The Development of an Enhanced Strain Measurement Device to Support Testing of Radioactive Material Packages*

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DISCLAIMER

Radioactive material package designers use structural testing to verify and demonstrate package performance. A major part of evaluating structural response is the collection of reliable instrumentation measurement data. Over the last four decades, Sandia National Laboratories (SNL) has been actively involved in the development, testing, and evaluation of measurement devices for a broad range of applications, resulting in the commercialization of several measurement devices commonly used today. SNL maintains an ongoing program sponsored by the U.S. Department of Energy (DOE) to develop and evaluate measurement devices to support testing of packages used to transport radioactive or hazardous materials. The development of the enhanced strain measurement device is part of this program.

Title 10, Code of Federal Regulations, Part 71 allows package designers the option of using analysis, testing, or a combination of analysis and testing to support the certification of radioactive or hazardous material packages (NRC 1994). In recent years, many packages have been certified by DOE or the Nuclear Regulatory Commission through a combination of analysis and testing. Testing facilities simulate the normal or accident environments defined in the regulations and provide response measurements. Data collected from testing of radioactive or hazardous material packages can be used directly to support package certification or, in the case of the analysis and testing certification option, can be used to verify the assumptions used to analyze the package. For certain package designs, package testing can be an economical alternative to complex analysis for the resolution of regulatory questions or concerns. The ability to provide reliable response measurements is an essential element in the certification process.

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Instrumentation measurement devices are major components in obtaining reliable data during testing of radioactive or hazardous material packages. Measurement devices developed at SNL in the past to support transportation testing include the high-output accelerometer, ruggedly constructed linear variable differential transformers, and evaluation channels to characterize the magnitude of unwanted external effects in measurement data. These measurement devices have increased the reliability of data collected to support testing of radioactive material packages.

Accelerometers and strain gages are the most common measurement devices used to support package testing. Strain gages are commercially available devices used to measure surface strain at the mounted location. The optimal measurement range for foil-type strain gages, used to measure surface strain during radioactive material package testing, is between 0.1% and 15% strain. Levels below 0.1% can produce output voltage measurement levels that may increase the uncertainty in the measurement data. In most cases, transportation systems are developed using material stresses in the range less than yield or approximately 0.2% strain. The activity described herein focused on the development of strain measurement devices with enhanced measurement capabilities in the lower strain range.

SNL's enhanced strain measurement system includes the foil-type strain gage and the enhanced strain measurement device. The enhanced strain measurement device contains an internal electronics package developed to produce the enhanced measurement characteristics. The measurement system has been designed to provide enhanced output measurement characteristics for single active-arm, resistive strain measurement applications. The system also incorporates all of the Wheatstone bridge conditioning, amplification, filtering, and line conditioning in a self-contained measurement package that can be located close to the actual strain measuring gage. The measurement system incorporates a small electronics package featuring a low-impedance true differential output with a Butterworth low-pass output filter and line drivers to maintain signal integrity over moderate to long lengths of conventional instrumentation cable. Excitation for the device can be supplied by any 10-volt (V) direct current (DC) supply. The electronics package is compatible with any commercially available foil-type strain gage with a 350-ohm resistance and a nominal gage factor of 2.0. The package output is matched to provide a differential full-scale voltage output of approximately ±2.5 V. The package can withstand environmental conditions including high shock and a moderate range of operating temperatures, and is sealed to provide moisture protection. The electronics were designed to produce electrical signals similar to a full bridge measurement device at the data collection recording system.

The large-output voltage level provided in this enhanced measurement device greatly improves the ability to monitor low-strain measurement levels and reduces the signal-to-noise ratio of the data, which in turn can reduce the uncertainty in this type of measurement data. In addition, the measurement system is reusable, offsetting the initial cost of the measurement electronics package. The combination of the enhanced measurement capabilities and the ability to use the device for multiple strain measurement applications adds to the available measurement capabilities needed to support radioactive material package testing. Table 1 shows the performance specifications for the device.

The design of the enhanced strain measurement device includes available monolithic semiconductor components. Figure 1 shows the basic electrical configuration of the device. The mechanical design and packaging are sized to achieve the required physical characteristics (Figure 2). The bridge completion network consists of a stable, precision 350-ohm, resistive arm to match the 350-ohm foil-type strain gage. The reference half-bridge consists of a tapped thick film resistor to ensure maximum tracking integrity. Offset adjustment has been accomplished by abrasive trimming of the 350-ohm resistive arms. The output signal has been amplified using a dual, monolithic, silicon operational amplifier. This amplifier optimizes the gain-bandwidth, slew rate, DC characteristics, and output driver capabilities. To ensure a minimum full-scale output of ±2.5V, a differential amplifier provides a nominal gain of 11 volts per volt. The output filtering design uses classic resistive and capacitive elements incorporated within the basic amplifier gain stage. This provides the required 2-pole low-pass Butterworth active filter. Operational amplifiers provide line conditioning. The enhanced strain measurement device drives conventional instrumentation cabling with length approaching 500 feet.

Prototype strain measurement devices have been evaluated for compliance with the performance requirements. Since the design is intended to measure single active arms of a Wheatstone bridge, and a change in resistance of the measuring strain gage results in a change in output voltage, the devices are tested using resistance changes representative of the change in resistance an actual measuring strain gage might experience. Figure 3 shows monitoring results for typical device output. The linear voltage change over the voltage measuring range can be seen in this data.

The device sensitivity to changes in input excitation voltage have also been evaluated. The input excitation was varied over a range of +5 V to +15 V, and the output of the device was monitored for changes in the output voltage level. Figure 4 provides representative data on the change in output voltage to applied input excitation voltage. As can be seen, the output level varies a maximum of approximately 60 mV over the range of excitation voltages tested.

The final performance-based test of the units determined the output sensitivity per unit change in indicated strain. Figure 5 shows the data from one of the devices that is typical of the response of the prototype units. The sensitivity calculations were based on a +10 V excitation and the output voltage was converted to units of microvolts/microstrain. The test was performed to simulate a measurement range from -50,000 microstrain to +50,000 microstrain. A least-squares fit on the experimental data was used to calculate the sensitivity of each device. The sensitivities ranged from 54.837 microvolts/microstrain to 55.038 microvolts/microstrain. In a typical measurement application where the expected measurement level is 2000 microstrain, the actual output of the device would be approximately 100 mV or about an order of magnitude greater than the output of a conventional Wheatstone bridge. Dynamic testing has been performed on the enhanced

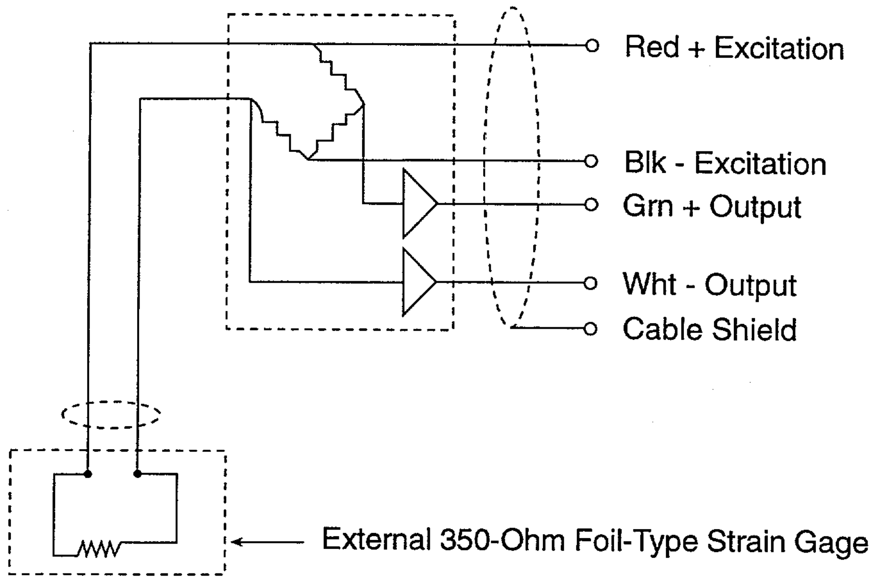

Figure 1. Basic Electrical Configuration of the Enhanced Strain Measurement Device

strain measurement device simulating actual test conditions. The results of the enhanced strain measurement device when compared to a conventional single active-arm Wheatstone bridge configuration indicated expected outputs that were comparable in amplitude and phase at input shock levels approaching several thousand g's. The results of these tests indicate the enhanced strain measurement devices have the capability of measuring surface strain in support of testing of radioactive material transportation packages

REFERENCES

NRC (U.S. Nuclear Regulatory Commission), U.S. Code of Federal Regulations, Title 10, Part 71.71, *Normal Conditions of Transport,* and Part 71.73, *Hypothetical Accident Conditions,* U.S. Government Printing Office, Washington, DC (1994).

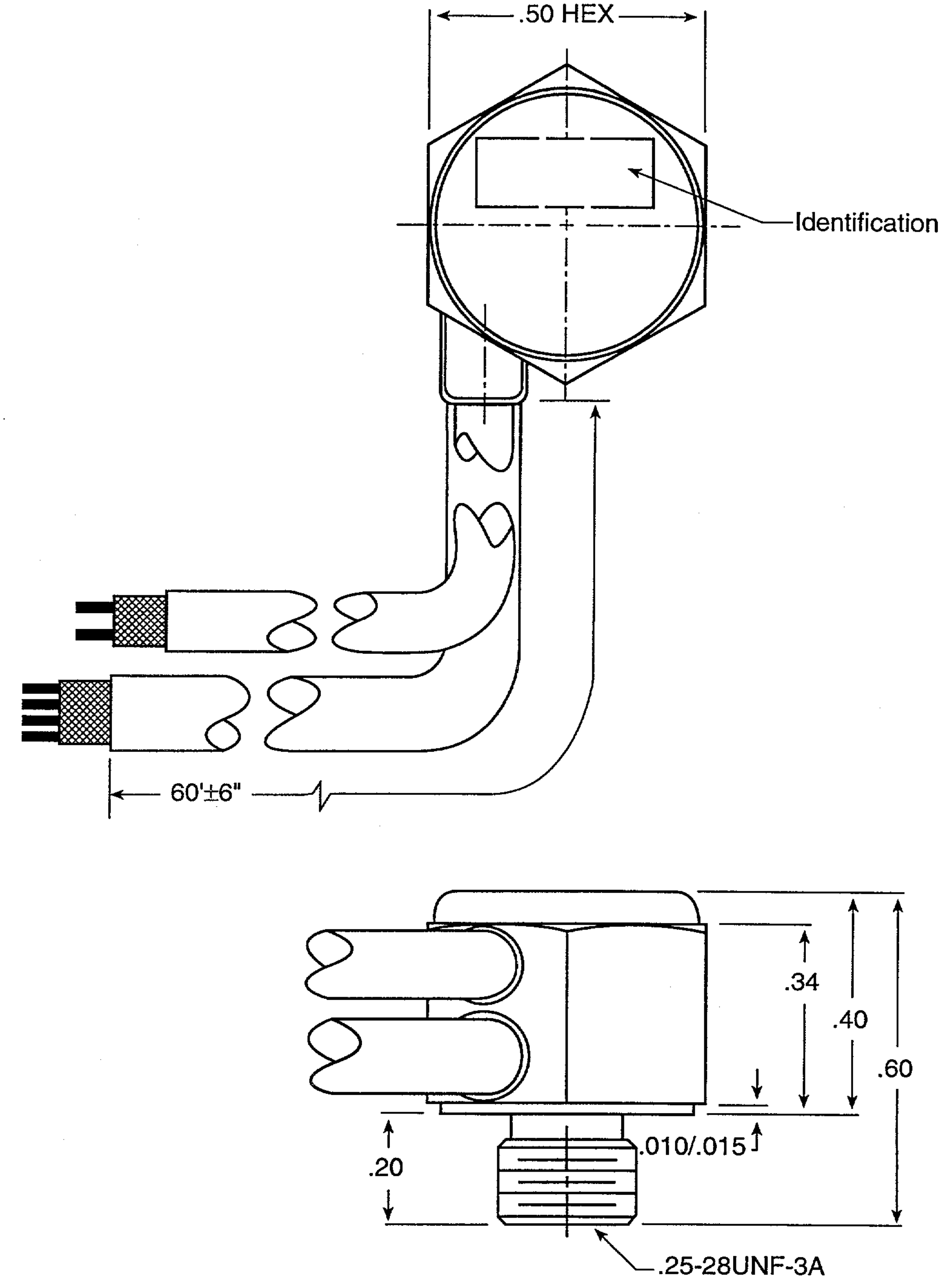

Figure 2. Mechanical Configuration of the Enhanced Strain Measurement Device

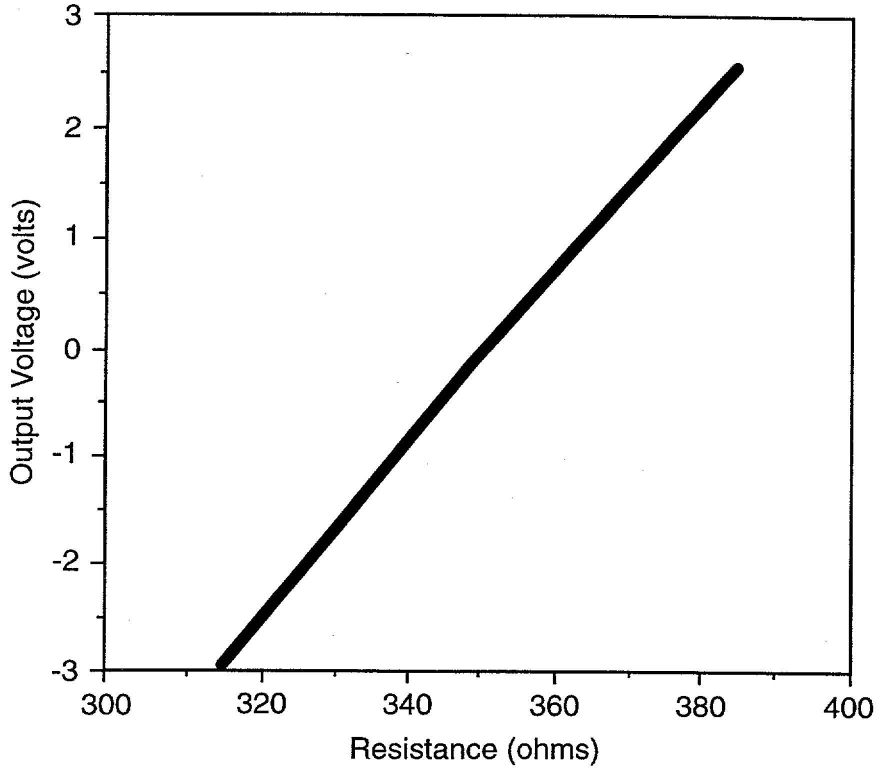

Figure 3. Enhanced Strain Measurement Device Output Voltage Versus Resistance Change

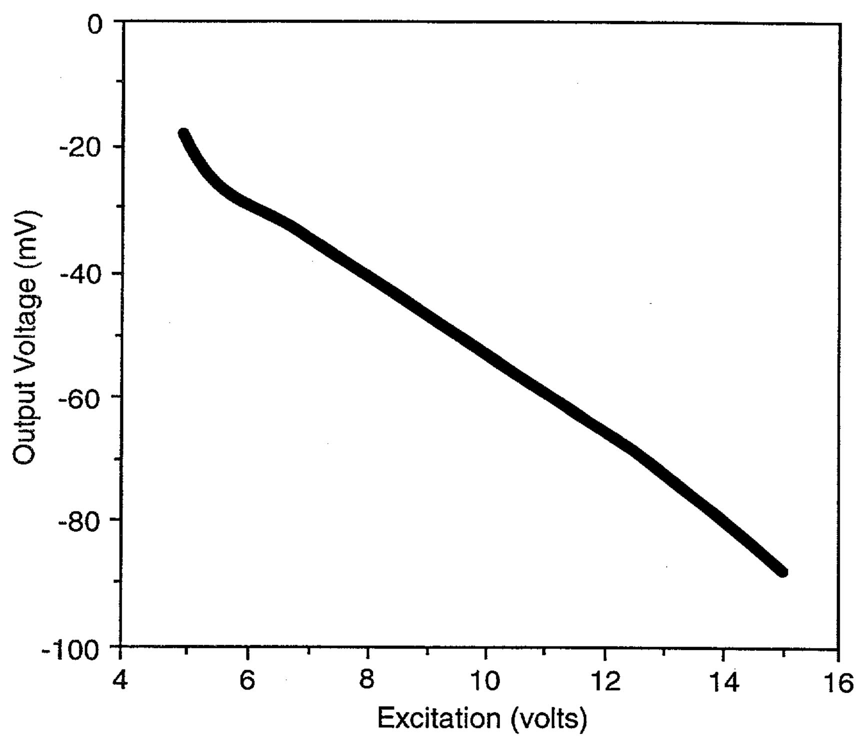

Figure 4. Enhanced Strain Measurement Device Output Voltage Versus Excitation Voltage

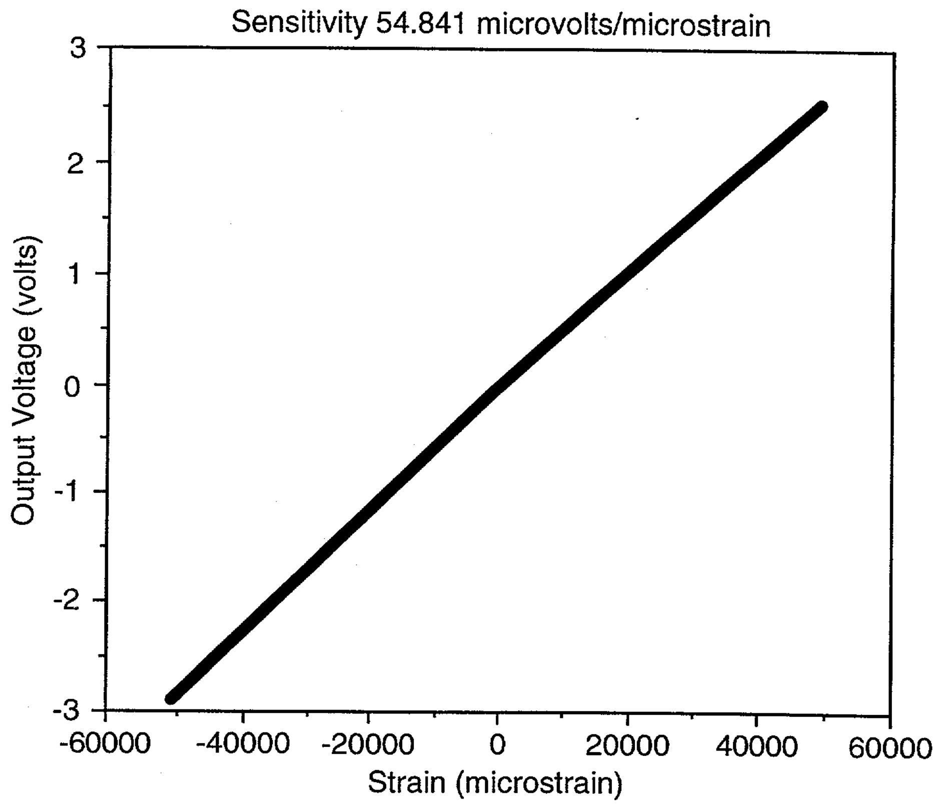

Figure 5. Enhanced Strain Measurement Device Sensitivity

Table 1. Enhanced Strain Measurement Device Performance Specifications

Performance Characteristics

Measurement Range	±50,000 με
Frequency Response	±5% dc to 20 kHz ±1 dB dc to 30 kHz
Resonant Frequency (Electronics Package)	120 kHz Minimum
Amplitude Linearity	±2% of Reading
Transverse Sensitivity	<5%
Temperature Response	±10% Maximum (-30°F to 150°F)
Thermal Zero Shift (Electronics Package)	< ±300 mV, (-30°F to 150°F)

Electrical Characteristics

Excitation	+10 V dc Nominal
Full-Scale Output	±2.5 V Minimum
Zero Offset (Electronics Package)	< ±150 mV @ 25°C
Grounding	Case Isolated From Signal Ground
Warm-Up Time	2 Minutes Maximum

Mounting

1/4 - 28 UNF Class 3 Threaded Case With a Recommended Mounting Torque of at Least 20 in. lb.

Environmental Characteristics

Temperature Range	
Operating	-30°F to 150°F
Nonoperating	-65°F to 250°F
Shock Limits	20 KG Minimum

Calibration

Sensitivity	mV/με or μV/με