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HYDRIDE BED/FUELCELL PROJECT

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Abstract

The Hydride Bed/Fuelcell Project will result in the development and production of a prototype Fuelcell Powerplant for Mining/Tunneling Locomotives. This powerplant will replace and outperform batteries, currently utilized for mining and tunneling. The Mine Locomotive Project is a project of the Fuelcell Propulsion Institute (FCPI) consortium.

Introduction

Mining/Tunneling Locomotives are a highly regulated resource essential to mining and tunneling. Powerplants for these Locomotives currently utilize batteries, tethered electric and diesel. The utilization of diesel fuel is highly regulated and very cost intensive due to the required air exchange in the enclosed spaces. Tethered electric resolves the exhaust issues but presents operational constraints and worker safety issues. Batteries are widely used; however, the power density of a battery is not as high as desired and a great deal of time and effort is utilized in maintenance and recharging.

The Mine Locomotive Fuelcell Powerplant prototype under development will represent an improvement over batteries by providing power over a longer use period, allowing rapid refueling, and increased productivity. The powerplant waste products are hot water and warm air. The Proton Exchange Membrane (PEM) Fuelcell Stacks produce DC electricity by combining hydrogen with oxygen from the ambient air (pumped through the Stack) with low-pressure gaseous hydrogen from the Hydride Bed. The waste products are water and heat. Part of the waste heat will be utilized to warm the hydride bed, making up for the negative heat of desorption of hydrogen from the metal-hydride.

The Fuelcell Propulsion Institute determined that a conventional battery powered Mine Locomotive could be powered by a Fuelcell Powerplant having the capability to produce 14 kW of peak electrical power. The storage of approximately 3 kg of hydrogen in the metal-hydride will provide more than 8 hours of operation for mining operations (Warren Electric).

Mining/Tunneling Locomotive powerplants represent a niche market for the Fuelcell Powerplant that is cost competitive with current technologies in use. A downside to the Fuelcell Powerplant, for many applications, is the weight of the metal hydride bed; however, Mine/Tunnel Locomotives are usually ballasted to enhance tractive efficiency. Fuelcell Stack costs are currently high due to limited demand; however, the cost benefits (productivity, safety and pollution) for Mine/Tunnel Locomotives outweigh these capital costs. Economic evaluation by FCPI predicts cost savings from the utilization of the Fuelcell Powerplant for Mine Locomotives (Gaibler and Miller, 1998).

The Hydride Bed/Fuelcell Project requires:

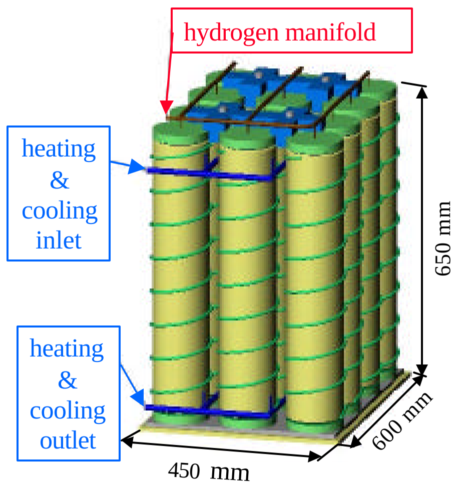
(1) The design, development and fabrication of a metal-hydride bed,
(2) The design and fabrication of Fuelcells (utilizing Fuelcell Stacks provided by Nuvera, of Milan, Italy), and
(3) The design, development and fabrication of a powerplant control system to integrate the Hydride Bed and the Fuelcells into a Mine Locomotive Fuelcell Powerplant.

Hydride Bed

A metal-hydride was chosen as the hydrogen storage media for the Mine Locomotive Fuelcell Powerplant to provide a safe, low pressure and large capacity storage of fuel. Hydrogen may be stored at approximately 1.5 weight percent in the metal-hydride. The goal of 3 kgm of hydrogen storage thus requires approximately 200 kgm of metal-hydride. The metal-hydride chosen for this prototype is Hydralloy C15 (a product of GfE, Nuremburg, Germany). Hydralloy C15 exhibits a plateau pressure of approximately two atmospheres at room temperature and has a good record of consistency after many recharges.

The Hydride Bed utilizes twelve aluminum cylinders having a proprietary internal configuration to control packing density and heat transfer. The bed will be warmed during operation via a re-circulating warming system utilizing water as the heat transfer fluid. Recharging will be likely accomplished by exchanging hydride beds (due to regulatory concerns about gaseous hydrogen underground). A conceptual picture of the Hydride Bed is shown in Figure 1. The recharging goal of 30 minutes is quite ambitious and may require further design modifications to effectively remove the heat of formation and keep the bed temperature to less than 50 degrees Celsius during charging at these high rates. The increase in Hydride Bed temperature increases the equilibrium overpressure of hydrogen, thus disallowing the Bed to absorb more hydrogen at the charging pressure of approximately 30 bars.

Figure 1. Mine Locomotive Hydride Bed

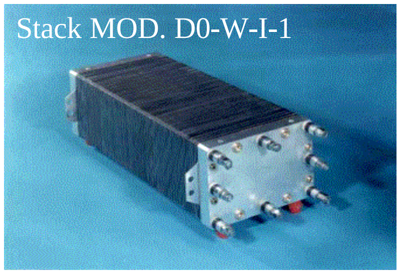


- Bed Weight ~ 350 kg
- Hydride: C-15 by GfE
- Capacity = 3 kg H_2
- Delivery Rate$_{max}$ ~ 170 slm
- Refueling time ~ ½ h

Fuelcells

The Fuelcell Stacks (see Figure 2.) are designed to produce 7 kW (52 volts at 135 amps) from each stack at peak power. The powerplant will contain two stacks, wired in series, to produce 14 kW (104 volts at 135 amps) at peak power. The peak power design requires air supplied at 1.5 bars and hydrogen supplied at 1.8 bar, the airflow rate at peak power is 24 cubic meters per hour for each stack. The air handling equipment to produce these pressures and flows is fairly large and power intensive (2 kW of electric power can easily be consumed at peak output). The demineralized cooling/humidifying water supplied to the Stacks is also at maximum flow rate during peak power demands. Fortunately, peak power demands are very short-term for the Mine Locomotive, the usual power demand will be 7 kW or less. Lower power requirements should allow the lowering of the air pressure, airflow rate and hydrogen pressure. The utilization of DC motors for the air pumps and water pumps allow pump speed/flow rate to be changed as power demand requirements vary.

Figure 2. Nuvera Fuelcell Stack



Courtesy Nuvera (De Nora)

Mine Locomotive Powerplant Fuelcells

- Stacks Required: 2
- Stack Voltage: 54 V
- Stack Current: 135 A
- Air Required: 400 slm/stack
- Air Pressure: 1.5 bar
- Hydrogen Required: 85 slm/stack
- Hydrogen Pressure: 1.7 bar
- Coolant Water Required: 100 lm/stack

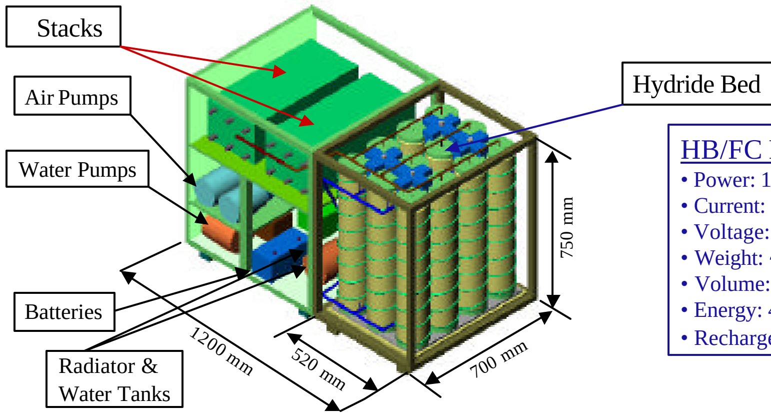
Fuelcell Powerplant

The Fuelcell Powerplant (see Figure 3. for conceptual layout) requires the integration of the Hydride Bed and Fuelcells through the use of a Control System that monitors power demand from the locomotive and adjusts air flow rate and pressure, hydrogen pressure, water flow rates and cooling fan speeds to optimize the efficiency of the powerplant and meet the Locomotive's demands. This portion of the project is in the early development stage.

Mine Locomotive

The Mine Locomotive with the prototype Fuelcell Powerplant will be displayed at MINExpo 2000 in Las Vegas, NV, October 9-12, 2000. Complete integration and test of the Mine Locomotive with the Fuelcell Powerplant will commence after it returns from the show. The Mine Locomotive and comparisons with battery power and the Fuelcell Powerplant are shown in Figure 4.

Figure 3. Mine Locomotive Powerplant

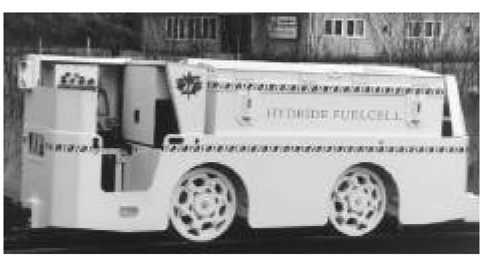


HB/FC Powerplant
- Power: 14 KW (gross)
- Current: 135 A
- Voltage: 104 V (series stacks)
- Weight: ~ 550 kg
- Volume: ~ 630 L
- Energy: 48 KWh
- Recharge time: ~ ½ h

Powerplant Concept Drawing--Work in Progress
- Designed for Battery Powered Mine Locomotives to aid in customer evaluation
- Will be interchangeable with a Four-Ton Mine Locomotive's Battery
- Hydride Bed may be easily replaced with a recharged one

Figure 4. Mine Locomotive

Four-Ton Mine Locomotive



Courtesy of R.A. Warren Equipment

Battery Power

- Power: 7.1 KW (net)
- Current: 76 A
- Voltage: 94 V
- Weight: 1650 kg
- Volume: 520 L
- Energy: 43 KWh
- Operating time: 6 h
- Recharge time: 8 h

Performance Capability Favors the Hydride Bed/ Fuelcell Powerplant!

HB/FC Powerplant
- Power: 14 KW (gross)
- Current: 135 A
- Voltage: 104 V
- Weight: <550 kg
- Volume: <650 L
- Energy: 48 KWh
- Operating time: 8 h
- Recharge time: ~½ h

Conclusions

The economic benefits of utilizing Fuelcell technology in mining and tunneling have generated serious industry interest in Fuelcell Powerplants. Progress to date has shown the viability of this technology for Mining/Tunneling Locomotive Powerplants. Future work includes the completion of the Fuelcell Powerplant and the Control System, followed by considerable testing above and below ground in the United States and Canada. Refueling processes must be worked out and the safety assessment completed by the Mine Safety and Health Administration (MSHA). Additional work is also planned on the design of the Hydride Bed to improve its refueling performance and with the air pump manufacturers to optimize the design required to supply the required air to the Fuel Stacks.

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References

Gaibler, D.W. And Miller, A.R., 7 December 1998, *Cost Model for fuelcell mine vehicles: conservative analysis of recurring and capital costs*, Fuelcell Propulsion Institute, Denver, CO, USA.