

# High Temperature Linear Position Sensor

Dr. Hong Wan  
*Honeywell International Inc*  
*hong.wan@honeywell.com*

Ed Mallison  
*Honeywell International Inc*  
*ed.mallison@honeywell.com*

Ryan Rieger  
*Honeywell International Inc*  
*ryan.rieger@honeywell.com*

Mike Freeman  
*Honeywell International Inc*  
*Mike.Freeman@honeywell.com*

Matthew Contons  
*Honeywell International Inc*  
*matthew.contons@honeywell.com*

## 1. Introduction

Linear position sensors play an important role in automation control where precision positioning is required. Many manufacturers strive for innovative technologies to meet today's needs of high reliability, long life and accuracy. [1] Applications in high temperature environment, such as aircraft engines or deep oil drilling wells, add another dimension of challenges. This paper reports a new development in Honeywell for a high temperature, non-contact, high precision linear position sensing based on a magneto-resistive sensor technology.

## 2. Technical Approach

This linear position sensor consists of a magneto-resistive sensor, precision amplifiers and a moving magnet object, shown in Figure 1. A permanent magnet provides a magnetic field as a target. A stationary sensor converts the magnetic

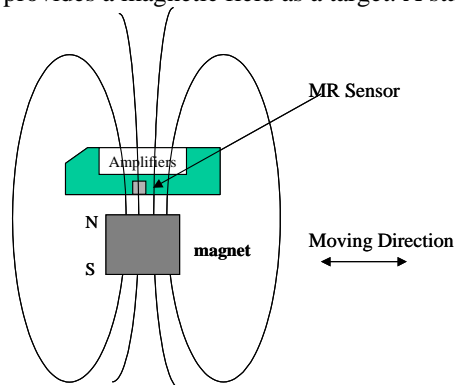


Figure 1. Linear Position Sensor Diagram

field angle direction into a differential voltage, then amplifiers and other discrete components provide signal conditioning for the sensor signal. The voltage output from amplifiers is proportional to the position of the magnet in the sensor linear range (Fig.2). The benefits of this approach for position sensing are a non-contact, long-lasting, solid-state design with no moving parts to wear out, and no dropped signals from worn tracks, as can occur in conventional contact-based position sensing [2]. This approach fits rugged environments, such as high temperature or high vibration.

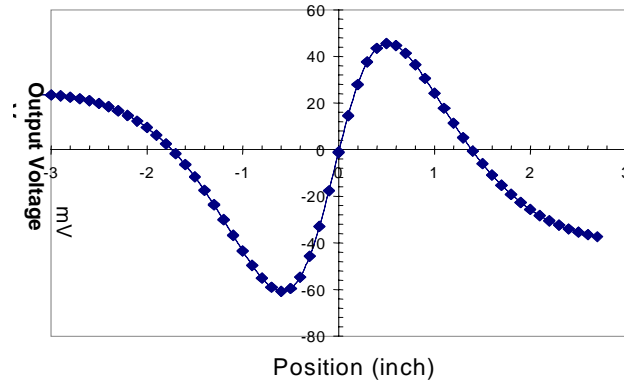


Figure 2. Sensor output vs. Magnet position  
Linear range in the middle is usable signal

High temperature magnetic sensors and high temperature precision amplifiers are housed in ceramic packages, respectively. High temperature magnetic sensors are based on magneto-resistive thin film technology. It is qualified to operate at temperatures up to 225°C. The high temperature amplifiers are based on Silicon-on-Insulator (SOI) CMOS technology. It is capable of operating at 225°C. A high temperature Polymer substrate was used to assemble the components along with a high temperature soldering process. The permanent magnet was made of Sm-Cobalt material, which has a Curie temperature, the critical magnetic phase transition temperature, higher than 600°C. Because the angle direction of the field from the magnet is measured, it is insensitive to the temperature coefficient of the magnetic field produced by the magnet. The system doesn't require temperature calibration and compensation for the target magnet; however, it is needed for the sensor and signal condition electronics. The temperature compensation can be performed either through hardware or software if a microcontroller is available at a low temperature zone. All the materials and assembly processes in the linear position sensor module are rated 225°C or higher for their high temperatures (Fig.3). The module has been evaluated in the temperature range from -55°C to 225°C.



Figure 3. High Temperature Components and The Position Sensor Module

### 3. Reliability Test Results

Reliability tests have been performed on the magnetic sensor, the key component for the linear position sensor. The device passed all performed Mil-STD 883F tests, such as temperature shock, temperature cycle, moisture resistance, mechanical shock/Vibration, and constant acceleration. We also performed a set of reliability tests tailored for the high temperature applications. High temperature storage tests at 275°C for 1000 hours were performed on 20 samples. 100% of the samples passed the test through their electric performances and wire bond pull strength test. An accelerated steady state life test has been performed on 48 parts at 225°C for 1000 hours. Power stimulation was applied to the units to simulate a typical application situation. It has 5V to Sensor Power, 5mA to offset strap and 300mA to set/reset strap with 0.1% duty cycle. Both offset and set/reset straps are on-chip coils, used in applications for sensor calibration, initialization or compensation. A digital voltmeter was used to monitor all the parts during the life test for circuitry continuity. 38 out of 48 units withstood the life test for 1000 hours. The 1st failure unit was observed at 486 hours. Failure analysis indicates that the set/reset strap with the high current pulses (0.3A) contributes 100% of

all the failures. Further analysis pointed to the separation of the wire bond pad and the wire due to metal migration in the condition of the high temperature and high current stress. However, this can be improved through double wire bond, or other known techniques.

#### 4. Linear Position Sensor Performances

The linear position sensor consists of a high temperature analog board and a standard temperature digital board. The digital board is made of an analog to digital converter (ADC) and a microprocessor. The digital board is not essential for this module, but allows us to add many nice features, such as smart diagnose system, power management and signal output modes. The microprocessor also enables us to expand the position sensing stroke length by adding multiple sensor channels through a patented algorithm. The algorithm is based on the characterization of this magnetic sensor responding to the magnet target, takes the data from all the channels, determines the nearest sensor



Figure 4. Three -Channel High Temperature Position Sensor Module

pair first, and then calculate the target position. The temperature calibration and compensation are also performed in the digital board.

Fig.4 shows a three-channel high temperature position sensor analogy board. This module covers a 30mm linear position range. Fig.5 is the data generated during characterization. Y-axis is the data from the position module, and X-axis is the data from a calibrated position. An accuracy of  $\pm 0.3\text{mm}$  (or  $\pm 1\%$  FS) has been achieved for the entire temperature of  $-55$  to  $225^\circ\text{C}$ . The stability or noise is  $0.04\%$  of FS and  $0.05\%$  of FS, at temperatures of  $25^\circ\text{C}$  and  $225^\circ\text{C}$ , respectively. The temperature sensor and temperature compensation track the change of temperatures in the position sensor module quickly enough so that it is still accurate while the temperature ramps as fast as  $10^\circ\text{C}/\text{min}$ .

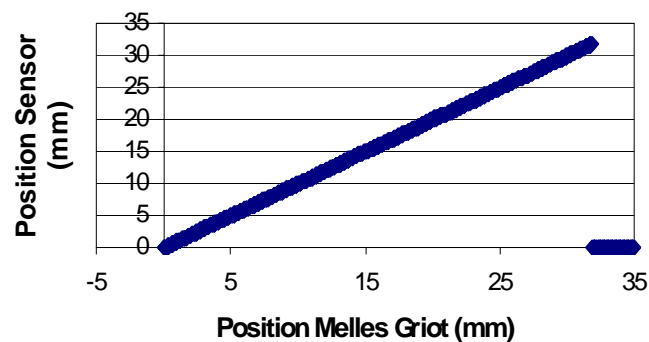


Figure 5. Linear Position Sensor Data at Temperature Ramp Rate of  $10^\circ\text{C}/\text{min}$  from  $-55^\circ\text{C}$  -  $225^\circ\text{C}$

The integration of the position sensor with a stainless steel actuator has been demonstrated. The target magnet was attached to the actuator piston rod, while the sensor board was mounted outside of the actuator house. The temperature and accuracy tests showed the same good results, with no impact from the integration.

## **5. Conclusions and Future Work**

High temperature magnetic sensor and high temperature amplifier components have been developed at Honeywell. We made the 1<sup>st</sup> attempt of high temperature life test at 225°C on magnetic sensors. No failure has been observed on the component level. Low rate of failure is associated with the package assembly, which is identified and may be improved in the future. The high temperature position sensor module made of magnetic sensors; operation amplifiers and other passive components were developed and demonstrated with a high temperature actuator. High accuracy, high temperature capability, wide range, and high vibration tolerance are among the many benefits that the high temperature position sensor module offers. We also explored a smart diagnose system that reports the status of the module and system redundancy required by many critical devices, and found that they are feasible.

For future work, we designed a ceramic package that will house both a magnetic sensor and a high temperature operational amplifier. We plan to integrate the magnetic sensor with electronics. It will offer a small size and a high temperature position solution.

## **6. References**

- [1] An interference-Based Incremental optical Encoder, Sensors Vol.17, No11, 40, 2000
- [2] Linear Position Sensing Using HMC1501, Application Note 210, Magnetic Sensor, Honeywell SSEC.

## **7. Acknowledgement**

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