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Development of Measuring Equipment of Magnetic Field in BIW Spot-welding Environment

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Abstract: Put forward a robot's automatic packaging and palletizing production line based on Modbus fieldbus control system, to improve efficiency of logistics and enhance the intelligence and versatility of packaging and palletizing system. The SIEMENS S7-1200 PLC sequence control is used to achieve the operation of material conveying line and packaging-palletizing line in automatic packaging and palletizing production line. Visual intelligence is used to recognize the information about shape, position and number of the workpieces to be packed. Through information exchange between MODBUS fieldbus and PLC, industrial robots, visual intelligent detection and host computer can enhance reliability and applicability of packing and palletizing system. It has been proved that the method improves the automation degree of the packaging and palletizing production line, the allocation of resources and system layout can be optimized, and the debugging cost can be saved.

1. Introduction

Spot welding is a short-term process. The instantaneous current of welding reaches tens of thousands of amperes and this momentary high current generates a strong magnetic field at the welding site. Welding operators who are exposed to this magnetic field for a long time may suffer adverse effects. In order to study the effects of electromagnetic exposure on the human body in spot welding environment [1-2], it is necessary to study the electromagnetic environment of spot welding. This paper proposes the development of measuring devices in spot-welding environmental magnetic field, which is the preliminary work of the research on the degree of influence of electromagnetic exposure on the human body in spot welding environment.

2. Characteristics of electromagnetic field of Spot welding [3-4]

Characteristics of time domain and frequency domain of electromagnetic field in spot welding process are the basis for selecting the sensor and measurement scheme. Therefore, understanding the characteristics of electromagnetic field generated by the spot welding process is a necessary condition to accurately measure the strength of spot-welding magnetic field.

2.1 Characteristics of Frequency

The frequency characteristics of the electromagnetic field are directly related to the frequency characteristics of the welding current. At present, power sources of spot welding mainly include AC, secondary rectification, DC shock wave, and intermediate-frequency inverter.

The characteristics of welding frequency which each type of welding power resource provides is different. The welding current output from the AC power supply is the power frequency current. The harmonic components of the current are different when the conduction angle is different. The power

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supply of secondary rectification and *intermediate*--frequency inverter provides the DC current with a certain pulsating component; and the pulsation frequency of the secondary rectification welder is related to the rectifier circuit, the pulsation frequency is several hundred Hz; the pulsation component of the intermediate--frequency inverter is related to the switching frequency of switching devices, and the pulsation frequency is several KHz or dozens of KHz; the DC shock wave spot welding provides a DC pulse, when the frequency characteristics of the current is calculated, it is replaced by a sine wave, and the period of the sine wave is four times of current's rising time. According to the electromagnetic classification, the welding current provided by the spot welding *power* source belongs to the ultra-low frequency signal, and the frequency is in the range of several dozen of KHz.

2.2 Characteristics of Amplitude

In spot-welding electromagnetic field, the magnetic induction value of each point in space is determined by the welding current and the distance between the measuring point and the welding circuit.

In order to estimate the magnetic induction value of the measuring point, the distance from the measuring point to the plane of the welding circuit is set to 20 cm, the welding current is 100 kA, and the welding circuit is simplified at the electrode, and the magnetic field around the electrode is regarded to be generated by a long straight wire. The current value on the wire is up to 100KA. Under this assumption, the value of the magnetic induction at 20 cm around the electrode can be obtained by the Biot-Savar theorem:

$$B = \frac{\mu_0 I}{2\pi r} \qquad (1)$$

In formula (1) : $\mu_0 = 4\pi \times 10^{-7} H/m$ is the magnetic permeability in vacuum, I is the current value on the wire, and r is the vertical distance from the measuring point to the wire. So the value of B is up to 100 mute.

2.3 Characteristics of Time domain

Different spot welding processes produce different characteristics of time domain of the magnetic field. The welding process of each solder joint lasts for several cycles, and in some workplaces welding is continuous, the time interval between the welding processes of adjacent solder joints is the same, so the magnetic field of the whole place also changes periodically; in some places, after a solder joint is welded, corresponding adjustments should be made before the solder joint can be soldered, so the change of magnetic field in the whole place does not have periodicity.

2.4 Characteristics of Spatial distribution

The spot-welding magnetic field studied in this paper belongs to the near-field category. The magnetic field does not have the characteristics of plane wave, and the strength of magnetic field decreases rapidly as the distance between the measuring point and the welding equipment increases. Since the structure of the welding equipment cannot be described by coils or long straight wires, plus the influence of the frame and other ferromagnetic materials, the magnetic field generated by the spot welding process is spatially complex and cannot be described by regular geometric shapes.

3. Design for measuring equipment of spot-welding magnetic field

Measuring equipment of magnetic field in spot welding process includes design of sensor and data acquisition and analysis.

3.1 Design of Sensor

The hollow coil is used as sensitive component of time-varying magnetic field. Three mutually perpendicular hollow coils form a magnetic field measuring sensor with the same identity; the area of each air-core coil is 100 cm ^{2}. Known by electromagnetics [2]:

$$E = N\frac{d\phi}{dt} = NS\frac{dB}{dt} \qquad (2)$$

In Formula (2): E is the induced electromotive force of the measuring coil in the electromagnetic field, N is the number of turns of the coil, S is the area of the turns, ϕ is the magnetic flux of each coil, and B is the magnetic induction in each coil. Know from Equation (2):

$$B = \frac{1}{NS}\int Edt \qquad (3)$$

Therefore, the measured electromotive force at both ends of the air-core coil is dealt to obtain value of B. It can be seen from the frequency characteristics of magnetic field in the spot welding process that the inverter frequency of a intermediate-frequency inverter spot welding machine is generally between several hundred Hz and 20 kHz. The maximum measurable frequency of the spot welding magnetic field equipment is set at 30K Hz.

In Equation 3, NS is constant after the completion of the air-core coil sensor, so while calibrating the sensor, as long as this constant is determined, the conversion coefficient of the sensor can be determined. The sensors designed in this paper are calibrated by the China's Metrology Academy. The NS (area of turns) values in three directions are: 0.084473m^2 in X direction, 0.084096 m^2 in Y direction, and 0.086583 m^2 in Z direction. The NS (area of turns) values in three directions has less than 1% nonlinear error in 0 ~ 30 KHz.

3.2 Design of measuring hardware

In this paper, the NIUSB6251 portable data-acquisition card is selected with a total sampling frequency of 1.25 MSPS and an AD conversion accuracy of 16 bits, which is used to measure the induced electromotive force of the air-core coils in three directions.

Measuring welding current while measuring magnetic field will help to analyze the problem. MIYACHI MB-500-15 type coils are used to measure welding current.

3.3 Design of software

The measured induced-electromotive force on the three coils in magnetic field respectively corresponds to the change rates of B value in the three coils, and according to the formula 3, calculating the integral of the induced electromotive force is to obtain the value of B.

Measuring the induced electromotive force at both ends of the coil of welding current corresponds to the changing rate of welding current, and in order to obtain the welding current value, the induced electromotive force on the coil needs processing in the form of integration.

In order to obtain current and magnetic induction, the data processing flow of this paper is shown in Figure 1. The integrated B value is calculated as Equation 4.

$$B_c(f) = \sqrt{B_x^2(f) + B_y^2(f) + B_z^2(f)} \qquad (4)$$

B denotes the magnitude of the magnetic induction intensity at the frequency *f* which is referred to herein as the integrated B value, and respectively represent the magnitude of the magnetic induction intensity in *x, y*, and *z* directions of the frequency.

The measuring equipment can give information such as: current, three induced electromotive forces on the measuring coil of magnetic field, current curve, magnetic induction curve in three directions, spectrum distribution of current, spectrum distribution of magnetic induction intensity in three directions and spectrum distribution of comprehensive Value of B.

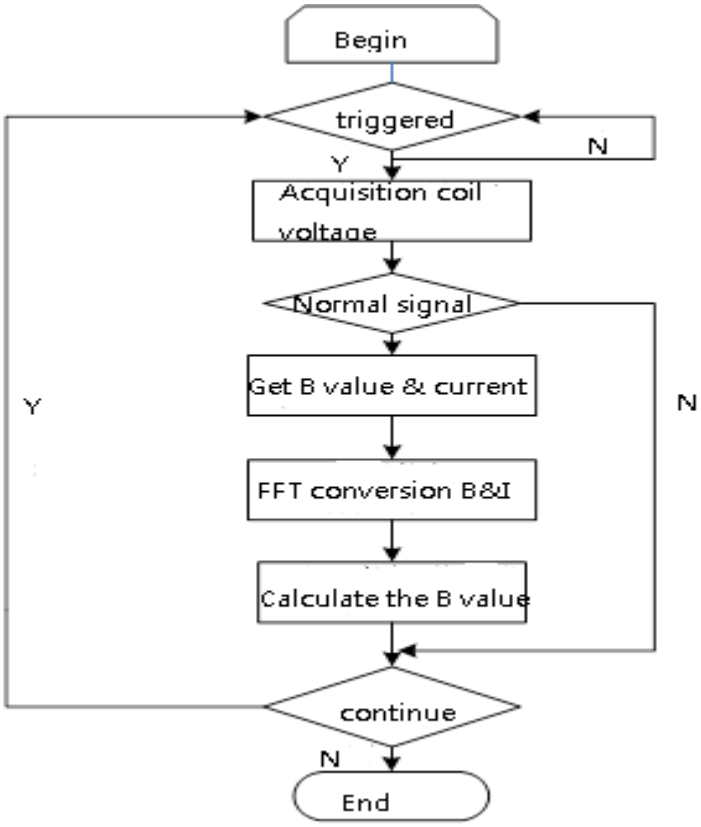


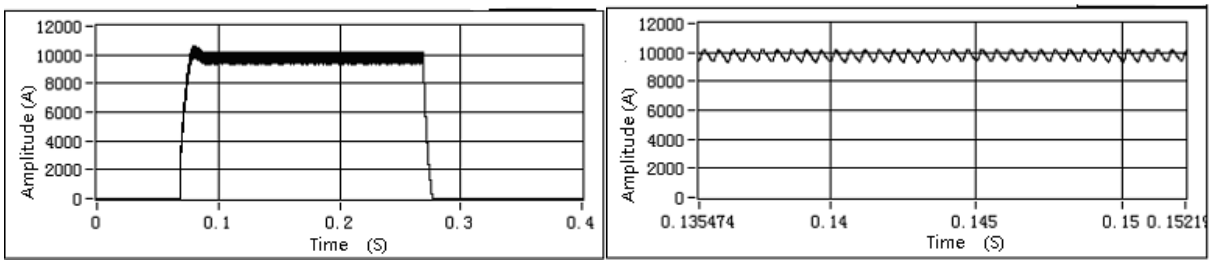
Figure 1. data processing flow

4. Applications

The magnetic field measurement system constructed in this paper is used to measure the electromagnetic field of the intermediate-frequency-inverter spot welding.

The welding machine used was an imported resistance welder of clamp-type and intermediate-frequency, the measuring point was selected on the side of the welding circuit, and the distance from the plane of the welding circuit was 25 cm.

Figure 2-a shows the current curve obtained in the place where the vertical distance of from the measuring spot to the welding circuit is 25 cm, this curve is obtained by the integration of the induced electromotive force on the current measuring coil. Since the inverter frequency of spot-welding machine is 1KHz, the output current is inverted and rectified, so 2KHz ripple current is superimposed on the curve of output current, as shown in Figure 2-b.

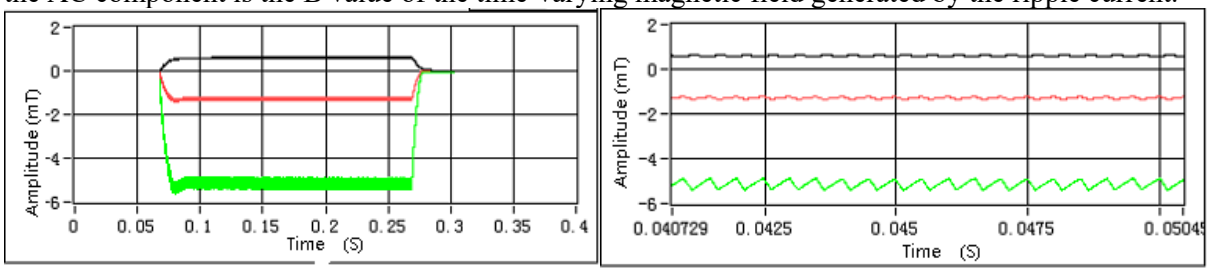


(a) (b)

Figure 2. curve of welding current

Figure 3-a shows the measurement result of instantaneous B value. Figure 3-b shows the magnetic induction curve at the constant current section. It can be seen that the magnetic induction curves and current curves in the coils in the three directions are similar, and they are DC signals superimposed

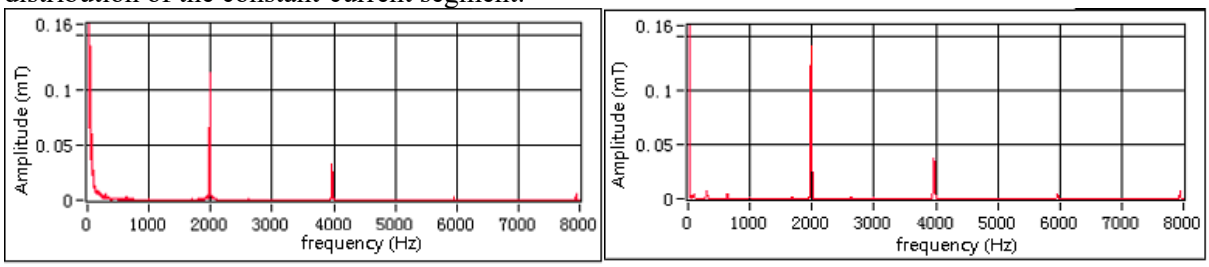
with AC component. The DC part is the static magnetic field generated by the constant current, and the AC component is the B value of the time-varying magnetic field generated by the ripple current.



(a) (b)

Figure 3. curve of instantaneous B-value

Figure 4 shows the frequency-domain distribution of integrated B-value. Figure 4-a shows the integrated B-value spectrum distribution of a complete welding process including the non-energization period, the current-rising period, the constant-current period, the current-dropping period, and the current cut-off period, etc. within 4 seconds; Figure 4-b only intercepts the B-value spectrum distribution of the constant-current segment.



(a) (b)

Figure 4. Spectrum distribution of integrated B values

It can be seen from Fig. 4 that when the frequency-domain distribution is calculated according to the B-value time-domain signal, different time periods of analysis will affect the final result. In Figure 4-a, the integrated B-value distribution at 1000 Hz is continuous, that is, it has a certain amplitude at each frequency; while in Figure 4-b, the data is discrete, that is, the B values are distributed at several discrete frequencies.

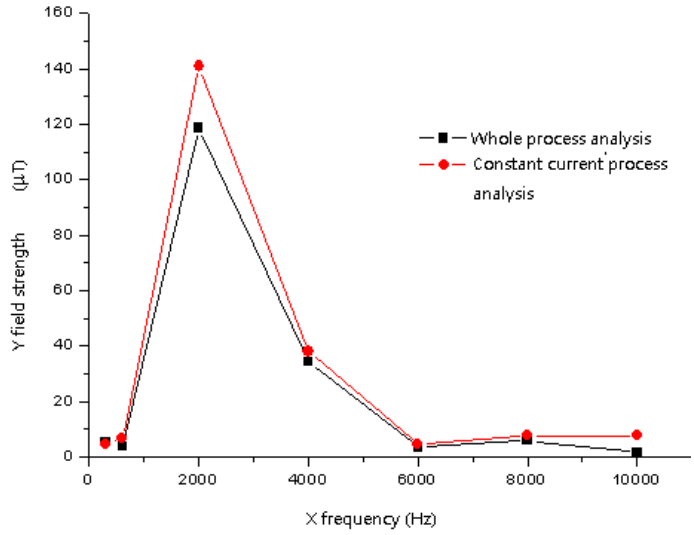


Figure 5. Comparison of comprehensive B values

The difference in this distribution is caused by the rising and falling sections of the current. The rising and falling sections of the current are non-periodic signals, so a continuous spectrum distribution is generated, and the constant current section is basically cyclical as shown in Figure 3-b,

so B values are only distributed at discrete frequency values. At the same time, in Figure 4-a and Figure 4-b, the amplitudes at each frequency are also very different. As shown in Figure 5, the amplitude obtained from the analysis of complete whole process is smaller than the amplitude in constant current process. This difference in amplitude is due to the fact that during the data processing, in mapping process from the time domain to the frequency domain, the time length will have a certain influence on the result of the Fourier transform.

5. Conclusion

The measuring device can quantitatively measure the magnetic induction intensity at a certain point in the spot welding environment, give the spectral distribution of the B value of the point, and provide a measuring means for studying the spatial distribution of the spot welding electromagnetic field.

When measuring the electromagnetic field in the spot welding process, the current at the beginning and end of the welding, the current with a non-periodic signal will cause continuous distribution of the amplitude in the frequency domain. For the short-term process of spot welding, selecting different periods of analysis will lead to totally different results. In-depth research will be conducted in subsequent work.

Acknowledgments

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