The Space Congress® Proceedings | 1997 (34th) Our Space Future - Uniting For Success

May 1st, 1:00 PM

Paper Session III-C - Proton Exchange Membrane Fuel Cells for the Next Generation Spacecraft Applications

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by
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Abstract

This paper presents the results of an assessment of the requirements and technology for the Proton Exchange Membrane (PEM) fuel cell as the electric power source for next-generation spacecraft, and particularly as an accepted upgrade to replace the current Orbiter alkaline fuel cell. As part of the technology assessment, a commercially available 4-kW PEM fuel cell was tested for over 400 hours at NASA-Johnson Space Center using hydrogen and oxygen as reactants. The findings of this evaluation, as well as a short summary of some test facility improvements and accomplishments as they relate to fuel cell testing in general, are presented. A short status of other items in the Orbiter PEM Fuel Cell Upgrade effort is also presented.

Proton Exchange Membrane Fuel Cells for the Next Generation Spacecraft Applications

Introduction

An in-house review of the requirements and technology for, and demonstration of, a Proton Exchange Membrane (PEM) fuel cell as the next generation electric power source for the Orbiter and future spacecraft applications has been completed and will be discussed in this paper. A need exists to replace the current Orbiter fuel cell with a new low cost, high power density fuel cell while maintaining the excellent reliability and safety record of the current system. PEM fuel cells offer the potential for significant long term cost savings, safety and reliability improvements, and a much greater assurance of continued technology readiness that would not be offered by continuing with the current alkaline fuel cell powerplant. Also, the alkaline fuel cell has lost to other types of fuel cells (PEM in particular) technology development supported by government and private industry funds. The electric car fuel cell development is almost exclusively in the hydrogen / air / PEM arena. To achieve low cost, service life beyond the current 2400 hours specification, and higher power density, a system employing simple design and low cost materials will be needed. All of these attributes can be found in a PEM fuel cell. Advances made in research, development, and even commercial market readiness, for the fuel cell powered electric car and related industry programs have significantly expanded the technology base. Other areas that the PEM fuel cell is being considered for use with are: (1) the Reuseable Launch Vehicle, (2) battery replacement for an advanced space suit for Lunar or Mars exploration, (3) ground based power systems for the Mars surface, and (4) electric power source for a possible upgrade of the Orbiter's APU/hydraulic actuator system with electromechanical actuators. The project cost for the spacecraft applications, if achieved, will be substantially low compared to what NASA pays for the current fuel cell today. The PEM stack power density obtained to date has been comparable to, if not better than, the current alkaline fuel cell. The primary issue identified in this review was fuel cell powerplant compatibility with micro-gravity and launch environment. Technology maturity and readiness for space application must be proven through extensive test evaluation. A program has been initiated to address the technical issues and provide data to support management decisions. One of the first tasks completed for this effort was the test of a 4-kW demonstrator unit for over 400 hours at the Johnson Space Center. The results of this effort are discussed below, as well as the status of the in-house design definition and technology programs.

Energy Partners 4-kW Fuel Cell Evaluation

The program initially began with the integration of a leased 15-cell, 4-kW Proton Exchange Membrane (PEM) Fuel Cell system manufactured by Energy Partners , Inc. (EPI), of West Palm Beach, Florida, into the Fuel Cell Test Bed at the Power Generation Test Facility (Building 354) of the Energy Systems Test Area (ESTA) at NASA, Johnson Space Center. This fuel cell was attractive to NASA as a candidate for shuttle upgrade because of its technology readiness and commercial availability. This test program was effectively the first part of a larger effort to evaluate PEM fuel cells for this upgrade effort. In an effort to eliminate the increasing costs to the government associated with on-going monthly lease extensions, the fuel cell system was purchased from the vendor during the test program. Each cell's active area was 0.75 square feet. Included in the fuel cell stack were pre-humidifying assemblies that provided a means of "passively" pre-humidifying the reactant inlet streams on their way to the reaction sites of the fuel cell. The manufacturer rated the fuel cell as capable of providing 4 kW when operating on hydrogen and oxygen and 2 kW when operating on hydrogen and air. The stack weighed 120 lbs with the end plates both weighing ~40 lbs each. This left the cell stack and internal pre-humidifier assembly at 40 lbs.

On reactant tests were performed in three phases from 5/96 to 10/96. The first phase (Phase 0) was structured primarily to become familiar with the operation and performance of both the fuel cell system and ESTA supplied support stand. Approximately 60 hours of operational time was accumulated over 14 days of testing during this phase. During this phase, a water separator chilling bath, automatic computer control of the electrical load profiles, user control of reactant delta pressures, and automatic control of the water separator drain valves were added to the stand as improvements to the as-delivered test system. The second phase (Phase 1) was structured to evaluate the effectiveness of the water separator chilling bath and the effect of reactant-to-reactant delta pressure. One week of round-the-clock testing was accumulated during this phase. The third phase (Phase 2) was structured to evaluate the effect of coolant loop temperature control and stack reactant absolute pressure on fuel cell performance. Three weeks of round-the-clock testing were accumulated during this phase.

In all, 440 hours of operational time was accumulated. The full manufacturer's (>4kW) rated performance was met with the ESTA testing. The test system operated continuously for ~110 hours during the last week of testing; no shutdowns occurred during that week. Average cell voltage degradation was 3 microV / hr , which compares very favorably over the 21 microV / hr average cell voltage degradation for the current alkaline fuel cell. The PEM fuel cell has tolerance for water removal system failures and flooding in that no permanent damage will have occurred after water is removed. Alkaline fuel cell flooding is almost always permanently damaging. There is not a requirement for precise reactant pressure control, and related expense, that is absolutely required for the alkaline fuel cell. Start up and shut down of the system involved providing reactants to the stack and starting the cooling water loop and oxygen circulation loop; there were no electrolyte concentration / flooding concerns that are inherent with the current alkaline fuel cell. The EPI fuel cell power production was ~80 % of the current alkaline fuel cell's power production at the point shown in Figure 1. It is important to note that two factors which affected the performance of the EPI stack were present. The first was the relatively low temperature of the stack during tests at ESTA. The second was the presence of inerts in the gas stream from two sources; these were: (1) definite high concentrations of argon (1900 ppm by volume) in the oxygen supply from the tube trailer supply and (2) a suspect 3-way solenoid valve (which was part of the vendor supplied fuel cell system) which exhibited a tendency to leak inerting nitrogen into the oxygen stream whenever oxygen pressure dropped due to increased supply demands from the fuel cell. The internal pre-humidifier supplied from the manufacturer caused performance shortcomings that have also been recognized by the manufacturer. The manufacturer of this fuel cell has moved towards external pre-humidification (separating the cooling and pre-humidification) as a means of increasing performance in general and offering greater operational control. The gravity-dependent water separator was another component of the fuel cell system which exhibited less than ideal operation. This was primarily due to the fact that the separator was designed for service in higher pressure (100-250 psig) compressed-air fluid systems. With the relatively low pressures (20-35 psig) involved with this system, the device's float-controlled, automatic drain did not always re-seat properly at the completion of a drain cycle. In an attempt to "fix" this problem, the JSC test team added a timer-controlled 2-way valve at the water outlet of the water separator. This greatly improved the overall reliability of the water separator process, but there was still a significant amount of excess oxygen flow carried with the out going water stream. Ideally, only bulk product water would be drained from the separator with very little extra oxygen gas being carried out with the exiting water stream.

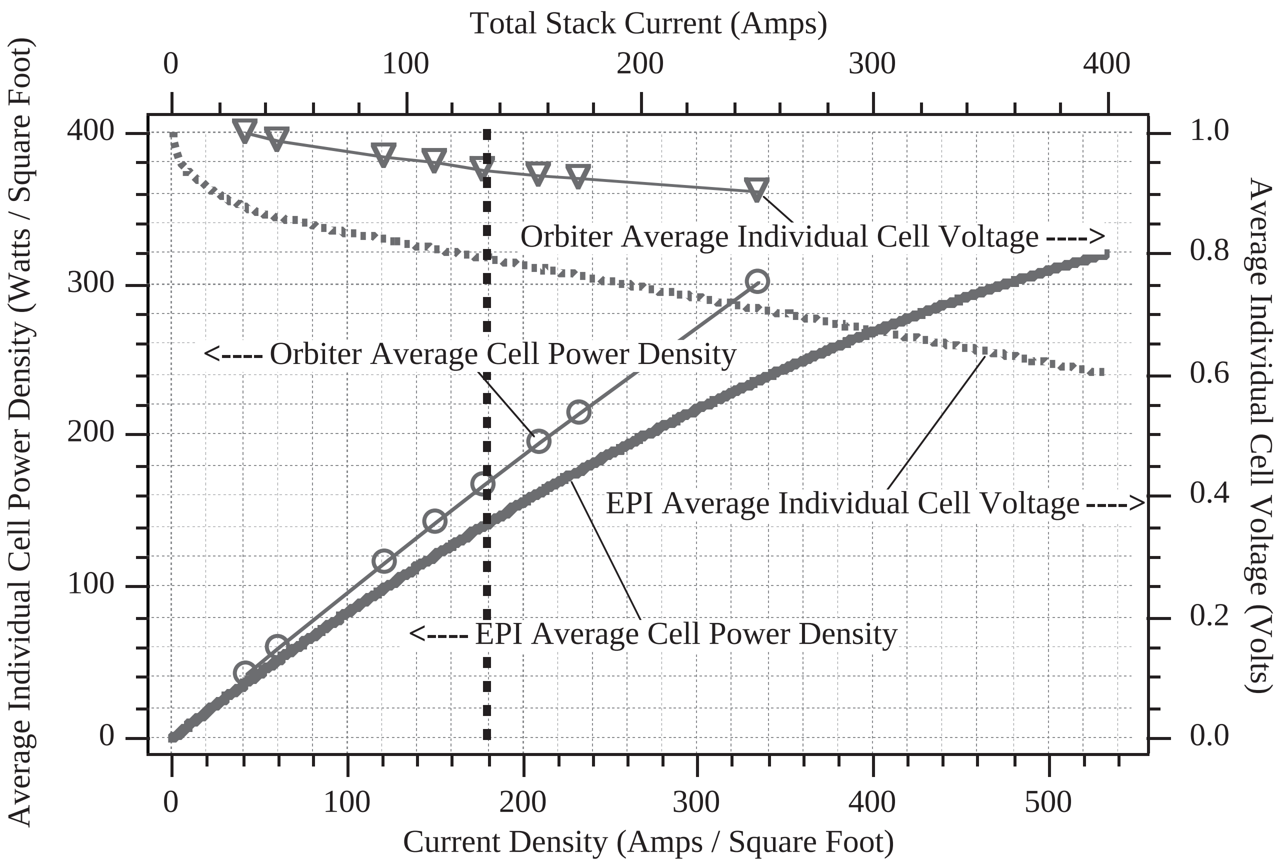

Figure 1. Average Cell Voltage and Average Cell Power Density vs. Total Stack Current and Cell Current Density for both the current Orbiter Alkaline Fuel Cell and the Energy Partners, Inc. Fuel Cell evaluated as part of the test program.

General Fuel Cell Test Improvements

During the planning phase of the test described above, the responsible parties of NASA-JSC have continued working in the area of equipment procurements and test facility modifications for the improved ability of the ESTA to support fuel cell testing for NASA and other government agencies, and also for possible outside organizations. These efforts have been focused primarily at Building 354 of the ESTA. Significant accomplishments are summarized as follows. Designs, supporting documentation, procedures, fabrication, functional check out, and safe use of the Fuel Cell Test Bed was completed to support the Energy Partners Fuel Cell Test. Three of the several available electronic load banks (with a combined power handling capability and current handing capability of 32000 watts and 2600 amps, respectively) have been used to directly support the fuel cell test mentioned above. These load banks were: (1) electrically connected in parallel to dissipate the fuel cell's electric load current, (2) controlled from their rear panel analog control input from the test computer's analog output ports, and (3) modified to allow remote control of their main load connection relays from dry contact relays controlled by the test computer. Equipment that was procured in fiscal year 1995 in anticipation of developing an Orbiter Improved Cell Performance Monitor breadboard development project was evaluated with its use as the individual cell and stack voltage measurement system for the fuel cell test mentioned above. Electronic pressure regulators procured in fiscal year 1995 were successfully used to control the reactant pressures to the fuel cell stack during the test discussed above. Sufficient experience was gained and some small procurements were completed that should allow for complete automation and unattended continuous operation of the test system for planned fuel cell test programs; this should result in significant labor cost savings in the long term.

Technology Development Status

The effort to characterize the state of technology readiness of PEM fuel cells for next generation spacecraft has resulted in the following set of indicators.
The primary development emphasis for terrestrial PEM fuel cells has been with the hydrogen / air systems. A few of the developers of these fuel cell systems have also produced hydrogen / oxygen systems for special purpose operating environments; the majority of these have provided a recirculating oxygen stream with the retention of their basic air planform. The recirculating oxygen stream replaces the excess air flow stream in order to effect water removal from the stack by entrainment. Since this could be considered the most common of the stack product water removal methods, the development of a launch-environment (high g's and vibration) and micro-gravity compatible water separator to use with the typical recirculating-oxygen stack has been recognized as a development item. Two areas of investigation and evaluation have been entered into by a team consisting of persons from several NASA centers. These are: (1) dynamic water phase separators much like the current Orbiter fuel cell powerplant's, and (2) passive (probably membrane-based) water separators. Related to this effort is a requirement to develop a reactant gas pre-humidifying system that is compatible with the gravity and vibration environments just mentioned.

Two additional fuel cell vendor's stacks are planned for testing at JSC in the next year. The first of these is one that was developed by International Fuel Cells as part of a DARPA funded program to develop a fuel cell replacement for the existing battery power source on an Unmanned Underwater Vehicle (UUV). The second is a stack from Ballard Power Systems, although the particular model had not been determined at the time of this writing. The team has initiated a NASA Cooperative Agreement Notice (CAN) effort for joint industry / NASA development of flight prototype hardware demonstrations including a sub-scale powerplant and potential flight experiment.