Force Balance
Sensor Technology

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Force Balance Technology Information

Technical Information

The servo force balance accelerometer offers significant performance and accuracy advantages. This fact is evident by their extensive use in applications requiring 0.1% or better overall accuracy. Unlike conventional accelerometers, the servo type contains a freely suspended mass constrained by an electrical equivalent mechanical spring.

There are two classes of servo force balance accelerometers: the pendulous type, having an unbalanced pivoting mass with angular displacement, and the non-pendulous type, having a mass which is displaced linearly.

The behavior of all accelerometers is explained by Newton's second law of motion: Force equals mass times acceleration.

$$F = ma$$

This equation tells us, for one thing, that if a mass is to be accelerated, a force proportional to the amount of acceleration must exist. If the force can be measured, the amount of acceleration can be determined.

For pendulous type accelerometer, the polar form of the equation applies: Torque equals pendulous mass times acceleration

$$T = (ml)a$$

Where (l) is the distance from axes of rotation to center of mass, and (ml) is the pendulous mass.

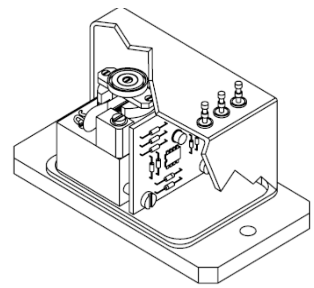

Fig 1—Force Balance Sensor

Why Choose a Force Balance Sensor?

The force balance sensor is intended for DC and low frequency acceleration measurements, such as those encountered in the motion of vehicles, aircraft and ships. These sensors are capable of measuring levels from as low as 0.0001g up to 200g's over a frequency range from DC to 1000Hz. In addition, due to their inherent sensitivity to gravity, the force balance accelerometers with certain modifications or special features become excellent instruments for measuring angles of inclination. This type of sensor, often referred to as an inclinometer is useful in applications such as platform leveling, pipeline leveling, gun sight control, borehole mapping and other low level seismic measurement applications.

Advantages

The force balance sensor has several advantages which result in exceptional performance in the type of applications mentioned above. Internal displacements within any accelerometer lead to inaccuracies and errors usually in the form of excessive hysteresis, stickiness, non-linearity and non-repeatability. LVDT, potentiometric, variable reluctance and similar type sensors all produce these errors due to the fact that the sensing element must move over some distance in order to produce a measureable change in output.

In contrast, the output signal from a force balance accelerometer dose not depend on the displacement of some internal element being a linear function of acceleration. Internal displacements are kept relatively small, typically less than one ten thousandth of an inch. In addition to minimizing static error the minute displacements associated with the force balance sensor contribute to this type of sensor having a relatively high natural frequency. A strain gage sensor does not require excessive internal displacements but does suffer from instability due to effects of temperature, creep and aging. Unlike other low frequency accelerometers which require a viscous media, dash pot or similar mechanical damping technique, the dynamic response of the force balance senor is easily damped and adjusted to a precise value by means of electronic networks.

The damping ratio may be set to near critical for a maximum usable response or to a higher degree or limited response and sensitivity to high frequencies. Normally in open loop types of transducers the ratio is either uncontrolled as in the case of piezoelectric devices or controlled by means of viscous media. In the latter case, the damping ratio cannot be controlled by any tight tolerance, due to viscosity changes vs. temperature. Many strain gage, potentiometric or LVDT type accelerometers include thermostatically controlled heaters in an attempt to stabilize damping characteristic. Furthermore, the force balance accelerometer in most cases is entirely self controlled, requiring no additional signal conditioning, and capable of interfacing directly with spectrum analyzers, oscilloscopes, data acquisition systems, digital volt meters and displays. The full scale output is normally in the order of several volts and requires no further amplification.

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How the Force Balance Sensor Works

The force balance sensor consists of a position detector, not necessarily one that is linear, an amplifier and an electromechanical system. This combination performs the function of converting a mechanical force into a proportional current which is in turn converted back into an equal opposing mechanical force. The position of a mass coupled to the force generator is monitored by the position detector. An externally induced change in mass position 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 equal to the input force through the calibrated mass. Refer to Fig. 2. With no acceleration present the current through the force generator is zero. The force generator current is monitored by means of a resistor in series with it thereby providing a voltage output exactly proportional to the original mechanical input. The electronic damping is supplied by a capacitor and placed across the sampling resistor. The capacitor and sampling resistor comprise a lead network which results in a reduction at high frequencies of the amplifier voltage necessary to drive the restoring current.

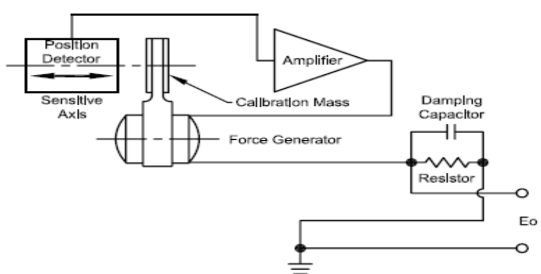

Fig. 2—Block Diagram of Force Balance Sensor

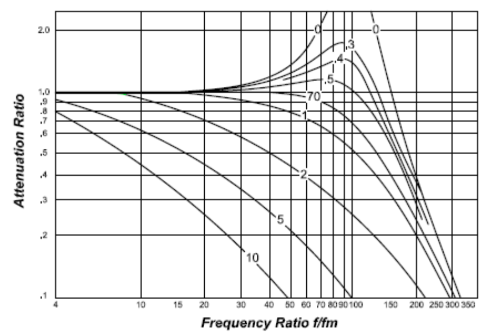

Fig. 3—Frequency Response

The Columbia "HP" (High Performance Torquer)

A force balance accelerometer requires a suspended mass in order to translate acceleration into a measureable force, also a means must be present to apply a current through a coil in a magnetic circuit in order to balance out the force caused by the applied acceleration. This assembly is referred to in force balance circles as a forcer or torquer. One of the most critical aspects of a torquer is the method employed to support the mass, ideally, the means of support should allow the mass to move in only a single, well defined direction and at the same time eliminate motion in remaining across axis directions. Also the support should not add forces of its own, such as friction or spring effects. The mass support must also be rugged enough to survive the required physical environments without degrading.

Three methods are commonly used by accelerometer manufactures. They include: flexures, taut bands and bearing. The flexure and taut band system both have similar advantages and draw backs. They are essentially frictionless and thus yield excellent repeatability. The flexure has good sensitive axis definition while the taut band sags under cross axis loading and thus must be supported in fluid in order to reduce its sensitivity to cross loads and vibration. Both are susceptible to damage from shock. Metal flexures can suffer permanent deformation, resulting in zero bias errors, while brittle non-metallic flexures fracture and fail catastrophically under the same conditions. Stiff flexures also produce non-linear output characteristics, due to their self-restoring tendency. This non-linearity is not evident in bearing type accelerometers.

CRL accelerometers make use of bearings to support a pendulous mass. The least expensive CRL accelerometer employ a pivot and jewel bearing. This system is more than adequate for applications where cost is a major concern and accuracy and environmental requirements are not severe.

The more sophisticated CRL accelerometers use a high performance all bearings suspension in place of the pivot and jewel. The physical tolerances of these bearing are some twenty times tighter than those of a typical pivot and jewel bearing. Their performance rivals the best flexures while at the same time they will survive severe shock and vibration environments. Other benefits of the COLUMBIA "HP" TORQUER include: low rectification, no pivot-flop, no progressive deterioration and excellent static performance under vibration. All standard and "HP" torquers are completely manufactured at CRL to guarantee consistent "unit to unit performance" and reliability.

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Explanation of Characteristics

The following section defines a number of specification s which should assist in evaluating and selecting force balance sensors for specific applications.

Scale Factor

Scale Factor is the ratio of a change in output to a change in the input intended to be measured or applied. The scale factor calibration supplied with CRL accelerometers is expressed volts/g or volts/radian/sec². The scale factor of the inclinometer is also expressed in volts/g. However, it must be used in conjunction with equation,

$$\theta = \sin^{1} \frac{Eo}{K}$$

To establish the measured angle Eo being the measured output and K being the output at 90° or one g. See Fig. 4. No conversion is necessary when the inclinometer is used with a CRL DVM calibrated to read directly in degrees.

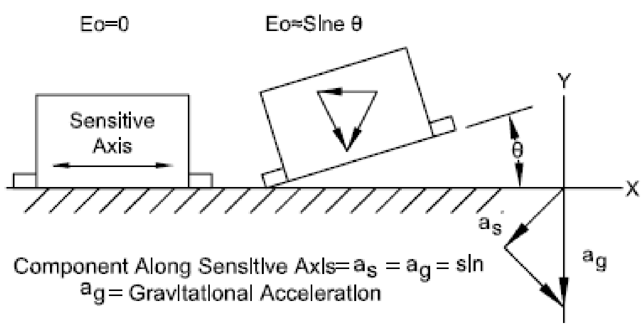

Fig. 4—Scale Factor

Bias

Bias is the measured sensor output when no mechanical input is applied.

Input Axis

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

Cross Axis Sensitivity

Cross axis sensitivity is the proportionally constant that relates a 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 specified output function. Composite error may include the effects of hysteresis, resolution, non-linearity, non-repeatability, and other uncertainties in the out put data. It is generally expressed as a percentage of the output range.

Repeatability

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

Non-Linearity

Non-linearity describes the deviation of the output data from the straight line defined by the zero input bias and scale factor coefficient. Refer to Fig. 5.

Hysteresis Error

Hysteresis error is the difference between output signals for increasing and decreasing inputs at that input for which the difference is maximum measured after cycling through the input scan. Refer to Fig. 5.

Resolution

Resolution is the largest value of the minimum change in input for inputs greater than the threshold, which produces a change in output equal to some specific percentage (at least fifty percent) of the change in output expected using the nominal scale factor. Ref to Fig 5

Threshold

Threshold is the largest absolute value of the minimum input that produces an output equal to some specified percentage (at least fifty percent) of the output expected using the nominal scale factor. Refer to Fig. 5.

Rectification Error

Rectification error is a steady state error in the output induced by vibratory disturbances acting on an accelerometer or inclinometer.

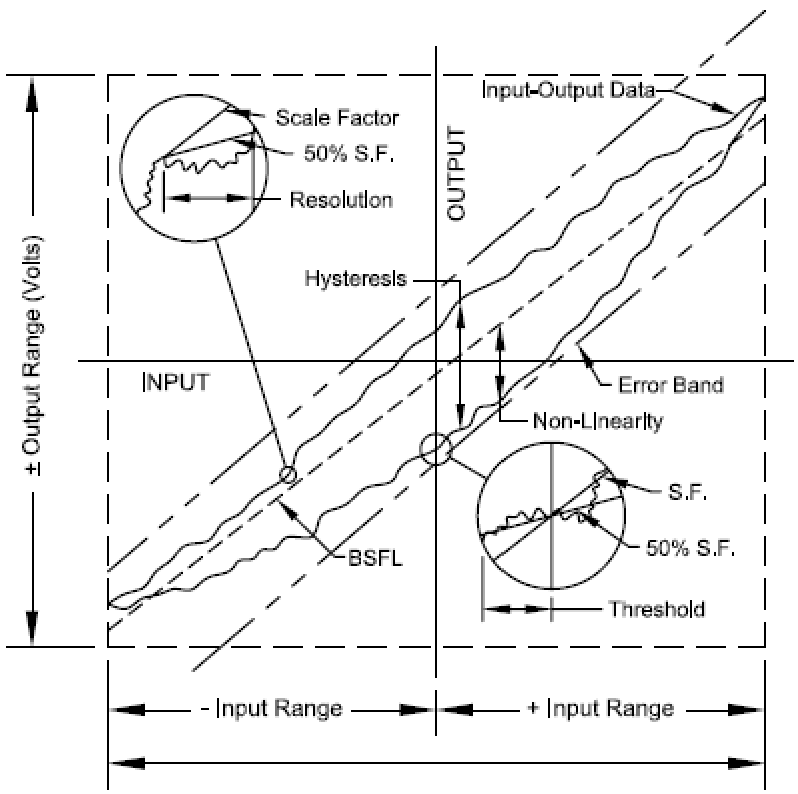

Fig. 5—Input-Output Characteristics of a typical Force Balance Accelerometer

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