5 Reasons That Your Electronic Compass Doesn't Work

The performance of the Jewell eCompass, or any magnetic compass, depends on how well its parameters are adjusted for the operating environment. Accuracy, repeatability, speed of response, rejection of anomalous measurements, and power consumption can be optimized by careful tuning of coefficients that adapts the eCompass to different conditions.

For all applications, the eCompass' accuracy should be verified in-situ by performing a magnetic calibration. This entails first capturing a vertical reference in a nearby location free of magnetic interference, then taking measurements about a circle with the eCompass mounted in place. The vertical reference can be skipped if you are convinced that there is no vertical component of hard iron.

Factors Affecting Accuracy

There are a number of factors that can potentially affect the accuracy and repeatability of the eCompass. The following list explains the mechanism of each factor and presents an order of magnitude of its effect on accuracy.

#1 Static Permanent Magnetism

The source of a local permanent magnetic field can be a piece of hard iron (hence the common name), a constant DC current, or some other type of magnet. This source of error can be significantly reduced by calibration. The curve in Figure 1 shows that a residual error of 0.1% of the earth's magnetic field on both X and Y axes produces a peak accuracy error of 0.2° at 66° inclination (dip angle in middle US latitudes).

The error varies sinusoidally with direction and produces a single cycle for each rotation of the eCompass. Phase depends on the signs and magnitudes of errors on each axis. The magnitude of the error depends on magnetic inclination because the residual hard iron error is expressed as a fraction of the total field strength.

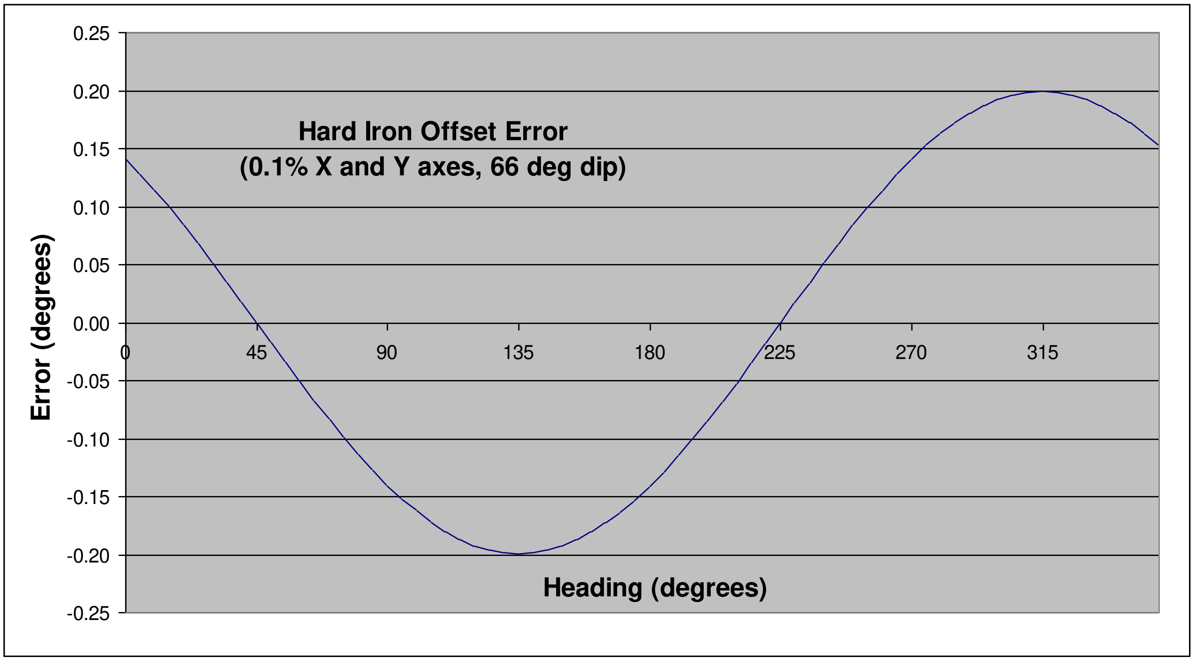

Figure 1 - Hard Iron Heading Error

Fortunately, a residual Z-axis error is less critical. This error comes into play only when the eCompass is tilted from level. At 30° tilt, a Z-axis error of 0.3% would be required to produce the same 0.2° peak accuracy error at 66° dip. The accuracy error decreases with decreasing tilt.

This is fortunate because it can be difficult to determine the Z-axis hard iron coefficient. When the eCompass is mounted in a large vehicle it is impractical to turn the vehicle over in order to get good calibration data. An estimate of the Z coefficient can be made as long as some tilted data is collected but a reasonable estimate may still require tilt angles that can't be achieved.

To eliminate this problem, the eCompass allows an optional two-step Z-axis calibration. Reference data is first collected outside the vehicle in an area free of magnetic interference. When the eCompass is mounted in the vehicle, the measured vertical component is compared to the reference data to calculate the coefficient. As long as the eCompass is within a few degrees of level during both measurements the calculated result is accurate.

2 Static Induced Magnetism

When you bring a magnet in contact with a metal paper clip the paper clip becomes magnetized. When the magnet and paper clip are separated, the paper clip no longer retains its temporary, or induced, magnetism. Soft iron, alloys of iron and nickel, common steel, and some types of stainless steel can all be easily magnetized, even in a weak field.

When these materials are in the vicinity of the eCompass and rotate with the eCompass, they become magnetized and demagnetized depending on their orientation to the earth's magnetic field. Instead of seeing a constant field that would produce a perfect circle as the eCompass turns, the eCompass sees a field of varying magnitude that maps an elliptical shape. This induced magnetism gives rise to a heading accuracy error as shown in the example of Figure 2.

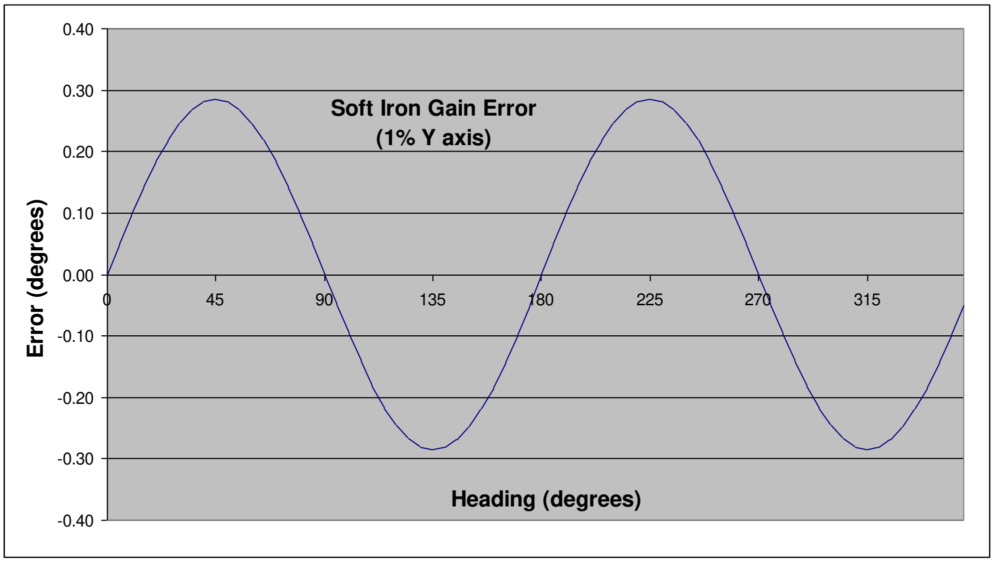

Figure 2 – Soft Iron Heading Error

When the eCompass is rotated in a level plane, the error varies sinusoidally and produces two cycles per revolution of the eCompass. In the figure, peaks are located at 45°, 135°, 225°, and 315° because the gain error is aligned with the Y axis, which would be the major axis of the ellipse. In real world applications, the major axis could be aligned at any angle.

In three dimensions, the locus of points would map to an ellipsoid instead of a perfect sphere. In this case, a 3x3 matrix of gain coefficients is needed to compensate. A minimum of 12 independent measurements is needed to determine 9 soft-iron gains and 3 hard-iron offsets.

If the eCompass is only being used near level, then a simpler, two-dimensional compensation may be adequate. The eCompass PC software includes an algorithm to estimate 2D soft-iron coefficients based on the approach set forth in "Direct Least Squares Fitting of Ellipses," by Fitzgibbon et al. in IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 21, No. 5, May, 1999. The software reports the ellipticity, in percent, of the ellipse that best fits the collected data. This metric can be used to decide if soft-iron compensation is needed.

In situations where soft-iron is significant, it may be better to relocate the eCompass. First, a two-dimensional compensation is only approximate, and small variations in tilt may produce dramatic changes in the soft-iron ellipse. Proper compensation may require that three-dimensional data be collected and analyzed to produce the full 3x3 gain matrix.

Second, soft magnetic materials that give rise to induced magnetism also exhibit varying degrees of remanence, the tendency to remain magnetized after a magnetizing force is removed. The magnetization of the material may change over time due to exposure to vibration, temperature changes, and varying electrical and magnetic fields. This results in hard-iron errors that must be periodically compensated to maintain accuracy.

If there is no alternative and 3D soft iron must be compensated, the eCompass PC program provides an option to collect 3D data and calculate the optimum 12 compensation coefficients. The iterative algorithm works to find the ellipsoid that best fits the collected data by minimizing the sum of the squared geometric distances between the collected data and the parametric ellipsoid.

#3 Time Varying Magnetic Fields

A time varying magnetic field in the vicinity of the eCompass cannot be compensated. Its frequency must be above the pass band of the eCompass (i.e. greater than 30 Hz), or it must be eliminated. The eCompass' measurement cycle rate of 27.5 Hz is chosen to maximize attenuation of 50 Hz to 60 Hz signals associated with AC power systems.

To estimate the order of magnitude effect of a DC current near the eCompass magnetometer, use Ampere's law to calculate the magnetic field near a long wire:

$B = \frac{\mu_0 i}{2\pi r}$, where $\mu_0 = 4\pi \times 10^{-3}$ Gauss-meter / amp.

A long wire carrying 25 mA of current located 50 mm from the magnetometer produces a 1 mG (100 nT) magnetic disturbance at the sensor. In the middle of the US, where inclination (dip angle) is roughly 66° and the earth's magnetic field strength is about 500 mG, this can result in a 0.3° heading error.

#4 Tilt Measurement Errors

Errors in pitch and roll measurements give rise to single-cycle heading errors that cannot be differentiated from heading error caused by residual hard-iron. The plot in Figure 3 shows how an error as small as 0.1° on both X and Y axes affects heading accuracy at 66° magnetic inclination (dip angle). The phase of this curve depends on the relative signs and magnitudes of the separate X-axis and Y-axis errors.

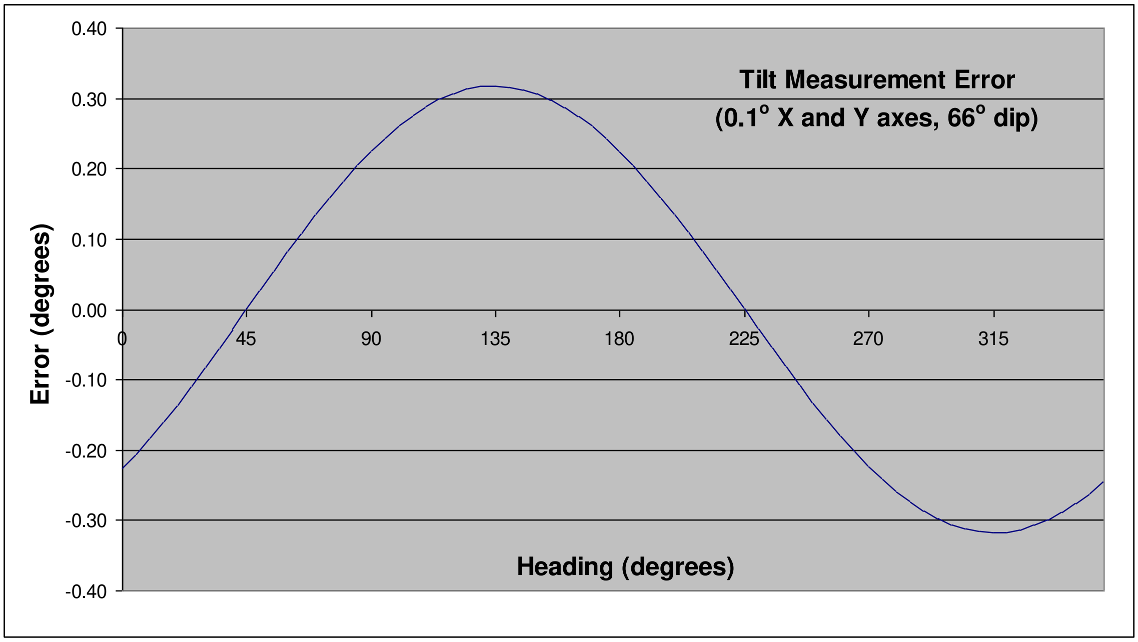

Figure 3 – Effect of Tilt Error on Heading Accuracy

Compare the shape and phase of the curve in Figure 3 to the hard-iron error curve in Figure 1. In this case, the curves are not in phase, and the two sources of error tend to cancel each other. The resulting peak error is reduced by a factor of three as shown in the curve labeled "Errors Cancel" in Figure 4. But change the signs on both pitch and roll errors, and the two curves align in phase, producing the "Errors Reinforce" result also shown in Figure 4.

Tilt measurement errors can be caused by one or more of the following:

1. sensor offset and/or gain errors
2. sensor cross-axis coupling
3. misalignment of tilt and magnetic sensor axes
4. uncompensated horizontal acceleration
5. poor sensor quality

In applications where the eCompass cannot be held perfectly steady, the error due to horizontal acceleration can be pronounced. Although the rate gyros (eCompass ECG and ECV) will initially compensate, if the acceleration persists, it will eventually affect the measurement. For a modest constant horizontal acceleration of 0.05g (roughly 1 mile per hour per second), the tilt measurement error is 2.9° (obtained by calculating

$\tan^{-1}0.05$). For the example 66° magnetic inclination used above, the result is a sinusoidal heading error of 6.5° peak magnitude.

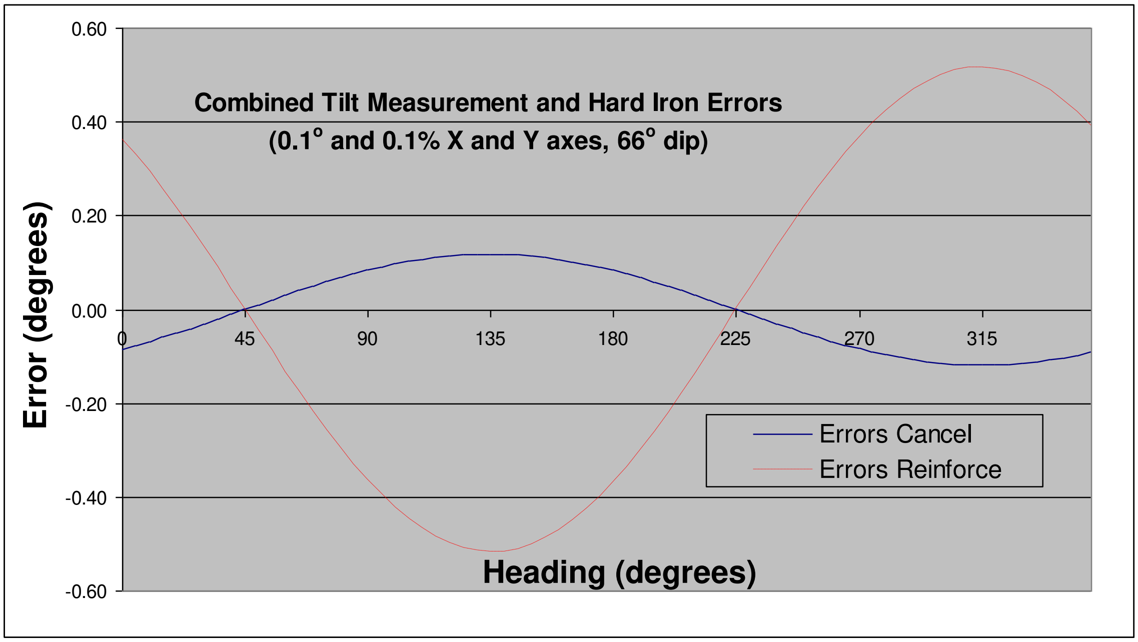

Figure 4 – Combined Effect of Hard Iron and Tilt Errors

#5 Magnetic Inclination (Dip Angle)

Near its magnetic poles, the overall strength of the earth's magnetic field increases. But the horizontal component decreases substantially, making navigation by magnetic eCompass nearly impossible. For mechanical eCompasses, the needle dips excessively, trying to align with almost vertical lines of force. For an electronic eCompass, accuracy decreases because the horizontal field is smaller and because the effect of tilt errors is more pronounced.

The map in Figure 5 shows lines of constant dip angle around the globe. Each of the lines is separated by 2°. The map is based on the US/UK world magnetic model for the year 2005

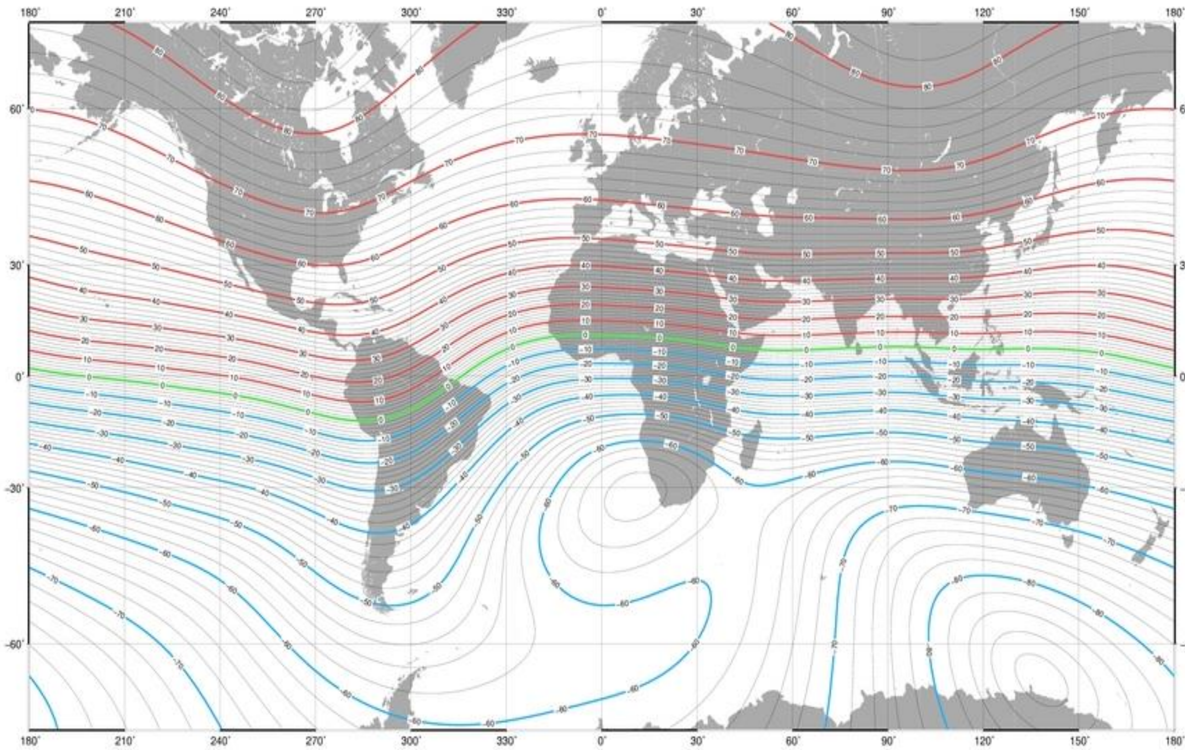

Figure 5 – Magnetic Inclination Contour Lines (in degrees)

Near the magnetic equator, tilt measurement errors have very little influence on eCompass heading. Between ±5° dip, a 1° error in tilt produces no greater than 0.09° heading error. In northern Alaska (80° dip), the same 1° tilt error results in as much as 6° heading error.

Summary

If you have any questions about optimizing eCompass performance, for Jewell's products or other manufacturers, please do not hesitate to contact us or visit our website www.jewellinstruments.com.