Honeywell

SENSOR PRODUCTS

APPLICATION NOTE

CROSS AXIS EFFECT FOR AMR MAGNETIC SENSORS

ABSTRACT

Honeywell's Anisotropic Magneto-Resistive (AMR) sensors are fabricated as wheatstone bridge elements to form magnetic field sensors. While these sensors tend to sense magnetic fields in the desired sensitive axis, there is a minor sensitivity to fields orthogonal to the sensitive axis. These orthogonal fields are calls cross-fields or cross-axis magnetic fields. The cross-axis effect is characterized amount of error voltage due to cross-field intensity. This application note shall describe the effect, the impacts of the effects, and ways to compensate for the errors.

THE AMR ELEMENT AND FIELDS

Each AMR wheatstone bridge sensor uses four identical AMR elements composed of permalloy thin films and metalization for biasing the element electrical current direction, and to sense the intensity of externally applied magnetic fields. By using diagonal metalization stripes, the element current direction (I) is biased 45 degrees in the permalloy film. The film itself has its magnetic domains aligned along the long dimension of the element to create an "easy axis" orientation. Figure 1 shows an example AMR thin film sub-element with magnetic field vectors and specified current direction.

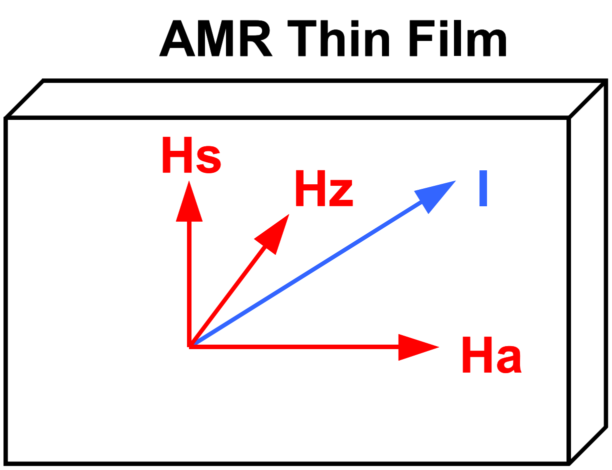

Figure 1
AMR Thin Film Sub-Element

When a magnetic field is applied along the Hs direction, the film domains rotate away from their easy axis (Ha) towards the hard or "sensitive" axis (Hs). With the current (I) at 45 degrees from both the easy and hard axis', a very linear resistance change with applied field occurs.

Cross-axis effects may occur from a number of sources, but mostly from the dimensional characteristics of the AMR element design. Magnetic fields in the Ha direction exhibit minor magnetic distortions. Also, the shrinking size of these sensor elements tends to increase magnetic field distortions. Typically, these crossfields will create only tenths to a few percentage points in value to form a cross-field error.

IMPACTS ON MEASUREMENTS

Traditionally cross-axis fields are ignored in wheatstone bridge output voltage computations, and the output voltage is the multiplicand of the sensitivity by the bridge voltage by the sensitive axis field strength as shown by the equation below:

Vo (volts) = Vb (volts) x Ss (volts/volt/Oe) x Hs (Oe)

(1 Oersted = 1 gauss in air)

The value for bridge sensitivity (Ss) is strictly for the field applied in the sensitive direction. For cross-field effects, the orthogonal field (Hc) is added in this equation and impacts the sensitivity and offset voltage.

$$Vo = Vb \{[Ss \times (1 + C \times Hc^2) \times Hs] + [D \times Hc]\}$$

With Ss being the usual sensitive axis sensitivity, and coefficients C and D being the cross-field sensitivity and offset values respectively. As mentioned above, the cross-field impact will likely be in the tenths to a few percent of the sensitive axis output voltage value. Coefficient C tends to be neglected as the sensitivity shift due to cross-fields tends to be very small. With the nominal value of C being around 0.002 and multiplied by sub-gauss squared, only the D coefficiant contributes a significant error voltage.

Reducing the equation to only the D cross-field coefficient, Vo becomes:

$$Vo = Vb [(Ss \times Hs) + (D \times Hc)]$$

With D dependent on the feature geometry of each sensor bridge, there is a reasonable consistancy of D for each sensor design. Once identified through data collection, a compensation algorithm may be employed to correct for cross-field susceptibility. The value of D maybe very low such as 0.003 (0.3%) or as high as 0.1 (10%).

Where cross-axis effect becomes a major issue is in electronic compassing. With two or three sensors orthogonal to each other, the cross-axis effect becomes a significant contributer to accuracy errors. This especially happens when one or more axis are in minimum field conditions and the other axis has most of the field strength. To show this, Figure 2 depicts an X-Y axis plot with a 10% cross-axis field effect applied to the x-axis with the Y-axis held perfect. Normally the X-Y plot is a perfect circle, with centering on the 0,0 coordinates no oval-ation.

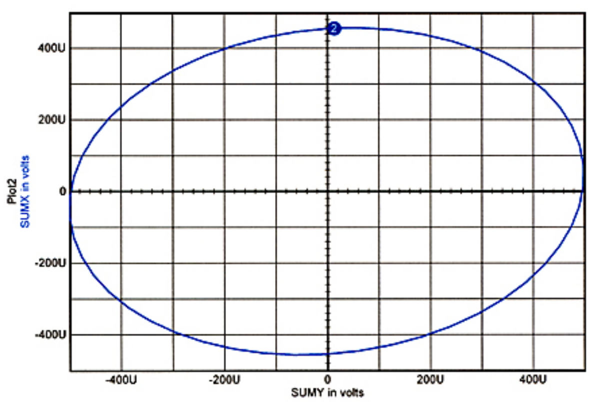

Figure 2
X-axis Cross-Field Effect

What we do see is a tilted elipse phenomenon in that as the X-axis goes towards zero and the Y-axis become maximum (easterly and westerly directions), there is an X-axis offset that is Y-axis strength dependant. This gives rise to the tilted elipse visual and a couple degrees of compass error, if not compensated for.

Now what happens when both bridges exhibit cross-axis effects? Figure 3 depicts a worst case scenario where both X and Y axis each have a +10% cross-axis effect.

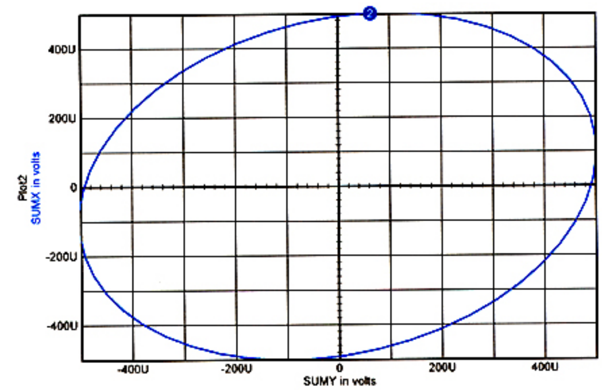

Figure 3
+10% Cross-Field Effect (X and Y)

As you can see, both mininum and maximum values for X and Y sensor voltages occur away from the zero points of the opposite axis. Figure 4 shows the same effect, but with –10% on each axis.

With Figure 4 the elipse is tilted in the opposite direction due to the negative cross-field factors.

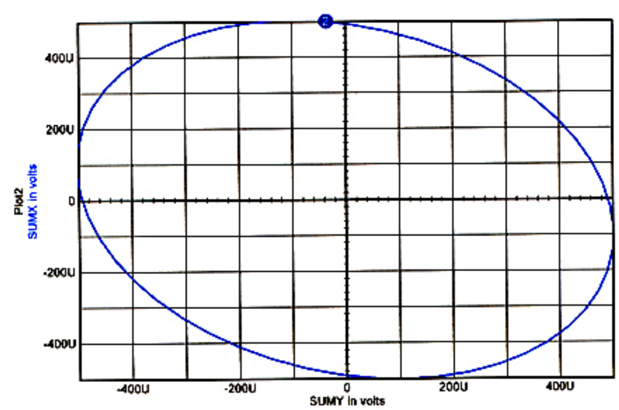

Figure 4
-10% Cross-Field Effect (X and Y)

As an example, a recent lot of HMC1052 2-axis magnetic sensors were characterized for cross-axis effect. Bridge A and B had a coefficient C value of 0.002 proving the negligible value in sensitivity change. Bridge A had a D coefficient of 0.0295 (2.95%), and bridge B had a D coefficient of 0.0461 (4.61%). Both offset values had standard deviations around 1%. Knowing these values and comparing them against zero cross-axis effect, we can circuit simulate the offset errors and compute the amount of heading for the HMR1052 compass circuits. Figure 5 show the results.

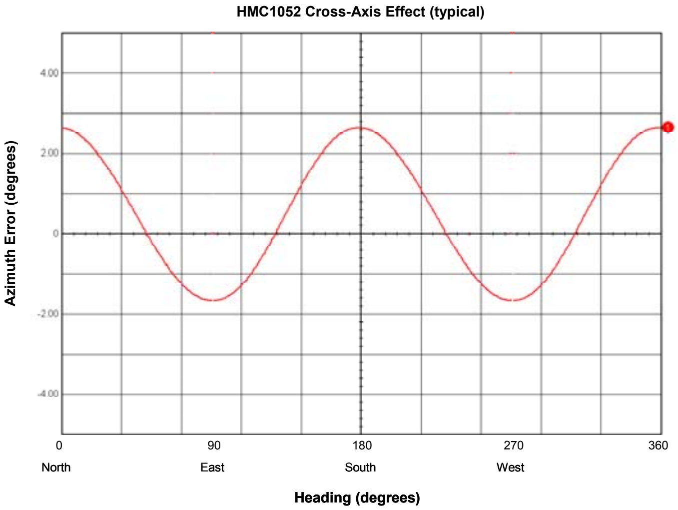

Figure 5
HMC1052 Cross-Axis Heading Error

ERROR COMPENSATION

Two popular methods for compensation of cross-axis effects are (1) implementation of statistical bias factors, or (2) 100% characterization of the sensors or sensor assemblies. The first entails taking a large sample of sensors and computing the cross-field sensitivity average and standard deviation for unique bridge. Products like Honeywell's HMC102X family can use only one set of statistics, as only one sensor per die exists. Products like the HMC105X family have A and B bridges and require separate statistics for each.

Whether characterizing sample lots or forgoing a 100% test regime, the following Equations can be used:

Vx = [(Sxx) x (Hx)] + [(Dxy) x (Hy)]

Vy = [(Syy) x (Hy)] + [(Dyx) x (Hx)]

Both Vx and Vy should be normalized for applied bridge voltage under test. Normal axis sensitivity factors (Sxx) and (Syy) are typical published values in the product data sheets and tend to be identical. Cross-Field offsets (Dxy) and (Dyx) are also published but must be tracked for 100% testing.

DATA COLLECTION

To gather data on cross-axis effects, typically a helm-holtz coil set is used, with the sensors or sensor assembly placed in the center. An alternate data collection method would be rotating sensors under test in precise north, south, east, and west orientations in substitute for the coil induced fields. Bridge voltage is applied plus reset followed by set pulses are applied to the set/reset strap between field changes in the coil set or orientation. These pulses are to get the most accurate sensitivity data and to minimize thermal effects (see app note AN-212 for further details).

Using the table below, four combinations of applied X and Y-axis fields are shown to collect sensitive axis and cross-field voltages. This table indicates bridges A and B to be the same as the X and Y-axis respectively.

Coil Set Applied Fields (milli-gauss)	Voltage at Bridge A	Voltage at Bridge B
Hx = 0, Hy = 300 (west)	Vcx1	Vy1
Hx = 0, Hy = -300 (east)	Vcx2	Vy2
Hx = 300, Hy = 0 (north)	Vx1	Vcy1
Hx = -300, Hy = 0 (south)	Vx2	Vcy2

From these collected bridge voltages with the four field directions from the Helmholtz coil set, the values for the bridge sensitivities Sxx and Syy and cross field offsets Dxy and Dyx can be computed. Note that the bridge voltages and sensitivities should be normalized to a per-volt applied basis, or divided by Vb.

Sxx = (Vx1 - Vx2) / [(2 x Hx) x Vb]

Syy = (Vy1 - Vy2) / [(2 x Hy) x Vb]

Dxy = (Vcx1 - Vcx2) / [(2 xHy) x Vb]

Dyx = (Vcy1 - Vcy2) / [(2 x Hx) x Vb]

Using some real values and parts as an example, lets take the HMC1052 2-axis sensor and apply a nominal +5 volts. With the helmholtz coil set in the first direction (Hy =+300 milli-gauss), Vy1 may be 1.40mV or 0.285mV/V normalized. In the opposite field direction should reveal Vy2 at about –1.45mV or -0.290mV/V normalized. The resulting Syy is 0.95mV/V/gauss.

In the orthogonal coil set direction (Hx = +300 milli-gauss), Vx1 can be 1.58mV or 0.316mV/V. In the opposite field direction could yield Vx2 at –1.57mV or 0.315mV/V. This results in a Sxx of 1.05mV/V/gauss.

The cross-axis offset coefficients Dxy and Dyx are derived from the ratios of the cross-field to the sensitive axis voltage ranges. If Vcx1 is 0.075mV and Vcx2 is –0.075mV, the resulting Dxy is 0.048mV/V/gauss or about +5% of normal sensitivity. If Vcy1 is 0.06mV and Vcy2 is –0.06mV, the resulting Dyx is 0.042mV or about +4% of normal sensitivity.

IMPLEMENTATION

To use these new found sensitivity numbers, we just subtract out the cross-axis offset voltage from the uncorrected sensor data. This already presumes the zero field bridge offset has been already corrected. These equations give the correction factors:

$V_x' = V_x - [(D_{xy}/S_{yy}) \times V_y]$

$V_y' = V_y - [(D_{yx}/S_{xx}) \times V_x]$

The Vx and Vy values can be in analog voltages, but usually is in Analog-to-Digital Converter (ADC) counts of each sensor after offset corrections, zero gauss referencing, and calibration factors have been factored in.

SUMMARY

Compensating for cross-axis effect may be as simple as subtracting out factory characterized percentages from the above X’ and Y’ equations. For more accurate applications, individual sensor parts would undergo 100% coil set characterization, with the Dxy and Dyx number computed and associated with each assembly.

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