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Overview of Canadian Defense Department's fuel cell centred AIP development program

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AN OVERVIEW OF THE CANADIAN DEFENCE DEPARTMENT'S FUEL CELL CENTRED SUBMARINE AIR INDEPENDENT PROPULSION (AIP) DEVELOPMENT PROGRAM

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INTRODUCTION

The Canadian Navy has an operational requirement that will necessitate the replacement of its ageing conventional diesel electric submarines with modern conventional SSKs. Along with the proposed submarine replacement program, there is a strong desire to increase significantly the submerged endurance of the new boats to be procured, with the fitment of an Air Independent Propulsion (AIP) system. Option analysis conducted over the past three years has suggested that electrochemical energy conversion systems, and in particular fuel cells, have a realistic potential to narrow the present gap between what technology can provide vis à vis what the operational requirement demands. Canada's Department of National Defence (DND) has concentrated its development effort on *Ballard Power Systems'* (BPS) solid polymer fuel cell (SPFC) technology and *Alupower Canada Limited's* aluminum based semi-fuel cell technology. Both companies were contracted to assess the feasibility of their particular technology's integration into the currently operational Oberon class submarine and a typical modern hull design. A net energy and power requirement of 100 MWHRS and 300 KW, respectively, were given as minimum requirements. The results of these studies, not surprisingly, indicated that both systems have a realistic potential of achieving the stated requirement, with only modest increases of approximately ten metres in overall hull length. At present, development work is continuing with both companies; concentrating on higher risk development issues. Further, near term development is planned, using the above mentioned two technologies, which will involve the development of scaled energy conversion systems, between 30 and 50 kilowatts, directed towards the uniqueness of the submarine environment.

THE ALUMINUM-OXYGEN SEMI-FUEL CELL OPTION

This semi-fuel cell option provides electrical power through the oxidation of an aluminium alloy in the presence of an alkaline solution and an oxygen cathode. The *Alupower* study for DND compared the performance of aluminum based systems. These included an aluminum-LOX system (Al/LOX), an aluminum-decomposed hydrogen peroxide system (Al/DH_2O_2), and an aluminum-hydrogen peroxide (Al/H_2O_2) system, where the peroxide would be introduced directly into the flowing electrolyte. The Al/H_2O_2 based system was deemed unacceptable owing to higher system volume, high heat levels, higher hydrogen off gassing, and the requirement of extremely high electrolyte flow rate. Both the Al/LOX and the Al/DH_2O_2 based systems circulate gaseous oxygen to the gas cathode, where oxygen is reduced to provide hydroxide ions for the cell reaction. The Al/LOX system involves the storage of subcritical (near boiling point) LOX, which is boiled off at the required rate, with the use of heaters internal to the liquid oxygen tanks and then heated to the required temperature. The Al/DH_2O_2 system involves the decomposition of hydrogen peroxide to produce oxygen and water. These are then separated, with the oxygen supplied to the cell stacks, and the water mixed with highly concentrated KOH solution to supply make-up electrolyte to the system. Both systems require a continual input of make-up electrolyte; to balance the quantity of electrolyte entrained in the sludge removed, to fill the cell space created by the anodes as they are depleted, and to provide water for the formation of alumina trihydrate (gibbsite). The Al/DH_2O_2 system supplies this make-up electrolyte as explained above, whereas the Al/LOX system stores the required volume of electrolyte pre-mixed, for gradual addition to the system.

Refuelling of either aluminum system would consist of removing the spent cell stacks, which are broken into 40 cell units housed in rigid containers, and reloading a new set into the submarine. A total of 64 such units would be replaced during each refuelling period, each of which would weigh approximately 500 kg. The gibbsite sludge would be pumped out, and the liquid reactants pumped in. Reloading of the cell stack units would require a dedicated refuelling hatch and handling system, much the same as is used to handle torpedoes.

It was concluded that the system supplied by LOX was the preferred option, and layout studies were carried out to develop the conceptual design. The extended endurance options were also investigated. With the larger diameter modern submarine, it was conceptually demonstrated that a remarkable, full 70 day mission at the 300 KW power level is possible, without surfacing or resorting to snort mast usage. Average power levels in the range of 50 to 1000 KW are readily accommodated by varying the design. Peak powers of up to three times the average level are also accommodated. The use of atmospheric air can be used via a snort mast to conserve LOX, without a loss in performance.

Future Al/LOX semi-fuel submarine development issues centre around; cell stack development, electrolyte management, the crystalliser and separator system, and gas management owing to safety and performance considerations. The next phase of development is the production of a 40 KW exploratory development model. This phase will encompass the development and integration of the above mentioned subsystems. If successful, a further, full scale land based development model will be required before either of the two fuel cells will be considered for eventual integration into a future Canadian Patrol Submarine.

THE SOLID POLYMER FUEL CELL OPTION

In the context of Solid Polymer Fuel Cell (SPFC) submarine AIP technology, there are the hybrid and monopower configurations. Both configurations maintain the present lead acid battery banks for high power demands and emergency backup. The hybrid submarine is one in which an SPFC power plant is added to the base diesel-electric design. The diesel generators provide power while on the surface and the SPFC power plant provides power while submerged. The SPFC power plant's fuel is methanol; oxygen gas is supplied to the fuel cells from liquid oxygen (LOX) storage. In the monopower submarine configuration, the diesel generators have been removed and the SPFC power plant with battery provides all necessary power to operate the vessel during surface and submerged operations. The only fuel is methanol; no diesel is required. Whilst on the surface or during snorting operations, air is supplied to the fuel cells. During submerged operations, liquid oxygen is supplied to the fuel cells as a gas.

Both SPFC options are comprised of several integrated subsystems. Reactant (methanol and oxygen) storage and processing systems provide hydrogen and oxygen gases to the fuel cells. The fuel cells convert these gases into electricity, potable water and heat. The water is stored for both domestic use, and recycled back to the reformer. Heat is recycled back to the reformer. A by-product of the fuel processing, carbon dioxide, is dissolved in seawater for silent discharge overboard. Electrical DC power is fed into the vessel's existing electrical system working in parallel with the main battery for backup. For redundancy, the power plant is split into two parallel systems, each providing half of the required power. The monopower submarine configuration includes air compression equipment to allow operation utilising atmospheric air.

Methanol was selected as the fuel owing to its safety in handling, good energy density, ease of refuelling, and low cost. It is converted to hydrogen through a steam reforming process. This common industrial process has been developed for use in conjunction with an SPFC at *BPS* under a separate DND contract. This work has already produced a compact and efficient 10 KW unit known as the Modular Methanol Fuel Processor (MMFP).

Supercritical liquid oxygen (LOX) storage was selected for stability and safety. Storage at higher pressures assures safe, passive relief overboard at any depth should it be required. Supercritical oxygen exists in a condition that can best be described as a cloud, without any liquid/gas interface that would result in sloshing, hence affecting vessel trim during vessel manoeuvring. LOX is converted to gas, utilising waste heat from the power plant.

The AIP SPFC provides 440 Volts DC regulated to the vessel's main electrical busbar. Output voltage is regulated by adjusting the oxygen concentration fed to the fuel cells. Ancillary systems (small circulation pumps and compressors), are deemed to have a negligible impact on the signature of the submarine.

Future SPFC development issues: with respect to submarine power plant development, require further investigation of and a number of development considerations and technical options. As operational requirements become further refined, the maximising of submerged endurance becomes critical. Choices of fuel and oxidant type need further investigation; i.e., methanol versus kerosene and LOX versus hydrogen peroxide. Higher risk technical development issues, such as, fuel reforming, CO_2 disposal, fuel cell performance and size, voltage regulation, and control and monitoring are presently being investigated. These issues, although not deemed to be insurmountable, must be further investigated if SPFC technology is to be eventually integrated into a future Canadian Patrol Submarine.

CONCLUSIONS

At this early stage of development, both technologies demonstrate promise in being able to fulfil a future mission requirement. To effect the desired operational requirement, further development of both systems is needed; primarily, directed towards mitigating some of the higher risk areas. It is planned that the two tier development approach will continue until at least the end of the exploratory development phase. At that decision point, it is envisaged that development directed towards a full scale integrated AIP system will proceed with the most promising of the two technologies.