ESTIMATION OF PROCESS STABILITY IN THE MAG WELDING PROCESS BY MONITORING THE WELDING PARAMETERS

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Abstract: This paper presents the distribution of the main welding parameters (welding voltage and welding current) for semiautomatic arc welding with the metal active gas (MAG) process, using both flux-cored and solid electrodes. Two different shielding gases were used: pure CO_2 and 82 % Ar + 18 % CO_2. Welding parameters were recorded by an on-line monitoring system. Besides reporting the distribution of the welding parameters, this paper presents some results of off-line analyses (such as spectral analysis, mean values, range, and standard deviations). From these data, we were able to estimate the stability of the welding parameters. Comparison of the stability data for different components permits the selection of optimal power sources, welding parameters, filler material, shielding gas, etc.

1. Introduction

There are several ways to estimate the stability of the welding parameters. One way is to compare a weld to fixed control limits developed from a previous series of welds, all of which had satisfactory weld joints properties.[1] If the monitored variables (voltage and current) for the weld stay within the control limits, the welding process is considered to be stable. This approach is very suitable for engineering practice.

Another way to estimate stability is an off-line approach based on a variety of statistical and other data-analysis methods. This paper will show results of off-line data analysis of MAG welding with solid and flux-cored wire, and two shielding gases. Off-line analysis can help to select the optimal welding parameters, or the best filler material and shielding gas. It is also a tool for studying and analyzing arc stability and material transfer in the arc. There are no national and international standards for validation of recorded data (welding parameters). Thus, each contribution in this field is valuable. These analyses supplement the experience and knowledge of the welding engineer.

2. Background on the MAG welding process with solid and flux-cored wire

MAG welding is a well-known process that has adapted to meet the new demands of production. Many welding stations still operate in the semiautomatic and automatic modes, but the process is ideally suited for flexible production systems (in combination with a robot). A schematic of the basic semiautomatic MAG welding process is shown in figure 1.

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1... Power source
2... Shielding gas
3... Control unit
4... Welding gun
5... Water for welding gun cooling
6... Shielding gas flow
7... Filler material (wire)
8... Base metal
9... Weld metal
10... Weld pool
11... Electric arc

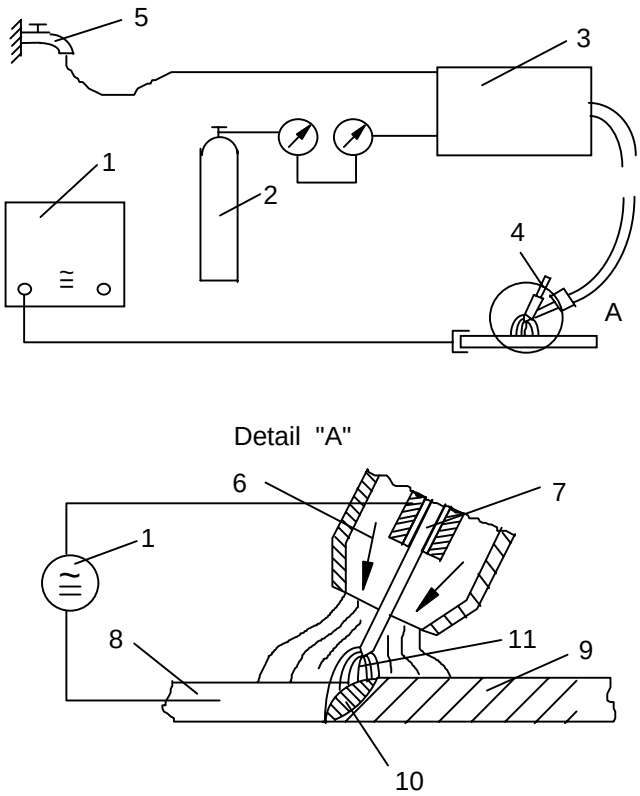

Figure 1. Schematic of the semiautomatic MAG welding process

The filler materials fit into one of the two broad categories by shape: solid and flux-cored electrodes (tubular, flux filled tubes that may be designed for use with or without additional shielding gas). Over the years, solid wires have dominated the market. One reason was that early flux-cored wires could be made only in large diameters (ϕ4 mm and ϕ5 mm) and so were most suitable for manual arc welding (with the use of shielding gas). Also, the higher production cost of flux-cored electrodes was an issue. Recently, advances in production of small-diameter electrodes at reduced costs, and development of higher productivity procedures have made flux-cored electrodes very competitive with solid electrodes. Figure 2 shows sketches of solid and flux-cored electrodes, and the sequence of steps used to reduce the diameter of flux-cored electrodes.

Through the selection of different slag systems for the flux-cored electrodes (such as from the basic or rutile families), it is possible to obtain additional advantages: better weld joint quality (better mechanical properties, fewer rejects due to flaws, a smoother bead surface), a higher deposition rate, or lower cost.
The disadvantages of semiautomatic MAG welding include: an uncomfortable level of radiated heat, an exceptionally bright arc, and the quantity of gases produced from flux (due to the higher welding current). Compared to solid electrodes, flux-cored electrodes have more resistive heating (Q) for a given constant current (*I*), due to their smaller cross-sectional area (A), as shown in the equations below.

$$Q = I \cdot R \cdot t = I \cdot \frac{l \cdot \rho}{A} \cdot t \quad [\mathrm{J}]$$

$$A_{flux\,\text{cored wire}} = \frac{\mathrm{d}_1 \cdot \pi}{4} - \frac{d_2 \cdot \pi}{4} = \frac{(d_1 - d_2)}{4}, \ \mathrm{mm}^2$$

$$A_{\text{solid wire}} = \frac{d_1 \cdot \pi}{4}, \mathrm{mm}^2$$

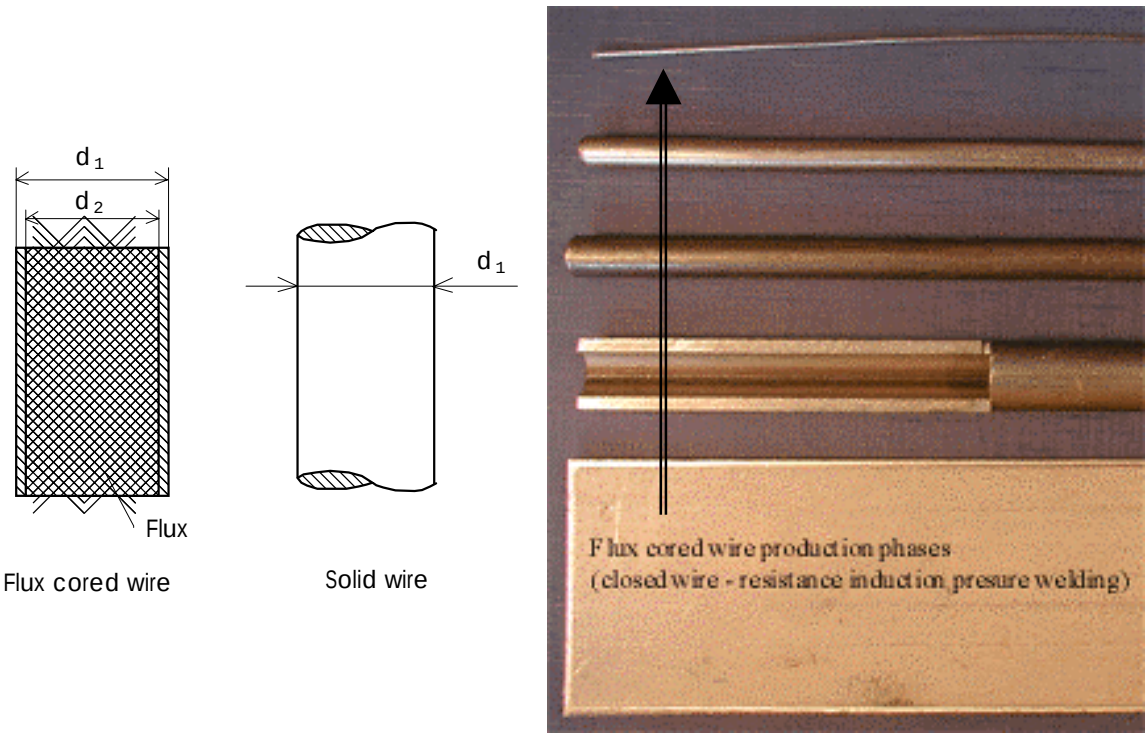

Figure 2. Sketch of solid and flux-cored electrodes, and sequence of producing a flux cored electrode.

By combining an on-line welding parameter monitoring system with some other sensors (such as light sensors or high-speed cameras), full control of automatic MAG/MIG welding can be achieved [2]. In this investigation, we monitored only the on-line welding parameters. The voltage and current records were used to compare solid and flux-cored electrodes, when used with different shielding gases.

3. Design of experiment

For the experimental matrix, two different electrodes (of the same diameter, 1,2 mm) and two shielding gases were selected (see table 1). Optimal welding parameters were selected for each combination of electrode and shielding gas).

Table 1. Design of experiment

Filler material/shielding gas	CO_2	82 % Ar + 18 % CO_2
Solid wire	A	B
Flux cored wire	C	D

A... Solid electrode (VAC60 Ø1,2 mm) with CO_2
B... Solid electrode (VAC60 Ø1,2 mm) with 82 % Ar + 18 % CO_2
C... Flux-cored electrode (rutile type, Ø1,2 mm) with CO_2
D... Flux-cored electrode (rutile type, Ø1,2 mm) with 82 % Ar + 18 % CO_2

3.1. The distributions of the welding current, voltage, and power data and spectral analysis

Welding parameters were selected and applied in the workshop. The parameters were recorded by the on-line monitoring system with a sampling frequency of 1 kHz (for 8 s for each

parameter). The shielding gas flow was kept constant at 16 L/s; other details of the welding procedures for the four welds are as follows:

A. Wire-feed speed: 5 m/min Current 265 A, Voltage 26 V.

B. Wire-feed speed: 5 m/min, Current 250 A, Voltage 27 V.

C. Wire-feed speed: 8,5 m/min, Current 200 A, Voltage 28 V.

D. Wire-feed speed: 8,5 m/min, Current 200 A, Voltage 28 V.

To avoid transients in the real-time welding-parameter distribution, a 1.5 s segment was removed from both the start and stop regions of the parameter record.

Figure 2 shows the real-time welding-parameter distribution (welding voltage and welding current for a period of 5 s) for each weld in the experimental matrix.

Figure 3 shows the spectral analysis of the welding parameters (welding voltage and welding current) for each weld in the experimental matrix.

Figure 4 shows the real-time distribution and spectral analysis of the welding power for each weld in the experimental matrix.

Figures 5 and 6 show the real-time distribution of welding voltage, current and power (for a typical period of 100 ms) for each weld in the experimental matrix.

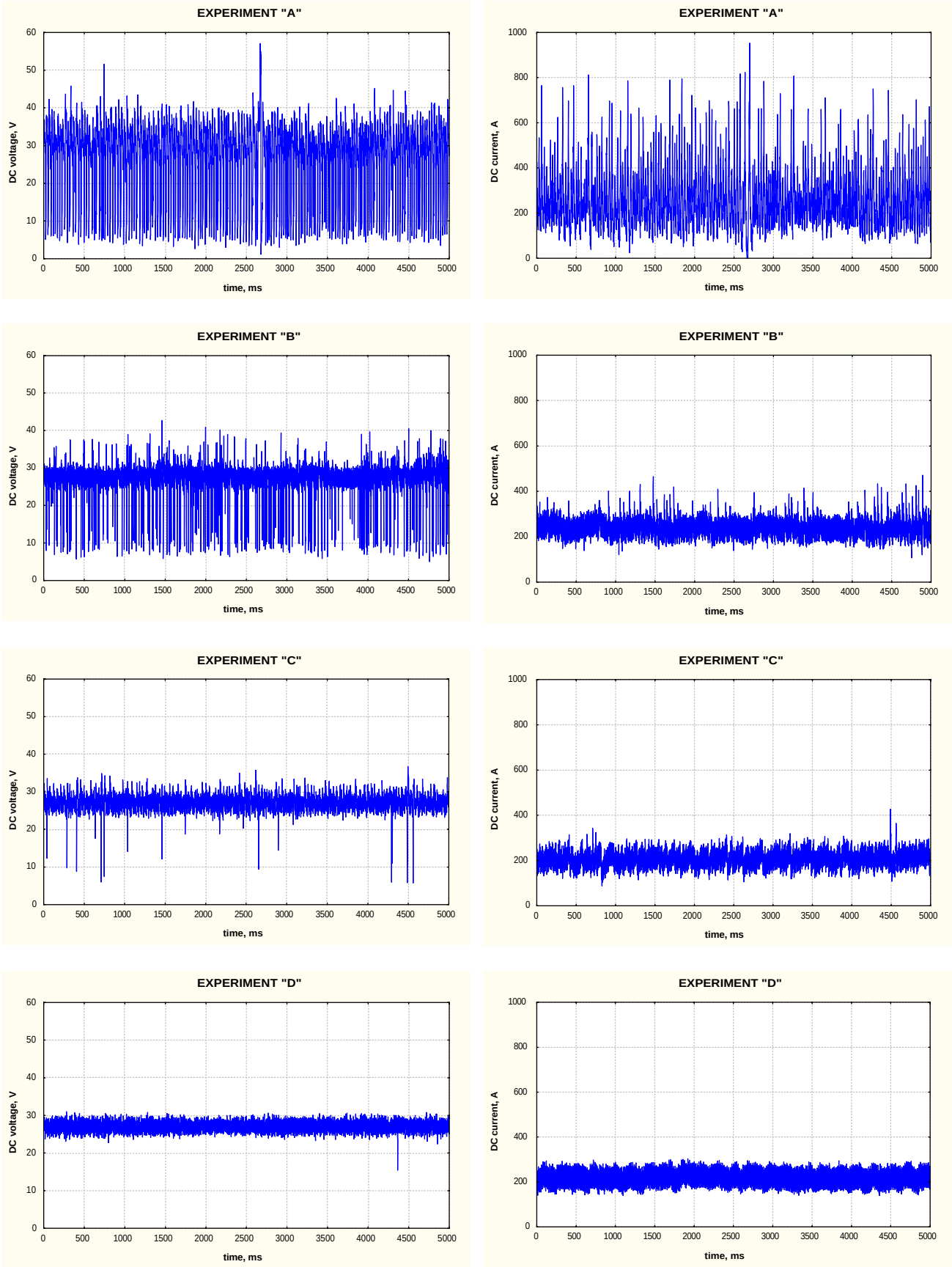

Figure 2. Real-time welding parameters distrbution during MAG welding with two electrodes (solid and flux cored), and two shielding gases (CO_2 and 82 % Ar + 18 % CO_2), according to the design of experiments in table 1. The left column shows the welding voltage, and the right column shows the welding current. Sampling frequency: 1 kHz.

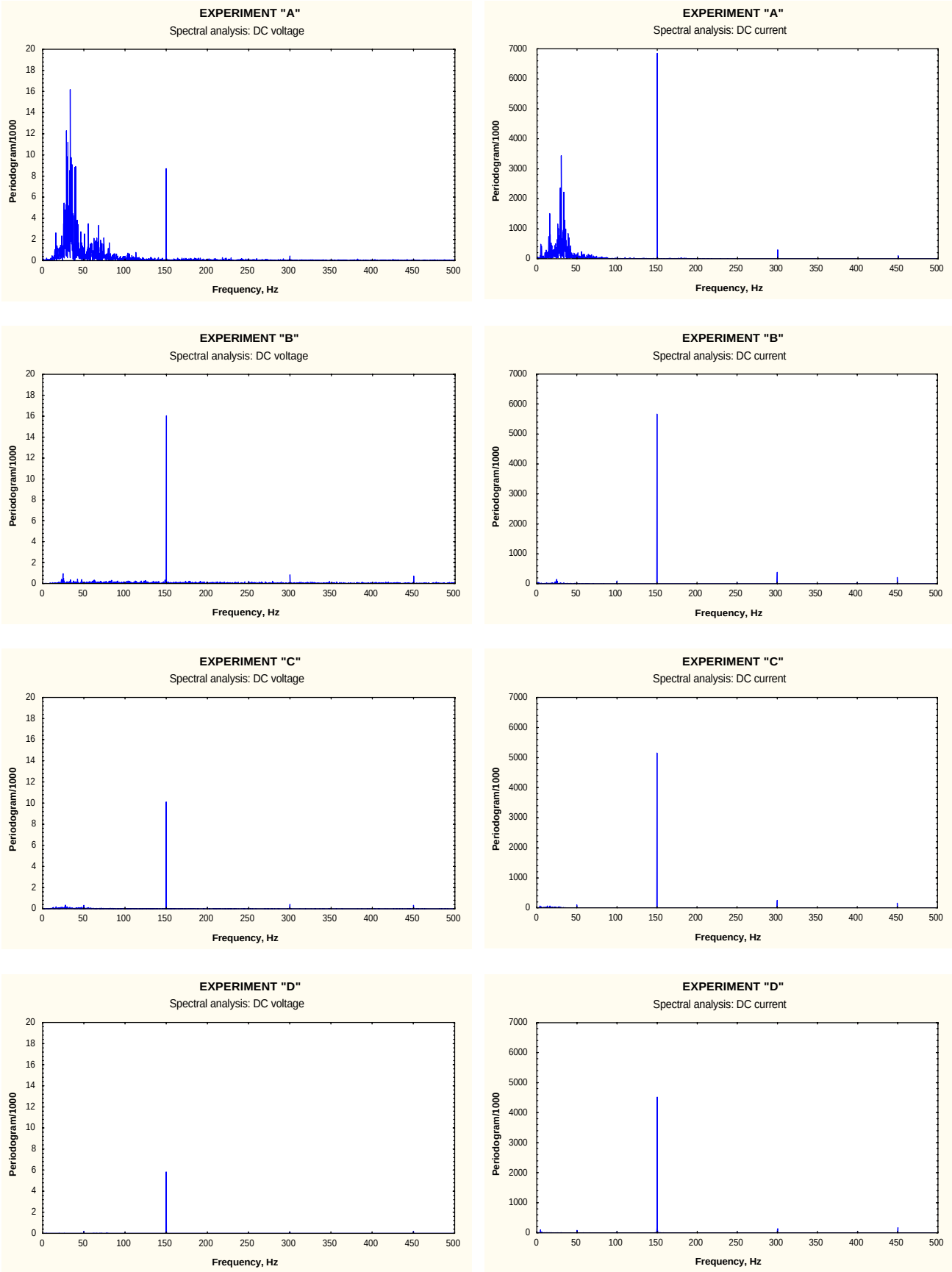

Figure 3. Spectral analyses of recorded welding parameters during MAG welding with two electrodes (solid and flux cored), and two shielding gases (CO_2 and 82 % Ar + 18 % CO_2), according to the design of experiment in table 1. The left column shows spectrograms of the welding voltage, and the right column shows spectrograms of welding current. Sampling frequency: 1 kHz.

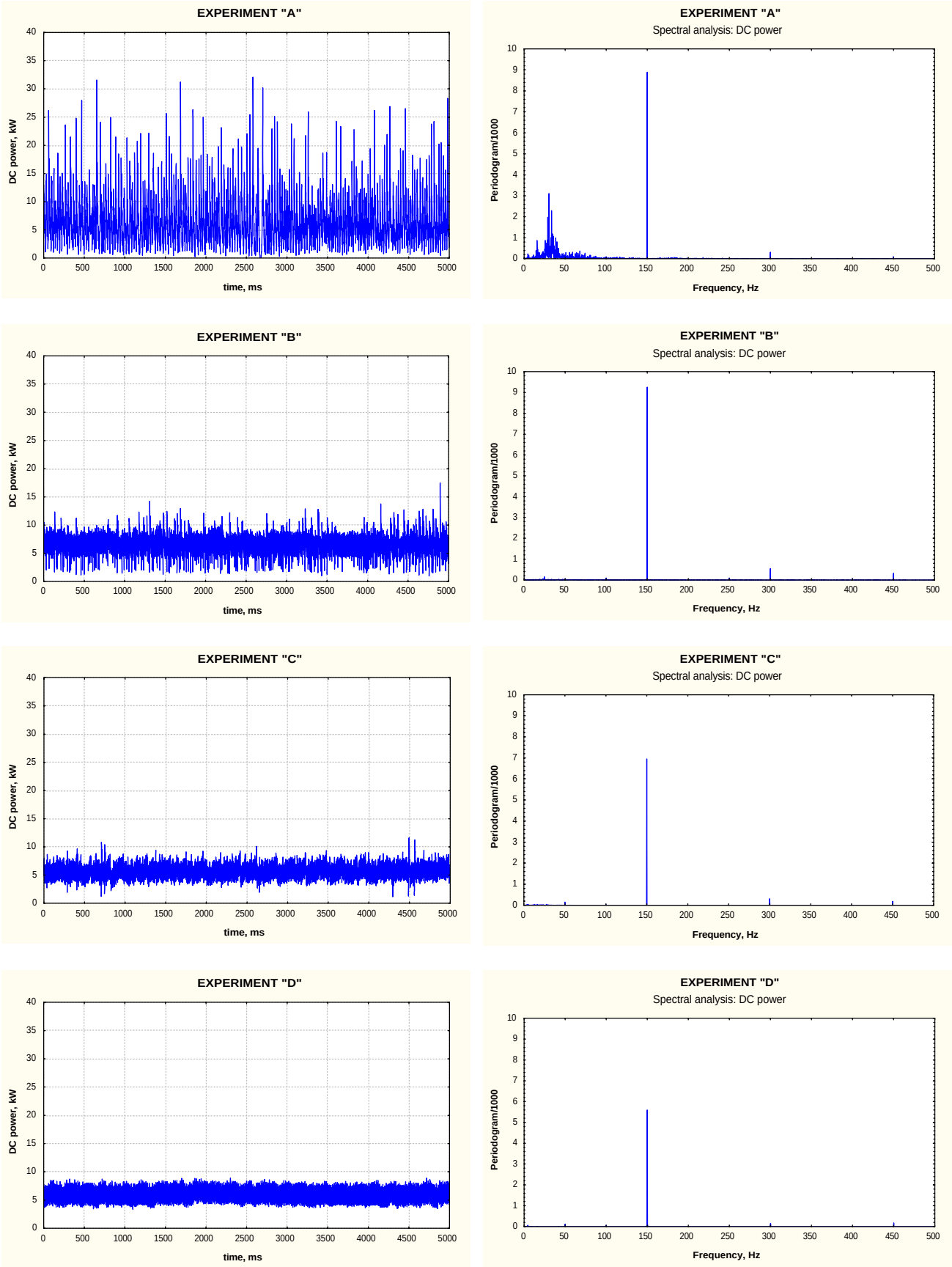

Figure 4. Real-time welding power (V x I, W) distribution (left column) and welding power spectrograms (right column) for data recorded during MAG welding with two electrodes (solid and flux cored), and two shielding gases (CO_2 and 82 % Ar + 18 % CO_2), according to the design of experiment in table 1. Sampling frequency: 1 kHz.

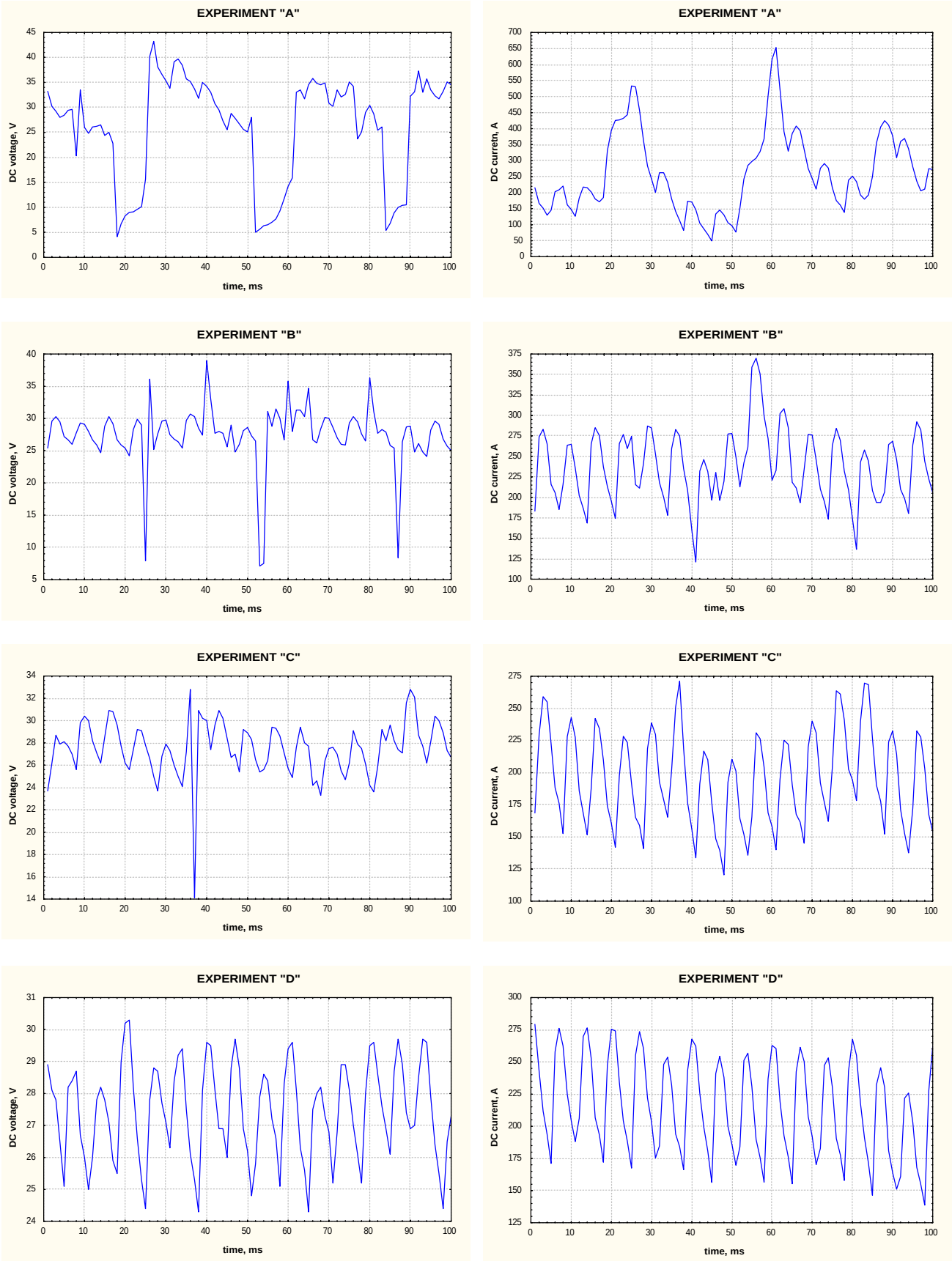

Figure 5. Real-time welding parameters distrbution during MAG welding with two electrodes (solid and flux cored), and two shielding gases (CO_2 and 82 % Ar + 18 % CO_2), according to the design of experiment in table 1. The left column shows the welding voltage, and the right column shows the welding current. Sampling frequency: 1 kHz.

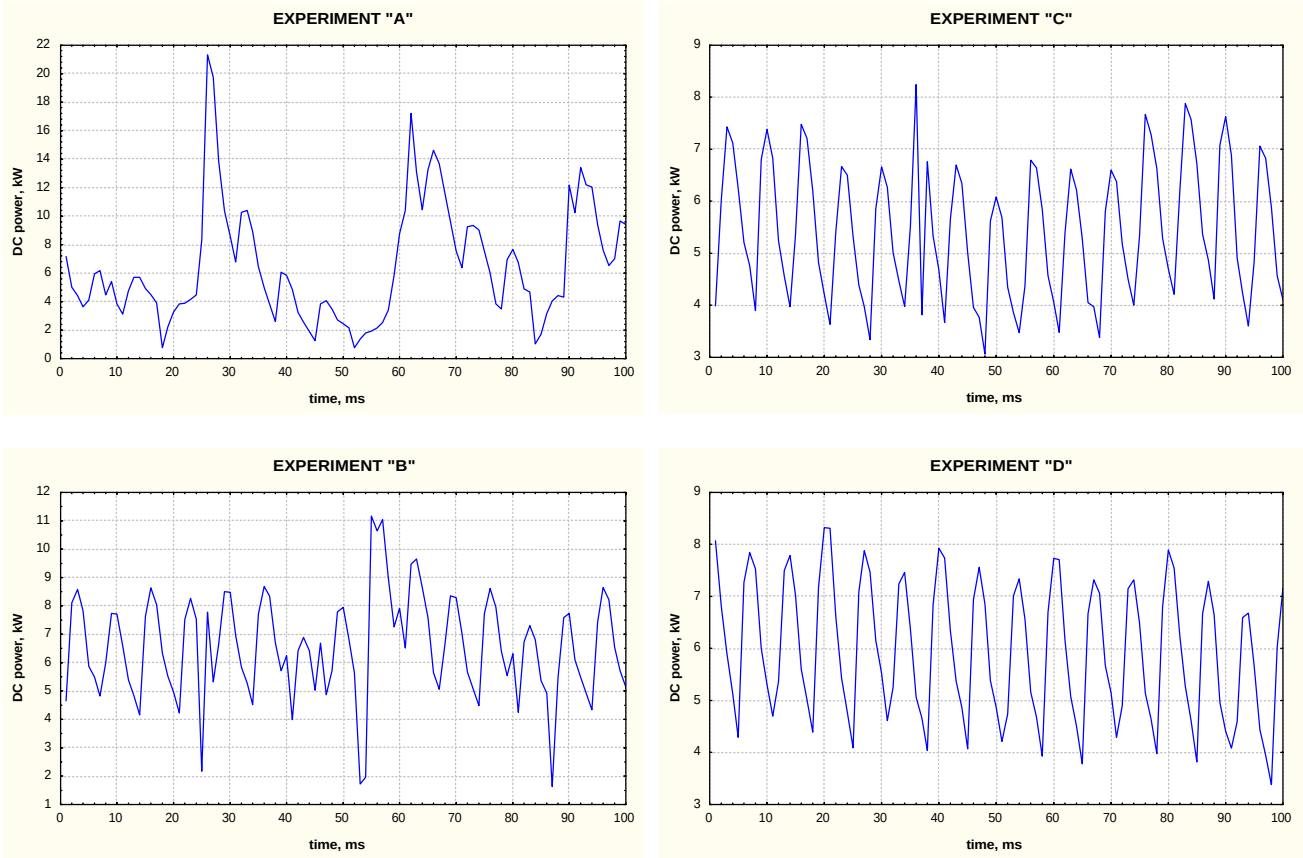

Figure 6. Real time welding power distribution during MAG welding with two electrodes (solid and flux cored), and two shielding gases (CO_2 and 82 % Ar + 18 % CO_2), according to the design of experiment in table 1. The left column shows the welding voltage, and the right column shows the welding current. Sampling frequency: 1 kHz.

3.2. Statistical processing of welding voltage, current and power

For the recorded welding parameters, we determined the arithmetic mean, standard deviation, and maximum and minimum values, as shown in table 2.

Figures 7 and 8 show the frequency histogram for welding voltage, current and power, and the relationship for current and voltage.

Table 2. Result of statistical processing of the recorded data according to the design of experiment

Experiment		Valid N	Mean	Median	Sum	Minimum	Maximum	Std.Dev.
A	DC current, A	5000	265.26	239.80	1326283	0.00	953.80	125.77
	DC voltage, V	5000	25.99	29.70	–	1.20	57.10	10.75
	DC power, kW	5000	6.61	5.73	33026	0.00	32.10	4.22
B	DC current, A	5000	244.91	245.20	1224544	107.60	471.10	44.83
	DC voltage, V	5000	27.10	28.00	–	5.00	42.60	5.04
	DC power, kW	5000	6.67	6.69	33336	0.95	17.43	1.92
C	DC current, A	5000	212.03	211.60	1060129	87.80	427.30	40.24
	DC voltage, V	5000	27.36	27.40	–	5.70	36.70	2.43
	DC power, kW	5000	5.84	5.80	29208	1.20	11.64	1.40
D	DC current, A	5000	221.90	222.55	1109514	138.70	302.80	37.34
	DC voltage, V	5000	27.24	27.40	–	15.40	31.00	1.47
	DC power, kW	5000	6.09	6.09	30454	3.38	8.91	1.29

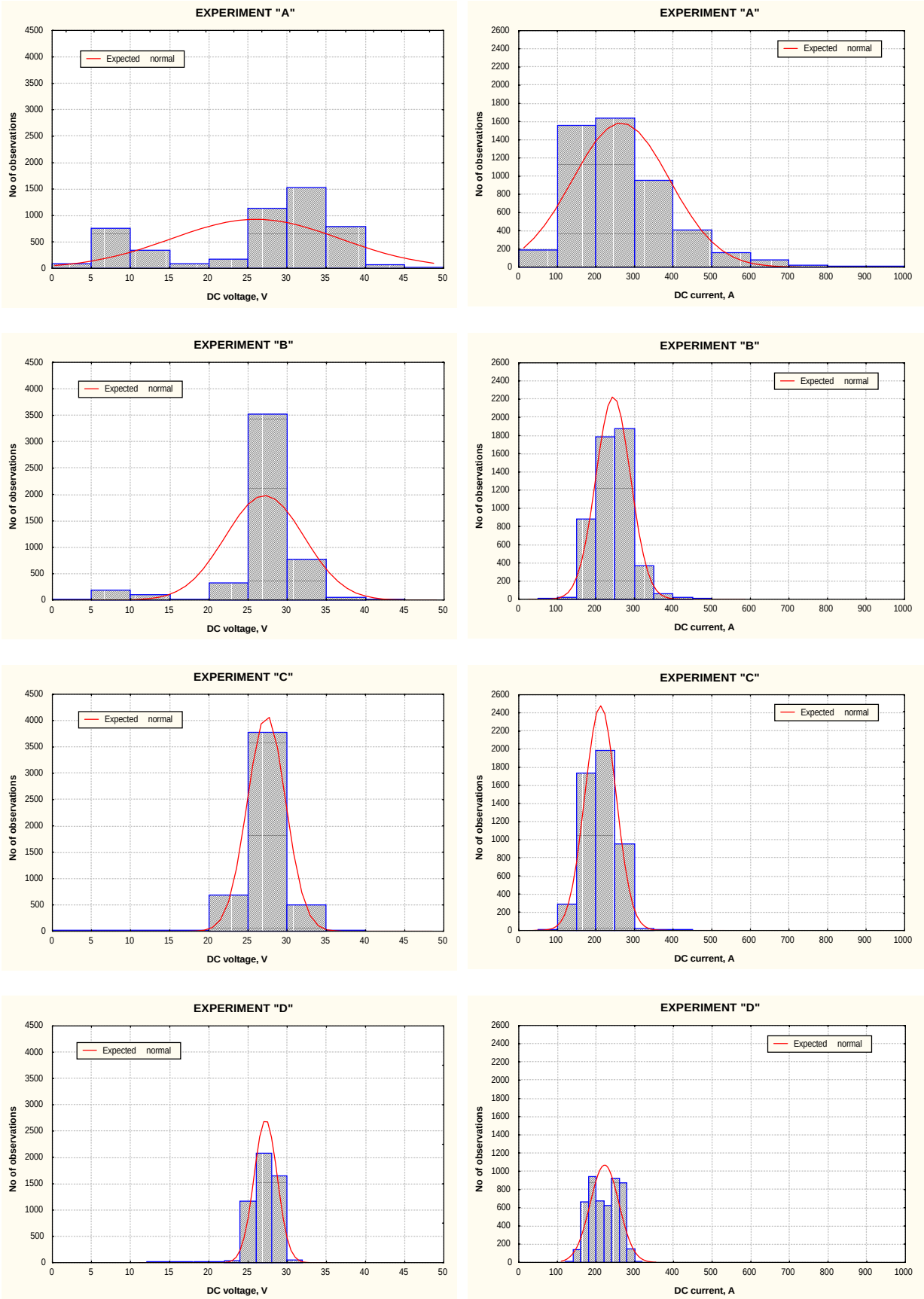

Figure 7. Frequency histograms for welding voltage (left columns) and current (right columns) for each weld in the design of experiment during MAG welding with two electrodes (solid and flux cored) and two shielding gases (CO_2 and 82 % Ar + 18 % CO_2).

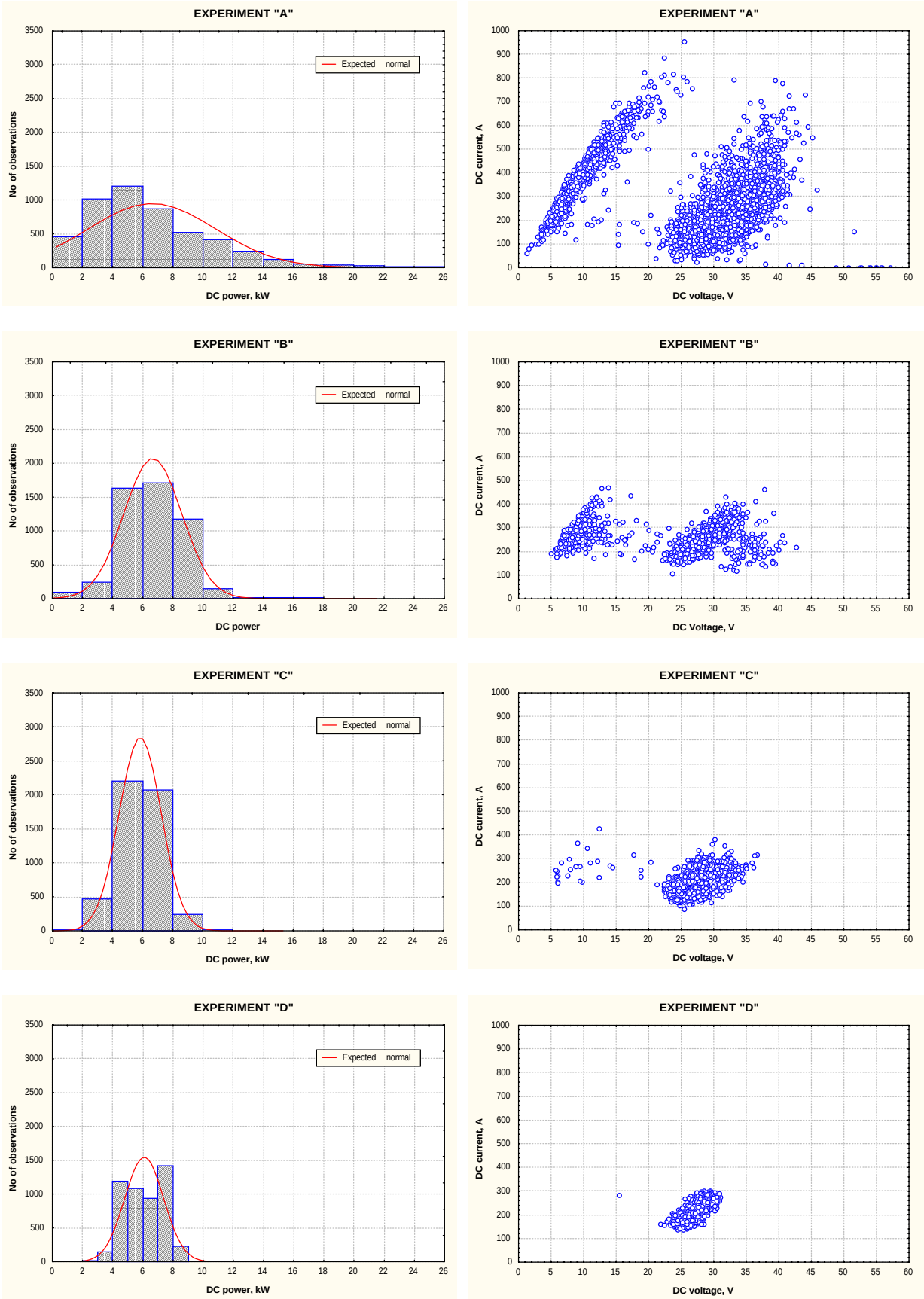

Figure 8. Frequency histograms for welding power for each weld (left column), and relationship for current and voltage (right column).

3.3. Discussion of the analysis of the off-line welding parameter data

Figure 2 shows the scatter in the real-time voltage and current distributions decreasing from experiments A to D as the matrix moved to flux-cored electrode and the 82 % Ar + 18 % CO_2 shielding gas. Smaller variations in current and voltage correlate to smaller electromagnetic forces in the arc and less arc instabilities, which suggests higher quality of these welds through a lower level of weld imperfections such as spatter or porosity.

Figure 3 shows a peak in the spectral analysis of voltage and current for experiments B, C and D near a frequency of 150 Hz. Previous work [2] has shown that this frequency is high enough to produce good welds, as the amount of metal transferred per pulse is relatively small. Also the spectral peak is narrow, indicating a stability of the welding process (figures 5 and 6). In experiment A, we observed more signals of lower frequencies (grouped around a frequency approx. 40 Hz), as well as some signals at 150 Hz. This bimodal distribution suggests an undesirable combination of weld transfer modes.

Statistical processing of the welding parameter data (table 2) provides mean values of voltage, current, and welding power for each experiment. The mean values for current and power are clearly lower for flux cored wire than for solid wire, and are explained by the higher resistivity of the core. Also, the wire-feed rate for the solid wire is lower (5 m/min) than for the flux-cored wire (8,5 m/min). Even though the core contains material that does not add to the weld pool, this higher feed rate permits a higher deposition rate.

Figure 8 also shows only small fluctuations in the current and voltage (right side) for experiments C and D, as expected of a spray transfer mode. The change from the short-circuiting transfer mode seen for experiments A and B is attributed to the higher energy density (W/mm^2) for the flux-cored wire, compared to solid wire.

Experiment B in figure 7 has a much narrower frequency distribution than experiment A, indicating the stabilizing effect of the mixed shielding gas (82 % Ar + 18 % CO_2) on the transfer. Once again, we would conclude that the transfer was mostly spray arc, a mode not possible with pure CO_2. The change in shielding gas had a small effect on the welding parameters, the current is a little higher in experiment A and voltage a little lower, but the welding power was virtually the same.

4. CONCLUSION

Overall, the best welding occurred for the combination of flux-cored wire with 82 % Ar + 18 % CO_2 shielding gas. For the solid wire, the best welding occurred when 82% Ar + 18% CO_2 shielding gas was used. This paper shows that the shielding gas and type of electrode are just as important as the traditional welding parameters in determining the material transfer mode and the arc stability.

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