Application of inductance in the field of liquid level sensors

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Abstract: Aiming at the application limitations of traditional inactive liquid level sensors (mainly ultrasonic and light waves), In this article, the relationship between inductance and medium is quantified in specific application scenarios, which can implement the functions of traditional liquid level sensors and solve different The influence of liquid composition and state on data, this research expands the application fields of liquid level sensors.

1. Introduction to existing liquid level sensor technology

The liquid level sensor converts the height of the liquid level into an electrical signal for output, and is widely used in various household appliances, industrial equipment, transportation, military scientific research and other fields[1].

The sensing methods of existing liquid level sensors are mainly divided into several categories, electrode type, photoelectric type, radar sensor, GSK/UQK/GKY, pressure sensor, ultrasonic sensor and so on. There are high-precision photoelectric sensors, radar sensors, pressure sensors, and ultrasonic sensors. Among them, the photoelectric sensor is easily affected by impurities, fog and the state of the medium. The pressure sensor has a large error; the ultrasonic sensor is easily affected by impurities, fog and the state of the medium; the radar sensor is large in size and high in cost, and is generally used in the industrial field. Therefore, it is of great significance to study a new type of liquid level sensor. In this paper, the influence of the medium on the inductance is used to study the application feasibility of the inductance on the liquid level sensor.

2. Factors affecting inductance and inductance:

\[ \text{Inductive resistance ohm}=2\pi F(\text{working frequency}) \times L(\text{Inductance}), \]

Inductance is generally composed of coils. Its inductance is related to the number of turns of the coil (the number of turns of the coil), the more the number of turns, the greater the inductance; Related to the shape of the coil, the smaller the distance between the turns of the coil, the greater the inductance, and the larger the area in the middle of the coil, the greater the inductance; Related to the medium in the middle of the coil (hollow, iron core, magnetic core, etc.)[3]. According to the calculation formula of the inductance of the winding inductance:

\[ L=W^2\mu S_m/L_m \]

The above formula shows that the inductance of a winding is proportional to the square of the number of turns W of its magnetic flux linkage, which is related to the space medium occupied by the magnetic field, is proportional to the area S_m that the magnetic flux passes through. It is inversely proportional to the path length L_m traversed by the magnetic flux[2], and the permeability \( \mu=\mu_0*\mu_s \), where \( \mu_0 \) is the vacuum permeability, and \( \mu_s \) is the relative permeability of the magnetic medium[5]. Under the circumstance that the number of turns of the inductance coil remains unchanged, the change of the
medium in the cross-sectional area of the coil will cause the magnetic permeability $\mu$ inside the coil to change, thereby causing the inductance to change.

In this article, a non-contact liquid level sensor is designed based on the relationship between "liquid (medium) level height-medium permeability-inductance-inductance-energy change of high-frequency electrical signal". This liquid level sensor is not affected by impurities, mist and medium conditions, and only needs to build a high-frequency transmitting signal and inductance circuit, which has the characteristics of low cost, small size, and high sensing accuracy.

3. Theoretical analysis and model verification

3.1. Theoretical analysis

Scheme 1: Based on the above calculation and analysis of inductance, set the basic circuit. As shown in the circuit diagram 1[4], the air-core inductor coil is placed vertically in the liquid, and the liquid can be passed through and the coil can be covered with plastic, thereby isolating the liquid from directly contacting the coil. The length of the inductance is determined according to the measuring range. In this program, the MCU transmits a fixed frequency (4Mhz) electric wave, processed by the modulation module, and sent from the NET2 end to the inductance end. When the signal passes through the coil, the inductance generates inductance to the high frequency AC signal $\text{ohm}=2*\pi*4M (\text{operating frequency}) *W^2\mu S_m/L_m$, the detection module NET1 collects the signal from the inductor output. Since the signal and the coil are fixed, when there is no liquid in the center of the inductor, the inductance value of the inductor depends on the permeability of the air ($\mu_s\approx1$). When the liquid level rises, the bottom inductive medium begins to change from air to liquid medium. As long as the relative permeability of the liquid medium is different from that of air, the value of $\mu$ will change. The height of the liquid medium level will affect the proportion of inductance corresponding to the liquid, and the size of the inductance determines the size of the inductive reactance. Here, the inductance can be divided into multiple extremely short inductances. Assuming that the liquid level is at the position of a/X (a≤X) of the coil height, the total inductance of the inductance is $\text{ohm}=((Xa)/X) 2* \pi*4M(\text{operating frequency}) *\mu(\text{air})*S* W^2/L_m +(a/X) 2*\pi*4M(\text{operating frequency}) *\mu(\text{medium})*S* W^2/L_m$, here is the only variable liquid The bit height determines the final inductive reactance value.

![Figure 1 Analog circuit](image)

Scheme 2: Based on the above calculation and analysis of inductance, set the basic circuit. As shown in the circuit diagram 2[4], the inductance coil is made into a rectangular planar inductor (picture 2 right) and placed in the liquid, and the coil is wrapped with plastic to isolate the liquid from directly contacting the coil. The height of the inductance is determined according to the range. In this solution, the MCU transmits a fixed frequency (4Mhz) electric wave, processed by the modulation module, and sent from the NET2 end to the inductance end. When the signal passes through the coil, the inductance also has inductance for high-frequency signals $\text{ohm}= 2*\pi*4M (\text{working frequency}) *W^2\mu S_m/L_m$. Since the surface space of a planar inductor is also within the space occupied by the electromagnetic field, the
medium around the inductor closest to the inductor plane can be equivalent to the inductor central medium. When there is no liquid around the inductor, since the signal and coil are fixed, the inductive reactance of the inductor The value depends on the relative permeability of air (μs=1). When the liquid level increases, the relative permeability of the medium changes; Assuming that the liquid level is at the position of a/X (a≤X) of the coil height, the concept of mixed permeability is proposed here, which is set as $\mu_h = \frac{\mu_{\text{medium}}a}{X} + \frac{\mu_{\text{air}}(X-a)}{X}$. According to the formula here: inductive reactance $\text{ohm} = 2\pi f M (\text{operating frequency}) \mu_h S W^2 L_m$, where the only variable liquid level height determines the final inductive reactance value.

The theory proves that when the permeability of the liquid medium is different from that of the air, the change of the medium level will change the size of the inductive reactance. When applied to the actual scene, due to various factors such as the manufacturing process, the inductive reactance of the same batch of products will be caused. In the end, a higher consistency cannot be guaranteed, and there are differences in inductance values; resulting in inconsistencies in the collected electrical signals. However, we can introduce a single-chip microcomputer program to calibrate the liquid level corresponding to the output electrical signal of each product, and then we can achieve the purpose of accurately measuring the liquid level, so there is no need to perform very accurate calculations on the theoretical value, only the same The inductive reactance of the product at the same liquid level remains the same.

### 3.2. Model verification

Build the model described in Scheme 2, where the height of the planar inductor is 150mm, the inductor input signal (as shown in Figure 3): frequency 4MHZ, peak-to-peak value 200MV, output peak-to-peak corresponding liquid level height is as follows:

| Liquid level height | 0mm | 50mm | 100mm | 150mm |
|---------------------|-----|------|-------|-------|
| peak-to-peak value  | 110mv | 37mv | 20mv | 7mv |
The model in the above figure is based on the influence of inductive reactance on electrical signals when tap water (water is paramagnetic) as the medium. Combined with the physical characteristics of inductance that only changes the energy of the electric wave without changing the frequency of the electric wave, the voltage signal is obtained after the signal is processed. After the liquid level sensor is calibrated, the actual liquid level height can be reflected by the output voltage signal, so the design theory of the inductive liquid level sensor is completed and verified in practice.

4. Conclusion
The inductive liquid level sensor can expand the application field of the liquid level sensor. Its characteristic is a non-active non-contact liquid level sensor, and is not affected by impurities, fog and the state of the medium. It only needs to set up a high-frequency emission signal and Inductance circuit. It has the advantages of low cost, small size, and high sensing accuracy. It is worth our promotion in practical applications.

In this article, two inductance layout schemes are designed to sense the change of liquid level. The schemes change the ratio of the medium in the effective area to change the inductance and inductance value, thereby changing the output value of the electrical signal, and finally realize the function of reflecting the liquid level; In application, it can be combined with actual scenes and layout product structure to realize functions.

References:
[1] Baidu Encyclopedia
[2] Li Langru, Chen Qiaofu, Zhou Libing. Principles of Electromagnetic Device Design [M]. Beijing: China Electric Power Press, 2017.P151-152
[3] Chen Lijia, Li Hongmei, Zong Hua, Li Wei. Electromagnetic fields and electromagnetic waves [M]. 2 edition. Harbin: Harbin Institute of Technology Press, 2020.P109-110
[4] Yan mi, Peng Xiaoling. Fundamentals of Magnetism and Magnetic Materials [M]. 2nd edition. Hangzhou, Zhejiang: Zhejiang University Press, 2019.P7
[5] Cao Shanyong. Magnetic field analysis and application examples [M]. Beijing: China Water Resources and Hydropower Press, 2010.P90-91