attaching the electrode walls to the sidewalls between Tests 1 and 2. This was necessary because the fiberglass support that the barrel nuts fit against was broken when these bolts were over-tightened. The change in placement of the bolts did not substantially affect the bolt pattern for wall sealing and did not bias the results in comparison with the 1A4 channel. Figure 5-2 shows the location of the problem. Figure 5-3 shows how the holes were modified. An inspection of the 1A4 channel assembly revealed no cracks in this area. Inspections of this area of the 1A4 will continue even after DVT testing commences.
- 5) New bolts with nuts were installed in the G11 penetrations where channel bar elements were not installed. The previous bolts had not penetrated completely through the 2.5-inch plastic in the nozzle sidewall.
- 6) Curing time for the RTV was increased to 8 days from the 4 days utilized on previous builds.

5.1.5 Leak/Proof Test Conduct and Results (Test 2)

The nozzle pressure test procedure and results for Test 2 are reviewed below.

- The nozzle test section was pneumatically pressurized to 6.25 psig and isolated. It decayed to 5.25 psig over a 2-hour period.
- The nozzle was pressurized with hot water (nominal 125°F) to 35 psig. The system was held at steady-state for 15 hours. A minor leak (estimated at 1 drip per minute) was observed at the barrel nut slot located at the location where the 2.5-inch plastic is glued to the 1-inch wide plastic.
- The test section pressure was varied as shown below. Only minor leaks were noted until the pressure was increased above the nominal operating pressure (75 psig). At 125 psig, the leaks were relatively large but pressure was maintained at the requisite level in order to complete the proof pressure tests.
- Results from the deformation measurements are shown in Figure 5-4.

Figure 5-2. Old Location of Bolt and Barrel Nut Cracked Fiberglass (4 Locations)

Figure 5-3. New Location of Bolt and Barrel Nut (4 Locations)

Time (hh:mm)	Pressure (psig)	Temperature (°F)
8:00	35	125
8:30	75	125
9:30	95	125
11:00	125	125
11:15	140	125
11:35	35	125
2:00	35	125

5.1.6 Discussion of Results

The nozzle proof test was conducted to verify the structural rigidity and rupture resistance of the integral nozzle. Two additional features were examined. The first was the integrity of the electrode wall/sidewall joint which forms the surface providing the gas-side seal. Another goal was to check the element water tube/plastic wall seal. A review of these test objectives is presented below.

5.1.6.1 Structural Test

The box mechanical integrity (i.e., fiberglass glued joints, fiberglass walls and bolting arrangements) was maintained at 140 psig test pressure. Results of deflection measurements in Figure 5-4 show that the

Figure 5-4. Nozzle Pressure Test Sidewall Deflection

maximum deflection was 16 mils at a pressure of 95 psig and 50 mils at a pressure of 140 psig. The trend is consistent with standard creep behavior of plastics. The deflection returned to zero when the pressure was reduced. There was not any permanent deformation.

5.1.6.2 Corner Joint Seals

Two minor leaks (characterized as wetting by observers) were noted in the sidewall-to-electrode wall joints during Test 2. These leaks did not increase appreciably as pressure was increased from 35 to 140 psig.

5.1.6.3 Tube/Bolt Penetration Seals

Seals around tubes and other penetrations were satisfactory during the nozzle proof test, although this is an area of concern. Proof testing did demonstrate that self leveling RTV (like that used in the 1A4) can prevent potential leaks and diminish existing leaks.

During Test 1, approximately 5 substantial tube leaks were observed at a pressure of 100 psig. These tubes were resealed from the outside with self leveling RTV 116 prior to the final proof test (Test 2). Hoses and clamps were also added and they did diminish the number and magnitude of leaks. Only three tube penetrations leaked at 95 psig during Test 2 (two of which were reworked penetrations). All of the leaks were minor and only one increased from a drip to a stream at 125 psig.

5.1.7 Conclusions and Future Work

The nozzle proof test section passed the proof test. No difficulties were encountered with structural features or with sealing the corner joint seals of the nozzle, and satisfactory performance is expected in the 1A4.

The leak test results were also satisfactory. However, the tube penetration design should be reviewed for future designs and supplemental means to improve the existing design would be looked at in the unlikely event a leakage in the high pressure nozzle section develops.

Sealing penetrations in the existing channel were investigated as part of the nozzle proof test. In particular, self-leveling RTV (with hoses butted up against this RTV) has reduced leaks without a retrofit.

Many possibilities exist for leak prevention measures in a retrofitted and/or future channel. These include:

- A double pitch electrode with a larger sealing surface, which may reduce the potential for leaks in the high pressure region. A preliminary design of double-pitch electrodes for the nozzle region in the 1A4 is now underway.
- The use of two-part RTV. Two-part RTV cured more quickly than RTV 159. This may lessen the chance of uncured RTV being extruded through sealing surfaces.
- The use of O-rings around the base of cooling water tubes. The feasibility of this is being examined.
- Chamfering the holes through which cooling water tubes pass. This would help assembly and make it more difficult for RTV to be extruded out when under pressure.

5.2 HARDWARE DESIGN CHANGES TO IMPROVE IRON OXIDE INJECTION

5.2.1 Introduction

Tests were conducted at the CDIF with the 1A1 channel to evaluate the effectiveness of injecting iron oxide through ports in the bottom wall, upstream of the subsonic nozzle. The tests were performed in order to compare the effect of this iron oxide configuration with results obtained during an earlier test series that incorporated the use of iron oxide injectors located on the sidewalls, adjacent to the cathode wall. Figure 5-5 is a schematic of a frame that bolts to the combustor second stage, upstream of the nozzle,

Figure 5-5. Iron Oxide Slurry Injector Location on Bottom and Sidewalls of 1A1 Channel showing both vertical and horizontal iron oxide injection configurations. As indicated in Figure 5-5, the placement of the cathode wall iron oxide injectors were positioned relatively close to the channel centerline. One advantage of locating the injector next to one another on the cathode wall was the possibility that the blockage of an injector could be compensated for by increasing the flow from the adjacent one. Thus, loss of iron injector flow from one port would not have as significant an impact on iron oxide distribution as would loss of flow from an injector located in the sidewall. In addition, iron injection for the Mark VI and Mark VII channels has always been performed using injectors mounted on the cathode wall. However, tests conducted with this injector scheme on the 1A1 did not support this premiss. Hence, a redesign of the 1A4 inlet frame was made to allow for placement of iron oxide injectors in the sidewall of the 1A4 channel inlet frame.

Plugging of the iron oxide injector ports has caused a reduction in (and in some cases a complete loss of) iron oxide supply to the channel through one or both injectors. Once the iron oxide flow is substantially slowed or is stopped, the iron oxide injector port becomes plugged due to a combination of coking of the oil in the iron oxide slurry and slag freezing over the injector outlet. The slag formation, although restricted to the injector tip, cannot be cleared by an increase in iron oxide injector or purge air pressure. The only way to clear the port has been to remove the injector after the test and remove the slag. Because of the problems that were encountered with slag freezing onto the end of an iron injector due to a flow stoppage, it was determined that a means to clear the slag breaker tip during test operations was necessary. To meet this requirement, a new injector was designed that incorporated the use of a pneumatically driven ram to clear the injector tip on-line if it becomes plugged. The design and testing of the injector are discussed below.

5.2.2 Iron Oxide Injector Testing

Nearly 40 hours of test operation were conducted using the iron injectors mounted on the cathode wall. When both injectors were operating, the iron was effective in reducing and/or eliminating high voltage gaps on the cathode wall. However, when an iron oxide flow stoppage occurred in one injector, high voltage gaps appeared on the cathode wall. The high voltage gaps could not be entirely alleviated by increasing the iron flow rate through the unplugged injector port, and in fact, increasing the flow had minimal affect on polarization of the slag on the upstream end of the cathode wall. These results most likely occurred because the spreading angle of the iron oxide injector was insufficient for the single injector mounted on the cathode wall to provide proper distribution of iron oxide to mitigate the effects of slag polarization. Thus, when flow through one injector was lost, the iron oxide was only partially covering the cathode wall, and polarization of the cathode wall was not entirely inhibited. Increasing the iron oxide flow to the unplugged cathode injector wall to compensate for the plugged injector only aggravated the problem. The increased flow resulted in a higher injection velocity, driving the iron slurry flow into the free stream. Hence, the slurry was carried downstream in the plasma core rather than becoming entrained in the boundary layer and depositing onto the cathode wall.

The test results indicated that a single injector on the sidewall relieved the cathode wall nonuniformities better than the single cathode wall port. This is likely because the side port injector tends to spread the iron oxide across the wall, adjacent to the boundary layer. Thus, increases in flow made to compensate for loss of one of the sidewall port injectors does not result in slurry injection into the free stream. Because increasing the iron oxide flow through a single sidewall injector resulted in better relief of cathode wall slag polarization than through a bottom wall injector, it was deemed more advantageous to inject the iron oxide slurry through the sidewall ports. This conclusion prompted a redesign of the 1A4 channel inlet frame as described below.

5.2.3 Design Description

Modifications were made to the channel inlet frame to allow placement of side port injectors in the sidewall, adjacent to the cathode wall. The injector ports were located relative to the cathode wall analogous to the ports used for the 1A1 channel tests discussed above. A schematic of the new channel inlet frame is shown in Figure 5-6.

In addition to modifying the inlet frame, a new iron oxide injector design was used that incorporated a pneumatically driven ram that can be cycled to clear the iron oxide injector tip if it becomes blocked. The iron oxide injector/ram arrangement is depicted in Figure 5-7. The injector is operated remotely, as needed during the test, to keep the iron injector port clear. The tip of the plunger is constructed from tungsten rod and is activated with a double action pneumatic cylinder. The tungsten plunger functions as a ram to clear blockages at the end of the iron oxide injector port.

Until the new channel inlet frame can be installed, the iron oxide will be injected in the TRW second stage at the existing injector port locations on the sidewalls, adjacent to the cathode wall.

5.2.4 Iron Oxide Injector Bench and System Testing

The ram was tested at TDS for 50 hours using an iron oxide circulation loop. During these tests, the ram was cycled several hundred times to evaluate its operability and determine if the ram pressure seal and wiper seal performed adequately under operating pressure with the iron oxide slurry. Subsequent to the completion of these preliminary tests, the injector was installed coincident with checkout tests of the iron oxide injector system at the CDIF. The injector was tested for 300 hours in the CDIF iron oxide slurry system. The ram was cycled every hour. No malfunctions of the ram or injector mechanism were noted. Inspection of the ram sealing arrangement subsequent to the tests did not show any evidence of wear. The new iron oxide injector arrangement was deemed suitable for use and will be installed in the 1A4 channel hardware for testing during the DVT test series.

Figure 5-6. Schematic of 1A4 Channel Inlet Frame with Iron Oxide Injector Ports in Sidewall

Figure 5-7. Schematic of Iron Oxide Injector with Slag-Clearing Ram

5.3 SPARE HARDWARE FABRICATION

With the completion of channel fabrication, attention turned to the manufacture of spare parts for the prototypical MHD generator components. Included herein is the fabrication plan (an overview), a fabrication schedule, and a status of spares fabrication at the end of this reporting period.

5.3.1 Fabrication Plan

An inventory of spare and replacement parts for the 1A4 channel is being fabricated. The purpose of this inventory is:

- To replace defective elements that are identified subsequent to the infant mortality test.
- To replace test coupons that are removed to perform destructive metalographic examinations in an effort to identify and quantify corrosion-erosion mechanisms.
- To replace excessively worn or damaged components that result from off-normal operating conditions or events.
- To provide tungsten capped/tungsten-copper based sidewall elements that can be used to replace tungsten capped/copper based elements in the event they become undercut. (Some undercutting of the bottom two rows of sidewall elements adjacent to the cathode wall may occur if iron oxide cannot be used or fails to reduce the high voltages caused by slag polarization).
- To furnish tungsten capped sidewall elements that may be used to replace tungsten-copper sidewall elements prior to the Illinois No. 6 coal test series.
- To provide new elements which will be utilized as coupons during the Illinois No. 6 coal test series.

To minimize the total inventory of parts (in order to keep costs down), yet provide timely delivery if they are needed, the spare parts will be kept on hand in various forms of completion. The spare parts plan includes the fabrication of:

- Finished ready-to-install subassemblies such as sidewall bars and inlet frames.
- Partially fabricated components such as platinum-to-tungsten cap subassemblies for anodes.
- Machined unassembled components such as tungsten cathode caps, plastic for walls, etc.
- Raw materials on hand such as precut braze alloy, tungsten plate and explosion bonded copper-to-stainless steel.
- Prebid open machining orders to allow the fabrication of specific anode or cathode copper bases.

5.3.2 Fabrication Schedule

The purchase of raw materials and the spares fabrication schedule is shown in Figure 5-8.

5.3.3 Spares Fabrication Activities and Status

During this reporting period, both of TDS's brazing ovens were prepared for spares fabrication by being cleaned and tested.

All spares fabrication conducted during this reporting period was for the sidewall. Table 5-2 outlines in detail the types of elements required, the number of elements required, plus the fabrication status of these elements at the end of this reporting period.

1A4 CHANNEL AND DIFFUSER SPARES FABRICATION SCHEDULE

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Figure 5-8. 1A4 Channel and Diffuser Spares Fabrication Schedule

**TABLE 5-2. 1A4 CHANNEL SIDEWALL SPARES FABRICATION
MAY TO JULY 1992**

Type	Needed	Brazed	% Completed
W Cap Cu House	50	53	100%
W Cap Cu House/Wire	300	72	24%
Split W Cap W/Cu House	450	0	0%
W/Cu Cap Cu House	100	0	0%
W Cap Cu Mid	450	185	41%
W Cap Cu Mid/Stud	300	0	0%
W Cap/Shim W/Cu Mid	450	20	4%
W/Cu Cap Cu Mid	50	0	0%
W/Cu Cap Cu Mid/Stud	50	0	0%

6. CURRENT CONSOLIDATION SUBSYSTEM DESIGN AND FABRICATION (TASK 5)

During this quarter, the construction of the cathode power cabinets and associated control system was completed. The cabinets will undergo a test program similar to that conducted on the anode equipment. The anode test program was reported in the 19th Quarterly report. After testing is complete, the cathode equipment will be shipped to the CDIF, where it will be installed along with the anode system in late October.

The two cathode power cabinets are essentially identical to the type used on the anodes, except that current flows from the electrode to the consolidation point in this case. Thus, there are differences in the internal wiring so that the anode and cathode systems cannot be interchanged. There are other minor differences such as the use of voltage sensors that are rated for 6 kV isolation capability, instead of the 20 kV type used on the cathode. However, essentially all of the other cathode construction features can stand-off up to 12 kV, even though the system operates at ground potential.

The cathode controls are also identical to that used on the anode, except that a rack of computer cards for data acquisition is not used here. All cathode signals are connected to a rack of computer cards in the anode control cabinet that collects all system information for display only in the central control room.

The construction of the cathode power cabinets and controls required approximately four months of effort. This was a very ambitious schedule, but the experience gained during the anode construction allowed this phase of the program to be accelerated.

7. CDIF TESTING

During previous reporting periods, testing of the workhorse hardware was completed. The prototypical MHD ITC combustion subsystem was installed at the CDIF and test preparations were made. During this reporting period the Combustor Hot-Fire Checkout Test Series was performed. This series focused on an initial evaluation of the design and performance characteristics of the combustor prior to installation of the prototypical channel. A total of 16.8 thermal hours were accumulated during 7 tests conducted as part of this test series. After this series was successfully completed, activities focused on facility preparations for 1A4 channel testing.

Section 7.1 describes the objectives and approach for the hot-fire checkout and design verification test (DVT) series. The combustor configuration for the initial hot-fire tests is described and the test results are discussed. Section 7.2 describes the facility preparations underway to prepare for the integrated combustor and channel design verification tests. Section 7.3 describes the status of the prototypical power train hardware activities, and Section 7.4 outlines the DVT test plans for next quarter.

The testing of the prototypical power train is divided into three distinct phases:

- 1) Hot-fire checkout of the individual components
- 2) Design verification testing (DVT) of the integrated power train
- 3) Duration testing of the integrated power train

The objectives and approach for the first two phases, i.e., hot-fire checkout and DVT, are described in the following sections.

7.1 HOT-FIRE CHECKOUT AND DVT TESTING

7.1.1 Objectives

The overall objective of the hot-fire checkout test series is to evaluate each topping cycle subsystem separately prior to integrated duration testing. The overall objective of the DVT test series is to verify that the design meets the Statement of Work objectives. Specific objectives of the checkout and DVT testing are outlined below.

7.1.1.1 Objectives of Combustor Thermal Checkout Testing

The combustor hot-fire checkout tests have three major objectives:

- 1) To confirm that the combustion subsystem has been correctly integrated into the facility.
- 2) To provide an initial evaluation of the performance of the prototypical coal-fired combustor and precombustor in terms of heat loss and slagging characteristics, as well as the Low Pressure Cooling Subsystem (LPCS).
- 3) To confirm the operational status of modified facility systems, including:
 - Fine coal delivery system
 - Afterburner/emissions controls system
 - Iron oxide slurry
 - Combustor instrumentation

7.1.1.2 Objectives of 1A4 Channel Thermal Checkout Testing

The channel thermal checkout tests have two major objectives:

- 1) To confirm that the channel subsystem has been correctly integrated into the facility.
- 2) To verify the structural and gas-side integrity of the 1A4 channel and demonstrate that cooling is adequate.

7.1.1.3 Objectives of Integrated Power Train DVT

In addition to demonstration of baseline power levels, initial power tests on the 1A4 channel will focus on confirming:

- 1) End to end channel wiring and high voltage room instrumentation.
- 2) Current controls wiring.
- 3) Resistive consolidation wiring.

7.1.1.4 Objectives of Current Consolidation DVT

The objectives of Current Consolidation DVT are:

- 1) To confirm the wiring interfaces between facility and current consolidation cabinets.
- 2) To confirm the active current consolidation characteristics meet performance requirements.

The current consolidation DVT will initially be performed with the 1A1 followed by an integrated test with the 1A4.

7.1.2 Approach

The overall approach for the prototypical hardware checkout and design verification testing is to use four phases to evaluate the individual subsystems prior to integrated power train duration testing. These four phases match the objectives that were described in Section 7.1.1.

- 1) Hot-fire testing of the combustor to determine heat loss, operational reliability, and slagging characteristics.
- 2) Hot-fire testing of the 1A4 channel to evaluate performance in terms of structural integrity, gas-side pressure containment, and cooling water adequacy.
- 3) Electrical (power) testing of integrated combustor and channel to demonstrate integrity of the electrical wiring and isolation systems.
- 4) Integrated power train testing with the current consolidation networks.

The individual approach to each of these four stages is detailed below.

7.1.2.1 Combustor Thermal Checkout Testing

The individual approach to the combustion subsystem hot-fire checkout test series is to subject the combustion subsystem to gradually increasing gas temperatures and gradually increasing operating durations in order to confirm the adequacy of the cooling of the hardware in a step-wise, low risk manner. The approach is as follows:

- 1) Verify LPCS is operational and all component cooling water flows are correct.
- 2) Start-up combustor with oil-fired vitiator only (1500°F gas temperature) for 15 minutes.
- 3) Operate combustor with oil-fired vitiator and precombustor (2900°F gas temperature) for 15 minutes.
- 4) Full combustion subsystem operation for 1 hour.
- 5) Two tests (4 to 8 hours) to provide an initial evaluation of combustion subsystem performance characteristics in terms of heat loss and slagging characteristics.

After each step, the combustor will be fully inspected for external hot spots, leaks, slag coverage, and internal wear.

7.1.2.2 1A4 Channel Thermal Checkout Testing

The individual approach to the channel subsystem hot-fire checkout test series is to subject the channel subsystem to gradually increasing gas temperatures and gradually increasing operating durations in order to

confirm the adequacy of the cooling of the hardware in a step-wise, low risk manner. The approach is as follows:

- 1) Start-up combustor with oil-fired vitiator only (1500°F gas temperature) for 15 minutes.
- 2) Operate combustor with oil-fired vitiator and precombustor (2900°F gas temperature) for 15 minutes.
- 3) Full combustion subsystem operation for 1 hour.
- 4) One test (8 to 12 hours) to provide an initial evaluation of integrated combustor and channel performance in terms of conductivity, heat loss, and slagging behavior.

After each step, the channel will be inspected for external hot spots, gas leaks, water leaks, and internal wear.

7.1.2.3 Combustor and Channel Power Testing

The approach to the integrated combustor/channel electrical test series is to subject the power train to gradually increasing power levels and gradually increasing operating durations. The approach is as follows:

- 1) High potential test of power train to 8 kV.
- 2) One-hour electrical test at steady-state conditions.
- 3) Eight-hour electrical test at steady-state conditions.
- 4) Electrical test for unlimited duration with different steady state conditions as required.

After each test in the series, the power train components will be carefully inspected for any internal or external hot spots, any signs of arcs or unacceptable electrical activity, gas leaks, water leaks, and internal erosion/corrosion.

7.1.2.4 Integrated Power Train DVT with Current Consolidation

- 1) Verify facility readiness with short test in resistive consolidation mode.
- 2) With 1A1 channel, verify nominal and off-nominal anode consolidation operation during series (2 to 4) of short tests ranging from 2 to 8 hours.
- 3) With 1A1 channel, verify nominal and off-nominal cathode consolidation operation during series (2 to 4) of short tests ranging from 2 to 8 hours.
- 4) With 1A1 channel, steady-state duration test of 24 hours.
- 5) With 1A4 channel, verify nominal and off-nominal operation.

7.1.3 Combustor Checkout Test Configuration

During this reporting period, the prototypical combustion subsystem was installed and the hot-fire checkout tests were completed. The combustor subsystem configuration for this series of tests is described in the TRW O&M manual and is summarized in the following paragraph.

The Prototypical Combustor (D441800) and Precombustor (D441755) were installed. The second stage configuration (E441333) matched the combustor to the 1A1 channel. The existing workhorse vitiator and slag tank were preserved. Oxygen, air, oil, coal and seed injector interfaces remained the same as on workhorse hardware. Iron oxide is injected on the cathode side of both sidewalls in the last second stage frame. Oxygen is injected in 14 side ports in the front of the second stage.

The Low Pressure Cooling Subsystem (LPCS) was used to cool the panels in the combustor and precombustor. Electrical isolators were installed in the piping between the LPCS and combustor. Conductivity measurement and high speed data were available.

7.1.4 Combustor Checkout Test Results

Seven hot-fire tests were performed in the Combustor Checkout Test Series accumulating 16.8 thermal hours. The test series followed the basic test approach outline in Section 7.1.2.1. Overall, the test series demonstrated the adequacy of the overall cooling of the combustion subsystem and provided an initial evaluation of the combustor performance in terms of heat losses and slagging characteristics. Specifically the following was determined:

- All cooling panels were adequately cooled and showed no signs of distortion or damage.
- No hot spots were detected on uncooled outer pressure shells or uncooled precombustor components.
- Heat losses were slightly higher than anticipated but were well within the design limits of the hardware.
- The grooved panels retained slag adequately and smooth (non-slagging) regions of the combustor performed properly.

A chronological summary report is tabulated in Table 7-1. A summary of nominal operating conditions and preliminary test results are tabulated in Table 7-2. Table 7-3 provides a summary of facility test operation/performance during the quarter.

At the conclusion of 92-COMB-07, the combustion subsystem hot-fire test series was terminated in order to provide sufficient time to complete the facility preparations for the channel installation and integrated combustor/channel design verification tests. The higher than anticipated heat losses identified during the test series will continue to be evaluated during the channel hot-fire checkout test series. Preliminary data evaluations have indicated that the three primary causes of the observed increase in heat losses are: 1) coolant tubes in the precombustor which are exposed to the oil-fired vitiator 1200°F gases, 2) the addition of the coal fines to the primary run coal which has resulted in increased combustion intensity, and 3) the addition of more coal to the precombustor (on a relative basis) due to a new method for calculating coal preheat temperature which accounts for heat losses in the precombustor and oil-fired vitiator. Changes will be implemented during the upcoming channel hot-fire checkout in order to evaluate the impact of each of these parameters. Specifically, 1) heat shields will be installed on the precombustor coolant tubes in order to reduce the convective heat transfer, 2) the slagging stage equivalence ratio will be reduced in order to reduce the combustion intensity, and 3) the coal flow to the precombustor will be reduced to the value utilized during the previous workhorse hardware test series.

TABLE 7-1. CDIF TESTING SUMMARY - 20TH QUARTER

Date	Designation	No. of Starts	OFV	CFPC	CFC	Magnet Time	Power at Condition	Ranking	Test Objectives
06/05/92	92-COMB-01	2	16	--	--	--	--	A	Test OFV only
06/08/92	92-COMB-02	1	24	21	--	--	--	A	Test CFPC
06/10/92	92-COMB-03	2	41	35	29	--	--	A	Test CFC
06/11/92	92-COMB-04	4	307	289	269	--	--	C	Thermal Checkout
06/15/92	92-COMB-05	2	103	92	79	--	--	C	Thermal Checkout
06/17/92	92-COMB-06	2	248	240	229	--	--	C	Thermal Checkout
06/18/92	92-COMB-07	1	415	409	402	--	--	A	Thermal Checkout

Ranking:

- A Met all test objectives
- B Met most test objectives but was consumables limited and required follow-up on next test
- C Met some test objectives
- F Met no test objectives

**TABLE 7-2. NONIMAL TEST CONDITIONS AND PRELIMINARY RESULTS -
20TH QUARTER**

Test Designation	Date	N/O	Preheat Deg. F	PHI1	PHI2	%K	(1) Additives	Load Voltage	Load Current	B Field	Power (MWe)
92-COMB-01	06/05/92	--	1800	--	--	--	--	--	--	--	--
		--	1200	--	--	--	--	--	--	--	--
92-COMB-02	06/08/92	--	2900	--	--	--	--	--	--	--	--
92-COMB-03	06/10/92	.80	2900	.58	.89	1.7	--	--	--	--	--
92-COMB-04	06/11/92	.71	2900	.54	.89	1.7	4.0	--	--	--	--
92-COMB-05	06/15/92	.70	2900	.55	.90	1.7	4.0	--	--	--	--
92-COMB-06	06/17/92	.71	2900	.55	.89	1.7	4.0	--	--	--	--
		.85	2900	.58	.90	1.7	2.5	--	--	--	--
92-COMB-07	06/18/92	.71	2900	.55	.89	1.7	4.0	--	--	--	--
		.85	2900	.58	.89	1.7	4.0	--	--	--	--
		.81	2900	.55	.90	1.7	4.0	--	--	--	--

Notes:

(1) C - Cathode Wall Only

7.2 FACILITY PREPARATIONS FOR MHD ITC POWER TRAIN DVT

In preparation for the channel thermal checkout testing and power train testing (see Sections 7.1.1.2 and 7.1.1.3), several facility modifications are underway.

7.2.1 Iron Oxide System

New iron oxide pumps and lines were installed for combustor hot-fire testing but were not yet fully operational at that testing. The iron oxide system has since been tested (100 hours on each pump) and is ready to support the design verification test series.

During the previous test series, there have been problems with maintaining a steady, uniform flow of iron oxide for the duration of the test. In general, these problems have been attributed to: 1) plugging in the iron oxide flow system due to foreign material mixed with the slurry and 2) plugging at the injector tip within the combustor. Both of these issues will be addressed during the upcoming design verification test series. Specifically:

- 1) MSE will procure a premixed, prefiltered slurry for the upcoming test series rather than mixing the slurry on-site. This approach should minimize the potential for foreign material to be introduced into the system.
- 2) TDS addressed the plugging of the injector tip by incorporating the following changes:
 - The injector design was modified to ensure that the tip is always recessed below the gas surface. In addition, a thin-walled injector tube will be utilized since it can be cooled more efficiently (by the iron oxide flow) than a thick-walled tube.
 - A mechanical slag breaker has been designed and bench tested (off-line). It will be installed at the CDIF following the channel DVT series. This type of slag breaker has been utilized successfully for keeping pressure ports clear in the TDS oil-fired, ash-injected burners.
 - The slurry will be injected in the sidewall adjacent to the cathode wall rather than on the cathode wall itself. Both injection schemes have been evaluated previously at the CDIF. The sidewall injection provides the benefit of: 1) less propensity for plugging, 2) improved distribution of iron oxide into the slag layer, and 3) easier implementation of a mechanical slag breaker scheme.

All of these changes were initiated during this quarter and will be evaluated during the 21st quarter as part of the DVT of the prototypical power train.

TABLE 7-3. SUMMARY OF FACILITY TEST OPERATIONS - 20TH QUARTER

Test Designation	Date	Quick Look Results
92-COMB-01	06-05-92	<p>There were problems lighting the ignitor; as soon as it was lit, the combustor would trip. After 4 or 5 attempts/valve adjustments, there was a successful startup of the ignitor and OFV, but a shut down occurred in 30 seconds due to high heat flux in the PC can. After shutdown, it was determined that the initiator preheat was around 1800 deg. F, plus additional heat loss on the outside of can due to open construction of the PC can shield.</p> <p>One more startup with the oil burner was made. After 16 minutes of operation, a controlled shut down occurred. The temperature stickers did not indicate any hot spots. The precombustor headend was removed and the internals looked good. The igniter tube had burned completely off due to off-nominal methane/oxygen mixture ratios.</p>
92-COMB-02	06-08-92	<p>The CFPC was fired on 06/08/92 and operated at nominal conditions for ~15 minutes. Planned duration was 20 minutes. However, TRW requested early shutdown in order to investigate skin temp. (i.e. pressure shell) on CFPC which was climbing. Post-test inspection indicated (per temperature stickers) 160 deg. F maximum temperature which is reasonable based on 100 deg. F cooling water temperature.</p>
92-COMB-03	06-10-92	<p>The first startup on main coal was aborted after 8 minutes due to coal flow dropping which caused high heat fluxes. On the restart, main coal was run for 30 minutes. Emergency shutdown was caused by hardware alarm on seed injector differential pressure. The seed feed system in building 20 had plugged.</p>
92-COMB-04	06-11-92	<p>The first startup was manually aborted because of electrical problems in the afterburner instrumentation. A restart ran for one hour, but the densevapor line was not refilling because the fill line contained slag. The last start went for 2.5 hours and systems operated smoothly. However, slag was not rejected because it had piled up on top of the grinder, probably during the initial densevapor problems. Post-test it was noted that the grinder was plumbed backwards and hence was not grinding the slag.</p>
92-COMB-05	06-15-92	<p>A 1-1/2 hour test was conducted. The conditions were not stable due to problems with coal flow; Ø1 varied from 0.4 to 0.7 and the test was eventually terminated due to heat fluxes at the Ø1=0.7 condition. Iron oxide flow at 2.5 lb/min was very stable (one port on cathode only); hi-speed data and conductivity measurements were taken for 1 hour. Problems continued with high delta P across screen in primary injector (coal) vessel. This has been a problem on all tests to date.</p>
92-COMB-06	06-16-92	<p>A 4 hour test was conducted; the test aborted due to flame-out on the CFPC as a result of a plug in the CFPC pinch valve. Several restart attempts were unsuccessful due to:</p> <ul style="list-style-type: none"> - Continuous flame outs - Slag rejector interlocks <p>One iron oxide line to the cathode wall experienced plugging problem on-line; cause of plugging unknown. The other iron oxide line also experienced temporary flow problem; however, this was traced to too low of a tank level and no further problems were experienced. Post-test inspection revealed stripping in slagging stage, primarily the air inlet section. The baffle bore grooves slagged well.</p>
92-COMB-07	06-18-92	<p>A 6-3/4 hour test was conducted. The operating conditions were very stable; test was terminated when the oxygen pump lost its prime and flow could not be maintained. Operating conditions were reduced to 45 MWt towards the end of the test in order to conserve oxygen and test as long as possible. Smooth shutdown (no trip).</p> <p>Post-test inspection revealed:</p> <ul style="list-style-type: none"> - Non-uniform slag coverage; sharp edges may indicate stripping on shutdown. - 3 small pieces of slag found in corners of transition section (top right, top left, bottom right - when viewed from slagging stage) at intersection with air inlet neck. Note that one piece (top right) had been observed following 3-1/2 hour test and had not been removed. - No slag was found in grinder - On-line-slag recovery measurements indicated ~50% recovery. Note: measured recovery on previous test was 40-50%.

7.2.2 Coal System Modifications

During the previous quarter, major modifications were made to the coal feed system. These changes were the result of recommendations provided by a team of consultants on methods to mitigate plugging of the coal feed system during simultaneous coal processing and coal flowing during a test. These changes, as described in detail in the 19th Quarterly, included the incorporation of a new scalping screen between the prepared coal storage bin and the feed injector vessel, and the incorporation of a new system to capture the fine coal particles rejected from the cyclone and re-inject them back into the processed coal flow in the prepared coal storage bin.

The initial on-line checkout of the coal feed system modifications was performed during this quarter as part of the combustor hot-fire checkout test series. Minor problems occurred with some of the new equipment during a few of the tests. The majority of these problems were resolved during the test series. The primary problem which remained at the end of the test series was plugging of the screen in the primary injector vessel.

Subsequent to the test series, a new filter was installed in the new SWECO scalping screen at the outlet of the coal processing system. The scalping screen removes the oversized particles from the processed coal. An off-line checkout test (SOTP) was performed following the installation of the new filter, and it was determined that the screen in the primary injector vessel (which was subject to plugging) was no longer required and, hence, it was removed. The design verification test series will be conducted with the new filter in the SWECO screen and without a screen in the primary injector vessel.

A new isokinetic probe was added to the system between the feed injector vessel and the filter receiver. Samples were taken approximately once every 20 minutes during testing when the coal was transferred between the two vessels. The existing on-line sampling location and method downstream of the primary injector in the main coal feed line was retained in order to provide a basis of comparison with previous samples.

A coal grind size distribution analysis was performed on several coal samples from the combustor hot-fire checkout test series in order to determine: 1) the impact of coal sample location on coal grind distribution, 2) the consistency of the coal grind distribution from test to test, and 3) the impact of the addition of coal fines on the overall coal grind size distribution. The results of this analysis is shown in Figures 7-1, 7-2, and 7-3. Figure 7-1 is a comparison of the new coal grind distribution taken from the two different sample locations. The samples were taken during test 92-COMB-05, approximately one hour apart. As shown, the two coal grind distributions are virtually identical. This, in essence, validates the coal grind distributions obtained during previous test series utilizing the old sample location and sampling method. Although an isokinetic probe is not utilized at the old sampling location, the existing sampling method does not appear to result in a bias in the coal grind distribution. Figure 7-2 is a comparison of the new coal grind distribution during two separate tests. As indicated, the coal grind distribution during the prototypical combustor hot-fire test series was fairly consistent from test to test. Figure 7-3 illustrates the impact of the re-introduction of coal fines into the primary coal on the overall coal grind distribution. The coal grind distributions from two of the tests during the workhorse test series (prior to the system modifications to re-introduce coal fines) are compared to the new coal grind distribution following system modifications. As shown, the new coal grind distribution is similar to the previous coal grind distribution and does not indicate a bias due to the re-introduction of coal fines. This result indicates that within the accuracy of the ability to accurately sample and analyze coal grind distributions, there is very little difference between the coal grind distribution utilized during the workhorse hardware test series and that utilized during the prototypical hardware test series. Additional coal analysis should be performed during the design verification test series to confirm these results.

The importance of utilizing wet sieve (versus dry sieve) analysis to determine coal grind distributions was also confirmed during this analysis effort. Figure 7-4 is a comparison of the coal grind distribution of two coal samples taken from the same test approximately 10 minutes apart. One coal sample was analyzed

COAL GRIND DISTRIBUTION COMPARISON WET SIEVE ANALYSIS (92-COMB-05)

Figure 7-1. Comparison of New Coal Grind Distribution at Two Different Sample Locations

COAL GRIND DISTRIBUTION COMPARISON WET SIEVE ANALYSIS

Figure 7-2. Comparison of New Coal Grind Distribution During Two Separate Tests

COAL GRIND DISTRIBUTION COMPARISON WET SIEVE ANALYSIS

Figure 7-3. Comparison of New Coal Grind Distribution (SWECO Separator and Fines Addition) to Previous Distribution

COAL GRIND DISTRIBUTION COMPARISON WET SIEVE VERSUS DRY SIEVE (92-COMB-05)

Figure 7-4. Comparison of New Coal Grind Distribution Utilizing Wet Sieve and Dry Sieve Analysis Methods

utilizing the dry sieve method and the other sample was analyzed utilizing the wet sieve method. As indicated, there is a large difference in the analysis results for the two methods. This is especially evident for coal grind sizes less than 200 mesh. It appears that during the dry sieve process, the particles agglomerate on the 270 mesh screen and, hence, the distribution analysis is inaccurate at mesh sizes less than 200 mesh. It should also be noted that the coal distributions obtained utilizing the dry sieve method showed more variation in grind size for different samples from the same test than observed utilizing the wet sieve than observed utilizing the wet sieve method. These results indicate that a wet sieve analysis method should always be utilized when it is important to know the coal grind distribution less than 200 mesh. Coal grind distributions are often simply categorized as percent through 200 mesh. As shown in Figure 7-4, both analysis methods indicate a total of 54% through 200 mesh even though the distribution of particle sizes less than 200 mesh is quite different.

7.2.3 Seed System

Seed system modifications were accomplished prior to the combustor hot-fire checkout. The modifications, including replacement of the silo rotary feeder, installation of a new filter receiver on the silo, and converting the fly ash bin to a dust collector, were completed and successfully tested. No problems were experienced with the seed delivery system during hot-fire testing.

7.2.4 High Voltage Room (HVR) Modifications

In preparation for the prototypical 1A4 channel installation, all of the electrical wiring between the channel and HVR has been removed and will be replaced prior to power train DVT. The instrumentation (i.e. panel meters) have also been replaced.

7.2.5 Emissions Compliance

In preparation for installation of an ammonia injection system to reduce NO_x emissions, a concrete pad and retaining wall were poured outside of Building 60. The ammonia system will be installed prior to starting DVT. The afterburner system installed to reduce CO emissions was used during the combustor hot-fire checkout and is fully operational.

7.2.6 Primary Cooling Water System (PCW)

The primary cooling water system (PCW) plumbing has been modified to adapt to the prototypical 1A4 channel and diffuser. Water chemistry controls and instrumentation will be installed prior to channel testing to meet the channel water quality requirements. These requirements were fully discussed in the 19th Quarterly report.

7.2.7 Oxygen System

The oxygen system is being modified to have 100-hour test capability. This is not a requirement for DVT, but the work is underway and should be completed next quarter. The system will be operational for the channel DVT, but not with 100-hour capability.

7.2.8 Nitrogen System

The nitrogen system is being modified to have 100-hour test capability. This is not a requirement for DVT, but the work is underway and should be completed next quarter. The system will be operational for the channel DVT, but not with 100-hour capability.

7.2.9 Low Pressure Cooling System (LPCS)

The LPCS system was operated successfully during combustor checkout testing, but it was operated with the understanding that the piping system would be repaired prior to power testing because it did not meet ANSI B31.1 code requirements. The piping repairs are almost complete and will be ready for DVT. No other modifications to the LPCS subsystem are required.

7.3 PROTOTYPICAL POWER TRAIN HARDWARE ACTIVITIES

The installation of the remaining MHD ITC power train components for DVT is also in process.

7.3.1 Predelivery Checks of the 1A4 Channel and Diffuser

The 1A4 prototypical channel and diffuser were shipped to the TDS Butte Field Office for final quality assurance acceptance tests. The 1A4 channel and diffuser were subjected to numerous pneumatic pressure and hydraulic checks at TDS's Butte Field Office. Figure 7-5 shows the pneumatic pressure check of the channel before it left TDS in Everett, Massachusetts as well as the pneumatic pressure test results measured shortly after the channel's arrival in Butte. The results indicate that the channel suffered no ill effects from the move. Each hydraulic circuit, six in total, was cycled from 0 to 350 psi 10 times. A pressure of 350 psi was maintained for a minimum of 8 hours on each circuit.

Figures 7-6 through 7-9 show pneumatic pressure checks of each of the four diffuser sections as measured at the TDS Butte Field Office. A similar characteristic was obtained for the three aft diffuser sections, before they were joined to the forward supersonic diffuser and delivered to the CDIF. The diffuser manifolding was complete at the end of the quarter, but final flow calibrations had not yet been performed.

7.3.2 1A4 Channel Delivery and Installation at the CDIF

The 1A4 channel was delivered from the TDS Butte Field Office to the CDIF on July 15, 1992 and it was hoisted into place the following week. The installation and mating of the channel to the TRW second stage went very smoothly, with no interference encountered after final tightening of the inlet frame to the combustor. Alignment was checked and was within specifications.

Preliminary clearance checks indicated a possible problem with an anode (water) transfer manifold. Supporting brackets were modified and reinstalled to provide additional clearance.

Figure 7-5. Channel Pneumatic Pressure Check

Figure 7-6. Forward (Segmented) Supersonic Diffuser Pneumatic Pressure Check

Figure 7-7. Aft Supersonic Diffuser Pneumatic Pressure Check

Figure 7-8. Forward Subsonic Diffuser Pneumatic Pressure Check

Figure 7-9. Aft Subsonic Diffuser Pneumatic Pressure Check

7.3.3 Miscellaneous Butte Field Office Activities

The TDS Butte Field Office is operational, and machinery is in place and wired. Additional storage cabinets have been delivered for the storage of spare current control components.

7.3.4 Initial Electrical Configuration for Design Verification Testing of the Prototypical Power Train

During this reporting period, the detailed electrical configuration for the Design Verification Testing (DVT) of the prototypical power train was finalized. The initial 1A4 electrical configuration will utilize resistive consolidation wired in series with the Westinghouse diodes as shown in Figures 7-10 and 7-11. The Westinghouse active consolidation circuits will be wired in parallel with the resistive consolidation network in anticipation of checkout testing with the modified 1A1 channel. The Westinghouse circuits will be deactivated by physically jumpering the resistive consolidation trigger switch located in the anode and cathode diode stacks. The detailed electrical configuration for the Westinghouse circuits was selected based on power management modeling results performed by the Busek Co.

7.3.5 Current Consolidation

The forward (anode) current consolidation cabinets were shipped to the CDIF for installation in the anode consolidation building. This work will be completed on an "as available" basis and will include all necessary system interconnects except the central control computer. This latter component has been retained at Westinghouse to support the acceptance testing of the aft cathode consolidation hardware. The cathode consolidation hardware will be shipped in the upcoming quarter.

7.4 PROTOTYPICAL POWER TRAIN DVT TEST PLANS

Testing of the 1A4 channel will be initiated next quarter. The testing will include the following basic steps:

- System Operating Test Procedure (SOTP) for all new or modified facility systems.
- Functional checkout of the channel/diffuser subsystem, including flow balancing of all water circuits.
- High potential test of power train to 8 kV in 1 kV increments.
- Hot-fire thermal testing to confirm stable combustor/facility operation.
- Proceed with power train DVT electrical testing.

Figure 7-10. Forward PTO Region Electrical Configuration for Initial Design Verification Testing

Westinghouse current consolidation circuit not installed as shown.

Figure 7-11. Aft PTO Region Electrical Configuration for Initial Design Verification Testing

8. TTIRC AND POC INTEGRATION TASK FORCE ACTIVITIES (TASK 8)

The Task 8 activities of the ITC program relate to the operation of the MHD Technology Transfer, Integration and Review Committee (TTIRC) and TRW's role in ensuring the integration of the three POC programs: Integrated Topping Cycle, Integrated Bottoming Cycle and Seed Regeneration Process. The integration function is the responsibility of the POC Integration Task Force.

The draft seventh and eighth semi-annual status reports were prepared and distributed to the DOE for review and comments.

9. PLANNED ACTIVITIES

Task 1

- Maintain the detailed, integrated schedule for the testing phase of the program.
- Complete the interface verification for the current consolidation hardware.
- Support prototypical combustion subsystem test activities including data analysis, modeling, and comparison with workhorse hardware experience.

Task 2

- Ship spare and contingency hardware to the CDIF.

Task 3

- Initiate design/fabrication of spares.

Task 4

- Install diffuser to support channel testing.

Task 5

- Complete assembly of the cathode local control system.
- Initiate and complete the system testing of the cathode consolidation circuits.
- Ship the completed cathode consolidation circuits to the CDIF.

Task 6

- Complete channel thermal hot-fire checkout.
- Initiate the power train DVT.

10. SUMMARY

Manufacturing, assembly, and checkout of all spare and contingency combustion subsystem hardware was completed. This hardware has been delivered to the CDIF. The water electrical isolators were also delivered to the CDIF.

A successful nozzle proof test was concluded. The purpose of the test was to evaluate the adequacy of the nozzle structure and to evaluate sealing of the sidewall-to-electrode wall joints, water tubes, and stud and wire penetrations at operating pressure.

Design modifications to the spare channel inlet frame were made in order to incorporate the capability for iron oxide injection. Results of tests performed in the CDIF 1A1 channel which compared the effect of different cathode wall iron oxide injection locations indicated that injection through the side port may be more effective in spreading iron oxide, particularly should one of the two ports become clogged. Design confirmation testing of a pneumatically driven ram to clear a plugged iron oxide injector tip was performed. The manufacture of spare and replacement parts for the 1A4 channel and diffuser was begun.

The construction of the cathode power cabinets and associated control system was completed.

The hot-fire checkout series was completed for the combustion subsystem. A total of 16.8 thermal hours were accumulated during 7 tests. This test series demonstrated the adequacy of the overall cooling of the combustion subsystem and provided an initial evaluation of the combustor performance in terms of heat losses and slagging characteristics.

Several major facility activities at the CDIF were accomplished including: 1) installation and testing of new iron oxide pumps, 2) initial on-line checkout of the coal feed system modifications, 3) modification of the seed system including replacement of the silo rotary feeder, installation of a new filter receiver on the silo, and conversion of the fly ash bin to a dust collector, 4) removal of all of the electrical wiring (used for the 1A1 channel) between the channel and HVR in order to install the 1A4 wiring, and 5) installation of the 1A4 channel.

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APPENDIX A. NOMENCLATURE

Abbreviations

1. AIC - Ash Injected Combustor
2. CDIF - Component Development and Integration Facility
3. CDR - Critical Design Review
4. CFC - Coal-Fired Combustor
5. CFPC - Coal-Fired Precombustor
6. CTS - Capistrano Test Site (TRW)
7. DCT - Design Confirmation Test
8. DOE - Department of Energy
9. DVT - Design Verification Test
10. FETS - Fossil Energy Test Site (TRW)
11. GOX - Gaseous oxygen
12. ITC - Integrated Topping Cycle
13. MEF - Material Evaluation Fixture
14. OFV - Oil-Fired Vitiator
15. PDR - Preliminary Design Review
16. POC - Proof-of-Concept
17. PRD - Project Requirements Document
18. PEM - Performance Evaluation Module
19. TTIRC - Technology Transfer, Integration and Review Committee

Symbols

20. β - Beta - Hall parameter
21. δ - Boundary layer thickness (Meters)
22. σ - Plasma Conductivity (Mhos/m) - There are several definitions for plasma conductivity, as follows:
 1. Mid-channel conductivity - the conductivity at the channel mid-point determined experimentally from a plot of conductivity vs. channel axial length. This is the conductivity most often used in presenting test results. Unless otherwise specified, σ refers to this conductivity.
 2. Inlet conductivity - the conductivity at the channel inlet. This parameter can be determined experimentally by extrapolating the conductivity vs. channel length curve to zero.
 3. Bulk conductivity - the conductivity determined in the 1A1 channel at CDIF by taking the voltage drop divided by the current. This parameter is available on-line and is used to spot conductivity changes during testing.
 4. PEM conductivity - the conductivity measured at the Performance Evaluation Module at CTS at subsonic (stagnation) conditions.
23. ϕ_{01} - Precombustor Equivalence Ratio - Ratio of oxygen input to the coal-fired precombustor combustion chamber to stoichiometric oxygen required for complete combustion of fuels.

24. ϕ_1 - First Stage Equivalence Ratio - Ratio of oxygen input to the first stage to stoichiometric oxygen required for complete combustion of fuels.
25. ϕ_2 - Overall Equivalence Ratio - Ratio of total oxygen inputs to stoichiometric oxygen required for complete combustion of fuels.
26. AR - Aspect Ratio - The height H (anode to cathode distance) divided by the width D (sidewall to sidewall distance) of the channel
27. B - Magnetic field (Tesla)
28. E_x - Axial electric field (volts/m)
29. I_e - Electric current (amps)
30. I_{sc} - Short circuit current (amps)
31. I_x - Axial current (amps)
32. I_{leak} - Constant current leakage that is proportional to the Hall voltage (relating to cathode wall nonuniformities, plasma nonuniformities, and/or voltage drops) (amps).
33. J_y - Faraday current density (amps/cm²)
34. %K - Amount of potassium injected as a percent of total mass flow through power train.
35. L/D - Length -to-hydraulic diameter ratio (second stage)
36. MW_e - Electric megawatts (power output)
37. MW_t - Thermal megawatts (heat input rate)
38. N/O - Molar ratio of nitrogen to oxygen inputs (all input streams).
39. N_{ovlp} - Number of overlapped electrodes in channel.
40. P - electrode pitch (m)
41. P_b - burner pressure (atm)
42. P_{diss} - Power dissipated in ballast resistors (watts)
43. R - Resistance between shorted cathode gaps (ohms/gap)
44. R_{leak} - An end-to-end resistance that is independent of Hall voltage (i.e., current transport through the liquid slag layer) (ohms/gap).
45. R_{link} - Resistance value of link resistor (ohms)
46. T₂₅₀ - Temperature at which slag viscosity equals 250 poise
47. V_{oc} - Open-circuit voltage (volts)
48. ΔV - Transverse voltage drop (e.g., ΔV_{bl} - across boundary layer) (volts)

Definitions

49. Heat Flux - Heat loss per unit area (watts/cm²).
50. Heat Loss - Sensible heat loss to cooling circuits, usually stated as a percent of total thermal input to the combustor.
51. Slag Recovery - Weight of dry slag collected in slag tank as a percentage of dry, SO₃ -free ash fed to the combustor (SO₃ is volatile and is not found in the slag).
52. Weight Percent Oxygen in First Stage (wt. % O₂) - Weight percent of oxygen in vitiated gases entering combustor first stage.

END

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