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Twenty-First Quarterly Technical Progress Report

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EXECUTIVE SUMMARY

This twenty-first quarterly technical progress report of the MHD Integrated Topping Cycle Project presents the accomplishments during the period August 1, 1992 to October 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 diffuser was completed.

The overall integrated schedule, including testing, was reviewed.

COMBUSTION SUBSYSTEM DESIGN AND FABRICATION (SECTION 4)

Combustor spare and contingency hardware was shipped to the CDIF.

PROTOTYPICAL CHANNEL SUBSYSTEM DESIGN AND FABRICATION (SECTION 5)

The manufacture of spare and replacement hardware for the 1A4 channel and diffuser continued. The adequacy of spare hardware will be reviewed at the conclusion of the post-DVT channel inspection.

Fabrication of a modified/spare channel inlet frame which incorporates the capability for iron oxide injection was completed.

CURRENT CONSOLIDATION SUBSYSTEM DESIGN AND FABRICATION (SECTION 6)

During this quarter, the cathode power cabinets, local controls and central control system were successfully tested at Westinghouse. As with the anode system, the circuits and controls met all of the design requirements. The cathode system was shipped to the CDIF and installed in the newly fabricated current consolidation building.

CDIF TESTING (SECTION 7)

During this reporting period, the hot-fire checkout test series was completed for the prototypical channel subsystem. This series of five tests demonstrated the adequacy of the overall cooling and gas containment of the nozzle/channel/diffuser and provided an initial evaluation of the channel subsystem performance in terms of heat loss and slagging characteristics.

The design verification testing (DVT) of the integrated power train was also completed. Twenty-four DVT tests were performed. The test series provided an initial evaluation of the integrated combustor and channel performance in terms of operating conditions, power output, conductivity, heat loss, slagging behavior, and gas-side wear characteristics. During the test series localized wear in the supersonic nozzle was observed on the right sidewall. The cause of the wear is presently under investigation.

A total of 120 thermal hours and 52 electrical hours were accumulated. At the conclusion of the DVT test series, the channel was removed and is being inspected for internal wear, evidence of arcing, hot spots, etc. Various components within the combustion subsystem will also be removed and/or inspected. Facility modifications continued in preparation for long duration testing.

TTIRC (SECTION 8)

Preparation of the ninth semi-annual status report was initiated.

SCHEDULE

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

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MHD ITC PROJECT Revised Schedule

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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 Twenty-First Quarterly Technical Progress Report covers the period August 1, 1992 to October 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. After completion of the channel installation, the integrated power train was tested for 120 thermal and 52 electrical hours as part of the channel hot-fire checkout and the design verification test series. The prototypical cathode current consolidation circuits 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 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)	Define system level requirements and specifications for the integrated topping cycle power train Provide test planning and performance data analysis support for CDIF power train testing Design, fabricate and deliver to the CDIF a prototypical coal-fired combustor for the integrated topping cycle power train 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
PROTOTYPICAL 50 MW _t CHANNEL (TASK 3)	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 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
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)	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 Review and integrate POC program schedules and integration issues and provide for technology transfer to potential future users
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 existing documentation, was completed this quarter for the diffuser. Interface verification will be completed next quarter for the current consolidation subsystem in conjunction with the system acceptance testing at the CDIF. The interface document will continue to 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 current consolidation subsystem and the varistor/inductor hardware was completed.

3.1.3 Integrated Schedule Review

The coordination of the master schedules for the POC testing and the CDIF modifications/installations continued during this reporting period. The primary focus has been the scheduling/coordination of the channel hot-fire checkout testing, DVT testing of the integrated power train, and long duration testing.

This activity will remain an ongoing task to ensure that the ITC program remains on schedule, all issues are addressed as they surface, and to provide the maximum amount of time to implement work-arounds.

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, spare and contingency hardware was shipped to the CDIF.

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 MW₁ combustor/channel characterization. Also completed and the results reported.

Subtask 2.2 includes the following elements:

- Subtask 2.2.1, Component fabrication and assembly. This subtask has been completed and the results reported.
- 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. Completed this reporting period.

4.1 COMBUSTION SUBSYSTEM DESIGN ACTIVITIES (SUBTASK 2.1.3)

The activities in this subtask have been completed. No additional activity will occur.

4.2 COMBUSTION SUBSYSTEM MANUFACTURING (SUBTASK 2.2.1)

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

4.3 COMBUSTOR SHIPMENT (SUBTASK 2.3)

The spare and contingency hardware completed under subtask 2.2.1 last quarter was shipped to the CDIF during this reporting period. No additional activity will occur.

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

Following the completion of channel fabrication and installation at the CDIF during the previous reporting period, attention has focused on the fabrication of spare and replacement parts for the 1A4 prototypical generator. The status of spares fabrication at the end of this reporting period is presented in Section 5.1.

Work was also completed on the fabrication of a modified channel inlet frame which incorporates the capability for iron oxide injection. A summary of this work is reported in Section 5.2.

5.1 PROTOTYPICAL CHANNEL SPARES FABRICATION

Since the completion of channel fabrication, attention has turned to the manufacture of spare parts for the prototypical MHD generator components in accordance with the schedule presented in the 20th Quarterly Technical Progress Report. In addition, some spares activity was performed in anticipation of the possible need for replacement parts based on observations of localized wear in the nozzle region of the 1A4 channel during design verification testing (DVT) performed at the CDIF. The following sections present the status of spares fabrication at the end of this reporting period.

5.1.1 Sidewall Spares Fabrication

At the end of this reporting period, over 840 sidewall elements were completed (cap brazed, tube and stud brazed, cleaned and inspected). This represents approximately 40% of the total planned spare sidebars for the 1A4.

Many more sidewall elements have completed the initial brazing stage of their construction (i.e., brazing of the top cap to the base). Table 5-1 indicates the required number of each type of element and the brazing status at the end of the previous quarter and at the end of this reporting period.

In addition to the standard sidewall elements, several "special" (i.e. non-standard) elements were fabricated during the reporting period. Special elements include horizontal billets (used in the subsonic nozzle) and sidewall transition pieces that fit between the horizontal billets and diagonal sidewall elements. Sixteen spare horizontal billets and 18 right sidewall transition pieces were completed during this reporting period. These will be available, if required, for installation following the DVT series.

5.1.2 Cathode Spares Fabrication

Eighteen spare cathode wall nozzle region elements were fabricated during this quarter. It is anticipated that these elements will be installed in the channel at the conclusion of the DVT series.

5.1.3 Anode Spares Fabrication

The fabrication of anode cap subassemblies began during this reporting period. Twenty-four 0.6-inch wide caps have been brazed by the end of this reporting period.

5.2 MODIFIED INLET FRAME FABRICATION

Modifications were made to the channel inlet frame design to allow placement of side port injectors in the sidewall adjacent to the cathode wall. The ports provide the capability to inject iron oxide slurry at the inlet to the channel. The injector ports were located relative to the cathode wall analogous to the ports used for the 1A1 channel tests. The rationale for the design modifications was discussed in the 20th Quarterly Technical Progress Report. A schematic of the new channel inlet frame is shown in Figure 5-1.

During this reporting period, preliminary machining of the copper window frame and oven brazing of the tungsten caps onto the gas-side surface were completed. After ultrasonic inspection of the brazes, final machining and plugging of the water passages was completed. The inlet frame was shipped to the TDS Butte Field Office and will be installed onto the 1A4 channel following the post-DVT inspection.

TABLE 5-1. 1A4 CHANNEL SIDEWALL SPARES - CAP BRAZING STATUS

	Amount Required	Percent Brazed at End of Previous Quarter	Percent Brazed at End of This Quarter
W Cap Cu House	50 Needed	100% Completed	100% Completed
W Cap Cu House/Wire	300	24%	100%
Split W Cap W/Cu House	450	0%	48%
W/Cu Cap Cu House/Wire	100	0%	90%
W Cap Cu Mid	450	41%	54%
W Cap Cu Mid/Stud	300	0%	50%
W Cap/Shim W/Cu Mid	450	4%	57%
W/Cu Cap Cu Mid	50	0%	0%
W/Cu Cap Cu Mid/Stud	50	0%	4%

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

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

During this reporting period, the acceptance test program for the cathode cabinets and associated controls was successfully completed. The test program was identical to that conducted for the anode system in March. The tests included simulations of transients that the equipment would be subject to during channel operation. As with the anode system, the cathode equipment met the key design requirements from the CDR such as step response times, output voltage ripple and electrical isolation. Details from the acceptance test program are reported in Section 6.1. Following completion of the acceptance tests, the cathode power cabinets were shipped to the CDIF.

6.1 CATHODE SYSTEM ACCEPTANCE TESTS

The goal of the cathode acceptance test program was to verify that the key design requirements presented at the Current Consolidation Subsystem CDR were met. An earlier test program verified that the requirements were met for the anode system. The same test program was conducted for the cathode equipment. The cathode system is essentially identical to the anode system, except that current flows from the electrode to the consolidation point. Thus the only key differences between the systems are in the internal wiring of the cabinets that account for the different directions of current flow. Due to this difference, the systems are not interchangeable.

6.1.1 Individual Circuit Tests

As a quality assurance measure, each individual consolidator circuit was tested to verify proper operation. Figure 6-1 shows the test configuration. The power supply voltage and the load resistance was varied to swing the consolidator output voltage. Figure 6-2 shows the type of test data gathered for each circuit.

Figure 6-1. Individual Consolidator Test Configuration

Cathode Consolidation Converter Test Data

Circuit Position: GTO #30

Switch Module No.: GTO M- C017

Load	Power Supply Voltage	Measured Load Current	Measured Sensor/Amp Voltage	Measured Consolidator Voltage
~ 22.5	~ 0	10.3	2.53	235
~ 22.5	~ 0	15.4	3.80	352
<del>~ 22.5</del> ~ 2.5	~ 0	-0.1	0.00	1
~ 2.5	~ 25	10.3	2.53	-3
~ 2.5	~ 160	10.3	2.53	-136

Figure 6-2. Example Test Data Sheet

The test configuration of Figure 6-1 was also used to check the step responses of individual circuits. A load resistance of 2.4 ohms was used since this is the maximum expected interelectrode resistance. As with the anode system, the responses reached steady-state for the first time within 50 msec. The time to settle at steady-state was 200 msec. The CDR requirement is a 300 msec response time.

A method for checking the frequency response that was not used previously on the anode system was employed. A wave generator was used to inject a variable frequency current reference change to a given circuit. This simulates the type of continuous fast reference changes that would be present during actual channel operation. With a response time at best of 50 msec, the circuits respond to changes in reference up to 20 Hz. At frequencies above this, the circuits will respond only to the average value of the changing reference, Figure 6-3AB shows the response to changes at 10 Hz and 50 Hz, respectively. At 10 Hz, the consolidator current follows the reference step changes. At 50 Hz, there is no change in output current. It should be noted that in both traces there is a 120 Hz component that is due to the current ripple output of the consolidator.

6.1.2 System Testing

Figure 6-4 shows the primary test configuration for groups of consolidators. The branch with the impedance "Z" and resistance "RID" represents the reference connection to the diffuser in the actual system. These were set to 104 mH and 2 ohms for most of the testing. The electrode resistances, RE_N , were set in an alternating pattern of 1 ohm, 2 ohm, etc. The load resistance, R_L , was set to 2 ohms during most of the tests. The power supply was rated for 150 V, 70 A, which provided for average current capability of 8.75 amps for an 8-electrode system. Due to the current limitation on the power supply, most tests were conducted in groups of eight electrodes. However, some of the programmed current distributions resulted

A

Reference Change at 10 Hz, 4 to 8 Amps
 Time Base - 50 msec/Div
 Top Trace - Output Current at 4 Amps/Div
 Bottom Trace - Current Reference Steps

B

Reference Change at 50 Hz, 4 to 8 Amps
 Time Base - 10 msec/Div
 Top Trace - Output Current at 4 Amps/Div
 Bottom Trace - Current Reference Steps

Figure 6-3AB. Current Response to Reference Changes

Figure 6-4. Primary System Test Configuration

in currents up to 14 amps in an individual electrode when operated in groups. Some tests were conducted with as many as 16 electrodes at low currents.

Transients were introduced in the system to determine the impact, if any, on system operation. In the first transient test, the distribution of current among the eight electrodes was instantaneously changed between the following two distributions:

	Consolidator Number							
	1	2	3	4	5	6	7	8
Distribution 1:	5%	7%	9%	11%	14%	16%	18%	20%
Distribution 2:	16%	18%	20%	14%	11%	9%	7%	5%

All collected data indicated proper system operation, and none of the design criteria was violated. In particular, the current in the reference connection did not exhibit excessive excursions during the transients.

One feature of the system is to automatically detect the loss of current in an electrode. This could be due to the loss of a facility fuse or connection. The system automatically adjusts the current references in the other operating electrodes to carry the current from the lost electrode to prevent current from flowing in the reference connection.

The status of the facility fuses is not directly available to the current consolidation system. Thus the system always compares the actual current flowing in an electrode to the current reference value for that

electrode. If an inconsistency persists, then the distribution is changed and that circuit is assumed failed. This same test detects a loss of a facility electrode connection as well.

The system was first tested with a fuse in series with an electrode to simulate the loss of a facility fuse. After the fuse was blown, the current in the reference connection carried the current from the lost electrode. After 1.5 seconds, the system reprogrammed the distribution so the current in the reference connection returned to zero. The system was also tested with a circuit left disconnected on startup which also was successfully detected and corrected.

There are two fuses integral to each consolidator which correspond to each semiconductor. If either fuse is lost, the consolidator is taken out of service because it cannot function properly on just one semiconductor. An undersized fuse was placed in one semiconductor leg for the test. Once the undersized fuse blew, the system effectively disabled the consolidator and reprogrammed the current distribution.

The system includes an algorithm that automatically calibrates out any steady-state current that is detected in the reference connection. This current is due to cumulative tolerance errors in the sensors and control circuitry. No more than 2% of the total load current should be flowing in the reference connection on a steady-state basis.

The present algorithm is activated and deactivated by the operator if it is determined that the reference connection current is excessive. To test this feature, the system was operated with as many electrodes as reasonably possible within the constraints of the DC power supply and the AC mains feeding the system. Sixteen electrodes were operated at a total current of 70 amps. Three amps of offset current were measured (or 4.3% of total) in the reference connection without any correction. The algorithm was then activated and reduced this error to 0.25 amps or 0.36% error. The 0.25 amps was a preset limit, and the algorithm can be set to correct the current to zero.

7. CDIF TESTING

During the previous reporting period, the combustor hot-fire checkout test series was completed, the prototypical MHD ITC channel subsystem was installed at the CDIF, and design verification test (DVT) preparations were made. During this reporting period, the channel hot-fire checkout test series and the integrated combustor and channel DVT test series were performed. The channel hot-fire test series focused on demonstrating and evaluating the thermal and slagging design characteristics prior to power operations. The DVT test series focused on establishing operating conditions for the duration test series and on accumulating 50 to 75 electrical hours on the prototypical hardware in order to assess "infant mortality" of the channel elements. Under prototypical operating conditions, the tests demonstrated channel power output, conductivity, and initial wear characteristics of the gas-side designs. A total of 120 thermal hours and 52 electrical hours were accumulated during 29 tests conducted as part of both test series. After these two series of tests were completed, activities focused on a thorough inspection of the prototypical hardware in preparation for long duration testing. The results of this inspection will be reported in the next quarterly report.

The testing of the prototypical power train is divided into three distinct phases. The details are documented in the ITC Test Plan.

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

Section 7.1 describes the specific objectives and approach for the hot-fire checkout and DVT test series. The combustor and channel configurations are described and the test results are discussed. Section 7.2 describes the on-going activities for facility preparation required to support DVT and long duration testing. Section 7.3 describes the status of the prototypical power train hardware activities.

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 DVT and long 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 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.

7.1.1.2 Objectives of Integrated Power Train DVT

Initial power tests on the 1A4 channel focused on confirming:

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

Once the above functional tests were completed, the focus of the DVT series was to establish the preferred operating conditions and baseline power levels for the duration test series with Western coal.

Additional DVT objectives were to:

- 4) Provide an inspection for "infant mortality" after accumulating between 50 and 75 power hours on the 1A4 channel, and
- 5) Verify the adequacy of the channel loading and power takeoff (PTO) topology.

7.1.2 Approach

The individual approach to the channel subsystem hot-fire checkout test series was 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 was as follows:

- 1) Startup 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 was inspected for external hot spots, gas leaks, water leaks, and internal wear.

The approach to the integrated combustor/channel electrical DVT test series was to subject the power train to gradually increasing power levels and gradually increasing operating durations. The approach was 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 were 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 of the gas-side surface.

7.1.3 Integrated Combustor/Channel Test Configuration

During the previous reporting period, the prototypical combustion and channel subsystems were installed in preparation for the channel hot-fire checkout tests and integrated combustor/channel design verification test (DVT) series. The combustor and channel configuration for this test series is described in the respective Operation and Maintenance (O&M) Manuals and is summarized in the following paragraphs.

The prototypical combustor (D441800) and precombustor (D441755) were installed. The second stage configuration (E441333) matched the combustor to the 1A4 channel inlet frame. The existing workhorse vitiator and slag tank were preserved. Oxygen, air, oil, coal, and seed injector interfaces remained the same as the workhorse hardware. Iron oxide is injected through side ports adjacent to the cathode wall in the last second stage frame. Oxygen is injected countercurrent to the bulk plasma flow in 14 side ports in the front portion of the second stage. The combustor/precombustor thermal panels are cooled using the Low Pressure Cooling Subsystem (LPCS). The LPCS is isolated from the combustor electrical potential using electrical isolators installed in the LPCS main supply and return piping.

The prototypical nozzle and channel were installed and interfaced at the combustor second stage exit and channel inlet frame. The first supersonic diffuser section (constructed like a channel, i.e. segmented) is interfaced at the channel exit flange. The remaining sections of the diffuser are of workhorse hardware design. The generator has 245 electrode pairs (anode and cathode), each with a pitch of 1.78 cm. There are

an additional 19 anode and cathode segments in the segmented nozzle region. The 1A4 channel operates supersonically with an inlet Mach number of 1.5. The channel has a single inverter load and is diagonally connected at a 36° angle from the vertical in a constant $n+12$ overlap. Each diagonal connection contains a current control circuit in the diagonal link. The power takeoff (PTO) regions are graded resistively for power extraction. The first 25 anodes and the last 25 cathodes are used for power extraction. External bleed resistors are installed on selected gaps in the segmented nozzle and diffuser regions to minimize high voltage gaps appearing in the magnetic fringe field. Figures 7-1 and 7-2 illustrate the topology selected for the forward and aft regions of the channel. Figure 7-3 shows the channel configuration during measurement of plasma conductivity.

7.1.4 Channel Subsystem Hot-Fire Checkout Test Series

Five tests were performed during the channel subsystem hot-fire checkout test series accumulating approximately 3.1 hours of full combustion system thermal operation. The test series included three starts of the main CFC combustor. The test series followed the basic test approach outline in Section 7.1.2. Overall, the test series was successful. The adequacy of the overall cooling and gas containment of the channel subsystems was demonstrated. In addition, initial indication of the integrated power train performance, in terms of slagging, heat loss, heat flux and conductivity, was obtained. Specific results from the test series were:

- All gas-side elements were adequately cooled and showed no signs of braze failures, distortion or damage.
- The gas containment of the channel was excellent as evidenced from the local gas (CO) monitors installed in the magnet bore.
- No hot spots or evidence of charring were detected on the uncooled plastic walls of the channel and diffuser.
- No external hose leaks were detected on the channel or diffuser.
- Heat losses were within the design limits of the hardware.
- All channel and diffuser walls retained slag well as evidenced from heat loss time history plots and post-test visual inspections.
- Installation of the CFPC heat shields and reducing the preheat temperature to 2700°F reduced the overall combustion subsystem heat loss to nominally seven percent.

A chronological summary report for the channel hot-fire checkout test series is tabulated in Table 7-1. A summary of nominal operating conditions is tabulated in Table 7-2. Table 7-3 provides a summary of the test results.

With the conclusion of 92-DVT-05, the channel subsystem hot-fire checkout test series was completed and preparations for the integrated power train design verification tests were initiated.

7.1.5 Integrated Power Train Design Verification Test Series

Twenty-four tests were performed during the integrated power train design verification test (DVT) series accumulating approximately 117.1 hours of thermal operation and 52.2 hours of power generation. The test series included 47 starts of the main CFC combustor, with the longest continuous test of 10.4 thermal hours and 9.3 power hours. The test series followed the basic test approach outline in Section 7.1.2. Overall, the test series demonstrated the integrity of the electrical wiring and isolation system, the adequacy of the PTO topology to support duration testing, and accumulated sufficient electrical hours to access initial wear characteristics of the channel gas-side surfaces.

A chronological summary report for the test series is tabulated in Table 7-4. A summary of nominal operating conditions is provided in Table 7-5.

Table 7-6 contains a summary of facility test operations and preliminary test results.

Figure 7-1. Forward PTO Region Electrical Configuration for Initial Design Verification Testing

Westinghouse current consolidation circuit not installed as shown.

Figure 7-2. Aft PTO Region Electrical Configuration for Initial Design Verification Testing

Figure 7-3. Channel Configuration for Conductivity Measurement

TABLE 7-1. PROTOTYPIC CHANNEL HOT-FIRE CHECKOUT - TEST SUMMARY

DATE	TEST DESIGNATION	CFC STARTS	RUN TIME (Minutes)			TEST OBJECTIVES
			OFV	CFPC	CFC	
09-01-92	92-DVT-01	N/A	15	---	---	• VERIFY CHANNEL SUBSYSTEM COOLING AND GAS CONTAINMENT DURING OFV OPERATION ONLY (1200-1500°F PREHEAT)
09-01-92	92-DVT-02	N/A	20	15	---	• VERIFY CHANNEL SUBSYSTEM COOLING AND GAS CONTAINMENT DURING OFV/CFPC OPERATION ONLY (2900°F PREHEAT) • ESTABLISH BASELINE PERFORMANCE OF CFPC WITH HEAT SHIELD INSTALLED
09-03-92	92-DVT-03	1	52	49	45	• VERIFY CHANNEL SUBSYSTEM COOLING AND GAS CONTAINMENT DURING FULL COMBUSTION SUBSYSTEM OPERATION • ESTABLISH BASELINE PERFORMANCE OF CFPC WITH HEAT SHIELD INSTALLED • ESTABLISH PRELIMINARY PERFORMANCE OF INTEGRATED POWER TRAIN FOR SLAGGING, HEAT FLUX, AND HEAT LOSS
09-09-92	92-DVT-04	1	52	50	43	• SAME AS 92-DVT-03 • DETERMINE STEADY-STATE CONDUCTIVITY AT REFERENCE OPERATING CONDITION • PRELIMINARY EVALUATION OF CHANNEL WIRING, PTO TOPOLOGY AND BLEED RESISTOR CONFIGURATION
09-11-92	92-DVT-05	1	110	103	97	• CONDUCTIVITY TEST OF INTEGRATED POWER TRAIN

TABLE 7-2. PROTOTYPIC CHANNEL HOT-FIRE CHECKOUT - NOMINAL TEST CONDITIONS

DATE	TEST DESIGNATION	PREHEAT (°F)	MW_t	PHI 1	PHI 2	N/O	%K	ADDITIVES⁽¹⁾ (lbm/min)
09-01-92	92-DVT-01	1500/1200	3	N/A	N/A	N/A	N/A	N/A
09-01-92	92-DVT-02	2900	10	N/A	N/A	N/A	N/A	N/A
09-03-92	92-DVT-03	2900	50	0.55	0.90	0.75	1.7	N/A
09-09-92	92-DVT-04	2900	50	0.55	0.90	0.75	1.7	4.0
09-11-92	92-DVT-05	2900/2700	50	0.55	0.90	0.70	1.7	4.0
				0.55	0.90	0.80	1.7	4.0

(1) ADDITIVES: TOTAL IRON OXIDE SLURRY 50/50 BY WEIGHT IRON OXIDE/OIL. INJECTION ALONG CATHODE WALLS IN TWO SIDE PORTS ON LAST SECOND STAGE FRAME.

**TABLE 7-3. PROTOTYPIC CHANNEL HOT-FIRE CHECKOUT
SUMMARY OF TEST RESULTS AND FACILITY OPERATIONS**

DATE	TEST DESIGNATION	QUICK LOOK TEST RESULTS
09-01-92	92-DVT-01	CHANNEL SUBSYSTEM COOLING WAS ADEQUATE. EXTERNAL INSPECTION REVEALED NO EVIDENCE OF HOT SPOTS OR GAS LEAKS. THE OFV WAS SECURED USING THE NORMAL SHUTDOWN SEQUENCE.
09-01-92	92-DVT-02	CHANNEL SUBSYSTEM COOLING WAS ADEQUATE. EXTERNAL INSPECTION REVEALED NO EVIDENCE OF HOT SPOTS OR GAS LEAKS. INTERNAL INSPECTION OF COMBUSTOR SHOWED PATCHY SLAG COVERAGE, GENERALLY PUMICE TYPE. THE SECOND STAGE AND CHANNEL WERE NOT SLAGGED. NO EVIDENCE OF INTERNAL WATER LEAKS. THE CFPC/OFV WAS SECURED USING THE NORMAL SHUTDOWN SEQUENCE.
09-03-92	92-DVT-03	CHANNEL SUBSYSTEM COOLING WAS ADEQUATE. CLEAR EVIDENCE FROM HEAT LOSS TIME HISTORY THE CHANNEL WAS SLAGGING. EXTERNAL INSPECTION REVEALED NO EVIDENCE OF HOT SPOTS OR GAS LEAKS. INTERNAL INSPECTION OF COMBUSTOR SHOWED REASONABLY GOOD SLAG COVERAGE: THIN, BLACK AND GLASSY. SOME EVIDENCE OF SLAG STRIPPING. SECOND STAGE PARTIALLY SLAGGED. CHANNEL WAS WELL SLAGGED. SEED FLOW WAS ERRATIC DURING TEST. SLAG REJECTION SYSTEM WOULD NOT OPERATE IN THE AUTOMATIC MODE. COMBUSTION SUBSYSTEM WAS SECURED USING THE NORMAL SHUTDOWN SEQUENCE. NO FOULING OBSERVED IN CFPC.
09-09-92	92-DVT-04	FACILITY PROCESS FLOWS REASONABLY STABLE, INCLUDING IRON OXIDE. CONDUCTIVITY ATTEMPTED BUT IMPROPER GROUNDING OF POWER SUPPLY PRECLUDED FURTHER TESTING. SLAG REJECTION SYSTEM WORKED IN AUTOMATIC MODE BUT DID NOT OPERATE FOR SUFFICIENT DURATION TO COMPLETE A FULL CYCLE. TEST TERMINATED USING NORMAL COMBUSTOR SHUTDOWN SEQUENCE DUE TO COAL SPILL IN COAL PROCESSING BUILDING. COMBUSTOR AND CHANNEL NOT INSPECTED INTERNALLY.
09-11-92	92-DVT-05	BASELINE CONDUCTIVITY MEASURED. HVR AND CHANNEL ELECTRICAL CONFIGURATION LOOKED GOOD (NO ANOMALOUS INDICATIONS). TEST TERMINATED WITH AN ESS CAUSED BY HIGH CURRENT LEAKAGE ACROSS SLAG REJECTION SYSTEM COLLECTION TANK. PROBLEM TRACED TO THE COLLECTION TANK OVERFILLING DUE TO FAULTY VALVE. SLAG SYSTEM OPERATED THROUGH A FULL CYCLE WITHOUT PROBLEMS. DUE TO ESS EVIDENCE OF SLAG STRIPPING, PARTICULARLY IN THE CHANNEL. EXIT SECTION HAS A LARGE ACCUMULATION OF SLAG ON THE BOTTOM. NO EVIDENCE OF CFPC FOULING, OR SLAG FORMATIONS IN THE TRANSITION SECTION. LOWERING THE CFPC PREHEAT TO 2700°F IN COMBINATION WITH THE INSTALLATION OF THE HEAT SHIELDS REDUCED THE CFC HEAT LOSS BY 1%. NO EVIDENCE OF INTERNAL WATER LEAKS.

TABLE 7-4. INTEGRATED POWER TRAIN DESIGN VERIFICATION - TEST SUMMARY

DATE	TEST DESIGNATION	CFC STARTS	RUN TIME (Minutes)				TEST OBJECTIVES
			OFV	CFPC	CFC	POWER	
09-15-92	92-DVT-06	5	184	173	154	CONDUCTIVITY MEASURED	• DETERMINE OPERATING CONDITIONS FOR DURATION TEST BASED ON SOW REQUIREMENTS • PROVIDE INITIAL EVALUATION OF INTEGRATED POWER TRAIN DURING POWER GENERATING CONDITION • VERIFY ELECTRICAL CONFIGURATION ACHIEVES THE DESIRED VOLTAGE AND CURRENT PROFILES • VERIFY ADEQUATE COOLING OF CHANNEL SUBSYSTEM UNDER POWER GENERATING CONDITIONS
09-16/17-92	92-DVT-07	2	452	401	393	CONDUCTIVITY MEASURED	• SAME AS 92-DVT-06
09-17-92	92-DVT-08	1	291	288	283	213	• SAME AS 92-DVT-06 AND 92-DVT-07
09-22-92	92-DVT-09	4	469	463	432	CONDUCTIVITY MEASURED	• DETERMINE OPERATING CONDITIONS FOR DURATION TEST BASED ON SOW REQUIREMENTS • MAP PROCESS INPUTS TO DETERMINE CONDITIONS WHICH MINIMIZE CURRENT FLUCTUATIONS UNDER CONDUCTIVITY
09-23-92	92-DVT-10	3	651	646	632	469	• PROVIDE INITIAL EVALUATION OF POWER TRAIN PERFORMANCE AT RETROFIT OPERATING CONDITIONS • ACCUMULATE 50-75 HOURS AT POWER TO ACCESS INITIAL WEAR AND INFANT MORTALITY ON THE 1A4 CHANNEL • EVALUATE STEADY-STATE OPERATION OF FACILITY AND POWER TRAIN
09-24-92	92-DVT-11	3	304	299	281	86	• SAME AS 92-DVT-10
09-24-92	92-DVT-12	1	546	544	539	436	• SAME AS 92-DVT-10 AND 92-DVT-11

TABLE 7-4. INTEGRATED POWER TRAIN DESIGN VERIFICATION - TEST SUMMARY (CONTINUED)

DATE	TEST DESIGNATION	CFC STARTS	RUN TIME (Minutes)				POWER	TEST OBJECTIVES
			OFV	CFPC	CFC			
09-29-92	92-DVT-13	2	186	182	172		100	• OPERATE UNDER TYPICAL POWER GENERATION CONDITIONS TO EVALUATE LOCALIZED WEAR OBSERVED POST-TEST 92-DVT-12 • EVALUATE SLAG TANK/TAP PLUGGING
09-30-92	92-DVT-14	0	6	5	0		0	• OPERATE THERMALLY (NO POWER) TO EVALUATE NOZZLE HEAT FLUX SYMMETRY AND SLAGGING BEHAVIOR • DETERMINE STEADY-STATE HEAT FLUXES AND SLAGGING BEHAVIOR OF COMBUSTOR AND CHANNEL AT VARIOUS OPERATING CONDITIONS • DETERMINE CONDITIONS WHICH PRODUCE SMOOTHEST AND STEADIEST CONDUCTIVITY PROFILES • EVALUATE SLAG TANK/TAP PLUGGING
10-05-92	93-DVT-01	1	217	215	210		CONDUCTIVITY MEASURED	• SAME AS 92-DVT-14 • OPERATE WITHOUT IRON OXIDE TO DETERMINE EFFECT ON HEAT FLUX AND SLAGGING BEHAVIOR • EVALUATE IMPACT ON LOCALIZED WEAR OBSERVED IN NOZZLE REGION
10-05-92	93-DVT-02	2	192	189	178		CONDUCTIVITY MEASURED	• SAME AS 93-DVT-01
10-06-92	93-DVT-03	2	192	190	177		CONDUCTIVITY MEASURED	• DETERMINE STEADY-STATE HEAT FLUXES AND SLAGGING BEHAVIOR IN THE COMBUSTOR AND CHANNEL AT VARIOUS OPERATING CONDITIONS • DETERMINE THE HEAT FLUX AND SLAGGING BEHAVIOR IN THE NOZZLE BY FLOWING IRON OXIDE FROM THE EAST INJECTOR ONLY • EVALUATE IRON OXIDE DISPERSION FROM EAST INJECTOR

TABLE 7-4. INTEGRATED POWER TRAIN DESIGN VERIFICATION - TEST SUMMARY (CONTINUED)

DATE	TEST DESIGNATION	CFC STARTS	RUN TIME (Minutes)				TEST OBJECTIVES
			OFV	CFPC	CFC	POWER	
10-07-92	93-DVT-04	1	225	222	217	CONDUCTIVITY MEASURED	- DETERMINE THE HEAT FLUX AND SLAGGING BEHAVIOR IN THE NOZZLE REGION BY FLOWING IRON OXIDE FROM THE WEST INJECTOR ONLY - EVALUATE IRON OXIDE DISPERSION FROM WEST INJECTOR
10-07-92	93-DVT-05	2	364	361	353	CONDUCTIVITY MEASURED	- DETERMINE THE HEAT FLUX AND SLAGGING BEHAVIOR IN THE NOZZLE REGION BY FLOWING IRON OXIDE FROM THE EAST THEN WEST INJECTOR (INDIVIDUALLY) AT A REDUCED SLURRY MASS FLOW AND REDUCED COAXIAL N₂ FLOW - EVALUATE IRON OXIDE DISPERSION FROM THE INDIVIDUAL INJECTORS AT REDUCED SLURRY AND COAXIAL N₂ FLOW
10-08-92	93-DVT-06	1	189	185	178	CONDUCTIVITY MEASURED	- DETERMINE THE HEAT FLUX AND SLAGGING BEHAVIOR IN THE NOZZLE REGION BY FLOWING IRON OXIDE AT REDUCED SLURRY FLOW AND COAXIAL N₂ FLOW THROUGH BOTH INJECTORS SIMULTANEOUSLY - EVALUATE IRON OXIDE DISPERSION OF THE IRON OXIDE INJECTORS AT REDUCED FLOW - DETERMINE CONDITIONS WHICH PRODUCE THE SMOOTHEST AND STEADIEST CONDUCTIVITY PROFILES AND SYMMETRICAL HEAT FLUXES PRIOR TO PROCEEDING TO POWER - EVALUATE SLAG TANK/TAP OPERATION AT VARIOUS OPERATING CONDITIONS
10-09-92	93-DVT-07	1	225	223	220	150	- OPERATE UNDER POWER CONDITIONS WITH REDUCED IRON OXIDE/COAXIAL N₂ FLOW TO EVALUATE LOCALIZED NOZZLE WEAR OBSERVED - EVALUATE CATHODE WALL POLARIZATION WITH REDUCED IRON OXIDE FLOW

TABLE 7-4. INTEGRATED POWER TRAIN DESIGN VERIFICATION - TEST SUMMARY (CONTINUED)

DATE	TEST DESIGNATION	CFC STARTS	RUN TIME (Minutes)				TEST OBJECTIVES
			OFV	CFPC	CFC	POWER	
10-12-92	93-DVT-08	3	668	664	650	470	- EVALUATE EFFECT OF SMALLER DIAMETER SECOND STAGE OXYGEN INJECTORS ON NOZZLE HEAT FLUX AND SLAGGING BEHAVIOR (0.36 VS. 0.30" DIAMETER) - EVALUATE LOCALIZED NOZZLE WEAR AND CHANNEL POWER WITH SMALLER DIAMETER SECOND STAGE OXYGEN INJECTORS - DETERMINE PROCESS CONDITIONS WHICH PRODUCE THE STEADIEST CONDUCTIVITY PROFILES WITH SMALLER INJECTORS - ACCUMULATE 50-75 HOURS AT POWER TO ASSESS WEAR AND INFANT MORTALITY OF THE 1A4 CHANNEL
10-13-93	93-DVT-09	2	358	355	347	104	- SAME AS 93-DVT-08 - SECOND STAGE OXYGEN INJECTORS REDUCED FROM 0.30 TO 0.28 INCH DIAMETER
10-14-92	93-DVT-10	1	633	631	617	552	- DETERMINE THE HEAT FLUX AND SLAGGING BEHAVIOR IN THE COMBUSTOR AND CHANNEL BY VARYING THE SEED CARRIER GAS FLOW - DETERMINE CONDITIONS WHICH PRODUCE THE BEST CONDITIONS (LEAST FLUCTUATION) FOR DURATION POWER OUTPUT - EVALUATE STEADY-STATE HEAT FLUXES AND SLAGGING BEHAVIOR IN THE COMBUSTOR AND CHANNEL AT VARIOUS OPERATING CONDITIONS - EVALUATE SLAG TANK/TAP OPERATION BY VARYING THE SEED CARRIER GAS FLOW
10-15-92	93-DVT-11	1	161	160	155	109	ACCUMULATE 50-75 HOURS AT POWER TO ACCESS WEAR AND INFANT MORTALITY OF THE 1A4 CHANNEL

TABLE 7-4. INTEGRATED POWER TRAIN DESIGN VERIFICATION - TEST SUMMARY (CONTINUED)

DATE	TEST DESIGNATION	CFC STARTS	RUN TIME (Minutes)				TEST OBJECTIVES
			OFV	CFPC	CFC	POWER	
10-21-92	93-DVT-12	3	50	46	4	0	• DETERMINE BEST OPERATING CONDITIONS FOR 1.0 AND 1.5 MW_e POWER GENERATION • PRODUCE 1.5 MW_e POWER OUTPUT FOR 1-2 HOURS, ADJUST CONDITIONS FOR 1.0 MW_e POWER OUTPUT • EVALUATE SLAG REJECTION BEHAVIOR WITH SLAG NECK RING INSTALLED • ACCUMULATE 50 TO 75 HOURS AT POWER TO ASSESS WEAR AND INFANT MORTALITY OF THE 1A4 CHANNEL
10-22-92	93-DVT-13	2	295	293	286	197	• SAME AS 93-DVT-12
10-26-92	93-DVT-14	1	178	173	168	84	• SAME AS 93-DVT-12 AND 93-DVT-13 • EVALUATE THE IMPACT OF SEED CARRIER GAS ON COMBUSTOR AND CHANNEL PERFORMANCE
10-27-92	93-DVT-15	3	329	325	312	148	• SAME AS 93-DVT-14 • EVALUATE PINTLE-TYPE SEED INJECTOR ON COMBUSTOR AND CHANNEL PERFORMANCE

**TABLE 7-5. INTEGRATED POWER TRAIN DESIGN VERIFICATION
NOMINAL TEST CONDITIONS**

DATE	TEST DESIGNATION	PREHEAT (°F)	MW_t	PHI 1	PHI 2	N/O	%K	ADDITIVES (lbm/min)
09-15-92	92-DVT-06	2700	50	0.55	0.90	0.70	1.7	4.0
09-17-92	92-DVT-07	2700	50	0.55	0.90	0.70	1.7	4.0
		2700	50	0.55	0.90	0.80	1.7	4.0
09-17-92	92-DVT-08	2700	50	0.55	0.90	0.80	1.7	4.0
		2700	50	0.55	0.90	0.70	1.7	4.0
		2700	50	0.55	0.90	0.75	1.7	4.0
09-22-92	92-DVT-09	2700	50	0.55	0.90	0.70	2.0	4.0
		2900	50	0.55	0.90	0.70	2.0	4.0
		2700	50	0.55	0.95	0.70	2.0	4.0
		2700	50	0.55	0.95	0.75	2.0	4.0
		2700	50	0.55	0.95	0.80	2.0	4.0
		2700	50	0.55	0.90	0.75	2.0	4.0
		2700	50	0.57	0.90	0.75	2.0	4.0
		2700	50	0.57	0.92	0.70	2.0	4.0
		2700	50	0.55	0.90	0.65	2.0	4.0
09-23-92	92-DVT-10	2700	50	0.55	0.95	0.80	2.0	4.0
		2700	50	0.57	0.92	0.75	2.0	4.0
		2700	50	0.55	0.95	0.83	2.0	4.0
09-24-92	92-DVT-11	2700	50	0.55	0.95	0.83	2.0	4.0
09-24-92	92-DVT-12	2700	50	0.57	0.95	0.78	2.0	4.0
		2700	50	0.57	0.95	0.80	2.0	4.0
09-29/30-92	92-DVT-13	2700	50	0.57	0.95	0.80	2.0	4.0
09-30-92	92-DVT-14	2700	10	N/A	N/A	N/A	N/A	N/A
10-05-92	93-DVT-01	2900	50	0.55	0.90	0.70	2.0	0
		2900	50	0.55	0.90	0.80	2.0	0
10-05-92	93-DVT-02	2900	50	0.55	0.90	0.80	2.0	7
10-06-92	93-DVT-03	2900	50	0.55	0.90	0.80	2.0	2.0(E)
10-07-92	93-DVT-04	2900	50	0.55	0.90	0.80	2.0	2.0(W)

**TABLE 7-5. INTEGRATED POWER TRAIN DESIGN VERIFICATION
NOMINAL TEST CONDITIONS (CONTINUED)**

DATE	TEST DESIGNATION	PREHEAT (°F)	MW_t	PHI 1	PHI 2	N/O	%K	ADDITIVES (lbm/min)
10-07-92	93-DVT-05	2900	50	0.58	0.90	0.80	2.0	1.2(E/W)
10-08-92	93-DVT-06	2900	50	0.60	0.90	0.80	2.0	2.5
		2900	50	0.60	0.90	0.75	2.0	2.5
		2900	50	0.58	0.90	0.75	2.0	2.5
		2900	50	0.58	0.90	0.75	2.0	2.5
10-09-92	93-DVT-07	2900	50	0.58	0.90	0.75	2.0	2.5
		2900	50	0.58	0.90	0.75	2.0	3.0
		2900	50	0.58	0.95	0.75	2.0	3.0
		2900	50	0.58	0.95	0.75	2.0	4.0
10-13-92	93-DVT-08	2900	50	0.58	0.90	0.80	2.0	4.0
		2900	50	0.58	0.95	0.75	2.0	4.0
		2900	50	0.58	0.95	0.80	2.0	4.0
		2900	50	0.55	0.95	0.80	2.0	4.0
10-13-92	93-DVT-09	2900	50	0.58	0.90	0.80	2.0	4.0
		2900	50	0.58	0.95	0.80	2.0	4.0
10-14-92	93-DVT-10	2900	50	0.58	0.95	0.80	2.0	4.0
		2900	50	0.55	0.95	0.80	2.0	4.0
		2900	50	0.58	0.95	0.75	2.0	4.0
10-15-92	93-DVT-11	2900	50	0.58	0.95	0.80	2.0	4.0
		2900	50	0.58	0.95	0.75	2.0	4.0
10-21-92	93-DVT-12	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10-22-92	93-DVT-13	2900	50	0.55	0.95	0.70	2.0	4.0
		2900	50	0.58	0.95	0.80	2.0	4.0
		2900	50	0.58	0.95	0.70	2.0	4.0
10-26-92	93-DVT-14	2900	50	0.58	0.95	0.80	2.0	4.0
		2900	50	0.58	0.95	0.75	2.0	4.0
		2900	50	0.58	0.95	0.70	2.0	4.0
10-27-92	93-DVT-15	2900	50	0.58	0.95	0.75	2.0	4.0
		2900	50	0.58	0.95	0.70	2.0	4.0

**TABLE 7-6. INTEGRATED POWER TRAIN DESIGN VERIFICATION TESTS
SUMMARY OF TEST RESULTS AND FACILITY OPERATION**

DATE	TEST DESIGNATION	QUICK LOOK TEST RESULTS
09-15-92	92-DVT-06	TEST NOT SUCCESSFUL. PROBLEMS WITH SEED AND COAL FLOW CAUSED SYSTEM TRIPS AND/OR SHUTDOWNS. SHORT DURATION TEST COMPLETED TO ASSESS FACILITY MODIFICATIONS. CONDUCTIVITY MEASURED. NO INTERNAL INSPECTION PERFORMED. NO EXTERNAL PROBLEMS (HOT SPOTS, WATER LEAKS) NOTED.
09-16/17-92	92-DVT-07	TEST PARTIALLY SUCCESSFUL. CONDUCTIVITY MEASURED AT CONDITIONS ANTICIPATED FOR POWER GENERATION. SYSTEM CONFIGURED FOR POWER GENERATION BUT INVERTER WOULD NOT OPERATE DUE TO A BROKEN POWER SUPPLY. COMBUSTOR AND CHANNEL ARE WELL SLAGGED WITH NO INTERNAL WATER LEAKS. SLAG REJECTION SYSTEM OPERATED CONTINUOUSLY IN AUTOMATIC MODE WITHOUT PROBLEMS.
09-17-92	92-DVT-08	TEST SUCCESSFUL. FIRST POWER GENERATION TEST WITH PROTOTYPICAL HARDWARE. INVERTER/MAGNET AT APPROXIMATELY 5.5 kV AND 3 TESLA. COMBUSTOR CONDITIONS VARIED TO MAP POWER OUTPUT. POWER TAKEOFF AND EXTERNAL BLEED RESISTOR TOPOLOGY ACHIEVED DESIRED CURRENT AND VOLTAGE PROFILES. IRON OXIDE ELIMINATED CATHODE WALL POLARIZATION BUT SOME HIGH VOLTAGE GAPS EXIST. POWER FLUCTUATIONS OBSERVED. COOLING OF CHANNEL SUBSYSTEM ADEQUATE UNDER POWER CONDITIONS. SLAG REJECTION SYSTEM OPERATED CONTINUOUSLY IN AUTOMATIC MODE WITHOUT PROBLEMS. TEST TERMINATED WITH EMERGENCY SHUTDOWN DUE TO AN INVERTER TRIP CAUSING THE VOLTAGE LIMITING DEVICE TO ACTIVATE. COMBUSTOR SLAG IS THICK AND CRAGGY AND NOT GOOD QUALITY. NO CFPC FOULING OR INTERNAL/EXTERNAL WATER LEAKS.
09-22-92	92-DVT-09	TEST PARTIALLY SUCCESSFUL. COMBUSTOR OPERATING CONDITIONS VARIED TO DETERMINE CONDITIONS WHICH PRODUCE THE MINIMUM FLUCTUATION IN CONDUCTIVITY CURRENT. CFPC PREHEAT, FIRST AND SECOND STAGE STOICHIOMETRY, AND OXYGEN ENRICHMENT VARIED. SECOND STAGE STOICHIOMETRY HAD THE GREATEST EFFECT ON THE FLUCTUATION IN CONDUCTIVITY CURRENT. PHI 2 = 0.95 HAD LESS FLUCTUATION THAN PHI 2 = 0.90. TEST TERMINATED WITH EMERGENCY SHUTDOWN DUE TO AN INVERTER CONTROL SYSTEM MALFUNCTION CAUSING THE VOLTAGE LIMITING DEVICE TO ACTIVATE. NO INTERNAL INSPECTION OF THE HARDWARE PERFORMED.
09-23-92	92-DVT-10	TEST PARTIALLY SUCCESSFUL. POWER GENERATED AT CONDITIONS DETERMINED FROM 92-DVT-09. INVERTER/MAGNET AT APPROXIMATELY 5.5 kV AND 3 TESLA. MAGNET/INVERTER SECURED DURING PERIOD OF UNSTEADY SEED FLOW AND RE-ESTABLISHED WHEN FLOW STABILIZED. SEVERE LOAD CURRENT FLUCTUATIONS CAUSED AN INVERTER TRIP WHICH WAS EVENTUALLY TRACED TO PLUGGING OF THE SLAG REJECTION SYSTEM. POST-TEST INSPECTION REVEALED THE SLAG TANK COMPLETELY PLUGGED FROM THE GRINDER UP TO THE SLAG TAP, SUGGESTING THE PLUG OCCURRED AT THE GRINDER PREVENTING THE REJECTION OF SLAG. THE CAUSE OF THE PLUG WAS LARGE CHUNKS WHICH APPEAR TO HAVE OCCURRED DURING SHUTDOWN FROM THE PREVIOUS TEST. DUE TO ESS, THERE WAS A SIGNIFICANT AMOUNT OF SLAG STRIPPING IN THE COMBUSTOR AND CHANNEL. NO FOULING OF THE CFPC.

**TABLE 7-6. INTEGRATED POWER TRAIN DESIGN VERIFICATION TESTS
SUMMARY OF TEST RESULTS AND FACILITY OPERATION (CONTINUED)**

DATE	TEST DESIGNATION	QUICK LOOK TEST RESULTS
09-24-92	92-DVT-11	TEST PARTIALLY SUCCESSFUL. POWER GENERATED AT CONDITIONS WHICH SIMULATE "RETROFIT" ELECTRICAL STRESSES. VOLTAGE AND CURRENT PROFILES ARE WITHIN EXPECTED VALUES. INVERTER/MAGNET AT APPROXIMATELY 5.5 kV AND 3 TESLA. TEST TERMINATED WITH A CONTROLLED SHUTDOWN TO INVESTIGATE SLAG REJECTION SYSTEM. SLAG REMOVAL SCREW CONVEYOR NOT OPERATING. NO INTERNAL INSPECTION OF THE HARDWARE PERFORMED.
09-24-92	92-DVT-12	TEST SUCCESSFUL. POWER GENERATED FOR OVER SEVEN HOURS CONTINUOUSLY, AT CONDITIONS WHICH SIMULATE "RETROFIT" ELECTRICAL STRESSES. INVERTER/MAGNET AT APPROXIMATELY 5.5 kV AND 3 TESLA. TEST TERMINATED WITH A NORMAL SHUTDOWN SEQUENCE WHEN SLAG REJECTION SYSTEM READING INDICATED PLUGGING AND LITTLE OR NO SLAG REJECTION ON-LINE. POST-TEST INSPECTION REVEALED THE SLAG TANK PLUGGED FROM THE GRINDER TO NEAR THE SLAG TAP. SLAG REJECTION RATES DECREASED AS THE TEST PROGRESSED INDICATING A PARTIAL PLUG FROM THE TEST START WHICH GOT PROGRESSIVELY WORSE OR A PLUG IN THE GRINDER ON-LINE. LARGE CHUNKS EVIDENT ON TOP OF GRINDER. CHUNKS SUSPECTED FROM PREVIOUS TEST SHUTDOWN. INSPECTION OF THE CHANNEL REVEALED LOCALIZED EROSION IN THE SUPERSONIC NOZZLE ON THE RIGHT SIDEWALL EXTENDING APPROXIMATELY 20 INCHES FROM THE NOZZLE THROAT. THE WEAR APPEARS LIKE A GROOVE AT THE INTERFACE BETWEEN THE CATHODE ENDBAR (HOUSE PIECE) AND THE CATHODE MIDBAR. THE WEAR IS MORE PREDOMINANT ON THE MIDBAR. THERE IS ALSO EVIDENCE OF WEAR IN THE FIRST SEVERAL CATHODES DOWNSTREAM OF THE NOZZLE THROAT. THE WEAR IS PRIMARILY ON THE ALUMINUM NITRIDE INSULATOR ADJACENT TO THE SIDEWALL. THESE AREAS ARE NOT IN THE ELECTRICALLY LOADED REGION OF THE CHANNEL BUT ARE EXPOSED TO CIRCULATING CURRENTS (FARADAY AND AXIALLY) DUE TO THE MAGNETIC FRINGE FIELD. ASYMMETRICAL HEAT FLUXES OBSERVED IN THE NOZZLE (SIDEWALL) WITH THE LEFT SIDE LOWER THAN THE RIGHT SIDE.
09-29-92	92-DVT-13	TEST SUCCESSFUL. SHORT POWER GENERATION TEST TO EVALUATE THE ASYMMETRY IN NOZZLE HEAT FLUX AND OBSERVED LOCALIZED WEAR. INVERTER/MAGNET AT 5.0 kV AND 3 TESLA TO PROVIDE A HIGHER AND MORE STEADY LOAD CURRENT. THE TEST WAS TERMINATED WITH AN EMERGENCY SHUTDOWN DUE TO A LOSS OF FACILITY SITE INSTRUMENT AIR. THE LOCALIZED WEAR IN THE NOZZLE REGION APPEARS SLIGHTLY WORSE WITH MORE EVIDENCE OF EROSION OF THE CATHODE ENDBAR TIP (HOUSE PIECE). CHUNKS OF SLAG WERE FOUND BRIDGED ACROSS THE GRINDER THAT PROBABLY RESULTED FROM THE PREVIOUS TEST SEGMENT SHUTDOWN. THE CHUNKS APPEAR TO SLOUGH OFF THE SLAG NECK AFTER SHUTDOWN.
09-30-92	92-DVT-14	TEST NOT SUCCESSFUL. TEST TERMINATED BEFORE FULL COMBUSTOR OPERATION WHEN FLUCTUATIONS IN OXYGEN FLOW WERE TRACED TO THE VAPORIZER NOT ACTIVATED. NO INTERNAL INSPECTION OF THE HARDWARE PERFORMED.
10-05-92	93-DVT-01	TEST SUCCESSFUL. OPERATED OVER EXPECTED RANGE OF COMBUSTOR OPERATION WITHOUT IRON OXIDE. NO NOTICEABLE INCREASE IN LOCALIZED EROSION IN NOZZLE. ASYMMETRY IN HEAT FLUX CONTINUED. SLAG REJECTION SYSTEM GRINDER CLEANED PRIOR TO TEST. POST-TEST NO EVIDENCE OF PLUGGING OR CHUNKS. SLAG GROWTHS OBSERVED IN SLAG TAP REGION.

**TABLE 7-6. INTEGRATED POWER TRAIN DESIGN VERIFICATION TESTS
SUMMARY OF TEST RESULTS AND FACILITY OPERATION (CONTINUED)**

QUICK LOOK TEST RESULTS		
DATE	TEST DESIGNATION	
10-05-92	93-DVT-02	TEST SUCCESSFUL. OPERATED POWER TRAIN WITHOUT IRON OXIDE. ASYMMETRY IN NOZZLE HEAT FLUX CONTINUED WITH NO APPARENT CORRELATION WITH IRON OXIDE. NO NOTICEABLE CHANGE IN LOCALIZED NOZZLE WEAR. SLAG TANK PLUGGED AT GRINDER WITH LARGE CHUNKS. GOOD SLAG COVERAGE IN COMBUSTOR AND CHANNEL.
10-06-92	93-DVT-03	TEST SUCCESSFUL. IRON OXIDE INJECTED ON EAST (RIGHT) WALL. HAD NO IMPACT ON HEAT FLUX ASYMMETRY. LEFT SIDE NOZZLE STILL LOWER THAN RIGHT. BASED ON SLAG COLOR (IRON OXIDE DOPED SLAG IS RED IN COLOR), THE IRON OXIDE COVERAGE (DISPERSION) IS GOOD ALONG FORWARD CATHODE WALL AND PARTIALLY UP BOTH SIDEWALLS. COVERAGE APPEARS SYMMETRIC DESPITE INJECTION FROM ONLY ONE SIDE. OVERALL SLAG COVERAGE IS GOOD BUT SLAG THICKNESS IS THICKER THAN OPTIMUM. SECOND STAGE IS WELL SLAGGED ENTERING THE CHANNEL. CHANNEL LOOKS WELL SLAGGED EXCEPT IN FORWARD RIGHT SIDEWALL (REGION OF WEAR). THE EROSION APPEARS TO BE UNCHANGED FROM PREVIOUS INSPECTIONS. THERE ARE LARGE CHUNKS ABOVE THE SLAG GRINDER, BRIDGING THE FUNNEL WHICH APPEAR TO HAVE FALLEN FROM THE SLAG TAP AFTER SHUTDOWN.
10-06-92	93-DVT-04	TEST SUCCESSFUL. IRON OXIDE INJECTED ON WEST (LEFT) WALL. HAD NO IMPACT ON HEAT FLUX ASYMMETRY. IRON OXIDE DISPERSION IS GOOD. RIGHT SIDEWALL HAS A GREATER CONCENTRATION (BASED ON COLOR) IN THE NOZZLE REGION BUT OVERALL THE SYMMETRY OBSERVED IN 93-DVT-03 CONTINUES. CONFIGURATION OF THE RIGHT SIDE INJECTOR MAY BE CAUSE OF HIGHER RIGHT SIDE CONCENTRATION. THE NOZZLE EROSION APPEARS UNCHANGED FROM PREVIOUS INSPECTIONS. THERE ARE MORE CHUNKS ON TOP OF THE GRINDER WHICH FELL FROM THE SLAG TAP POST-TEST. OVERALL SLAG COVERAGE NOT GOOD. SLAG IS THICK AND NOT GLASSY.
10-07-92	93-DVT-05	TEST SUCCESSFUL. REDUCED IRON OXIDE MASS FLOW AND COAXIAL N ₂ FLOW DID NOT SIGNIFICANTLY CHANGE THE OBSERVED DISPERSION OR COVERAGE, ALTHOUGH THE IRON OXIDE WAS NOT AS HIGH UP ON THE SIDEWALLS AS WITH PREVIOUS TESTS. THE HEAT FLUX ASYMMETRY WAS UNCHANGED. OVERALL THE COMBUSTOR WAS WELL SLAGGED FROM THE HEADEND THROUGH THE SECOND STAGE. CHUNKS WERE AGAIN OBSERVED ON THE GRINDER POST-TEST, WHICH FELL FROM THE SLAG TAP AFTER SHUTDOWN.
10-08-92	93-DVT-06	TEST SUCCESSFUL. REDUCED IRON OXIDE FLOW AND COAXIAL N ₂ FLOW DID NOT CHANGE FROM PREVIOUS IRON OXIDE TESTS. GENERALLY THE IRON OXIDE COVERAGE IS UNIFORM, ALTHOUGH HIGHER ON THE SIDEWALLS THAN DESIRED. NOZZLE HEAT FLUX ASYMMETRY STILL EVIDENT BUT OCCASIONALLY THE VALUES CONVERGE WITH THE LEFT SIDE INCREASING TO THE VALUE OF THE RIGHT WALL. ALTHOUGH DIFFICULT TO ASSESS, THE EROSION IN THE NOZZLE REGION HAS NOT SIGNIFICANTLY INCREASED. CHUNKS WERE AGAIN OBSERVED ON THE GRINDER POST-TEST. AS WITH 93-DVT-05, THE CHUNKS FELL FROM THE SLAG TAP AFTER SHUTDOWN.

**TABLE 7-6. INTEGRATED POWER TRAIN DESIGN VERIFICATION TESTS
SUMMARY OF TEST RESULTS AND FACILITY OPERATION (CONTINUED)**

DATE	TEST DESIGNATION	QUICK LOOK TEST RESULTS
10-09-92	93-DVT-07	TEST PARTIALLY SUCCESSFUL. REDUCED IRON OXIDE MASS FLOW NOT SUFFICIENT TO ELIMINATE CATHODE WALL POLARIZATION. INVERTER/MAGNET AT 5.0 kV AND 3.0 TESLA. TEST WAS TERMINATED WITH A NORMAL SHUTDOWN SEQUENCE DUE TO ERRATIC SEED FLOW. NOZZLE HEAT FLUX ASYMMETRY STILL EVIDENT ALTHOUGH THE VALUES WOULD CONVERGE PERIODICALLY AND GENERALLY WERE CLOSER IN VALUE THROUGHOUT THE TEST. OVERALL SLAG COVERAGE IN THE COMBUSTOR WAS EXCELLENT, BLACK AND GLASSY. NO EVIDENCE OF CFPC FOULING. AGAIN CHUNKS OBSERVED ON TOP OF GRINDER FROM SHUTDOWN. SECOND STAGE AND CHANNEL ARE EVENLY AND WELL SLAGGED. RIGHT NOZZLE REGION IS UNSLAGGED. LOCAL EROSION IS NOT NOTICEABLY CHANGED FROM PREVIOUS OBSERVATIONS.
10-12-92	93-DVT-08	TEST SUCCESSFUL. POWER GENERATED FOR NEARLY EIGHT HOURS AT 5.0 kV AND 3 TESLA INVERTER/MAGNET SETTINGS. SMALLER DIAMETER OXYGEN INJECTORS DID NOT APPRECIABLY AFFECT THE POWER FLUCTUATIONS SINCE PHI 2 OF 0.95 CONTINUED TO BE SMOOTHER THAN PHI 2 OF 0.90. HEAT FLUXES OF THE LEFT AND RIGHT SIDEWALLS WERE SIMILAR DURING THE TEST. OVERALL SLAG COVERAGE IN THE COMBUSTOR WAS EXCELLENT. NO EVIDENCE OF CFPC FOULING. OVERALL CHANNEL SLAGGING APPEARS MORE UNIFORM BUT RIGHT NOZZLE REGION IS UNSLAGGED. IRON OXIDE COVERAGE IS UNIFORM AND EXTENDS UP BOTH SIDEWALLS 2 TO 3 INCHES. THE EROSION IS NOT NOTICEABLY CHANGED. NO EVIDENCE OF SLAG TANK BLOCKAGE POST-TEST.
10-13-92	93-DVT-09	TEST NOT SUCCESSFUL. POWER GENERATED FOR 1 1/2 HOURS BUT SEED FLUCTUATIONS OCCURRED THROUGHOUT THE TEST. TEST TERMINATED WITH EMERGENCY SHUTDOWN DUE TO AN INVERTER TRIP. DURING OPERATION WITHOUT SEED FLOW, THE SLAG DUMP NECK HEAT FLUX INDICATED THAT THE CHARACTERISTIC SLAG BUILDUP AND SLOUGHING DID NOT OCCUR. EROSION IN NOZZLE REGION DOES NOT APPEAR WORSE THAN PREVIOUS INSPECTIONS. NO SLAG CHUNKS ON GRINDER OR IN THE SLAG TAP REGION.
10-14-92	93-DVT-10	TEST SUCCESSFUL. POWER GENERATED FOR OVER NINE HOURS CONTINUOUSLY, AT CONDITIONS WHICH SIMULATE "RETROFIT" ELECTRICAL STRESSES. INVERTER/MAGNET AT 5.0 kV AND 3 TESLA. THERE WERE STEP CHANGES IN POWER OUTPUT WHICH REQUIRED ADJUSTMENTS IN COMBUSTOR CONDITIONS. INCREASING THE SEED OXYGEN FLOW RATE RESULTED IN A SLIGHT INCREASE IN THE MAGNITUDE AND A SIGNIFICANT INCREASE IN THE STABILITY OF THE SECOND STAGE AND NOZZLE HEAT FLUXES. THE TEST WAS TERMINATED BY AN EMERGENCY SHUTDOWN CAUSED BY A FAULTY COAL CARRIER GAS FLOW METER. THERE WAS AN UNIQUE SLAG GROWTH HANGING FROM THE SLAG NECK POST-TEST. THE SLAG EXTENDED FROM THE NECK TO THE SLAG TANK WATER AND SPREAD ACROSS THE WATER SURFACE. IT WEIGHED APPROXIMATELY 1500 POUNDS. THE GRINDER AND TANK WERE CLEAR. THE SECOND STAGE AND CHANNEL WERE EVENLY SLAGGED ALTHOUGH THE RIGHT SIDE NOZZLE REGION WAS UNSLAGGED. THERE MAY BE AN INCREASE IN NOZZLE EROSION IN THE CHANNEL, BUT THIS IS DIFFICULT TO SUBSTANTIATE OR QUANTIFY. THERE MAY BE UNDERCUTTING ON THE CATHODE ENDBAR NEAR THE CATHODE-SIDEWALL INTERFACE.

**TABLE 7-6. INTEGRATED POWER TRAIN DESIGN VERIFICATION TESTS
SUMMARY OF TEST RESULTS AND FACILITY OPERATION (CONTINUED)**

DATE	TEST DESIGNATION	QUICK LOOK TEST RESULTS
10-15-92	93-DVT-11	TEST PARTIALLY SUCCESSFUL. TEST TERMINATED USING A NORMAL SHUT DOWN SEQUENCE DUE TO LACK OF POTASSIUM SEED. GOOD SLAG COVERAGE IN COMBUSTOR. NO CHUNKS ON SLAG GRINDER OR SLAG TAP BLOCKAGE. NO CHANGE IN NOZZLE EROSION.
10-21-92	93-DVT-12	TEST NOT SUCCESSFUL. NO STEADY-STATE TESTING. HIGH QUENCH DUCT TEMPERATURES AND POWER FLUCTUATIONS AT THE MONTANA POWER COMPANY SUBSTATION CAUSED TEST ABORTS.
10-22-92	93-DVT-13	TEST PARTIALLY SUCCESSFUL. POWER GENERATED AT NOMINAL STATEMENT OF WORK POWER LEVEL (1.5 MW _e) AND AT SIMULATED "RETROFIT" ELECTRICAL CONDITIONS (1.0 MW _e). POWER OUTPUT VARIED DURING STEADY-STATE OPERATION. SLAG NECK MODIFICATION AIMED AT ELIMINATING POST-TEST CHUNKS AND ON-LINE SLOUGHING WAS INCONCLUSIVE. SLAG CHUNKS OBSERVED ON GRINDER AND SLAG NECK HEAT FLUX INDICATED SLOUGHING. NO CHANGE IN CHANNEL/NOZZLE PERFORMANCE OR OBSERVED WEAR.
10-26-92	93-DVT-14	TEST PARTIALLY SUCCESSFUL. POWER OUTPUT WAS BELOW EXPECTATION. COMBUSTOR WAS RUNNING "COLD" POSSIBLY DUE TO COAL FLUCTUATIONS AND COAL MOISTURE. DECREASE IN SEED OXYGEN FLOW CAUSED AN INCREASE IN THE SLAG DUMP NECK HEAT FLUX AND APPEARED TO MINIMIZE THE CHARACTERISTIC SLAG BUILDUP/SLOUGHING BEHAVIOR. DECREASE IN SEED OXYGEN FLOW DID NOT AFFECT SECOND STAGE AND NOZZLE HEAT FLUX WITH ANY TREND. NO CHANGE IN CHANNEL/NOZZLE EROSION.
10-27-92	93-DVT-15	TEST SUCCESSFUL. DVT TEST SERIES CONCLUDED, OVER 50 POWER HOURS ACCUMULATED. SEED PINTLE INJECTOR PERFORMED WITH MIXED RESULTS. HEAT LOSSES WERE HIGHER IN BAFFLE AND EXIT SECTIONS. NO CHUNKS ON SLAG GRINDER OR EVIDENCE OF SLOUGHING. SEED NOT CARRYING THROUGH BAFFLE TO SLAG TAP. RESULTS ON POWER GENERATION INCONCLUSIVE DUE TO COAL FEED FLUCTUATIONS. DETAILED INSPECTIONS DELAYED UNTIL HARDWARE DISASSEMBLY.

7.1.6 Design Verification Test Results

The twenty-four tests which comprised the design verification test series resulted in two unexpected results: 1) localized erosion in the supersonic nozzle along the right sidewall, and 2) periodic plugging of the slag rejector system. As a result of these findings, the test series focused on understanding the root cause of these performance issues and resulted in four distinct test groups as outlined below (specific test objectives and results can be obtained from Tables 7-4 and 7-6, respectively):

- 1) 92-DVT-06 through 92-DVT-13 - Determine the best operating conditions for duration testing. Accumulate 50 to 75 hours of electrical operation to evaluate "infant mortality" of the channel gas-side elements and determine the adequacy of the electrical configuration to support duration testing.
- 2) 92-DVT-14 through 93-DVT-07 - Evaluate iron oxide injection and impact/role in the localized nozzle erosion.
- 3) 93-DVT-08 and 93-DVT-09 - Evaluate the second stage oxygen injection configuration and impact/role in the localized nozzle erosion.
- 4) 93-DVT-10 through 93-DVT-15 - Evaluate potassium seed injection and impact/role in the localized nozzle erosion and the periodic plugging of the slag tank. Evaluate the effect of operating conditions and hardware modifications on the behavior of the slag rejection system.

The initial DVT tests (92-DVT-06 through 92-DVT-13) of the integrated power train were focused on determining the best operating conditions for the duration testing based on Statement of Work requirements and on accumulating 50 to 75 hours of electrical operation. This latter objective would allow an initial evaluation of gas-side wear characteristics and "infant mortality" of the brazed elements. Specific results from this portion of the DVT series were:

- The power takeoff (PTO) electrical topology resulted in acceptable voltage and current profiles and were consistent with model predictions by the Busek Co.
- Electrical isolation of the combustor and slag rejection system, and the electrical isolation of the LPCS were excellent.
- Interelectrode voltages and electrode currents were within design limits.
- No evidence of braze failures, distortions or water leaks in the gas-side elements.
- The fluctuation in the power output at steady-state conditions was higher than expected, particularly at lower values of global equivalence ratio.
- The slag rejection system periodically plugged from large slag chunks which would not pass through the grinder.
- Asymmetry in the left and right sidewall nozzle heat fluxes was observed with the right sidewall higher than the left sidewall.
- After approximately 70 thermal hours and 20 electrical hours, localized wear in the supersonic nozzle region along the right sidewall was observed.

As a result of the localized wear observation, the focus of the DVT series shifted to understanding and eliminating the cause of the wear. The following were considered as possible causes:

- 1) Internal water leak
- 2) Flow nonuniformity from the second stage
- 3) Mechanical erosion from iron oxide
- 4) Chemical attack
- 5) Electro-chemical corrosion

Items 1, 2 and 3 could be evaluated "on-line" and specific tests were developed in order to determine the impact of each item on the observed nozzle erosion. Items 4 and 5 could not be evaluated until the channel was removed for careful inspection. The following paragraphs describe each of these issues in more detail.

The possibility of an internal water leak was investigated by performing a careful inspection of the channel with the facility primary cooling water (PCW) system under full pressure. No evidence of leaking or wetting was observed.

Flow nonuniformity of incomplete mixing was considered a possible cause of the observed asymmetric heat fluxes on the left and right sidewalls in the nozzle region. Incomplete mixing/combustion of the oxidizer in the second stage could result in a region of high oxygen partial pressure and/or combustion in the channel which could be localized along one wall. The incomplete mixing could be caused by blocked or misdirected oxygen jets (due to slag interference) and/or low momentum flux ratio of the oxygen jets to the primary axial flow. Since tungsten is susceptible to oxidation at temperatures greater than 1000°F, a localized high oxygen partial pressure coupled with combustion at or along the right wall could cause the observed heat flux asymmetry as well as contribute to the erosion/corrosion. This would also be consistent with the wear occurring at the corners and peaks of the tungsten caps which are the most difficult areas to cool.

Erosion and/or corrosion from the iron oxide injection was also considered a possible cause of the localized wear. In previous testing, erosion from iron oxide injection has been observed to occur quite rapidly. However, it usually initiates at the point of injection. Iron oxide can also contribute to electro-chemical corrosion due to its ability to increase the slag layer conductivity and resulting leakage current. When the distribution of iron oxide in the slag layer is nonuniform, localized erosion/corrosion can occur.

Chemical attack was also considered a possible cause of the localized wear and will be further investigated when the channel is inspected after the DVT series and the affected elements are removed for analyses. As indicated previously, tungsten is susceptible to oxidation at elevated temperature and reacts with KOH at elevated temperature. Elemental iron, either naturally occurring in the slag or through iron oxide injection, is an aggressive species (fluxing agent) for chemical attack. Chemical attack in conjunction with some other mechanism could cause the localized wear observed.

Electro-chemical corrosion was also considered. The elements are in a low magnetic field with low Faraday voltages which are unlikely to result in sufficient leakage current to cause the wear. Axial leakage driven by the Hall potential, however, could, in conjunction with other wear mechanisms, cause the localized erosion/corrosion observed.

Tests 92-DVT-14 through 93-DVT-07 evaluated the role of iron oxide on the local nozzle erosion. The tests were conducted without iron oxide, with injection from one side (left or right), with reduced slurry mass flow rate, and with reduced coaxial N₂ gas flow rate. The results are qualitative in nature. The parameters varied did not impact the heat flux asymmetry in the nozzle region. Post-test observations indicated that the iron oxide slurry was uniformly dispersed on the cathode and both sidewalls. There was no evidence of direct impingement on the right sidewall in the region of localized wear. During one test, there did appear to be a slightly darker red color on the right sidewall at the throat which may indicate a heavier concentration of iron oxide in this region. However, in general, the iron oxide was uniformly dispersed and extended 2 to 3 inches (from the cathode) up both sidewalls in the nozzle region. Reducing the slurry mass flow and/or the coaxial N₂ gas flow did not have a significant impact on the dispersion pattern. The iron oxide slurry flow rate was increased to nominal levels during 93-DVT-07 since the reduced flow rate was insufficient to eliminate cathode wall polarization. The results of this series of tests indicated that iron oxide was uniformly distributed and hence, by itself, was probably not the cause of the localized erosion/corrosion on the right sidewall. However, since the right sidewall was not slagging, it was more susceptible to erosion/corrosion caused by the iron oxide and/or combustion of the oil slurry.

Tests 93-DVT-08 and 93-DVT-09 evaluated the role of the second stage of the combustor on the nozzle heat flux asymmetry and on localized nozzle erosion. The tests evaluated the impact of reduced oxygen injector jet diameters on the second stage and nozzle heat fluxes. The reduction in oxygen jet diameters increases the momentum flux ratio of the second stage oxidizer to the primary axial flow. Past experience suggests a potential to improve the overall mixing process within the second stage with higher momentum flux ratios. The injector diameters were reduced from 0.360-inch diameters to 0.300-inch diameters to a final value of 0.280-inch diameters. In general, there was a reduction in the nozzle heat flux asymmetry observed between the left and right wall when the smaller diameter jets were utilized. The left wall heat flux increased to approximately the same magnitude as the right wall. Post-test observations indicated that the supersonic nozzle region on the right sidewall continued to be unslagged. The results of these tests indicated that second stage mixing may be playing a role in the observed heat flux asymmetry. Surprising, however, power output, which has historically been a sensitive diagnostic for second stage mixing and flow nonuniformity, did not change.

Tests 93-DVT-10 through 93-DVT-15 evaluated the role of seed injection on the second stage and nozzle heat fluxes. In addition, it appeared that seed played a role in the formation of the slag clinkers which occasionally obstructed the grinder. Specifically, during 93-DVT-09, it was observed that the characteristic slag buildup and sloughing did not occur when seed was not flowing.

Increasing the seed oxygen flow rate resulted in a slight increase in the magnitude and a significant increase in the stability of the second stage and nozzle heat fluxes. Decreasing the seed oxygen flow rate resulted in an increase in the slag dump heat flux, since seed was no longer injected at a high enough velocity to flow through the baffle.

The parameters evaluated included oxygen carrier gas mass flow, seed mass flow, and a pintle-type seed injector. In addition, the slag tap region did not exhibit the characteristic slag buildup/sloughing behavior. The decrease in seed oxygen did not result in any noticeable trend in the second stage and nozzle heat fluxes. The impact of the pintle-type seed injector was inconclusive, primarily due to process flow fluctuations during test 93-DVT-15. The results of these tests indicated that seed may play a role in both the second stage and nozzle slagging behavior as well as the slag tap slagging behavior. Additional tests should be performed to confirm these results.

For 93-DVT-12 through 93-DVT-15, an Inconel ring was installed in the slag dump neck to reduce the diameter of the slag tap from 14 to 12 inches. The purpose of the ring was to provide a "knife-edge" to prevent the slag from attaching to the sidewalls of the slag tap as well as to simulate the neck diameter utilized during workhorse testing. It was suspected that the slag clinkers which were occasionally plugging the grinder were caused by slag growths attached to the sidewalls of the tap which would fall off at shutdown of the combustor or "slough-off" on-line. Evidence of this sloughing has been observed based on the slag dump neck heat fluxes. The slag dump neck ring did mitigate, but not eliminate, both sloughing and the frequency of chunks found on the grinder. Further investigations into both precombustor/slugging stage combustor performance is ongoing to understand the slag rejection system problems.

7.2 FACILITY PREPARATIONS FOR MHD ITC POWER TRAIN TESTING

In preparation for the channel hot-fire checkout test series, the integrated power train DVT test series, and long duration testing, several facility modifications were made.

7.2.1 Low Pressure Cooling Subsystem (LPCS)

The stainless steel piping system on the LPCS was reworked to meet ASME B31.1 piping code requirements. Several of the pipe segments were replaced and the work was finished prior to the start of the DVT test series.

Periodic maintenance was performed on the LPCS following the DVT test series. The pumps, instrumentation, and wiring were inspected and no problems were detected.

The facility control power to the LPCS main pumps is being modified to prevent loss of pump power during operation. Pump power was lost twice during DVT testing.

7.2.2 Primary Cooling Water (PCW) System

Water chemistry controls and on-line chemistry measurement were installed and were fully operational for the DVT test series.

7.2.3 Coal System

During previous reporting periods, major modifications were made to the coal feed system, including the removal of the screen in the primary injector vessel and the installation of a new filter in the SWECO screen. These modifications were fully operational for the DVT test series. Removal of the primary injector screen eliminated the plugging problems experienced during the combustor hot-fire checkout test series.

Toward the end of the DVT test series, the coal feed load cell behaved erratically. The load cell will be recalibrated in preparation for the next test series.

7.2.4 Iron Oxide System

The iron oxide system operated successfully throughout the DVT test series. The only problem occurred when the iron oxide injectors were accidentally inserted into the gas stream, leading to plugging problems, melting of the tip, and possibly poor iron oxide distribution for those tests.

The iron oxide plunger was not installed for the DVT series and will not be installed for the next test series. The next test series will focus on evaluating different locations for iron oxide injection; thus there are no plans to install the plunger at this time.

7.2.5 Oxygen System

Oxygen pump prime and/or pump vibration caused shutdown of tests (or delayed test starts) on occasion. After the DVT series, the oxygen pumps were overhauled.

For the next series of tests, the second stage oxygen manifold will be split into left and right manifolds with separate flow measurements to provide a measurement of flow to each side of the second stage.

7.2.6 Emissions Compliance

The ammonia injection system for NO_x reduction was completed prior to the start of the DVT series. The entire emissions compliance system is operational.

7.2.7 Slag Removal System

A new sump pump is being installed in the pit of the slag removal system to aid in the removal and prevent buildup of slag fines on the floor of the pit during testing.

7.2.8 High Voltage Room (HVR) Modifications

The rewiring of the HVR was completed. The new channel wiring and instrumentation operated successfully during power testing of the 1A4 prototypical channel.

7.3 PROTOTYPICAL POWER TRAIN HARDWARE ACTIVITIES

The focus of the power train hardware activities was the removal and inspection of the combustion and channel subsystems after the conclusion of the design verification test series. Since the hardware removal occurred at the end of the quarterly reporting period, the results of the detailed inspection will be reported in the next quarterly report.

7.3.1 Current Consolidation

The aft (cathode) current consolidation power cabinets arrived from Westinghouse and were installed in the newly fabricated cathode current consolidation building outside Building 50. The facility interconnect activities are currently underway and will be completed on an "as available" basis. If available, the current consolidation system will be interconnected and a system test conducted during the post-DVT inspection.

The system test will use a power supply in lieu of the MHD channel to verify proper installation and functionality of the subsystem prior to testing with the 1A1 channel.

With the delivery of this component, all prototypical power train components have been delivered to the CDIF.

7.3.2 1A4 Channel Removal and Inspection

The 1A4 channel was removed from the test cell and transported to the TDS Butte Field Office on October 28, 1992. The process proceeded smoothly.

The channel will undergo a rigorous evaluation to investigate the localized nozzle erosion, any initial wear patterns, and infant mortality type failures. The observations and hardware replacement activities will be documented and the channel will be available for reinstallation at the CDIF on December 7, 1992.

7.3.2.1 Anode

Preliminary inspection of the anode wall showed some loss of platinum top caps. The 30-mil thick platinum appeared to be debonding from the tungsten subcap on approximately 80 to 100 (from a total of over 2500) anode caps. The cause for the failures will be evaluated during the inspection period. There was some localized damage to the anode/sidewall ceramic insulators (aluminum nitride). The ceramic appeared broken (i.e. not worn), possibly due to thermal shock.

7.3.2.2 Cathode

Overall, the cathode wall looked excellent with no evidence of accelerated wear or cap failures. There was some localized wear of the cathode/sidewall ceramic (aluminum nitride) insulators and adjacent tungsten caps in the nozzle region. The plan is to replace the ceramic insulators with solid tungsten.

7.3.2.3 Sidewalls

The left sidewall was in excellent condition. Very minor wear was observed in the nozzle region and some electrical wear is evident in areas along the sidewall. The right sidewall was badly worn in the nozzle region on the lower half of the sidewall (adjacent to the cathode wall). The wear was sufficient to smooth out the tungsten elements to the point where the slag retention groove is no longer evident. The wear is primarily concentrated along the cathode endbar and cathode midbar with a "groove" extending from the nozzle throat downstream approximately 24 inches (30 to 35 elements). The groove occurs at the endbar-midbar interface.

7.3.2.4 Channel/Diffuser Interface

Inspection also revealed that arcing had occurred between the aft anode bar (Anode 245) and the first diffuser element. The G10 fiberglass had been burned in some localized spots on the channel and diffuser. Preliminary indications are that the arcing was a result of a breakdown of the insulating gap at the channel/diffuser interface. A minor wiring change should remedy the situation.

7.3.2.5 Current Controls

A total of 13 current control boards had been replaced during the DVT series. Failures were experienced at different electrodes at various locations in the channel. Severe electrical transients caused by the inverter are suspected as the cause. A rigorous failure mode analysis is currently in progress.

7.3.3 Combustion Subsystem Inspection

Various components within the combustion subsystem will be removed and/or inspected. In addition to the combustor components, the following will be inspected:

- Slag rejection assembly, vent line, slag grinder
- Water electrical isolators
- Water corrosion coupons and LPCS

Based on a preliminary inspection, the hardware looked excellent with no signs of erosion or corrosion.

7.3.3.1 Precombustor (CFPC)

The precombustor refractory was intact, with some cracking from thermal stress relief. The refractory liner (cage) was in good condition. The precombustor combustion can was in good condition and was clear of any slag growths. The precombustor transition to air inlet (main combustor) was also clear of slag and in good condition.

7.3.3.2 Main Combustor (CFC)

There was general good slag coverage with a thin layer of black, glassy slag. The slag retention teeth on the panels are in good condition.

Workhorse-type slag retention pins (1/8-inch diameter x 3/8-inch long) were installed on two of the panels in the headend region of the slagging stage at 11:00 and 2:00 looking downstream. The pins were installed to aid with slag retention in this relatively cold region of the combustor (low PHI) where slag layers are relatively thick. The pins on the panel at 2:00 retained slag and burned back to a nominal 1/4-inch height. The pins on the panel at 11:00 did not retain slag and in fact did not burn back which indicates a very cold local temperature.

Low alloy steel panel gaps filled with RTV showed little corrosion. Gaps not protected with RTV (hot sleeve, seed adapter) showed varying degrees of corrosion and will be protected.

The occasional buildup of slag in the slag tank still has to be solved.

7.3.3.3 Second Stage

Typical uniform slag coverage was observed in the second stage. Second stage surfaces were in excellent condition, virtually not worn at all.

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.

Status reports from the various MHD contractors were received and preparation of the ninth semi-annual status report was initiated.

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 power train test activities including data analysis, modeling, and comparison with workhorse hardware experience.

Task 5

- Complete assembly of the cathode local control system.
- Ship the completed control system to the CDIF to support acceptance and power train testing.

Task 6

- Complete the post-DVT channel inspection and repair/replace hardware as required.
- Initiate the long duration testing of the integrated power train.

Task 7

- Continue the design/fabrication of spares and contingency hardware.

10. SUMMARY

Combustor spare and contingency hardware was shipped to the CDIF. The manufacture of spare and replacement hardware for the 1A4 channel and diffuser continued. Fabrication of a modified/spare channel inlet frame which incorporates the capability for iron oxide injection was completed.

The cathode power cabinets and associated control system were successfully tested at Westinghouse and met all design requirements. The cathode system was delivered to the CDIF and installed in the current consolidation building. With the delivery of this component, all prototypical power train components have been delivered to the CDIF.

The hot-fire checkout of the channel subsystem and the design verification test series of the integrated power train were completed. A total of 29 tests were performed accumulating 120 thermal and 52 electrical hours. The test series demonstrated the adequacy of the overall cooling of the channel subsystem and provided an initial evaluation of the integrated combustor and channel performance in terms of operating conditions, power output, conductivity, heat loss, slagging behavior, and gas-side wear characteristics. During the test series localized wear in the supersonic nozzle was observed on the right sidewall. The cause of the wear is presently under investigation. At the conclusion of DVT test series, the channel was removed for a detailed inspection.

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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_{O1} - 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. T_{250} - 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.

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