element14 ESSENTIALS

Mechatronics II: Magnetic Encoders

Sponsored by VISHAY

1. Introduction

As robotics and automation systems are increasingly used in machines in manufacturing and other industries, various sensors are necessary to provide the required feedback for accurate and repeatable operation. For example, the accurate movement and position of a robotic arm relies on a position sensor's feedback information about the robotic arm's placement. This information is typically recorded by a rotary encoder. Encoders are sensing devices that convey the needed assessment about motion parameters such as speed, direction, distance, or position of the actuator. Various encoders are available, and they work with different motion types, communication, and detection methods. This learning module discusses the essentials of rotational absolute magnetic encoders, including their structure, operation, and applications.

2. Objectives

Upon completion of this module, you will be able to:

- Explain the basic concept of encoders
- Discuss the different type of encoders and their operation
- Understand Vishay's Rotational Absolute Magnetic RAMK series encoders
- Describe applications based on rotary encoders

3. Basic Concepts and Analysis

An encoder converts mechanical motion (linear or rotary) into an electrical signal in a digital code or pulse train using magnetic or optical sensing methods. This code contains information concerning position, velocity, and direction. Encoders are integrated into assembly robots, welding robots, automatic guided machines, and other industrial robots. Figure 1 shows an industrial robotic arm with a functional block diagram. Each joint in this robotic arm is a closed-loop motion system, with rotational absolute magnetic position and speed feedback sensors or encoders.

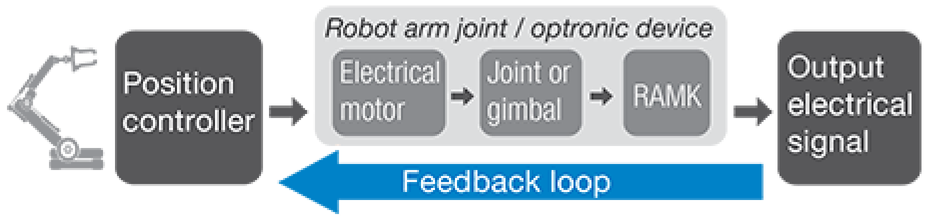

Figure 1: Industrial Robotic Arm and Encoder Functional Block Diagram

The classification of encoders is based on their detection methods and output format. Encoders are classified into two main groups: rotary encoders and linear encoders. A rotary encoder senses rotational motion and a linear encoder recognizes movement on a linear path. The scope of this module is limited to rotational (rotary) encoders.

- 3.1 Optical Encoders

An optical encoder consists of a light-emitting device (LED), photosensors, and a code disc (or code wheel) with slits in the radial direction. A convex lens collimates the light from the LED, transforming directionless diffused light into parallel beams (Figure 2). A code disc is attached to a rotating shaft, such as the shaft found in a motor. An optical pulse is generated when the light passes through the slits of the rotating code disc. A photosensor detects this optical pulse and converts it into an electrical signal. Because this method is blind to rotational direction changes, the code disc is designed to generate two pulses, which are distinguished by the quarter-cycle shift. These two pulses are termed Phase A and Phase B. Rotational direction depends on which one of the two pulses (A or B) rises first. A precise determination of the amount of rotation, even with rotational direction changes, is found by subtracting the pulse tally in reverse rotation.

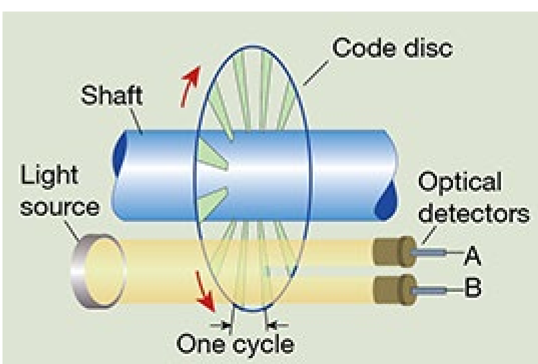

Figure 2: Optical Rotary Encoder (Image Source: Machine Design)

In the context of structure, optical encoders are classified into two types: a transmissive type, in which the code disc is positioned between the photosensor and light-emitting device (LED), and the reflective type, where the photosensor and LED are on the same side, with the code disc reflecting light.

Resolution can be improved by increasing the number of slits on the code disc. Optical encoders are typically used in servo control and other tasks that require precise motor control. The encoder's immunity to magnetic fields makes it suitable for use in applications with a strong magnetic field.

- 3.2 Magnetic Encoders

A primary magnetic encoder has a permanent magnet attached to the tip of a rotating body, such as a motor shaft, and a magnetic sensor called the Hall sensor. A Hall sensor takes advantage of the Hall Effect, the phenomenon where a transverse electric field is generated in a material carrying an electric current when the material is placed in a magnetic field that is perpendicular to the current. Magnetic encoders detect rotational position as the magnetic field changes, converting this information into electrical signals, which are then sent to the output. The Hall sensor is mounted on a PCB in a location where it can detect changes in the magnetic field caused by the movements of the permanent magnet on the shaft. When the permanent magnet rotates (with the shaft), the direction of the magnetic field changes; this change is detected by the Hall sensor and converted to a sine wave output with a frequency equal to the rotational speed of the shaft.

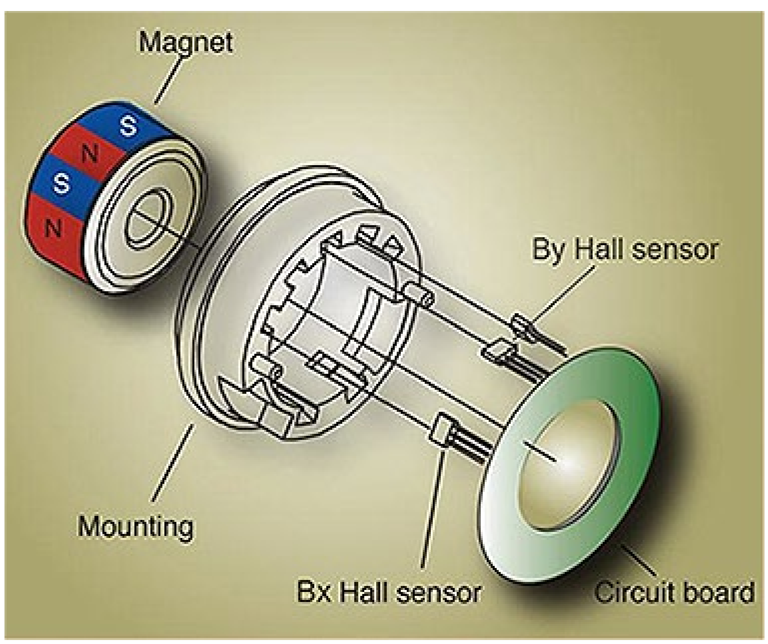

Figure 3: Magnetic Rotary Encoder (Image Source: Machine Design)

The rotation of the permanent magnet causes its magnetic field to rotate. The magnetic field near the rotation axis revolves with a constant strength. The Hall sensor converts this variation of magnetic field distribution into an electrical signal. Because the Hall sensor can only detect a magnetic field in a single direction, two Hall sensors, Bx and By, are required to compute the rotational position of the XY rotation plane. An analog-to-digital converter is used to convert the electrical signal from the Hall sensors into a digital signal. A trigonometric function is employed to convert the signals into angular information. Synthesizing the X-axis and Y-axis components orthogonally to each other forms a plane figure called a Lissajous waveform or Lissajous figure. Many oscilloscopes are able to display Lissajous figures.

- 3.3 Angular Error and Correction

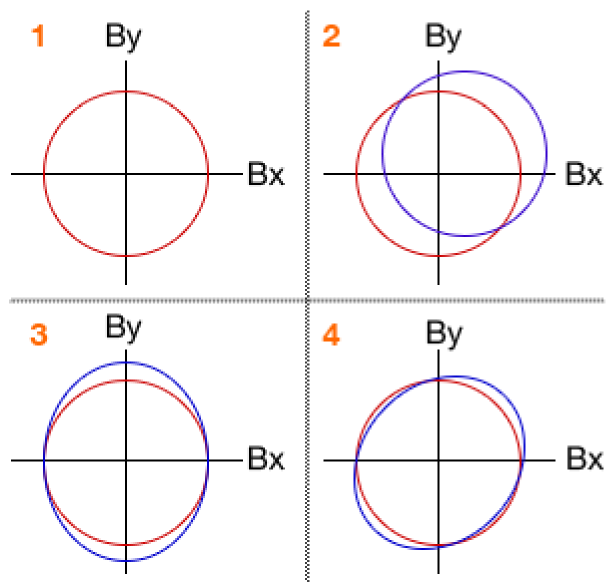

Figure 4: Lissajous Example – diagram 1 is for a theoretically perfect device; the three following diagrams show various angular errors compared to the perfect figure.

Lissajous figures can be used to reveal errors and anomalies. Absent any misalignment, a Lissajous figure will, in theory, be rendered as a perfect circle. A typical Lissajous figure, however, is not a perfect circle, indicating the presence of one or more angular errors. Figure 4 illustrates the Lissajous figures for an error-free sensor, as well as Lissajous figures representing sensors with various angular errors. Angular errors can occur for several reasons; for example, a misalignment of the Hall sensor could result in distortion in the input magnetic field. Additional causes of angular errors include stray magnetic fields, incorrect mounting inclination (or tilt) of the Hall sensor, and the production deviations in the Hall sensor or surrounding electronic components.

There are various techniques to reduce the effects of angular errors. The Hall sensor can be placed at the center of a ring magnet, shielding it from stray magnetic fields. Additionally, the input magnetic field can be strengthened, increasing the signal-to-noise ratio, thus reducing unwanted effects due to noise generated from the Hall sensor.

Other types of detection method-based encoders are the mechanical/contact type and the electromagnetic induction type. A contact-type encoder uses a variable resistor (potentiometer) to detect the rotational position, showing a change in resistance proportional to the rotation angle. The electromagnetic induction method reads changes in the magnetic field generated between the induction coil and the fixed coil attached to the motor shaft.

- 3.4 Incremental and Absolute Type Encoders

A rotary encoder generates output for rotation and angular information in two distinct ways: relative angle or absolute angle. The output signal format of each encoder type differs: relative angle encoders indicate the number of angles that passed before and after moving, whereas absolute angle encoders show the number of completed degrees from the initial position.

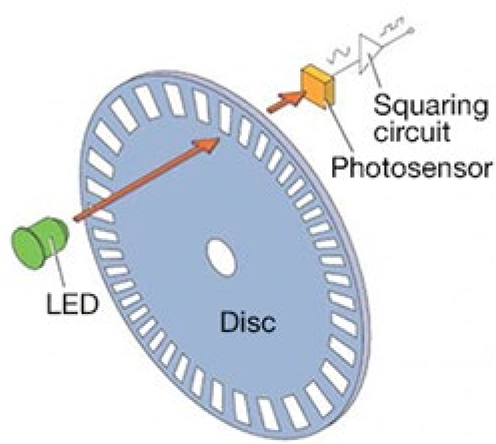

Figure 5: Incremental Type Rotary Encoder (Image Source: Machine Design)

Incremental encoders detect movement from one position to the next and generate output in the digital serial pulse train according to the rotation. The incremental technique has a single row of slits, as shown in Figure 5, and produces serial pulse output.

The disk's movement (angular change) is the number of pulses. With a four-slit arranged row, there are four pulses per rotation. One pulse rotates 360° / 4 = 90°. If there are eight slits, a single pulse rotates 360° / 8 = 45°. A larger number of slits mean a higher resolution of angular change and a finer representation of movement.

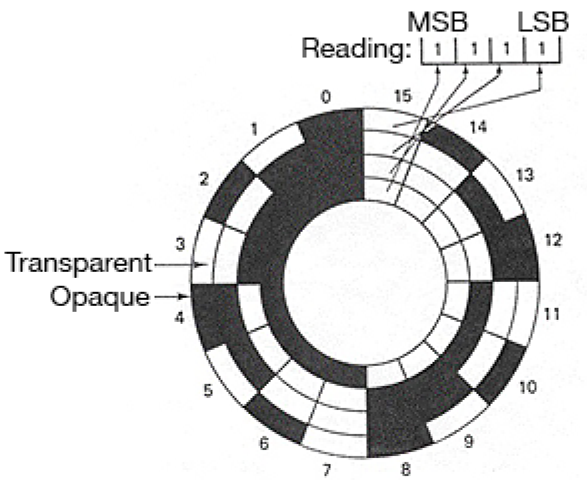

Figure 6: Absolute Rotary Encoder with 4 Rows of Slits (Image Source: K. Craig, NYU Engineering / Analog IC Tips)

Absolute Angle Detection Encoders detect the distance from the home position. This type of encoder outputs current absolute angle or an analog voltage in digital serial code in response to microcomputer instructions. This output method is called an absolute method.

An absolute method consists of multiple rows. The presence of slits in four rows implies an absolute possible 16 angles of position, from 0000 to 1111 in a binary number. If the row of slits doubles to eight, the absolute positions of 256 different angles can be recorded (from 00000000 to 11111111). With the increase in the rows of slits, the angle change resolution also increases, permitting a more precise representation of the quantum of movement.

- 3.5 Vishay's Robotic Magnetic Encoder

Vishay offers various encoders for robotics applications, including the Rotational Absolute Magnetic Kit Encoder (RAMK) series, which converts a mechanical angular position into a digital signal with high precision. Based on Hall-Effect magnetic technology, these position sensors offer better performance, accuracy, and resolution than traditional Hall Effect sensors for industrial robotics and other applications. Contactless technology enables greater than 13-bit accuracy, greater than 16-bit repeatability, and 19-bit resolution, while maintaining sturdiness against vibration, mechanical shock, external magnetic fields, moisture, airborne pollution, and temperature changes. The RAMK series has an electrical angle of 360° and functions over a –40°C to +85°C temperature range, with greater maximum temperatures available.

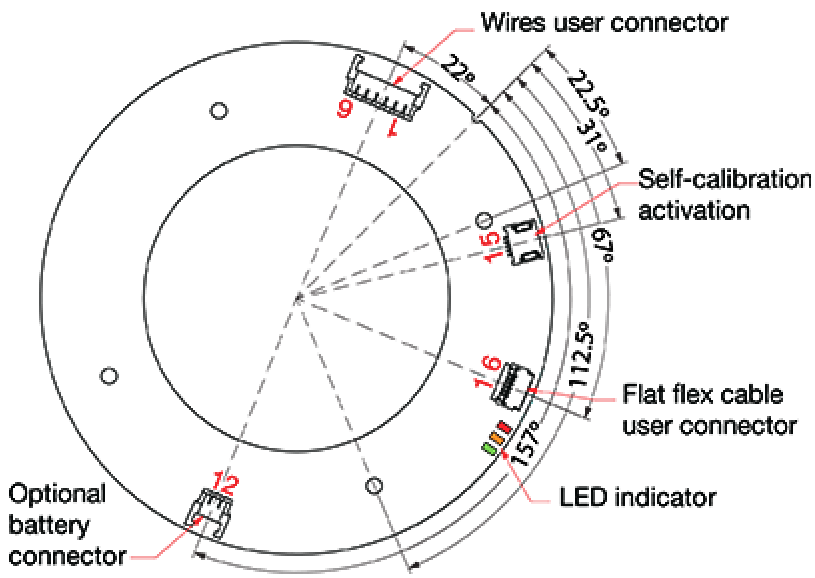

Figure 7: RAMK Series Encoder patented design and User Connections

The RAMK060's Rotor + Stator kit, with its off-axis design, slim ~6.5 mm profile, and lightweight (< 55 g), make it suited for applications where little space is available. Its accuracy enables easy detection of angular positions. It has a 60 mm outside diameter and a 25 mm inner diameter. Several multi-turn variants are available. These encoders are available in SPI, SSI, or Biss-C output signals. The main advantages of this series are self-calibration for mechanical misalignment compensation, integrated self-monitoring, and last absolute position memorization before power-off. RAMK060M11319FB661, RAMK060M11319JB663, and RAMK060M11319LB659 are some examples of this series.

4. Applications

Encoders are appropriate for applications with repetitive and precise movements. Examples include arm joints for collaborative and industrial robots, machine tools for printing, textile manufacturing, steering wheels for automated vehicles, and milling. Here we will discuss how encoders fit into some of these applications.

Collaborative Robot Arm

Robots assemble, shift, weld, and paint heavy payloads. They need enormous, expensive, and complex systems to ensure system safety. Collaborative robots are now a part of the human environment, assisting operators by performing heavy lifting tasks, supporting precision movements, and substituting for humans in regular, repeatable tasks with more consistency and accuracy.

A Collaborative Robot Arm (Cobot) is a robot intended for direct human-robot interaction inside a shared space where humans and robots work closely together. They are composed of a series of rotational joints, each driven by a motor, and precision controlled using encoder feedback. High-resolution rotary encoders enable better detection and granular control. The RAMK060 series magnetic encoder is an ideal solution when it comes to better detection and minute control. Figure 8 illustrates the assembly of this encoder with a motor. Cobots have many uses, including information robots in public spaces, logistics robots that transport materials within a building, and industrial robots that help people move heavy parts or operate machine feeding or assembly operations.

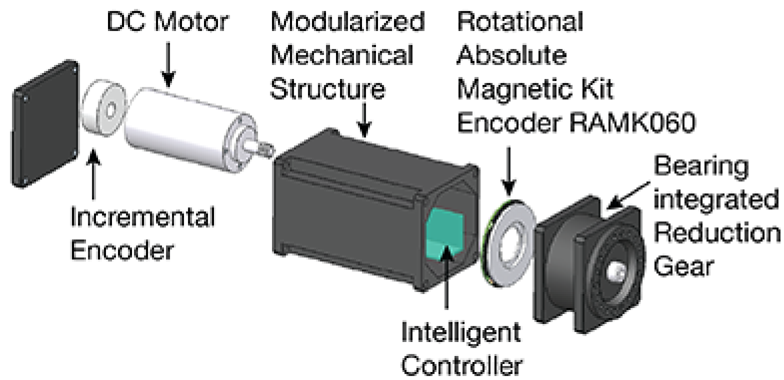

Figure 8: RAMK060 Magnetic Encoder assembly with DC Motor on Joint

Automated Guided Vehicles

Automated guided vehicles (AGVs), also termed autonomous mobile robots (AMRs), are applications that require accurate and high-resolution rotary encoders. These are self-driven transport systems used for heavy-duty tasks managed by forklifts, conveyor systems, or manual carts. AGVs perform repetitive tasks, such as moving large quantities of material in various applications in the automotive industry, logistics, smart warehouses, food and beverage, and pharmaceutical industries. An encoder must provide accurate position information for the AGV to determine its exact position when loading, unloading, and stacking the material. The precise automation of wheel steering controls in AGVs is enabled by the encoder's accurate feedback about the wheel’s angular position. An operator-adjusted AGV wastes time, resulting in low efficiency and affecting the entire manufacturing process.

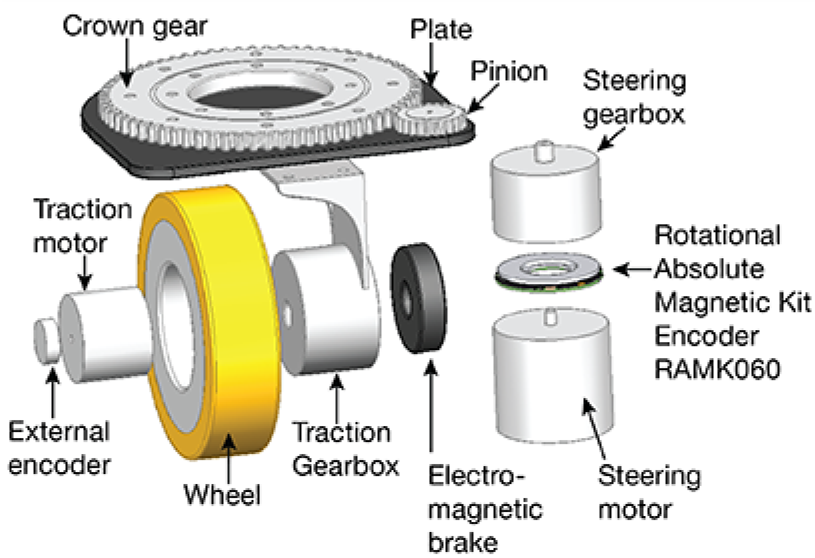

Figure 9: Assembly with RAMK060 Encoder for Wheel Steering Control

AGVs operating in a plant or warehouse inevitably experience shocks and impacts, due to harsh or cluttered environments. The selected encoder must be highly resistant to shock and vibration, and capable of maintaining its accuracy in a complicated environment. Vishay's RAMK060 series encoders can achieve all of these positional feedback requirements, as they are accurate with a precise resolution, plug and play, easy to mount, and have high customization capability. They are immune to moisture, pollution, temperature, and external magnetic fields, and are resistant to shocks and vibrations. Figure 9 shows an assembly with an RAMK060 encoder to control wheel steering.

5. Conclusion

As industries rapidly evolve towards automation, encoders that control the motion of machinery must become more accurate and reliable. Rotary encoders are a crucial part of the feedback system in the motors of arms, control wheels, and any type of machinery with rotating parts. Rotary encoders use several technologies, including optical and magnetic, and can be designed to the accuracy and precision needed to support automation and robotics. Vishay's RAMK series of magnetic encoders delivers accuracy and precision in a compact and durable package, and is well suited for use in modern day machinery.

Glossary

- **Absolute Position:** A position value determined by reading the distance away from the home position.

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- **Biss:** A bidirectional/serial/synchronous protocol based on a real-time interface designed to work in B mode and C mode (continuous mode). It enables secure serial digital communication between the controller, sensor, and actuator.

- **Hall Sensor:** A magnetic sensor that works based on the Hall Effect. The principle of the Hall Effect states that when a current-carrying conductor or a semiconductor is introduced to a perpendicular magnetic field, a voltage can be measured at the right angle to the current path.

- **Precision:** Describes the repeatability of measurements. It is the amount that successive measurements differ from each other.

- **Repeatability:** A measurement of how consistently an encoder (or any system) can return to the same commanded position.

- **Resolution:** The number of measuring segments in one revolution of an encoder, commonly measured in pulses per revolution (PPR) for incremental encoders and bits for absolute encoders.

- **SPI (Serial Peripheral Interface):** A synchronous serial com munication interface specification used for short-distance communication.

- **SSI (Serial Synchronous Interface):** A serial interface standard for industrial applications between a master (e.g. controller) and a slave (e.g. sensor). SSI is differential, simplex, and non-multiplexed and relies on a time-out to frame the data.

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