Advanced Electronic Compass for Oil Drilling Applications.

Eli Marianovsky
Advanced Orientation Systems, Inc.

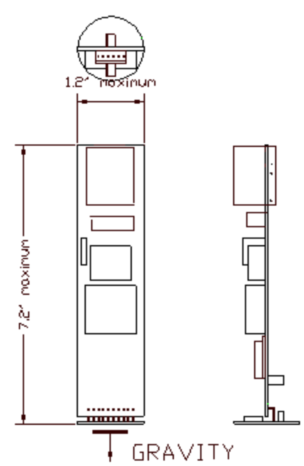
How many times have you questioned what the final position of the hole is, or what is its actual orientation? Was the desired point and orientation reached ? Is more drilling needed ?

How confident are you with the answer?

Trial and error may work well in a laboratory but when it comes to oil drilling, there is no room for error and no time or money for trial. With elevated costs for large diameter hole drilling the industry has shown a shift to smaller diameter holes; consequently increasing the demand for smaller diameter and more complex tooling which can assist in drill orientation and positioning. As the Millennium approaches the oil-drilling industry shows growing demand for low cost tools which help to increase drilling accuracy, provide information on the profile of the finished hole, and allow accurate multi-drilling alignment. This is notably true in applications where GPS can not provide valid directional or total orientation information.

AOSI, (Advanced Orientation Systems, Inc.), a Linden, New Jersey, USA based manufacturer of tilt sensors, inclinometers and electronic compasses has the answer to these questions. By completing the development of a miniature Three-Axis Tilt Compensated Compass, which can easily fit into a standard 1.2" diameter tool, AOSI puts oil-drilling engineers back in control.

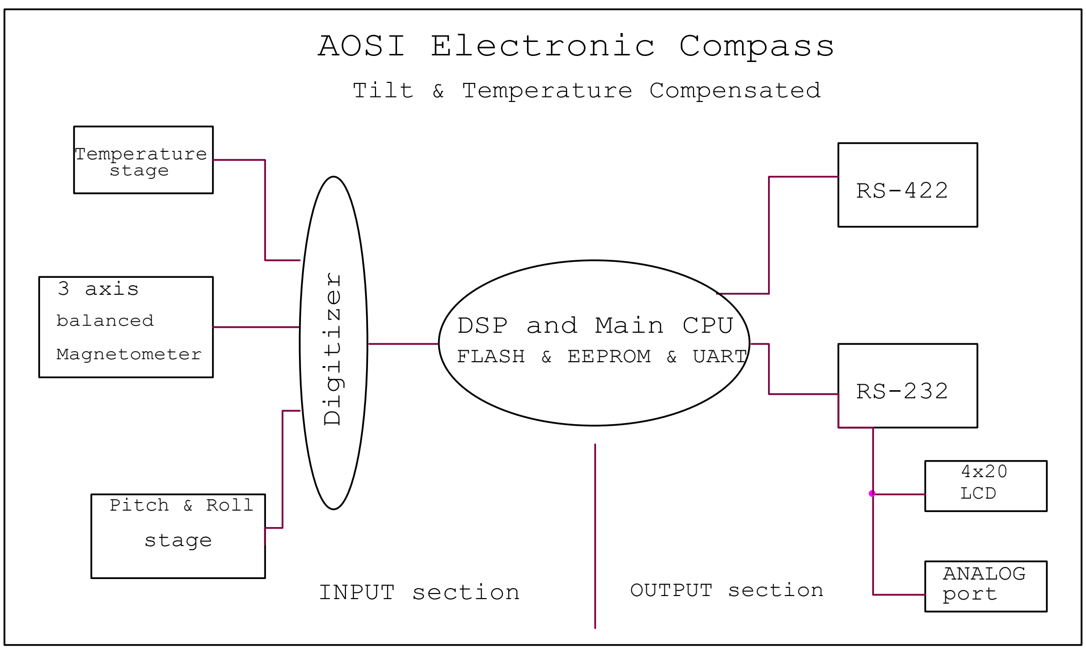
This new compass is able to read magnetic fields exceeding in magnitude the magnetic field of Earth. Generally the intensity of Earth's magnetic field is about 600 mGauss, and has components parallel to the earth's surface, which always points to magnetic north. Magnetic North is defined as Earth's magnetic pole and it usually differs by about 11.5 degrees from the True North, which is Earth's rotational axis. At some locations on Earth, the Magnetic North can differ from True North by as much as 25 degrees. This difference or so called 'declination angle' can be found in special tables generated by various geographic organizations.



COMPASS DESIGN

New developments in magneto-resistive (MR) technology and thick film metal deposition led AOSI to the development of numerous types of electronic compasses. The most advanced type (EZ-COMPASS-3) includes a balanced three axis magnetometer with concurrent pitch and roll compensation, which enables the use of this compass in excess of 45 arcdeg of tilt without having the compass mechanically gimbaled. EZ-COMPASS-3-DRL electronic compass incorporates in its design the finest and the most reliable components and materials which facilitate reliable long-term operation in a standard industrial environment. The high performance Motorola 68HC711 Microprocessor, not only controls the general data flow and conversion sequence, but also provides excitation to the Pitch and Roll sensors, converts and normalizes data, performs thousands of floating point calculations, facilitates multi-protocol output communication and allows custom upgrades for numerous digital filters and error checking routines.

The following diagram demonstrates general schematic and major interconnection of key sections of the AOSI's EZ-COMPASS.



For many years coil based magnetic sensors; such as Fluxgate and Magneto-inductive; were used to detect changes in magnetic field. However, with the higher complexity of applications and the shrinking tool size these bulky sensors become unusable. In comparison to old type Fluxgate magnetic sensors, which are clumsy and slow; AOSI uses the new advanced magneto-resistive MR magnetic sensors. These sensors are small, fast and have absolutely no mechanical parts. The magnetic data can be read as fast as 1000 times per second; which is paramount in non-static applications. These sensors are constructed with special micro traces of magneto-resistive alloy deposited and sealed in an IC type package. These special alloy traces change their resistance in the presence of a magnetic field. The change in resistance is then processed and the magnetic field is extrapolated.

THE MAGNETOMETER

The magnetometer is composed of three sensors positioned orthogonally to each other. The direction of each sensor corresponds to the direction of each component to Earth's magnetic field. The forward or X sensor points to the direction of x field vector; Right or Y sensor points to the direction of y field vector; and the Down or Z sensor points in the direction of z field vector. The sensitivity of each sensor is well matched to the direction of the field vector and has low cross axis error. Analog output changes from each sensor are amplified and captured for DSP processing. The AOSI compass is calibrated to saturate at about 2 Gauss. With 12-bit A/D conversion, the magnetometer will be able to resolve magnetic fields of less then 1mGauss. With such a high sensitivity these sensors are well suited to measure actual X and Y magnetic fields; which are in a range of 200 to 300 mGauss, with upward change at the equator, and lower at the poles.

Only two components of Earth magnetic field (X and Y) are sufficient to calculate azimuth.

Azimuth = arcTan (Y/X)

The above relationship is generally true if the orientation of the sensing instrument is parallel to ground. In case the sensing instrument is tilted, the azimuth reading will show an error. The magnitude of error is dependent on the geographical location and the tilt angle. To compensate for the error induced by tilt, AOSI has installed two linear tilt sensors, which measure Pitch and Roll of the compass. The Pitch direction is defined as the angular movement in a Front to Back direction while roll is defined as angular movement in a Right to Left plane. The compass is programmed to monitor Pitch and Roll sensors and mathematically translate the three magnetic vectors back to the horizontal. Standard translation formulas are used for this rotational translation:

Xr = Xcos(a) + Ysin(a)sin(b) - Zcos(b)sin(a)

Yr = Ycos(b) + Zsin(b)

Xr is X field translated to the horizontal plane.

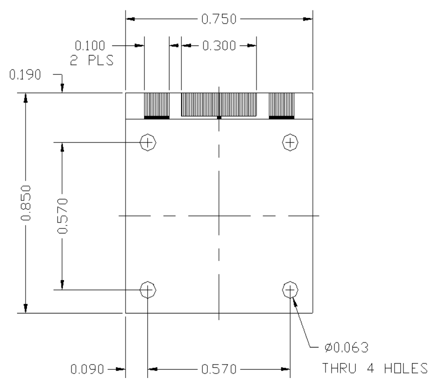
Yr is Y field translated to the horizontal plane.

"a" is a tilt angle in Pitch plane

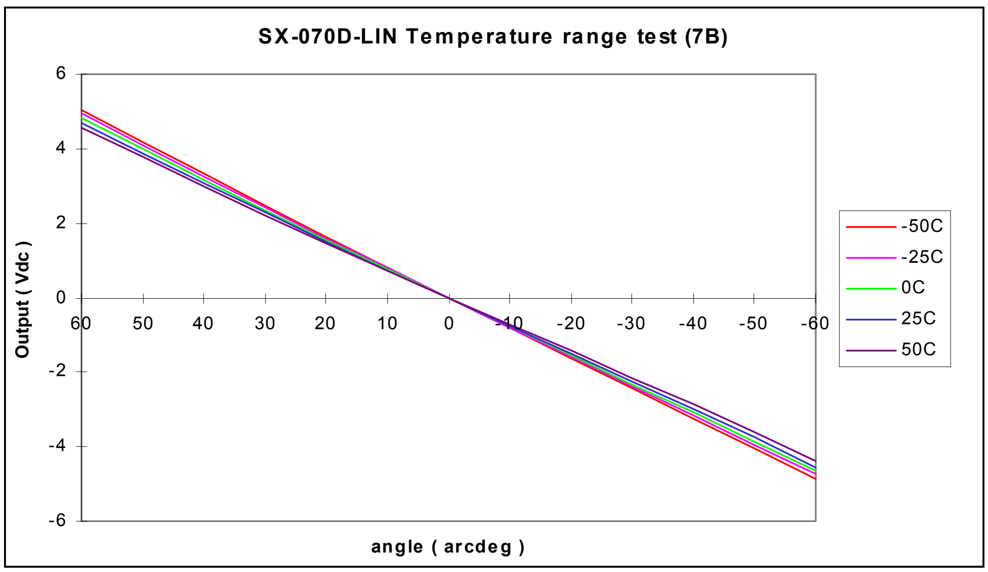
"b" is a tilt in a Roll plane.

From these equations it is clear that the Z field plays a very important role in a total compensation technique and in many cases contributes in a major way to the total field result.

As demonstrated in the translation formulas, the compass must continuously update tilt angles for both Pitch and Roll axis. For tilt measurement, AOSI utilizes SX-070D-LIN high performance wide range linear tilt sensors. These small size single axis devices are able to measure tilt angle in access of +-75 arcdeg with a resolution of < 0.005 arcdeg.



SX-070D-LIN sensors are linear in the full +-70 arcdeg range and have a predictable and well defined thermal characteristic, which is -0.08%/degC. Tilt readings are concurrently compensated for thermal changes in ambient by utilizing the onboard temperature sensor. The temperature is available in °C as an independent output.



The above graph demonstrates the performance of the SX-070D-LIN linear tilt sensor in a +-60 arcdeg tilt range while being subjected to a thermal change from -50°C to +50°C.

COMPASS and the ENVIRONMENT

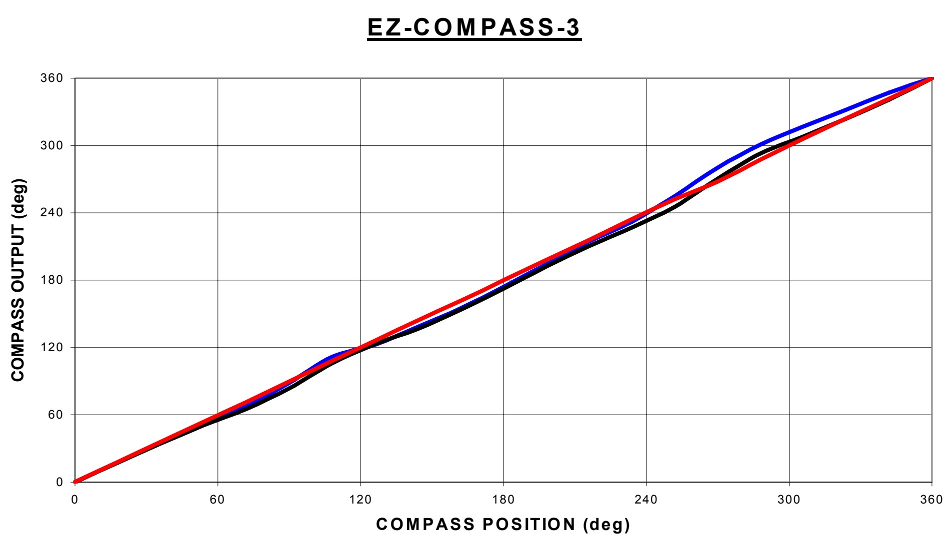
For proper operation of the compass it is important to teach the compass its surroundings. One important item is Compass's proximity to ferrous effects or objects. If the compass operates in an open field without any magnetic or ferrous interference, the response of the compass will be without any distortions. The combined functions of X and Y fields will create a non-distorted circular response. In case the compass is placed in an area where the magnetic flux is distorted, the output of the compass looses its accuracy and linearity. The most common ferrous distortions are:

1. Placing the compass inside a vehicle
2. Driving over a metal bridge or over utility pipes.
3. On a ship
4. Near a transformer or any random ferrous object

As a result of these field disturbances the response of the compass changes from circular to elliptic. If a field distortion is detected, it is recommended to perform HARD IRON compensation. The purpose of HIC is to mathematically convert the elliptical output shape to a circular shape. In case the compass is installed *in or near* a strong field or a metallic object, it is recommended to rotate the complete compass structure 360 CW or CCW for about 1-2 minutes while the compass records magnetic data during the <calib> mode. After the calibration is competed the compass will calculate translation coefficients which are used to correct the output curve. The resulting output shape of the compass output after Hard Iron compensation looks more like a circle.

For applications requiring high compass accuracy or having multiple ferrous field disturbances, the EZ-COMPASS-3 includes a Dynamic Soft Iron compensation option. The idea behind this compensation is to segment the output curve into smaller segments and correct for linearity error in each segment individually. This compensation will remove the residual influence of multi-pole magnetic field interference and most linearity errors. The user is able to select the number of correction intervals (10 to 72) and then the compass will store the raw compass value and automatically instruct the user to all steps of calibration. The calibration sequence takes only one full revolution. Upon completion of the full rotation the "soft iron" calibration automatically calculates and stores all correction formulas. Laboratory testing showed that with 72 point calibration compass's accuracy was well within 0.25 deg.

The following graph demonstrates the output of an EZ-COMPASS-3 at all stages of calibration.



Blue trace: Raw uncompensated output with random field distortion.
Black trace: Output after one turn Hard Iron compensation.
Red trace: Output after 20 point Soft Iron correction.

CONCLUSION

State of the art electronic semiconductor compasses are becoming more popular for their friendly interface, fast update rates and small size. It will not be long before these slick powerful instruments become the standard in hole-orientation-measurement all over the oil drilling industry. These compasses provide a very economical solid state solution for integrating a compass into the rough, dynamic and size hungry environment. EZ-COMPASS-3 proves to be the logical alternative to old style, bulky and slow coil based instruments. EZ-COMPASS-3 can be used with similar success in underwater dredging, ROV navigation, pan & tilt camera orientation among other high tech applications.

About the writer:

With over 20 years experience in the electronic industry, automation and sensor design, Eli Marianovsky is a V.P. of Engineering at AOSI (Advanced Orientation Systems, Inc.). A graduate of Univ. Of Rhode Island in 1983 and advanced studies at MIT and CCNY, he is involved in all stages of development of advanced tilt and navigation instrumentation.