

Technical Note

The AE-800 Series Sensor Elements



1. Introduction

The AE-800 series sensor elements are designed to be general purpose and easy to use tools in the measurement of mechanical properties such as position, pressure, force and acceleration. This note is written as additional information to the data sheet for customers starting to use the elements in building their own transducers or measuring set-ups. The note gives more detailed information about the elements and the principle being used.

The basic difference between these sensor elements and most other semiconductor strain-gauges is that they are preassembled on a header, making them more easy to use and attach to electrical connections. They are half-bridge sensor elements containing two active resistors, one on each side of the silicon die.

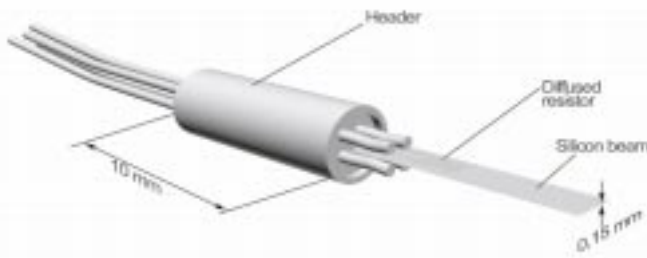
Being silicon strain-gauges, they have the advantage of high sensitivity and good long term stability.

The AE-800 sensor elements are well proven after being used in transducer products for many years covering applications within medical, military, industrial and automotive instrumentation.

2. Description of the Sensor Elements

The sensor elements consist of two main parts, the silicon cantilever beam itself and the header to which the beam is mounted. The beam is made of single crystal N-type silicon and has one ion-implanted P-type resistor on each side. The surface of the beam is passivated with thermally grown silicon dioxide. In order to obtain a creep free mounting of the beam, an alloying technique has been developed for joining the four pins of the header to contact areas on the beam. Thus the four pins of the header serve both as mechanical mount as well as electrical connections for the resistors.

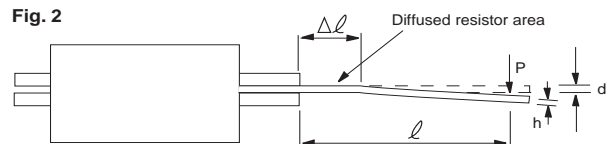
Fig. 1



3. Principle of Operation

The sensor element has two resistors, one on each side of the beam. When the tip of the beam is deflected, the areas where the resistors are located will be set under mechanical stress. Because of the piezoresistive effect in silicon, the resistors will hereby change in value. The resistor on the compressed side will decrease in value, and the resistor on the other side will increase. The change in resistance is determined by various parameters such as deflection and beam dimensions.

The deflection d of a cantilever beam, loaded by a single force as shown in figure 2, is given by equation 1.



E : Modulus of elasticity = 1.6 10¹⁰ kp/mm² for silicon
 I : Moment of inertia of beam crosssection =
 ϵ_{max} : Max strain in the beam

Loading of the sensor element by adding a force at the tip.

$$(Eq. 1) \quad d = \frac{P}{EI} \cdot \frac{l^3}{3} = \frac{2}{3} \epsilon_{max} \cdot \frac{l^2}{h}$$

where P , l and h are given in the figure above.

The average strain in the resistors can be calculated by equation 2.

$$(Eq. 2) \quad \epsilon_m = \epsilon_{max} \cdot \frac{l - \Delta l / 2}{l}$$

The relative resistance change is given by equation 3.

$$(Eq. 3) \quad \frac{\Delta R}{R} = \lambda \cdot \epsilon_m = \lambda \cdot \frac{l - \Delta l / 2}{l} \cdot 1.5 \frac{h}{l^2} \cdot d$$

where λ is the gauge-factor of the resistors.

When the active resistors are made part of a Wheatstone bridge as shown in figure 3, the unbalance of the bridge due to a deflection d is given by equation 4.

$$(Eq. 4) \quad \Delta U = U \frac{\Delta R}{2R} = 0.75 \cdot U \cdot \lambda \cdot \frac{l - 0.5}{l} \cdot \frac{h}{l^2} \cdot d$$

4. Mechanical Characteristics

4.1 Mechanical Strength

Single crystal silicon is nearly an ideal elastic material that can be bent almost to the breaking point without any hysteresis effects. Hysteresis in the sensor element output signal is therefore very low and does not usually contribute to significant signal error. As part of the quality assurance in the sensor element production, each element is being bent in both directions to an output signal of 30 mV/V corresponding to movement of the tip of the beam of about 60 - 80 μm. When used, the sensor element should not be bent more than corresponding to this output signal.

4.2 Stiffness

The stiffness of the beam can be calculated from equation 1. Normally the stiffness is expressed through the spring constant, see equation 5.

$$(Eq. 5) \quad C = \frac{P}{d} = \frac{E \cdot b \cdot h^3}{4l^3}$$

4.3 Resonance Frequency

The main resonance frequency of a cantilever beam is given by the equation 6.

$$(Eq. 6) \quad f = \frac{1}{4\tau} = 1.875^2 \frac{h}{l^2} \sqrt{\frac{E}{3p}}$$

where p is the specific mass of the beam material.

For a silicon beam the equation simplifies to

$$(Eq. 7) \quad f = 1.31 \cdot 10^6 \frac{h}{l^2}$$

(h and l in mm give f in Hz)

For the AE-800 series standard elements 0.15 mm thick this gives a resonance frequency of about 10 kHz.

5. Electrical Characteristics of the Sensor Element

5.1 Linearity

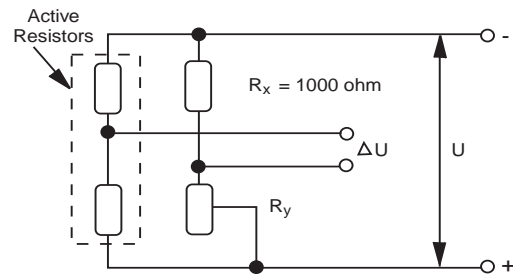
The resistors will change their value depending upon the imposed strain. To a first approximation the relation between strain and resistance change is linear. The deviation from linearity increases with the deflection of the beam. The non-linearity of the output signal is measured to be:

Output Signal (OS)	Non-linearity (in % of OS)
10m V/V	0.05 - 0.1
20mV/V	0.1 - 0.2
30mV/V	0.2 - 0.4

5.2 Zero Shift

An unloaded sensor element will experience a zero-shift with changing temperature. During manufacturing the zero-shift for

Fig. 3

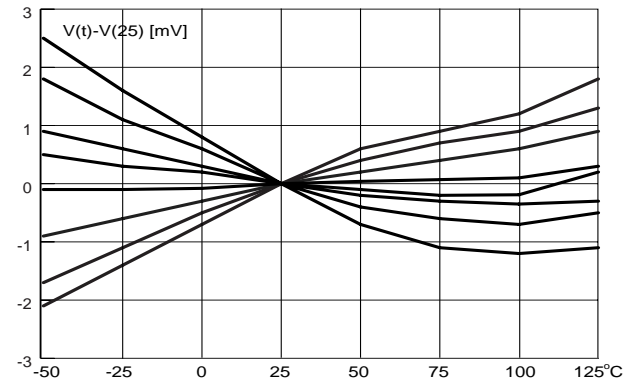


Balancing bridge Zero-shift with resistor Ry.

each element is measured in the temperature range 20-70°C and the shift is calculated and expressed in % of a full scale signal of 30 mV/V. At this point of the test the sensor elements are selected into different accuracy groups. The elements AE-801 have a thermal Zero shift better than ±0.005%/FS/°C. The value of the balancing resistor Ry needed to balance the bridge when Rx in figure 3 is 1000 Ω, and can be given on the certificate upon request.

Typical change in Zero-point with temperature over a larger temperature range for AE-801 sensor elements is shown in figure 4.

Fig. 4



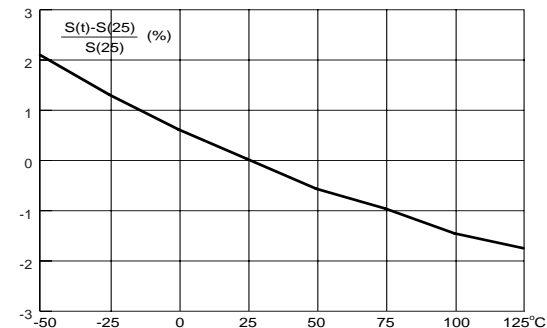
Change in Zero-point with temperature.

5.3 Sensitivity-Shift

The sensitivity expressed through the gauge-factor of the diffused resistors will change with temperature. Temperature coefficient of the sensitivity is in the data sheet specified to be - 0.17 + 0.03/°C.

This is an average value when measured at 20 and 70°C. Figure 5 gives the typical change in sensitivity over a larger temperature range.

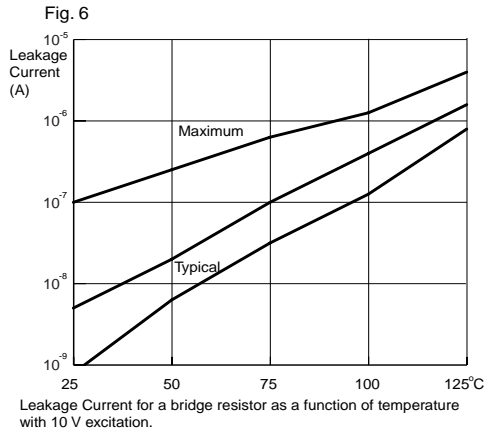
Fig. 5



Relative change in sensitivity with temperature.

5.4 Leakage Current

Leakage current may have an effect on the measuring signal at high temperature. Typical leakage current for a bridge resistor is shown as a function of temperature in figure 6.



5.5 Maximum Voltage Excitation

Maximum excitation voltage that should be used will usually be limited by the internal power dissipation in the sensor element. Resistance values are chosen relatively low to obtain the best possible long term stability of the output signal. Internal power dissipation $P=U/R$ is causing a temperature rise in the sensor element about 1 C/mW used in free air and about 0.25°C/mW in oil. If this temperature increase is too high, it may lead to leakage currents in the resistors that may effect bridge output voltage. Avalanche breakdown voltage between resistors is specified to be higher than 15 V. This voltage is conservatively set. Typical breakdown voltages will be 50 V or higher.

6. How to Use the Sensor Element

The sensor element is in principle a miniature position sensor with low hysteresis, good linearity and relatively high spring constant. It can be used in basically two different ways.

When the sensor element is used as an accelerometer or as a balance, the applied load can act directly on the beam. In this case the silicon beam acts both as position sensor and spring element. In the other case the beam is used as a position pick-up sensor for other spring elements such as diaphragms and bourdon-tubes.

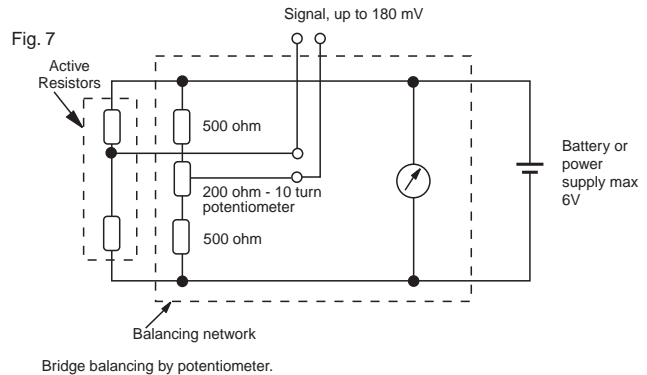
When the beam is used for measuring the position of a spring element, it is important that the beam is rigidly mounted so that no unwanted movement between the beam and the spring mount can take place. Because of the small movement needed to give the beam the full-scale deflection, unwanted mechanical distortions must be kept to fractions of a micron to obtain reliable results. This again makes it necessary to use small, compact and rigid designs.

In all designs where the sensor elements is to be used, precaution must be taken that the strain in the beam does not exceed the value of breakage because of the overload. When designing overload protection, one must bear in mind that the allowable deflection is in the order of 60-80 μ m.

7. Electrical Circuitry for use with the Sensor Element

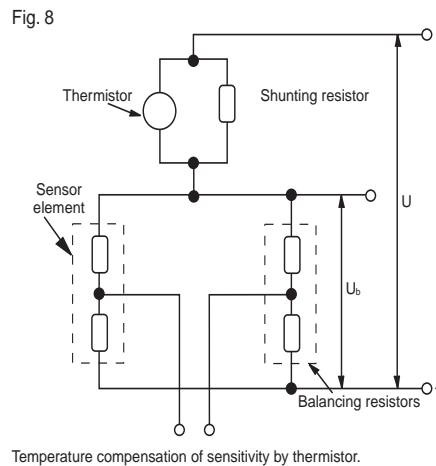
For temperature controlled measurements where the physical size must be at a minimum, it is recommended that the balancing part of the Wheatstone bridge is located away from the measuring device containing the beam.

In the case of a potentiometer solution, the balancing circuitry shown below in figure 7 has been found useful.



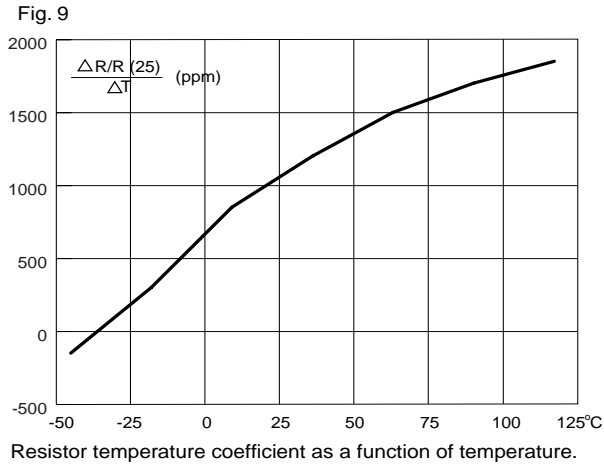
The output signal can be fed directly to a millivoltmeter or a recorder without a pre-amplifier.

If the transducer containing the sensor element is exposed to large variations in temperature, the balancing resistors should be at the same location as the sensor, and provisions must be made to compensate for the change in gauge-factor. A simple way to do this is to place a thermistor-network in series with the bridge as shown in figure 8. The thermistor-network must be dimensioned so that the voltage across the bridge rises at the same rate as the sensitivity decreases.

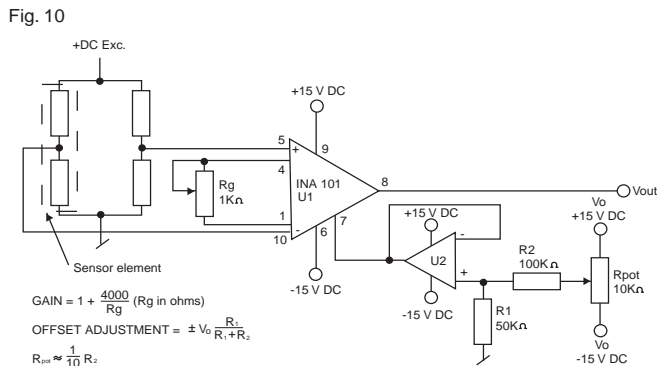


If balancing resistors and temperature compensation should be an integral part of the transducer housing, hybrid integrated circuit technology is one good way to make the solution rugged and compact. In this case, individual calibration of zero-point and sensitivity can be done by laser trimming.

The circuit solutions given are all based on voltage excitation. If current excitation is used, the effect of resistance change with temperature must also be taken into consideration. Resistance variation with temperature is given in figure 9. The temperature coefficient given in the data sheet is the average value measured between 20 and 70°C.



In case a higher output signal should be needed, the basic circuit shown in figure 10 can be recommended. With this kind of circuit FS-output signals in the order of 5 V can be achieved.



8. How to Handle the Beam

When handling the sensor elements, one must make sure that the beam is not overstressed. In order to avoid too large a force being transferred to the beam, one should preferably handle the sensor element by holding only one of the leads and as far out on the leads as possible. When handling the element this way, it can be inserted through small openings and it will not break even if the beam touches the wall. The same precaution should be taken when removing and inserting the elements into the glass-tubes used for storage and transport.

The header can be assembled by pressing into a conical hole or by gluing the header body to a cylindrical hole.

Leads can be bent up 180° with radius of down to 0,4 mm. Lead soldering up to 250°C, 10 sec.

The resistors are designed to be as robust as possible against surface contamination on the sensor element die, but should be handled to avoid contact with acids, bases, salty solutions and other corrosive media. High cleanliness should be used in all assembly operations and in use.

The elements should not be used in electrical conducting media.

Touching the silicon beam with naked fingers should be avoided because contamination from fingers (sodium and potassium) can lead to long term drift of resistance values and leakage currents, in particular at high temperature. If it is necessary to touch the silicon by hand, clean plastic or cotton gloves or finger tip protections should be used. Finger prints may be rinsed away in electronic grade hot trichlorethylene followed by rinsing in acetone and isopropyl alcohol.

9. Custom Design

Other geometric and designs may be developed upon customers' request. Due to the engineering cost of doing special designs, a minimum quantity will be required.

The following mechanical related parameters may be altered:

- Beam length (2.5 to 10 mm)
- Beam thickness (0.10, 0.15 or 0.28 mm)

The following electrical related parameters may be altered:

- Value of resistors (1 k Ω to 10 k Ω)

If any of these changes are wanted, please contact the company for details and quotation. Minimum orders for other beam lengths are 500 pcs, and 10000 pcs for all other changes.

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