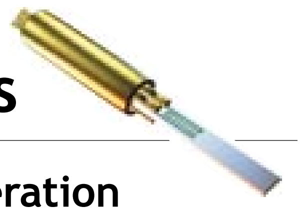
Technical Note

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.

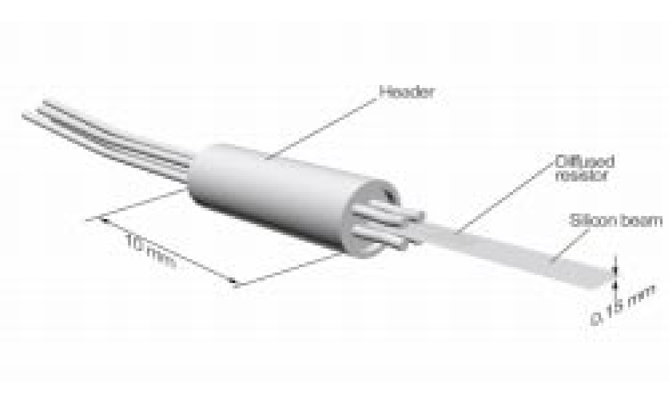
Being silicon strain-gauges, they have the advantage of high sensitivity and good long term stability.

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 silicondioxide. 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

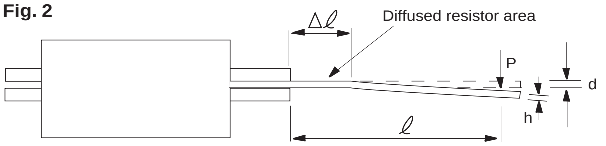


3. Principle of Operation

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.

Fig. 2



E : Modulus of elasticity = 1.6 10 kp/mm for silicon

I : Moment of inertia of beam crossection =

ε_{max} : Max strain in the beam

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

$$\text{(Eq. 1)}\quad d = \frac{P}{E\,I}\,\frac{\ell^{3}}{3} = \frac{2}{3}\,\varepsilon_{max}\cdot\frac{\ell^{2}}{h}$$

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

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

$$\text{(Eq. 2)}\quad \varepsilon_{m} = \varepsilon_{max}\cdot\frac{\ell - \Delta\ell/2}{\ell}$$

The relative resistance change is given by equation 3.

(Eq. 3)

$$\frac{\Delta R}{R} = \lambda\cdot\varepsilon_{m} = \lambda\,\frac{\ell - \Delta\ell/2}{\ell}\cdot 1.5\,\frac{h}{\ell^{2}}\cdot d$$

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)

$$\Delta U = U\,\frac{\Delta R}{2\,R} = 0.75\cdot U\cdot\lambda\,\frac{\ell - 0.5}{\ell}\cdot\frac{h}{\ell^{2}}\cdot d$$

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 m V/V corresponding to movement of the tip of the beam of about 60 - 80 um. 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) $$C = \frac{P}{d} = \frac{E \cdot b\, h^3}{4\ell^3}$$

4.3 Resonance Frequency

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

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

where p is the specific mass of the beam material.

For a silicon beam the equation simplifies to

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

(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

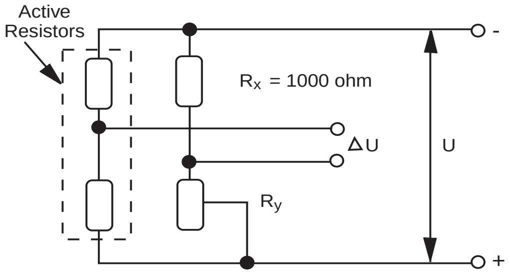
The resistors will change their value depending upon the imposed strain. To a first approximation the relation between strain and resistance change is linear. The deviation form linearity increases with the deflection of the beam. The non-linearity of the output signal is measured to be:

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 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.

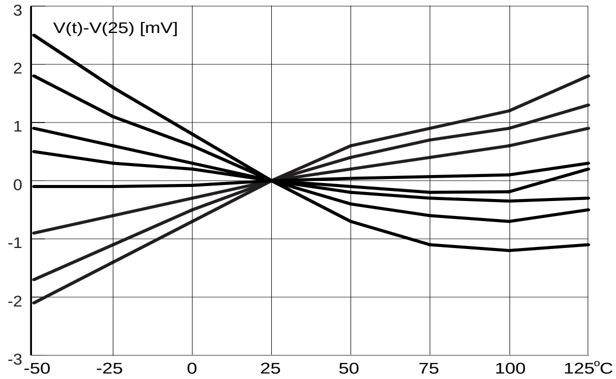
Fig. 3



Balancing bridge Zero-shift with resistor Ry.

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

Fig. 4

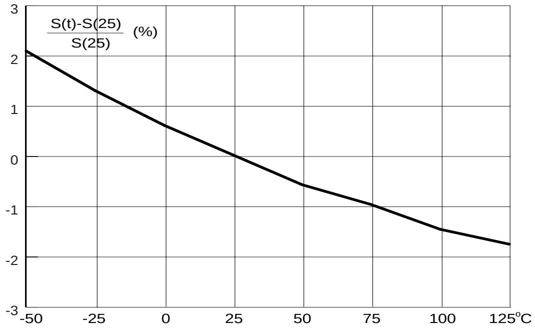


Change in Zero-point with temperature.

5.3 Sensitivity-Shift

The sensitivity expressed through the gauge-factor of the diffused resistors will change with temperture. 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

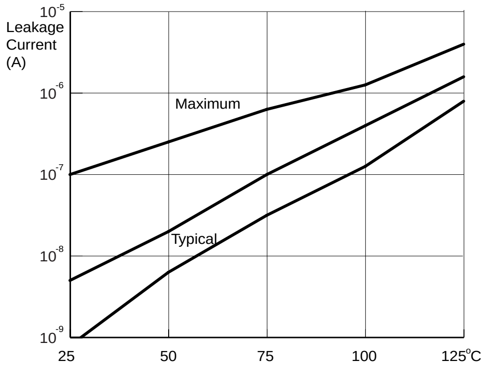


Relative change in sensitivity with temperature.

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.

Fig. 6



Leakage Current for a bridge resistor as a function of temperature with 10 V excitation.

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 $P=U^2/R$ 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.

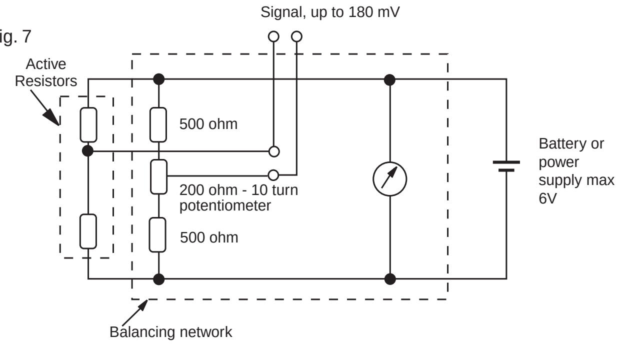
In all designs where the sensor elements is to be used, precaution must be taken that the strain in the beam does not exceed the value of breakage because of the overload. When designing overload protection, one must bear in mind that the allowable deflection is in the order of 60-80 m.

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.

Fig. 7

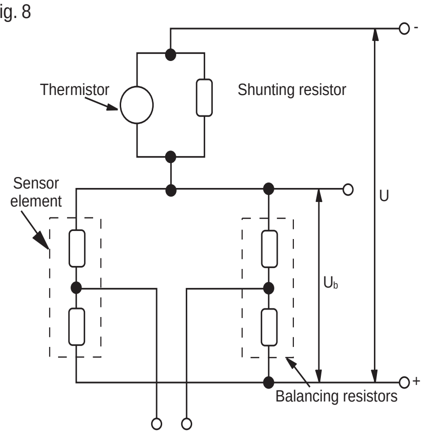


Bridge balancing by potentiometer.

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.

Fig. 8



Temperature compensation of sensitivity by thermistor.

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.