Baumer
Passion for Sensors

White Paper

Force measurement with strain sensors

Forces are measured with a force sensor, of course. Or maybe not? In fact, it's not as obvious as it might seem at first glance, because strain sensors can be a useful alternative in many cases. Especially when it comes to measuring large forces, they are often the more cost-effective and easier to integrate choice.

Content

1 Introduction

This white paper provides guidance on how strain sensors can be used specifically in a project and answers the following key questions:

- How does force measurement with strain sensors work?
- Which strain sensor is the optimal choice for my application?
- Which components do I need for my measurement chain?
- How to mount and place them correctly?
- How do I calibrate my strain measurement?

2 Force measurement with strain-sensors

In contrast to force sensors, which are installed directly in the force flow, strain sensors are used in the force bypass: they detect the deformations that occur when a machine structure is loaded by measuring the strain between the screw-on surfaces using strain gauges (DMS). The measured surface strain is $\varepsilon(\Delta L/L)$ proportional to the applied force and depends on the material cross-section A and the modulus of elasticity E.

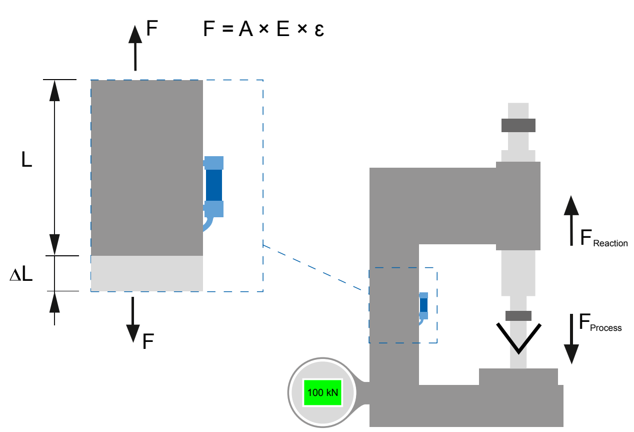

Figure 1: Force measurement in the force bypass

In this process, the strain gages convert the mechanical strain that occurs when the machine structure is deformed into a change in electrical resistance and act as a mechanical-electrical converter. As a result of this change in resistance, they generate a voltage change proportional to the strain. With the aid of the intelligent interconnection of the individual strain gauges to form a Wheatstone bridge, even the smallest strains can be measured The measuring signal of the bridge is proportional to the supply voltage (ratiometric).

The typical measuring signal of strain gauge strain sensors is between 0.4...2.0 mV/V. Strain sensors are designed to be fatigue-proof and are ideally suited for cyclic applications. Short cycle times in the millisecond range are easy to monitor. However, strain sensors with appropriate measuring mechanics are also well suited for static applications. It should be noted that strains that are not caused by the stress but by external factors such as temperature changes may distort the output signal. However, there are measures that can compensate for these effects.

3 Selecting the right strain sensor

Baumer offers a comprehensive product portfolio of screw-on strain sensors that covers the majority of possible application scenarios. These include options for limited space, normal industrial applications, and use in harsh outdoor conditions. The great advantage of screw-on strain sensors with hot-bonded strain gauges is that they represent a long-term stable, high-quality and reproducible solution for series production, whereas cold-bonded strain gauges are rather used in development trials.

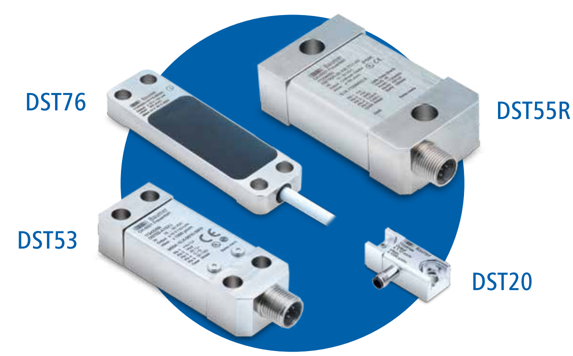

Figure 2: Portfolio for versatile applications

The **Strain Sensor DST76** is the standard option for indirect force measurement in industrial indoor applications such as factory automation use in plant and machine construction.

The **DST53** is the performance strain sensor for industrial indoor applications especially for smaller and larger measuring ranges. Due to the low stiffness, the structure to be monitored is minimally affected.

The **miniaturized strain sensor DST20** is particularly well suited for applications with limited installation space, for example in machine and equipment construction or process automation. It also represents a long-term stable solution for replacing cold-bonded strain gauges from initial tests in the test laboratory in series production where space is limited.

The particularly **robust strain sensor DST55R** is suitable for outdoor industrial applications under harsh conditions, such as mobile automation, thanks to its solid construction, the use of resistant materials and the comprehensive sealing concept.

In addition to the screw-on strain sensors, there are also versions that determine strain via a drill hole. Measuring lances and measuring dowels are available. These are used, for example, in the tie bars of injection molding and die casting machines for monitoring the mold clamping force.
Which of these is the appropriate strain sensor for a specific application can be decided based on these criteria:

- First of all, the application environment is crucial: Is it a harsh outdoor application or an industrial interior?
- The design characteristics of the structure to be monitored then determine whether a screw-on strain sensor can be used or if it is better to measure the strain via a drill hole, for example.
- The space available must also be taken into account; if installation space is limited, a miniaturized version is the best solution.
- The measurement range of the strain sensor should be selected according to the expected strain at the intended position. If the expected strain is not specified yet, it is better to choose a strain sensor with a larger measurement range for an initial trial.

3.1 Components for the measuring chain with a strain sensor

The selection of the required components for a measurement chain with strain sensors is often dictated by the existing control system. Most Baumer strain sensors have built-in amplifier electronics that provide standard signals such as +/- 10V, 4..20 mA, CANopen, IO-Link. These strain sensors can be connected directly to the controller. The DST53 and DST76 can additionally be easily optimized for the specific application via the IO–Link interface.

For passive strain sensors that provide an mV/V output signal, Baumer offers the appropriate connecting cables and amplifiers so that the strain sensor outputs a standard signal and can be easily connected to the controller. The amplifier should be placed close to the sensor in order to reach the controller with amplified signals over longer distances. Some controllers already have internal cards with mV/V input. There, passive sensors can simply be connected directly to the controller via a connecting cable.

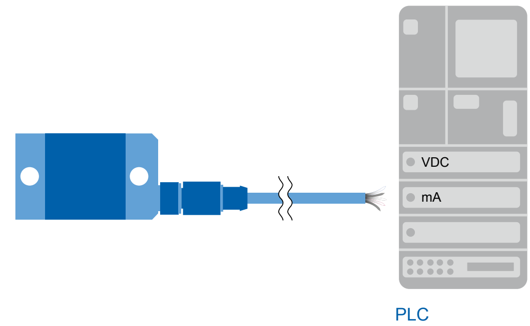

Figure 3: Strain sensors with integrated amplifier electronics

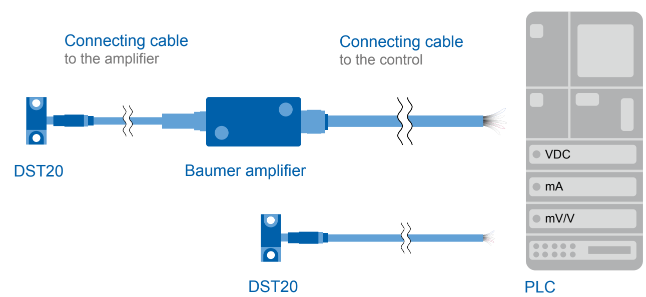

Figure 4: Measuring chain with and without amplifier

Further details can be found in the operating instructions.

3.2 Mounting and optimal placement

Screw-on strain sensors are easy to install and can detect very small strains in the micrometer range on a structure that are caused by the application of force. Therefore, they are firmly screwed onto the component for good measurement results. For thinner structures they are fastened with through holes and a nut, otherwise with the help of the supplied fastening screws in blind holes.

To find the optimal place for positioning a strain sensor and obtain the best possible results, some points need to be observed:

- The strain sensor should be placed in positions where measurable strains in the required direction due to the application of force can be expected on the structure. These are mostly strains or mechanical tensions that are generated by bending as well as pull/compressive stress. The finite element method can be used to determine the expected surface strain and direction for multi-axial strain situations and thus the required measurement range for the intended position.

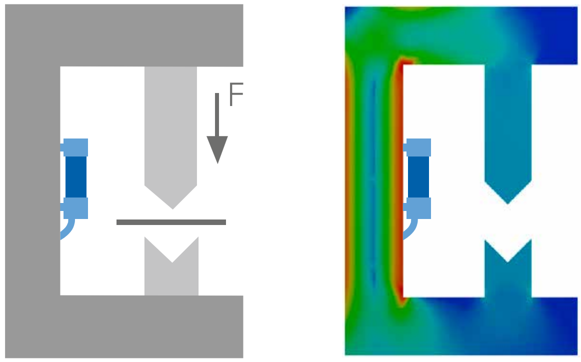

Figure 5: Optimal placement of strain sensors

- If this option is not possible, the easiest approach is to carry out a trial with a strain sensor that has a larger measurement range, e.g., 750 or 1000 µm/m, and thereby determine the actually occurring strain at the selected point.
- In addition, factors such as the involved construction design, accessibility, or protection of the strain sensor also play an important role in the positioning of strain sensors.
- It is important to note for accurate measurement results that the sensor is properly mounted on a clean, machined flat measurement surface. The respective handling procedures, installation screws, hole distances, and diameters are listed in the respective operating instructions.
- If it is difficult to prepare the installation surfaces in the required quality, ball shims can be used to equalize surface angel errors or angular hole deviations. There are also diamond-coated friction shims available on the market that equalize slight unevenness and increase friction.
- Usually, the mounting causes a slight distortion of the strain sensor and thus already a strain signal. By taring on the unloaded machine structure, this assembly influence is tared away similar to a scale.
- We also recommend regular taring of the sensor after installation to compensate for zero point changes, e.g. due to temperature influences.

3.2 Calibration during force measurement

Usually in the development phase, it is a good idea to calibrate the machine to be monitored once with a known force. This provides a simple correlation to the corresponding strain on the structure being monitored.
For this purpose, the measured strain under load is compared with a force sensor. Thus, finite element method calculations can be checked at the same time.

For higher accuracy requirements, each machine in the series can also be calibrated if necessary. Since the strain sensor measures in the force bypass, this also means that the machine is part of the measuring system. As a result, manufacturing tolerances also have an influence on measurement accuracy. Baumer strain sensors are already calibrated for strain during production. This means that they can be easily replaced on the structure to be measured in the event of a replacement and will provide the same measured value again after installation.

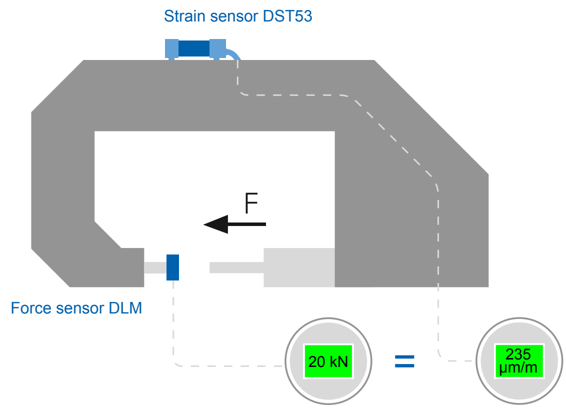

Figure 6: Strain sensor calibration

4 Summary

- Strain sensors are a cost-effective alternative to force sensors for large forces.
- Screw-on strain sensors from Baumer can be easily integrated into the machine and offer a suitable solution for all areas of application.
- By observing the points listed in this white paper, initial functional tests can be easily carried out on existing machines or new projects for later series integration.

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