CEDRAT TECHNOLOGIES
Innovation in Mechatronics

STRAIN GAGES SENSORS FOR HIGH STABILITY PIEZO ACTUATORS

HIGH PRECISION AND HIGH STABILITY STRAIN GAGES SENSORS (SGS) FOR PIEZO-ACTUATORS

INTRODUCTION

Space, military, and industrial applications require precision position sensors in order to perform closed-loop control or to monitor the state of a system. Those applications usually come with constraints such as wide thermal range, long lifetime, high stability, and compactness.

Different position sensing technologies can be used to answer partially those specific requirements, such as capacitive sensors, or eddy current sensors. The main issue with those sensors is the required volume, and the integration constraints.

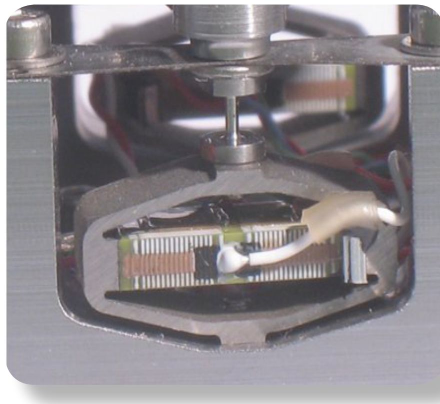


Fig1: SGS on the piezo ceramic

Strain Gages Sensors (SGS) are good candidates from the point of view of the compactness, but they are often considered as low-cost, and low-performance solution. In practice, SGS offer a good linearity, bandwidth and SNR. The main concern is about the thermal and long-term stability of those sensors.

Thanks to its extensive experience and know-how with SGS, Cedrat Technologies managed to obtain a long term and excellent thermal stability, as well as a long lifetime. Those improvements bring the performance of the SGS to the same level as competing technologies, making them very attractive for the above-mentioned applications. Those improvements are obtained without degrading the compactness of the solution, which remains the biggest advantage of the SGS. As shown on the Fig1, the SGS is barely visible on the piezo-ceramic. The actuator volume is not increased with the sensor, except for the additional number of wires required for the SGS.

CEDRAT TECHNOLOGIES KNOW-HOW

Strain gages sensors (SGS) are commonly used to measure stress in materials. For a given material, the stress measurement directly relates to the extension of the material. This means that the SGS can be used to measure the elastic displacement of a material. Cedrat Technologies masters this position sensing technology, especially for its piezo-actuators and mechanisms. Simple in appearance, the implementation of SGS for high precision position sensing requires precautions. Cedrat Technologies has thoroughly investigated the issues in the implementation of the SGS, in order to enhance their performance. In particular, the gluing process of the strain gages elements on the piezo-ceramics was optimised. This gluing process has been space-qualified. Thanks to this high quality gluing process, a stable behaviour is obtained versus temperature and throughout the entire lifetime. SGS can thus provide a trustful position measurement.

For sensing the displacement, only bridge topologies with 4 gages elements are employed. The reason is the higher sensitivity, and the intrinsic capability of those topologies to compensate some measurement errors. Depending on the application, Poisson or Wheatstone bridges can be implemented:

- Poisson bridges have lower sensitivity, but it is possible to use 2 dedicated integrated half bridges, which eases the integration and cabling.

- Wheatstone bridges are used for most demanding applications, since they have a higher sensitivity. However, it is required to use 4 independent gages elements, which requires more effort on the integration and cabling. This explains why Wheatstone bridges are not systematically used.

The output of the SG bridge has few mV amplitude, thus high gain amplification is used to get an exploitable amplitude. From the electronic point of view, Cedrat Technologies uses specific balancing techniques, allowing to trim the SG bridge offset without altering the bridge thermal balance.

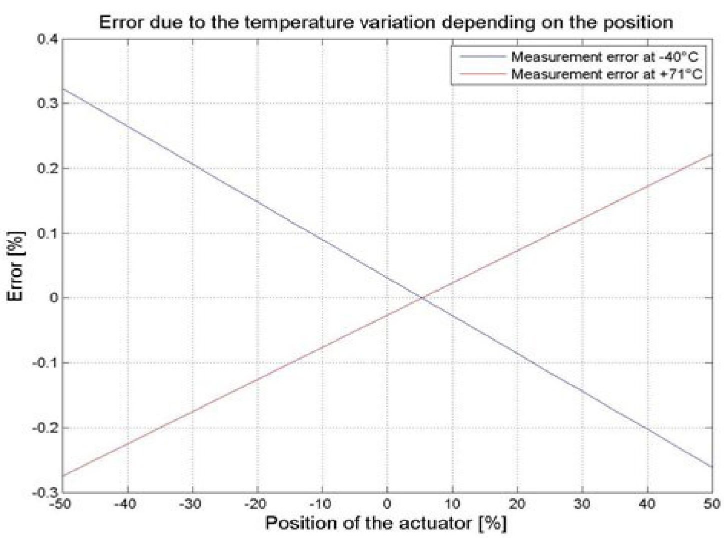
SG trimming is required to avoid saturation of the conditioner due to the high gain involved. Several conditioning topologies are known and used by Cedrat Technologies to read the SG bridges. The choice of the conditioner depends again on the application targeted. For standard application with laboratory temperature range, the standard product SG75 strain gages conditioner is used.

It should be noted that Cedrat Technologies' know-how extends to the use of SGS for more classical types of measurements, such as stress or force.

THERMAL BEHAVIOUR OF THE SGS

Ideally, the position sensors are insensitive to the temperature changes. In practice, the temperature variation has an impact on the measurement. The temperature creates an offset error and a gain error, which induce a measurement error. For a reduced temperature range, this error is often considered negligible. For demanding applications, an extended temperature range of [-40°C ; +71°C] is usually specified, which corresponds to the classical military temperature range. On such a wide temperature range, the thermal behaviour of the SGS has to be studied. If no precaution is taken, the error due to the temperature can be significant. Cedrat Technologies has studied the thermal behaviour and managed to reduce the thermal error of the SGS.

At the SG level, a dedicated integration process of the SG allows to obtain a thermally balanced bridge. A specific trimming topology is used to adjust the bridge offset before conditioning, without jeopardising the thermal balance. The figure below shows the thermal error with those techniques implemented. It is assumed that the calibration is performed at 20°C, Tmin=-40°C, and Tmax=+71°C.



Thanks to the improvements, the SG bridge is almost perfectly thermally balanced, and the offset error is of 10ppm/°C. Since the offset error is very small, the main contributor is the gain error of 50ppm/°C. This gain error is due to the thermal gain variation of the SGs, and it can't be corrected by the topology. The conditioning of the SGS is also responsible for some measurement error on the temperature range. Different conditioning topologies are used by CTEC, (the SG75 is not studied here since it is a rackable product for laboratory use, not optimised for temperature stability). Two different topologies are proposed by CTEC to improve the thermal stability of the measurement. For both solutions, the gain error of the conditioning is considered negligible, as the gain is very stable in temperature. The difference between the two solutions lies in the offset error and bandwidth:

1) The first solution is simpler and exhibits a bandwidth of 15kHz, which allows to target highly dynamic applications. The drawback is that there still remains an offset error of 35ppm/°C, which adds to the previous errors.

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2) The second solution is more complex, and the bandwidth is limited to a few kHz, thus it applies to systems with moderated dynamics. This solution of compensated conditioning allows to remove the offset error of the conditioner, i.e. the errors added by the conditioner are negligible.

Ultimately, Cedrat Technologies can perform a thermal calibration of the whole sensing chain, to characterise the offset and gain error of the SGS versus temperature. This calibration data is stored in a very compact memory on the system, together with a temperature probe. Software compensation is then implemented, which uses this calibration data and the temperature measurement to remove the remaining thermal error from the SGS measurement. With this technique, the final SGS measurement error becomes negligible. However, this technique requires to calibrate thermally each system, which is time consuming.

To summarize, the SGS measurement error due to the temperature variations depends on the requirements of the application. Cedrat Technologies can propose three complete SGS solutions with different thermal performance. For all solutions, high quality SG integration is implemented, as well as dedicated trimming solution.

1) The first solution (and the most common) is the solution with an optimized conditioner. In that case, the SGS measurement has a total 45ppm/°C offset error and 50ppm/°C gain error.

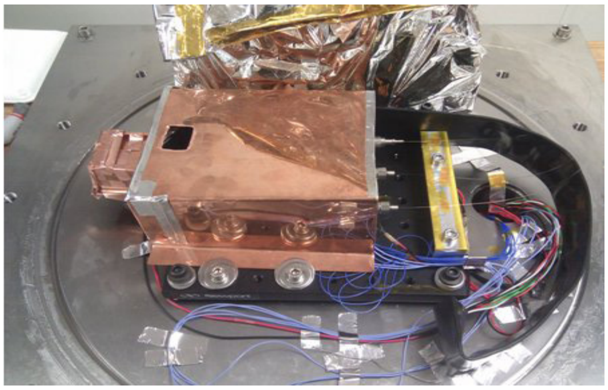
2) The second solution is the solution with the fully compensated conditioner. In that case, the SGS measurement has a total 10ppm/°C offset error and 50ppm/°C gain error.

3) The last solution is the solution featuring a compensated conditioner with software compensation. With this solution, the SGS thermal error is almost completely removed.

LONG-TERM STABILITY OF THE SGS

Another important aspect of the position measurement is the capability of the sensor to provide a stable measurement over time. Many applications require long-term position stability, which relates to the notion of absolute precision over time. Until now, the long-term stability of SGS was questionable. Using its know-how of SGS and new measurement equipment, Cedrat Technologies has managed to achieve long term nanometric position stability of a closed-loop piezo-mechanism with SGS.

A measurement in the nanometric range requires a very specific instrumentation setup. In the nanometric range, contributions that are usually considered negligible become main contributors. A dedicated test bench has been designed and implemented by Cedrat Technologies in order to perform high precision instrumentation of systems. This equipment is based on an ultra-high precision laser interferometer that is used as a reference position sensor. The interferometer targets the system to monitor its position, and a bench is designed to hold the mechanism and the laser heads. This bench is usually in INVAR to limit the thermal expansions contributions. The bench is attached on a thermally regulated plate. The temperature regulation is performed by a Peltier effect device. Everything is placed inside a primary vacuum chamber. A view of the inside of the vacuum chamber is shown on the following figure:



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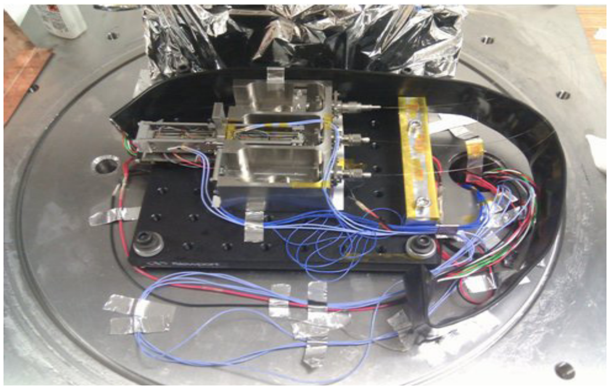
The objective of the bench is to minimise the environmental influences, such as pressure variations and temperature variations:

- Pressure variations create an error on the laser interferometer measurement. Thanks to the vacuum chamber, the pressure stabilises around 20mT, and varies only of few mT in several weeks. The pressure impact on the reference laser measurement is thus negligible.

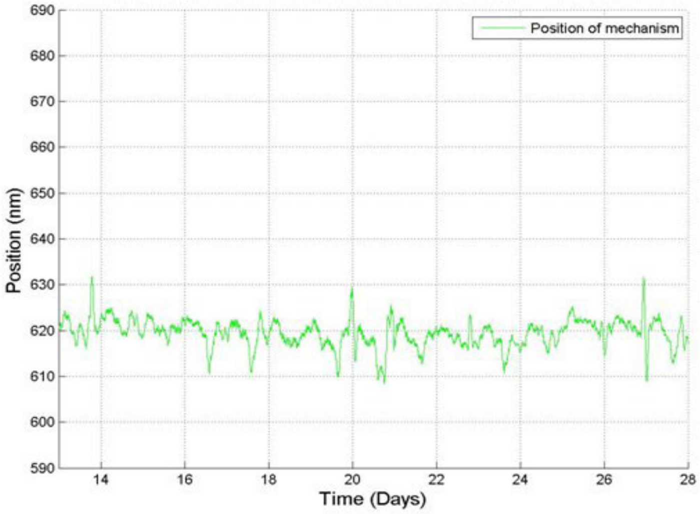
- Even though the materials employed have low thermal expansions, temperature variations can create parasitic displacements on the mechanical elements of the equipment (bench, laser head support,…) larger than few nm. The thermal regulation allows to maintain the temperature to a fixed setpoint, with a stability better than ±0.2°C. The temperature impact on the reference measurement is thus minimised.

With this bench, a new space compliant PPA40M-SG-based Push-Pull mechanism has been tested to verify nanometric position stability in closed-loop thanks to SGS. The mechanism on the test bench is shown below:



For this mechanism, high quality SG integration was implemented, together with the specific trimming technique. For the conditioning, standard SG75 is sufficient, since the temperature of the laboratory is stable. The SGS are used to perform closed-loop position control of the mechanism. The objective of the test is to verify that the position of the mechanism is stable over time for a fixed position command. The measured position of the mechanism is shown on the following figure for a 2 weeks testing time.

This test shows that after 2 weeks of testing, the position of the mechanism exhibits no drift. This demonstrates the capability of SGS to offer a nanometric long-term stability, which opens a wide range of new possibilities for industrial, aeronautical, or space applications



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