Development of an Angular Measurement System by Linear Hall Sensors on Stepping Motors

Lee,Yun Yao, and Lai,Yi-Rui.

Abstract—An non-contact type application on the permanent magnet and linear Hall-effect sensors gauging rotary system is introduced in this paper. For such a contactless system, there will be low wear exhaust. This leads to a longer life span in association, and in particular, high reliability to achieve continuous use. The main component of the angular gauge depends on the Hall voltage under the rotation of the magnetic induction. This kind of system is low-cost and holds reliable operation in special environmental conditions, such as high vibration, humidity, or dust. Higher accuracy and precision can be achieved as shown in the experimental results.

***Keywords*---** sensors, gauging, rotary, vibration, humidity, dust.

I. Introduction

THIS Nowadays, analog potentiometers are wildly used for angular measurements because of their accuracy, low cost and easiness of setup. Currently, ohmic contact potentiometers with ring-shaped resistive layers are widespread. The main drawbacks of this type of angular devices, such as heavy wear, limited lifetime, poor reliability, and great susceptibility to harsh environment are focused. And promising for its high performance and low cost, there is conflict. Usually, high precision performance is proportional to the cost.

Therefore, contactless encoders have become attractive [1-7]. With the rapid growth of automation in industrial production demands, amongst other types of motion sensors, contactless encoders provide an easier and more precise solution for angle measurement. However, the prices are still related to the demands of the precision.

A new technique is presented in this paper to sense the directions of the magnetic field, enabling a new generation of a contactless 360^{o} angle measurement. A trade-off approach between the IC compatibility, low price, reliability, accuracy is a rotating permanent magnet located over mutually perpendicularly placed silicon micro sensors, such as linear Hall-effect sensors.

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These two-dimensional systems simultaneously detect in-plane x-y magnetic fields, providing complete information of : (i) the value of the resulting magnetic field by the sine and cosine output signals as a function of the rotation angle, and (ii) the angle value of the turning magnet relative to its reference position [4,8].

The design and operation of the whole device structure are discussed in section 2, the experimental results and discussions will be shown in section 3, and the last section will make conclusions and show the prospections and future works.

components B_x and B_y, providing complete information of: (i) the value of the resulting magnetic field B (B_x, B_y) by the sine and cosine output signals as a function of the rotation angle θ, and (ii) the angle value θ of the turning magnet relative to its reference position [4,8].

II. Device Structure And Operation

This feature is important for accurate angle sensing and allows compact integration of the complete sensor-magnet system. Angular-positioning measurements can be realized with the Principle and structure of Fig. 1. The Hall-effect (linear Hall-effect) sensors are orthogonally placed to measure the X-axis and Y-axis directions of the rotating magnetic field. The projections of the external magnetic field give the sine and cosine of the rotation angle θ. Thus, we are able to extract the angle over 360° without discontinuity or dead angle.

The Hall Effect is the production of a voltage difference (the Hall voltage) across an electrical conductor, transverse to an electric current in the conductor and a magnetic field perpendicular to the current. It was discovered by Edwin Hall in 1879, i.e., 132 years ago.

The Hall coefficient is defined as the ratio of the induced electric field to the product of the current density and the applied magnetic field. It is a characteristic of the material from which the conductor is made, as its value depends on the type, number, and properties of the charge carriers constituting the current. Then the linear Hall-effect sensor is optimized, sensitive, and temperature-stable. The ratio-metric linear Hall-effect sensor provides a voltage output proportional to the applied magnetic field.

The construction of the magnetic modulating system is accomplished using two semi-ring shaped permanent magnets made of a semi-ring outside N pole and inside S pole (on other hand, outside S pole and inside N pole). The dimensions of the permanent magnetic ring are: height 8 mm, internal diameter 28 mm, and external diameter 10 mm. The magnetic flux density maximum is ±10 G. The ring is fixed to a non-magnetic POM (Polyacetal) shaft, as shown schematically in Fig. 1. This allows the linear Hall-effect sensors to obtain distance d without contact.

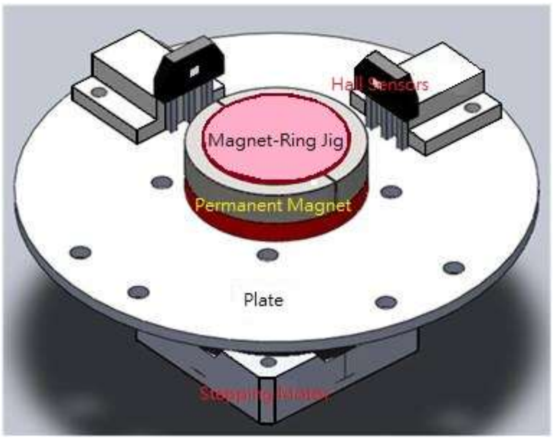

Fig. 1 Schematic view of the Angular Position Device containing Two Semi-Ring Shaped Magnets, connected with Attractive Poles and Double Linear Hall Sensors.

The shaft with the semi-ring magnets holder is positioned symmetrically in the orthogonal direction around the magnetic ring outside with minimal tilt error. There are more ways to design a structure than by choking it with the linear Hall-effect sensor. The procedure used for this purpose is as follows. Precisely rotating the shaft with the ring magnet within the 0°–360° range, the double linear Hall-effect sensors output channel voltages V_X and V_Y are measured (Figure 2).

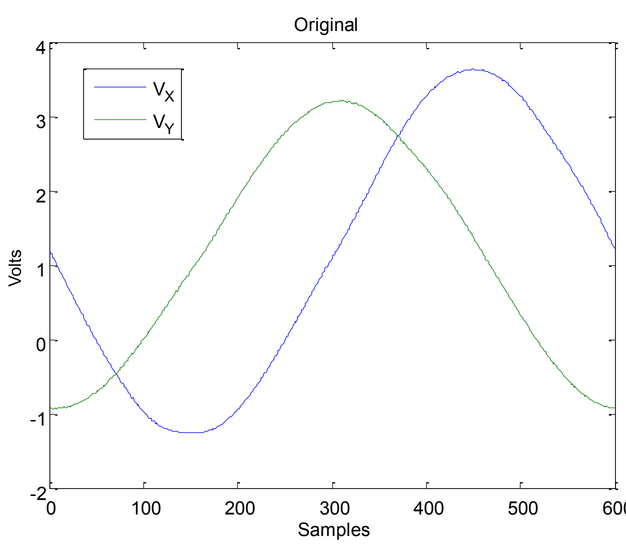

Fig. 2 Magnetic Field Induction Hall Voltages-VX & VY . The 0°–360° range obtains 600 steps (samples).

The angular position information (i.e., θ) is extracted from those two signals through a Digital Signal Processing core featuring a Coordinate Rotational Digital Computer algorithm.

$$\theta = tan^{-1}\left({}^{V_Y}/_{V_X}\right)$$

The resulting sensor is sensitive to the direction of the flux density and not its strength. Through the quotient V_Y/V_X, the transfer characteristic (1) is stable over temperature and lifetime even if the flux density strength changes. This statement is valid as long as the thermal variations of both components magnetic flux B_X and B_Y and the resulting voltages on the linear Hall-effect sensor (i.e. V_X and V_Y) are matched. The thermal mismatch between the magnet and the sensitivity does not play a critical role anymore.

III. Result And Discussion

Degree (angle) definition: A degree (in full, a degree of arc, arc degree, or arc degree), usually denoted by ° (the degree symbol), is a measurement of plane angle, representing 1⁄360 of a full rotation; one degree is equivalent to π/180 radians. It is not an SI unit, but can be used with the SI system by the aforementioned π/180 radians conversion. Measurement is the process or the result of determining the magnitude of a quantity, such as length or mass, relative to a unit of measurement, it is requested to calibrating system before measure use it. Figure 5 shows the rotary position system by calibration.

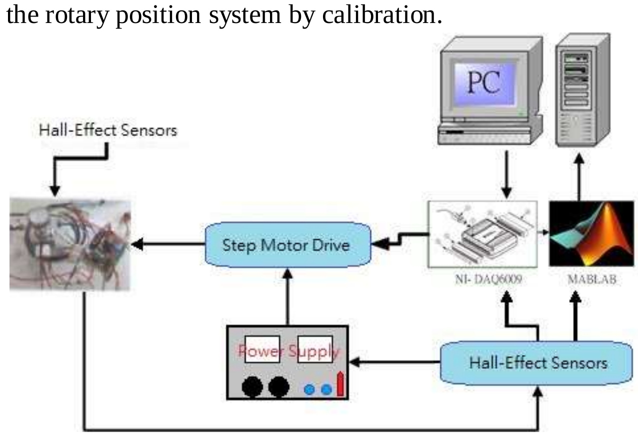

Fig. 3 The rotary position system of calibration –block diagram.

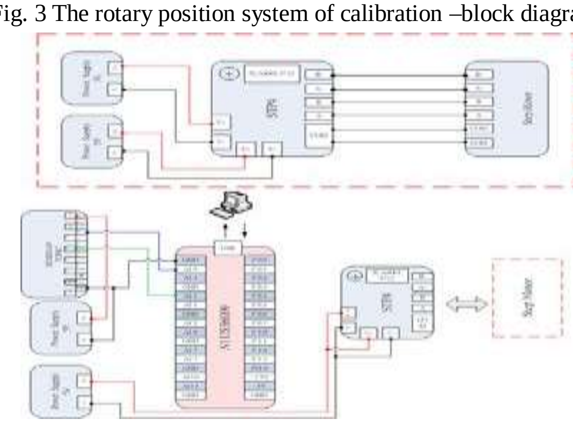

Fig. 4 Linear Hall Effect measurement system wiring diagram

The reference strand material is a stepper motor, offering high reliability of angle. Stepping motors are electromagnetic, rotary, incremental devices that convert digital pulses into mechanical rotation. The amount of rotation is directly proportional to the number of pulses and the speed of rotation is relative to the frequency of those pulses.

After performing the angular measurement of calibration, the stepper motor made 3 cycle turns and the shaft with the rotating permanent magnet made a cycle turn. The one sample data is 0.6° (i.e., 360°/600 steps).

The angle is extracted from the sine and cosine function following offset compensation (Figure 5), with the four quadrant inverse tangent function of these two values. The angle is obtained without discontinuity or dead angle over a full 360°.

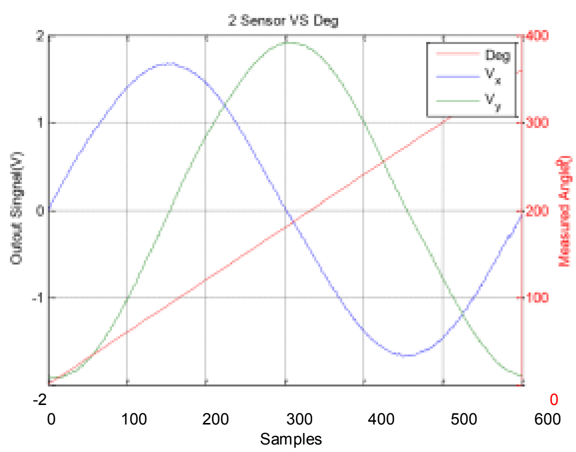

Fig. 5 Signals at the output of the rotating in a magnetic field. After offset normality, they correspond to the sine and cosine of the rotation angle. A linear response after extraction of the angle is obtained using the arctangent function.

By rotating the axis 360° with the permanent magnet fixed on it, two sine curves, phase shifted by 90°, are obtained at the output of the electronic circuit, as shown in Fig. 5. Next, these signals are processed to extract the value of the angle. The signals data use normal compensation between the Hall sensors of both axes. The graph shown in Fig. 6 represents the measured angle as a function of the mechanical angle. The signal processing used to obtain this result was digital.

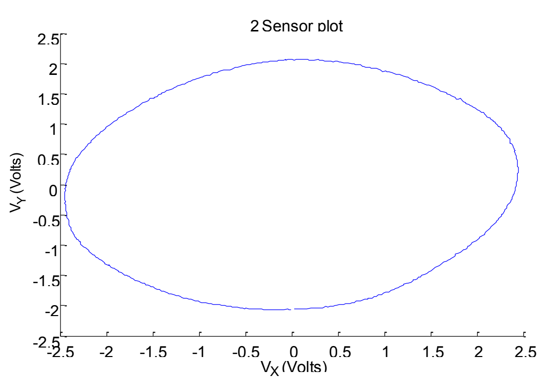

Fig. 6 After offset normality for X-axis and Y-axis output signal.

The angle θ is obtained by the ratio of the two output voltages V_Y/V_X, i.e., by calculating the Inverse trigonometric functions (arc. tangent) $\theta = \tan^{-1}(V_Y/V_X)$. Correction of the sensor channel data is required. The angle θ measured with the implemented angular position setup following the offset compensation of the outputs at room temperature is shown in Fig. 7. The good correlation and linear regression reach 99.999%.

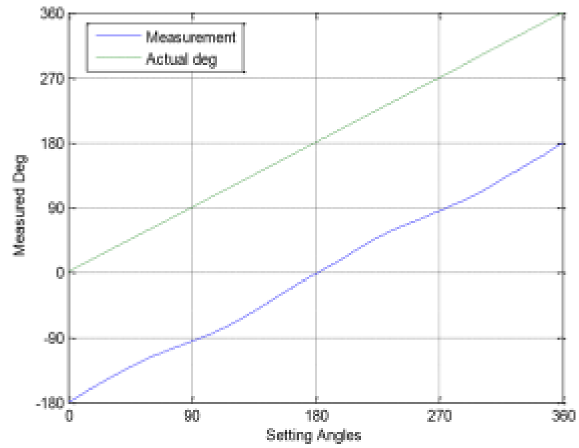

Fig. 7 Comparison between an ideal absolute angle phase and the measured angle phase.

This contactless angular measure drive was tested using a brushless (stepper) motor. Assembly consists of fixing a semi-ring permanent magnet on the rear end of the motor shaft. Then, the Hall sensors are positioned in front of this magnet. However, the system measured in the range 0° to 720°, as shown in Fig. 8.

The clear result is continuous without a dead angle after the transfer characteristic.

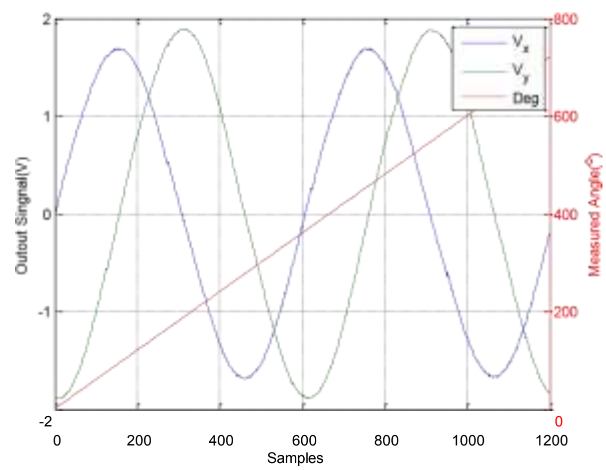

Fig. 8 The signals output transfer characteristic for 720 degrees.

Figure 9 displays a 720 degree measured result. Both Hall sensors output signals make a cycle. The bottom of figure show is two lines. The oblique dotted line is a real angle (Actual Deg), another line is that examines the result from transfer characteristic (Measurement). Observe the result is a discontinuous straight line within 600 steps. That is that a transfer characteristic happens among 360° to 0°.

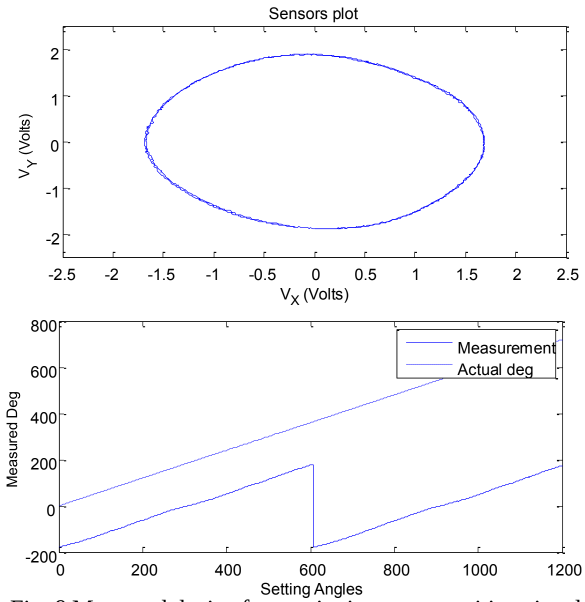

Fig. 9 Measured device for continuity rotary position signal phase and angleresult.

While the above results indicate successful operation of the device principle, and offer considerable promise for enhancedsensitivity over linear Hall sensors, Fig. 9 shows an interestingeffect. Further work on this device will consider suchphenomena by alterations to the design.

IV. Conclusion

The angular position system based on a semi-ring magneticand linear Hall-effect sensors has a precision of ±0.6° for acomplete rotation around the shaft (motor axis). This studyshows the possibilities for building sensors insensitive tomechanical plays, simple in structure, and giving a signal thatis easy to treat. The rotary position device is quite rugged,offering reliable operation in environments where highvibration, temperature, moisture, or dust may exist.Furthermore, the experimental measurement accuracy canbe verified in the further work.

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