STUDY OF DYNAMIC RESISTANCE BASED CONTROLLERS FOR RESISTANCE SPOT WELDING PROCESS

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ABSTRACT

This work deals with the study of dynamic resistance based controllers namely 1) Proportional Integral Controller and 2) Fuzzy Logic Controller. These two controllers were tested under different external disturbances. All welds were performed on 1 mm to 1mm low carbon steel sheets. The relevant data were collected and the behavior of the dynamic resistance was studied. Destructive tests were performed on the welded samples to measure the strength of the welds. The test results show that the controllers based on dynamic resistance produced good welds even under external disturbances.

Keywords : *Resistance spot welding, PI controller, fuzzy logic controller, dynamic resistance, and low carbon steel.*

INTRODUCTION

Resistance spot welding is a welding technique that uses electric current to produce the heat required to weld joints. It is a widely used welding process, which finds utility in many industries such as the automobile industry, sheet metal production industry, etc. [1]. Mass production in these industries brings about the need for fast and accurate control techniques. It is necessary to use controllers that can automatically monitor the welding process and ensure good quality welds, without the destruction of the joint. Ever increasing standards, nationally and internationally, mean that the welds must conform to strict quality measures. To serve this purpose, it is necessary to use efficient welding controllers.

Many controllers are available to monitor weld joint quality [2,3,4]. They are based on different criterion. Weld joint or nugget quality can be monitored by control of various criteria such as current, voltage, dynamic resistance, thermo emf [5], welding energy, thermal expansion, infrared energy, acoustic emission, ultrasonic energy, etc. Because of the strong influence that the dynamic resistance exerts on the quality of the weld nugget, it is efficient to design controllers based on this criterion. Also, dynamic resistance is convenient to measure. This has made dynamic resistance based controllers very popular [6].

Dynamic resistance is the resistance across the feying surfaces of the two metal sheets that are to be welded. The dynamic resistance is called so because it changes constantly throughout the weld cycle. A better understanding of the theoretical behavior of the dynamic resistance during the weld cycle can be obtained from [7,8]. In order to obtain high quality weld joint, the dynamic resistance can be monitored and regulated at an appropriate level during the entire weld cycle. This eliminates the need to test the weld joint by destructive techniques, after the formation of the joint.

The performance of dynamic resistance based controllers can be evaluated by testing them under various influences such as poor fit up conditions, poor surface conditions, and presence of secondary impedance. The occurrence of these disturbances during welding can be understood from the following.

In industrial conditions, the sheets to be welded may not fit together properly. This is known as poor fit up condition. To imitate this condition, small sheets were sandwiched between the edges of the sheets to be welded, producing a small gap [9]. Sometimes, large size of material may be welded. The presence of large material in the secondary side of the transformer of the welding machine will cause variation of current at different positions. This condition was artificially created by introducing a plate of mild steel (size : 100 x 150 x 10 mm) in the secondary side of the transformer. Plates to be welded may also be exposed to extreme weather or industrial conditions. Thus a coat of rust or oil might be present on the surface of the plates. In this study, rusted sheets were used.

EXPERIMENTAL WORK

Experiments were conducted using the two controllers, namely,

1. Proportional Integral (PI) Controller with Feedback (Developed by Welding Research Institute, BHEL, Tiruchirappalli.
2. Primary Feedback Fuzzy Logic Based Controller [10].

The connections were made as shown in Fig. 1. Welds were made using a rocker arm type spot welding machine of 30 k VA capacity, having electrode tip diameter of 6 mm. Experiments were carried out on 1 mm to 1 mm low carbon steel sheets. For the fuzzy controller only a single sample was welded for each experimental condition. A weld time of eight cycles was used for these experiments. In the case of the PI controller, ten samples were welded for each condition in order to take scattering into consideration. These experiments were carried out with weld current of 65% and 75% heat percentage and weld time of 12 cycles. For both the controllers, the experiments were carried out under various influencing factors such as poor fit up conditions, poor surface conditions, and presence of secondary impedance. During the experiments, voltages and currents were measured using an HBM make, computer based, data acquisition system. The voltages were measured by means of pick up coils attached to the welding electrodes. The currents were measured using a toroid coil. From these values of currents and voltages, the dynamic resistances were calculated [11,12,13] and the corresponding curves were drawn. The dynamic resistance is the ratio of voltage to current. The ΔR values were calculated for each of the dynamic resistance curves. ΔR is defined as the change in dynamic resistance per cycle. Further, in order to confirm

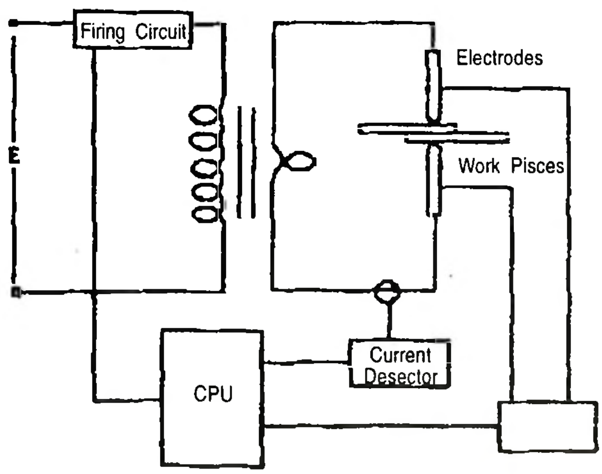

Fig. 1 : Experimental Setup

the strength of the welds, tensile shear tests were performed in a universal testing machine.

RESULTS OF THE EXPERIMENTS

Behavior of Dynamic Resistance when using PI Controller

Fig. 2 shows the variation of dynamic resistance with weld time, with heat percentages of 65% and 75% under the varying influences, that is normal conditions, poor fit up conditions, presence of secondary impedance, and poor surface conditions.

Fig. 2 a) shows the dynamic resistance curves for weld current of 65% for normal samples. Although the positive slopes are different for each of the ten samples (ΔR ranges between 0.005 and 0.009 mΩ), the slopes for the last few cycles, i.e. cycles 9-12, are about the same (ΔR is ~ 0.005 mΩ for all samples). Samples 1,2,6,7,8,9 and 10 all have similar positive slopes (~ 0.004 mΩ) and negative slopes (~ 0.002 mΩ)

Fig. 2 b) shows the dynamic resistance curves for normal conditions and heat percentage setting of 75%. There is a steep increase in the dynamic resistance, where ΔR is 0.026 mΩ, followed by a gradual decrease in resistance, where ΔR is 0.005 mΩ. In samples 3, 4 and 5, a sudden drop in dynamic resistance can be seen. This sudden drop in resistance is due to flash that occurred during welding. When flash occurs, some metal is expelled from the sheets. This reduces the thickness of the sheets, i.e. the path of the current, which causes a reduction in resistance. Samples 6-10 exhibit similar slopes, ΔR on the positive slope is 0.006 mΩ and ΔR on the negative slope is 0.003 mΩ.

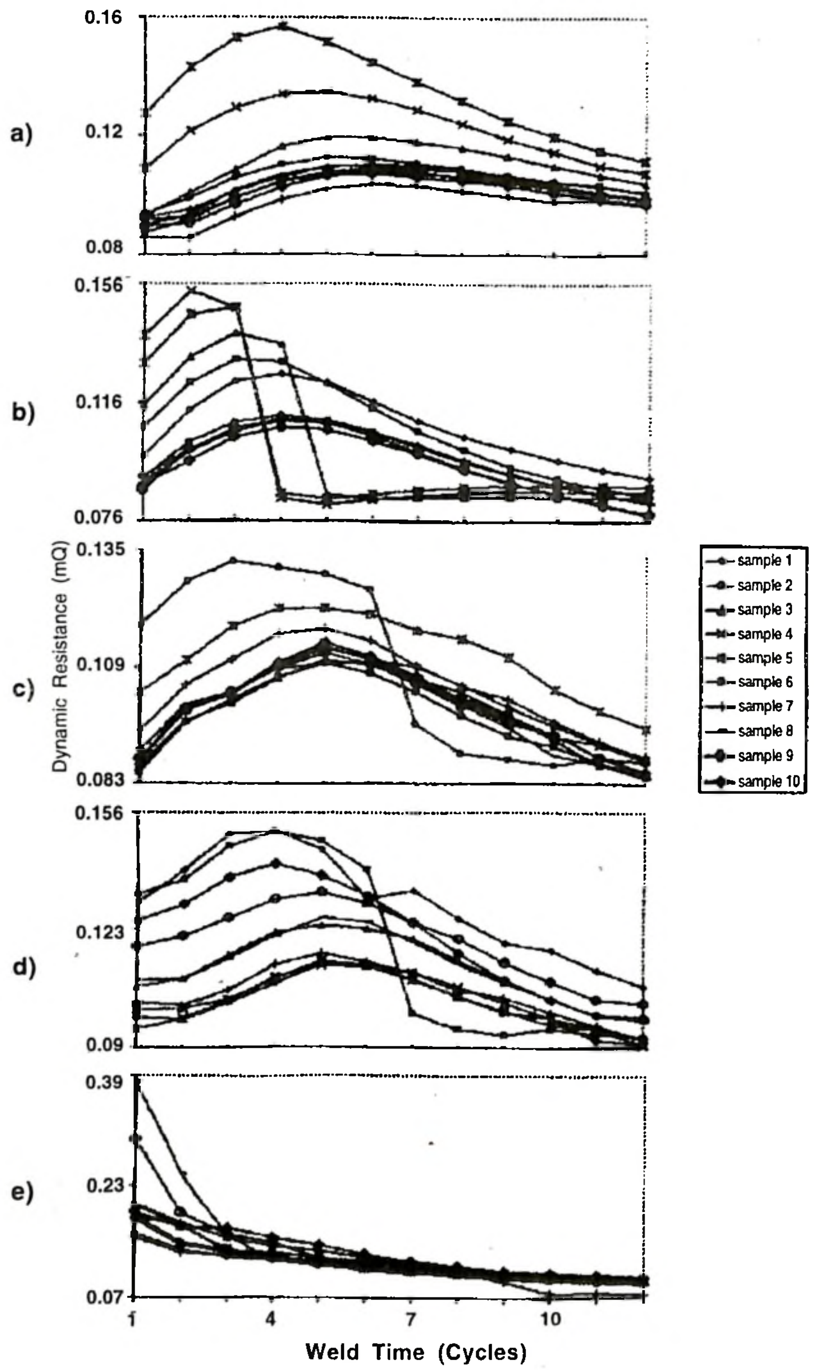

Fig. 2 : Variation of Dynamic Resistance with Weld Time for a) Weld Current of 65% for Normal Samples b) Weld Current of 75% for Normal Samples c) Weld Current of 75% for Samples having Poor Fit Up Condition d) Weld Current of 75% for Samples under the influence of Secondary Impedance, and e) Weld Current of 75% for Samples having Poor Surface Condition.

All remaining samples were welded with 75% heat percentage under different conditions. The dynamic resistance curves for poor fit up condition are shown in Fig. 2 c).

For all samples, the curves are similar except for a sudden drop in the dynamic resistance in cycle 6 of sample 6. For the slopes on the positive side, ΔR is 0.007 mΩ and on the negative slope it is 0.005 mΩ in all the cases except sample 6.

Fig. 2 d) shows the dynamic resistance curves for welds made under the unfluence of secondary impedance. In Fig. 2 d), samples 3-8 have similar ΔR values and the nature of the curves are the same. ΔR on the positive slope is 0.004 mΩ and on the negative slope is 0.0035 mΩ. Sample 2 shows a sudden drop in the dynamic resistance in the sixth cycle. The curves of samples 1.9, and 10 are slightly different even though the general trends of the curves are the same. The values of ΔR are ~0.004 mΩ on the positive slope and 0.005 mΩ on the negative slope.

The dynamic resistance curves for welds made under poor surface conditions are shown in Fig. 2 e). The curves are distinct in the fact that there is no rising portion of the curve. The dynamic resistance starts at an initial high value and takes a deep plunge. In samples 1-5, the value of dynamic resistance starts at as high as 0.203 mΩ and drops to as low as 0.09 mΩ. Samples 6-10 exhibit values as high as 0.157 and 0.38 mΩ and drop to between 0.75 and 0.099 mΩ. The absence of the rise in the dynamic resistance in the curves for poor surface condition can be attributed to the presence of rust. Rust on the surface of the weld samples is very brittle. It has an initial high resistance. But as soon as pressure is applied at the start of the weld cycle, the brittle, rusty surface breaks down forming good contact between the sheets. Thus the resistance suddenly drops. This can be seen as the presence of the steep down slope of the dynamic resistance curve, without any initial rise in dynamic resistance.

BEHAVIOR OF DYNAMIC RESISTANCE WHEN USING FUZZY CONTROLLER

Figs. 3 a) and b) show the dynamic resistance curves for samples welded using the fuzzy logic controller under the different

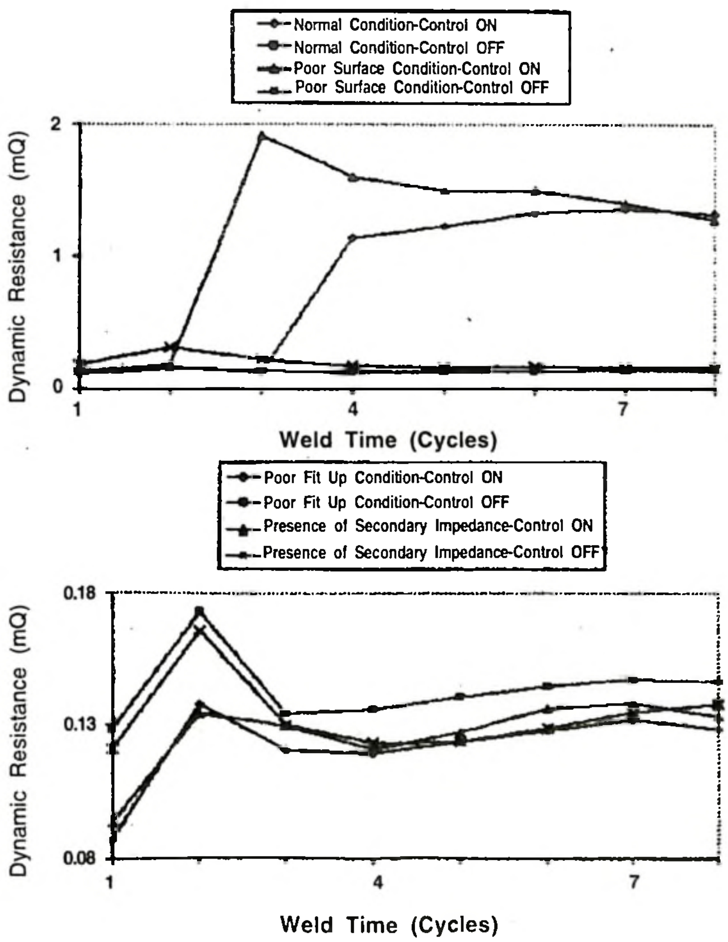

Fig. 3 : Variation of Dynamic Resistance with Weld Time
a) For Normal Conditions and Poor Surface Conditions
b) For Poor FR Up Condition and Presence of Secondary Impedance

influences with the control ON and OFF. Only one sample was welded under each condition. In Fig. 3 a), the weld made under normal condition with control ON shows a flat region followed by a sudden increase in dynamic resistance after cycle 3. During the increase ΔR is 1.009 mΩ Then there is a gradual rise where ΔR is 0.045 mΩ. For the weld under normal condition with control OFF, there is a gradual rise in dynamic resistance where ΔR is 0.040 mΩ and then a gradual fall where ΔR is 0.001 mΩ.

In Fig. 3 b), the dynamic resistance curves for welds made under poor fit up conditions with control ON and OFF are similar except for the initial values. There is a steep increase of the dynamic resistance where ΔR is 0.05 mΩ with control ON and 0.45 mΩ with control OFF. This is followed by a steep decrease, where ΔR is 0.017 mΩ with control ON and 0.40 mΩ with control OFF. And finally, a gradual increase in dynamic resistance can be observed, where ΔR is 0.004 mΩ for both cases.

In Fig. 3 b), during the initial steep rise in the dynamic resistance curves under the influence of secondary impedance, ΔR is 0.04 mΩ with control ON and 0.045 with control OFF. In the next stage there is a decrease in dynamic resistance, where ΔR is 0.006 mΩ with control ON and 0.021 mΩ with control OFF. Finally the dynamic resistance gradually increases, where ΔR is 0.005 mΩ with control ON and 0.003 mΩ with control OFF.

For the sample with rusted surface and control ON, in Fig. 3 a), the curve exhibits a steep increase in dynamic resistance, where ΔR is 0.742 mΩ. This is followed by a decrease in resistance, where ΔR is 0.106 mΩ. For the sample with control OFF, there is a slight increase in dynamic resistance, during which ΔR equals 0.121 mΩ, followed by a gradual fall in resistance, during which ΔR equals 0.024 mΩ.

TENSILE SHEAR TEST RESULTS FOR PI CONTROLLER

The results of the tensile shear tests can be plotted and studied to compare the influence of the three external factors, on the production of a satisfactory weld. Figure 4 shows the tensile shear test results for the PI controller under the influence of the various disturbances. The tensile shear load is calculated as the ratio of the actual shear load to the expected shear load as per DVS specification for 1 mm to 1 mm samples (6-10 kgf). The results show that the tensile shear ratio is

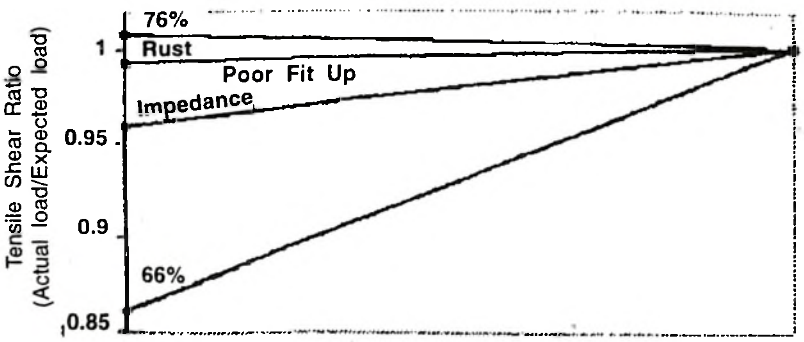

Fig. 4 : Tensile Shear Test Results (PI Controller)

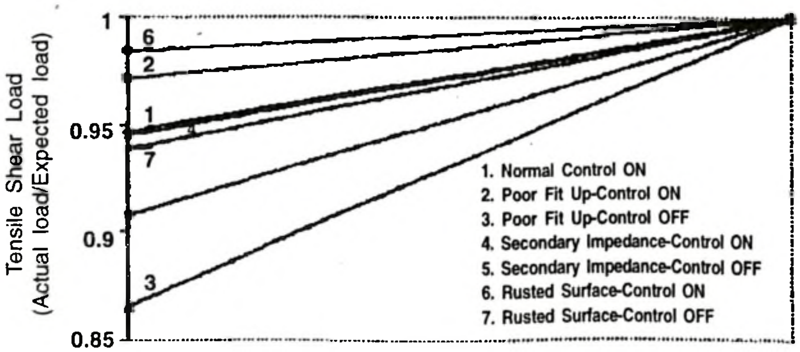

Fig. 5 : Tensile Shear Test Results (Fuzzy Controller)

significantly low only in the case of the weld performed with low weld current, that is heat percentage of 65%. The weld strength was low only for low heat percentage. It is high for the other cases. This indicates that the controller was able to perform well for all other external disturbances.

TENSILE SHEAR TEST RESULTS FOR FUZZY CONTROLLER

The tensile shear load ratios for fuzzy controller under the influencing parameters are shown in Figure 5. This figure shows that the tensile shear load ratio is significantly lower only with feedback controller OFF. This indicates that the strength of the weld is only reduced in this case. Thus it can be shown that the fuzzy controller based on dynamic resistance has been able to compensate effectively for all three disturbances.

CONCLUSIONS

These studies show how the dynamic resistance curves behave under normal and varying conditions such as, poor fit up, presence of secondary impedance, and poor surface conditions. Also, the following conclusions can be made.

1. The behavior of the dynamic resistance in response to the variation of fit up, surface condition, and presence of secondary impedance was different.
2. The external disturbances affected the process control only in the first few weld cycles. There was no subsequent effect on the weld quality due to the compensation made by the controller.
3. Both the PI controller and fuzzy controller based on dynamic resistance were able to perform well and produce good welds even under the influence of external disturbances.
4. From the results of the analysis of the two controllers, dynamic resistance has proven to be a good criterion for the control of the quality of welds in resistance spot welding process.

REFERENCES

1. Arthur L. Phillips, Ed., "Welding Handbook Sec. 5 : Applications of Welding", American Welding Society, Macmillan and Co., 1967.
2. H. Polrolniczak, "Equipment for quality control of resistance spot welding — A comparison of their capabilities and their selection criteria", Proceedings of resistance welding conference, Duisburg, Germany, p. 80, 1989.
3. K. Asok Kumar, Dr. W. Faber, N. Winkler, "Correlation of process recordings with weld quality and evaluation of the controllers", Workshop on Trends in resistance welding in Indian industries, Welding Research Institute and Indian Institute of Welding, Tiruchirappalli, India, November, 1995.
4. S. Manoharan, V.R. Samuel, K. Asok Kumar, Dr. K.G.K. Murti, "Feedback controller to achieve 100% weld quality - state of art", Workshop on Trends in resistance welding in Indian industries, Welding Research Institute and Indian Institute of Welding, Tiruchirappalli, India, November, 1995.
5. S. Manoharan, K. Asok Kumar, V.R. Samuel, Dr. K.G.K. Murti, C. Krishna, S. Srinivas, "Development of Real Time Feedback Controller for Resistance Welding", Symposium on Joining of Materials, 1996.
6. K. Asok Kumar, S. Manoharan, V.R. Samuel, Dr. K.G.K. Murti, "Evaluation of dynamic resistance as quality criterion for resistance spot welding", Welding in automobile industry, national seminar, IIW, Jamshedpur, April 1996.
7 Arthur L. Phillips, Ed., "Welding Handbook Vol. 2: Welding Processes: Gas, Arc, and Resistance", American Welding Society.
8. Arthur L. Philips, Ed., "Welding Handbook-Section 1-Fundamentals of Welding", American Welding Society, Cleaver-Hume Press Ltd., 1963.
9. Jerry E. Gould, Menachem Kimchi, Tom Mitchell, "Effect of fit up conditions when using constant current control systems for resistance spot welding".

   International Congress and Exposition, Detroit, Michigan, U.S.A., 1993.
10. Miyachi Technos Corporation, *"Method of controlling resistance welding using Fuzzy reasoning"*, European patent office, publication number 0 669 182 2A.

11. Peter Kuy, "Monitoring dynamic resistance during the formation of resistance spot welding", *Welding Journal, 1974.*

12. S. Bhattacharya and D. Andrews, "Significance of dynamic resistance curves in the theory and practice of resistance spot welding", *Welding and Metal Fabrication,* September, 1974.

13. D.W. Dickinson, et al, "Characterization spot welding behavior by dynamic electrical parameter monitoring", *Welding Journal,* June, p. 170 S, 1980.

14. Yongjoon Cho, Sehun Rhee, "New technology for measuring dynamic resistance and estimating strength in resistance spot welding", *Measurement Science and Technology,* vol. 11, no. 10, Aug., p. 1173-1178, 2000.

15. Goran Andersson, "Advanced control of the spot welding process", *Svetsaren/ A welding review,* vol. 53, no. 3, p. 24-27,1998.

16. Hallie Forcinio, "Tighter process control ensures weld quality", *Robotics World,* Vol. 17, no. 1, Jan-Feb., p. 17-20, 1999.

17. Anon, "Evaluating the integrity of spot weld joints in metal", Insight: Nondestructive testing and condition monitoring, vol. 40, no. 11, Nov., p. 778-779, 1998.

■

OBITUARY

We are deeply mourn about the sudden demise of

Mr. K. BHALARIA

Representative of our
Industrial Corporate Member,
M/s Kanubhai Electricals, Kolkata

&

our Life Member

Mr. G. M. SEN

Kolkata

May their Soul rest in Peace