INFLUENCE OF WELDING FORCE ON DYNAMIC RESISTANCE IN SPOT WELDING

[1]Tomáš BURKET, [1]Marie KOLAŘÍKOVÁ, [1]Vít JANOUCH

[1]*Czech Technical University in Prague, Faculty of Mechanical Engineering, Prague, Czech Republic, EU*
Tomas.Burket@fs.cvut.cz

https://doi.org/10.37904/metal.2024.4936

Abstract

This paper focuses on the effect of contact force on dynamic electrical resistance in resistance spot welding which effects amount of heat generated in time. Methods for welding parameters monitoring and signal processing are presented. Changes in the positions of significant peaks (corresponding to certain events during the welding cycle) with increasing forces (1,3 – 3,8 kN) are used to describe resistance curves. The diameters of the weld nuggets were measured and the correlation with the peaks was evaluated. The results show that the welding force has a significant effect on the dynamic resistance curve shape and affects final weld size. Spot weld analyser with given method for signal processing used in this study has proven to be useful for measuring dynamic resistance signals during different welding forces.

Keywords: Resistance spot welding, dynamic resistance, welding force, automotive industry, weld quality

1. INTRODUCTION

Resistance spot welding (RSW) is a highly productive welding process used in automotive manufacturing due to its fast-welding times, robot implementation, and convenient holding mechanism. However, nondestructive visual inspection is not possible due to the location of the weld between the parts being welded and the occurrence of unpredictable conditions such as electrode wear, fitting gaps, and sheet surface contamination. For those reasons, and because of the huge number of welds performed, it is important to optimize the process, validate it, monitor parameters and the variables entering the process. Online spot-welding quality inspection applications focus on monitoring of welding parameters (I, U, F, t), dynamic electrical resistance (DR), electrode displacement, thermographic testing, ultrasonic testing or monitoring of electrode wear [1, 2].

A spot weld is created by the Joule heat generated by the passage of current through sheets. The heat generated is proportional to the total resistance, which is composed of several partial resistances, including specific resistivity of the materials to be welded and the electrode material, contact resistances between electrodes and sheets and contact resistance between welded sheets. The highest resistance value is almost always at the faying surface of sheets, allowing the weld nugget to form and grow exactly where it is needed.

The resistance of material to be welded depends on its thickness, effective current flow cross-section, and significantly on temperature. Resistance changing in time during the welding cycle is therefor called dynamic resistance. The contact resistance increases with the resistivity of the materials and is inversely proportional to the contact area and surface roughness. Surface roughness limits the real contact area, forcing electrons to flow through narrow areas, causing excessive heating. When electrode force is applied, asperities collapse, increasing the area and reducing contact resistance and temperature extremes. This means that, in general, higher forces lead to less heating due to reduced contact resistance [1, 3]. On the other hand, larger electrode forces also reduce workpiece geometrical uncertainties (such as excessive gaps) and improve consistency [4]. Dynamic resistance has been reported to give a good indication of weld quality [5].

This paper focuses on measurement of dynamic resistance, its possible application for quality control and especially examines the effect of changing welding force on its waveform. To describe the variations in the resistance curve, changes of positions of significant peaks that correspond to certain events during the welding cycle are used.

2. EXPERIMENT

2.1. Materials and equipment

The aim of the experiment is to examine the behavior of dynamic resistance in spot welding of hot dip galvanized steel sheets HX 180 BD + Z100 of thickness 0.7 mm. This cold forming interstitial free steel is used in the automotive industry and has the following mechanical properties: yield strength 210 MPa, ultimate strength 320 MPa and ductility 39 %. The weight of the coating for both sides is 100 g/m2 (average thickness 7 μm). Pneumatically driven press-type resistance spot welder DALEX PMS 11-4 with 180 kW MFDC medium frequency 1000 Hz inverter was used for welding. The control unit is MEGA 1 MF QSF/S with software SER MEGA 2. Cooling is provided by a 2.7 kW PL 80/100 Cool-3 closed-cycle cooling system.

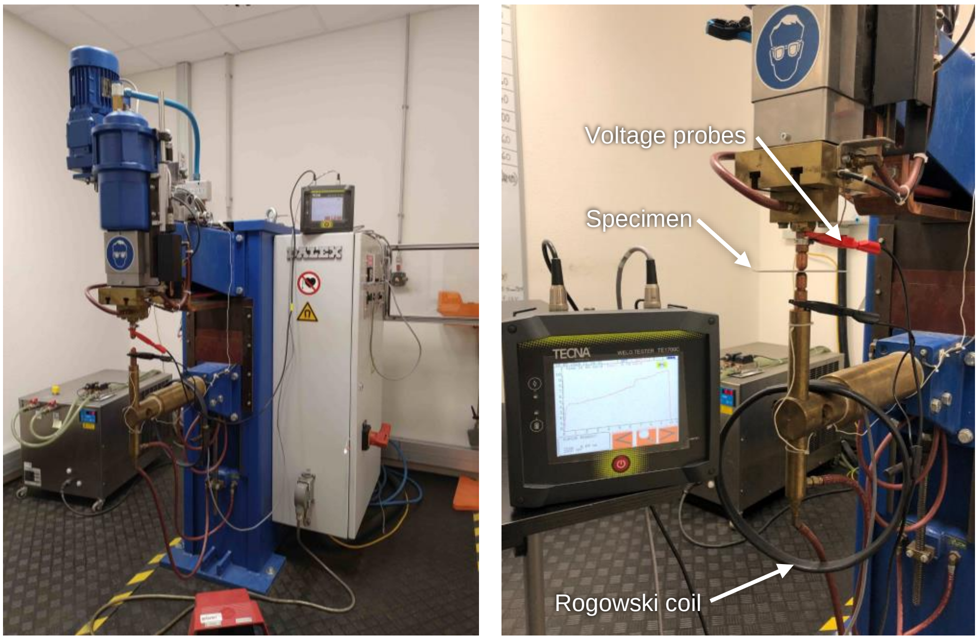

Figure 1 Resistance spot welder DALEX PMS 11-4 with welding analyser TECNA connected.

The electrode caps used for the experiment are Type 39 D 1978-2 according to WV internal standards. The most important dimension is the contact area diameter of 5 mm. The electrode material is CuCr1Z - a high copper alloy with small amounts of zirconium and chromium added to improve its mechanical properties. The chemical composition is: 98,98 % Cu; 0,9 % Cr; 0,12 % Zr (A 2/2 classification according to ISO 5182).

For the recording of parameters during the welding of samples analyser TECNA TE1700C was used. It is a universal and portable device. For voltage measurements, the probes are connected directly to the electrodes and the current measurement is done by a Rogowski coil. The analyser is also able to use a force measurement probe. The sampling frequency was 8.33 kHz (0.12 ms). **Figure 1** shows used apparatus.

2.2. Experimental procedure

Optimized parameters for this material in this experiment (welding current 7 kA, force 2.3 kN and time 240 ms) were obtained by ISO 14327 procedure. A simple welding cycle without pulses was used. A series of six force values was established in the range of 1.3 – 3.8 kN to examine the effect of changing welding force on dynamic resistance.

Table 1 Various welding parameters used in the experiment.

HX 180 BD + Z100		
Current (kA)	**Force (kN)**	**Time (ms)**
7	1.3	240
	1.8	
	2.3	
	2.8	
	3.3	
	3.8	

In the first step analyser TE1700C was used to verify desired forces. For every force setting (total of 6 values) five welds were carried out, while current and voltage were measured. The illustration of the measurement can be seen in **Figure 2**. In detail in **Figure 3 (right)** it is clear to see that signals are corrupted with harmonic and subharmonic components of two frequencies super positioned on itself. These components are the same in every sample. By clearing the signal, we can process them further and compare positions of peaks.

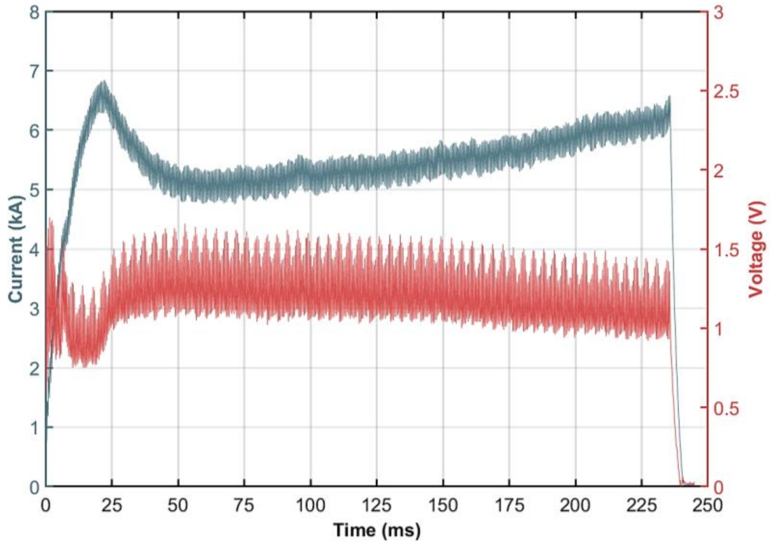

Figure 2 Typical raw signals of welding current and electrode voltage.

In this case Discrete Fourier Transform (DFT) can be used to recognize the frequency components present in the finite sequence signal. DFT is a mathematical method used to transform a sequence of time-domain samples into a frequency-domain representation. As an efficient algorithm for computing the DFT can be used Fast Fourier Transform (FFT). It reduces the computational complexity from $O(N^2)$ to $O(N\log N)$, where n is the data size [6].

DFT definition using FFT algorithm can be written using this formula (equation (1)):

$$X(k) = \sum_{n=0}^{N-1} x(n) \cdot e^{-j2\pi kn/N} \qquad (1)$$

where $X(k)$ is the complex DFT result at frequency index k, $x(n)$ is the original signal at discrete time index n, N is the total number of samples and $e^{-j2\pi kn/N}$ represents a complex sinusoidal function at frequency k [6].

In **Figure 3 (left)** is Single-sided amplitude spectrum of X(t) for current signal. Frequencies up to half of sampling frequency i.e. Nyquist frequency are plotted, two of which are significant. These are 2030 Hz and 4020 Hz.

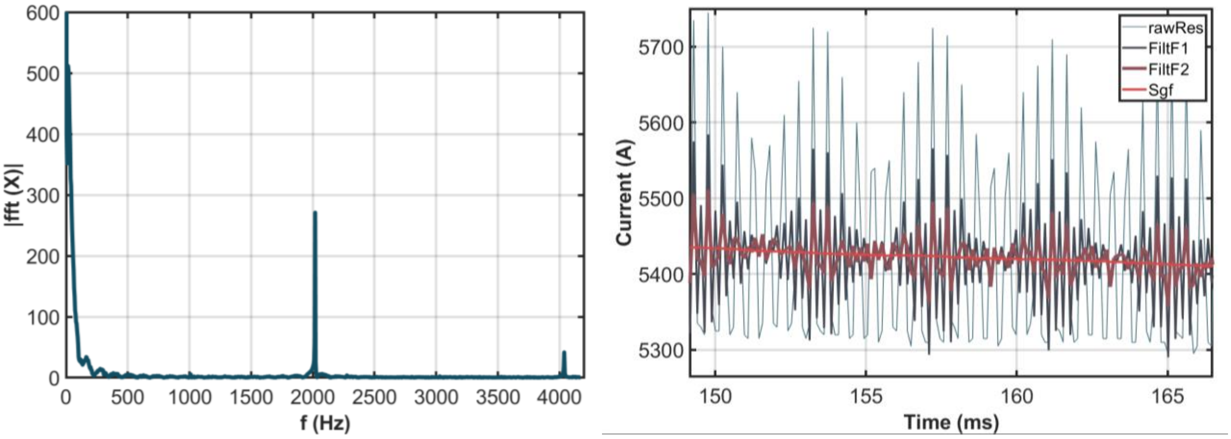

Figure 3 Single-sided amplitude FFT spectrum of current signal (left). Application of filters on signal (right).

Once these components are identified, they can be reduced or eliminated, thus cleaning the signal. A Bandstop Filter can suppress amplitudes of specific frequencies within a certain range while allowing frequencies outside this range to remain. In other words, it is creating a notch in the frequency spectrum. In **Figure 3 (right)** application of Bandstop filter for notable frequencies (F1, F2) from FFT is illustrated on current signal. After filtering two frequencies, Savitzky-Golay filter (Sgf) is implemented in a way that a method of linear least squares is used to fit successive subsets of adjacent points with a low-degree polynomial.

3. RESULTS AND DISCUSION

After filtering voltage and current signals on their own, dynamic resistance curve is calculated by dividing welding voltage by current and is plotted in one graph in **Figure 5 (left)** with the forces distinguishable by colour.

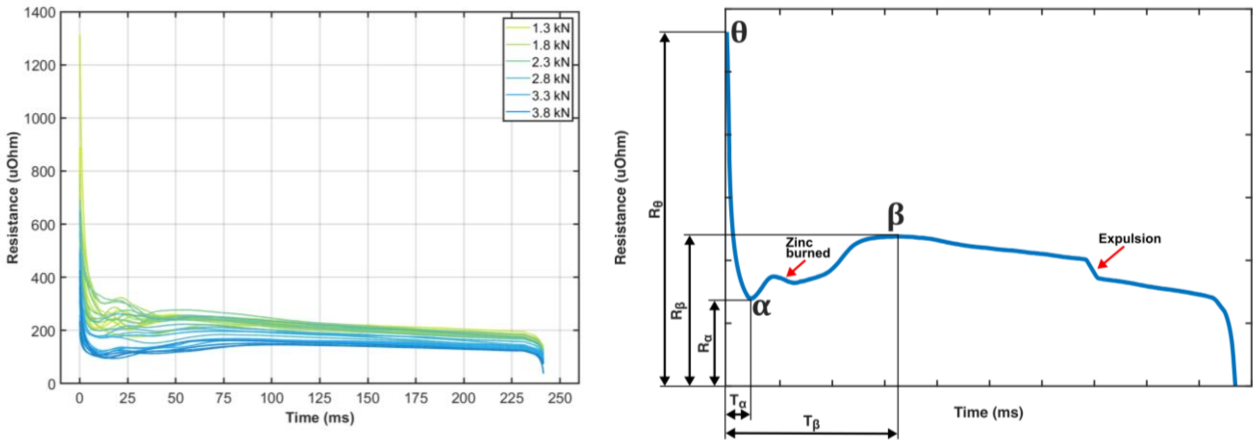

Figure 4 DR curves with increasing force (left). Generalized DR curve with significant peaks (right)

On every dynamic resistance curve, three significant peaks can be seen, which is illustrated on **Figure 4 (right)**. Their progression with increasing force can be seen in **Figure 5**. Parametric formulation of each peak movement is in equation 2.

First Θ peak at time 0 ms represents a moment at the start of current cycle, before the asperities collapse so the contact resistance is prevailing. Lower electrode force leads to a smaller area of electrical contact thus larger contact resistance. Drop in Θ peak resistance with increasing force is most significant of all.

The α peak resistance drops less than the Θ peak with increasing force and does not move in time. From this can be concluded that distinctive increase in temperature (reason for the raise of R after α peak) occurs at the same time for all forces, but higher forces result in faster decline of contact resistance. However, this is in a contradiction with [7], where authors observe movement of α peak to longer times.

Third significant peak β moves to lower resistance values in similar rate as α peak but it shifts to longer times with increasing force. It is assumed that this is since to reach the β peak the beginning of the weld formation (melting of the material) must be achieved. With overall smaller resistance values it takes more time to happen. After this peak the size of molten portion of material increases (decline of R after β peak). During this time, from β peak to the end of welding cycle, the nugget can grow. As this time shortens with increasing weld force it results in reduced nugget size [7]. This was verified experimentally. Average values of the diameters of the weld nuggets are shown in **Table 2**.

Table 2 Average diameter of weld nugget for each group of samples with a particular welding force value.

Welding force (kN)	1.3	1.8	2.3	2.8	3.3	3.8	4.3	4.8
Avg. weld diameter (mm)	6.1	5.8	4.3	4	3.8	3	1.5	0

On the other hand, too much low welding forces result in increased occurrence of spatter. This can be seen on illustration curve in **Figure 5 (right)**, spatter appears as a sharp drop on the dynamic resistance curve.

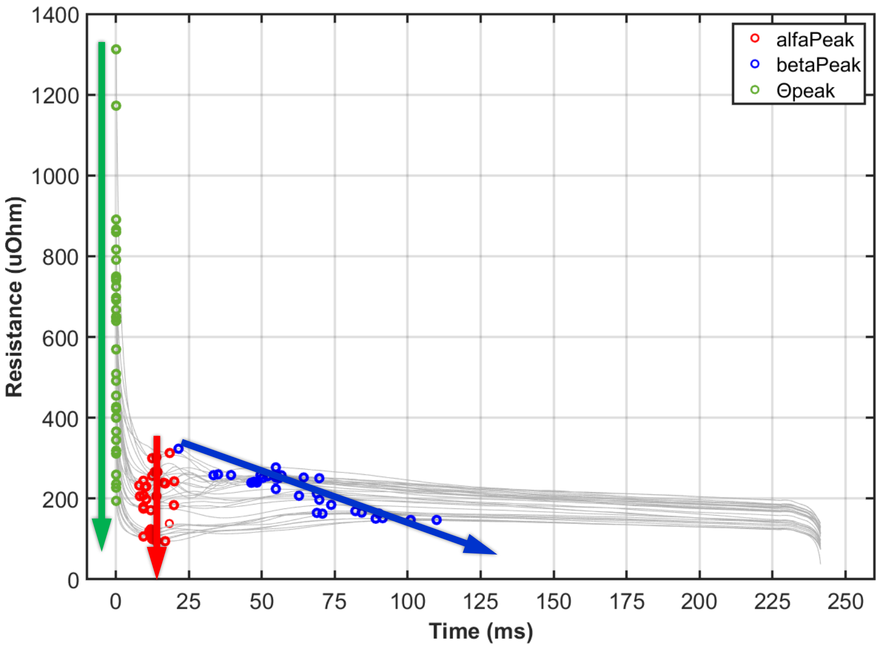

Figure 5 Movement of significant peaks with increasing force

$$R_{theta} = -213.18\,F + 1085 \quad \text{(uOhm)}$$
$$T_{alfa} = -1.06\,F + 15.82 \quad \text{(ms)}$$
$$R_{alfa} = -31.33\,F + 261.76 \quad \text{(uOhm)} \qquad (2)$$
$$T_{beta} = 13.93\,F + 30.07 \quad \text{(ms)}$$
$$R_{beta} = -37.01\,F + 308.41 \quad \text{(uOhm)}$$
$$F \in \langle 1.3, 3.8 \rangle$$

In some cases, small peak between β and α appeared, but wasn't so significant in every sample. This is referred to because of zinc coating becoming completely molten at all interfaces thus contact resistance decreases to nearly zero [3]. Boiling point of zinc is 907 °C. Resistance just before the end of cycle is known to be strongly correlated with weld nugget diameter [2] so it is in this case. The range in which end resistance varies is only 80 uOhms. Resistance value of β peak which also has a strong correlation (coefficient of determination $r^2 = 0.82$) varies in 190 uOhms.

4. CONCLUSION

Spot weld analyser used in this study has proven to be useful for measuring dynamic resistance signals during different welding forces. Measured signals can be after filtering compared to each other through positions of significant peaks. The following conclusions can be drawn for the changes in dynamic resistance when comparing waveforms with increasing force:

- The Θ peak at the start of the current cycle moves to lower resistance values by biggest rate with increasing force.
- The α peak does not move in time, suggesting that the distinctive increase in temperature occurs at the same time regardless of force. But higher forces result in a faster decline of contact resistance.
- The β peak moves to lower resistance values at a similar rate as the α peak but furthermore shifts to longer times with increasing force. This suggests extended duration preceding the start of weld formation with overall smaller resistance values due to lower electrode forces.
- In some cases, a small peak appears between the β and α peaks, likely due to the zinc coating becoming completely molten at all interfaces, thus decreasing contact resistance to nearly zero.
- Both the end resistance and β peak strongly correlated with the weld nugget diameter, but β peak resistance varies over a wider range.

ACKNOWLEDGEMENTS

The research was supported by the project SGS22/156/OHK2/3T/12 (Influence of surface treatments on the quality of production technologies).

REFERENCES

[1] DICKINSON, D. W., FRANKLIN, J. E., STANYA, A. Characterization of Spot Welding Behavior by Dynamic Electrical Parameter Monitoring. *Journal of Scientific & Industrial Research*. 1980.

[2] GEDEON, S. A., SORENSEN, C. D., ULRICH, K. T. Measurement of Dynamic Electrical and Mechanical Properties of Resistance Spot Welds. *Welding Journal*. 1987, vol. 66, no. 12, pp. 378-385.

[3] ZHOU, K., CAI, L. Study on effect of electrode force on resistance spot welding process. *Journal of Applied Physics*. Online. 28 August 2014. vol. 116, no. 8. DOI 10.1063/1.4893968.

[4] RUSSO SPENA, P., DE MADDIS, M., D'ANTONIO, G., LOMBARDI, F. Weldability and Monitoring of Resistance Spot Welding of Q&P and TRIP Steels. *Metals*. Online. 2016, vol. 6, no. 11. DOI 10.3390/met6110270.

[5] WAHAB, M. F., GRITTI, F., O'HAVER, T. C. Discrete Fourier transform techniques for noise reduction and digital enhancement of analytical signals. *TrAC Trends in Analytical Chemistry*. Online. 2021, vol. 143. DOI 10.1016/j.trac.2021.116354.

[6] VERMA, R., ARORA, K. S., SHARMA, L., CHHIBBER, R. Experimental investigation on resistance spot welding of dissimilar weld joints. *Proceedings of the Institution of Mechanical Engineers,* Online. 2021, vol. 235, no. 2, pp. 505-513. DOI 10.1177/0954408920968351.

[7] GUOCHENG, X., WEN, J., WANG, Ch., ZHANG, X. Quality monitoring for resistance spot welding using dynamic signals. In: *2009 International Conference on Mechatronics and Automation*. Online. 2009, pp. 2495-2499. [Accessed 8 February 2024]. DOI 10.1109/ICMA.2009.5246513.