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# Advanced Health Management of a Brushless Direct Current Motor/Controller

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**_June 2003_**

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National Aeronautics and
Space Administration

Marshall Space Flight Center • MSFC, Alabama 35812

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## LIST OF ACRONYMS

| | |
|---|---|
| CDDF | Center Director's Discretionary Fund |
| EMA | electromechanical actuator |
| HMC | health management computer |
| RTD | resistance temperature device |
| TVC | thrust vector control |

TECHNICAL MEMORANDUM

# ADVANCED HEALTH MANAGEMENT OF A BRUSHLESS DIRECT CURRENT MOTOR/CONTROLLER

## 1. INTRODUCTION

The primary objective of this research is to demonstrate that health management can be taken to the component level for electromechanical systems. The same techniques can also be applied to take any health management system to the component level, based on the practicality of the implementation for that particular system. This effort allows various logic schemes to be implemented for the identification and management of failures. By taking health management to the component level, integrated vehicle health management systems can be enhanced by protecting box-level avionics from being shut down in order to isolate a failed component. For example, using thrust vector control (TVC), the power transistor stage can be managed without shutting down the whole control electronics box.

## 2. BACKGROUND

Traditionally, electromechanical actuators (EMAs) for space applications have been used in lower power applications, such as valve actuation. Currently, satellites utilize EMAs for pointing control; however, a new area of application is for TVC. A baseline for EMA's was developed for the National Launch System, and the Space Launch Initiative is including EMAs in its TVC trade studies. The TVC application is at a considerably higher power level, where overheating and overcurrent are major health management concerns. Utilizing advanced health management techniques, both can be managed at the component level to prevent failures. The currents in question are those going through power transistors in a three-phase bridge circuit. A health management computer (HMC) can monitor temperatures and currents. They can be compared against redline levels for shutdown before an error occurs, saving the component for reuse. In the event of a total component failure, the component can be shut down in favor of a backup without sacrificing the whole electronics box. This reduces part counts, thus, saving weight, reducing cost, and increasing reliability.

## 3. APPROACH

The initial goal of this research was to breadboard out the individual components of a brushless dc motor/controller. The only intended redundant component was the three-phase bridge; however, this proved to be beyond the resources of this effort. This effort was able to demonstrate the health management techniques that utilize a box of electronics with redundant channels of control electronics that were used in previous Center Director's Discretionary Fund (CDDF) research. The redundant channels contain a chip (PW–82350P6–120) that has the three-phase bridge desired for investigation with this effort.

A personal computer was utilized as the HMC, which commands the control electronics through an AIM104–MULTI–IO card. Also, the current from the motors is available from the PW–82350P6–120 chip, which is read into the HMC from the MULTI–IO card. Motor temperatures are monitored through a sensory card to resistance temperature devices (RTDs) via the HMC (fig. 1).

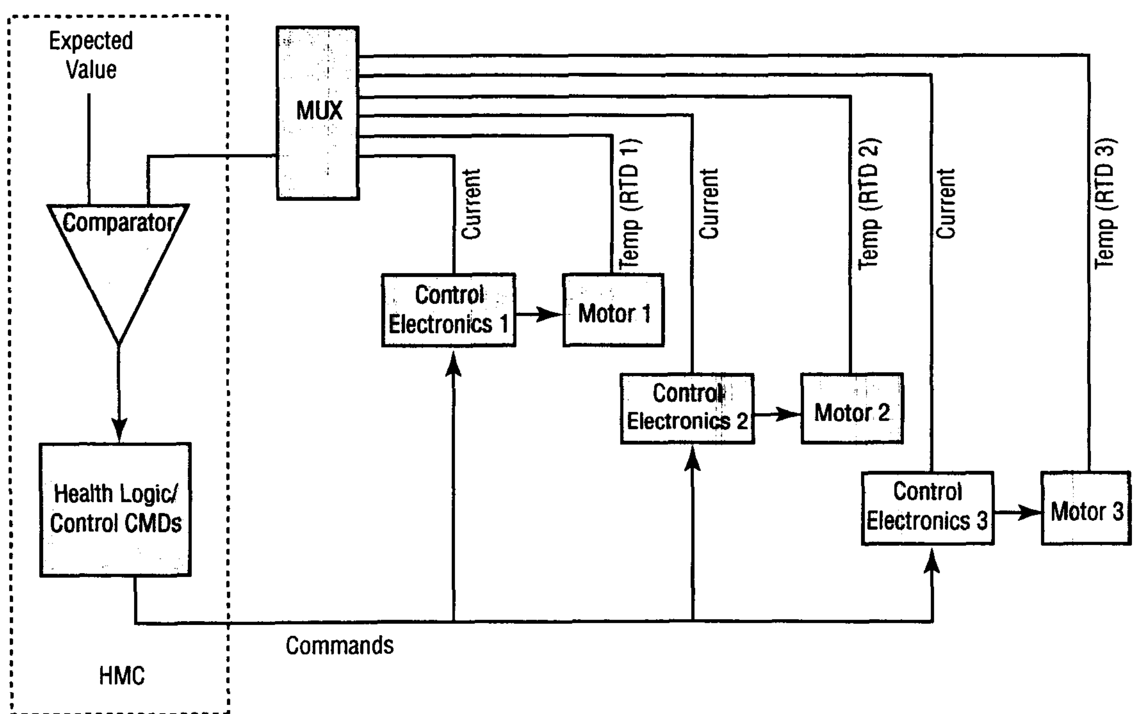


Figure 1. Block diagram of the motor/controller unit.

Software monitors motor temperatures and currents. The motor temperatures are compared against a redline condition, and the current is fed into a motor model within the software. The health management logic (fig. 2) is implemented in the code. For the case of all three RTDs reading overtemperature, the HMC shuts down the hot motor and switches to the redundant motor. If two RTDs are reading overtemperature, the HMC checks the model for a redline condition, and if it is yes, shuts the overheated motor down in favor of the redundant motor. For this demonstration, if only one RTD reads overtemperature, it is assumed that the RTD is bad, and nothing is done. In the event that the backup motor is in overtemperature and motor 1 has cooled sufficiently, the HMC switches back to motor 1. For the case where both motors are overheated, the HMC would command a safe condition for a real life application.

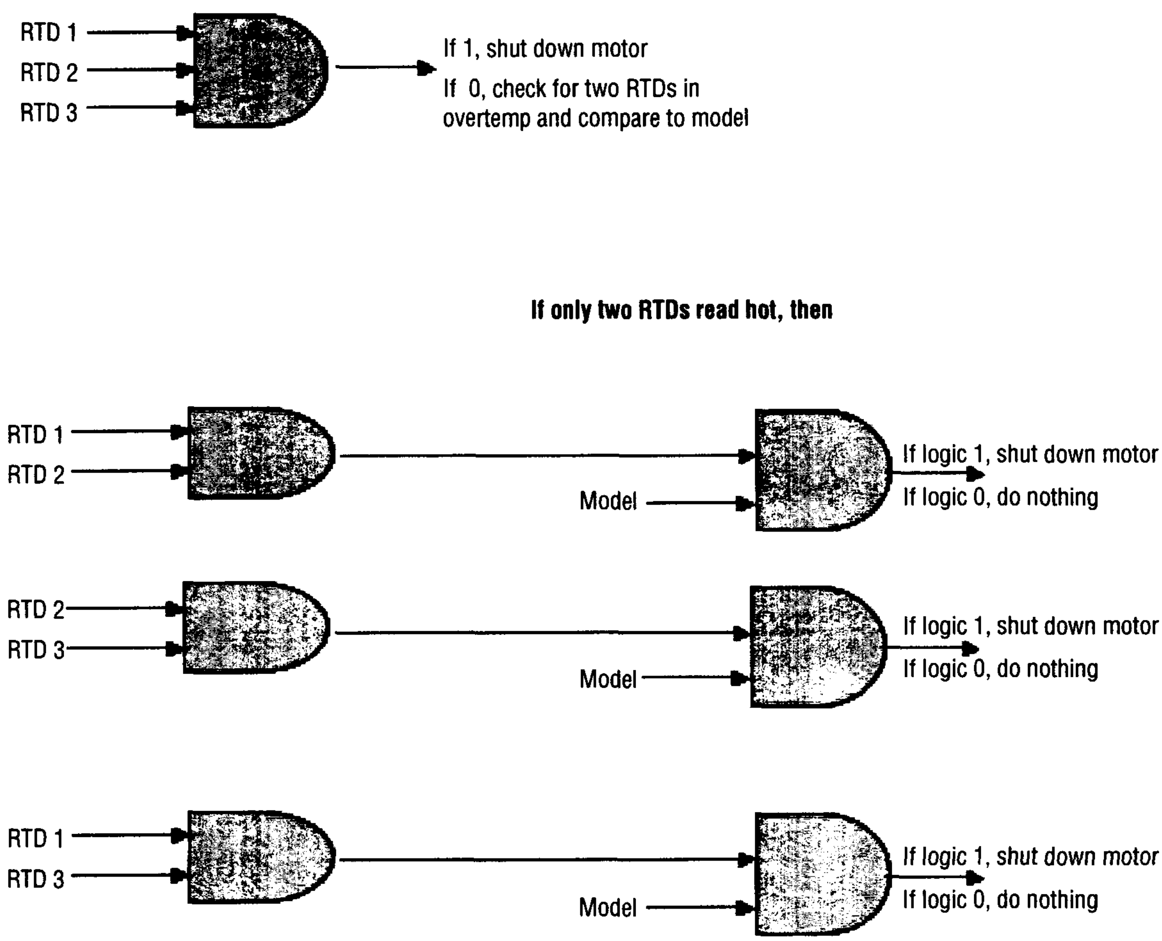


Figure 2. Health management logic.

Current was monitored for two reasons: (1) For input into the temperature model and (2) for a zero current condition for 1 s, which would indicate a blown transistor. In such an event, the HMC switches to a backup channel.

For demonstration purposes, overheating in the motor is induced by taking the motor to near stall for ≈5 min via a dynamometer. See figure 3 for a complete demo setup.

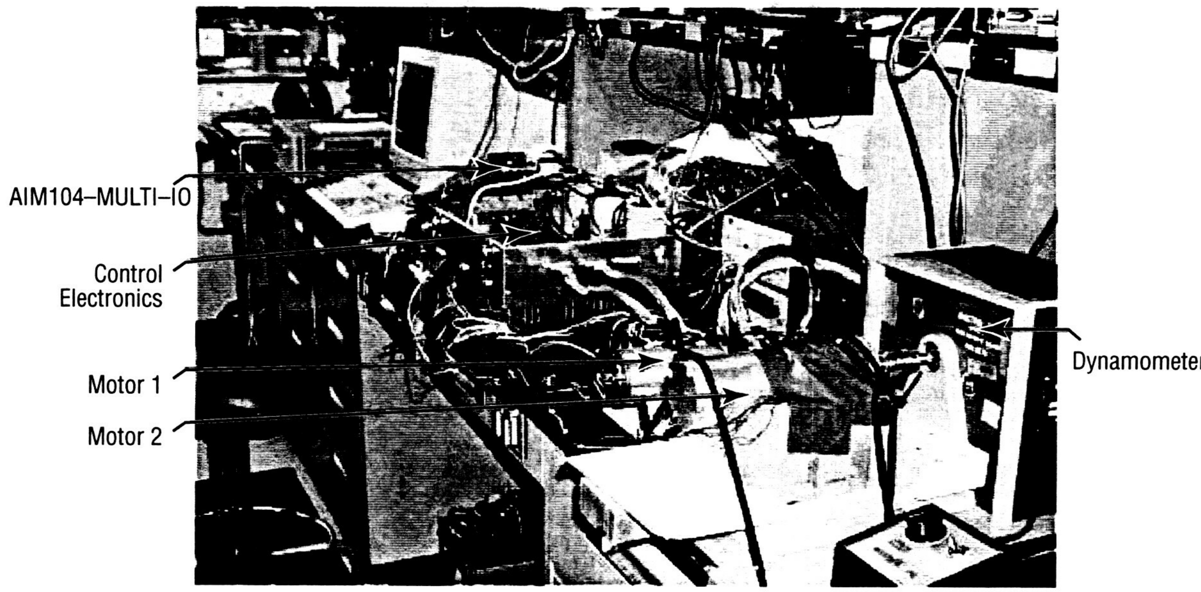


Figure 3. Complete demo setup.

One motor used, the BMHST–1202–A, came from the TVC program for the FASTRAC engine. Its temperature rise is 2 °C per Watt. Since the voltage is constant, the wattage is a scale factor multiplied by the current. An S-curve was used in the software as a model of the wattage verses temperature. The other motor used is a triple-winding motor left over from previous CDDF research. This motor takes health management to the component level by having redundant windings for the same magnetic rotor since the windings are the component most likely to fail. For demonstration purposes, two motors were used in order for the health management to be observable.

## 4. ACCOMPLISHMENTS

The previous CDDF effort for which this electronics box was built was not completed at that time. However, the demonstration of its goals, which are similar to the goals of this effort, was accomplished. Also, the main goal of this effort—health management at the component level—was demonstrated. However, the effort failed to single out the three-phase bridge, as intended.

The dual redundant wound motor is a good concept for flight hardware. This effort demonstrated the practicality of that concept. Also, it demonstrated the practicality of monitoring redlines and switching to a backup component before a failure occurs. Delays in switching were kept to a minimum, and all indications are that the concepts work when applied.

For a brushless dc motor, the current must be commutated; i.e., directed through the correct windings at the correct time. Hall-effect devices sense the rotor position, then control logic switches the correct transistor on for the correct amount of time. Typically, motor-driven systems use motor drives consisting of a three-phase bridge of power transistors switched on and off via control circuitry (fig. 4). The brushless dc motor has windings A, B, and C. Power transistors T1 through T6 are utilized in the three-phase bridge. For example, control logic will have transistors T1 and T6 on; then voltage, V, is applied so that current, I, goes through windings A and C to ground. If any power transistor blows due to overcurrent or overheating, the open circuit condition renders the power stage nonoperable, and thus, the brushless dc motor nonoperable. Only by switching to a backup component will operation of the brushless dc motor be allowed to continue. For this effort, hybrid chip PW–82350P6–120 was utilized as the power stage, control logic, and motor current-sensing card. The box contains three independent channels for driving a brushless dc motor, power conditioning circuitry, and position feedback control, if desired (fig. 5). Two channels were utilized for this demonstration.

With correct health management, the power transistor stage can be monitored for temperature and current to prevent overtemperature or overcurrent conditions that would blow one or more transistors. In case of overtemperature, the transistor can switch to a backup component until enough cooling has occurred to allow a no-fault operation.

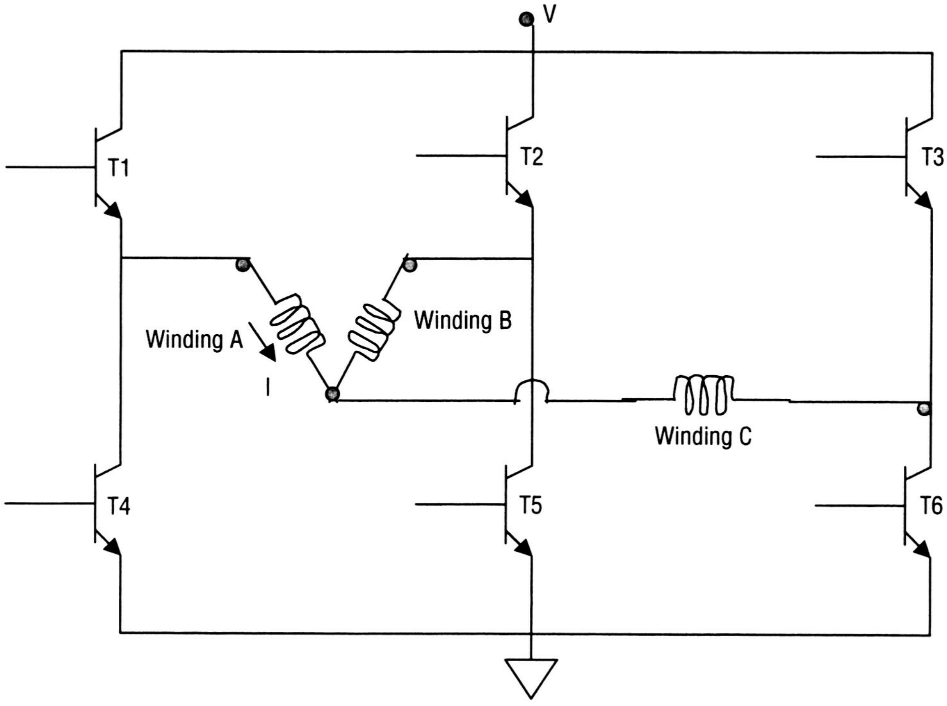


Figure 4. Power transistor three-phase bridge.

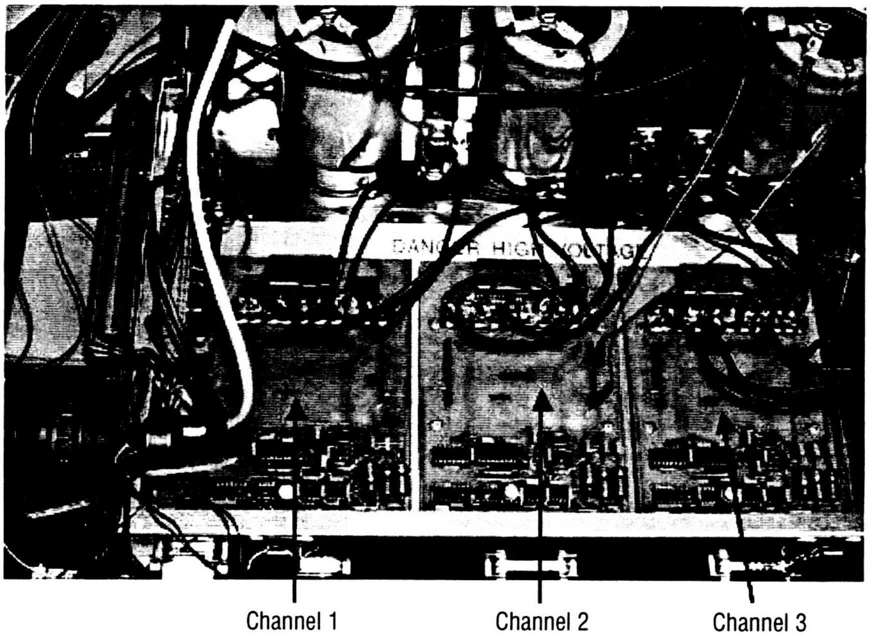


Figure 5. Control electronics using three channels.

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This effort demonstrates that health management can be taken to the component level for electromechanical systems. The same techniques can be applied to take any health management system to the component level, based on the practicality of the implementation for that particular system. This effort allows various logic schemes to be implemented for the identification and management of failures. By taking health management to the component level, integrated vehicle health management systems can be enhanced by protecting box-level avionics from being shut down in order to isolate a failed computer.

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