Practical Strain Gage Device Signal Conditioning Calibration And Application

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Abstract
Typically, signal-conditioning applications incorporate a ratio-metric calculation to convert the measurand to an engineering unit. Some techniques are better than others at achieving the desired results. In an ideal ratio-metric measurement, the output of the device is determined by dividing the excitation voltage into the strain gage mV output, or mV/V. The resultant mV/V signal is divided by the full-scale mV/V signal demonstrating the percentage of full-scale output. The percentage value is then multiplied by the full-scale force unit to arrive at an engineering unit equal to the applied force. In our not so perfect world some signal conditioners use an assumed constant voltage regulated power supply and then simply apply a fixed gain amplifier to the signal. These excitation supplies rarely meet their own specification for voltage regulation resulting in significant measurement error. Calibration techniques utilizing Wheatstone bridge simulators and voltage standards are discussed. Focus will be on trending of calibration data for strain gage devices and utilizing a best-fit straight-line method for determining uncertainty. Techniques employed to overcome systematic error incorporated by fixed signal conditioning; the application of slope and intercept calculations for transducers used in data acquisition systems. Shunt calibration versus using applied force, why we should be wary of the results that shunt calibration provides, and some other interesting facts about shunt calibration are discussed.

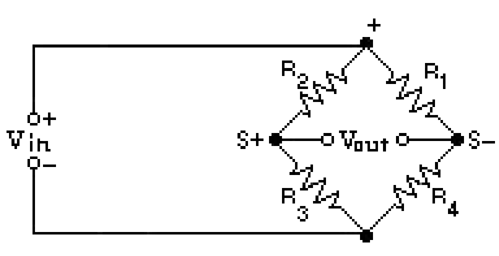
Introduction
Of all the measurement devices available, truly the workhorse of most physical testing laboratories is the strain gage based transducer. The strain gage has been adapted to measure more physical attributes than any other device. Unfortunately, a lack of understanding of the basic operation of transducers using strain gage technology can lead to increased measurement error. The steps necessary for achieving optimal performance from strain gage transducers are not extensive and minimal care is needed to insure confident measurements. This paper will attempt to guide the operator through the various sources of error and assist in their elimination. Throughout this paper it is assumed the strain gage transducer is constructed in a full bridge and requires a 10 VDC excitation supply, and has an impedance of 350 ohms with a sensitivity of approximately 3mV/V.

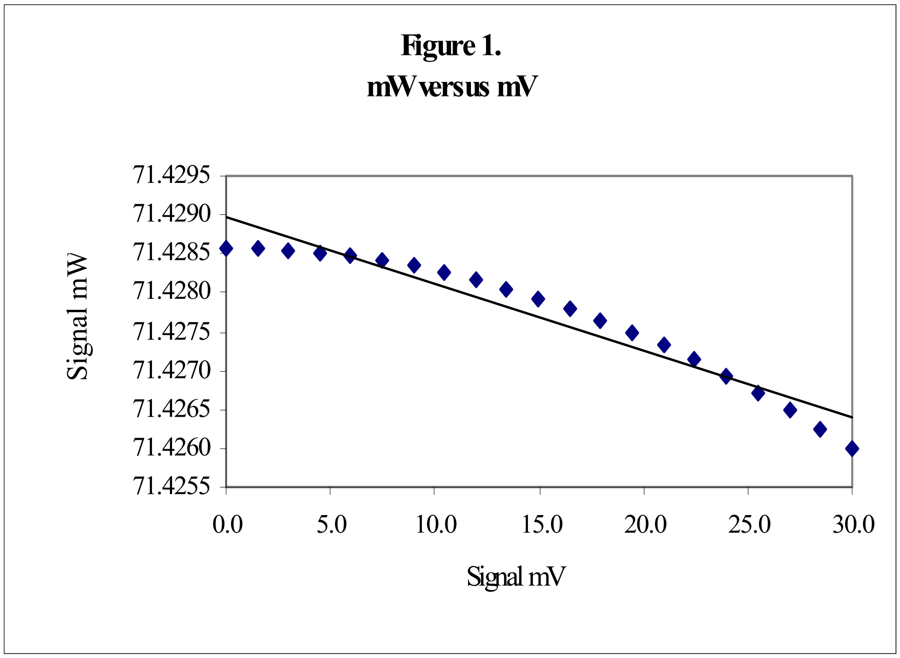
The Wheatstone Bridge
To better express the challenges associated with strain gage based transducer signal conditioning, a brief review of the Wheatstone Bridge is required. A balanced Wheatstone Bridge consists of 4 resistors of equal value connected to form a quadrilateral; an excitation constant voltage supply is connected across one of the diagonals (excitation), and a voltage measurement device across the other diagonal (signal). The voltage at the signal outputs is the result of 2 equal voltage

dividers. When balanced the voltages are both equal to half of the excitation voltage, there is no potential difference between the signal outputs. The current through both voltage dividers is equal when balanced. Signal variations occur when the resistance of one or more legs is varied. The unbalancing of a single leg of the bridge causes the current to change inversely proportional to the total resistance change of that half of the bridge. The change in current causes the signal voltage to experience a non-linear change not proportional to the resistance. The non-linearity is of a small magnitude, as the unbalanced condition increases, the non-linearity also increases. The non-linearity of an ideal quarter bridge transducer is illustrated in Table 1. Non-linearity of strain gage based transducer, and Figure 1. Signal milli-watts versus signal milli-volts.

Table 1. Non-linearity of strain gage based transducer

EXC	mV	R2	R3	+SIG	fixed I	R1	R4	-SIG	SIG I	Total I	SIG mW	Calc -SIG	SIG mV	error mV	%FS
10	0.0	350	350	5	0.0143	350	350.0000	5.0000	0.0143	0.0286	71.4286	5.0000	0.0000	0.0000	0.00
10	1.5	350	350	5	0.0143	350	349.7913	4.9985	0.0143	0.0286	71.4286	4.9985	1.4915	0.0085	0.03
10	3.0	350	350	5	0.0143	350	349.5825	4.9970	0.0143	0.0286	71.4285	4.9970	2.9839	0.0161	0.05
10	4.5	350	350	5	0.0143	350	349.3738	4.9955	0.0143	0.0286	71.4285	4.9955	4.4772	0.0228	0.08
10	6.0	350	350	5	0.0143	350	349.1650	4.9940	0.0143	0.0286	71.4285	4.9940	5.9713	0.0287	0.10
10	7.5	350	350	5	0.0143	350	348.9563	4.9925	0.0143	0.0286	71.4284	4.9925	7.4664	0.0336	0.11
10	9.0	350	350	5	0.0143	350	348.7475	4.9910	0.0143	0.0286	71.4283	4.9910	8.9624	0.0376	0.13
10	10.5	350	350	5	0.0143	350	348.5388	4.9895	0.0143	0.0286	71.4283	4.9895	10.4592	0.0408	0.14
10	12.0	350	350	5	0.0143	350	348.3300	4.9880	0.0143	0.0286	71.4282	4.9880	11.9570	0.0430	0.14
10	13.5	350	350	5	0.0143	350	348.1213	4.9865	0.0143	0.0286	71.4281	4.9865	13.4556	0.0444	0.15
10	15.0	350	350	5	0.0143	350	347.9125	4.9850	0.0143	0.0286	71.4279	4.9850	14.9551	0.0449	0.15
10	16.5	350	350	5	0.0143	350	347.7038	4.9835	0.0143	0.0286	71.4278	4.9835	16.4556	0.0444	0.15
10	18.0	350	350	5	0.0143	350	347.4950	4.9820	0.0143	0.0286	71.4277	4.9820	17.9569	0.0431	0.14
10	19.5	350	350	5	0.0143	350	347.2863	4.9805	0.0143	0.0286	71.4275	4.9805	19.4591	0.0409	0.14
10	21.0	350	350	5	0.0143	350	347.0775	4.9790	0.0143	0.0286	71.4273	4.9790	20.9623	0.0377	0.13
10	22.5	350	350	5	0.0143	350	346.8688	4.9775	0.0143	0.0286	71.4271	4.9775	22.4663	0.0337	0.11
10	24.0	350	350	5	0.0143	350	346.6600	4.9760	0.0144	0.0286	71.4269	4.9760	23.9712	0.0288	0.10
10	25.5	350	350	5	0.0143	350	346.4513	4.9745	0.0144	0.0286	71.4267	4.9745	25.4771	0.0229	0.08
10	27.0	350	350	5	0.0143	350	346.2425	4.9730	0.0144	0.0286	71.4265	4.9730	26.9838	0.0162	0.05
10	28.5	350	350	5	0.0143	350	346.0338	4.9715	0.0144	0.0287	71.4263	4.9715	28.4915	0.0085	0.03
10	30.0	350	350	5	0.0143	350	345.8250	4.9700	0.0144	0.0287	71.4260	4.9700	30.0000	0.0000	0.00





Many transducer manufacturers incorporate active elements in the bridge circuit to offset the effects of this inherent non-linearity. Additionally, manufacturers include balancing resistors and temperature compensation resistors. These devices extend operating conditions and improve the transition between compression and tension of the unbalanced bridge. Bridge excitation voltage is specific to the design of the transducer and should be maintained per the manufacturer specification. Exceeding the recommended excitation voltage will cause self-heating of the strain gage element resulting in significant error. Zero drift without applied force is evidence of excessive excitation voltage. Lead lengths in excess of 3 meters can cause excitation supply voltage to drop. When lead lengths exceed 3 meters a voltage sensing circuit should be applied to monitor the excitation voltage at the transducer. Virtually no current should flow through the sense leads and the constant voltage supply will compensate for voltage drops resulting from lead resistance.

In most cases, measurements of linear devices incorporate an End-Point Linearity or Terminal Base Linearity method to identify the linearity of a device. For strain gage based transducers this method will identify a worst case linearity as a percent of full-scale. Most manufacturers of strain gage based transducers utilize a Best Fit Straight Line method of determining linearity. Calculation of slope (m), (y=mx+b) and intercept (b) values will provide a line through the transducer data that will represent the Least Squares Best Fit to the transducer data. Trending of the data will result in values of output voltage of the transducer to an applied force that fall on the best fit straight line. With the advent of computer based data acquisition utilizing fixed strain gage signal conditioning, slope and intercept calculations provide direct characterization of the device. Computer-based data acquisition systems using fixed signal conditioning have demonstrated that strain gage transducers having zero shifts will maintain slope.

Signal Conditioners

Signal conditioners are often neglected. Many facilities do not understand the requirements for the proper calibration of signal conditioners. Some may not be aware of the methods required to calibrate signal conditioners. In any case, improper calibration of a signal conditioner can result in measurement error. Many facilities opt to have a transducer and signal conditioner calibrated as a system (set-up and verified). Provided the devices have been independently calibrated and proven to have adequate uncertainty, having the calibration laboratory set-up and provide data on the system is acceptable. Independent calibration of devices allows for the freedom of transferring devices between systems while maintaining traceability. Should a system be solely calibrated as a system without independent data, the devices are restricted to that specific system alone. Additionally, system calibrations increase the risk that one or more functions, ranges, etc. may not be verified.

Calibration of signal conditioners should be accomplished using a Wheatstone Bridge simulator. Actual Wheatstone Bridge Calibrators are available, but most simulate the output of a bridge. The reason for using a simulator is to test the signal conditioner using its own excitation supply. In a truly ratio-metric measurement the ratio of the signal to the excitation supply determines the measurand. With regard to signal conditioners applying an AC excitation, a Wheatstone Bridge simulator is the only practical method of calibration. For DC excitation signal conditioners in the absence of a Wheatstone Bridge simulator, a DC voltage standard may sometimes be employed. Care must be taken to maintain the ratio-metric relationship. A measurement of the excitation supply under load is required. For example, a signal conditioner having a fixed 10VDC regulated excitation supply measuring 9.5 VDC when loaded would provide a signal of 28.5mV at 3mV/V. If the signal conditioner output (Analog Output, Display) were calibrated with a 30mV signal from a voltage standard, the actual output gain would be approximately 105% of the nominal. The beta for a 5VDC Analog Output with a 30mV signal is 166.67, for a 28.5mV signal the beta is 175.44. Provided the signal conditioner does not employ a signal isolation scheme, direct input of DC voltage may be employed.

Shunt Calibration

Placing a shunt resistor across a leg of a Wheatstone Bridge reduces the effective resistance of the leg resulting in an output voltage. The voltage output represents an equivalent signal for an applied force. Shunt calibration allows for the scaling of transducers without a mechanical force applied. Application of shunt calibration also reduces the effects of lead wire resistance.

Shunt calibration is accomplished by first setting zero/balance with no force applied. Once zeroed, the shunt resistance is applied and the signal conditioner span is adjusted for an output equal to the shunt value divided by the full-scale value and multiplied by the desired full-scale engineering unit. To better fit the shunt value, multiply the set point by the transducer slope. This will result in a value that falls on the Best Fit Straight Line. Because analog signal conditioners have interaction between zero and span adjustments, this process is repeated until there is no deviation from the desired values. Care must be taken to apply the shunt resistance across the same leg of the bridge as the calibration. Most manufacturers of strain gage based transducers establish a predetermined shunt connection. In cases where a transducer is used for both tension and compression, shunt values are established for each direction. Improper application of a shunt resistor will result in measurement error. If the shunt resistor is provided with the transducer and remains with that transducer, the precision of the resistor is not important. If the shunt resistor is not supplied, but the value of the resistor is noted, a high precision resistor should be used, typically ±0.02% or better. If a transducer whose manufacturer provides a shunt value for a resistance connected between –signal and – excitation is used with a signal conditioner that applies the shunt resistor between +signal and +excitation, a new shunt value must be established. Shunt values can be established at any time, using the calibration full-scale output to calculate a set point. The addition of components to balance, thermally compensate, and improve linearity cause an inequality between halves of the bridge circuit making the shunt value valid only where connected by the calibrating facility. Without the addition of these devices, the shunt values would be the same on both halves of the bridge. Obviously, different manufacturers prescribe different connections, and some signal conditioner manufacturers dictate their own connection for shunt resistors. Some manufacturers of strain gage based transducers include the shunt resistor in the transducer. A potential problem is that the lead resistance may not be included in the scaling, and the resistance of the wire to switch the shunt becomes added to the shunt resistance. During the calibration process, shunt values should be established to compliment all signal conditioning methods available.

Unique Shunt Application

With regard to absolute pressure transducers, the shunt resistor is applied in opposition to conventional applications, -signal to +excitation for example, without unloading the transducer. The output provided by the shunt resistor is a negative signal proportional to an applied vacuum. The signal conditioner is set up by adjusting the span for the ambient absolute pressure. With the shunt resistor applied, the zero is set to the ambient absolute pressure minus the shunt value.

Conclusion

Application of strain gage based transducers require calculation of calibration data establishing a Best Fit Straight Line to attain the accuracy specified by the manufacturer. When installed per the manufacturer recommendation, desired results are attainable. Shunt calibration allows traceable set-up when applied per the recommendation of the manufacturer.

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