Research on the Sensor of Welding Seam Tracking Based on the Same Plane Electrode

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Abstract. Capacitive sensors have a wide range of applications, but its edge effect is severely restricted by the detection accuracy. In this paper, we put forward a kind of capacitance sensor based on the edge of capacitance. It has a wide range of static and dynamic measurement (mm) and high measurement accuracy. And its mathematical modeling, through the analysis proves that the model is correct and feasible. At the same time also used in the finite element analysis software ANSYS, three-dimensional model of the sensor was established, and the optimization and analysis of the sensor's output characteristic of sensor specific structural parameters, the final determination of the optimal structure parameters of the capacitive sensor. Finally, the experimental results show that the output signal of the sensor is good.

1. Introduction
The urgent problem of modern manufacturing industry is how to improve the production efficiency [1]. As is known to all, the traditional manual welding, not only the working environment of workers actively hostile, and welding of the quality of the products also can't meet the requirements, so the welding automation is the world industry is presented, and the necessary requirement of welding [2]. Therefore, this paper presents an edge effect type capacitive seam tracking sensor to realize the automatic tracking of the weld seam. It has the advantages of simple structure, stable performance, strong anti-interference, groove to a wide range, and can adapt to different types of groove tracking, only need a certain structure changes of the sensor according to different forms of groove.

2. The establishment of mathematical models
The space area occupied by the two electrode of the same plane capacitance sensor is $\Omega_1$ and $\Omega_2$. The space occupied by the detected object is $\Omega$. The boundary surface of the space $\Omega_1$, $\Omega_2$ and $\Omega$ were $\partial \Omega_1$, $\partial \Omega_2$ and $\partial \Omega$. The derivation of the mathematical model of the same plane capacitance sensor is
introduced in the following details:

\[
\begin{align*}
\nabla_2 V &= 0, (x, y, z) \in \Omega \cup (R_3 - \Omega_1 - \Omega_2 - \Omega) \\
V|_{\Omega_1} &= V_1, V|_{\Omega_2} &= V_2 \\
\lim_{r=\sqrt{x^2+y^2+z^2} \to \infty} V &= 0 \\
V_n|_{\partial \Omega_1} &= V_0|_{\partial \Omega_1} \\
d \frac{\partial V_1}{\partial n} \bigg|_{\partial D_2} &= \tilde{d} \frac{\partial V_0}{\partial n} \bigg|_{\partial D_2} \\
\end{align*}
\]

(1)

For the same plane capacitance sensor model, the spatial region occupied by the two electrode is:

\[
D = \left\{ (x, y, z) \mid -b/2 \leq x \leq b/2, -k/2 \leq y \leq k/2, 0 \leq z \leq c \right\}
\]

(2)

\[
D_2 = \left\{ (x, y, z) \mid -b/2 \leq x \leq b/2, -k/2 \leq y \leq k/2, 0 \leq z \leq c \right\}
\]

(3)

The space occupied by the measured work-piece is in the range of:

\[
D = \left\{ (x, y, z) \mid -m/2 \leq x \leq m/2, -1/2 \leq y \leq 1/2, c + d \leq z \leq c + d + n \right\}
\]

(4)

Through the above for both electrodes of the capacitive sensor and the work-piece in the boundaries of space constraints, The steps to obtain the relationship between the capacitance of the same plane capacitance sensor and the measured work-piece are as follows: The two electrodes of the sensor and the work-piece are D, D_1 and D_2. When the electrode D_1 and D_2 on the potential to determine the V_1 and V_2, It can be assumed that the distance between the sensor and the work-piece is d. By the following differential equation:

\[
\begin{align*}
\nabla_2 V &= 0, (x, y, z) \in D \cup (R_3 - \overline{D}_1 - \overline{D}_2 - \overline{D}) \\
\lim_{r=\sqrt{x^2+y^2+z^2} \to \infty} V &= 0 \\
V_n|_{\partial D_0} &= V_n|_{\partial D_{out}} \\
V_n|_{D_1} &= V_1, V_n|_{D_2} = V_2 \\
d \frac{\partial V_1}{\partial n} \bigg|_{\partial D_2} &= \tilde{d} \frac{\partial V_0}{\partial n} \bigg|_{\partial D_{out}}
\end{align*}
\]

(5)
The potential distribution function of the space in the working range of the capacitance sensor can be determined as $V(x, y, z)$.

The electric field intensity distribution is obtained by the gradient of the potential distribution function $V(x, y, z)$:

$$\mathbf{E} = \nabla V$$

Using the change of the spatial electric field intensity, the relationship between the sensing capacitance value $C$ and the distance $D$ of the work-piece can be obtained from the same plane capacitance sensor:

$$C = \frac{E_0 \pi \varepsilon S}{d (V_1 - V_2)}$$

In the formula, $V_1$ and $V_2$ two electrode potential, $S$ under the working area of the capacitive sensor, $\varepsilon$ as a dielectric constant interval; $E$ Electric field strength for electrode excitation. By using the above formula, we can see that when the external factors interfere with the welding process, when the potential difference between the two electrodes is a fixed value, the dielectric constant and electric field intensity are the excitation set to a fixed value. So the distance between the work-piece and the capacitance value is a nonlinear change. The traditional capacitance calculation formula is similar, which further shows the correctness of the model.

3. Modeling and Simulation of the same plane capacitance sensor based on Analysis

According to the mathematical model of the same plane electrode, the mathematical model of the capacitance sensor can be used to deal with the fixed parameters only when the simulation is used [3-4], Some factors which influence the electric field distribution and the electric field size of the sensor are also neglected, Interference factors consider only the quantitative parameters of the sensor itself, welding position of welding gun and welding process in the possible interference [5]. Finite element analysis method is used to simulate the interaction of the electrode with the same plane capacitance sensor.3D Analysis analysis model was established [6], as shown in Figure 1.

![Figure 1](image_url)

Figure 1. the 3D ANSYS model of the same plane capacitance sensor
In the process of ANSYS modeling, considering the welding environment of the sensor, the whole analysis model is set up with the air bag, which is 4 times the size of the whole analysis area [7]. Unit type selection of three dimensional solid element solid122, the degree of freedom is the electric potential. The material attribute is defined as a silicon dioxide material, and the electrode is a copper electrode. The mesh is divided into free grid, and the results are shown in Figure 2. After loading, solving and post-processing results.

![3D ANSYS mesh of the same plane capacitance sensor](image)

**Figure 2.** 3D ANSYS mesh of the same plane capacitance sensor

4. Simulation results and Analysis

4.1. The effect of electrode parameters on the capacitance of the sensor

![Graph showing capacitance vs electrode parameters](image)

**Figure 3.** Relationship between the main parameters of the electrode and the capacitance value

In the simulation, the relationship between the electrode thickness D, the electrode radius R, the distance between the electrode h and the electrode width s and the capacitance of the sensor is mainly studied. When the measurement is assumed, the distance between the work-piece and the sensor is...
5mm, and the size of the measured object is 50 x 50 x 5mm metal sheet. At the same time, the simulation of a single variable in the study of a single variable Where D, R, h, s and the simulation of the relationship between the capacitance as shown in Figure 3.

From the Figure can be concluded that D, h, s have a maximum value, more than the maximum value of the sensor capacitance will become smaller. And the electrode radius R will be as the radius of the sensor capacitance becomes larger, taking into account the assembly and practicality, and other factors, the choice of a radius of 10mm as the standard.

4.2. Research on sensing properties
In the study of the effect of the distance between the electrode and the work-piece on the capacitance of the sensor, the size of the electrode is selected as the optimum size of the electrode, and the distance from the 2mm to the 14mm is changed from the distance between the work-piece and the work-piece. As shown in Figure 4, the output capacitance value and the variation law of the distance between the work-piece is approximately proportional to the inverse proportion, and the formula (7) is consistent with the change trend.

5. Experimental verification and Analysis
Based on Analysis finite element simulation software for electrode wound with each structure design of planar capacitance sensors and analyzing the influential factors of the output results. A simple sensor probe is made in this experiment, Specific electrode structure parameters with reference to the conclusions drawn from the above simulation: electrode thickness 2.5mm, electrode radius 10mm, the distance between the electrode and the 2mm, the electrode width 1.5mm. Then by using the waveform generator input frequency 50Hz sine wave oscillation excitation, through the power amplification circuit input to two sensor electrodes and two electrodes produce changes in the capacitance of the output by capacitance voltage conversion circuit through digital oscilloscope view. The sensor itself is not fixed together with the torch in front of the torch 1cm and 4Hz frequency swing. The sensor overall probe and welding of steel plate work-piece for V groove welding, torch and work-piece weld distance 7mm, sensor and the work-piece weld distance of 1cm, plate 5mm thick. By constantly adjusting the
welding torch with respect to the weld position, check the voltage waveform at the output of the digital oscilloscope, specific experimental data as shown in Figure 5.

![Graph showing the voltage waveform](image)

**Figure 5.** the output curve of the capacitive seam tracking sensor

By the diagram shows the capacitance sensor each swing scanning through the weld, the output voltage waveform presents certain regularity, by waveform can clearly analyze sensor at the moment the position, so you can see changes in capacitance sensor to sense the position of welding seam in good condition, can meet the requirements of welding conditions are required for the signal.

6. Conclusion

- A new type of electrode cross wound with the same plane capacitance welding seam tracking sensor based on edge effect is presented.
- Analysis finite element analysis software was used to build the three-dimensional model of the sensor and the sensor electrode structure of the various parameters were optimized.
- The output characteristic of the sensor is analyzed and the structure of the capacitive sensor suitable for seam tracking is determined. Finally, the conclusion is validated by experiments.

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