THEORY ANALYSIS OF A NEW ABSOLUTE POSITION SENSOR BASED ON ELECTROMAGNETISM

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Abstract

Rotating angle of joint is an important factor in control field of robot arm. In the paper, a new sensor to test the absolute rotating angle of robot arm joints is designed. Firstly, structure of the magnetic field emitter is presented. Secondly, the generating process of signals sine and cosine is introduced. Then, working principle of the senor is described. At last, a new encoder is designed. The emitter working together with the encoder can test the absolute rotating angle and the calculation process is given in the paper. At the end of the paper, advantages of the sensor are listed.

1 Introduction

Future automotive electronic systems will further improve driver safety, as well as comfort, engine efficiency and performance. The strongly increasing application of these systems will create a strong demand for reliable, high performance and low cost sensors, leading to the development of new technologies[1]. Many technologies can be applied to position sensors such as the simple resistive potentiometer, the capacitive effect systems, the optical effect sensors, optical sensors and magnetic sensors. Comparing with these sensors, magnetic sensors offer several key advantages. Nowadays, magnetic field sensors are widely used in many applications to control rotational speed, linear or angular position[2]. When developing sensors for measuring angular signal in miniature systems, it becomes obvious that the basic sensor has many limitations and imperfections[3].In some domains, they compete against for the measurement and the accuracy ranges. Moreover, their great advantage with respect to the preceding sensors is their ability to work under severe conditions without altering their performances. In fact, they are insensitive to non magnetic dust, humidity and vibrations. They are particularly robust[4]. Therefore, in automation technology, magnetic sensors are used in process control, robot drives and machine tools[5, 6].

Magnetic materials can be divided into diamagnetic materials, paramagnetic materials and ferromagnetic materials. Many everyday materials, e.g., water, wood, glass, and polyethylene, as well as many elements, e.g., H2, N2, Ar, Cu, Ag, Pb are diamagnetic. When a diamagnetic material is placed in an external magnetic field, it becomes magnetized and it will be opposite to the direction of magnetic field. If the field is removed the magnetization of a diamagnetic substance vanishes. Besides, diamagnetism is essentially independent of temperature[7].

In the paper， main structure of the emitter is analyzed. According to the magnetic theory, the magnetic field will be affected if some magnetic material such as copper is moved into it. Based on this, a copper bar is designed and under its effect, regulated signals can be generated. Then we illustrate the generating process of the output signals—sin+, sin-, cos+ and cos-. Therefore, an encoder comprised with many copper bars can be designed to generate a group of signals. In the paper, an encoder which has 170 copper bars in the outer circle and 169 copper bars in the inner circle is designed according to the dimension of the robot arm. To be easy understood, we take the encoder which comprised with 9 copper bars in the outer circle and 8 copper bars in the inner circle for example to illustrate working principle of the sensor. At last, advantages of the sensor are listed to show application field of the sensor.

2 Main structure of the emitter

The main structure of the emitter can be seen as Fig.1.

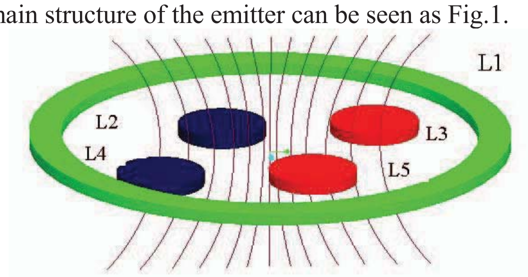

Figure 1. The main structure of the emitter

In the Figure 1, there are five windings which are L1, L2, L3, L4 and L5. L1 is the main winding which is injected into current. According to the law of electromagnetic induction, there will be a magnetic field around L1. L2, L3, L4 and L5 have the same dimension and are comprised with the same coil wine. Besides, L2 and L3, L4 and L5 have the same position relative to the main winding L1. Therefore, the voltage affected by L1 in L2, L3, L4 and L5 are equal. We connect L2 and L3 together, but they are opposite rotation. It is same to L4 and L5. Therefore, the output voltage of groups L2-L3 and L4-L5 are zeros. However, when there is a disturbance, for example, if we place a magnetic object under the windings, the equality will be disturbed. The output voltages of these groups are not equal to zero any more.

According to the quality of the diamagnetic material, it can generate magnetic field under the external magnetic field which has the opposite orientation compared with the original one. In the paper, we place a copper bar under the windings, some regulate signals will be generated by these groups. In the following serial figures, the generating process of the output signal sine will be shown. The generating process of cosine will be elided for the reason it is much the same to the generating process of sine.

3 Signal generating process

In Figure 2, we can see that L1 is the main winding to generate the magnetic field and L2 and L3 are the secondary coils to generate the output signals. In this process, we just analyze the output generate by the copper bar of AB.

As Figure 2 shows, AB is in the position which has little influence to the magnetic field of L2 or in this position the copper bar AB and the proceeding one have the same effect to L2 and L3. Therefore, the output voltages of L2 and L3 are equal and opposite in direction and the output value equals to zero.

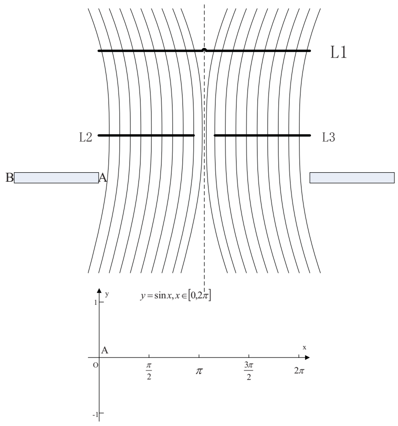

Figure 2. The first step of the signal sine generating process

As copper bar AB moving into the magnetic field of L2 and L3, the flux flews into L2 and L3 begins to be effected by AB and the Figure 3 mainly shows the influence lead by AB. As we know, AB is the copper bar and the material of copper has the attribute to reject the external magnetic field. Therefore, the flux flows into L2 is getting decreased and the other one L3's is becoming increased. When AB is totally moved into the magnetic field of L2, the output signal sine becomes the maximum absolute value. In the figure below, sin+ is the actual value generated by the emitter and sin- is produced by the signal process circuit to minimize errors of sine.

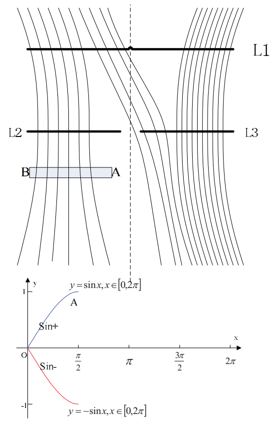

Figure 3. The second step of the sine generating process

As copper bar AB moving on, it processed into the region under L2 and L3, partly. As a result, the flux flows into L2 will get more compared with the process of the second step while it becomes less to L3. Consequently, the output value of signal sin is decreased. When AB getting to the position as Figure 4 shows, it has the same impact to magnetic field of L2 and L3. As a result, the output value of sine becomes zero at this position.

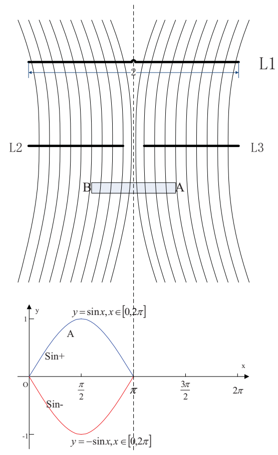

Figure 4. The third step of the sine generating process

As copper bar AB getting processed, it locates under L3. The influence of AB to the magnetic field of L3 is much like in the process of the second step. The flux flow into L3 is getting less while it becomes more to L2. The absolute value of sine increases as the copper bar AB moving on. Figure 5 shows one position of AB in this process to illustrate the generating process of the signal.

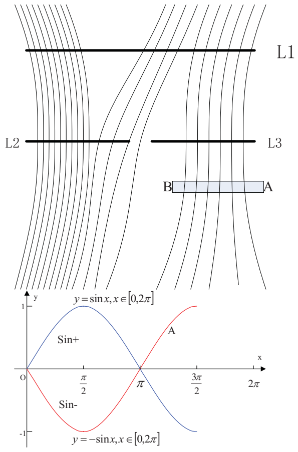

Figure 5. The fourth step of the sine generating process

Figure 6 shows the last stage of the generating process of the signal sine. In this process, it is much like the third step. As the influence to L3's magnetic field is getting less, the output signal is becoming weaker. The whole process ends until the output value of sine become zero the third time and it is also the beginning of a process of a new signal.

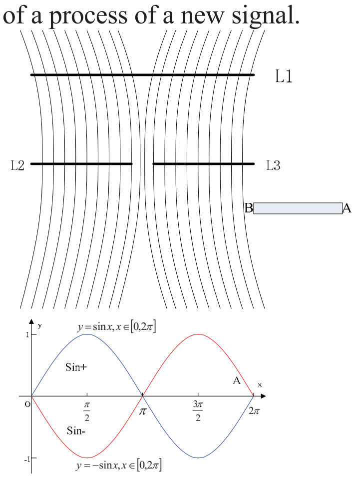

Figure 6. The fifth step of the sine generating process

Reviewing the whole generating process of the signal, we can get the inclusions as follows. The first step and the fifth step are much the same which show the copper bar is out the magnetic field. The maximum absolute values of sine are generated in the process of the second and the fourth step. However, for the reason of the processing electrical circuit, they are in the opposite value. The third step is a special one in all the steps. In this process, AB is in the middle of L2 and L3. According to the Maxwell Theory, it has the same impact to the magnetic field of L2 and L3. For this reason, we can see the output value is zero at this point.

As windings L4 and L5 play the same roles as L2 and L3, the signals generated by them are the same such as they have the same period, maximum value and minimum value. However, L4 and L5 is half circle behind L2 and L3, respectively. Therefore, the signal of L4 and L5 is 90 degrees behind sine and it is cosine. This is all the signals produced by the emitter that are sine and cosine signals.

Based on the analysis above, we decide develop a new absolute position senor to monitor the rotating angle.

4 Working principle of the sensor

To be illustrated, we take a simple encoder which has 9 copper bars in the outer circle and 8 copper bars in the inner circle for example. All the copper bars are listed on the two circles uniformly and the main structure of the encoder can be seen in Figure 7.

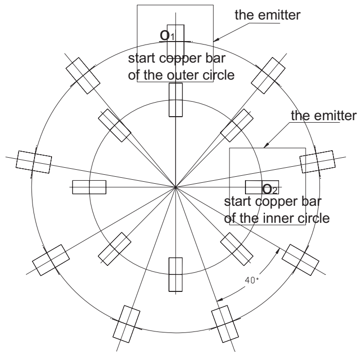

Figure 7. Main structure of the encoder

As shown in Figure 7, the outer circle has 9 copper bars and the inner circle has 8 copper bars. From the analysis in the Ⅱ section of the paper, we can see that each copper bar can generate one sine signal. Therefore, there will be 9 sine signals in the outer circle and 8 in the inner one. All the signals can be listed in Figure 8.

We count the signals of the outer circle and the inner circle at the same time. So the beginning and the ending time point are at the same time as the Figure 8 shows. Based on this, we processed to calculate the absolute position. As Figure 7 showing, the outer emitter is under the vertical copper bar and the inner emitter is under the horizontal one. To begin the calculation, we should assume some parameters.

θ_{outer}, θ_{inner} --rotating angle of the outer emitter and the inner emitter relative to the rotating center

n --total copper bars of the outer circle and n-1 is the number of copper bars of the inner circle

m_{outer}, m_{inner} --numbers of the copper bars the outer and inner emitter have rotated

p_{outer}, p_{inner} --the rotating angle of the outer emitter and the inner one which is less than the angles between two copper bars

The rotating angle of the outer emitter relative to the rotating point can be calculated as follows:

$$\theta_{outer} = \frac{360°}{n} \times m_{outer} + p_{outer}$$

The inner one is:

$$\theta_{inner} = \frac{360°}{n-1} \times m_{inner} + p_{inner}$$

As we know, the outer emitter and the inner emitter in fixed at one object. Therefore, θ_{outer}=θ_{inner}.

$$p_{outer} - p_{inner} = \frac{360°}{n-1} \times m_{inner} - \frac{360°}{n} \times m_{outer}$$

From Figure 8 we can see that within the stage of OA the number of copper bars rotated by the emitters is zero. So, m_{outer}=m_{inner}=0 and we can get:

$$p_{outer} - p_{inner} = \frac{360°}{n-1} \times m_{inner} - \frac{360°}{n} \times m_{outer} = 0$$

When these two emitters rotate to the stage of AB, m_{outer} equals to 1 and m_{inner} equals to 0. Therefore, p can be calculated as follows:

$$p_{outer} - p_{inner} = \frac{360°}{n-1} \times m_{inner} - \frac{360°}{n} \times m_{outer} = \frac{360°}{9-1} \times 0 - \frac{360°}{9} \times 1 = -40°$$

With the emitters moving on, they step into BC stage and in this process m_{outer}=m_{inner}=1.

$$p_{outer} - p_{inner} = \frac{360°}{n-1} \times m_{inner} - \frac{360°}{n} \times m_{outer} = \frac{360°}{9-1} \times 1 - \frac{360°}{9} \times 1 = 45° - 40° = 5°$$

In the process of CD, m_{outer}=m_{inner}+1=2.

$$p_{outer} - p_{inner} = \frac{360°}{n-1} \times m_{inner} - \frac{360°}{n} \times m_{outer} = \frac{360°}{9-1} \times 1 - \frac{360°}{9} \times 2 = 45° - 80° = -35°$$

As the emitters processed into the next stage CD, m_{outer}=m_{inner}=2.

From Figure 9, we can see the values are different from each other, apparently and it can prove the rightness of our theory. Form the sample example of the encoder which has 9 copper bars in the outer circle and 8 ones in the inner circle, we can conclude the common equations to calculate the absolute position sensor.

- when m_{outer}=m_{inner}=m,

$$p_{outer} - p_{inner} = \frac{360°}{n-1} \times m_{inner} - \frac{360°}{n} \times m_{outer} = \frac{360°}{170-1} \times m - \frac{360°}{170} \times m = 0.01253m$$

- when m_{outer}=m_{inner}=m,

$$p_{outer} - p_{inner} = \frac{360°}{n-1} \times m_{inner} - \frac{360°}{n} \times m_{outer} = \frac{360°}{170-1} \times (m-1) - \frac{360°}{170} \times m = 0.01253m - 2.1302°$$

5 Design of a new encoder

Therefore, this method can be applied to the encoder which has more copper bars. According to the actual application, we design an encoder which has 170 copper bars in the outer circle and 169 copper bars in inner circle. It main structure can be shown in Figure 10.

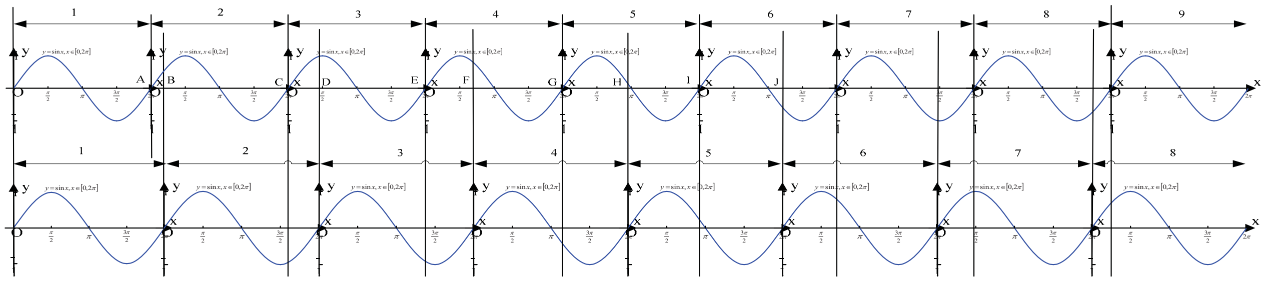

Figure 8. All signals of the encoder

$$p_{outer} - p_{inner} = \frac{360°}{n-1} \times m_{inner} - \frac{360°}{n} \times m_{outer} = \frac{360°}{9-1} \times 2 - \frac{360°}{9} \times 2 = 90° - 80° = 10°$$

When the emitters are in the positions between E and F, m_{outer}=m_{inner}+1=3.

$$p_{outer} - p_{inner} = \frac{360°}{n-1} \times m_{inner} - \frac{360°}{n} \times m_{outer} = \frac{360°}{9-1} \times 2 - \frac{360°}{9} \times 3 = 90° - 120° = -30°$$

From all the equals above, we can obtain the following equations:

(1) when m_{outer}=m_{inner}=m,

$$p_{outer} - p_{inner} = \frac{360°}{n-1} \times m_{inner} - \frac{360°}{n} \times m_{outer} = \frac{360°}{9-1} \times m - \frac{360°}{9} \times m = 5m$$

(2) when m_{outer}=m_{inner}+1=m,

$$p_{outer} - p_{inner} = \frac{360°}{n-1} \times m_{inner} - \frac{360°}{n} \times m_{outer} = \frac{360°}{9-1} \times (m-1) - \frac{360°}{9} \times m = 5m - 45°$$

According to these two equations above, we can know the value of m according to the difference between P_{outer} and P_{inner}. Consequently, we can obtain m_{outer}=m_{inner}. The question is that 5m should not equals to 5m-45^{o}. Obviously, 5m can not equals to 5m-45^{o}. So we can get the unique value of m and the rotating angle of the emitter can calculated.

To be easy understood, we draw the picture of the value of P_{outer} minus P_{inner}.

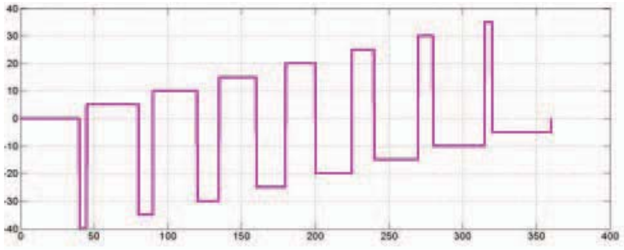

Figure 9. Angle difference between Pouter and Pinner

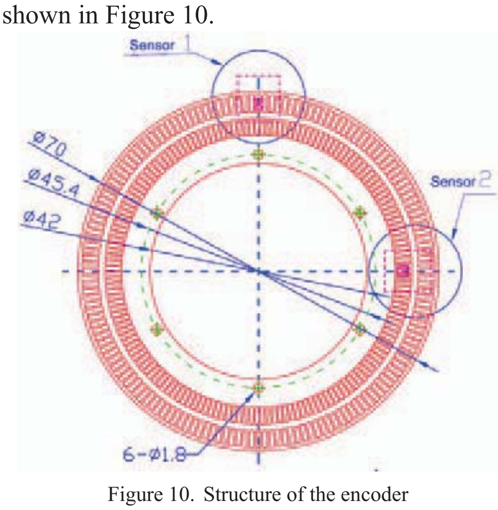

Figure 10. Structure of the encoder

According to the structure of the 170-169 encoder and the calculation equations of the absolute position angle, we can draw the angle difference between P_{outer} and P_{inner} which is shown in Figure 11. From the figure, we can see that the difference result like two parallel line but they do not have interaction. Therefore, the absolute position can be calculated. First, we make a table which contains all the possible difference results of P_{outer} and P_{inner}. Then we can determine the angle in a short range. At last, according to the calculation equation of θ_{outer} or θ_{inner}, we can easily calculate the angle value. Using this method is much sample to determine the position.

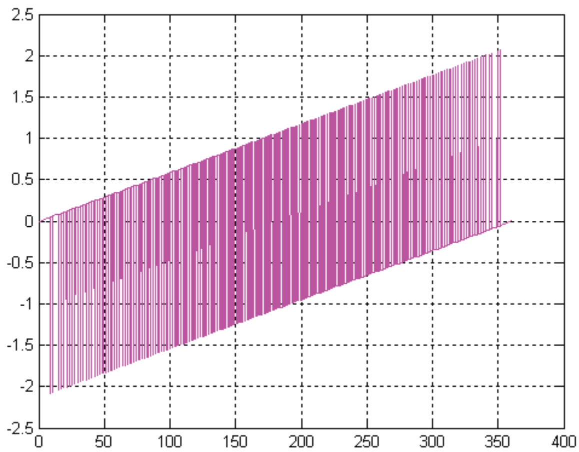

Figure 11. Angle differenc between Pouter and Pinner of the encoder

All the analysis above is the whole process calculating the absolute rotating angle. This method is easily to be understood and it can increases the signal processing by the central control unit (CPU) because the CPU just need to scan the table we established in the program and many instructions can be elided.

6 Advantages of the sensor

Based on the analysis above, we can know the advantage of the sensor.

First, it is a contactless absolute position sensor. The emitter and the encoder is contactless with each other, therefore, the sensor has relative long lifetime and can stand more vibration from the surroundings.

What is more, it takes a little space. The thickness of the sensor is less than 4mm, so it has superiorities in the application which has a high space recommend.

Last, it is insensitive to particles, dust, oil, humidity and liquids which mean it has a wide using field especially the complex environment, airspace and so on and so forth.

7 Conclusion

In the paper, we introduced a new absolute rotating angle sensor. We discussed the working principle of the emitter and the generating process of signals sine and cosine. We designed a encoder based on the working principle of the emitter to calculate the absolute rotating angle and the calculation process was presented. At last, we show the advantages of the sensor and the applications.

In the paper, we just want to introduce a relative new idea about testing the absolute rotating angle. The more detailed situations such as the experiment results, the process of the signal processing were not given.

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