

PRINCIPLES OF HALLPOT® ANGLE SENSORS

INTRODUCTION

The **hallpot®** non-contacting magnetic potentiometer is an angle-measuring device that produces an output voltage that is a controlled function of angular position. Specifically this function is a sine voltage of exactly one cycle per revolution. All **hallpot®** devices operate mechanically through 360 degrees. Models that produce a single sine wave are useful as position feedback sensors through angular deflections of less than +/- 90 degrees. Typically they will replace resistive potentiometers or rotary differential transformers. We call them by our registered trade names, **hallpot® Potentiometers**, **hallpot® angle sensors**, or **hallpot® angle position sensors**.

Characteristic of a sine function is that it is nearly linear (within 1%) in two regions throughout a range of +/- 30 degrees. These two regions occur around 0 degrees and 180 degrees with opposite slopes. A sine function does not have significant angular resolution in the peak and valley regions near + 90 and -90 degrees. Also every voltage represents two different positions. An excellent solution exists to enable reading through 360 degrees.

Addition of a second identical sine function, displaced at or near 90 degrees, is a cosine function. The cosine function provides a steep slope for good resolution throughout the peak and valley regions of the sine function. It also "resolves" the double valued ambiguity of the sine function. It enables accurate measurement of angle through a full 360 degrees. We call this device by our registered trade name, a **sin-cos hallpot® resolver**

ADVANTAGES of hallpot® ANGLE SENSORS

Primary advantage of a **hallpot® Position Sensor** is that **it doesn't have any inherent wear or failure characteristic**. Output signal is generated by changing the position of a magnet near a hall effect sensor. As a result, in comparison to resistive sensors, there is no stiction, no backlash, no contact bounce, and no changes in signal due to element wear. In comparison to rotary differential transformers and resolvers, there is no need for oscillators to excite them or demodulators to regain the sine and cosine signals. A **hallpot®** device is energized only by regulated + 5.00 Volts DC. The sine and cosine outputs occur naturally with no additional components. Several versions have electronics built in so that unregulated voltages may be used. Some versions, particularly those with ball bearings on the shaft, can operate indefinitely at speeds of several thousand rpm. They may be used as tachometers while simultaneously measuring position. Bandwidth is in the order of DC to ten kilohertz.

PRINCIPLES OF OPERATION

Figure 1 displays the basic configuration of a **hallpot®** potentiometer from an edge view of both a rectangular shaped magnet and a Hall effect element. A uniform field (FLUX B) from the face of the North Pole of the MAGNET (N) traverses a Hall effect element with center at (C). Uniformly distributed current (I) flows into the Hall effect element perpendicular to the magnetic field and generates a voltage across terminals T1 and T2. The magnet revolves around the center (C) of the Hall effect element keeping its North Pole face, N, perpendicular to the radius of revolution.

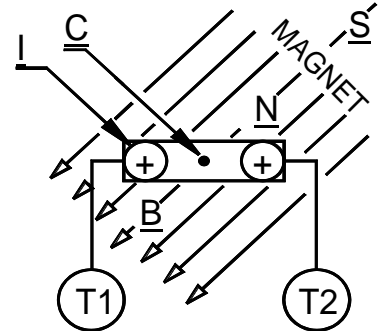
This magnetic field can be represented as three vectors portrayed in **Figure 2**. B is the vector in the direction of the magnetic field that represents flux density. Bn is the magnetic field component normal to the Hall effect element and Bp is the parallel component. Bn contributes to the voltage developed across terminals T1 and T2. Bp contributes little or nothing. Output voltage, (Eh), across the terminals of the Hall element is related to rotation by:

Elweco, Inc IS THE SOURCE OF ALL HALLPOT® ANGLE SENSORS

Figure 1 -- Basic

Configuration of magnet and Hall effect sensor.

Edge views are shown

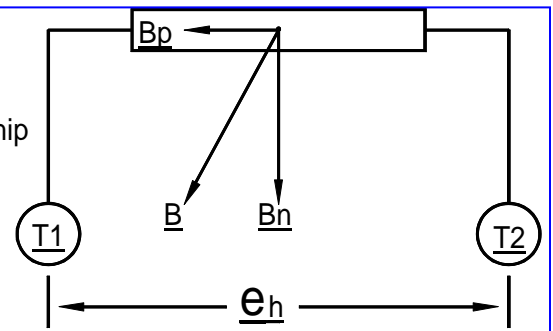


$$1) \quad e_h = K_g \cdot I \cdot B \sin \theta$$

(This is a slight variation in the expression of Lambert's Cosine Law). K_g is a constant determined by the Hall effect sensor and geometry. We

Figure 2 --

Vector Relationship



choose θ to equal zero in the plane of the Hall effect sensor to correspond with the way finished **hallpot®** rotation sensors are manufactured and specified. θ increases in a counter-clockwise direction to conform to convention. The output signal is represented by:

$$(2) \quad e_h = K_h \sin \theta$$

with K_h representing the combined values of K_g, I, and B. Note that e_h is a differential voltage across the Hall effect element.

An actual Hall effect sensor in a three lead package has an associated built-in integrated circuit which converts the differential signal to a single-ended signal in reference to the common terminal. This causes the output signal to be super-imposed on a quiescent voltage equal to about half of the power supply voltage, V_h, applied to the Hall effect sensor package. This quiescent voltage is designated as E_{bo}. The resulting signal voltage relationship, e_s, obtained from a **hallpot®** potentiometer is:

$$(3) \quad e_s = E_{bo} + E_p \sin \theta$$

E_{bo} is an intrinsic parameter of the Hall effect sensor chosen. E_p is a parameter that is controlled in the manufacturing process of the **hallpot®** potentiometer. Typical parameters are for actual devices. As applied to newer designs in equation form they are:

$$(4) \quad e_s = 2500 + 2400 \sin \theta, \text{ in millivolts}$$

RESPONSE OF A HALLPOT® POTENTIOMETER

Figure 3 is a representation of equation (4) which shows one complete cycle of a sine wave with a quiescent voltage as developed by a **hallpot®** potentiometer. There are two very nearly linear regions that cover an angular variation of +/- 30 degrees. A positive slope region exists around 0 degrees and a negative slope region exists around 180 degrees that facilitates inverting the response merely by rotating the body 180 degrees

Over a span of +/- 30 degrees, a sine wave is linear to within +/- 1%

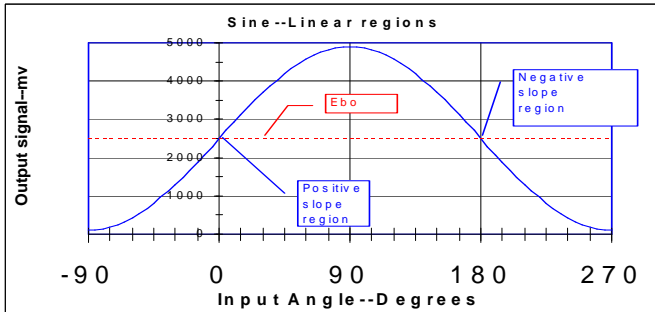


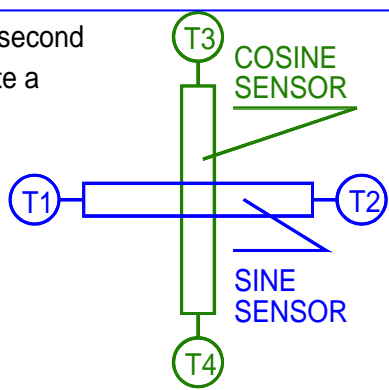
Figure 3 --- Positive and negative slope, linear regions around Ebo origin.

(around 0 and 180 degrees). Repeatability is even better. Note that in the peak and valley regions near +/- 90 degrees, a sine wave becomes insensitive. Also note that a sine function is bi-valued such that each voltage represents two different angles. This is not troublesome for measuring angles of less than +/- 60 degrees. As a result a single **hallpot® potentiometer** will give good measurements over a total operating angle of less than +/- 60 degree with +/- 30 to +/- 60 degrees being good ranges. This characteristic will fill the measurement and control functions needed in most systems, but not in all of them because some need to measure larger angles. There is a very good way to resolve this situation and enable accurate measurement through 360 degrees.

hallpot® RESOLVER

An added Hall effect sensor at right angles is shown in **Figure 4**. Response of this second sensor is $\sin(\theta+90)$ function and therefore is $\cos\theta$. The $\cos\theta$ function provides a steep slope to be used in each insensitive region of the $\sin\theta$ function. It has a different slope in these regions. Therefore it "resolves the ambiguity" and we call it the **sin-cos hallpot® RESOLVER**.

Figure 4- Addition of a second Hall sensor will generate a cosine signal



If the Ebo and Ep parameters are selected to be close in value, then **Figure 5** shows the resulting relationships between the two waveforms.

SOFTWARE DECODING

The **sin-cos hallpot® RESOLVER** is very easy and inexpensive to use in modern systems. No additional hardware is needed to excite the

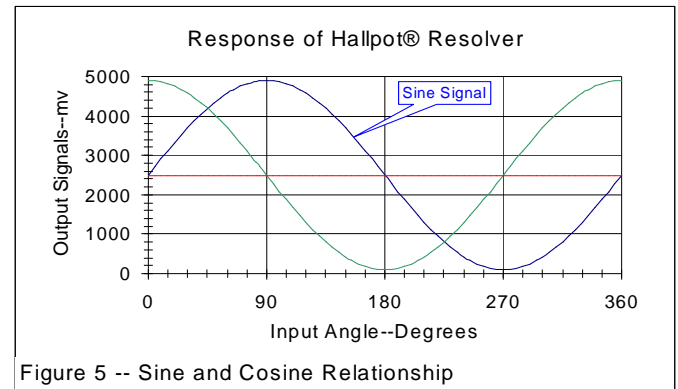


Figure 5 -- Sine and Cosine Relationship

device other than the application of +5.00 volt power. No additional hardware is normally needed to decode the position signal which can also provide velocity. Software that is normally associated with modern systems is used by most designers to provide the decoded outputs in the form of position and velocity.

APPLICATIONS

hallpot® Potentiometers are made to be used in a variety of machinery. The simplest versions use anodized aluminum journal bearings with molybdenum disulfide lubricants. These work very well to control dancer arms on such equipment as magnetic tape machines, film projectors, wire handling equipment or nearly any machine that has a controllable "loop" of material. **Journal bearing types** can withstand severe shock and short term excessive loads.

Ball bearing types provide much longer life and have a slightly better repeatability because there is no need for shaft clearance as required in journal bearings. They will tolerate continuous moderate side loads but will not tolerate as much shock as journal bearings.

Some versions have **built-in amplifiers** that produce rail-to rail output voltages over specified operating angles. These amplifiers permit the manufacture of identical interchangeable devices.

Severe pressure versions will operate while immersed in oil and subjected to **pressures exceeding 10,000 psi**. These are used to control hydrofoils, cameras, and manipulator arms on underwater vehicles.

Most models will operate over the temperature range of **-40 to +125 degrees C**.

They can be used to control **robotic arms** of numerous designs.

Some versions have **zero torque** and can be used in sensitive torque meters. These types can be used in **abrasive atmospheres** and will not wear or fail.

They can be used as manual inputs on control levers for machinery or on **joystick controls**. This includes measurement of **throttle position**.

Units without amplifiers can be used with **pulsed power to reduce current drain** to near 20 microamperes. Information describing Pulsed Operation is available from Elweco, Inc.

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