Inverter Resistance Spot Welders with Servo Gun System

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Abstract - Resistance spot welding is widely employed in a manufacturing process. In recent years, the requirement for more sophisticated quality control procedures has been in the mass production industries. The requirements for high productivity and good welding qualities have lead to the development of more widely available microprocessor or computer based control. In this study, the inverter-type power source and welding servo gun are developed.

I. INTRODUCTION

Along with the rapid growth in microelectronics and power electronics technologies, various advanced control methods have been successfully implemented in real time and shown to be useful in controlling resistance spot welding systems with high dynamic performance.[1-4] In this paper, a nonlinear feedback controller is chosen that can control the resistance spot welding system with high dynamic performance by means of the recently developed feedback linearization techniques.

During welding, heat is generated at the surfaces of the metal specimens and this heat is proportional to the product of the square of the weld current, resistance to the flow of current and the welding time. Due to generation of heat during the welding interval, physical changes also occur at the sheet-to-sheet interface and in the weld nugget. The temperature of the weld nugget and its surrounding area rise, resulting in the expansion of components and the variation of their resistances. In the constant current control method for resistance spot welding systems, the generated heat is varied due to the change of the specimen resistance. Spatter is increased when the generated heat is arbitrarily varied. This problem can be avoided by means of the constant power control. This method controls the output power which is the product of the output current and the output voltage of the resistance spot welding systems to be constant. As the result, the generated heat can be kept constant, resulting in less spatter. However, the overall constant power control systems generally have nonlinear dynamics. So, the gain tuning of power control system is very difficult and we can not obtain the high dynamic performance of resistance spot welding systems.

In this paper, we propose a new power control scheme for resistance spot welding systems. We attempt to control the nonlinear power control system for spot welders to be a fully linearized system by applying the recently developed nonlinear feedback linearization techniques based on differential geometry theories.[5,6] Also, the servo gun and torque control system are developed. As the results, we have some advantages over the previous methods such as pneumatic gun systems. One of them is that the precise control of the pressure can be attained during the welding process. In addition, production time and cost can be decreased.

II. CONVENTIONAL POWER CONTROL

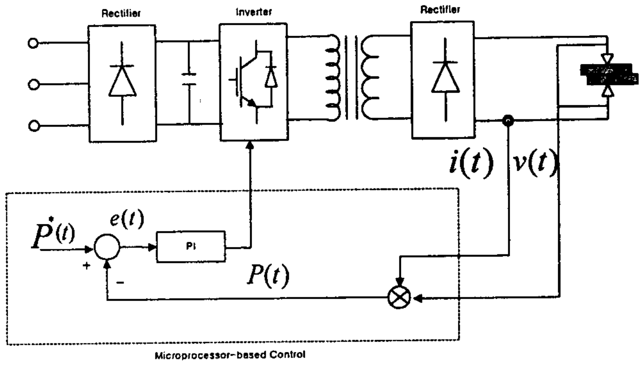
In this section, we describe the conventional approach to constant power control of the resistance spot welding system whose block diagram representation is shown in Fig. 1. The nomenclature for the symbols and notations that appear frequently in our development is as follows.

$P^*(t)$	: power command
$P(t)$	: measured power $(= v(t)\, i(t))$
$e(t)$	: $P^*(t) - P(t)$
$v_{tr1}(t)$	: primary terminal voltage
$v_{tr2}(t)$	: secondary terminal voltage
$v(t)$	: voltage between electrode tips
$i(t)$	: secondary current
R	: resistance between electrode tips
L	: load inductance
N	: transformer turn ratio $(= N_1 / N_2)$
K	: power amplifier gain
k_p	: proportional gain
k_i	: integral gain

It is assumed that the power transformer of the constant power control system shown in Fig. 1 is ideal. Then, the ideal transformer and the load can be described as Fig. 2. From Fig. 2, we have

$$v_{tr2}(t) = L\frac{di(t)}{dt} + Ri(t) \tag{1}$$

$$P(t) = v(t)i(t)$$
$$= Ri^2(t) \tag{2}$$



Fig, 1. configuration of the constant power control system for resistance spot welders

$$v_{tr1}(t) = K\{k_p e(t) + k_i \int e(t)dt\} \quad (3)$$
$$= Nv_{tr2}(t)$$

where

$$e(t) = P^*(t) - P(t) \quad (4)$$

As mentioned earlier, the resistance varies as the temperature of the weld nugget and its surrounding area rise. However, if the resistance is assumed to be constant for a short period, the following transfer function can be obtained.

$$\frac{I(s)}{V_{tr2}(s)} = \frac{1}{Ls+R} \quad (5)$$

$$\frac{V(s)}{V_{tr2}(s)} = \frac{R}{Ls+R} \quad (6)$$

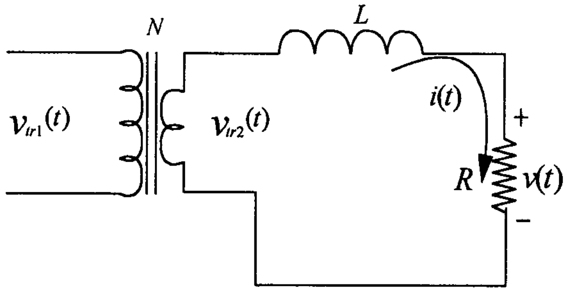


Fig. 2. Equivalent circuit of the ideal transformer and the load

III. LINEARIZATION OF THE POWER CONTROL SYSTEM

Since it is usually difficult to analyze and design nonlinear systems, it would be desirable to attempt to linearize them. In this section, a nonlinear feedback controller is proposed that can control the resistance spot welding system with high dynamic performance by means of the recently developed feedback linearization techniques. Taking the time derivative on both sides of the eq. (2), we have

$$P(t) = v'(t)i(t) + v(t)i'(t)$$
$$= (-Rv(t)/L + Rv_{tr2}(t)/L)i(t)$$
$$+ (-Ri(t)/L + v_{tr2}(t)/L)v(t)$$
$$= -\frac{2R}{L}i(t)v(t) + 2v_{tr2}(t)v(t)/L$$
$$= -\frac{2R}{L}P(t) + 2v_{tr2}(t)v(t)/L \quad (7)$$

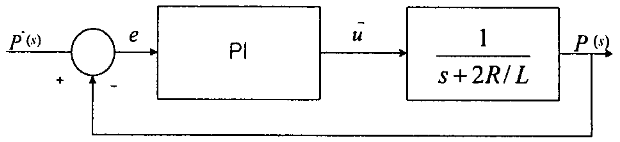


Fig. 3. Block diagram of the completely linearized power control system.

Let the new input $\bar{u}$ be defined as

$$\bar{u} = 2v_{tr2}(t)v(t)/L \quad (8)$$

Then, eq. (7) can be written as

$$\frac{d}{dt}P(t) = -\frac{2R}{L}P(t) + \bar{u} \quad (9)$$

Let the new input $\bar{u}$ be chosen as the following PI controller.

$$\bar{u} = k_p e(t) + k_i \int e(t)dt \quad (10)$$

As shown in Fig. 4, the input-output characteristics of the closed-loop system consisting of (4), (9), and (10) are completely linear. Combining (8) and (10), we have

$$v_{tr2}(t) = \frac{L}{2v(t)}(k_p e(t) + k_i \int e(t)dt) \quad (11)$$

This, with (3), leads to (12).

$$v_{tr1}(t) = \frac{NL}{2v(t)}(k_p e(t) + k_i \int e(t)dt) \quad (12)$$

If the power amplifier gain is K, the D/A converter output of the microprocessor-based control system should be v_{tr1}/K. The microprocessor-based control system designed for resistance spot welding systems is shown in Fig. 4.

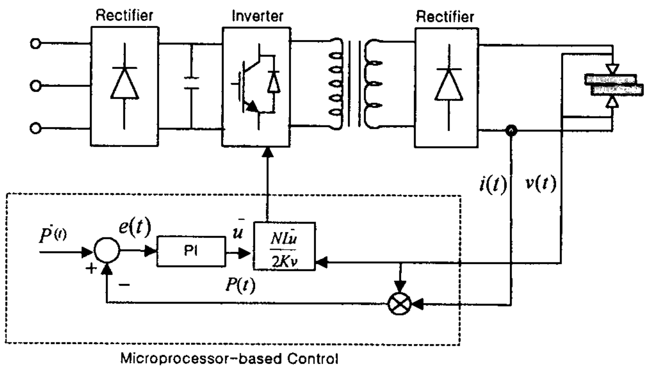


Fig. 4. Configuration of the microprocessor-based control system

IV. DESIGN OF A SERVO GUN SYSTEM

In this paper, the servo gun and torque control system for spot welders are developed as shown in Fig. 5. As the results, we have some advantages over the previous methods such as pneumatic gun systems.

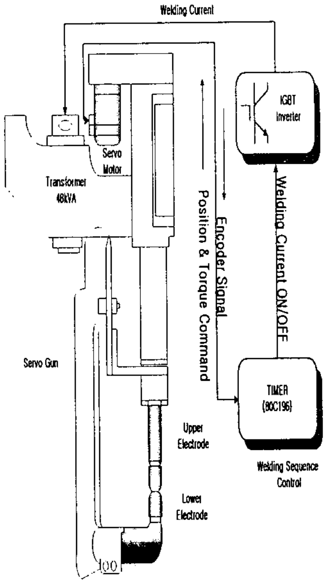


Fig. 5. Servo gun system for spot welders

One of them is that the precise control of the pressure can be attained during the welding process. In addition, production time and cost can be decreased. The torque generated in the servo motor is transferred to the electrodes via timing belt, ball screw, and LM guide as shown in Fig. 6.

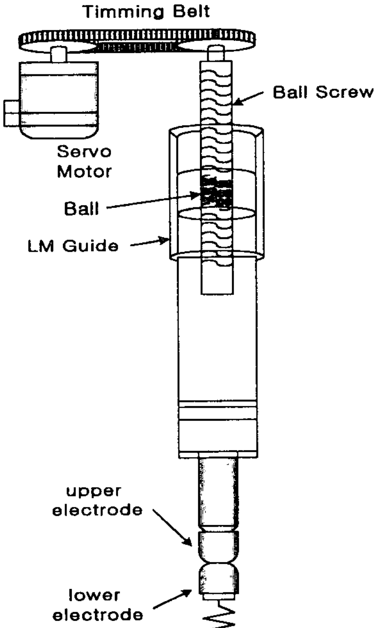
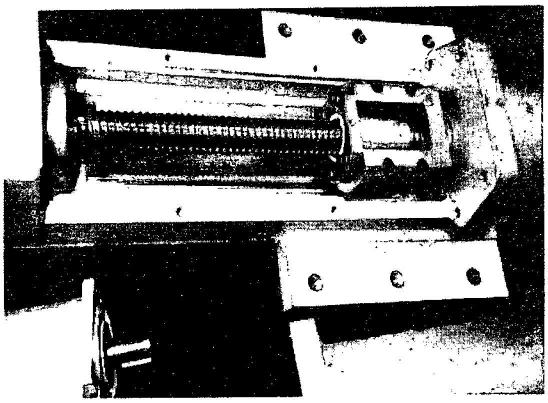


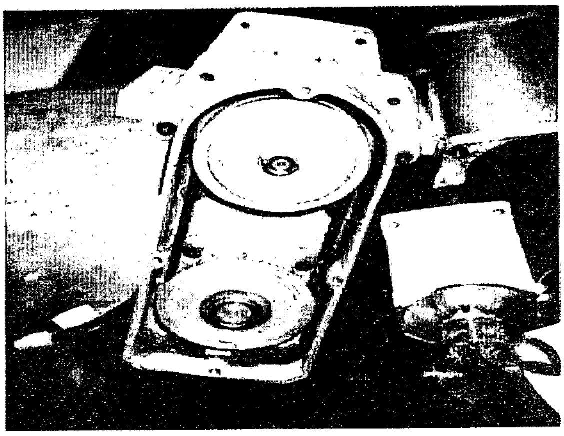
Fig. 6. Torque transfer of the servo gun

V. EXPERIMENTAL RESULTS

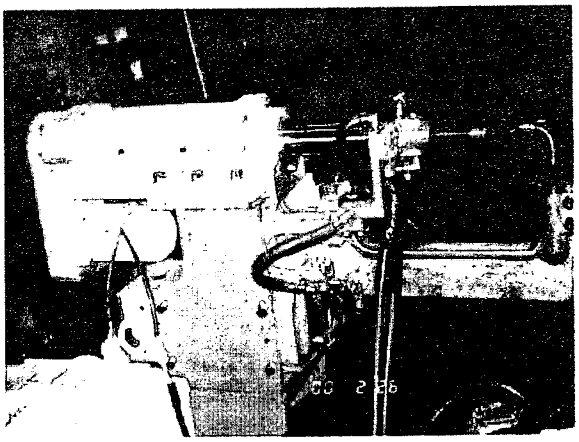
The performances of our control scheme developed in the preceding sections were studied through some experiments. For performance evaluation of torque controller, we have implemented the servo gun system as shown in Fig. 7. The motor is a 3 phase AC synchronous servo motor with rated power of 750Watt, rated speed of 3000rpm, and rated torque of 2.4Nm.



(a) Ball screw and LM guide



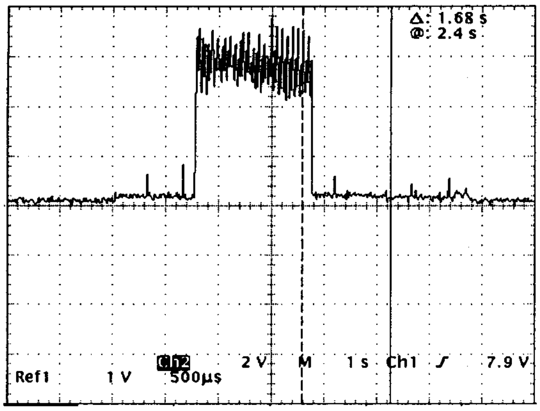
(b) Timing belt



(c) servo gun

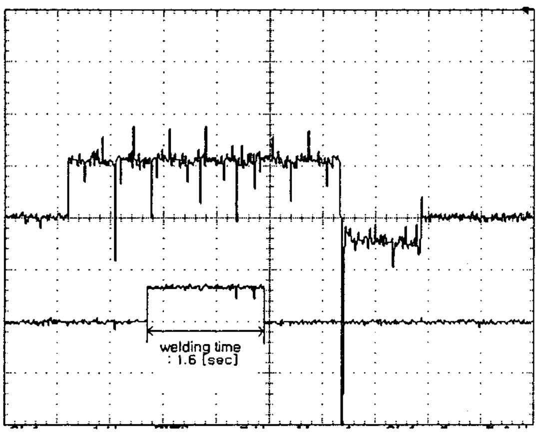
Fig. 7. Implemented servo gun system

In order to evaluate the performance of the proposed power control system in Fig. 4, we implemented a inverter power source with rated power of 75kVA. The constant power command of 15kW is applied to the power control system in Fig.4. The experimental result is shown in Fig. 8. Then, the constant torque command of 250kgf is applied to the servo gun system. We could obtain the experimental result as shown in Fig. 9.



(5kW/div)

Fig. 8. Experimental result of constant power control



(200kgf/div)

Fig. 9. Constant torque control during spot welding

Finally, the spot welding was done on the 0.5t steel using the power control system in Fig. 4 and servo gun system in Fig. 7. The experimental result is shown in Fig. 10.

VI. CONCLUSION

In this paper, we controlled the nonlinear power control system for spot welders to be a fully linearized system by applying the recently developed nonlinear feedback linearization techniques. Our control scheme is simple. In addition, the easy gain tuning as well as the high dynamic performance of resistance spot welding systems could be obtained. Also, the servo gun and torque control system are developed. As the results, we have some advantages over the previous methods such as pneumatic gun systems. One of them is that the precise control of the pressure can be attained during the welding process. In addition, production time and cost can be decreased.

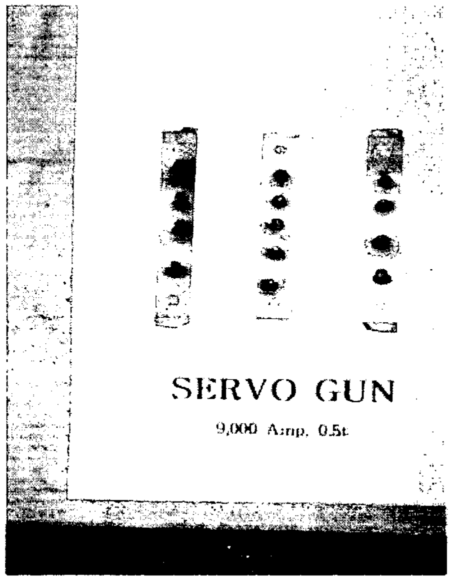


Fig. 10. Spot welding results

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REFERENCES

[1] B. N. Waller and P. M. Knowlson, "Electrode separation applied for quality control in resistance welding," *Welding Journal*, Vol.44, No.4, pp.168-174, 1965

[2] W. F. Savage, E. F. Nippes, and F. A. Wassel, "Dynamic contact resistance of series spot welds," *Welding Journal*, Vol.57, No.2, pp.43-50, 1978

[3] D. W. Dickinson, J. E. Franklin, and A. Stanya, "Characterization of spot welding behavior by dynamic electrical parameter monitoring," *Welding Journal*, Vol.59, No.6, pp.170-176, 1980

[4] S. R. Patange, T. Anjaneyulu and G. P. Reddy, "Microprocessor-based resistance welding monitor," *Welding Journal*, Vol.64, pp.33-38, Dec., 1985

[5] I. J. Ha, "The standard decomposed system and noninteracting feedback control of nonlinear systems," *SIAM J. Contr. and Optim.*, vol.26, pp.1235-1249, 1988

[6] I. J. Ha, A. K. Tugcu, and N. M. Bostany, "Feedback linearizing control of vehicle longitudinal acceleration," *IEEE Trans. Automat. Contr.*, vol.34, no.7, pp.689-698, July, 1989

[7] Jun Seo-Moon, Gyu-Sik Kim, Jae-Mun Kim and Chung-Yuen Won, "Power Control of Resistance Spot Welding System with High Dynamic Performance," *Proceedings of IEEE IECON'97*,vol.2 pp.845-849, 1997.