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PEGASUS: A MULTI-MEGAWATT NUCLEAR ELECTRIC PROPULSION SYSTEM

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DISCLAIMER

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Introduction

With the Space Transportation System (STS), the advent of space station Columbus and the development of expertise at working in space that this will entail, the gateway is open to the final frontier. The exploration of this frontier is possible with state-of-the-art hydrogen/oxygen propulsion but would be greatly enhanced by the higher specific impulse of electric propulsion. This paper presents a concept that uses a multi-megawatt nuclear power plant to drive an electric propulsion system. The concept has been named PEGASUS, PowEr GenerAting System for Use in Space, and is intended as a "work horse" for general space transportation needs, both long- and short-haul missions.

The recent efforts of the SP-100 program indicate that a power system capable of producing upwards of 1 megawatt of electric power should be available in the next decade. Additionally, efforts in other areas indicate that a power system with a constant power capability an order of magnitude greater could be available near the turn of the century. With the advances expected in megawatt-class space power systems, the high specific impulse propulsion systems must be reconsidered as potential propulsion systems. The power system is capable of meeting both the propulsion system and spacecraft power requirements.

Magnetoplasmadynamic (MPD) Thrust System

The MPD system is composed of thrusters, propellent tanks, and thermal control subsystems. A schematic of the major components of the MPD thruster system is shown in Figure 1. Power control and regulation is confined to adjustments of the power system alternator output. Based upon ongoing work at the Jet Propulsion Laboratory (JPL) (King and Vondra 1984) to evaluate thruster lifetime with subscale devices, and the present understanding of cathode physics, thruster lifetime (which is limited by the cathode) is estimated to be 2,000 hours. But life test of a multimegawatt MPD thruster can only follow a vigorous development program, which is not presently included in NASA's research program.

The MPD thruster accelerates propellent by means of a magnetic body force. Exhaust speeds of 15,000 to 80,000 m/s have been measured on a thrust stand using a variety of propellents (Burton et al. 1983). Thruster conversion efficiency of electrical power to directed kinetic energy has been measured at 35% on a thrust stand, and analysis suggests that 50-60% is ultimately possible (Burton et al. 1983 and King et al. 1981).

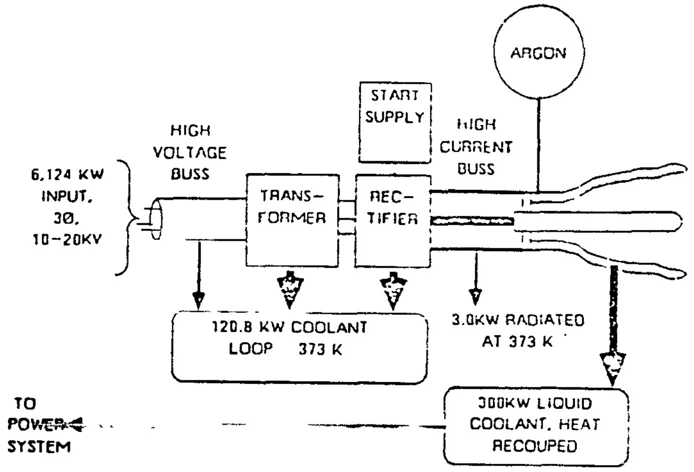

FIGURE 1. MPD THRUSTER SYSTEM COMPONENTS

The net propulsion system mass for this conceptual design (excluding power system and the coolant plant) is 5,144 kg, assuming the electrical system efficiency of 98% and 50% conversion efficiency for the MPD thruster.

The MPD thruster has been studied extensively with argon propellent. The cryogenic storage of argon presents no unusual constraints or problems, and a 16,301 kg storage tank has been designed with a mass of 721 kg (Eberhardt et al. 1981) which is shuttle compatible. Potassium is the working fluid in the dynamic conversion equipment. Since its ionization potential is about one-fourth that of argon, potassium should provide a higher thrust efficiency than argon. Potassium offers a simpler storage problem in that it can be stored in a solid form, but the small fraction of the exhaust that flows back toward the spacecraft may plate out on many surfaces and cause operational problems. Though potassium may be a better propellent from a performance and storage standpoint, contamination of the spacecraft surfaces may require argon propellent.

Nuclear Electric Power Source

The proposed power source for the electric propulsion system is an 8.5 MWe boiling liquid metal, space-based nuclear power system. The system employs a direct Rankine power cycle and is designed to provide 6 MW of electrical power for the electric propulsion system with an additional 1.0 to 1.5 MW of electrical power available for mission-specific tasks and/or experiments on board the space craft. The power system comprises five major subsystems. These are a cermet-fueled, boiling liquid metal fast reactor; a four-pi contoured man-rated reactor shield; an axial flow turbine and superconducting alternator for power conversion; a power conditioning subsystem; and a heat rejection and thermal control subsystem. A schematic diagram of the system is shown in Figure 2, and a discussion of the basic design of these subsystems follows.

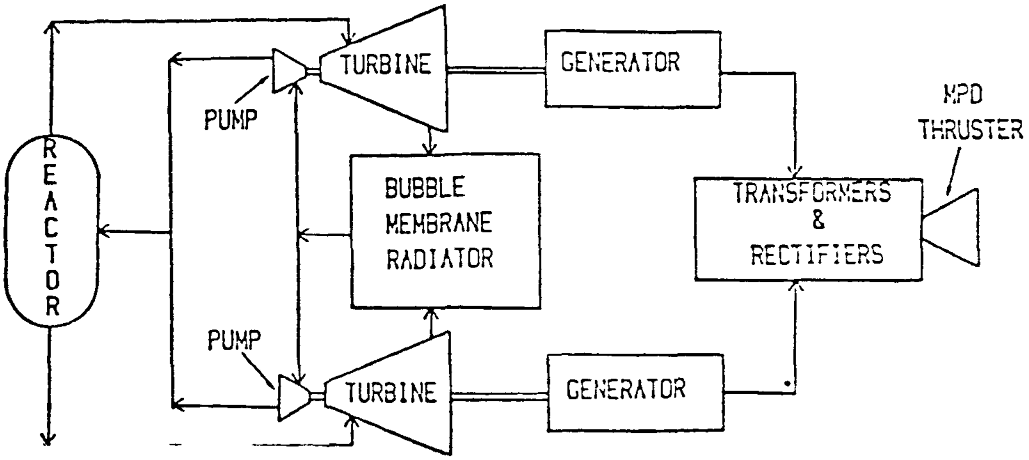

FIGURE 2. PEGASUS SCHEMATIC DIAGRAM

The reactor is a right cylinder approximately 53 cm long and 50 cm in diameter with mass of 3730 kg. A preliminary thermal analysis of the cermet fuel, assuming full power operation and stable nucleate boiling, indicates that a peak centerline fuel temperature of 1300°C can be expected for a coolant channel bulk temperature of 1100°C. (It should be noted, however, that detailed thermal analysis of this system, or any system involving two-phase flow, will require additional experimental and theoretical work.)

The shield is a composite material of LiO, W, and LiH. To maintain the physical integrity of the shield, it is cooled by the reactor inlet coolant. The mass of the shield is estimated at 28,350 kg and will require that the major portion of it be delivered to orbit on a separate shuttle load, to be installed as the system is developed.

Power conversion is accomplished by a pair of alternators driven by a counter-rotating multi-stage radial flow turbine design. This is a saturated potassium vapor turbine design, with optimum turbine efficiency obtained at blade speeds of 300 to 600 m/sec. Actual system shaft speeds will be determined through trade-off studies involving stress analysis of the turbine components at desired operating temperatures and size optimization of the system.

Superconducting alternators were chosen to develop the electrical power because of their high power-to-weight ratio. Each superconducting alternator is expected to operate at 1500 Hz and 20 to 20 kVA, with the capability of providing a continuous electric power output of 5.0 megawatts. The overall power conversion subsystem is expected to mass on the order of 840 kg and have a specific weight of approximately 0.05 kg/kW with an efficiency of 85%.

The power conditioning system design is dictated by the needs of the MPD. This consists of the transformers, rectifiers, and transmission cables necessary to provide the 25,000 amperes DC needed for full power operation of the MPD.

Heat rejection for the power system is accomplished by high- and low-temperature heat rejection subsystems. The high-temperature system handles waste heat rejection from the turbine exhaust, and the low temperature system handles waste heat from the alternator and other components. The high-temperature heat rejection system consists of a bubble membrane radiator, associated pumps, piping, and structure sized to reject 21.5 MW of waste heat during full-power operation. The low-temperature heat rejection system consists of an auxiliary cooling system designed to reject waste heat produced within the alternator and other equipment operating at much lower temperatures. The auxiliary cooling system has its own working fluid, pumps, and radiator, utilizing helium as its working fluid. It is composed of a Stirling cycle cryogenic cooler, an auxiliary chiller, a low-temperature radiator, and associated pumps and piping.

Conclusion

The total mass of the PEGASUS system for this conceptual design is 41,644 kg, with the capability to produce up to 8.5 MW of electrical power.

The size and mass limitations of the STS are a prime consideration in the design, and the collapsed system will be capable of lower earth orbit insertion by two shuttle missions. Development of this power system could be completed by the mid 1990s with the complete propulsion system available near the turn of the century. Since this is an advanced system concept, some development efforts are still needed in the fuels, heat rejection, and turboalternator areas.

Acknowledgement

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