MHD Advanced Power Train

Phase I Final Report

Volume 3

Power Train System Description And
Specification For 200MWe Plant

Prepared For

**THE UNITED STATES DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER**

Contract DE-AC22-83PC60575

AUGUST 1985

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Government Technical Project Officer:

Dr. Harold F. Chambers, Jr

Contract DE-AC22-83PC60575

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by

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1.0 SCOPE

This System Design Description and Specification provides the basis for the design of the magnetohydrodynamic (MHD) Power Train (PT) for a nominal 200 MWe early commercial MHD/Steam Power Plant. This document has been developed under Task 2, Conceptual Design, of Contract DE-AC22-83PC60575 and is to be used by the project as the controlling and coordinating documentation during future design efforts. Modification and revision of this specification will occur as the design matures, and the Westinghouse MHD Project Manager will be the focal point for maintaining this document and issuing periodic revisions. This document is intended to delineate the power train and power train components requirements and assumptions that properly reflect the MHD/Steam Power Plant in the PT design. The parameters discussed in this document have been established through system calculations as well as through constraints set by technology and by limitations on materials, cost, physical processes associated with MHD, and the expected operating data for the plant. The specifications listed in this document have precedence over all referenced documents. Where this specification appears to conflict with the requirements of a reference document, such conflicts should be brought to the attention of the Westinghouse MHD Project Manager for resolution.

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2.0 MHD/STEAM PWR. PLANT GENERAL DESCRIPTION AND REQUIREMENTS

2.0 MHD/STEAM POWER PLANT GENERAL DESCRIPTION AND REQUIREMENTS

2.1 OVERALL PLANT DESCRIPTION

Figure 2-1 is a block diagram of the overall power plant and its major systems. As shown, the MHD Power Train (PT) is a major system of the plant. A schematic diagram of the overall power plant including the PT is shown in Figure 2-2 and a plot plan of the overall plant is shown in Figure 2-3.

The plant is fueled with Montana Rosebud sub-bituminous coal which is burned in a preheated gas of air enriched with oxygen. The coal is dried with combustion gas and conveyed to the combustor by a gas carrier, e.g., nitrogen. The combustion gas is also used for seed drying. The seed is based on potassium compounds. Potassium was selected for its low ionization potential, and is necessary to obtain the required electrical conductivity of the plasma. Seed processing is handled by a recovery and regeneration system which uses CO provided by a coal-fired gasifier.

The steam turbine is a tandem compound, single reheat, multi-flow unit. Extraction steam for regenerative feed water heating is provided to the feed water train composed of closed-type heaters and a deaerator. Feed water heating is also accomplished by recovering topping cycle heat at an economizer and from the APT channel cooling system.

Oxygen is provided by an on-site air separation unit. This unit is may be electric or turbine-driven using steam provided by the bottoming plant. The product is a dry mixture of oxygen and nitrogen with a N_2/O_2 ratio of 30/70. This mixture is combined with incoming air to form the oxidant having the desired oxygen concentration for efficient combustion of the coal.

2.2 NOMINAL OVERALL PLANT ASSUMPTIONS

Top level requirements and assumptions for the overall power plant are discussed in the following sections.

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Figure 2-1. Major 200 MWe MHD/Steam Power Plant Systems and Advanced Power Train Subsystems

Figure 2-2. 200 MWe Early Commercial MHD/Steam Power Plant Schematic

Figure 2-3. Plot Plan of 200 MWe MHD/Steam Power Plant

2.2.1 Plant Site

The plant is assumed to be located at hypothetical Middletown, USA having the following ambient design conditions:

Dry Bulb Temperature, °C,	15
Relative Humidity, %	60
Atmospheric Pressure, atm	1

2.2.2 Plant Rating

The plant, with the following characteristics, shall provide power to a utility grid.

Total Net Power, MWe	193
Total Thermal Power, MWt	483
Total Gross Power, MWe	200
Voltage, kV	35
Frequency, Hz	60

The voltage shall be compatible with the utility grid, and the current shall be three-phase.

2.2.3 Plant Fuel

The plant shall be designed to burn coal from the Montana Rosebud seam. As received coal properties include:

Max Water Content, %	23
Max Ash Content, %	11
Max Sulfur Content, %	1
Higher Heating Value, kJ/kg	21000

2.2.4 Plant Efficiencies

The plant shall be designed to have an net overall efficiency of 40 percent (coal pile to bus bar).

2.2.5 Lifetime

The plant shall be designed and constructed in accordance with utility practices and has the following characteristics:

Plant Life, yr	30
Number of Operating Cycles	200

2.2.6 Availability/Capacity Factor

The plant shall have, as a design goal, at least a 74 percent availability when operating under commercial power generation conditions. This value is consistent with a 65 percent plant capacity factor goal.

2.2.7 Load Range of Generating Capabilities

The plant shall be capable of continuous operation over a range of from 75 percent to 100 percent of the (reference) plant rating.

2.2.8 Operational Modes

The plant shall be expected to operate as a baseload power plant. However, the ability to handle multiple startups, standbys, and shutdowns shall be a strong factor in the selection and design of power equipment. The operational modes shall include baseload, cold startup, hot standby, cold standby, and shutdown. Baseload is defined as operation of the plant at any steady state load that is maintained consistently within the range of the plant's generating capability.

Standby is a no-load condition of the power generating equipment. Components that are not serviced during standby shall be maintained at as high a temperature as appropriate for an anticipated restart of the plant. These components shall be ready for operation. Components to be serviced shall be allowed to cool for handling by plant personnel. The two basic modes are hot standby and cold standby.

Shutdown shall be a transient mode of operation from normal baseload conditions to standby or dead plant conditions. During shutdown appropriate procedures

shall be followed to bring the plant to the required standby mode or dead plant condition. Equipment limitations shall not be exceeded during shutdown.

2.2.9 Plant Regulation and Response

The plant regulation range shall be from 75 percent to 100 percent of the reference power. The plant shall be capable of reducing power output from the rated load to 75 percent of the rated load and of increasing the power output from 75 percent of the rated load to the rated load at a rate of at least 3 MW/min.

When the plant is connected to the grid and the grid frequency deviates by more than ± 5 percent from 60 Hz, the plant shall be separated from the grid for protection. If the duration of operation below 57.5 Hz is indeterminate or if the frequency falls below 57 Hz, this condition shall result in tripping the plant. A deviation greater than 0.06 percent of the frequency (equal to the dead band) shall result in a restoring response within 0.2 seconds. Design operation at steady state shall be based on frequency changes not to exceed +0.02 Hz or -0.04 Hz. The deadband shall not exceed 0.036 Hz.

The PT shall be designed to be stable under manual and automatic control while connected to the grid system. The power plant shall be capable of accommodating load changes from the steady state power levels at a rate of at least 3 MW/min.

2.3 POWER TRAIN DESCRIPTION AND REQUIREMENTS

The Power Train (see Figure 2-4) is a major system within the plant topping cycle and consists of the combustor, an integrated MHD generator, diffuser, and instrumentation and control. The integrated generator includes MHD channel, magnet, nozzle connecting the channel and the combustor and power conditioning equipment.

Direct current (dc) electric power is generated in the MHD channel through the expansion of a slightly ionized high-velocity plasma within the field of a high strength super conducting magnet. The resulting electric current from this

Figure 2-4. Power Train

interaction is collected by electrodes built into the channel walls. The electrode currents are consolidated and the power flow controlled locally by solid state circuitry. The current from these dc sources is inverted to an alternating current for transmission by the utility grid.

The plasma required for power generation is produced by combusting pulverized coal with a pressurized preheated oxidant and adding a seed of potassium compounds. The high temperatures needed to ionize the seed and achieve the required electrical conductivity are obtained by enriching air with oxygen to form the oxidant and preheating it to high temperatures in state-of-the-art metallic recuperators. Approximately 90 percent of the oxidant required for complete coal combustion is provided to the combustor. This limits the production of thermal nitrous oxides, i.e., NO_x ($x = 1, 2, \dots$), and provides the necessary reducing conditions in the Heat Recovery/Seed Recovery System.

Coal ash, released in the combustion process, flows through the PT with the plasma. A portion of this ash condenses as slag on the inner walls of the PT providing thermal insulation and protection from erosion and the high temperature plasma. However, the ash also tends to reduce the plasma conductivity and may combine with the seed in the HRSR to make the seed uncoverable. Therefore, the combustor is designed to reject a large fraction of the ash prior to the introduction of the seed.

The plasma enters the MHD channel from the combustor through a nozzle which accelerates it to the high velocity needed (above the speed of sound in this case) for electric power production. The total pressure, total temperature, and conductivity of the plasma drop as it expands in the channel. Power generation in the channel becomes uneconomical when the power density becomes too low. The exhaust is then introduced into a diffuser which reduces the velocity and increases the pressure to meet the requirement of the HRSR (1 local atm).

The combustion gases lose large quantities of heat to the PT component walls. This heat energy must be recovered for use in the steam cycle to improve plant

performance. This is done by cooling the components with boiler feed water. (Note that a separate circuit with a heat exchanger is used to cool the channel.)

The design of the PT shall properly account for thermal expansion. The nozzle, channel, and diffuser are joined together by rigid bolted flanges such that the entire assembly is located axially from the combustor. Thermal expansion is accommodated in the axial direction by wheeled tracks. A flexible expansion joint at the diffuser outlet shall accommodate the total expansion motion of the assembly. The differential pressure across this joint is small so that a simple, reliable design is possible. The design shall minimize the external channel dimensions and magnet bore.

In addition to the top level power plant assumptions and requirements itemized in Section 2.2, there is a set of PT assumptions and requirements unique to the power train. Qualitatively these requirements include AC power generation, lifetime, controllability, maintainability, low heat losses and proper interfacing with the balance of plant. Additional PT requirements are quantitative and these requirements are specified in the component sections that follow.

2.3.1 Combustor

The Combustor Subsystem consists of the following major elements:

- First stage combustor
- Second stage combustor
- Slag tank
- Continuous slag removal equipment
- Mechanical supports

- Cooling
- Voltage isolators
- Flowmeters and temperature sensors

The combustor design shall be based on the two stage slagging coal combustor design under development at the 10, 20 and 50 Mwt power levels (see Figure 2-5). The two stage approach separates the functions of solid particle combustion and slag rejection from those of plasma generation. Coal is devolatilized and the char is oxidized sub-stoichiometrically (fuel-rich) in the first stage which is effectively a confined vortex flow gasifier. After slag rejection, the flow is forced through a 90° turn in the de-swirl section and enters the second stage where seed addition and combustion to MHD operating conditions take place. The two stage approach minimizes heat as well as seed losses to the slag. The required plasma conductivity is achieved in the second stage. The combustor opening at the exit shall have a square cross section to match the nozzle/channel.

The combustor shall be designed for maximum carbon utilization, minimum pressure drop, and minimum heat loss. High temperature feed water cooling shall be provided for heat removal. All materials shall be non-magnetic metals. Wall surfaces exposed to the combustion gases shall be designed to be slag coated to reduce heat losses and erosion. A large fraction of the ash content of the coal is to be continuously separated from the product gases in the first stage of the combustor and rejected as liquid slag. The slag removal equipment shall be designed to maintain the combustor pressure and voltage isolation from ground while adequately cooling and processing the slag for discharge to the Slag and Ash Management System. The mechanical support system shall be able to take thrust loads expected during operation as well as to bear the weight of the components.

The nominal combustor characteristics are given in Table 2-1. In addition to nine sets of combustor interfaces specified in Section 3.1, general combustor requirements include a 15 year useful life, a six months refurbishment period, and a 25 percent combustor turndown.

Figure 2-5. Combustor Assembly

TABLE 2-1. NOMINAL COMBUSTOR CHARACTERISTICS

<u>Parameter</u>	<u>Value</u>
Coal & Seed Input, MWt	480
Exit Coal Moisture, % by wt	5
Total Mass Flow, kg/s	104
Slag Rejection, %	85
Combustor Dimensions	
First Stage	
Length, m	3.5
Diameter, m	1.9
Second Stage	
Length, m	4.5
Side, m	0.7 by 0.7
Stoichiometry Ratio	
First Stage	0.6
Second Stage	0.9
Max Heat Loss, MW	32
Operating Pressure, atm	5
Max Pressure Drop, atm	0.23
Cooling Water Pressure, atm	190
Cooling Water Temperature, °C	330
Voltage Standoff, kV	25

2.3.2 Integrated MHD Generator

The MHD generator consists of the nozzle, channel, magnet and power conditioning. These elements are addressed in the Sections 2.3.3 through 2.3.6. Because the magnet per se was outside the scope of the contract, only the characteristics of the magnetic field are presented.

2.3.3 Nozzle

The nozzle, physically connects the combustor and the channel and modifies the plasma exiting the combustor to provide the required Mach number for entrance to the channel. The nozzle shall be cooled by the high pressure boiler feed water and shall be designed to operate in the environment of the fringe magnetic field. The nozzle shall have a square cross section and consist of a non-magnetic, water-cooled shorted conductor with external thermal insulation to limit heat transfer to the magnet. The nozzle characteristics are given in Table 2-2.

TABLE 2-2. NOMINAL NOZZLE CHARACTERISTICS

<u>Parameter</u>	<u>Value</u>
Nozzle Dimensions at Exit, m	0.56 x 0.56
Nozzle Length, m	1.7
Supersonic Nozzle Length to Throat Height Ratio	0.13
Slag Coated Wall Temperature, K	1800
Exit Mach Number (Average)	1.3
Max Heat Loss, MW	6

In addition to the three sets of nozzle interfaces specified in Section 3.2, general nozzle requirements include a 4000 hour useful life and a six months refurbishment period.

2.3.4 Channel

The channel shall be based on diagonal electrical frames in a box design with a square cross section, see Figure 2-6. In this design the half frames are split and electrically isolated by a thin conduction cooled boron nitride insulator at the position on the sidewall diagonal where the current would nominally be zero. The frames are similarly electrically isolated from each other by thin conduction cooled boron nitride insulators. This design shall

Figure 2-6. The MHD Channel

have no electrically floating metal wall elements, thus permitting the power conditioning equipment to collect current from and control the voltage of each channel element. Containment of the channel plasma shall be provided by the structurally reinforced fiberglass box. Shielded, air cooled electrical leads from each electrode elements shall be used to extract the current. The electrical leads shall be equipped for quick connection/disconnection, which are all made at the outlet end of the channel. Structural reinforcement of the channel is required to prevent excessive deflection of the thin fiberglass insulating walls. Good contact shall be maintained between components to avoid overheating of the insulators and to prevent leakage of the plasma gas.

The channel design shall conform to a set of practical engineering and manufacturing constraints as well as to limiting operational constraints that represent existing technology for hardware evolved from limited endurance testing. These result in a number of major design constraints. Nominal side wall frame thickness shall be maintained at its minimum practical value of 0.01 m. This results in a center line channel electrode pitch of $0.01/\cos \phi$ m. Because of the active nature of the Integrated Power Management System a voltage difference of up to 50 V shall be safely maintained between adjacent anodes without short term channel failures due to electrical faults. This coupled with the channel pitch angle results in constraining the channel Hall fields to $5000 \cos \phi$, V/m. To obtain the required 4000 hour operating life necessary for a practical MHD power plant, the Faraday current density shall be limited to 6000 A/m^2 . To avoid potential uncertainties in channel operation at high Hall parameters, the Hall parameter, β , is limited to a value ≤ 4 .

The nominal channel characteristics are given in Table 2-3.

TABLE 2-3. NOMINAL CHANNEL CHARACTERISTICS

<u>Parameter</u>	<u>Value</u>
Channel Dimensions at Entrance, m	0.56 x 0.56
Channel Dimensions at Exit, m	1.13 x 1.13
Channel Active Length**, m	7.4
Channel Overall Length***, m	11
Inlet Mach Number	1.3
Outlet Mach Number	1.0
DC Power, MWe	≥ 74
Slag Coated Wall Temperature, K	1800
Number of Electrode Pairs: Anodes	560
Cathodes	593
Generator Enthalpy Extraction, %	15.5
Isentropic Efficiency, %	75
Generator Heat Loss, MWt	≤ 17

**Length from 0.8 B* to 0.8 B', Figure 2-6A

***Length 0 to L, Figure 2-6A

In addition to the five sets of channel interface requirements specified in Section 3.3, Table 2-4 lists several general channel requirements.

TABLE 2-4. GENERAL CHANNEL REQUIREMENTS

<u>Parameter</u>	<u>Value</u>
Fault Pulse Energy, J	≤ 1000
Steady Fault Power, W	≤ 150
Maximum Magnetic Field, T	6.5
Hall Parameter β	≤ 4
Hall Field, V/m	$< 5000 \cos \phi$
Faraday Current Density, A/m ²	≤ 6000
Minimum Channel Operational Life Before Replacement, hr	4000
Refurbish Period, mo	6

2.3.5 Magnetic Field

The superconducting magnet required by the MHD channel for power generation has a warm bore with a truncated cone cross section in which the channel is mounted. The bore has a diameter of 1.36 m on the inlet side of the generator and 1.93 m on the outlet side of the generator. An electrically insulated liner considered part of the magnet bore, protects the magnet from electrical breakdown and/or possible burn out of PT components. The magnet bore shall be accessible only from the ends for purposes of maintenance and repair. It shall be necessary that all wiring and piping from the channel is brought out through the ends. Clearances shall be provided for withdrawing the channel and associated parts from the bore. The magnet winding and associated structure which are thermally insulated shall be continuously cooled by cryogenic fluids. The magnet will be kept at cryogenic temperatures except during extended "dead plant" periods. Significant fringe magnetic fields will exist externally to the magnet enclosure. Components shall be magnetically shielded or located so that personnel and equipment are protected. The steady state field, peak field on-axis, field profile on-axis, and uniformity of the transverse field shall be established to meet the requirements to produce electrical power. The cavity dimensions shall be able to accommodate the

channel as well as the mechanical supports located within the magnet. For purposes of the PT design, the maximum time required to excite the magnet from zero to the design field strength shall be no greater than 1 hour. The time to dump the stored energy in the magnetic field shall not exceed 3 minutes when the magnet is discharged through the (emergency) dump resistor. The maximum discharge time shall be no greater than 1 hour, when the magnet is discharged under normal (non-emergency) conditions.

The magnetic field (B), in Figure 2-7, which was scaled from the existing superconducting magnet, shall be maximized without exceeding any of the generator or magnet constraints in Table 2-5.

TABLE 2-5. MAGNET CONSTRAINTS

<u>Parameter</u>	<u>Value</u>
Maximum Magnetic Field B*, T	6.5
(dB/dx) Max at Channel Inlet, T/m	3.6
(dB/dx) Min at Channel Outlet, T/m	-2.0
Central Field Decay Constant, m	0.725

Note: Although the supersonic generator may have a lower development cost and have a number of characteristics which make it more attractive than an alternate subsonic generator when the plant is operating at its design point, the off-design operation of an MHD plant with a supersonic generator should be evaluated in future effort. Prior studies of MHD plants with subsonic generators indicated their potential for excellent off-design performance.

2.3.6 Power Conditioning

The power conditioning subsystem is that portion of the integrated MHD generator which collects the multi-terminal DC electric output from the MHD channel and converts it into 3-phase AC power at the required voltage for feeding to the utility grid. It consists of the following major elements.

- A) Limits on Magnetic Field Profile Resulting from Coil Assumptions and Hall Parameter Constraint. Channel height is h ; h^* is height at x^* .

DETAILED CHANNEL INLET AND EXIT MAGNETIC FIELDS

- B) Detailed Channel Inlet and Exit Magnetic Fields to be Used In Evaluation of Detailed Channel Inlet and Exit Construction.

Figure 2-7. Magnetic Constraints

- Power management components to control power flow within the MHD channel and between this channel and the utility grid.
- Inverters for bulk conversion of DC to commercial frequency AC.
- Harmonic filters.
- VAR generator (note: all or part of VAR requirements of inverter may be met from the associated plant alternator).
- Protective devices.
- Instrumentation and control.
- Cabling from channel electrode connectors to power conditioning and inverter components.
- Quick cable disconnects to facilitate rapid channel replacement.

The power management components shall be designed to control power flow both within the MHD channel and between the MHD channel and the bulk inversion components. They shall be designed in a cost effective manner, preferably as a single level. One conceptual approach is described in Volume 4, MHD Advanced Power Train, Phase I Final Report, APT Design Approaches, pp. 2-29. They shall be located so that the operation will not be impaired by the magnet fringing field. This power flow control will be accomplished by appropriate power electronic circuits and will include such controls as are necessary to achieve stable operation under all specified conditions. The control shall be applied to the electrode currents or inter-electrode voltage and shall be specified in terms of maximum allowable electrode current, maximum inter-electrode voltage, maximum fault power, and maximum fault energy.

Harmonic filters and VAR generation will be included to ensure that the inverted DC output of the MHD channel shall have the wave form characteristics required by the utility grid and that the VAR requirements of the line commutated inverter shall be provided. If the VAR requirement can be met by the associated plant alternator, the provision of VARs shall be the responsibility of the alternator designers and the VAR requirements will be included in the power conditioning plant busbar interface.

The dynamic operating range of the MHD channel due to load changes, plant transients and system transients will require protective devices in both the bulk inverter and the power management components. These protective devices will take into the account the low inertia of the MHD channel.

The bulk inverter shall consist of one or more line (externally) commutated DC/AC converters to convert the DC output or outputs of power management components to the station busbar conditions. The inverter(s) shall be assembled from solid state bridge circuits and shall be capable of handling the output of the MHD channel over the entire dynamic operating range.

Cooling is required for the inverters to maintain component temperatures within the design and allowable limits. The type of coolant and degree of cooling will be determined by the component design. In the event of a malfunction, the inverters shall automatically shut down and force both the dc bus current and the ac current into the inverter bus to zero.

Instrumentation and control shall be provided for the entire power management subsystem both to ensure that the system operates in a stable manner in accordance with plant requirements and also to enable the overall plant control system to instruct the power management subsystem under all plant conditions.

The dipole magnetic far field produced by the superconducting magnet, requires cabling runs from the channel electrode connectors to a location where the solid state power conditioning equipment can function without interference from this magnetic field. The cabling must be designed to carry the individual electric currents to the power management components and provide the insulation between individual cables in accordance with the Hall potential developed along the MHD channel. The cable voltage drop shall be chosen so as not to impair the inter-electrode voltage control function. In keeping with the requirement for rapid channel replacement, a quick disconnect arrangement shall be included in this cabling at the point where the cabling leaves the superconducting magnet bore and beings the runs to the power conditioning subsystem.

The Power Conditioning characteristics are given in Table 2-6.

TABLE 2-6. NOMINAL POWER CONDITIONING CHARACTERISTICS

<u>Parameter</u>	<u>Value</u>
Output ac Power, MW	71
Output ac Voltage, kV	35
Output Frequency, Hz	60
Number of Inverters	TBD
Inverter Efficiency, %	97
Power Factor	TBD

In addition to the interface requirements specified in Section 3.4, a list of general power conditioning requirements is given in Table 2-7.

TABLE 2-7. POWER CONDITIONING GENERAL REQUIREMENTS

<u>Parameter</u>	<u>Value</u>
Inter Anode Voltage Control, V	TBD
Inter Anode Shorting Resistance, Ω	TBD
Anode Current Control, A	TBD
Cathode Current Control, A	TBD
Time Constant Anode V to I Control, sec	TBD
Time Constant to Short Anodes, sec	TBD
Design Life, Yr	TBD

2.3.7 Diffuser

The Diffuser Subsystem consists of the following major elements:

- Settling duct
- Subsonic diffuser

The diffuser is required to perform two basic functions: 1) to convert the dynamic pressure of the gas at the channel exit to static pressure (about one atmosphere); and, 2) to reduce the gas flow velocity before it enters the radiant boiler which is part of the Heat Recovery/Seed Recovery System. The characteristic features that make this diffuser different from any other is the combination of the high inlet Mach number (M), high inlet boundary layer flow blockage, and overshoot velocity profiles.

Pressure recovery in the diffuser at transonic speeds ($0.6 < M < 1.6$) and with more than a few percent blockage (2 to 3 percent) is more difficult than in the usual subsonic diffuser with thin inlet boundary layers. Even under the most ideal conditions, the combination of adverse pressure gradients and wall divergences thicken the viscous layer near the wall substantially more than in a constant area duct or in single boundary flow. This effect increases for blockages greater than 5 percent of the diffuser area and is pronounced for values in the range of 15 percent to 25 percent (maximum for a fully developed profile) which may be encountered in large scale MHD channel exit flows. Large velocity distortions, including velocity overshoot profiles combined with nearly separated flow in local zones, and increased sensitivity of pressure gradients to small area changes, characteristic of transonic flows, further complicate the problem of pressure recovery in the diffuser.

The diffuser geometry considered for the plant subsystem consists of a constant area settling duct where the thick boundary layer profiles and overshoot profiles mix together to form a near classical boundary layer profile, followed by a diverging duct for pressure recovery. The settling of the profiles before expansion enables control of the pressure recovery in the diverging section with more confidence and also assures a more stable diffuser operation.

The three basic performance parameters to be considered in diffuser operation are pressure recovery, exit velocity, and heat loss. As mentioned above, the exit velocity will be much higher than acceptable at the radiant boiler inlet and hence a transition section (dump tank) with a larger cross sectional area (possibly with a blast plate) shall be necessary at the beginning of the Heat Recovery/Seed Recovery System. Figure 2-8 shows such an arrangement.

The diffuser shall operate in strong magnetic fields and non-magnetic materials such as stainless steel shall be used where necessary. The basic method of construction shall be the same as that of the second stage of the combustor, using tubular walls for cooling water from the high temperature, high pressure boiler feed water. Since the diffuser operates at internal pressures near atmospheric, the mechanical design will be constrained by the stresses due to the high pressure cooling water in the tubes, the thermal cycles, and cycle lifetime. The diffuser shall be constructed in two sections connected by water-cooled flanges and bolted together for easy removal for maintenance. This also allows for rapid channel removal and replacement. A continuous slag layer shall be maintained on the surface of the water-cooled diffuser walls to reduce metal erosion as well as heat losses. This shall be accomplished in a design using grooves or pins on the inner surface of the diffuser.

The diffuser characteristics are given in Table 2-8. In addition to the diffuser interfaces defined in Section 3.5, general requirements include design lifetimes of one and 15 years for the upstream and downstream components, respectively.

TABLE 2-8. NOMINAL DIFFUSER CHARACTERISTICS

<u>Parameter</u>	<u>Value</u>
Outlet Dimensions, m	3.6 x 3.6
Diffuser Length, m	12
Mass Flow Rate, kg/s	104
Inlet Gas Velocity, m/s	990
Exit Gas Velocity, m/s	TBD
Inlet Gas Temperature, K	2280
Slag Cooled Wall Temperature, K	1800
Max Heat Loss, MW	25

Figure 2-8. The Diffuser

TABLE 2-8. NOMINAL DIFFUSER CHARACTERISTICS (CONT'D)

<u>Parameter</u>	<u>Value</u>
Exit Pressure, atm	1
Pressure Recovery Coefficient, %	50
Cooling Water Inlet Pressure, atm	186
Cooling Water Inlet Temperature, °C	355

2.3.8 Instrumentation and Control (I&C)

The major elements of the Instrumentation and Control Subsystem are:

- Remote and local control panels
- Controller signal cabling
- Sensors and actuators
- Controller and data highway

The Instrumentation and Control Subsystem shall be designed to inform the supervisory control system (Facility Control System) of the status of the PT and detect abnormal operation. It shall be designed to stabilize the power train within its operational range through coordinated control of the combustor and the power conditioning circuitry.

This subsystem controls and regulates the combustor operation and the plasma conductivity by adjusting the coal, oxidant, and seed input to the combustor for the required power level demand and operating conditions. The subsystem shall be designed to control the MHD channel electrical load through the Power Conditioning Subsystem. It shall be designed to regulate the flow of dc electrical power into the inverters and to connect or disconnect the channel from the inverters.

The I&C components shall consist of commercially available equipment where possible. Commercially available control systems, sensors, and actuating devices shall be applied to meet system requirements. In the case that new sensing and/or actuating device requirements evolve resulting in the need for component development, the appropriate programs shall be identified. The isolation and shielding of I&C equipment from high voltages and high magnetic fields shall be incorporated in the design. For example, pneumatically operated devices operating in strong magnetic fields shall be constructed of non-magnetic material.

The I&C general requirements include a design life of TBD years and time constants of TBD. I&C interfaces are specified in Section 3.4.

3.0 PLANT AND POWER TRAIN SUB- SYSTEM INTERFACE DESCRIPTIONS

3.0 PLANT AND ADVANCED POWER TRAIN SUBSYSTEM INTERFACE DESCRIPTIONS

With the close integration of the subsystems and components in a MHD/Steam power plant, the individual component design for any one of the major subsystems of the PT will strongly interface with the plant as well as the other individual subsystems and restrict the establishment of the parameters. Therefore, the key parameters for the PT have been set through system calculations of a plant case selected based on a compromise between the overall plant efficiency and the total cost of energy. In this process, parameters have also been constrained to values representing the best estimates of attainable technology. These additional design constraints include such parameters as materials limitations due to high temperatures, electrical limitations on the MHD channel, and time and temperature limitations on the completion of critical chemical reactions. In addition to the subsystem-to-subsystem interfaces, the PT system interfaces with the following eleven plant systems:

- The coal supply
- The seed supply and recovery
- The process gas supplies
- The high temperature, high pressure feed water
- Slag management
- Plant rails and tracks
- Structures and supports
- Electrical grid and auxiliaries
- Plant instrumentation and control
- Waste heat removal

The locations of the physical interfaces between the PT and most of the other plant systems are shown in Figures 3-1 and 3-2. The process conditions at each of these interfaces are presented in the following sections. Several of the parameter values are computed from heat and mass balance equations.

<u>INPUTS</u>	
①	OXIDANT
②	COAL + CARRIER GAS
③	SEED + CARRIER
④	SLAG TANK WATER

<u>OUTPUTS</u>	
⑤	SLAG + WATER
⑨	PT EXHAUST

NOTE: ⑥, ⑦, ⑧ ARE
EXITS OF COMBUSTOR,
NOZZLE, & CHANNEL
RESPECTIVELY

Figure 3-1. The Process Gas Supply/Power Train Interface

Figure 3-2. The Steam Feed Water/Power Train Interface

3.1 COMBUSTOR SUBSYSTEM INTERFACES

This section presents the interface data and information for the Combustor Subsystem. The combustor interfaces with nine other subsystems.

3.1.1 Combustor/Coal Supply Interface

Montana Rosebud coal, dried to $\leq 5\%$ moisture, and ground 70% through 200 mesh shall fuel the combustor. Circular flanged connections provide the mechanical interfaces. Micromotion flowmeters or the equivalent and voltage isolations of the feed lines shall be provided. See Figure 3-3 for a schematic of the interface. See Table 3-1 for key parameters associated with this interface.

TABLE 3-1. COMBUSTOR/COAL SUPPLY SUBSYSTEM INTERFACE DATA

<u>Parameter</u>	<u>Value</u>
Flange Inside Diameter, m	TBD
Coal Flow Rate, kg/s	19
Carrier Gas Flow Rate, kg/s	1.9
Higher Heating Value, kJ/kg	~ 25400
Content, %	
Moisture	5
Volatiles	36
Fixed Carbon	48
Ash	11
Total	<u>100</u>
Ultimate Analysis, %	
Sulfur	1
Hydrogen	5
Carbon	63
Nitrogen	1
Oxygen	19
Ash	11
Total	<u>100</u>
Ash Analysis	
Silicon dioxide (SiO_2)	39
Aluminum oxide (Al_2O_3)	18
Iron oxide (FeO)	5
Titanium dioxide (TiO_2)	1
Calcium oxide (CaO)	11

Figure 3-3. The Combustor/Coal Supply Interface

TABLE 3-1. COMBUSTOR/COAL SUPPLY SUBSYSTEM INTERFACE DATA (CONT'D)

<u>Parameter</u>	<u>Value</u>
Magnesium oxide (MgO)	4
Sodium monoxide (Na ₂ O)	3
Potassium monoxide (K ₂ O)	1
Sulfur trioxide (SO ₃)	18
Total	<u>100</u>
Initial Deform Temperature, °C	1200
Softening Temperature, °C	1220
Fluid Temperature, °C	1250
Dryer Outlet Temperature, °C	100

3.1.2 Combustor/Oxidant Supply Interface

The combustor/oxidant supply subsystem interface data are given in Table 3-2. The oxidant is oxygen enriched air with injection points in both stages of the combustor. The flanges are rectangular in shape and are water cooled. Instrumentation shall consist of flowmeters, and the oxidant lines shall be voltage isolated. See Figure 3-4 for a schematic representation of the interfaces.

TABLE 3-2. COMBUSTOR/OXIDANT SUPPLY SUBSYSTEM INTERFACE DATA

<u>Parameter</u>	<u>Value</u>
1st Stage:	
Flange Size, m	TBD
Exit Pressure, atm	5.0
Oxygen Enrichment, %	36
2nd Stage:	
Flange Size, m	TBD
Exit Pressure, atm	4.9
Oxygen Enrichment, %	36
Oxidant Flow Rate, kg/s	~ 85
Oxidant Preheat Temperature, K	920

Figure 3-4. The Combustor/Oxidant Supply Interface .

3.1.3 Combustor/Seed Supply Interface

The seed shall be potassium compounds and the carrier gas shall be nitrogen or another appropriate gas. The seed to gas carrier ratio shall be 10:1 by weight, and the potassium flow rate shall be 1 to 1.5% (by weight) of the total flow in the combustor. The flanged connectors shall be circular in shape. Instrumentations shall consist of flowmeters, and all electrical lines shall be voltage isolated. See Figure 3-5 for a schematic of the interfaces. See Table 3-3 for more details.

TABLE 3-3. COMBUSTOR/SEED SUPPLY SUBSYSTEM INTERFACE DATA

<u>Parameter</u>	<u>Value</u>
Flange Diameter, m	TBD
Total Seed Flow Rate, kg/s	2.1
Temperature, °C	TBD
Pressure, atm	4.9

3.1.4 Combustor/Boiler Feed Water Interface

The boiler feed water shall cool the combustor. The mechanical interface shall be made through circular flanges, and the number of manifolds between the boiler feed water and the combustor shall be determined for each of the two stages as the design is developed. Voltage isolation in all lines shall be required. Flowmeters, temperature sensors, and pressure transducers shall be the required instrumentation. See Table 3-4 and Figure 3-6 for more details on the interface.

TABLE 3-4. COMBUSTOR/BOILER FEED WATER SUBSYSTEM INTERFACE DATA

<u>Parameter</u>	<u>Value</u>
Flange Diameter, m	TBD
Cooling Water Flow Rate, kg/s	148
Inlet Cooling Water Temperature, °C	316
Inlet Cooling Water Pressure, atm	190
Outlet Cooling Water Temperature, °C	334
Outlet Cooling Water Pressure, atm	187

Figure 3-5. The Combustor/Seed Supply Interface

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Figure 3-6. The Combustor/Boiler Feed Water Interface

3.1.5 Combustor Slag Management Interfaces

The mechanical interface shall be made through circular flanges and electrically isolated support structures. The Slag Management System components include a slurry grinder, a positive displacement slurry pump, and a dispenser. See Table 3-5 and Figure 3-7 for more details on this interface.

TABLE 3-5. COMBUSTOR/SLAG MANAGEMENT INTERFACE DATA

<u>Parameter</u>	<u>Value</u>
Flange Diameters, m	TBD
Slag Capture, %	~ 85
Slag Tank Pressure, atm	5
Quench Water Flow Rate, kg/s	TBD
Aux. Water Flow Rate, kg/s	TBD
Inlet Quench Water Temperature, °C	Ambient
Cooling Water Flow Rate, kg/s	TBD
Inlet Cooling Water Temperature, °C	TBD
Outlet Cooling Water Temperature, °C	TBD
Compressed Air Pressure, atm	TBD
Compressed Air Flow Rate, kg/sec	TBD

3.1.6 Combustor/Magnet Interface

The combustor/magnet interface is summarized in Table 3-6 and shown schematically in Figure 3-8. The magnetic field strength variations are shown in Figure 2-7.

TABLE 3-6. COMBUSTOR/MAGNET INTERFACE DATA

<u>Parameter</u>	<u>Value</u>
Distance Within Magnet Bore, m	TBD
Inlet Side Magnet Bore, m	1.36
Clearance, m	TBD
Peak Magnetic Field, T	0.5
Maximum Current Density Due to Magnetic Field, A/cm ²	TBD

Figure 3-7. The Combustor/Slag Management Interface

Figure 3-8. The Combustor/Magnet Interface

3.1.7 Combustor/Instrumentation and Control Interface

The interface between the combustor and the instrumentation and controls consists of flanges, taps, holes, etc. as required. Flanges shall be required for coupling shafts of pneumatic motors, pumps, etc. This interface will be established in more detail as the design evolves.

3.1.8 Combustor/Support System Interface

The combustor/support system interface shall provide the capabilities to bear the weight of the combustor as well as to properly align, allow displacements, dampen motions, and maintain clearances during the operation of the APT. Supports shall be properly isolated electrically to stand off the Hall voltage plus margin. See Table 3-7 and Figure 3-9 for more information on this interface.

TABLE 3-7. COMBUSTOR/SUPPORT SYSTEM INTERFACE DATA

<u>Parameter</u>	<u>Value</u>
Design Voltage, kV	-25
1st Stage Length, m	2.4
1st Stage Diameter, m	1.9
2nd Stage Length, m	4.0
2nd Stage Diameter, m	1.1
Combustor Weight, kg	3300
Slag Tank Assembly Weight, kg	TBD
Slag Tank Length, m	2.6
Slag Tank Diameter, m	2.0
Support Stand Weight, kg	TBD

3.1.9 Combustor/Nozzle Interface

Water-cooled, rectangular window frame flanges shall provide the mechanical interfaces between the combustor and the nozzle. The nozzle cooling shall be provided from the combustor cooling system in a parallel circuit arrangement. See Tables 3-8, 3-9, 3-10 and 3-15 and Figure 3-10 for more details.

Figure 3-9. The Combustor/Support System Interface

TABLE 3-8. COMBUSTOR/NOZZLE INTERFACE DATA

<u>Parameter</u>	<u>Value</u>
Flange Inner dimensions, m	0.7 x 0.7
Plasma Temperature, K	2800
Plasma Pressure, atm	4.9
Plasma Flow rate, kg/s	104
Plasma Velocity, m/s	1100
Nozzle Heat Removed, MW	6
Inlet Water Pressure, atm	190
Inlet Water Temperature, °C	316
Outlet Water Pressure, atm	187
Outlet Water Temperature, °C	331
Water Flow Rate, kg/s	27

TABLE 3-9. COMBUSTOR OUTLET PLASMA ATOMIC SPECIES

<u>Atom</u>	<u>Atomic Fraction</u>	<u>Flow Rate, kg/sec</u>
Al	0.00013318	0.0288
A	0.00239776	0.7665
Ca	0.00008223	0.0264
C	0.12726240	12.2337
Fe	0.00002503	0.0112
H	0.11844901	0.9556
K	0.00332558	1.0406
Mg	0.00003888	0.0076
N	0.45289959	50.7797
Na	0.00003933	0.0073
O	0.29319573	37.5483
Si	0.00024581	0.0552
S	<u>0.00190547</u>	<u>0.4891</u>
Total	1.00000000	103.9500

TABLE 3-10. CARRYOVER OF SOLID/LIQUID SLAG SPECIES (1800 K)

<u>Species</u>	<u>Flow Rates, kg/sec</u>
Al_2O_3	0.0225
CaO	0.0369
FeO	0.0144
$MgAl_2O_4$	0.0445
SiO_2	<u>0.1182</u>
Total	0.2365

TABLE 3-11. VARIATION OF MACH NUMBER AT COMBUSTOR EXIT
(FROM COLD FLOW TESTS)

$\frac{Y}{H} =$	$\frac{X}{H} =$								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.125	0.178	0.173	0.180	0.180	0.180	0.180	0.178	0.178	0.177
0.25	0.173	0.170	0.172	0.173	0.173	0.173	0.173	0.174	0.177
0.375	0.172	0.170	0.170	0.173	0.173	0.173	0.173	0.173	0.176
0.5	0.178	0.173	0.180	0.180	0.175	0.173	0.170	0.172	0.178
0.625	0.185	0.179	0.180	0.179	0.177	0.173	0.175	0.173	0.178
0.75	0.192	0.187	0.183	0.182	0.180	0.180	0.175	0.178	0.182
0.875	0.193	0.187	0.186	0.190	0.190	0.190	0.188	0.187	0.187

Figure 3-10. The Combustor/Nozzle Interface

3.2 NOZZLE INTERFACES

This section presents interface data and information for the nozzle which interfaces with three other subsystems.

3.2.1 Nozzle/Combustor Interface

See Section 3.1.9.

3.2.2 Nozzle/Magnet Interface

Square flanges concentric with the magnet bore shall provide the mechanical interface. The supports shall limit radial motion of the nozzle relative to the bore which has a diameter of 1.36 m on the inlet side of the channel. Electrical isolation shall be maintained between the nozzle and the magnet. The fringe magnetic fields at the nozzle shall be no more than 0.5 T. Non-magnetic materials shall be used. See Figure 3-11 for a schematic of the interfaces.

3.2.3 Nozzle/Channel Interface

The nozzle shall interface with the channel through a square flange. Cooling water shall limit the channel temperatures as set by requirements on the fiberglass layers in the channel. Alignment and concentricity requirements shall be met through shimming the the channel undercarriage. The flange shall be of a quick disconnect design. The nozzle shall be designed to be removed as an integral unit with the nozzle, as well as to have provisions for removal with the channel remaining in place. See Table 3-12 and Figure 3-12 for more details.

TABLE 3-12. NOZZLE/CHANNEL INTERFACE DATA

<u>Parameter</u>	<u>Value</u>
Flange Inside Dimensions, m	0.56 x 0.56
Plasma Pressure, atm	2.0
Plasma Temperature, K	2500
Plasma Flow Rate, kg/s	104
Nozzle Temperature, °C	330
Channel Temperature, °C	150

Figure 3-11. The Nozzle/Magnet Interface

Figure 3-12. The Nozzle/Channel Interface

Figure 3-13. The Channel/Magnet Interface

3.3 CHANNEL INTERFACES

This section presents interface data for the MHD channel. Five other subsystems interface with the channel.

3.3.1 Channel/Magnet Interface

The channel/magnet interfaces shall provide for alignment, concentricity, thermal expansion accommodation, and electrical isolations requirements. Electrical isolation shall include potting around the water and electrical connections to the channel. Fiberglass coolant headers connected by plastic tubing to the metal tubing stubs on the channel shall provide electrical isolation through the cooling circuit. The supports shall allow for rapid removal and replacement of the channel. Instrumentations for the measurement of the air characteristics (humidity, temperature, gas analysis, etc), and of strain on supports shall be provided. See Figure 3-13 for a schematic of the interfaces.

3.3.2 Channel/Cooling Water Interface

The cooling water shall be deionized and provided through quick disconnects. The water shall be in a closed loop with the heat transferred to the low-pressure low-temperature boiler feed water through an intermediate heat exchanger. Cooling shall be provided to electrodes, sidebars, and insulators. See Table 3-13 and Figure 3-14 for more details.

TABLE 3-13. CHANNEL/COOLING WATER INTERFACE DATA

<u>PARAMETER</u>	<u>VALUE</u>
Flange Diameter, m	TBD
Electrical Conductivity, mho/m	TBD
Flow Rate, kg/s	106
Water Pressure, atm	5
Inlet Temperature, °C	85
Outlet Temperature, °C	127
Number of Manifolds	4

Figure 3-14. The Channel/Cooling Water Interface

Figure 3-15. The Channel/Diffuser Interface

3.3.3 Channel/Diffuser Interface

The channel/diffuser interface shall be provided through a square flange which provides capabilities for alignment of assemblies, maintaining the temperature conditions required for the fiberglass, and quickly disconnecting the two components. The flange shall be of non-magnetic materials. Flow chemical constituents entering the diffuser are the same as those entering the channel. See Tables 3-9 and 3-10. See Table 3-14 and Figure 3-15 for more details.

TABLE 3-14. CHANNEL/DIFFUSER INTERFACE DATA

<u>PARAMETER</u>	<u>VALUE</u>
Flange Inside Dimensions, m	1.1 x 1.1
Flange Outside Dimensions, m	TBD
Plasma Pressure, atm	0.7
Plasma Temperature, K	2280
Plasma Flow Rate, kg/s	104
Plasma Mach Number	1
Velocity Profiles	TBD

3.3.4 Channel/Temporary Rails Interface

Rails capable of rapid deployment shall interface with the channel. A temporary track shall be deployed after the removal of the outlet portion of the diffuser. The track shall extend the magnet bore track into the area previously occupied by the outlet portion of the diffuser. The channel shall be wheeled onto the track and dispatched to a work area for repair or maintenance. See Figure 3-16 for a schematic representation of the interface.

3.3.5 Channel/Nozzle Interface

See Section 3.2.3.

3.4 POWER CONDITIONING SUBSYSTEM INTERFACES

The interfaces among the Power Conditioning Subsystem and other APT and plant systems are provided in the following sections. These interfaces are shown schematically in Figure 3-17.

Figure 3-16. The Channel/Temporary Rails Interface

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Figure 3-17. Power Conditioning Subsystem Interfaces

3.4.1 Channel Electrode/Cable Connection Interface

The electrode/cable interface (No. 1 on Figure 3-17) defines the cable connectors between the channel electrodes and the power management equipment. The cables/connectors shall be forced air cooled through a central cooling passage in the cables and shall be designed for quick connection. The cables contain conductors from a group of adjacent electrodes and are routed to the power conditioning equipment supported in overhead racks as well as in floor trenches. Their size and rating will be established by the maximum steady state channel electrode currents, the maximum voltage between electrodes in the group connected by a cable, the maximum voltage to ground of an electrode to be connected by a cable, and the amount of heat which will be generated in the cable/connectors. The maximum conditions are for cables originating near the inlet end. Conditions in the remaining cables are reduced, progressively, toward the outlet end of the channel. See Table 3-15 for more details. Design currents and voltages for the anodes and cathodes are listed Appendix C.

TABLE 3-15. CHANNEL ELECTRODE/CABLE CONNECTION INTERFACE DATA

<u>PARAMETER</u>	<u>VALUE</u>
Number of Cathodes*	593
Number of Anodes*	560
Number of Cables	20
Number of Conductors per Cable	18
Conductor Size (AWG)	4
Max Current per Conductor, A	70
Heat Removal per Conductor, W/m	4
Max Voltage, kV	30
Inter-Electrode Voltage, V	50
Conductor to Conductor Insulation, cm	0.11
Conductor to Cable Shield Insulation, cm	0.88
Maximum Cable Operating Temperature, °C	TBD
Cooling Air Path Area, cm ²	13.5
Minimum Cable Bend Radius, cm	TBD
Maximum Cable Diameter, cm	9.86
Maximum Connector Diameter, cm	0.82

*Difference in number of electrodes (anodes or cathodes) is due to increasing height of channel along the length.

3.4.2 Station Switchyard/Power Conditioning Interface

The interface with the switchyard (No. 2 on Figure 3-17) is at the points where cables or bus bars from the station switchyard connect to take the power developed by the Power Conditioning Subsystem. The connections shall be made at the system ac disconnect device. The amount of reactive power (Volt-Amperes) which must be provided through the station switchyard to compensate for the low power factor of the Power Conditioning Subsystem output shall also be specified at this interface.

3.4.3 Plant Instrumentation and Control/Power Conditioning Instrumentation and Control Interface

The interface between Instrumentation and Control (I&C) systems (No. 3 on Figure 3-17) shall be made through the plant data highway. Either fiberoptic or electrical cables shall be used. Transfer data and control signals between the systems shall be in digital form. Standardized listings shall be used to identify characteristics and intended uses of the signals transmitted across the interface. The measurement requirements are listed in Table 3-16. The control requirements are listed in Table 3-17.

TABLE 3-16. MEASUREMENTS REQUIREMENTS LIST FOR THE I&C INTERFACE

<u>Device</u>	<u>Measure</u>	<u>Alarm</u>	<u>Logged</u>	<u>Range</u>	<u>Response</u>
Output Power	Yes	-	Yes	TBD	TBD
Rate of Power Change	-	Yes	Yes	TBD	TBD
DC Current to Inverter	Yes	-	Yes	TBD	TBD
Stack 2C Thyristors	Yes	Yes	Yes	On-Off	-

TABLE 3-17. CONTROL REQUIREMENTS LIST FOR THE I&C INTERFACE

<u>Device</u>	<u>Control</u>	<u>Indicate Status</u>	<u>Logged</u>	<u>Range</u>	<u>Remarks</u>
AC Power Output	Yes	Yes	Yes	TBD	System Set Point
Output Circuit Breaker	Yes	Yes	-	Open-Shut	---
Cable Cooling Air Flow	-	Yes	-	TBD	Interlocks

3.4.4 Auxiliary AC Power/Power Conditioning Interface

The auxiliary power and power conditioning interface (No. 4 on Figure 3-17) shall consist of the connections to ac power sources required to operate the Power Conditioning Subsystem equipment. An uninterruptable type of connection with sufficient capacity to permit orderly system shutdown and monitoring during any plant casualties shall be included. Listings shall identify and specify electrical loads at this interface. See Table 3-18 for the requirements list.

TABLE 3-18. POWER REQUIREMENTS LIST FOR THE POWER INTERFACE

<u>Load Description</u>	<u>Voltage/Phases</u>	<u>Load, kW</u>	<u>Remarks</u>
Control Power	120 V(ac)/1- ϕ	1.5	
UPS Power	120 V(ac)/1- ϕ	1.2	Ungrounded
Cabinet Fans	120 V(ac)/1- ϕ	TBD	
Main Transformer Fans	480 V(ac)/3- ϕ	TBD	

3.4.5 Waste Heat Removal/Power Conditioning Interface

The waste heat removal/power conditioning interface (No. 5 on Figure 3-17) shall define the requirements for removal of waste heat from two sources within the system. The first source of waste heat shall be the resistive losses of the channel cables. These cables shall be cooled by compressed air. A second source shall be the solid state switching devices used in the power electronic circuits, and these devices shall be water cooled. Cooling fans shall be required for the main system power transformer or for equipment panels, and they shall be powered from auxiliary ac power connections and shall not be considered part of the waste heat removal interface. See Table 3-19 for more details.

TABLE 3-19. WASTE HEAT REMOVAL/POWER CONDITIONING INTERFACE DATA

<u>PARAMETER</u>	<u>VALUE</u>
Cable Cooling Air	
Flow Rate, kg/s	TBD
Pressure, atm	TBD
Temperature, °C	TBD
Maximum Relative Humidity, %	TBD
Water Cooling	
Flow Rate, kg/s	TBD
Inlet Pressure, atm	TBD
Return Pressure, atm	TBD
Inlet Temperature, °C	TBD
Return Temperature, °C	TBD
Maximum Conductivity, mhos/m	TBD

3.5 DIFFUSER SUBSYSTEM INTERFACES

This section presents the detailed interface data and information for the Diffuser Subsystem. The diffuser interfaces with five other subsystems.

3.5.1 Diffuser/Channel Interface

See Section 3.3.3.

3.5.2 Diffuser/Cooling Water Interface

The diffuser/cooling water interface shall be made through circular flanges and shall provide for the cooling of the diffuser. The cooling water is a recirculating system using water from the steam plant steam drum. Instrumentation shall consist of flowmeters, temperature sensors, and pressure sensors. See Table 3-20 and Figure 3-18 for more details.

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Figure 3-18. The Diffuser/Boiler Feed Water Interface

TABLE 3-20. DIFFUSER/COOLING WATER INTERFACE DATA

<u>PARAMETER</u>	<u>VALUE</u>
Flange Diameter, m	TBD
Flow Rate, kg/s	47
Max Heat Loss, MWt	25
Number of Manifolds	TBD
Inlet Cooling Water Temperature, °C	340
Inlet Cooling Water Pressure, atm	TBD
Outlet Cooling Water Temperature, °C	360
Outlet Cooling Water Pressure, atm	184

3.5.3 Diffuser/Radiant Boiler Interface

The interface between the diffuser and the radiant boiler, i.e., the dump tank transition section of the Heat Recovery/Seed Recovery System, shall be made through water-cooled rectangular flanges with provision for growth. See Table 3-21 and Figure 3-19 for more details.

TABLE 3-21. DIFFUSER/RADIANT BOILER INTERFACE DATA

<u>PARAMETER</u>	<u>VALUE</u>
Flange Dimensions, m	3.6 x 3.6
Temperature, K	2280
Pressure, atm	1
Flow Rate, kg/s	104
Mach Number	TBD

3.5.4 Diffuser/Magnet Interface

The diffuser/magnet interface shall involve the magnetic fields at the diffuser, the clearances within the magnet bore, and the replacement and maintenance features of the two subsystems. See Table 3-22 and Figure 3-20 for more details. Magnetic field strength variation is shown in Figure 2-7.

Figure 3-19. The Diffuser/HRSR (Dump Tank Transition Section) Interface

Figure 3-20. The Diffuser/Magnet Interface

TABLE 3-22. DIFFUSER/MAGNET INTERFACE DATA

<u>PARAMETER</u>	<u>VALUE</u>
Distance Within Magnet Bore, m	TBD
Outlet Side Magnet Bore, m	1.93
Clearance, m	TBD
Peak Magnetic Field in Diffuser, T	0.2
Maximum Current Density Due to Magnetic Field, A/m ²	400

3.5.5 Diffuser/Structures and Supports Interface

The diffuser interface with the structures and supports shall provide capabilities for bearing the weight of the diffuser, movement due to thermal expansion, and the removal of components. The diffuser has a total mass of 28.2 tonne. See Figure 3-21, for more details.

Figure 3-21. The Diffuser/Structures and Supports Interface

4.0 BASIS OF POWER TRAIN DESIGN REQUIREMENTS

The various requirements that have influenced the selection of the specifications for the PT design are given in this section.

4.1 OPERATIONAL

The PT operational requirements are consistent with the PT operating as part of an electrical power plant meeting a set of overall plant performance requirements.

4.2 STRUCTURAL

The PT requirements are established to ensure that the structural integrity of each component is maintained under all loads that will occur during normal, off-normal, and accident conditions.

4.3 CONFIGURATIONAL

The configuration of the PT components assure that they integrate properly, both from an assembly and operational point of view with all interfacing components and also with an electrical utility plant environment.

4.4 ENVIRONMENTAL

The environmental requirements on the design and operation of the APT have been selected so as not to violate the constraints set by the Environmental Protection Agency on plant emissions, e.g., NO_x and SO_x , and on standards set for the magnetic field strengths and high electrostatic field strengths in areas remote from the PT, and for thermal pollution to the environment.

4.5 SAFETY

The safety requirements on the design, operation, assembly, disassembly and maintenance of the PT are consistent with normal electric utility safeguards practices. They are also consistent with the safeguards necessary for those unique features of the MHD plant that are not accounted with standard steam

power plants, i.e., high magnetic fields, cryogenic conditions, and large inductively stored energies. Any unusual health and safety considerations will be identified for the MHD plant.

4.6 MAINTENANCE

The PT requirements assure that the components can be assembled/disassembled and maintained efficiently. The design, based on these requirements, assures the practicality of maintenance and is consistent with the specified useful lifetime and mean-time-between-failure goals.

4.7 QUALITY ASSURANCE/CODES AND STANDARDS

The PT requirements are consistent with all of the nationally recognized quality assurance standards such as for the American Society of Mechanical Engineers. The requirements are selected to assure high quality.

4.8 SHIPPING AND HANDLING

The PT requirements are consistent with transporting components by rail, and assure that the design permits ease of handling during assembly/disassembly and maintenance.

As defined in the Development Plan for the PT (see Section 5.0 of that plan), tests of the components are scheduled to either confirm or lead to alterations in the PT design requirements.