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MODIFICATION OF A FUEL-CELL ENGINE FOR CONTROL BY A DIGITAL COMPUTER

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16. Abstract

A manually operated fuel-cell system was modified to be monitored and controlled by a digital computer. The purpose was to have a test item with which to study possible system-computer interface problems. The modification consisted of installing solenoid valves, circuitry, transducers, and limit switches on the system. These modifications permit computer control of load current, reactant purge, water removal, and electrolyte concentration and computer initiation of system shutdown.

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MODIFICATION OF A FUEL-CELL ENGINE FOR CONTROL BY A DIGITAL COMPUTER

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SUMMARY

A manually operated fuel-cell system was modified to be monitored and controlled by a digital computer. The purpose was to have a test item with which to determine computer reliability, to study computer-system interface problems, and to refine programming techniques. When these goals have been accomplished, the digital computer will be used in long-term life testing of advanced fuel-cell systems.

The system modifications consisted of replacing hand valves with solenoid-actuated valves, designing circuitry to allow computer signals to initiate control functions or shutdown, installing transducers to generate data inputs to the computer, and adding limit switches for protection against computer failure or programming errors.

The system functions which can be controlled by the computer include load changes, reactant purges, product water removal, and electrolyte concentration adjustment.

INTRODUCTION

In preparation for long-term life testing of advanced fuel-cell systems, a digital data acquisition system has been obtained. This system, in addition to scanning and putting out data, can perform control actions by closing any one of 31 internal electronic switches. It is intended that this system shall monitor and control fuel-cell system life tests.

In order to examine the reliability of the computer system and to develop the necessary programming techniques, a demonstrator fuel-cell system has been modified for mating to the computer. This system was originally designed for manual operation. It has been redesigned to respond to control signals from the computer.

The modifications (to be discussed in this report) enable the computer to vary load current and electrolyte concentration, to purge reactants, to dump product water, and to shut down the system in a safe and nondamaging manner, if necessary. To guard against computer malfunctions, each operating parameter of the fuel-cell system, in addition to being monitored by the computer, is sensed by a limit switch which can initiate control action or shutdown.

OPERATION OF ORIGINAL FUEL-CELL SYSTEM

A piping schematic of the fuel-cell system is presented in figure 1. Reactant gases (hydrogen and oxygen) are supplied to the fuel-cell module at 1.73×10^5 newtons per square meter (25 psig). Gas purging is initiated by activation of three-way solenoid valves by a 5-minute timer. Product water leaves the cell module by diffusion from the hydrogen chamber, through an asbestos matrix saturated with potassium hydroxide (KOH), and into a water vapor chamber. The electrolyte (KOH) concentration in the fuel cells is maintained within acceptable limits by holding the vapor pressure in the water vapor chamber at some fixed value with a hand-operated vacuum regulator. The water vapor is condensed, and the liquid drains to a reservoir.

The fuel-cell module consists of four single cells wired so that two pairs of parallel-connected cells are connected in series. The electrical load for the module consists of a carbon pile resistor in series with a load contactor which must be energized before load can be applied.

The module is heated by an airstream blown over resistance heaters and then upward along edge fins on each fuel cell. The temperature is held constant by an on-off indicating temperature controller.

The water reservoir is drained by turning off the vacuum pump, isolating the reservoir from the condenser, pressurizing it by a manual three-way valve, removing the fuel-cell load, and opening the drain valve.

OPERATION OF MODIFIED FUEL-CELL SYSTEM

Either nitrogen or reactant gas can be supplied to the system through solenoid valves. The nitrogen (N_2) pressure is controlled by a hand regulator (R1), and the reactant pressures by dome-loaded regulators (R2 and R3) activated by regulated nitrogen pressure (fig. 2). Closing either switch S6 or switch S8 (fig. 3) closes one of the valves in the N_2 system (SV1 or SV2) and opens the valve (SV3 or SV4) in the corresponding reactant system. Pressure transducers downstream of the system reactant regulators (R4 and R5) provide inputs to the computer. Differential pressure switches downstream of the reactant rotameters detect any imbalance between reactant pressures and initiate shutdown. Orifices on each side of the differential pressure switches prevent pressure surges, caused by reactant purging, from triggering the switches. Reactant purging through the three-way solenoid valves (SV5 and SV6) can be on a time basis (switch S4), manual (switch S5), or on computer command (2(V)CR). Orifices between the fuel-cell module and the purge valves prevent rapid decompression of the reactant gas cavities.

The vacuum source for the water removal system can be either the sliding-vane pump on the engine or an air ejector available in the test facility. The choice is made by using a three-way hand valve (V1). A vacuum switch upstream of this valve will cause shutdown if vacuum is lost because of source failure.

The pressure level in the water removal system can be controlled by either manually setting vacuum regulator (R6) or opening and closing a solenoid valve (SV7) located between the vacuum source and the water reservoir. This valve is energized either by the computer (3(V)CR) or by a vacuum switch located between the module and the condenser ("hard" vacuum switch). An orifice between the solenoid valve and the vacuum source lessens surging when the valve is opened. The mode of vapor pressure control is established by setting hand valves in the regulator-orifice loop.

If the vacuum regulator is being used, the solenoid valve is held open by closing S14, which energizes relay 7CR. Since this relay also isolates the water dump relay (1CR), bypass switch S16 must be closed, too.

A pressure transducer in the water vapor line near the module generates a signal for the computer, and a vacuum switch at the same location ("soft" vacuum switch) will cause shutdown if vacuum is lost because of rupture of the water removal matrix.

Product water can be drained from the reservoir by computer signal (1(V)CR), by closure of the level switch in the reservoir, or by manual opening of switches S7 and S2 and closure of switch S11. Any of these methods will close the vacuum source valve (SV7), remove the load from the fuel cell, isolate the reservoir from the condenser (SV8), pressurize the reservoir, and open the drain valve (SV9). If water dumping is initiated by the computer or the level switch, a time-delay relay (TDO-1) locks in. After approximately 1.5 minutes the relay opens and resets, and the system returns to normal operation.

The fuel-cell module is enclosed in a plexiglass bonnet within which the heated airstream circulates. A hydrogen (H_2) sniffer is inserted in the bonnet, and any detection of H_2 leakage will close switch "hydrogen sniffer CR" (fig. 4) and initiate shutdown. A temperature sensing meter relay (API bonnet temperature) measures the temperature near the bottom of the module. Low temperature at this point indicates a heater failure and leads to shutdown. High temperature near the top of the module will close switch "API set point 2" and also result in shutdown. Both of these temperatures are provided as computer inputs.

Two low set point meter relays (low-voltage, cell 1 and 2) monitor the single cell voltages, and shutdown will occur if either cells fails. These two voltages, along with a current shunt voltage, are fed to the computer.

If any parameter being monitored by the computer or any calculation based on these parameters should fall outside prescribed limits, the computer will close switch 4(V)CR, and shutdown will ensue.

Finally, should the vent fan in the test facility fail or pressure be lost in any of the facility gas manifolds, the test will be terminated by the closing of switch ERB-CR.

When any of the limit switches, or 4(V)CR, are closed, voltage is applied to selector switch S-9. In the alarm position, S9 will cause a buzzer to sound, calling for operator attention. In the shutdown mode, relay 8CR is energized and locked in. This will remove power from the fuel-cell engine, drop the fuel-cell load, and deactivate the water dump, heater, fan, vacuum pump, and reactant purge circuits. Relays 5CR, 6CR, and 7CR will be deenergized, which will cause reactants to be replaced by nitrogen at the fuel-cell inlets and close the vacuum source valve. A vacuum release valve (SV10) located in the water removal system will open, and that system will return to atmospheric pressure. After 1.5 minutes TDO-2 will open, and the vacuum release valve will close.

Whenever one of the limit switches closes, the energizing of the corresponding relay will, besides powering switch S9, close a switch in a "first-on" annunciator system. A flashing light will be activated and give immediate indication of the source of trouble.

The fuel-cell module has been equipped with an electronic constant-current load bank. In the manual mode, this load bank permits continuous variation in current from zero to 150 amperes. In the automatic mode, switch closures by the computer provide for seven discrete load levels, in 20-ampere increments, from zero to 120 amperes. These computer switch closures, along with those used for engine control or shutdown, are approximately 15 milliseconds long. In order to ensure adequate pull-in time for the various relays and solenoids, these switch closures are "stretched-out" electronically.

CONCLUDING REMARKS

A fuel-cell system, designed originally for manual operation, was modified so that its performance could be monitored and controlled by a digital computer. The modification consisted of replacing hand valves with solenoid-actuated valves, designing circuitry that would permit switch closures originating at the computer to initiate control action or system shutdown, and adding transducers to provide data inputs to the computer.

The purpose of these modifications was to provide a test item with which to examine the reliability of the computer, pinpoint interfacing problems, and develop programming capabilities. For this reason, all the system parameters monitored by the computer are also sensed by limit switches installed on the engine. In the event of computer malfunction, or programming errors, these limit switches will initiate appropriate control actions or a shutdown sequence.

The control actions which can be triggered by the computer include load changes, reactant purges, dumping of product water, and adjustment of electrolyte concentration.

After gaining the desired experience in the development program, the digital computer will then be used to monitor and control long-term life tests of more sophisticated fuel-cell systems.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, April 12, 1972,
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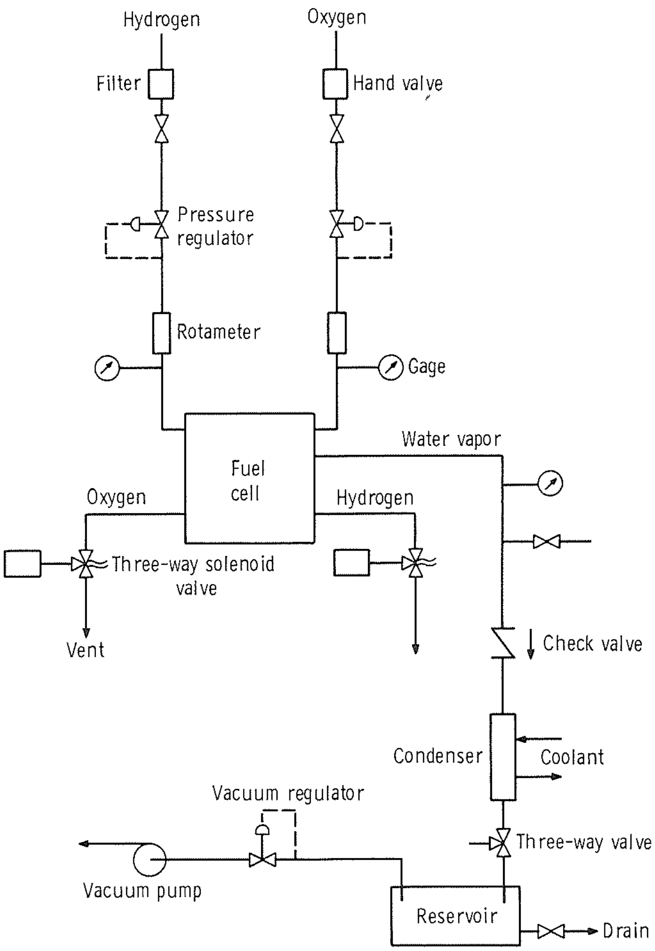

Figure 1. - Schematic of fuel-cell system.

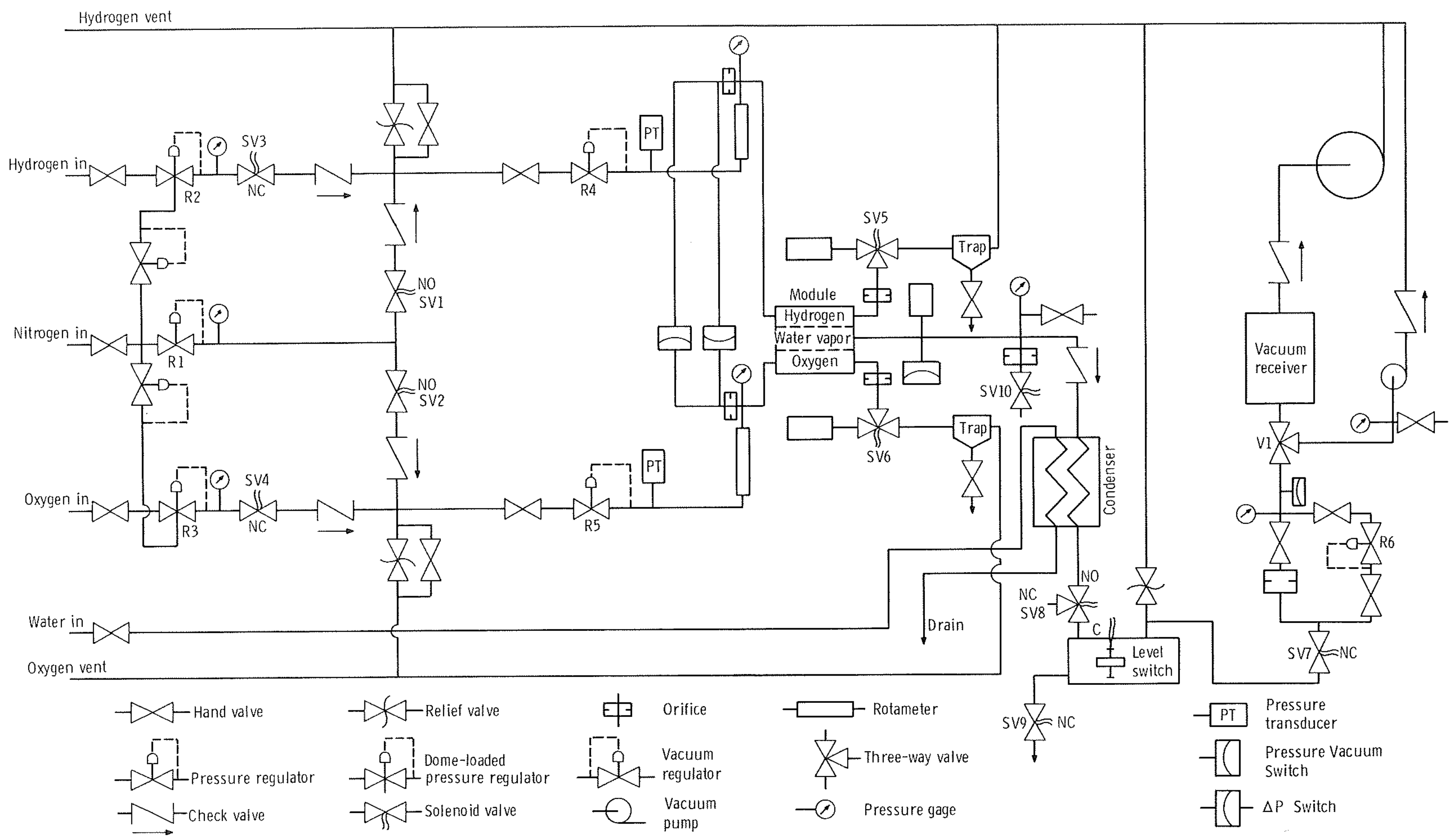

Figure 2. - Schematic of modified fuel-cell system.

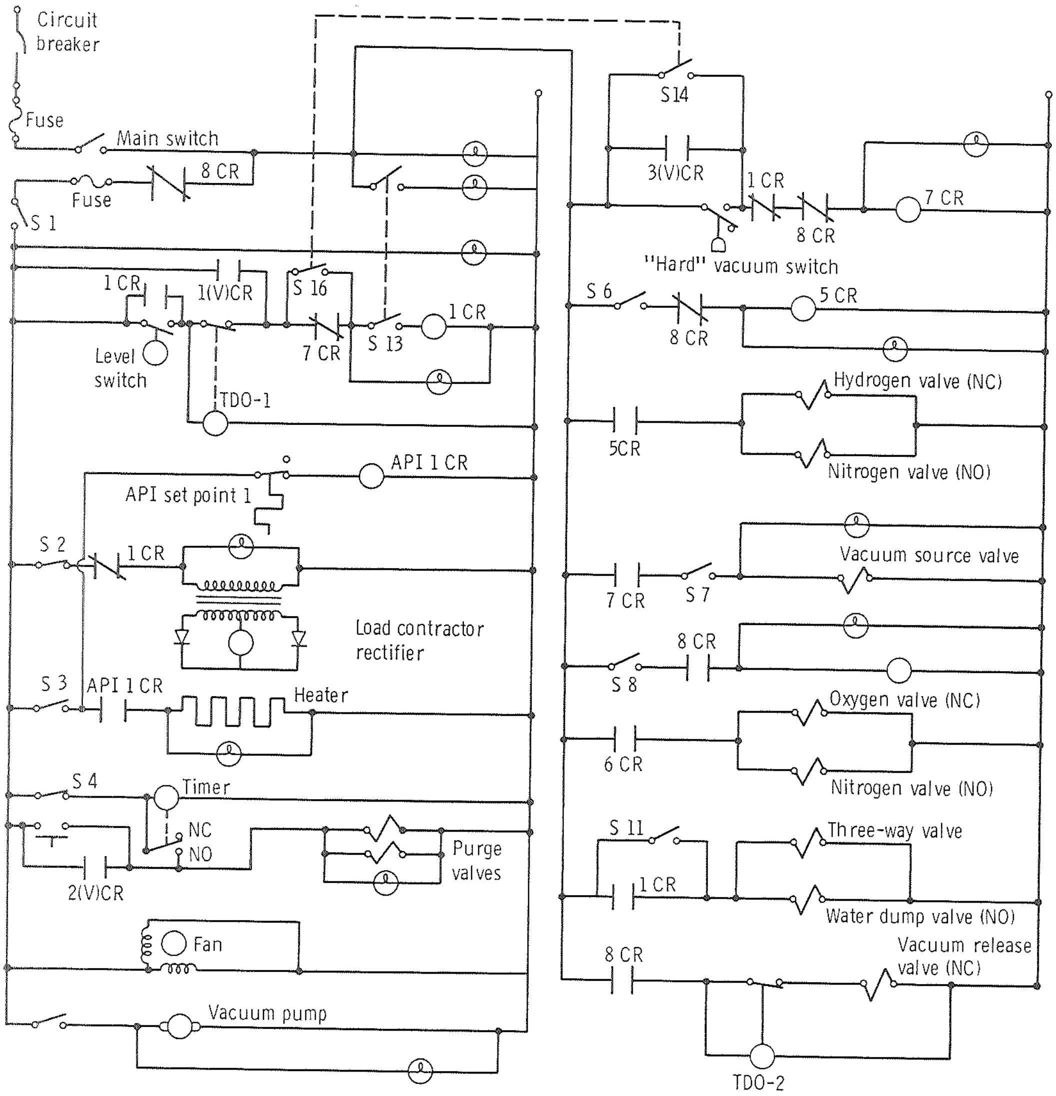

Figure 3. - System and solenoid valve circuits.

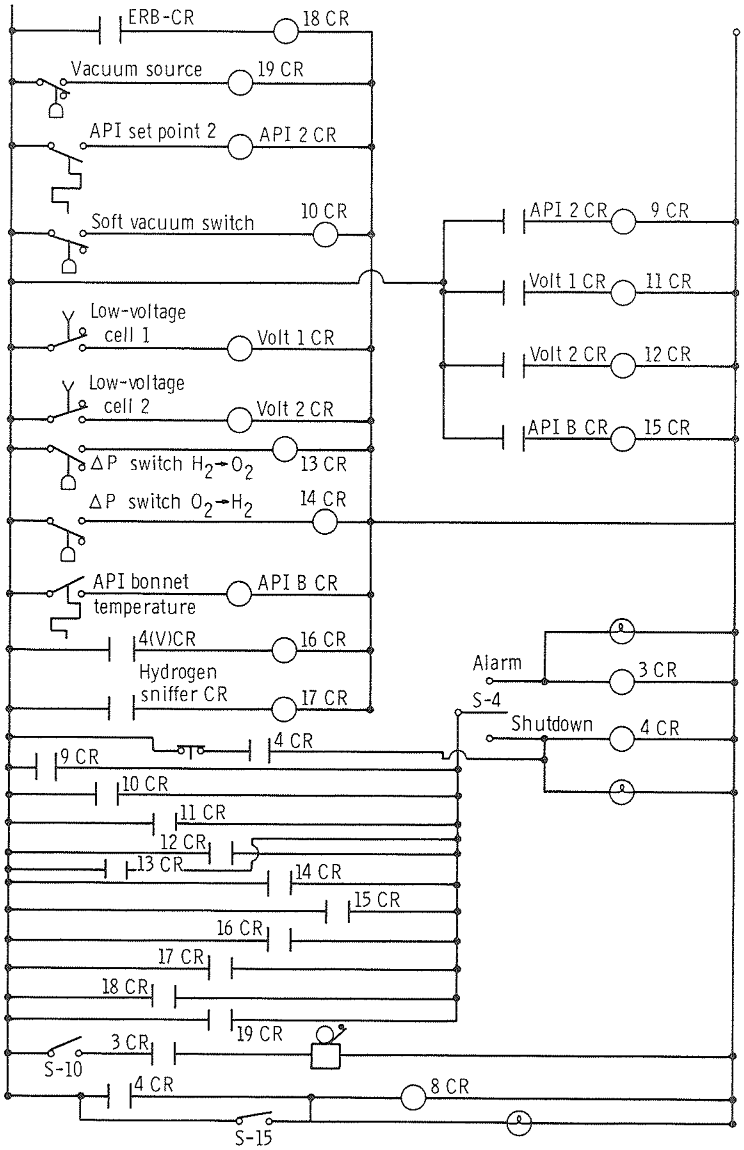

Figure 4. - Limit switches and shutdown circuits.

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