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Research on the application and prospects of variable reluctance inductive sensors

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Abstract. Variable reluctance inductive sensors are extensively utilized in the industrial field due to its unique working mechanism and good performance characteristics. Based on the working principle of Variable Reluctance Inductive Sensors, this paper reviews its development history, application in industrial automation and medical industry. Through the analysis of variable reluctance inductive sensors, variable reluctance inductive sensors have the advantages of high sensitivity, low cost and reliability which can support its wide application in precision measurement, position detection and motion control, but it is susceptible to the interference of the external magnetic field and the influence of the temperature which limits its development space and scope. However, the advancement of new materials, intelligent technologies and multi-mode integration has broadened the potential of future development of sensors and created more challenges for the development of variable reluctance inductive sensors. The update of new research conditions also provides a valuable reference of research and application in related fields

Keywords: Variable reluctance inductive sensors, reluctance effect, sensors, Inductive coil, position detection.

1. Introduction

As a kind of sensor, variable reluctance inductance sensor plays an important role in the field of industrial control and position detection because of its unique working mechanism and good performance characteristics. Its working principle is based on the magnetoresistive effect, and the position information of the object is determined by detecting the change of the magnetic circuit impedance. Variable reluctance inductance sensors are used in a wide range of applications, especially in the industrial sector, and are ideal for detection, process monitoring, control, positioning, motion, safety and fault diagnosis. With the advent of integrated circuits and microprocessors, inductive sensors have become more miniaturized and intelligent. This paper describes the working principle and development history of the variable reluctance inductance sensor, lists the common applications of the variable reluctance inductance sensor in the fields of liquid level monitoring, robot arm positioning system, flow monitoring, vehicle speed detection and magnetic medical equipment, and summarizes the advantages and disadvantages of the variable reluctance inductance sensor.

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With the gradual reduction of feature size and the highly integrated circuit, the development of future sensors will follow four directions: miniaturization, flexibility, passive wireless, and sensor fusion. I hope this paper can provide some reference value for future readers.

2. Operating principle

The variable reluctance inductance sensor is mainly composed of an induction coil and one or more ferromagnetic moving chips, as shown in figure1. Its working principle is based on the magnetoresistive effect in electromagnetism, which describes the effect of changes in the magnetic field inside a substance on an electric current. This type of sensor is designed to convert object motion into a measurable change in resistance.

When an electric current passes through the induction coil, it creates a magnetic field, and the distribution of magnetic potential lines around the coil changes depending on the position of the sensing object and the material properties. A change in the position of a moving chip (for example, due to physical movement, vibration, or proximity) can affect the local distribution of the magnetic field, thereby altering the magnetic flux. These changes in the magnetic field cause the induced electromotive force (i.e. the voltage generated by electromagnetic induction) to change. By measuring inductance or reflected impedance, an electrical signal that is proportional to the distance or speed the object is moving can be obtained [1].

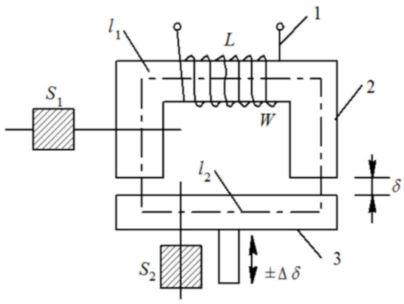

Figure 1. Variable reluctance inductance sensor schematic diagram

3. History of development

The history of sensor development dates back to the mid-19th century. As early as 1856, British physicist Sir William Thompson discovered that in general materials, the change in resistance is usually less than 5%, and this effect is later called "constant magnetoresistance". With the development of electronics, these early magnetoresistive concepts were translated into sensor technology for measurement and control. In the initial stages, such sensors are used in the industrial and military fields for basic position detection tasks.

After decades of development, the design and manufacture of modern variable reluctance inductance sensors have been significantly improved in terms of accuracy, stability and reliability [2]. Advances in materials science in particular have driven the development of these sensors, such as the use of new soft magnetic materials that can reduce hysteresis and improve response speed [3]. With the advent of integrated circuits and microprocessors, variable reluctance sensors have become more efficient and intelligent in data processing and transmission [4].

4. Application example

Variable reluctance inductance sensors are used in a wide range of applications, especially in the industrial sector, and are ideal for detection, process monitoring, control, positioning, motion, safety and fault diagnosis.

4.1. Level monitoring

Variable reluctance inductance sensors play a key role in liquid level monitoring, and their usefulness comes from their ability to accurately monitor the height change of liquid level. The use of variable

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reluctance inductance sensors in liquid level monitoring is based on the magnetoresistive effect, that is, when a conductor or semiconductor passes a current, its resistance value will change with the change of the magnetic field. The sensitive unit mainly consists of a reluctance inductor coil and its matching magnet system, and the magnet system is usually directly related to the level of the measured medium.

In specific applications, the sensor's sensitive unit usually consists of a coil made of one or more magnetic materials, whose inductance value is affected by the strength of the nearby magnetic field. The change in level causes the position of the buoy to change, and the buoy is fitted with a magnet that can move relative to the inductor coil. With the rise and fall of the liquid level, the up and down movement of the buoy will change the relative position of the magnet and the inductor coil, thus changing the magnetic flux density in the coil [5].

Since the magnetoresistance of an inductor coil is related to the magnetic flux density, a change in the liquid level actually causes a change in the magnetoresistance in the coil. A change in coil reluctance causes a change in the magnetic field generated by the current passing through the coil, so that the inductance value of the alternating current passing through the coil changes accordingly. This change in the inductance value can be detected by the circuit, for example, the coil can be used as a component of the RLC oscillation circuit, and the change in its inductance value will cause the resonant frequency of the circuit to change. The change in frequency can be easily detected by a frequency meter or other electronic measuring device and is ultimately converted into an electrical signal proportional to the level of the liquid level. These electrical signals are processed by data and can be used to automatically trigger the opening and closing of the pump or valve to control the discharge and filling of the liquid.

Such a system can not only ensure the automatic control of the liquid level in the storage tank, but also prevent the risk of overflow or dry burning, and is widely used in the liquid level control process in the chemical, water treatment and food and beverage industries. With this non-contact level measurement method, the variable reluctance inductance sensor ensures height measurement accuracy and system reliability, while reducing the need for maintenance and repair. The simple design of these sensors, which do not contain any moving parts, makes them ideal for level measurement, especially in situations where maintenance is critical or mechanical buoys are not appropriate. In addition, variable reluctance inductance sensors also have good environmental adaptability and long-term stability, which makes them widely used in liquid level monitoring. Commonly used instruments for liquid level detection are shown in figure2.

Figure 2. Liquid level detector

4.2. Positioning system of industrial robot arm

Multiple variable reluctance sensors are installed on the robot arm to accurately measure the joint position, as shown in figure3. As the robot arm moves, the ferromagnetic core in the joint moves in the induction coil, causing the magnetic circuit impedance to change accordingly. This change in impedance results in a change in the induced voltage in the coil, and this voltage signal is amplified, filtered, and converted analog-to-digital into the control system. The control system uses these data to

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calculate and adjust the movements of the robot arm to reach the predetermined working position and ensure the accuracy of the assembly or handling task [6]. In this process, the sensor's linear output range and accuracy are critical, as they affect the performance of the final control system.

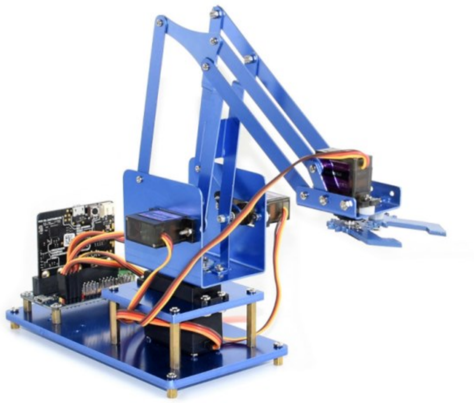

Figure 3. Robot arm

4.3. Flow monitoring

In flow control applications, variable reluctance inductance sensors can monitor and manage the flow of a variety of media, including liquids, gases and powders. Not only does it provide critical information about the magnitude, energy consumption, and efficiency flowing through the medium, but it also allows the overall flow output to be optimized by adjusting the inlet and outlet of the medium. The application of this sensor ensures the real-time adjustment and fine management of the flow control process, thus meeting the demand for accurate flow control in complex systems [7]. Common instruments for flow detection are shown in Figure 3.

Figure 4. Flow detector

4.4. Vehicle speed monitoring

The traditional speed monitoring equipment of vehicles is often interfered by the complicated environment such as road and wheel sliding. In contrast, the variable reluctance inductance sensor can measure the speed by detecting the rotation state of the gear or axle of the speed sensor, and the detection result is fed back to the vehicle control system. Therefore, the application of variable reluctance inductance sensors in automobile speed detection is often in the form of wheel speed sensors, as shown in figure4.

In variable reluctance inductance sensors, the sensing unit usually consists of a fixed reluctance inductor coil and a rotating gear or magnetic marker. This gear or magnetic marker is usually mounted on a wheel or drive shaft with periodic magnetic markers or teeth that affect the magnetic field passing through the sensitive unit environment. As the wheel rotates, magnetic markers or teeth pass at a fixed distance through a magneto-resistive inductive sensor fixed nearby. In this way, the local strength of the magnetic field changes with each rotation through a mark or tooth. As the magnetic field strength changes, the reluctance generated by the inductor coil also changes accordingly, thus affecting the

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inductance value through the inductor coil. With the change of wheel speed, the speed of the magnetic tooth through the induction coil also changes, resulting in a corresponding change in the frequency of the inductance value on the coil. These changes can produce an alternating voltage through the inductor coil, the frequency of which is proportional to the frequency of the magnetic mark or tooth passing through the coil (i.e. the rotational speed of the wheel). By measuring the frequency of this generated alternating voltage, the wheel speed of the vehicle can be determined very accurately, which is further converted to the vehicle's traveling speed [8]. In order to improve the availability of the signal, the original generated signal is usually conditioned, such as filtering and pulse shaping, so as to obtain a clearer and more accurate speed representation signal.

Variable reluctance inductance sensors use the reluctance effect to detect the speed of the wheel or related rotating parts, thereby indirectly measuring the speed of the car. This type of sensor is widely used in the speed measurement and control system of modern automobile because of its advantages such as no contact, high accuracy and fast response speed.

Figure 5. Wheel speed measuring sensor

4.5. Magnetic medical equipment

Magnetic medical devices include MRI(nuclear magnetic resonance imaging apparatus as shown in figure5), MRS(nuclear magnetic resonance spectrometer) and SQUID(superconducting quantum interferometer). Among these devices, the application of variable reluctance inductance sensors in magnetic medical devices is often based on their ability to accurately measure changes in the magnetic field and convert these changes into electrical signals.

In medical imaging devices such as magnetic resonance imaging (MRI), sensors can be used to monitor and calibrate the strength of highly uniform magnetic fields generated by the device. The sensitive unit in such applications is mainly composed of a magnetoresistive material, whose resistance value changes in response to small changes in the external magnetic field. Any change detected by the magnetoresistive inductance sensor indicates a deviation in the strength of the magnetic field. The magnetoresistive material inside the sensor will change its resistance value with the change of the magnetic field, and then the change of resistance value is sensed by the bridge circuit connected to it, and the voltage change of the bridge output is related to the change of the magnetic field strength. In this way, magnetic medical devices can monitor the strength and uniformity of the magnetic field in real time [9].

The resulting voltage signal can then be converted into a digital signal and processed by the algorithm inside the device to ensure that the magnetic field conditions required for the imaging process are met. This precise control is the key to high-quality magnetic resonance imaging.

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Figure 6. MRI

5. Advantages and disadvantages

The variable reluctance inductance sensor provides non-contact measurement, which means there is no mechanical wear in the system. Thanks to its design based on the magnetoresistive effect, it can achieve very high measurement accuracy with good repeatability and response speed. In addition, their relatively simple design makes this class of sensors very reliable and easy to maintain, reducing maintenance costs.

However, the performance of these sensors is significantly affected by changes in temperature, which can alter the properties of magnetic materials, requiring the necessary temperature compensation. In addition, for non-ferromagnetic materials, the detection effectiveness of variable reluctance sensors is limited, because these materials have relatively little effect on the magnetic field. Therefore, they are usually designed for position measurements of ferromagnetic objects.

6. Conclusion

As a mature and reliable sensor technology, variable reluctance inductance sensors play a vital role in many modern industrial and scientific research fields. Although their performance in non-ferromagnetic material detection and high-temperature environments will be limited, these shortcomings are gradually being overcome through technological innovation and material improvement. In the course of future development, it can be foreseen that variable reluctance sensors will continue to maintain their core position and gain wider applications in the field of automation and intelligent systems.

Due to my limited ability and time, there are still many areas worth further research and improvement in this topic, including the failure to conduct parameter measurement and comparison experiment of variable reluctance inductance sensor, and the scope of application examples of variable reluctance inductance sensor is not wide. In the subsequent optimization, relevant experiments will be added to demonstrate the point of view, and discussions in amplitude measurement, thickness measurement, eddy current inspection and other aspects will be added.

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