Short Guide to Strain Gauging Methods

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This document is designed to provide an inexperienced user with an introduction to the use of strain gauges within experimental stress analysis. More detailed information is provided in the HBM strain gauge catalogue and the textbook “An Introduction to Measurements using Strain Gauges” by Karl Hoffmann.

Before selecting strain gauges, adhesives and protective coatings, you need to be clear about the measurement objectives. Once you know this, you can decide on the optimum location of the strain gauges. However, before you take any further steps, you need to have an understanding of the possibilities offered by the Wheatstone Bridge circuit.

A. The Wheatstone Bridge

The Wheatstone Bridge circuit is fundamental to the use of strain gauges for measurement tasks. Sir Charles Wheatstone formulated this resistance circuit in 1843. The circuit consists of four resistances, arranged in a square.

![Wheatstone Bridge Diagram](image)

Figure 1

One or more of these resistors can be replaced by a strain gauge. As gauges are strained, their resistance alters causing an imbalance in the bridge output between points A and B.

Consider a simple example, where R1 is replaced by an active strain gauge, whose resistance increases by one ohm under loading. The bridge output
would be 2.1 mV with an excitation voltage of one volt, as shown in figure 2. An important point to note is that the output voltage is positive if there is an increase in R1.

![Wheatstone Bridge diagram](image)

**Figure 2**

Normally, however, the output is expressed as a ratio of the mV output divided by the excitation voltage. In this case the excitation voltage is 1V, so the output remains numerically unchanged at 2.1mV/V. If the excitation voltage is increased to say 10V, the output becomes 21.0 mV, which is also 2.1mV/V. The dimensionless unit mV/V is therefore independent of the excitation voltage used.

We can extend this example by changing R2 for an active strain gauge, rather than R1. See figure 3. An increase in R2 of one ohm produces a similar output, but the effect is negative (–2.1mV/V). Further analysis shows that an increase in both R1 and R3 has a positive effect on the bridge output, while an increase in R2 and R4 produce a negative effect.

This is a useful result when applying the Wheatstone Bridge to strain gauge applications.
B. Loading Cases

B1. Bending

Consider a bending beam, with positive strain on the top surface and negative strain on the bottom. A simple means of measurement would be to apply one gauge on the top or bottom and relate the measured strain to the applied bending. A problem with this installation is the potential error due to thermal effects. Heat will cause a strain reading, which cannot be distinguished from a bending force. One way to overcome this problem is to apply two active gauges and connect them within the same Wheatstone Bridge circuit in positions R1 and R2. This is known as a half-bridge circuit.
Under bending the top gauge is subjected to a tension, giving a positive strain; the gauge underneath is subjected to compression, producing a negative strain. However, as the gauge underneath is connected as R2 in the Wheatstone Bridge circuit, a double negative occurs, so the output of the two gauges is added together. This larger signal is better for measurement purposes, but must be divided by two to provide the correct strain value.

The added benefit is that under any axial loading, or thermal strain, the output of each gauge will be the same. These outputs will cancel each other out within the Wheatstone Bridge, allowing only bending to produce an output.

This installation can be further enhanced using two additional gauges, with two on the top and two on the bottom connected as a full bridge.

![Bending load diagram](image)

Figure 5

B2. Axial

Now consider axial loading.

The same thermal problems exist when using a single gauge on an axial application. To overcome this, the half bridge circuit can be used again, but the second gauge is installed perpendicular to the direction of loading. As the test material strains, a negative strain occurs perpendicular to and proportional with the principal strain. This proportion is governed by a material constant known as the Poisson ratio ($\gamma$). The gauge parallel with principal strain is connected as R1 in the $\frac{1}{2}$ bridge circuit and R2 is the perpendicular gauge.

As R2 has a negative effect on the bridge output and is under compression, again (negative strain) a double negative is produced. The R2 strain is therefore added to that of R1. The correct strain value is obtained by dividing the output by the factor of $1 + \gamma$. The added benefit of this configuration is that any thermal influences produce the same strain on both gauges. With one having a negative effect on the bridge and the other a positive effect, the thermal strains cancel each other out.
This application can be also refined by using four active gauges, connected as a full bridge, see figure 6.

All gauges can be mounted on one common carrier. These are HBM VY gauges and can be found in the HBM strain gauge catalogue and on the HBM website.

To eliminate bending, while measuring axial loads, two perpendicular gauges can be installed on both the top and bottom surfaces. The two gauges parallel with the beam need to be connected to R1 and R3 within the Wheatstone bridge, while the two perpendicular gauges need to be connected to R2 and R4.

Under bending the gauges parallel with the beam will experience strains equal in magnitude, but one is under tension, the second in compression. As they have the same sign within the Wheatstone Bridge, they cancel each other out. The same is true for the gauges installed perpendicular to the beam.
B3. Unknown Directions

A rosette must be used in situations where the magnitude and direction of the two principal stresses are unknown. Three strain measurements are required to calculate the three unknowns. These measurements are made in known directions relative to each other, as defined by the layout of the rosette. From these measurements, a series of well-established simultaneous equations can be applied to determine the value of the desired unknowns. These calculations are available in HBM’s catman software. Further reading is available in Hoffmann, section 8.2.

C. Strain Gauge Selection

The HBM strain gauge catalogue is indispensable for selecting strain gauges. Should you require assistance, kindly contact your local sales engineer or your local HBM sales office.

For experimental stress analysis, most measurements are performed using HBM’s “Y” series of gauges. There are a number of issues to consider with strain gauge selection. The main ones are geometry, length, and resistance.

C1. Geometry

If very little is known about the magnitude and direction of principal stresses, then a rosette (RY) of three gauges has to be used. A number of pattern variations are available. The choice between them can be quite arbitrary.

Single gauges (LY) or gauges with two grids, either perpendicular (XY) or parallel (DY), are used in stress states with known directions. Gauges are installed to measure axial or bending loads, within a ¼, ½, or full Wheatstone bridge circuit, as described above. Further information can also be obtained from HBM's white paper “Elementary Load Cases with Strain Gauges”, and Hoffmann, section 8.4.

C2. Length

A strain gauge is an integrable device. It measures the average strain value along its length. If therefore you want to determine a strain profile, perhaps adjacent to a structural detail such as a hole, then you need to use a short gauge. HBM offer gauges down to 0.6mm long for this purpose. In addition, chain gauges are available (KY), with 10 short gauges mounted on a common carrier to make it easier to measure strain profiles.
On occasion it is useful to take advantage of the integrable properties of the strain gauge. With composite materials, inclusions of material may produce a local and unrepresentative strain. Under these circumstances it is prudent to use a longer gauge, which is five times longer than any inclusion.

The other factor to consider when choosing your gauge length is simply the ease of handling. Small gauges can be more difficult to bond well, particularly for the inexperienced user.

**C3. Resistance**

HBM offers 4 gauge resistances: 120, 350, 700 and 1,000 ohms. The resistance exists within a parallel resistive circuit with the gauge’s insulation resistance. Any degradation in the installation resistance, perhaps due to the presence of moisture, will create a measurement error. This error is greatest with a higher gauge resistance, such as 1,000 ohms. However, resistance selection is often a compromise and, in some circumstances, a low resistance of say 120 ohms is not always the best choice.

Strain gauges consume power and act as small heating units. The power consumed is governed by the equation:

\[ Power = \frac{V^2}{R} \]

In certain situations it advantageous to reduce power consumption by selecting a higher gauge resistance. Some composite materials, such as glass fibre, are poor heat conductors and fail to dissipate heat generated by the gauge, causing measurement drift. Also some XY2 and XY4 gauges, used for torque measurement, are powered by a battery mounted on the torque shaft. Higher resistance gauges are often selected for this application to reduce power consumption, hence prolonging battery life.

**C4. Material of Adaptation**

The thermal output of a strain gauge can be managed by selecting a gauge which is appropriate for the workpiece material. HBM offers eight different material options.
D. Adhesive Selection

Before any adhesive can be used, the workpiece must be prepared for strain gauge bonding. Preparation methods vary depending upon the workpiece material and the adhesive, but would usually involve both roughening the surface and cleaning with a solvent (RMS1). Details of such preparation fall outside the scope of this document, but are described in the HBM booklet “Practical Hints for the Application of Strain Gauges”.

Adhesives fall into two types: cold curing and hot curing. Cold curing adhesives are easy to use, requiring pressure and ambient humidity to set. The most popular adhesive is Z70 Cyanoacrylate, which is suitable for most simple applications. It forms a thin bonding layer, providing excellent transmission of workpiece strain to the strain gauge. However, the thin adhesive does not perform well on porous surfaces. Z70 is limited to an operating temperature of 120 degrees centigrade.

The X60 adhesive, is thicker than Z70 and can be used on porous surfaces. X60 works well in low temperature applications, operating down to ~200°C. X60 is widely used as a general purpose adhesive for gluing down such things as measuring cables or accelerometers.

The main benefit of the X280 epoxy adhesive is its ability to operate to 280°C, whilst being cold curing. This is very useful if a workpiece is too large to be placed in an oven or the application of localised heating is troublesome.

In applications where elevated temperatures can be expected, or where the durability of the strain gauge installation is important, hot curing adhesives should be considered. HBM offers two hot curing adhesives. The most popular is the EP310S, which can operate to 310°C. On porous surfaces EP250 can be used.

E. Protection Selection

It is important to protect a strain gauge installation against chemicals, moisture and mechanical damage. The user must determine the appropriate protection by considering the operational environment and measurement duration. HBM offer 6 protection products.

For most workshop applications, only basic protection against moisture is required. Applying a thin coat of PU120 polyurethane paint usually provides adequate protection.

Where the potential for mechanical damage exists, SG250 silicon rubber is popular. The transparent silicon can be squeezed from a tube over the gauge and will air dry within a few hours. It also provides good protection against water at room temperature as well as some acids.
For many external applications, where protection is particularly required over an extended time against rain, snow, ice and even high humidity, HBM's AK22 putty is ideal. The same putty can also be provided in sheets with aluminum foil, which acts as a diffusion barrier. This product is known as ABM 75.

For installations around petrol or diesel engines NG150 nitrile rubber is recommended, as it provides excellent resistance to petroleum products.

For high temperature applications up to 450°C, SL450 transparent silicon resin can be used. However, hot curing is required for this product.

Chemical compatibility is an issue that should be treated with care. Many standard references are available. The HBM catalogue contains a table on chemical compatibility, which is helpful for most strain gauge users.

F. Making a Measurement

Having completed your installation you will need to connect the strain gauge(s) to a suitable measurement amplifier.

F1. Wiring

Any wiring has to be connected to a suitable solder point. It is prudent to use shielded cable, especially where electrical or magnetic interference is likely to occur. Such cable is available from HBM.

A simple two-wire connection should be avoided, as it is very susceptible to cable resistance changes due to temperature. A three-wire connection is widely used, with two leads on one side of the gauge. One is connected to R2, the bridge completion resistor, the second across the bridge output. In this configuration, any thermal effect on the leads is balanced within the bridge.

HBM also offers a four-wire connection with the MGCplus amplifier. The two measurement leads are supported by two sense wires. The sense wires monitor any change in voltage across the gauge and regulate the excitation voltage accordingly. With this method it is possible to have a 1 km connection to a single strain gauge, with the bridge completion resistor mounted in the amplifier.
F2. Amplifier

HBM offers two main amplifiers for strain gauge measurement. For a simple application, the Spider8-30 is a popular choice.

The Spider8-30 allows the connection of between 4 and 64 input channels. Either ¼, ½ or full-bridge circuits can be software selected.

The Spider8-30 is about the size of a laptop and is light and portable. It can easily be connected to a PC, using the printer port.

For applications with a greater number of channels, or where types of input need to be considered too, the MGCplus amplifier is recommended. For further information on these products, please contact your local HBM sales engineer.

F3. Software

HBM’s catman software provides an easy means of acquiring data, performing post process analysis, and data visualisation.

The software is driven by configuration, rather than by programming. It is operated using drop down menus and mouse clicks. For further information contact your local HBM sales engineer.