USING REDROCK™ TMR MAGNETIC SENSORS RR120/130 FOR SPEED AND DIRECTION ESTIMATION IN ROTATING SYSTEMS

Background

Speed and direction of rotation are the bases for measurement in applications such as utility metering, motor position and other indexing applications, where the turn of a shaft is directly related to a quantity to be measured. For instance, measurement of an amount of gas/liquid/electricity consumed, length of string paid out or reeled back in onto a spool, and distance travelled are all functions related to speed and direction. Magnetic sensing technology is now the most commonly employed method in these applications. However, electronic engineers have more factors than functionality to consider when designing their devices. The sensors chosen also must work within the constraints associated with these applications, e.g. available space, a requirement for a large air gap between the sensor and a rotating shaft, or demand for low to no current draw in battery-operated equipment. Additionally, designers must be cognizant of budgetary restrictions.

The RedRock™ TMR magnetic sensors from Coto Technology utilize Tunneling Magnetoresistance (TMR) technology to sense the magnetic field with high sensitivity. The RedRock™ RR120 and RR130 are two terminal unipolar devices in this line of products, operating at 2.7-3.6v and nanoamperes operating current. Their small size, high sensitivity and low current consumption make them ideal for speed and direction measurement applications.

Sensor Characteristics and Speed Measurement

The RedRock™ TMR magnetic sensors, RR120/130, are sensitive to magnetic fields in one direction, as shown in Figure 1a (from the product catalog), and in Figure 1b as it would relate to a bar magnet.

This becomes useful in a rotating application where a magnet mounted on the shaft sweeps its north and south magnetic field over the sensor once every turn, as shown in Figure 2a. The output of the RR120/130 becomes active (digital low)

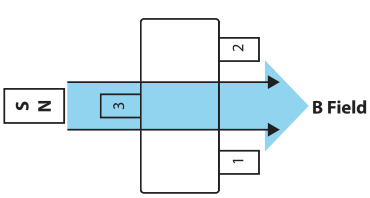

Figure 1a: Sensitive direction of RR120/130

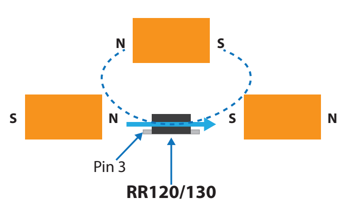

Figure 1b: Different Magnet positions that activate the RR120/RR130

whenever this magnetic field at the sensor exceeds the Operate Point B_{op} in the forward direction, and becomes inactive (digital high) when the field drops below the Release Point B_{rp}. As a result, in a rotating magnet arrangement, the output from the RR120/130 will cycle from high to low and then back to high for every rotation; this is shown in Figure 2b. Therefore, a measurement of the output cycle frequency directly provides a measurement of rotation speed.

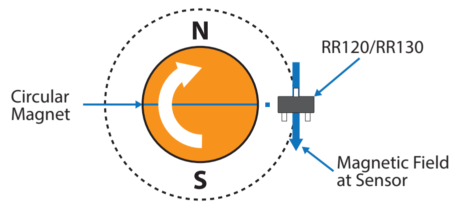

Figure 2a: RR120/130 with a circular magnet

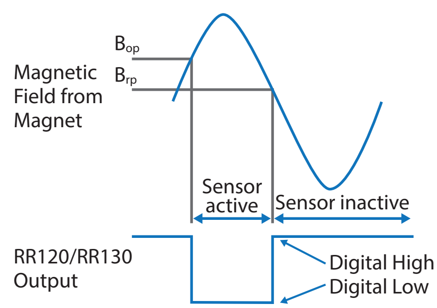

Figure 2b: Output from RR120/130 with rotation of circular magnet

However, since the field strength from a magnet diminishes with distance and the field direction varies depending on position, a careful analysis must be made of the field components at the sensor when positioning the sensor in an application. Figure 3 shows a representation of the sensor output activation region surrounding a round magnet, where the field strength satisfies $B>B_{op}$ and $B<B_{rp}$ for activation and deactivation.

The Figure 3 shows that when the sensor is mounted at radius A, (where the field is strong) it stays active for a longer period than it stays inactive. Conversely, when the sensor is mounted at a farther radius C, (where the field is weak) it stays inactive for a longer time than active. At positions outside the activation region (Field strength $<B_{op}$), there will be no output from the sensor. At radius B, output from the sensor is active and inactive for approximately the same time. This position (radius B) is ideal for these applications because it divides the rotation period into equal active and inactive periods, and allows the

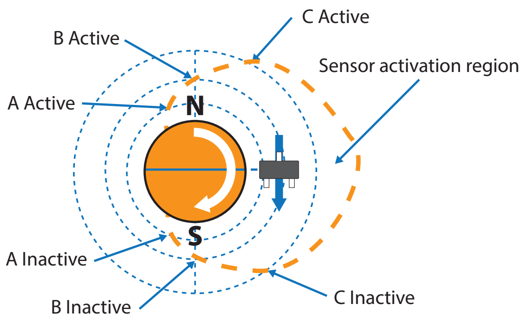

Figure 3: Activation region for RR120/130 around a circular magnet

greatest time for an external system to detect active and inactive periods by sampling the output signal at twice the sensor output signal frequency.

Step and Direction Sensing

In many applications, the direction of rotation changes; and it is necessary to either determine speed and direction or to keep track of net position. While speed can be estimated in the manner outlined earlier, a second sensor is generally employed to determine direction. The second sensor (S2) is usually positioned 90 degrees away from the first sensor (S1), as shown in Figure 4.

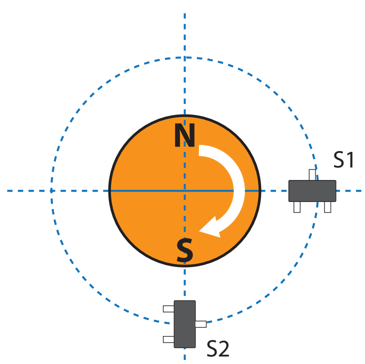

Figure 4: Two sensor arrangement for speed and direction measurement

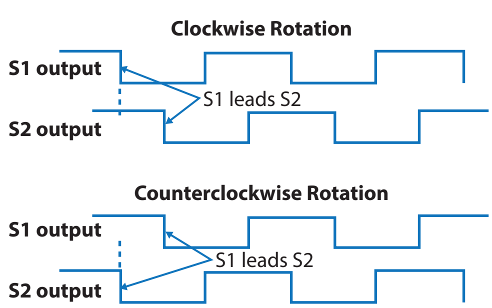

Figure 5: Output from sensors S1 and S2 with magnet rotation

In the arrangement shown in Figures 4 and 5, each time the output of either S1 or S2 changes, a step is registered. Rotation frequency and Revolutions Per Minute (RPM) is calculated as:

$$\text{Rotation frequency} = \frac{\text{Steps per second}}{4}$$

$$\text{Rotation RPM} = \frac{\text{Rotation frequency}}{60}$$

When the magnet rotates in the CW direction, it sweeps past S1, then past S2; and when it rotates CCW, it sweeps past S2 first, and then past S1. Figure 5 shows output signals from S1 and S2 for CW and CCW rotation. The direction of rotation determines whether S1 or S2 leads. During CW rotation, S1 is active first, then S2, i.e., S1 leads S2, and during CCW rotation, S2 leads S1. As the magnet turns through a full rotation, outputs of S1 and S2 go through high and low states as shown in Figure 6, for CW rotation, and in Figure 7 for CCW rotation.

Clockwise Rotation			
Angle	Step #	S1 Output	S2 Output
0	0	Low	High
90	1	Low	Low
180	2	High	Low
270	3	High	High

Figure 6: Output states from sensors S1, S2 with Clockwise rotation of magnet

Counterclockwise Rotation			
Angle	Step #	S1 Output	S2 Output
0	0	Low	High
90	1	High	High
180	2	High	Low
270	3	Low	Low

Figure 7: Output states from sensors S1, S2 with Counterclockwise rotation of magnet

From Figure 6 and 7, it is evident that output states from S1 and S2 for CCW rotations follow in reverse order when compared to CW rotation. Therefore, direction of rotation can be determined by comparing the current state of S1 and S2, to the previous state. For example, when the current state is Step 2, (S1=High, S2=Low) and the previous state was Step 1, (S1=Low, S2=Low) then the rotation is CW. However if the previous state was Step 3, (S1=High, S2=High) then the rotation is CCW. This lookup process is generally conducted in a digital state machine such as a Field Programmable Gate Array (FPGA), a Programmable Logic Device (PLD); or lookup may be implemented in a dedicated peripheral block in a microcontroller. In a simple system, a D-flip flop may be used to determine direction using S1 and S2 and speed using S1 (or S2), as shown in Figure 8.

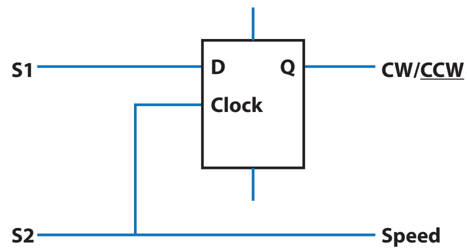

Figure 8: Simple Digital logic for Speed and Direction

In systems where a round magnet cannot be used, a magnet embedded in the rotating system can serve to measure speed and direction using sensors S1 and S2 positioned as shown in Figure 9. In this case, spacing between S1 and S2 must be such that active periods from both sensors will overlap for a period as the magnet sweeps by, as shown in Figure 10. Just as in the case of a round magnet, output from S1 leads in case of CW rotation, and output of S2 leads in case of CCW rotation. Speed of rotation can also be determined as equal to the frequency of S1 (or S2) output signal.

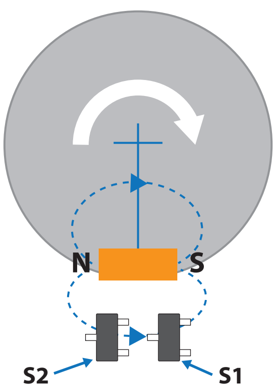

Figure 9: Sensor arrangement for magnet mounted on rotating arm

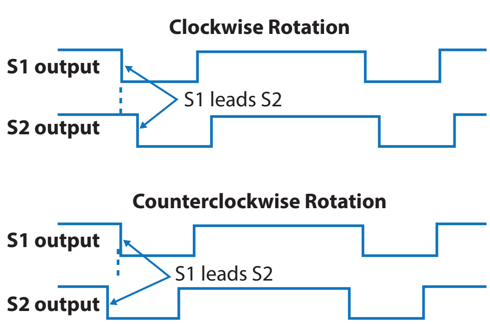

Figure 10: Output from sensors S1, S2 with magnet rotation

In more robust systems, where a high degree of reliability is needed to guard against counting spurious pulses on the line, a separate high-frequency oversampling clock is used to monitor the states of S1 and S2 at a much faster rate and register a valid output condition only after multiple clock cycles confirm the same states of S1 and S2. A valid change in S1 or S2 then corresponds to a step. This, in an application, may indicate a volume of gas/liquid moved, or a certain distance travelled. Speed and direction information may also be used by the microprocessor to generate appropriate feedback for correct system operation.

The lookup algorithm for speed and direction measurement can also be implemented in software within a microcontroller; however because of the time involved in the execution of multiple instructions, it may be used only in case of slower rotation systems. Figure 11 shows a simplified algorithm flowchart to keep track of step position (integrating step counting and direction monitoring) in a system where the shaft may rotate in CW or CCW direction.

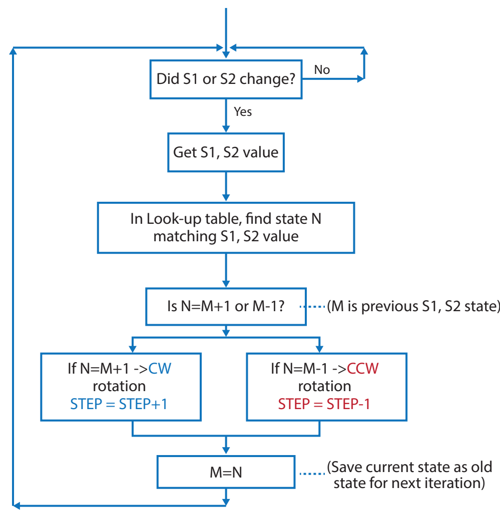

Figure 11: Flowchart for step (speed) and direction

Concluding Remarks

TMR devices such as the RedRock™ Magnetic Sensors, RR120 and RR130 from Coto Technology can be used effectively for speed and direction measurement in rotating systems. Coupled with their high sensitivity, the RedRock™ magnetic sensors can work with smaller magnets (reducing system cost) or at greater distance from the magnet. Additionally, with their very low current consumption, they can further reduce system cost by minimizing the size of the battery needed for a specified operating profile, or, for a given battery, extend its operational life.

For further application assistance, please contact Coto Technology's Sales and Applications Engineering team. (appsupport@cotorelay.com).

