Angular Position Sensor for Angular Position Tracking

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***Abstract*—This paper describes a brief summary of similar devices and researches about the angular position tracking sensor of an antenna. Also describes several methods for the sensor with the advantages and disadvantage of each method. As for the methods of the sensor, this paper describes several types of encoders that can be used in this application. This paper describes the most suitable method to the device which can be used to measure the angular position of an antenna among all pre proposed methods**.

I. INTRODUCTION

Angular position tracking of an antenna is very important for antenna radiation pattern measurements. Angular position tracking of an antenna is also used to find the better pointing direction of an antenna. It is most important in military purposes, satellite tracking antennas and navigational purposes etc.

The rotary encoders are the main type of sensors which can be used to find the angular position of an antenna. This is an electro-mechanical device which converts the angular position of an antenna to a digital or analog code [1]. Encoders also used in many applications which require very precise data like robotics, rotating radar platforms and photographic lenses.

To measure the angular position of an antenna, a rotating table with a suitable encoder can be used. When the table is rotating, the encoder gives a digital or analog signal as an output. Then, the correct resolution can be obtained using suitable computer programming algorithm.

II. LITERATURE REVIEW

There are variety of angular position measuring sensors can be seen among the modern market. This section describes such commercial sensors and their operational method, key features, advantages and also their disadvantages.

"Rotary Inductive Encoder Kit ID1102C" is an example to an inductive encoder which can be commonly seen in today's market [7]. The brand name of this product is "POSIC". "POSIC" is a privately-owned company which specialized in miniature inductive encoder kits. This product is based on the "coil-on-chip" technology. There are some advance features of this product.

- Highly miniaturized: 6.8 x 9 x 1 mm
- Robust against oil grease, liquids and dust particles.
- Programmable resolution and max speed.
- Optional with holder, cable and connector.

The ID1102C incremental encoder kit consists of an encoder and a code wheel. The code wheel is a PCB with passive copper strips. The resolution and the maximum speed of the ID1102C encoder are user-programmable or can be programmed ex-factory. That can be illustrated as the main important key specification of this sensors. The range of the speed of this encoder is 0 to 23000 RPM. Airgap vary from 0.1 to 0.6 mm. The operating temperature range of this product is from -20℃ to 100℃. The unit price of this product is $127.74.

"Rotary position sensor RCS2100" is also an angular position measuring sensor [8]. This is a magnetic angular rotary encoder. This device is fully designed and manufactured by ATEK Research and development team in Turkey. Magnetic technology has been used in this product. This is a high-precision non-contact measurement device. This device has a 0.5% accuracy. Due to the zero mechanical friction, this device has an extremely long durability. This device is suitable for outdoor uses with IP67 protected Ratio metric. Different measurement range options can be seen in this device from 0° .30° to 0°... 360° in 10° increments. This device gives a noise reduced output signal. The response frequency of this device is 250Hz. Hall effect (also known as the magnetic field measuring principle), allows the sensor to be more durable against harsh environmental condition such as dirt, humid and dust etc. This consist with stainless steel shaft and robust Aluminum body. The operating temperature range of this product is from -

25℃ to 85℃.

There is a patent to an Apparatus which is used for measuring and indicating the angular position of an antenna [9]. This patent describes about a device that use special gear arrangement in order to increase the resolution of the angular indication and to decrease the electrical error of a synchro transmitter. There, the synchro converts the amplified mechanical indication to an electrical position signal that is transmitted to position indicating apparatus. The gear arrangement steps up or amplifies the angular position of the antenna. The gear arrangement designed to substantially minimize the combined mechanical error which occur due to the gear arrangement, electrical error which occur due to the synchro and the backlash between the gears.

In modern market there's plenty of varieties of optical encoders. Normally, they have a simple technology than inductive encoders. POSITAL is a sensor manufacturer for motion control and safety assurance systems. "OCD-S401G-0016-S060-PRQ" is an absolute rotary encoder which was manufactured by this company [10]. This is a 16-bit optical rotary encoder. The accuracy of this encoder is ±0.0220° for (14 – 16 bit) and ±0.0439° for (≤13 bit). There is a Gray Scale in this encoder to measure the angular position. The power consumption of this device is less than 1.5W and the start-up time is less than 1s. Those are very useful features in commercial industries. Reverse polarity protection and short circuit protection can be found in this product. As environmental specification of this product, this product has IP65 protection class for shaft and the housing. The operating temperature range of this sensor is from -40℃ to 85℃. The friction torque is less than 3Ncm at 20℃. This is a small product. So, the weight of this product is almost 285g.

III. METHODS

A rotary encoder is a type of position sensor which is used to determine the angular position of a rotating shaft. It generates an electrical signal that is analog or digital according to the rotation movement. Rotary encoders are classified by the type of output signal or by the sensing technology.

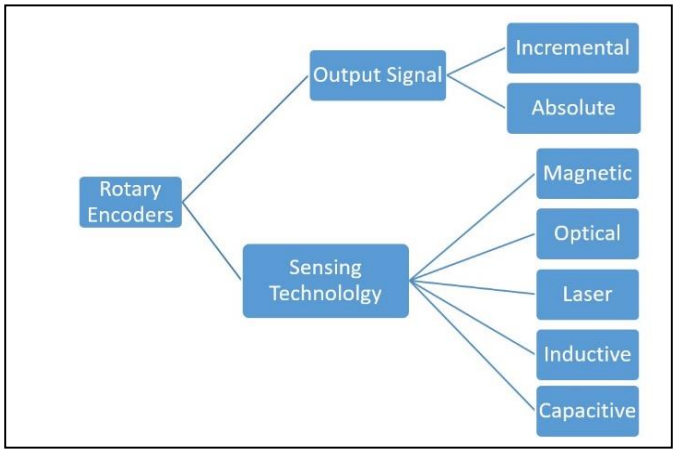

Fig. 1. Classifications of the rotary encoders

A. INCREMENTAL ENCODER

Incremental encoders are one of the most commonly used rotary encoders that converts the angular motion or the position of a shaft into an analog or digital code to identify the position or motion of a rotating shaft. These type of encoders are used in positioning and motor speed feedback applications, which includes servo/light industrial or heavy-duty applications. Since there are few sensors involved, the systems of the incremental encoders are both simple and inexpensive. Also, it provides excellent speed and distance feedback.

- Heavy Duty: Demanding environment with a high probability of contaminants and moisture, higher temperature, shock, and vibration requirements as seen in pulp, paper, steel, and wood mills.
- Industrial Duty: Factory operating environment which requires standard IP ratings, moderate shock, vibration, and temperature specs as seen in food and beverage, textile, generally factory automation plants.
- Light Duty/Servo: Controlled environment with high accuracy and temperature requirements such as robotics, electronics, and semiconductors.

For an incremental optical encoder, an optical sensor detects light as it passes through a marked disc. That provides a specified amount of pulses in one rotation of the encoder. The output can be a single line of pulses (an "A" channel) or two lines of pulses (an "A" and "B" channel) that are offset in order to determine rotation. This phasing between the two signals is called quadrature(90 degrees). If the two output signals(A & B) have opposite values when the signal(A) changes from high to low or low to high each time, the encoder has a clockwise rotation. Vice versa, If the two output signals(A & B) have equal values when the signal(A) changes from high to low or low to high each time, the encoder has a counterclockwise rotation. By using those values, the encoder determines the position and the rotation direction. Incremental encoders provide changing information only.

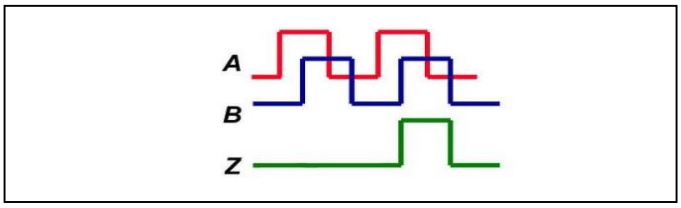

Fig. 2. Pulses of a rotary encoder

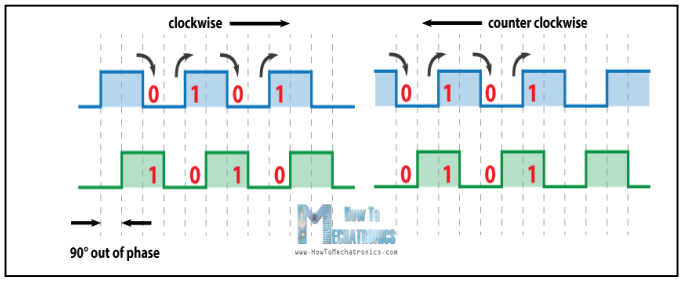

Fig. 3. Pulse patterns when table rotates clockwise and anticlockwise

B. ABSOLUTE ENCODER

Absolute encoders are feedback devices that provide speed, position information by outputting a digital bit in relation to motion. This type of encoders output unique bits for each position. The following advantages can be taken by using absolute encoder instead of incremental encoder.

- Higher overall resolution
- Better startup performance because of low homing (initial positing) time
- Accurate motion detection along multiple axes
- Multiple output protocols for better electronics integration
- Better recovery from system or power failures

In an absolute optical rotary encoder, a slotted code disc on a shaft is used with LEDs and photoelectric sensors. As the disc turns with the shaft, the encoder produces unique binary code for each configuration along the disc. This binary code is used to determine the exact position. This type of encoders measures actual position by generating a stream of unique digital codes that represent the encoder's actual position and therefore do not require an index or reference point. This also provides absolute encoders an advantage in applications returning to a home position may present issues in the event of a power loss. This type of measurement is preferred in application requiring a great degree of certainty such as when safety is a primary concern. Because the encoder knows its definitive position at all time. Absolute encoders can be "single-turn" or "multi-turn". Single-turn encoders are used for measurements of short distances. Multi-turn encoders would be more suitable for longer distances and more complex positioning requirements.

Code disc can be designed in a special method called "Gray Scale". The encoders which are designed in this method, are called Gray code encoders or Reflected binary code encoders. These encoders produce only a single bit change at each step, which can reduce encoder communication errors. When the data is in binary format, multiple bits may change per step and in some instances, all bits may change between each read. In high speed applications, this may cause errors or complicated programming. Gray code reduces the bit change to only one data bit per measuring step at a time.

Decimal	Binary	Gray Code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111
11	1011	1110
12	1100	1010
13	1101	1011
14	1110	1001
15	1111	1000

Fig. 4. Binary format and Gray code format

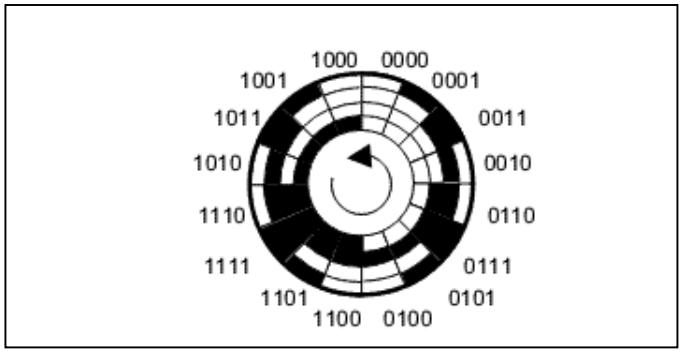

Fig. 5. Gray code

C. OPTICAL ENCODER

Optical encoders interpret data in pulses of light which can be used to determine such things as position, direction, and velocity. The shaft rotates a disc with opaque segments that represent a particular pattern. The encoder creates an electrical signal by operating LEDs, LDRs, and that pattern. By analyzing that signal rotary encoders can determine the movement of an object for rotary or shaft applications while determining the exact position in linear functions. Optical encoders are used in various applications such as printers, CNC milling machines, and robotics. Optical encoders may be "Absolute" or "Incremental" with respect to the application purpose. Incremental encoder can be designed easily than absolute encoder but there are more advance features in absolute encoders. The major advantage of the optical encoder is the absence of contact in the sensor system with the rotating shaft, which helps preventing the wear and it's therefore quite convenient in terms of costs, since it doesn't require maintenance and has a potentially infinite durability.

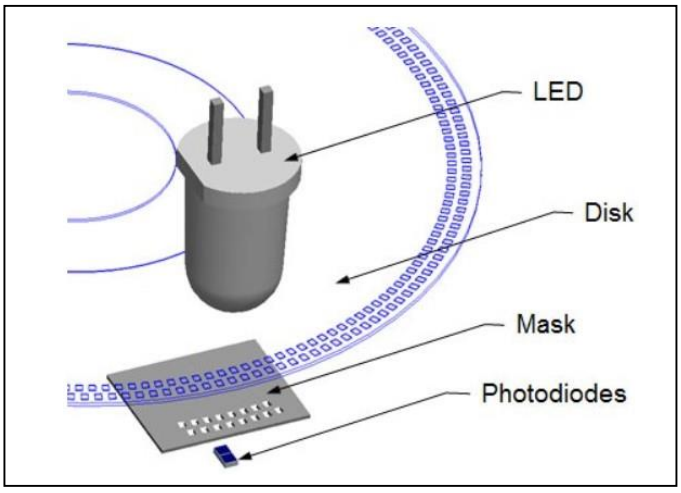

Fig. 6. Working pinciple of a optical encoder

D. MAGNETIC ENCODER

Magnetic encoders employ a signal detection system based on the variation of the magnetic flux generated by a magnet (one or more pole pairs) placed in rotation in front of a sensor, usually fixed to the encoder's shaft. Magnetic rotary encoders have three main parts. They are disk, sensor and conducting

circuit. The resolution of magnetic rotary is determined by the number of magnetic poles around the disk and the number of sensors as shown in the Fig.07. The variation of the magnetic field is sampled by the sensor and converted into a sinusoidal electric pulse, which determines the position; the magnetic technology could be of two types: on axis or off axis.

Magnetic encoders detect the rotational position information by using the changes of the magnetic field. Normally simple magnetic encoder consists of a permanent magnet and a magnetic sensor. As the primary design of a magnetic encoder, the permanent magnet is attached to the tip of a rotating body such as a motor shaft as shown in Fig.08 and the magnetic sensor attached to the printed circuit board(PCB).

The main benefit of the magnetic technology is the absence of contact in the detection system, which helps preventing the wear and it's therefore quite convenient in terms of costs, since it doesn't require maintenance and has a potentially infinite durability. Also it is suitable for environments with a lot of dust, oil, and water. Magnetic encoders are particularly suitable for heavy duty applications that require high robustness, speed and a wide range of operating temperature, and they ensure, at the same time, an excellent reliability and high precision in the generation of signals. Since it has a very simple structure, maintenance of the encoder is convenient. By the way, complicity of the manufacturing process of the sensor, can be illustrated as a major disadvantage.

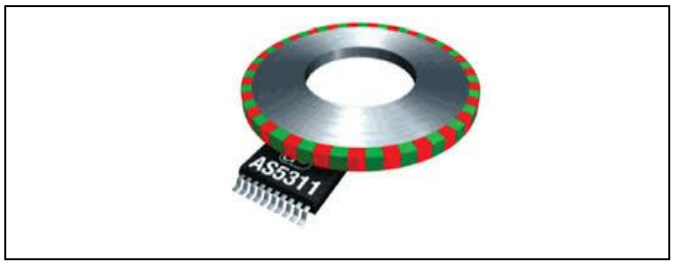

Fig. 7. Rotary magnetic encoder

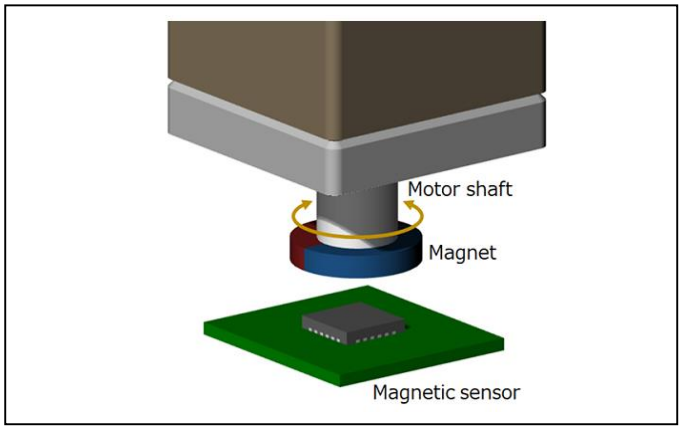

Fig. 8. Magnetic encoder diagram

E. LASER ENCODER

Laser encoders or displacement interferometers are often used in applications where the highest levels of accuracy are required. A laser encoder includes compact detector that holds the interferometer, reference-path optics, fringe detector, and beam steerer. Fiber optics deliver laser light from a single source to detectors measuring different axes, which simplifies the optical path and facilitates alignment and installation. Only one external optic is needed. Placing the laser source outside the detector also saves space and keeps heat away from the measurement axis to reduce thermal drift. The laser beam is a frequency-stabilized laser beam such that the laser beam that is reflected back to the heterodyning detector is frequency-shifted by the movement of the moving base relative to the fixed base so that the amount of movement (either rotational or linear) of the moving base can be accurately determined.

The laser encoders can be used in conjunction with a high energy resolution monochromator for accurately determining the rotational movement of an arm in the monochromator or can be used in conjunction with a closed looped motion controller for providing feedback on the rotational displacement of the arm of the monochromator so that the arm can be accurately positioned.

There are few benefits to be described in these kind of encoders. As the main benefit, the end retroreflector enables the encoder to be readily self-aligned such that the alignment time is substantially reduced and the three-dimensional optical path configuration results in a compact and integrated optical design which optimizes the system's anti-vibration performance. Intrinsically high resolution, minimized errors, capable of working in harsh environments can be determined as the other major advantages.

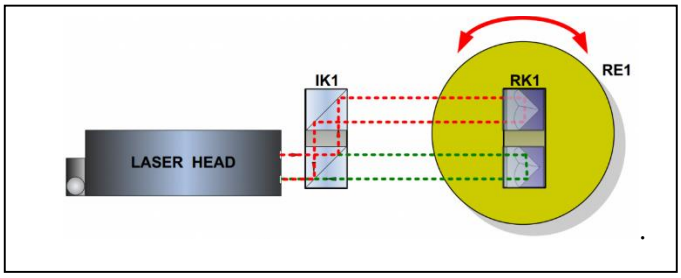

Fig. 9. Working principle of Laser encoder

F. MECHANICAL ENCODER

Mechanical rotary encoders, also called shaft encoders, are electro-mechanical devices that convert the angular motions (movement around fixed points) of rotary shafts into either analogue or digital signals.

A metal disc containing a set of concentric rings of openings is fixed to an insulating disc, which is rigidly fixed to the shaft. A row of sliding contacts is fixed to a stationary object so that each contact wipes against the metal disc at a different distance from the shaft. As the disc rotates with the shaft, some of the

contacts touch metal, while others fall in the gaps where the metal has been cut out. The metal sheet is connected to a source of electric current, and each contact is connected to a separate electrical sensor. The metal pattern is designed so that each possible position of the axle creates a unique binary code in which some of the contacts are connected to the current source and others are not.

One of the mechanical encoder methods can be shown as "Contact Type Mechanical Encoders" and this method detects the rotational position with a variable resistor whose electrical resistance changes in proportion to the rotation angle. When the slider moves on resistors, the resistance value of the potentiometer changes in proportion to the moving distance of the slider.

Mechanical encoders are not common in commercial activities because of this brush-type contacts are susceptible to wear. So, they can be found in low-speed applications such as manual volume or tuning controls in a radio receiver.

G. INDUCTIVE ENCODER

An inductive encoder is a non-contact sensing technology that works using transformer principles to measure position or speed. These encoders are very high reliability in extreme environments. They are resilience to dirt water and condensation. There is no need to periodic replacements or service and maintenance because of there are no contacting and delicate or wearing parts. These encoders can make very small and low weightily. So, it is easy to customization. Inductive encoders can use in large temperature range.

Inductive encoders are used in medical, industrial, defense applications and aerospace applications. Normally, inductive encoders are used in medical applications like CT scanners and Robots because they fit nicely in general automation systems and work well with different types of servo motors.

The working principle of inductive encoders are little more complicated than other encoders. Therefore, there are only few companies got the technology to produce this encoder. Therefore, this is not easy to manufacture like other encoders.

IV. SPECIFICATONS

- Increment per 200 step motor = 1.8°
- Advance per 1 revolution on input = 360'
- Gear ratio 1:1 latency
- Travel 0-360°+
- Rotary table diameter 6 inch
- Device;
  length = 12 inch, width = 8 inch, height = 6 inch
- Device weight 2.5 kg
- Maximum input torque 50 oz-in
- Maximum weight of antenna 2 Kg
- Operating temperature 0 to 180°F (-18 to 82°C)

The turning table is rotated by a step motor with an increment of 1.8° with 200 steps that advance 360° in one revolution. 1.8° step sized step motors are commercially available in market and also that step size is much suitable for the desire application. The max input torque of the table is around 50 oz-in. Due to the torque deviation and latency problems, 1:1 gear ratio has been applied in the system. Rotary table is a planar circular disk with a diameter of 6 inches. Rotary table disk has been considered as to be a light weight and robust disk because the disk is driven by a small motor with limited torque value and the disk also have to carry up the antenna that will be used in the project. The max weight of the antenna that can be used in this table is around 2.5 kg and that peak value can be increased on future desires. Since a gray scale has been added to measure the angular position, 0° to 180° Fahrenheit can be allowed as the operating temperature of the sensor.

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