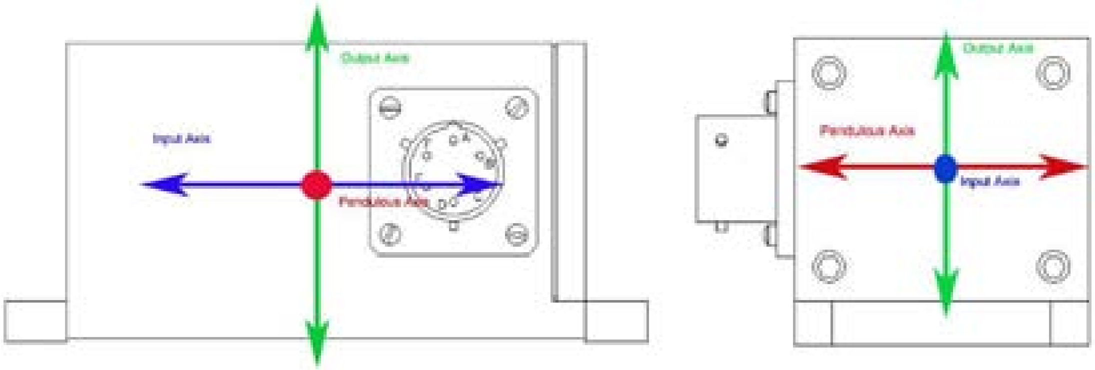
Inertial Tech Note:

Cross Axis Sensitivity Of Inertial Sensors

Cross axis sensitivity is somewhat of a complex topic. In many ways this is due to the varying definitions within the industry. Jewell Instruments utilizes the IEEE for the basis of all definitions. As defined within IEEE Standard 528, cross-axis sensitivity is the proportionality constant that relates a variation of output to input applied in a plane normal to the input reference axis. In many cases, cross axis sensitivity is thought of as an output resulting from an input in the axis perpendicular to and within the same plane as the sensing axis, which is the axis defined by Jewell as the pendulous axis. However, in fact, there are two axes that can be defined as cross axes. In addition to the pendulous axis the output axis, normally defined as the Z axis or the axis that is vertical when the mounting surface of the sensor is horizontal with respect to earth, is a cross axis as well. Please see figure 1 below for an illustration of the axes. It is important to note that the input axis of the sensor is the sensitive axis.



(Side View) (End View)

Figure 1

Again, cross axis sensitivity is usually thought of as the error resulting from an input within the pendulous axis as shown in Figure 1. With this in mind, true cross axis sensitivity is independent of misalignment and is typically very low for servo sensors. Cross axis sensitivity independent of misalignment is typically specified as 0.001g/g. If the sensitivity is known (i.e. 0.001g/g), the error induced in the output can be calculated using the equation shown in EQ1. Note that the equation solves for the error in Volts. Obviously the equation shown in EQ1 can be manipulated algebraically to solve for the sensitivity if the error from the input is the known value as shown in EQ2.

$$Error(V) = \sin(a_{tp}) \times K_{ip} \times K_1$$

Where:

a_{tp} = *Applied tilt component across the pendulous axis in degrees*
K_{ip} = *Cross axis sensitivity in g/g*
K_1 = *Scale Factor in Volts/g*

EQ1

$$K_{ip} = \frac{Error(V) \times K_1}{\sin(a_{tp})}$$

Where:

a_{tp} = *Applied tilt component across the pendulous axis in degrees*
K_{ip} = *Cross axis sensitivity in g/g*
K_1 = *Scale Factor in Volts/g*

EQ2

When considering EQ1 and EQ2, it is very important to remember that an inertial sensor will respond to both earth's gravity, as at it does when used to measure tilt, and change in velocity or acceleration/deceleration. This is true of both inputs within the input or sensitive axis and inputs within the cross axes. The equations EQ3 and EQ4 illustrate the changes to EQ1 and EQ2 respectively when this is considered.

$$Error(V) = [\sin(a_{tp}) + a_{ap}] \times K_{ip} \times K_1$$

EQ3

$$K_{ip} = \frac{Error(V) \times K_1}{\sin(a_{tp}) + a_{ap}}$$

Where:

a_{ap} = *Applied acceleration component across the pendulous axis in g's*
a_{tp} = *Applied tilt component across the pendulous axis in degrees*
K_{ip} = *Cross axis sensitivity in g/g*
K_1 = *Scale Factor in Volts/g*

EQ4

Jewell does not specify cross axis sensitivity in this manner on its sales literature because misalignment contributes to the output error induced by an input applied in a non-sensitive axis and is likely to be the dominating error. Jewell specifies the misalignment of the true axes to the reference surfaces of the sensor, which is typically the bottom mounting surface and one of the sides. Note that Jewell specifies transverse axis misalignment on its sales literature, which is the vector sum of the pendulous axis misalignment and the output axis misalignment. It is also important to note that in some cases, an error was made in specifying the misalignment and the term “input axis misalignment” was used on some of the literature. The correct term is transverse misalignment. This has been resolved for future literature.

As mentioned previously, in many cases cross axis sensitivity is associated with the pendulous axis as defined in Figure 1 above. In addition, misalignment is typically the dominant error when considering the errors associated with applying an input in the pendulous axis. This includes both internal misalignment and misalignment within the application. The equation below, EQ3, illustrates how the result error is calculated from the input applied and the misalignment angle.

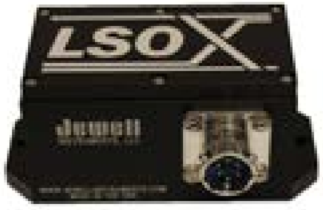
$$Error(V) = [\sin(a_{tp}) + a_{ap}] \times \sin(\delta_p) \times K_1$$

Where:

a_{ap} = *Applied acceleration component across the pendulous axis in g’s*
a_{tp} = Applied tilt component across the pendulous axis in degrees
δ_p = Pendulous axis misalignment in degrees
K_1 = Scale Factor in Volts/g

EQ5

It is important to point out as the IEEE does, the misalignment angle(s) include angular errors of the mounting fixture, dividing head errors, and errors in mounting as well as misalignment of the axes with respect to the reference surface. It is very important to remember that alignment within the application is a significant part of the errors induced, even if a sensor is perfectly within alignment (zero misalignment error with respect to the reference surfaces) and the sensor is misaligned within the application an error will result. It is also important to remember that Jewell provides the misalignment data, which can be utilized to compensate for the misalignment. Misalignments are typically compensated for in two ways. Physically offsetting the sensor with respect to the reference surfaces by the amount of misalignment indicated on the data sheet. Note that shims are typically used when compensating for misalignment. The misalignment is also



commonly compensated for mathematically. For example, the misalignment can be compensated when calculating the angle from the output of the sensor. The equations EQ6 thru EQ9 illustrate a typical method used.

$$(\mathrm{FSO}) = (\mathrm{FRO}) / 2$$

EQ6

$$\text{Sensor range (g)} = \sin\text{(range of sensor in degrees)}$$

EQ7

$$\text{SF (output units/g)} = (\mathrm{FSO}) / \text{range of sensor in g}$$

Where:

FSO = Full Scale Output
FRO = Full Range Output

EQ8

$$\text{Angle}\ (^\circ) = \sin^{-1} \times \frac{E_o - K_o}{K_1} + \delta_o$$

Where:

E_o *= Output of the sensor in output units (i.e. V or mA)*
K_o *= Bias of sensor in output units*
K_1 *= Scale Factor (SF) in output units (i.e. V/g or mA/g)*
δ_o *= Output axis misalignment in degrees*

EQ9