



WHITE PAPER

Why Choose a Force Balance Sensor?

Download this white paper to learn more about the benefits of force balance sensors.

The servo force balance sensor can deliver exceptional performance and accuracy with several advantages. This fact is clearly demonstrated by their extensive use in applications requiring 0.1% or better overall accuracy.

Unlike traditional accelerometers, the servo type incorporates a freely suspended mass bound by an electrical equivalent mechanical spring.



The behaviour of all force balance accelerometer can be explained by Newton's second law of motion:

Force = mass x acceleration: $F = ma$

This equation demonstrates that if a mass is to be accelerated, a force relative to the amount of acceleration must also exist. If the force can be determined, the amount of acceleration can be measured.

For pendulous type accelerometer, the polar form of the equation applies:

Torque = pendulous mass x acceleration: $T = (ml)a$

Where (l) represents the distance from axes of rotation to the centre of mass (m). ML is the pendulous mass.

The force balance sensor is geared towards DC and low frequency measurements, such as those found in the motion of vehicles, aircraft, and ships. These sensors have the capacity to measure levels from as low as 0.0001 g up to 200 g across a frequency range from DC to 1000 Hz.

Additionally, due to their innate sensitivity to gravity, making specific modifications or introducing special features to the force balance accelerometers makes them excellent instruments for measuring angles of inclination.

This kind of sensor, generally known as an inclinometer, is practical for use in applications such as borehole mapping, gun sight control, platform levelling, pipeline levelling and other low level seismic measurement applications.

Advantages

The force balance sensor offers several advantages that produce excellent performance in the aforementioned applications. Internal displacements within any accelerometer generate inaccuracies and errors typically in the form of disproportionate levels of hysteresis, stickiness, non-linearity, and non-repeatability.

LVDT, potentiometric, variable reluctance and similar kinds of sensors all have the potential to cause these errors, which results from the fact that the sensing element must travel over some distance to generate a measurable change in output.

Conversely, the output signal from a force balance accelerometer is not contingent on the displacement of some internal element being a linear function of acceleration. Internal displacements remain comparatively small.

In addition to minimizing static error, the minute displacements relative to the force balance sensor contribute to the relatively high natural frequency this type of sensor possesses. A strain gage sensor does not necessitate excessive internal displacements but is vulnerable to effects of temperature, creep, and aging, which can result in instability.

Opposed to other low frequency accelerometers, which need viscous media, dash pots or similar mechanical damping techniques, the force balance sensor's dynamic response can be damped and adjusted with ease to a specific value by way of electronic networks.

The damping ratio can be modified to near critical for a maximum usable response or to a limited response and sensitivity to high frequencies.

Generally, in open loop types of transducers, the ratio is either controlled by means of viscous media or uncontrolled, as in the case of piezoelectric devices. In the former case, it is not possible to control the damping ratio by any tight tolerances due to viscosity changes vs. temperature.

Several strain gage, potentiometric or LVDT type accelerometers incorporate thermostatically controlled heaters in an attempt to stabilize damping characteristics.

Additionally, in most cases, the force balance accelerometer is completely self-controlled, which means additional signal conditioning is not necessary, which means they have the capacity to directly interface with spectrum analysers, oscilloscopes, data acquisition systems, digital voltmeters and displays.

The full-scale output is typically in the order of several volts and necessitates no additional amplification.

How the Force Balance Sensor Works

The force balance sensor is comprised of a position detector, as well as an amplifier and an electromechanical system. This combination facilitates the conversion of a mechanical force into a proportional current which then converted back into an equal opposing mechanical force.

The position of a mass paired with the force generator can be tracked using the position detector. A change in mass position, which is externally induced, results in a combination position detector, amplifier output such as that the force generator drives the mass back to its original position.

The output of the sensor is a measure of the current through the force generator, this current being proportional to the restoring force, which is equivalent to the input force through the mass (see to Fig. 2). With no acceleration, the current through the force generator is zero.

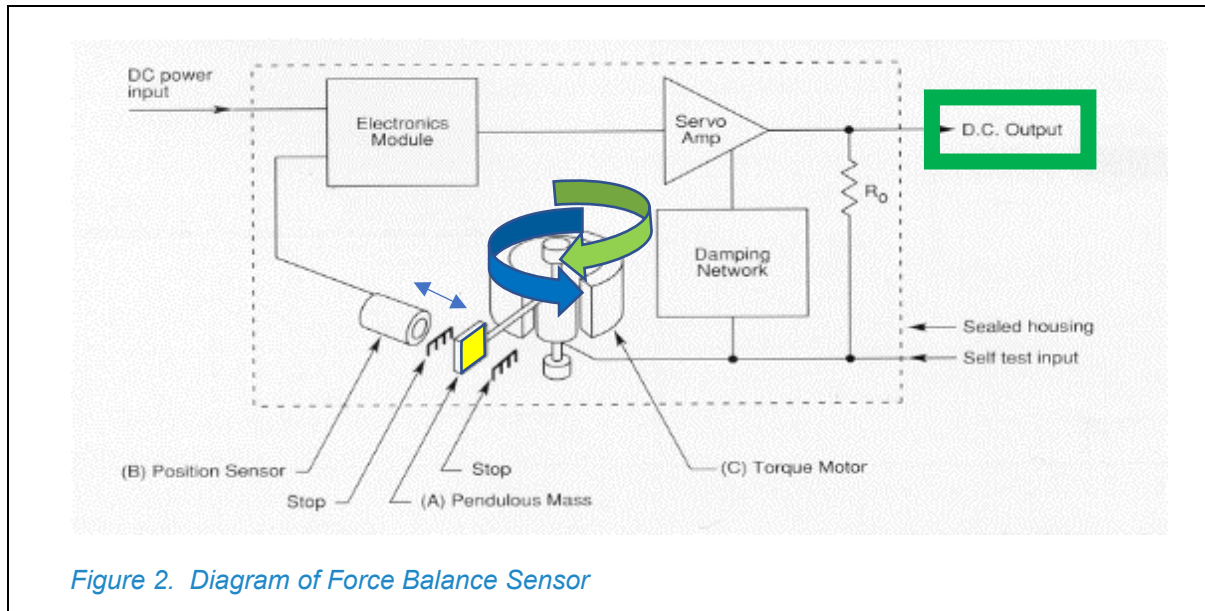


Figure 2. Diagram of Force Balance Sensor

If the sensor is accelerated, a force is exerted on the mass, and it will attempt to move from the null position. When the position detector detects motion, the coil current is increased by means of a servo amplifier to maintain the null position.

The current provides the restoring force required to maintain the null position and this current will be in direct proportion to the applied acceleration.

The Sherborne High-Performance Torquer

A force balance accelerometer necessitates a suspended mass to effectively translate acceleration into a measurable force. There must be a means to apply a current through a coil in a magnetic circuit for the purpose of balancing out the force caused by the applied acceleration. In force balance circles, this assembly is referred to as a forcer or torquer.

One of the most critical aspects of a torquer is the technique employed to support the mass. Preferably, the means of support should enable the mass to move in only a single, well-defined direction and, at the same time, eradicate motion in remaining across axis directions.

Ideally, the support should not introduce its own forces, such as friction or spring effects. The mass support must also be robust enough to endure the required physical environments without degrading.

Three methods are frequently employed by accelerometer manufacturers. They include flexures, taut bands and bearing. The flexure and taut band system possess similar advantages and drawbacks. They are effectively frictionless and thus produce exceptional repeatability.

The flexure has exceptional sensitive axis definition, while the taut band is prone to sagging under cross axis loading and should be supported in fluid as to limit its sensitivity to cross loads and vibration.

Metal flexures can experience permanent deformation, which can cause zero bias errors, while brittle non-metallic flexures can fracture and catastrophically fail under the same conditions.

Stiff flexures also create non-linear output characteristics due to their tendency to self-restore. This non-linearity is not apparent in bearing-type accelerometers. Sherborne accelerometers utilize bearings to support a pendulous mass.

The most economical Sherborne accelerometer employs a taut band bearing. This system is ideal for applications where cost is a primary concern and accuracy, and environmental requirements are not determining factors.

Their performance is up there with the very best flexures, and they will also survive in adverse environments enduring excessive shock and vibration.

Explanation of Characteristics

The following section outlines several specifications which should assist in the assessment and selection of force balance sensors for specific applications.

Scale Factor

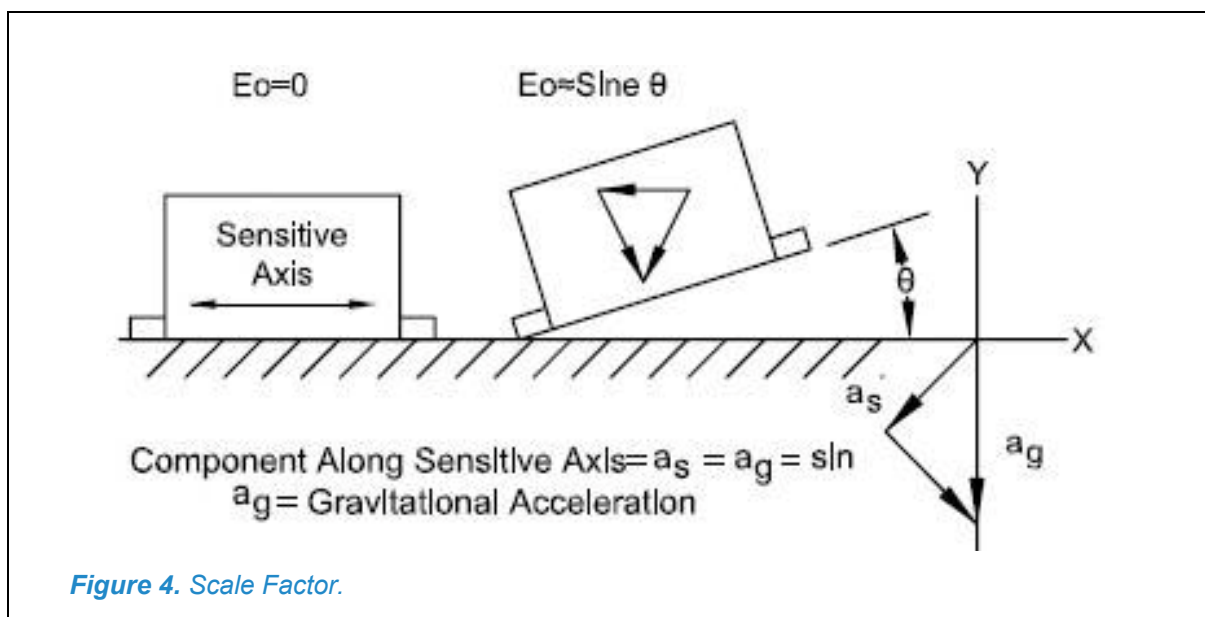
Scale Factor is the ratio of a change in output to a variance in the input intended to be measured or applied.

The scale factor calibration featured in Sherborne accelerometers is expressed volts/g.

The inclinometer's scale factor is also expressed in volts/g. However, it must be employed in parallel with the equation:

$$\theta = \text{Sin}^{-1} \frac{E_o}{K}$$

To determine the measured angle, E_o is the measured output and K represents the output at 90° or one g (see Fig. 4).



Bias

Bias is the measured sensor output when there is no application of mechanical input.

Input Axis

An input axis is an axis along which an acceleration or inclination of the case results in maximum output.

Cross Axis Sensitivity

Cross axis sensitivity describes the proportionally constant relative to the variation of accelerometer and inclinometer output to cross acceleration or inclination.

Composite Error

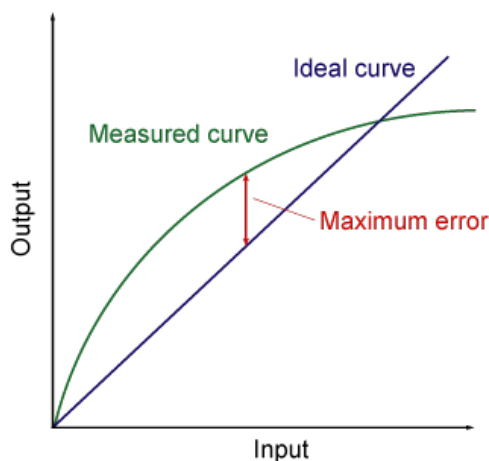
Composite error is the maximum deviation of the output data from the determined output function. Composite error can include the effects of hysteresis, resolution, non-linearity, non-repeatability, and other uncertainties in the output data. It is typically expressed as a percentage of the output range.

Repeatability

Repeatability refers to the property of a sensor to reproduce a given output of performance characteristics under identical input and environmental conditions. Repeatability incorporates the effects of threshold, resolution, and uncertainties in other performance characteristics.

Non-Linearity

Non-linearity refers to the deviation of the output data from the straight line determined by the zero-input bias and scale factor coefficient.



Resolution

Resolution refers to the greatest value of the minimum change in input for inputs more than the threshold, which yields a change in output equal to some distinct percentage (at least fifty percent) of the change in expected output utilizing the nominal scale factor.

Threshold

Threshold refers to the greatest absolute value of the minimum input that generates an output equal to some specific percentage (at least fifty percent) of the anticipated output using the nominal scale factor.

Rectification Error

Rectification error refers to a steady-state error in the output caused by the vibratory disturbances that act on an accelerometer or inclinometer.