On-Line Estimation of Electrode Face Diameter Based on Servo Gun Driven by Robot in Resistance Spot Welding

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Abstract. Enlargement of electrode face diameter in resistance spot welding was the main factor that led to undersize nugget diameter. A mathematics model was established to estimate electrode face diameter by applying the characteristic that servo gun can detect axial wear online but not equip additional measurement apparatuses. Firstly the precision of servo gun was compensated to assure it can meet the requirement of axial wear measurement online. Then the model was established to estimate electrode face diameter online by a minimum amount of experiment data to determine the numerical constant in the model. To verify the model, electrode life tests for welding different galvanized steels were carried out. It was shown that estimation results of the model agreed well with the experiment results and spot welding the steels with higher electrode wear rate would result in a shorter electrode life.

1 Introduction

More coated steels with high strength have been used in auto body manufacturing to improve corrosion resistance and safety requirements of automobile. Resistance spot welding was the main joint method to assembly auto body. But spot welding of these coated steels required higher electrode force, welding current than uncoated steels and was easer to alloy and stick with electrode face because of their special physics and chemistry properties [1, 2]. It took serious and uncertain electrode wear when welding these steels, which resulted in short electrode life and inconsistent weld quality.

Electrode wear led to electrode face diameter enlargement, pitting on electrode face and electrode length reduction. Electrode face diameter enlargement reduced current density and pressure on electrode face, which was the main factor that affected weld quality. Some methods were presented to estimate electrode face diameter at different wear stages. D.bracun applied image processing technology to capture indentation shape in work-pieces to estimate the electrode face diameter by analyzing the characteristics of indentation shape [3]. Wei Li established a model to estimate electrode face diameter by measuring dynamic resistance at different weld numbers [4]. But additional apparatuses such as camera devices and resistance measurement instruments had to be equipped on gun arm if applying these methods to inspect electrode face diameter, which was not convenient to be widely used in product line online and the signals were easily disturbed by poor working conditions.

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Servo gun is a new developing gun to be used in spot welding, which adopt servo motor as driving power. Compared with pneumatic gun, servo gun has more accurate electrode force control [5]. It can control electrodes softly touch work part, which reduce impact on electrodes and improve electrode life [6, 7]. As the encoder of servo gun can feed back electrode displacement online, so the axial electrode wear can be gotten by analyzing the data in encoder at different wear stages. This paper studied to apply the method that servo gun can expediently measure axial wear but not equip additional measurement apparatuses to achieve electrode face diameter estimation online.

2 Calibration of Axial Wear Measured by Servo Gun

Robot integrated with servo gun was shown in Fig.1. The robot is six-axis freedom robot, which has the maximal load of 200kgf and repeating position accuracy of ±5um. Up-electrode of servo gun mounted on robot arm is driven as the seventh axis of robot. Robot move servo gun to a preordered position along pre-designed route, and then the up and down electrode were closed to clamp parts. When electrode force was increased to a pre-determined value, robot controller gives a welding signal to welding controller, which runs welding programs to finish welding.

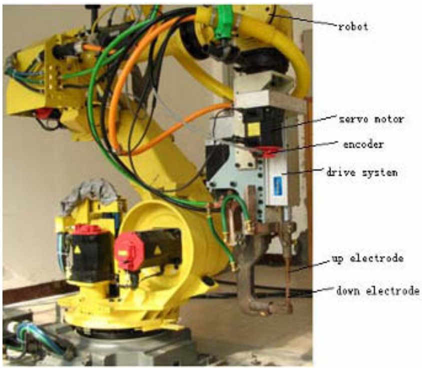


Fig. 1. Robot integrated with servo gun

The encoder of servo gun can feed back electrode displacement online, when a new set of electrodes was replaced on servo gun, robot controller run the initialization program to record the displacement of new electrodes. As shown in Fig.2, the up-electrode was moved to softly touch a calibration board to record the electrode displacement, and then the up and down electrode were closed, so the displacements of new electrodes were recorded by the encoder. After about some weld spots, electrode length was reduced because of electrode wear, then detection program of axial wear was run to record the displacements of worn electrodes. Compared with the two

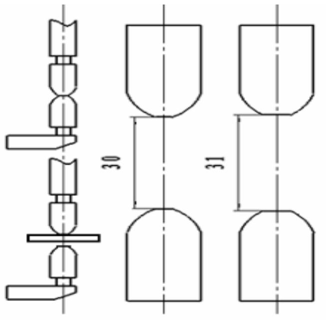


Fig. 2. Procedure of axial wear detection by servo gun

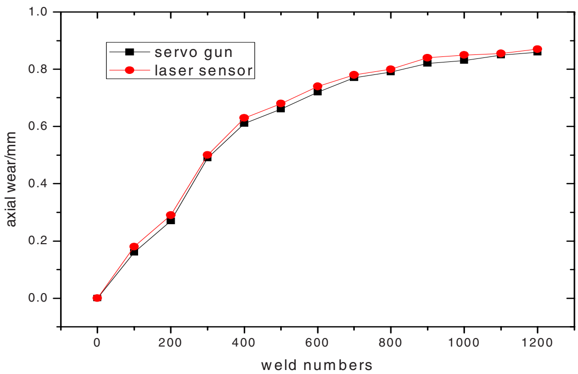


Fig. 3. Calibration of axial wear

displacement values of new electrodes and worn electrodes recorded by encoder, the axial wear at different weld numbers could be expediently gotten by servo gun online.

Axial wear of welding coated steels was only about 90 um per 100 welds [8], which had high precision requirement for servo gun. A feeler gauge was used to simulate axial wear to calibrate measurement precision of servo gun. It was shown that the measurement precision of servo gun was about 20um. To verify the precision of servo gun, axial wear measured by servo gun and laser sensor with 0.25um precision was carried out during the electrode life test. As shown in Fig.3, axial wear measured by servo gun was always about 10um less than laser sensor, which was mainly induced that transmitting error of servo gun reduced the feedback displacement recorded by encoder. As the transmitting error was a system error, so it could be compensated. Measurement precision of servo gun improved to 10um after compensating the system error, which can meet the requirement of axial wear measurement online. In Fig.3, Axial wear measured by servo gun included up and low electrode wear. Generally, up and low electrode had uniform wear for AC weld gun [9], so each electrode axial wear could be calculated.

3 Model of Electrode Face Diameter Estimation Online

As welding current and electrode force were constant in electrode life test, so electrode wear rate was mainly affected by current density and pressure on electrode face for fixed steel. The higher current density would result in a higher temperature on electrode face, so the propensity of alloying and sticking between the electrode face and steel sheet was enhanced, which accelerated material removal from electrode face and increased electrode face diameter. Similarly, the higher pressure would facilitate extrusion of softened electrode face material to the face periphery and result in electrode face diameter enlargement. During electrode life test, the current density and pressure on electrode face were decreased with electrode face diameter increasing because of electrode wear. So electrode wear rate and material removal from electrode face were inconstant with electrode face diameter increasing.

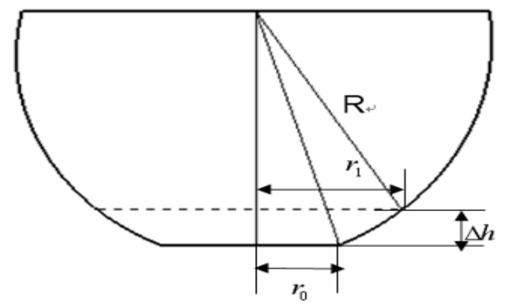


Fig. 4. Electrode face geometry

The quantity of material removed from electrode surface could be assumed to be linearly proportional to the product of the pressure and welding current density on the electrode face [10]. Therefore,

$$\Delta V = kPD \tag{1}$$

Where ΔV is the volume of material being removed, k is the proportional constant, P is the average pressure on the electrode face, and D is the current density on the electrode face. After welding some welds, as shown in Fig.4, the electrode face radius was enlarged from r_0 to r_1, and electrode length was accordingly reduced Δh. The volume of this slice of material removed can be expressed by

$$\Delta V = (\pi / 6)\Delta h(3r_0^2 + 3r_1^2 + \Delta h^2) \tag{2}$$

Where Δh is the electrode length reduction, r_0 is the initial radius of new electrode, r_1 is the radius of worn electrode. In equation (1), the pressure P and current density D can be expressed by

$$P = F / \pi r_1^2 \tag{3}$$

$$D = I / \pi r_1^2 \tag{4}$$

Where F and I are the electrode force and welding current respectively. Substituting equations (2), (3) and (4) into equation (1) gives

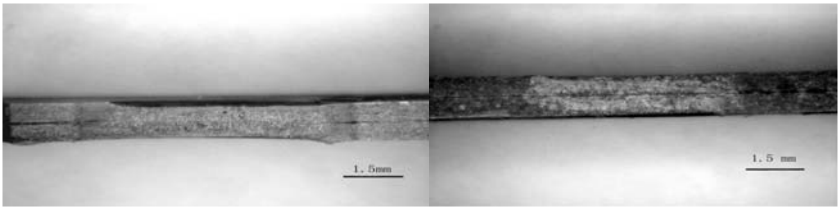
$$(\pi / 6)\Delta h(3r_0^2 + 3r_1^2 + \Delta h^2) = kFI / \pi^2 r_1^4 \tag{5}$$

In equation (5), r_0, F and I were known, Δh could be gotten by servo gun online and r_1 could be measured by carbon imprint method, so k could be calculated by substituting these experiment data into equation (5) and taking the average of the results derived from electrode life test. When the axial wear Δh was detected by servo gun online for every some welds, the worn electrode radius r_1 could be estimated according to equation (5).

4 Model Verifying

To verify the model, electrode life tests were carried out on four different galvanized steels. Spherical electrode with electrode face diameter of 5mm was applied. Electrode force was kept at 2200N and welding time was set at 10 cycles. The welding current was set just below the expulsion limit for each of the tested steels. Tensile shear test was performed every 100 welds and each shear test had three samples to record maximum shear force as weld strength. Carbon imprint method was used to get electrode face conditions and electrode diameters at different weld numbers. Electrode life was defined as the weld number when weld strength fell to below 80% of the maximum value.

Electrode face diameter enlargement (radial wear) reduced current density and pressure on electrode face. When the electrode face diameter increased beyond a certain value, the current density was too low to achieve acceptable nugget size, and then electrode life was end.



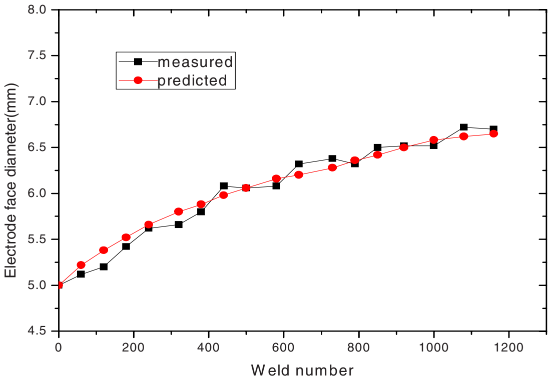
200 welds 1200 welds

Fig. 5. Weld cross sections at different weld numbers

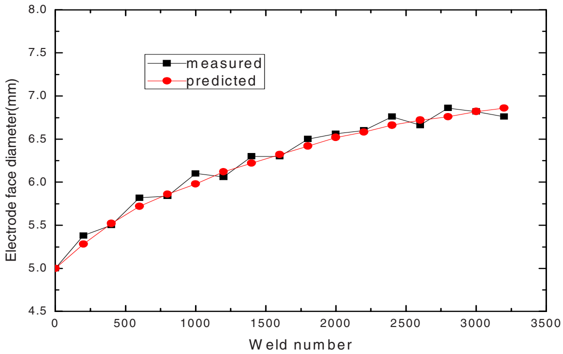
Weld cross sections of welding steel A at different weld numbers were shown in Fig.5. A good weld with shearing force of 9.3kN was formed at 200 welds, whose nugget diameter (measured from cross section of weld spot) was about 5.8mm. But at 1200 welds, there was no nugget formed and shearing force was only about 7.2kN because the enlargement of electrode face diameter decreased current density and pressure on electrode face, which formed undersize nugget. Especially spot welding of coated steels would result in serious and uncertain electrode wear, so estimation of electrode face diameter online could reduce the effect of electrode wear on weld quality.

From equation (5), it could be seen that increasing welding current and electrode force would accelerate electrode wear rate. It also could be seen that a less diameter would induce faster electrode wear rate, which agreed well with the experiment results that higher electrode wear rate would be resulted in at earlier weld stage. For example, the average axial wear rate of welding steel A was about 0.86um per weld before 300 welds and then decreased to 0.23um per weld after 600 welds. The wear rate of electrode face diameter was faster at earlier welds than at later welds. Physically, coefficient k in equation (5) is primarily determined by material and coating characteristics as well as welding parameters. During electrode life tests, spot welding the steel with higher electrode wear rate would result in a shorter electrode life and a larger k value. Therefore, coefficient k indicated the propensity of materials to be removed from the electrode face and k was different for different steels.

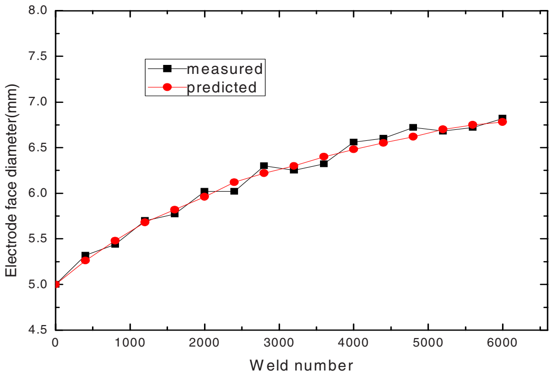
According to the experiment data derived from electrode life tests, the verifying results of estimation model for four steels were shown in Fig.6. It was shown that the measured electrode face diameters had a certain amount of variation. For instance, the actual welding current level fluctuated around the average value from weld to weld with a deviation of about 200A and the measurements of electrode face diameter from carbon imprints could also induce some errors. In addition, the axial wear measured by servo gun also had an error of about 0.01mm. Despite of these error factors, the estimation results derived from the model based on servo gun detecting axial wear online agreed well with the experiment results.



(a) Galvanized steel A



(b) Galvanized steel B



(c) Galvanized steel C

Fig. 6. Estimation of electrode face diameter for different steels

5 Conclusions

A mathematics model was established to estimate electrode face diameter online by applying the new characteristic that servo gun can detect axial wear online in resistance spot welding. The main conclusions were as follows:

1. The measurement precision of servo gun improved from 20um to 10um after compensating the transmitting error, which can meet the requirement of axial wear measurement.
2. Different galvanized steels were used in electrode life tests to verify the model. It was shown that the prediction results of the model agreed well with the experiment results.
3. The model revealed that higher welding current and electrode force would accelerate electrode wear and higher electrode wear rate would be induced at the earlier welds for a less electrode face diameter.

Acknowledgements

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