EMBEDDED SMART SENSOR TECHNOLOGY FOR HEALTH MONITORING OF ROCKET MOTOR GRAINS

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A B S T R A C T

Bond stress is an important aspect of structural integrity of a solid propellant rocket motor and can be the critical parameter in health monitoring. The ability to monitor this parameter using embedded sensors has been a major development in Integrated Health Management. The maturity, robustness and functionality of the Micron Instrument **D**ual **B**ond **S**tress and **T**emperature (DBST) sensor have been proven. Details of the latest improvements to the sensors will be reviewed and results from recent testing to demonstrate this technology will be discussed. All aspects of calibration and performance will be considered. As calibration checks of the sensor after casting of the propellant grain are not possible, it is essential that the units used for long term monitoring are accurate and stable. The improved DBST sensor is stable and robust. Future possible developments will also be discussed which would provide a system that can be multiplexed and operated from one source of control with data storage. This embedded system would be ideal for remote interrogation and integration with RRAPDS or ATOS technology.

INTRODUCTION

The primary objective of the program of work reviewed in this paper is to develop the technology that will provide the capability to install an embedded bond stress sensor system into a rocket motor grain and to monitor data essential for service life determination. The program will also demonstrate the capability to install the embedded bond stress sensor system into a rocket grain in the production environment, and to monitor environmental data essential for service life determination. Motor testing will also demonstrate that the motor's structural integrity has not been compromised. Aerojet, formerly Atlantic Research Corporation (ARC), the major army rocket motor supplier, has been appointed as a sub-contractor for the rocket motor part of this program and details of the program is given in a companion paper.

Future possible developments will be discussed which would provide a system that can be multiplexed and operated from one source of control with data storage. The technology is now sufficiently mature to make a miniature system containing a processor, high-resolution analog to digital converter and excitation supply with the sensor on a common buss. The sensor will be capable of multifunctional sensing in the same DBST body to monitor normal bond stress, shear stress (one or two axis), temperature, humidity, acceleration (one, two and three axis), shock and chemical sensing. It would also allow the individual intrinsically safe "smart sensors" to be installed onto a miniaturized communication line with redundancy so that any number or type of sensor may be used. Each sensor would retain calibration and performance data with time stamps even with power loss and be capable of operating at low and high frequency logging with event retention. This unit could also have wireless communication to a central processor so that remote interrogation of motor health, via hand held unit or satellite at any time would be possible.

MANUFACTURE OF IMPROVED SENSORS

Semiconductor Gage Manufacture

Manufacturers of semiconductor gages sell their gages in thermally matched sets of two or four. Unlike foil or wire gages, the semiconductor gage has a very large change in resistance with temperature. If not thermally matched for slope and intercept, temperature compensation for balance would be difficult and performance would be compromised.

For thermal testing, gages are normally installed (soldered) free standing on circuit boards so that induced stress is minimized. The circuit board is designed to go into a temperature chamber. Air that is heated or cooled enters the chamber from one side and exits at the opposite side. Small temperature chambers are used to minimize the thermal differential across the chamber. Approximately fifty gages are installed onto a circuit board and four boards are inserted and form a three dimensional array in the center of the chamber. The requirement is to accurately record the temperature and minimize the thermal differential across the chamber.

To read the gage resistance, power is applied from a constant current supply and the circuit compensates for any line resistance change. A computer measures the gage resistance taking multiple readings over a finite period of time and averages them. This is done to reduce noise error and increase the accuracy. Resistive readings are taken at –50, 0, 78 and 278 °F. The gage sets are matched within ± two ohms. Due to the thermal differentials across the three dimensional array of circuit boards, thermal resistive errors of up to ± four percent of the ambient resistance is possible. These resistive errors increase the thermal non-linearity and decrease the long-term stability when used in bridges for sensor application.

Precision Gage Thermal Matching System

New software and equipment permitting the semi-conductor strain gages to be critically matched over the full temperature range have been developed. These gages are thermally matched between -50°F and +278°F to within ± one ohm.

Two types of noise were observed when analyzing the data. The first is sixty Hz noise from the temperature chamber motors and electronics. Secondly, there are thermal fluctuations due to the instability of the flow patterns and slower changes when the chamber heaters are turn on. The low temperature is provided by liquid CO_2, which vaporized as it enters the temperature chamber. There is less measured turbulence at –50 ° F than at 278 ° F. Digital filtering was required to get precise thermal data. A sophisticated program was written to remove the 60 Hz system noise which is superimposed on the precision RTD and semiconductor gage DC output. This is accomplished by sampling both measurements 17 times at a one-millisecond rate. The total time for this is 17 milliseconds, the period of one sixty Hz cycle, and the average of the seventeen measurements is called a data point average (DPA). This digital averaging takes out the 60 Hz noise but not the temperature chamber hot air fluctuations which is most pronounced at 278 ° F. The semiconductor strain gage, (SSG), is susceptible to the airflow because its mass is more than 100 times less than the RTD.

To digitally minimize the hot air flow fluctuations, a number of averaging techniques were tested and the following scheme was selected. Forty DPA values were averaged (680 data points called a data point group (DPG)). Next, forty DPG values were averaged and called a data point group average (DPGA). The forty-first DPG is taken and compared to the DPGA. If less than 0.1 °F for the RTD or 0.2 % of reading for the SSG, the data is recorded and the next gage or RTD is considered. If over the above settings, the first DPA of the DPGA is deleted and the forty-first DPA added to the DPGA and the new DPGA average is calculated. A forty-second DPA is taken and again compared to the DPGA. If out of the specification limits, the process is repeated until the latest DPA is within the deviation allowed when compared to the latest DPGA average. This close matching will reduce fabrication time and improve both long-term stability and performance.

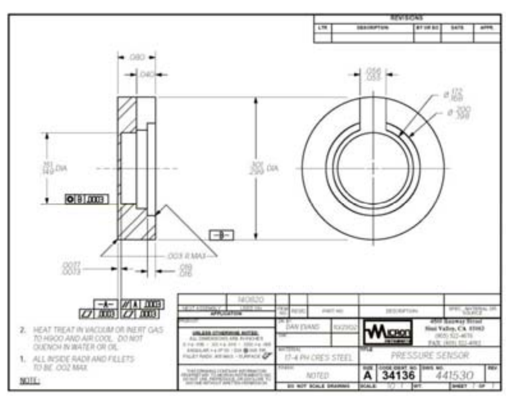


Figure 1. New DBST Sensor

Improved DBST Sensor Design

A photograph of the new sensor taken during manufacture and a drawing is shown in Figure 1. The design changes to the sensor improve sealing at the exit of the electrical connection. The six-conductor round electric cable has been replaced with a flat thin circuit board, which connects to a thin six-conductor flex cable. This also requires a modified exit from the sensor body with the result of stiffening the sensor wall giving less compliance and higher sensor accuracy. The rear lid has also been modified to facilitate a good sealing surface.

The six-conductor flex cable is 0.080 wide by 0.010 thick and five and ten feet lengths have been procured. By virtue of its properties and size it causes less perturbation to the normal stress field, is easier to bond to, and is more adapted to the motor manufacture processes. A shield can be incorporated if required. The connector between the sensor and flex has been selected and procured, and the connection at the bridge completion module is a miniature re-usable connector, which will allow easy disconnection.

Calibration and Testing

Pressure manifolds for calibrating the new DBST sensors were designed and built with embedded temperature measurement. Under each of the two DBST positions is a precision RTD. New manifolds were required to accommodate the design changes to the DBST and this presented an opportunity to improve the test and calibration accuracy. The measured change in the zero stress mill-volt output of the DBST between –50 °F and +150 °F was small. The typical offset error for the old sensor was less than five psi from 50 °F or 0.05 psi/ °F. Typical sensitivities of the new precision matched DBST is shown in Table A with the average values and standard deviations for the first batch of 20 sensors. The corresponding temperature element sensitivity is shown in Table B together with the span for -50° F to 50 ° F and 50° F to 150 ° F to indicate linearity. The data provided by the new calibration system permits correction to 0.1 psi for stress and 0.1 ° F for temperature.

TABLE A

PRESSURE SENSITIVITIES

(OUTPUT FOR 100psi)

	-50°F (mV)	**50 °F (mV)**	**150°F (mV)**
	20.1	20.4	20.2
	19.8	19.9	19.9
	19.4	19.7	19.7
	19.6	19.8	19.6
	20.1	20.4	20.2
	19.7	19.9	19.7
	19.8	20.0	19.8
	19.6	19.8	19.5
	18.8	19.0	19.2
	19.2	19.5	19.5
Batch Average	19.5	19.8	19.6
Batch SD	0.35	0.40	0.37

TABLE B

TEMPERATURE ELEMENT SENSITIVITY

(OUTPUT FOR 200 °F)

	Sensitivity (mV)	**Span –50 to 50°F**	**Span 50 to 150 °F**
	202.1	101.2	101.0
	204.2	102.4	101.8
	202.2	100.4	101.8
	204.3	101.0	103.3
	204.3	102.5	101.8
	200.8	100.1	100.8
	203.7	101.2	102.4
	200.5	100.4	100.2
	202.4	100.9	101.5
	200.5	100.4	100.2
Batch Average	203.5	101.4	102.1
Batch SD	1.84	0.91	1.29

It is necessary to use Finite Element Analysis, (FEA), to estimate the difference between the gas pressure used to calibrate the DBST and a true bond stress reading at the sensor position in the motor grain. For most applications, there is less than a one percent error when looking at the equivalent bond stress.

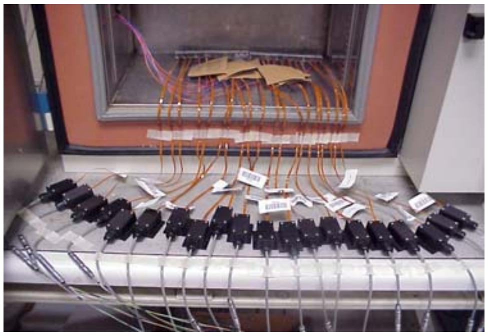


Figure 2. Thermal Hysteresis Testing

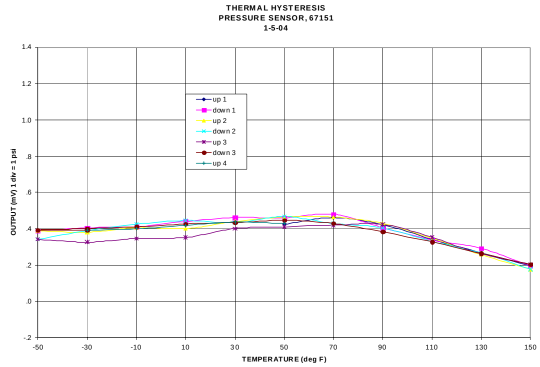


Figure 3. Typical Result

The thermal hysteresis was obtained by placing the sensors in a temperature chamber and assuming the two hours allowed for stabilization was sufficient for all the sensors to be thermally stable. Investigation showed that the temperature chamber had significant temperature differential from front to rear and side-to-side and does not repeat the temperatures as accurately as required. Therefore, a manifold made of aluminum was designed and manufactured which contained three RTD (Platinum Resistance Precision Thermal Device) elements to monitor the temperature at the eleven DBST test positions. Sensors were inserted into the manifold and thermal hysteresis tests were conducted between –50 °F and +150 ° F in 20 °F steps starting at 50 °F and with two-hour stabilization time at each temperature. The control software accurately calculates the mill-volt slope of the DBST stress and temperature sensor and corrects the outputs from any thermal difference between the desired test temperature and actual temperature in the chamber. Twenty sensors ready for test are shown in Figure 2 and typical result given in Figure 3.

Pressure testing of the old design of sensors after installation into the motor tube was difficult because of leakage of the round cable seal in the sensor body, particularly at low temperature. The new design enabled an improved seal to be used and this was tested to 100 psi over the operating temperature range in the pressure bomb shown in Figure 4. Successful tests were also carried out at ambient and150 ° F.

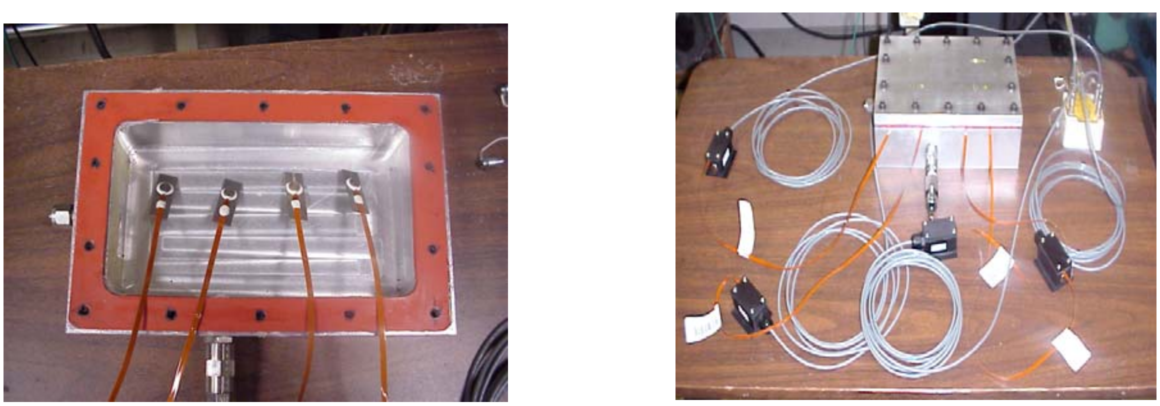
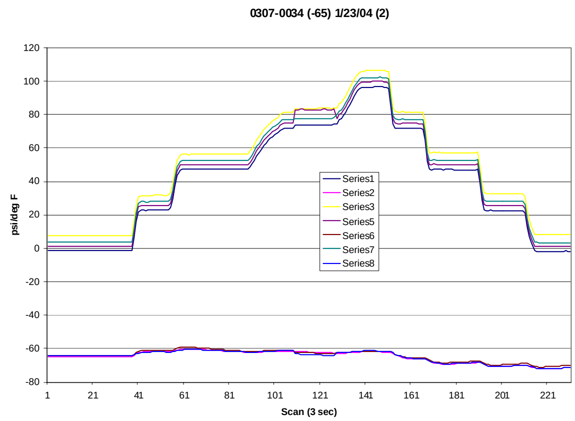


Figure 4. Pressure Test Bomb

All the sensors passed the test as can be seen in Figure 5, which shows results of pressure testing of four sensors at the low temperature of -65°F. The pressure bomb has also been used to confirm the elastic behavior of the diaphragm under both compressive and tensile loads. The effect of ±4, ±8 and ±12psi pressure loads are shown in Figure 6. As can be seen at these low pressures the sensor behaves elastically.



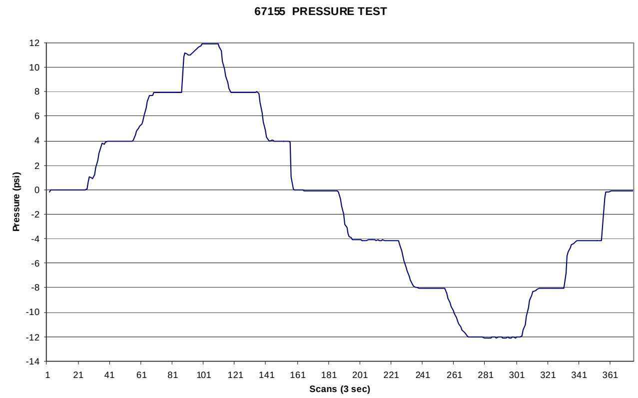
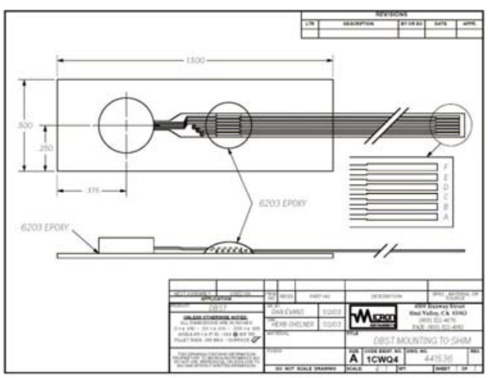


Figure 5. Test Results at -65° F **Figure 6. Tension & Compression Test**

Sensor System Configuration

The calibrated sensor is bonded onto a shim with curved back surface to match the ID of the motor case. The ribbon cable is joined as shown in Figure 7 to interface with the chosen cable installation scheme. The complete system with cables and connectors is shown in Figure 8.



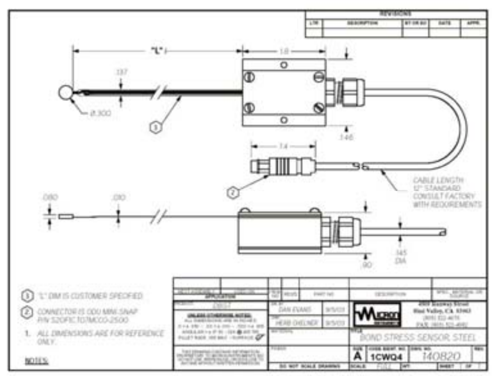


Figure 7. Sensor Bonded to Shim **Figure 8. New DBST Sensor System**

ML1008-A LOGGER DESIGN CHANGES

The new ML1008-A logger design has incorporated all of the known changes to both the logger engine and signal conditioner printed circuit boards (PCB). The current build standard, as shown in Figure 9, retains the eight channels per logger, and the capability of monitoring four DBST sensors. For a variety of reasons, including the current availability and cost of EEProm memory chips, a change in part type was made from the original loggers. Since the new parts were more reliable than the older ones, and less than half the price, it was decided to add additional chips, effectively doubling the data storage of the logger from 2048 scans of 8 channels, to 4096 scans.

Electrical Connectors

The old ML 1008-1 loggers and associated DBST sensors utilized a miniature circular connector. Over the past several years, these connectors (and their source) have proven to be unreliable. Many instances of corrupted data, which appeared as sudden shifts in the measured data, have been attributed to intermittent connections between the contacts. Further, the connector was a screw-together type, and occasionally would be over-tightened, resulting in failure of the connections to the printed circuit board.

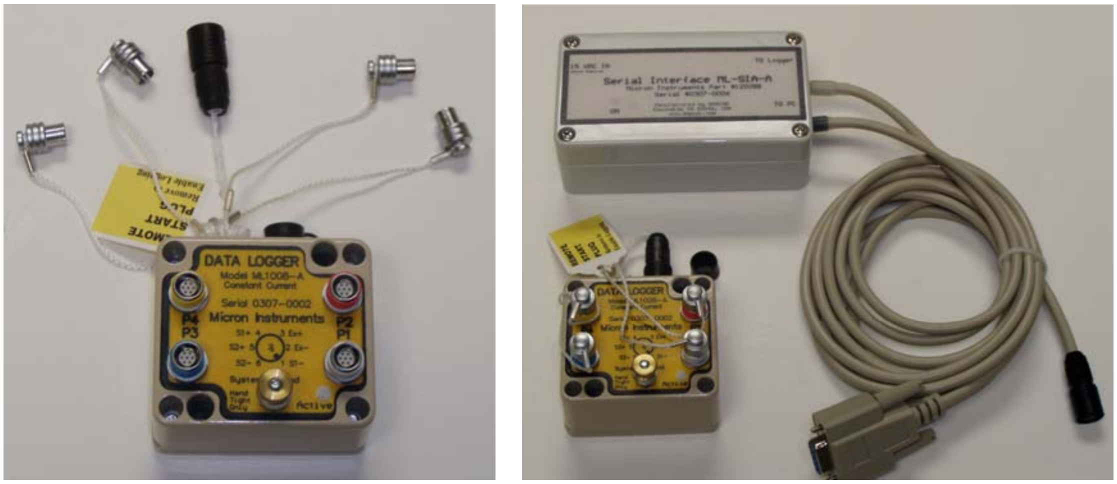


Figure 9. ML 1008-A Logger and Interface

Alternative connectors were examined, but most were rejected based on inappropriate materials of construction, overall size, or mounting configuration. Ultimately an ODU brand metal-shell circular connector with a push-pull action was chosen. This connector was also available from Fischer Connectors as a second source. Although the ODU connectors are significantly more expensive than the Microtech, to date there have been no known failures of the bulkhead receptacles in the data loggers. A new connector was also selected for use with the SIA (Serial Interface Adapter) module. However, the requirements were less stringent and a plastic connector pair from Hirose was chosen as can also be seen in Figure 9.

<u>Elimination of Shorting Plugs</u>

Over the course of the development of the logger electronics, different Instrumentation Amplifiers, (InAmp), were tried. With a choice based primarily on lower costs, an Analog Devices InAmp was used in the first production loggers. One of the drawbacks of this amplifier was a tendency to drift to the high power rail if no signal were present on its inputs. Since the rails were above the acceptable input limits of the Analog to Digital Converter (ADC), if the drift were all the way to the rail, then it was possible for the loggers to “lock up” and stop working. For lower drifts, the ADC would report incorrect values on the other channels. To avoid these issues, shorting plugs were required to be installed in unused channels as a standard operating procedure.

With further testing, it was determined that a Burr Brown InAmp was more suitable for the application. When used as a direct replacement for the Analog Devices part, the output would drift (typically) between the zero offset voltage point and ground, which were acceptable inputs to the ADC, and eliminated the need for shorting plugs.

<u>Common Mode Issues</u>

In addition to drift issues, the two InAmps also had differing requirements for allowable common mode voltages. In order to successfully use the Burr Brown InAmp without clipping or other distortions of input and output signals approaching the limits of the device, it was necessary to set the input signal voltage for the pressure bridge as close to zero (ground) as possible. Since the signal was bi-polar (i.e. is swung both positively and negatively around ground), it was also necessary to provide a negative analog voltage supply rail.

<u>Noise Suppression and Ground Bonding</u>

Typically, noise on the conditioned pressure signal outputs, as measured by the logger ADC, was 10-20 counts, many ADC counts higher than anticipated. The system ADC is a 12-bit resolution device, with a full-scale input of 0 to 4.095 volts. Since 12-bit resolution corresponds to 4096 counts, or one part in 4096, one ADC count in this case is equal to one milli-volt.

A long-term effort was made to identify the source of the noise, and eliminate it. This effort was successful in reducing the peak-to-peak noise to 1-2 counts, and 0-1 counts for most channels, even at the higher gains of the pressure channels. In general, the solution consisted of adding bypass caps on several components, RC filtering of the analog power supply rails, excitation supplies, and limited RC filtering on the signal inputs to the ADC converter. Further noise reduction tests indicated a link to the calibration system used to setup and test the loggers. Bonding the common ground on the logger PCB's to the case, and then bonding the case to the bench ground eliminated this source of noise completely. All ML 1008-A loggers include the internal bond, and a terminal with a thumbnut on the case for bonding the logger to the rocket motor. The unused seventh pin on the sensor connectors was also tied to the PCB ground, and is available for providing a ground path for sensor cable shields.

Serial Interface Adapter

The Serial Interface Adapter (SIA) was completely repackaged into a new NEMA-4 case. In the process, an additional handshake line was added which allows the host PC and application software to verify that the SIA is both present and provided with external power before attempting to communicate with the ML 1008-A data loggers. An option was provided in the software to allow this check to be over-ridden when an older SIA is being used. Also, as mentioned in Section 3.1, the connector to the logger was changed to a more robust push-pull type from Hirose.

The external power supply was upgraded to an international unit capable of running off of 80-240 VAC at 50 or 60 Hz, with a set of interchangeable plugs for operation in the U.S., the U.K., Europe, and Australia. In addition, this new regulated switching power supply has helped to eliminate logger signal noise when powered from the utility mains. Finally, the power supply connector was changed to a type that significantly reduces the possibility of sparking which was present in the older version.

PERFORMANCE TESTING OF LOGGER ML 1008-A

Calibration Issues

The input stages of the logger signal conditioner have been matched to the impedances of the DBST sensor, and any calibration system needs to approximate the internal resistances of the DBST sensor. In order to measure the output when each bridge is balanced (referred to in the Logger Calibration Sheets as "offset"), it is necessary to tie the two input signal leads together (shorted). However, it is equally important that there be approximately 600 Ohms between the signal leads and ground for the temperature sensor, and another 400 ohms between the signal leads for the temperature and pressure bridges. The excitation supply (plus) connection should be made to the top of the stack. This will insure that the common mode voltage requirements are also met.

In order to simulate a stimulus, a small resistor may be used in place of the shorting connection. The resistor should be as small as possible, but still give a signal offset sufficient to generate an output signal to the ADC in the 3.5-4.0 volt range. An isolated voltmeter with very high input impedance can be used to measure the voltage drop across the small resistor, which would be equivalent to the input signal to the signal conditioner gain stage.

Table C gives the range of the calibration results for the first batch of ten loggers, which gives an idea of the manufacturing variances in the ML1008-A data loggers for the tested functions. Both Gains and Excitation current are set with a single precision resistor (0.1%, 10 PPM tempco) of a standard value (hence the slight, but consistent variations from the ideal values such as 1000.00 μa for the excitation current). The offsets have a higher variation as they are set using two precision resistors in a voltage divider configuration, and are also reflecting the variations between InAmp's, as well as the two different gains. This measured unit-to-unit variation is considered excellent and is well within the required specification.

TABLE C
LOGGER CALIBRATION VARIATION

	Excitation	Offset (psi)	Offset (°F)	Gain (psi)	Gain (°F)
Min	1015.80	2,023.16	1,016.00	328.96	69.08
Average	1017.51	2,054.73	1,021.98	329.70	69.20
Max	1020.95	2,080.70	1,029.00	330.72	69.55
+/- max	2.58	28.77	6.50	0.88	0.24
+/- Error	0.25%	1.40%	0.64%	0.27%	0.34%
3*Sigma	2.70	39.43	2.72	0.36	0.08

Effects of Temperature on Calibration Values

In order to determine the behavior of the data loggers over temperature, two ML 1008-A loggers were chosen at random, and calibrated at several different temperatures. It should be emphasized that the scale on the plots is large, and the actual changes over temperature are typically less than 1% over the range of –30 º C to +85 º C. When used in a laboratory environment, at relatively constant temperature, the loggers will provide stable readings. Also, since the curves are generally predictable, they could be used to further correct the measurements for logger temperature, leaving only system noise and drift with time as sources for error.

While reviewing the following charts, it should be noted that the logger resolution is 12-bit, or 1 in 4096, or about 244 ppm. Excitation current varies in a consistent parabolic curve, as shown in Figure 10. The values change from approximately 1016.0 uA to 1017.4 uA at the temperature extremes, a total of about 1.4 uA or approximately 24 ppm/ º C. Over the normal ambient range of 5-45 º C, the change would be less than 0.1uA or 4 ppm/ º C.

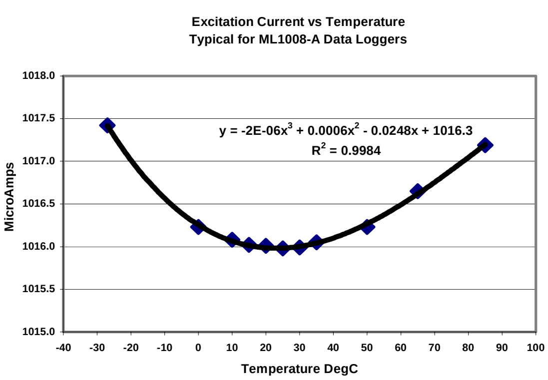


Figure 10. Effect of Temperature on Excitation Current

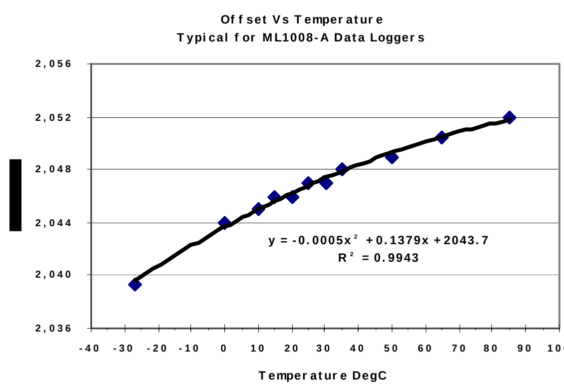


Figure 11. Effect of Temperature on Offset

As can be seen in Figure 11 the Offset varies in a consistent slightly non-linear curve from approximately 2040 to 2054 mV over a total range of 115 º C, which gives a change of about 60 ppm/ º C. From the manufacturing variation results discussed in Section 4.1, it should be noted that offset exhibits the most changes. The gain results show a wider spread in the readings than the Excitation and Offset as can be seen in Figure 12. This is most likely the result of variations internal to the InAmp that overlay the basic temperature coefficient of the gain setting resistor. The overall gain change with temperature in this example is 1 in 328 or about 26 ppm/ º C.

Operating Software and Documentation

Several features of the earlier logger operating software, which were deemed to be a hindrance to the use of the package, have been removed. These included the Administrator, Depot, and Organization options with their related password system, and the delayed start option. Access to other features such as the real-time screen, strip chart and additional fields have been streamlined. A "clipboard" and "save/read to file" commands have been added to the calibration screen to avoid the repetitious entry of data when changing sensors. Finally, additional calculations are performed during the setup of each channel, and the operator is warned if clipping of the sensor signals will result from a mismatch between the sensor and the hard-wired setup of the signal conditioners.

Documentation and procedures associated with the data loggers have been upgraded. A new compilation of setup and calibration procedures has been created. The Dascor generated Logger Calibration Forms have been reworked to include additional statistical information and to make it easier for the test operator to enter the required information into the data loggers. Micron has also upgraded the DBST Calibration Report Forms to highlight specific data that needs to be entered into the data loggers. Copies of the operating software, calibration data and the calibration and set-up procedure are provided with each logger.

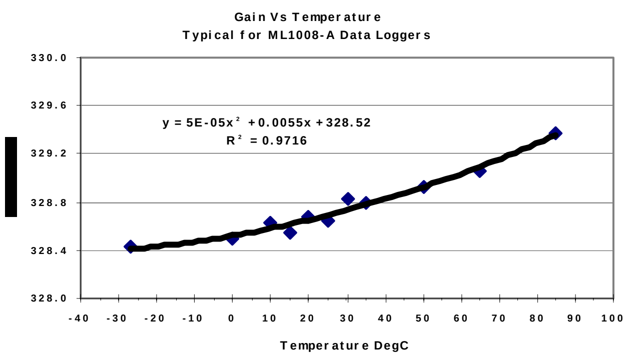


Figure 12. Effect of Temperature on Gain

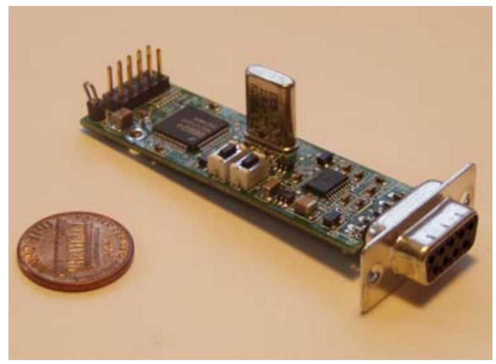


Figure 13. Smart Sensor Bread Board

FUTURE SENSOR DEVELOPMENT

The next generation of sensors will utilize a new sub-miniature, U-shaped, 3000 Ohm semiconductor strain gage that has been developed and is currently in limited production. Use of this gage in other products has indicated an improved long-term stability and thermal hysteresis performance. If used in the present DBST configuration, lower power consumption or higher output signal would be expected. Utilization of the above gages with a recently developed 2.0 mm square circuit, which will fit inside the current DBST cavity, would permit transmission from two lines using an induced field. Sufficient energy is transmitted into a small button to activate the sensor and transmit the sensor signal when a hand held palm pilot is held over the button. This would require no contact, eliminates cable management problems and gives no battery replacement issues.

An FEA was recently performed on the present DBST geometry and it indicated that the present design, with no dimensional changes, is capable of accurately reacting to shear stress. The semiconductor gages will require relocating on the inside surface of the sensor diaphragm. The same bridge completion circuit board, flex cable, and computer augmented temperature compensation routines will apply. The only change is a fixture to permit calibration in shear instead of pressure. Using the fore mentioned sub-miniature gage can further enhance performance. This is considered a low risk probability.

With changes in the flex circuit and circuit board, bi-directional shear stress, and temperature is possible. Also unidirectional or bi-directional shear stress with normal stress (and temperature) would be a future option. Use of recently developed smart electronics will replace the need for the bridge completion module. This signal conditioning board replaces the requirement for temperature compensating the DBST, using a passive resistor network. It would use the temperature element signal and generate a reference table to correct for offset and sensitivity changes with temperature. In addition it has optional outputs of 0 to 5 volts, 0 to 10 volts and 4-20 mA. These circuits will also offer the following advantages:

- These circuits have a high output signal which would reduce the signal to noise ratio
- The 4-20 mA option would compensate for external power fluctuations
- A RS-485 interface option would permit multiplexing with the installation of many sensors on a common communication line
- The sensors could be re-balanced and re-ranged without removal
- The original calibration data, sensor serial number and other information could be stored in non-volatile memory.
- The cost of temperature compensation would be significantly reduced.

FUTURE LOGGER DEVELOPMENTS

The logger variant (called the M3) currently at the breadboard/proof of concept stage, as shown in Figure 13 is based on an integrated system IC that includes a microprocessor, a 16-bit/1-MS/sec or 24-bit/100S/sec resolution Analog to Digital Converter (ADC), a Programmable Gain Amplifier (PGA), a multiple-input multiplexer (MUX), and support for 2 serial communications ports, an I2C port, and a full 8-bit data and 16-bit address bus. The chip itself is about 5/8" square, and with a minimal set of support components could fit in about one square inch of PCB space.

With the high resolution of the ADC, and ability to program input gains and offsets, the chip can read almost any sensor directly, and strain gage bridge based devices in particular, with NO additional signal conditioning, other than an excitation current or voltage supply (and the processor can control the excitation supplies for power conservation). The available MUX inputs can handle up to 8 single-ended inputs, or 4 full-differential inputs, plus common. Additional MUX inputs can be added as options.

In the case of silicon bridge sensors, the processor has adequate capacity to measure both the bridge resistance, which can be used as a measure of sensor temperature, and as well as bridge output. The two readings can be combined to both linearize and temperature compensate the sensor (limited only by the calibration data available). With this technique, both temperature and pressure can be derived directly from the single bridge. Memory chips located with the sensor can be used to contain calibration data so that calibration information would be transferable with the sensor.

The processor chip holds its program in flash memory, which allows it to be re-programmed in the field to accommodate updates to the firmware, or completely different firmware to support other applications. For example, changing from time domain event logging to Waterfall or peak event logging. With two serial ports, the unit can be adapted to a variety of interfaces, including RS232, RS485 multi-drop, RS422, fiber optic, and RF Modem. In addition, a port can be dedicated to external devices such as GPS receivers (location and precision time base), LCD panels for text or graphic displays, and keyboards for field setup.

Perhaps the most interesting application area is using the M3 as a dedicated sensor conditioner. With a variant of the processor chip, both voltage and current outputs are available in addition to the digitized signal, which can be used for normalized outputs of 0-5 volts or 4-20 mA current loops. Presently two analog outputs can be supported with full temperature compensation and linearization.

With addressable modules using an RS485 multi-drop protocol, multiple sensor/M3 combinations can be placed on a single 4/6 wire communications bus that operates at 5-volts or less, and milli-amps of current. An example of this use would be to directly associate the M3 circuitry with DBST sensors on the mounting shim. Multiple sensors could then be mounted inside a rocket motor case, connected with a simple 4/6 conductor flex circuit, and managed by an external controller. With bus voltages on the order of 5 volts or less, and current draws of 1-2 mA per sensor, the system could be made intrinsically safe. Further, a single flex circuit linking the sensors would simplify installation, as well as the motor penetration for connection to the external controller.

For dedicated logger applications, non-volatile high-speed fRAM memory, EEprom, and high capacity flash cards (to 1 GB) can be supported. Operation of the processor and memory chips has been proven to over 125 Degrees C.

A high-speed multi-channel rugged and portable data acquisition unit is in the final stages of development for a transportation load monitoring system with the board for one channel shown in Figure 14. The system is enclosed in a shock-mounted enclosure for use in conditions presenting extreme shock and vibration.

Specifications:

Number of Channels - 8 channels of thermocouple inputs, 8 channels of isolated voltage inputs, 8 counter/timers, 2 event channels, and 8 channels per group of high speed inputs for accelerometers and strain gages. The high-speed channels may be expanded in 8-channel increments to any number. The system features simultaneous sampling on high speed channels at up to 40,000 samples per second per channel. Each channel has its own ADC, its own 64 Mb of flash memory storage providing 30,000,000 samples of storage at 16 bit resolution, a dedicated programmable filter, and programmable gain amplifier with gains to 1000.

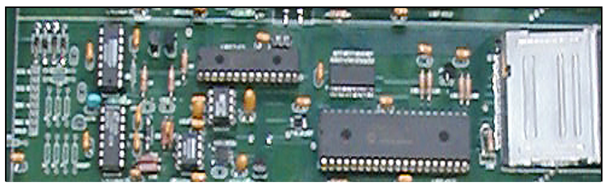


Figure 14. High Speed TL logger Board

Slow Data Rate Channels can be sampled at rates from 1 Hz up to the maximum rate. All programmable features are user settable with a Windows based application. Data acquisition can be controlled with a handheld switch module or by event input from a digital source or by level detection from accelerometers. A GPS receiver is provided for time and location tagging of measurements. A solid-state hard drive is optionally available to enhance the data storage capacity of the system. The system is either AC or DC powered. User application software is included. The software is Windows based and provides for easy setup of all system parameters. The onboard data is easily transferred to PC based EXCEL compatible files after data acquisition is completed.

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