Jewell Instruments

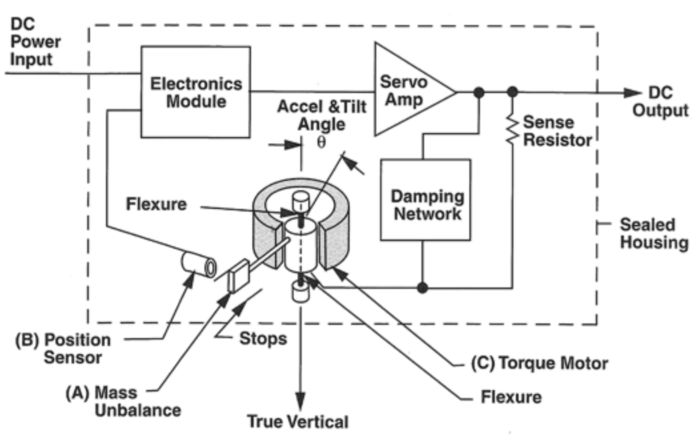
MAKING SENSE OUT OF MOTION

INERTIAL SENSOR THEORY 101

OPERATION

Jewell accelerometers and inclinometers are precision inertial instruments. They utilize closed loop sensor technology to produce a highly accurate output with virtually infinite resolution. The inertial sensor output is an analog voltage, current, or digital signal proportional to applied acceleration and tilt from DC through a specified frequency.

The sensing element in a Jewell inertial instrument is the torquer, a D'Arsonval mechanism designed specifically for sensor use. Jewell has produced inertial instrument torquers and complete acceleration sensing assemblies for many years. Hundreds of thousands of acceleration sensors have been manufactured. Jewell sensors are used throughout the world for detecting acceleration and tilt from less than one µG (one µRadian) to more than 50G.



The torquer mechanism (Torque Motor) is the fundamental subassembly in a servo sensor. An accelerometer torquer is intentionally unbalanced (Mass Unbalance) in its plane of allowable angular motion. When acceleration or tilt is present, a torque proportional to the mechanism unbalance and the physical input is developed. The torque results in an angular motion detected by a Position Sensor. The Position Sensor output is compared to a reference voltage in the Electronics Module, and the difference is an error signal that is the input to a servo amplifier (Servo Amp). The servo amplifier output current is applied to the Torque Motor in opposition to the acceleration or tilt torque. At a constant inertial input, the Mass Unbalance angular position is minutely different from the zero g position. The Servo Amp output current is directly proportional to the applied acceleration or sine of the input tilt angle. An analog voltage is produced by measuring the servo current with a Sense Resistor.

Note that an accelerometer and an inclinometer are the same device. The distinction is one of application, not operation. Accelerometer users typically sense changes in velocity and characterize outputs and errors in g. Inclinometer users sense changes in angular position and think of outputs and errors in units of angular measurement. An inertial instrument responds to both earth's gravity and acceleration.

SPECIFICATIONS

The following describes how Jewell engineers interpret performance characteristics and error sources often listed in inertial instrument specifications. The interpretation is generally consistent with IEEE accelerometer test conventions.

Range & Scale Factor

The range of an accelerometer or inclinometer is the input from + to – over which the transducer is expected to yield the specified output. A ±2g accelerometer has a full range input of 4g. The scale factor is the change in output per unit of input. A ±2g full range accelerometer with ±5 Volts output will have a scale factor of 2.5 Volts/g. Jewell inertial sensors operating at ±15 Volt bipolar input power have an operating overrange capability of 50% to 100%. A 30° inclinometer, for example, will operate without meaningful performance degradation to 90°. The sine of 90° (1.00) being twice the sine of 30° (0.50). Beyond 100% overrange, the output voltage will begin to clip. The overrange capability for unipolar input power units is typically limited to less than 25% by the available input or output voltage. Units with 4-20mA output are limited by the voltage to current converter at less than 5% overrange, and digital output sensors normally do not have output overrange capability to maximize resolution. The scale factor tolerance for standard units is typically ±1.0%, but can be improved to ± 0.10% where required. For servo accelerometers, the scale factor temperature sensitivity is primarily a function of the torquer magnet thermal characteristics. For most sensors, higher temperature causes lower magnet flux density and; therefore, an increasing accelerometer scale factor. The magnet thermal sensitivity curve is not linear. Thermal sensitivities improvements of approximately 2 to 1 are possible. The nonlinear thermal performance of the magnet requires that applications requiring improved scale factor temperature sensitivity must be evaluated on an individual basis.

Natural Frequency & Damping

The accelerometer or inclinometer dynamics can be treated as second order for most Jewell designs. The natural frequency is the frequency at which the phase of the accelerometer or inclinometer output lags the input by 90°. The damping ratio characterizes the shape of the sensor dynamic response. Typical natural frequencies range from 0.5 Hz for low range inclinometers to 200 Hz for 10 g accelerometers with damping ratios in the range of 0.5 to 1.0. Inertial sensor bandwidth is defined as the frequency range below the frequency at which the amplitude of the output is 3dB down relative to the input. Changes to natural frequencies, damping ratios and bandwidths are available, but the changes must be evaluated for individual applications.

Bias

The bias is the accelerometer output when no acceleration is applied. Bias results from residual suspension torque and electronic offset voltages. The output from a stationary accelerometer or inclinometer on a flat surface is a combination of bias, misalignment and noise. Bias temperature sensitivity is caused primarily by temperature induced changes to internal alignments. Published data sheet initial bias setting accuracy and bias temperature sensitivity can generally be improved by 2 to 1 for requirements where improved bias enhances the sensor’s application suitability.

Input Axis Misalignment

The input axis misalignment is the geometric sum of the transverse, rotation (output) and pendulous, axis misalignments relative to the base and a reference side of the sensor. The standard alignments are a function of sensing range and production tolerance considerations. Improved alignment accuracy of ±0.125° is readily available. The alignment specification in the data sheets applies to both axes. An inertial instrument responds to cross axis acceleration or tilt as a function of the sine of the misalignment angle.

Nonlinearity

Nonlinearity is the largest deviation in the accelerometer output over its specified input range when the output is compared to a least squares best fit straight line. Improvements to nonlinearity are generally not required or practical. For inclinometers and accelerometers of 5g full scale or less, nonlinearity errors are often small enough to be ignored.

Resolution & Threshold

Threshold is the smallest input change that will result in an output change at least 50% of calculated at zero initial input. Resolution is the smallest input change anywhere in the operating range that will result in at least the 50% of calculated output change. Resolution and threshold errors are not always the same for inertial instruments, but in either case are usually so small that they can be treated together and essentially ignored. The resolution and threshold for standard units is, in fact, infinitely small. Specifying threshold and resolution errors is more a test definition than a performance indicator.

Repeatability

Repeatability defines an area of output uncertainty within which the sensor may yield different outputs for identical inputs. The uncertainty is primarily a function of moving system suspension friction and position errors. Flexure suspension units have relatively small repeatability errors. Observed repeatability is application dependent. Many sensors have better than expected “real life” repeatability when environmental vibration is present. The vibration energy reduces suspension friction.

Noise

Noise is the dynamic output from the accelerometer when no acceleration input is present. Measuring true servo accelerometer noise output is a challenging task since there is almost always some environmental vibration present, and the sensor noise is extremely low. Environmental accelerometer pass band noise of 0.001g in an office, and 0.005g to 0.010g in a factory, is not surprising. The published noise specification reflects what a typical user might find when looking at accelerometer AC output in a laboratory or office, not the actual transducer noise. Accelerometer broadband noise tests results of less than 20 µvolts rms are typical. The true output noise level is not likely to be a significant error to most users.

Input Voltage

The input voltage specified is the range of voltages over which the sensor is expected to operate within specification. It is not advisable to operate most units above the rated input voltage. Typical accelerometers will continue to operate at input voltages slightly lower than the rated input, although the output voltage clipping level and overrange capability are decreased. Alternate input power choices including 5 volts, 12 volts and 24 volts unipolar as well as ±5 volts bipolar are available.

Input Current

The input current is the current the accelerometer or inclinometer will draw from a power supply set to the sensor's rated input voltage. The positive and negative currents are not necessarily balanced for bipolar input units. Applied acceleration and tilt increase the current requirement by approximately one to three mA/g. It is possible to reduce the current requirement, but applications must be evaluated on an individual basis.

Output Impedance

Output impedance is the impedance presented by the sensor output to a load. The standard output configuration for most Jewell inertial products is an operational amplifier with 100 ohms in series. There are other configurations including direct output across a sense resistor which can exceed 5,000 ohms. Individual data sheets must be referenced where sensor output impedance is critical to an application.

Operating Temperature Range

The operating temperature range defines the temperature extremes over which the accelerometer or inclinometer will work without temperature induced failure or a permanent change in some output characteristic. A unit will continue to operate at temperatures somewhat higher or lower than stated in the standard specifications.

Shock & Vibration

Shock and vibration specifications indicate the highest level that the accelerometer or inclinometer can be exposed to without causing a permanent change to the unit. The specified shock cannot be applied an infinite number of times. Random vibration limits are specified for 3 hour exposure to white noise in the bandwidth 20 Hz to 2000 Hz. For most standard sensors, the highest continuous acceleration level that can be applied without damage is 30G.

Seal

Sealing specifies the design technique selected to prevent moisture, dust, or other external contaminant from entering the sensor housing. Various sealing approaches are implemented for Jewell sensors. An epoxy seal is effective for normal transducer use as water, dust or other typical contaminants will not enter the housing. Hermetic seals having leak rates less than 10-7 cc/sec/atmosphere are also available.

Survival Temperature Range

The survival temperature range defines the temperature extremes an unpowered unit can be exposed to without damage.