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APPLICATION OF FAST FOURIER TRANSFORM (FFT) IN THE ANALYSIS OF A WELDING CURRENT INSTANTANEOUS VALUES WAVEFORMS DURING WELDING WITH A COVERED ELECTRODE

ZASTOSOWANIE SZYBKIEJ TRANSFORMATY FOURIERA (FFT) DO ANALIZY PRZEBIEGÓW WARTOŚCI CHWILOWYCH NATĘŻENIA PRĄDU SPAWANIA PRZY SPAWANIU ELEKTRODĄ OTULONĄ

The article presents the process of production of coated electrodes and their welding properties. The factors concerning the welding properties and the currently applied method of assessing are given. The methodology of the testing based on measuring and recording of instantaneous values of welding current and welding arc voltage is discussed. The article presents the application of Fast Fourier Transform (FFT) for the analysis of instantaneous values of welding current and welding arc voltage. The results of coated electrodes welding properties are compared. Finally the conclusions drawn from the research are presented.

Keywords: welding stability, arc welding, actual welding signals

Omówiono proces produkcji elektrod otulonych oraz ich wymagane właściwości spawalnicze. Przedstawiono wskaźniki właściwości spawalniczych oraz stosowaną dotychczas metodykę oceny. Omówiono metodyką badań polegającą na pomiarze i rejestracji wartości chwilowych natężenia prądu spawania i napięcia łuku spawalniczego. Przedstawiono sposób wykorzystania Szybkiej Transformaty Fouriera (FFT) do analizy wartości chwilowych natężenia prądu spawania i napięcia łuku spawalniczego. Zestawiono wyniki badań właściwości spawalniczych elektrod otulonych. Zaprezentowano wnioski z wykonanych badań.

1. Introduction

Covered electrode production is a complex process where many requirements should be met simultaneously. The functional properties of these electrodes, i.e. chemical composition and mechanical properties of the deposited metal and the whole range of the factors referred to as weldability are the reference points in this case [1, 2]. One of the most important components of the covered electrodes weldability assessment is the stability of the welding process. It is well known fact that only stable process makes it possible to obtain a weld of a correct geometry, with practically not changing width and height of a weld face and penetration depth in the whole length of a joint, what increases the probability of obtaining the joint of the required mechanical properties. In the literature this relation is referred to as technological stability [2, 3]. In the production process during the final acceptance the individual batches of electrodes are subjected to the thorough inspection of welding properties basing on the detailed assessment criteria determined for the specified electrode types. The traditional way to verify welding properties of electrodes is the assessment made by a classifying welder on the basis of the observation of the process during numerous welding trials. It is natural that the assessment made by a classifying welder is of a subjective character, however it is the only method used in practice so far. The classifying welder gains the experience and intuition in the evaluation over the course of the years. This specialist creates or even becomes a certain knowledge base used for the testing and assessment of electrodes [4].

The range of testing during welding trials includes following components:

– the ability to stable welding arc burning,
– the manner of the liquid metal transfer into the weld pool,
– behaviour of a liquid slag during welding,
– steady melting of the electrode (core and covering),
– spatter size,
– ability to arc ignition and reignition,
– ability to chipping off the slag and its residues on the weld face.

The voltage and current waveforms are the valuable sources of information on the quality and stability of the welding process. The voltage and current signals converted to digital signals can be analysed by use of various signal processing and analysis methods.

Analysis of the voltage-current signals has not yet been applied in the assessment of a welding process for the larger scale [5, 6]. This is due to the imperfection of the present monitoring systems and lacking of the unequivocal assess-

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ment criteria. Therefore those systems cannot be compared to the knowledge and experience of a welder and his ability to associating and assessing the welding conditions [7].

2. Processing and analysis of signals. Fast fourier transform FFT

In practice the signals processing and analysis are used in all fields of science and technology. The signal processing is the whole of the actions leading to depicting the observed signal in the form suitable for its further analysis, including standardisation and matching signals values, converting signal analogue values into digital ones, filtration and averaging of signals (real) values in time or transformation of the signal from one value space to the another (e.g. Fourier or Wavelet Transform, etc) [8, 9]. The signals analysis should be understood as a searching for and determining of signals features that makes it possible to identify information on the character and variability of the physical process being described by the signal. In practice the majority of analogue signals are converted into the digital form and all analysis operations are conducted on this type of signals. Digital signals differ from the analogue ones in that their values are described in discrete-time domain as a sequence of instantaneous values of the physical quantity being examined. In order to differentiate constant and discrete signals in time various notations (forms of recording) are being used [8], namely:

– notation **x(t)** used traditionally in the recording of constant analogue signals in time,
– notation **x(n)** is applied for the recording of discrete time digital signals.

Both digital and analogue signals most frequently are denoted and depicted in time and amplitude domains. Fig. 1 shows the example of continuous (Fig. 1a) and discrete (Fig. 1b) signal in time and amplitude domains (x and y axis respectively).

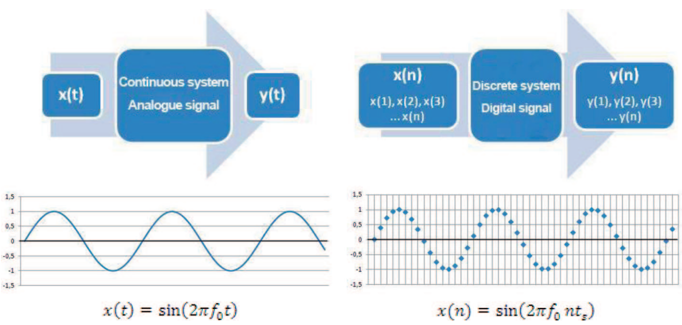

Fig. 1. a. Analogue signal, continuous in time x(t) f_o – frequency [Hz], t – time [s]; b. Digital signal, discrete in time x(n) f_o – frequency [Hz], n – sequence of natural numbers, t_s – sampling period [ms]

Each signal of any physical quantity which is variable in time can be depicted as the linear combination of harmonic functions also called as harmonic components, which is illustrated in Fig. 2b. Therefore one of the most frequently used methods of digital processing of signals is converting them from the time domain to the frequency domain, where the signal is presented in the form of lines representing signal frequency components. Frequency domain very often provides interesting information on the nature and genesis of the physical quantities.

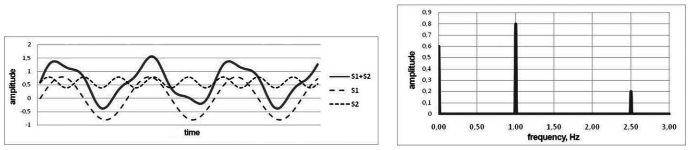

Fig. 2. a. Main signal (S1+S2) and harmonic components S1 and S2; b. Frequency spectrum. Lines of frequency components 1Hz and 2,5Hz

In the case of welding voltage and current waveforms for better understanding the character of signals and phenomena occurring during the process, besides the analysis of time and amplitude, it is possible to analyse the same signals in the frequency domain. The analysis mainly consists in the determination of harmonic components associated with various periodical phenomena generated in the welding process [10]. One of the most popular procedures used in this field is Discrete Fourier Transfer (DFT), which is most often determined with very efficient algorithm of Fast Fourier Transfer (FFT). Fourier theory makes an assumption that any signal can be decomposed into a number of fundamental components depicted with harmonic functions. For discrete signal it can be written in the formula (1) [9].

$$X(m) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)e^{-j2\pi n\frac{m}{N}} \tag{1}$$

where:
$x(n)$ – discrete signal in time domain,
$X(m)$ – signal discrete spectrum,
N– number of input samples,
m – number of lines in the spectrum.

As the result of the application of Fourier transform for discrete signals the m complex numbers are being determined $X(m) = X_{real}(m)+ jX_{imag}(m)$, which usually are shown in the form of power spectral density signal power spectrum or signal amplitude spectrum.

3. Objective and range of research

Research is aimed at testing the possibility to apply Fast Fourier Transform FFT for the description and analysis of voltage-current signals of covered electrode welding process. This article presents amplitude unilateral spectra making it possible to conduct the quantity assessment and compare the selected frequency components of various welding parameters, electrode types and DC welding power sources.

Welding trials and recording of voltage and current waveforms were performed at Welding Department of the Institute of Mechanic Technology being the part of the Faculty of Mechanical Engineering and Computer Science of Częstochowa University of Technology. The processing and analysis of the obtained signals was conducted in the collaboration with the Institute of Fundamentals of Machinery Design at The Faculty Of Mechanical Engineering, Silesian University of Technology.

The station for recording instantaneous values of signals contains measuring and recording computer system based on multi-channel analogue-to-digital converters A/D of LC-011/16 type. Filtration system based on noise galvanic separator is the integral part of the slotted line.

During research two constant current welding power sources were used:
– conventional thyristor rectifier of PSP 250,
– inverter source FalTig 200.

For testing electrodes Omnia 46 of diameter ø3.2×350 mm (E380R11 in accordance with PN-EN ISO 2560-A) were selected. Besides the electrodes of the first grade also defective electrodes of a clearly worst weldability were tested; in faulty batch sodium silicate Na_2O was applied instead of potassium silicate K_2O traditionally used for this type of electrodes (basing on which proper electrodes were produced).

For each group of electrodes the series of measurements of instantaneous values of voltage and current waveforms in real time for three ranges of welding current: 90, 110 and 130A were performed. Padding welds were built up manually in flat position on metallically pure testpieces of dimensions of 150×80×5 mm of steel grade S235JR in accordance with PN-EN 10027-1:1994; welding speed was in the range of 20-25 cm/min, the angle between an electrode and material was 70°.

4. Analysis of research results

Real welding voltage and current signals recorded in the digital form were transformed from the time domain into frequency domain using the algorithm of Fast Fourier Transform FFT. It was performed using Matlab program.

The selected spectra of the signals are shown in Figures 3-12. The signals spectra of electrodes of good weldability are given it the left column (Figures 3-12 denoted with letter "a"), while right column (Figures 3-12 denoted with letter "b") presents spectra determined using the electrodes of poor weldability.

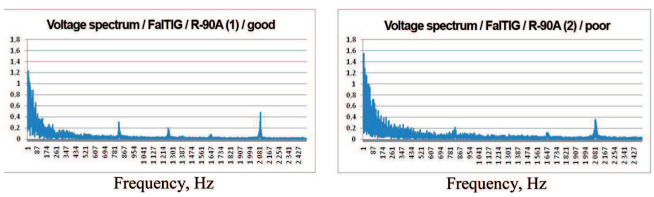

Fig. 3. a. Voltage spectrum. Electrode: Omnia 46 Weldability: good. Source: Faltig 200. Current: 90A; b. Voltage spectrum. Electrode: Omnia 46 Weldability: poor. Source: Faltig 200. Current: 90A

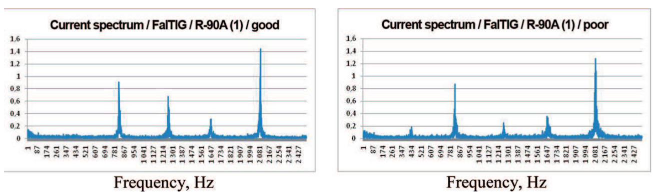

Fig. 4. a. Current spectrum. Electrode: Omnia 46 Weldability: good. Source: Faltig 200. Current: 90A; b. Current spectrum. Electrode: Omnia 46 Weldability: poor. Source: Faltig 200. Current: 90A

The results obtained from two different DC power sources are arranged similarly:
– Faltig200 Figures from number 3 to 6,
– PSP250 Figures from number 7 to 12.

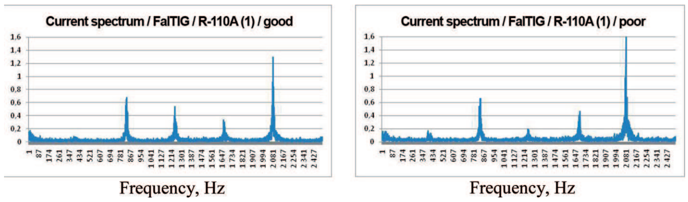

Fig. 5. a. Current spectrum. Electrode: Omnia 46 Weldability: good. Source: Faltig 200. Current: 110A; b. Current spectrum. Electrode: Omnia 46 Weldability: poor. Source: Faltig 200. Current: 110A

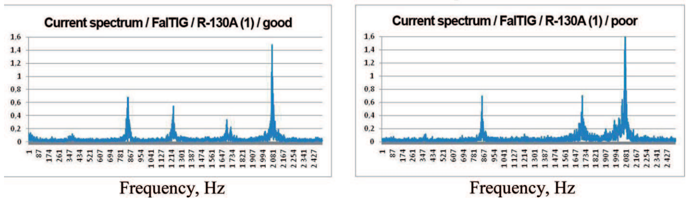

Fig. 6. a. Current spectrum. Electrode: Omnia 46 Weldability: good. Source: Faltig 200. Current: 130A; b. Current spectrum. Electrode: Omnia 46 Weldability: poor. Source: Faltig 200. Current: 130A

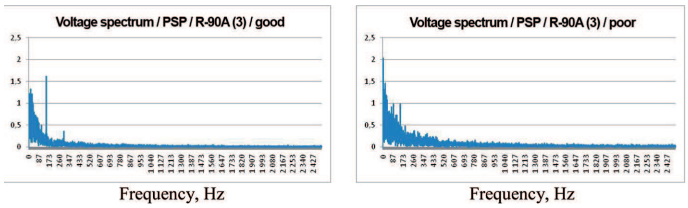

Fig. 7. a. Voltage spectrum. Electrode: Omnia 46 Weldability: good. Source: PSP250. Current: 90A; b. Voltage spectrum. Electrode: Omnia 46 Weldability: poor. Source: PSP250. Current: 90A

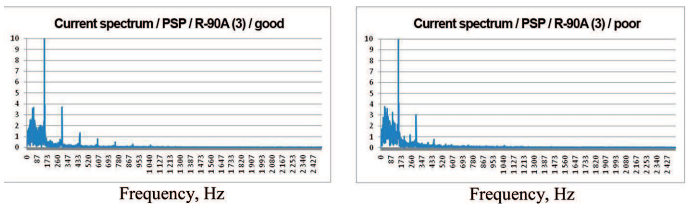

Fig. 8. a. Current spectrum. Electrode: Omnia 46 Weldability: good. Source: PSP250. Current: 90A; b. Current spectrum. Electrode: Omnia 46 Weldability: poor. Source: PSP250. Current: 90A

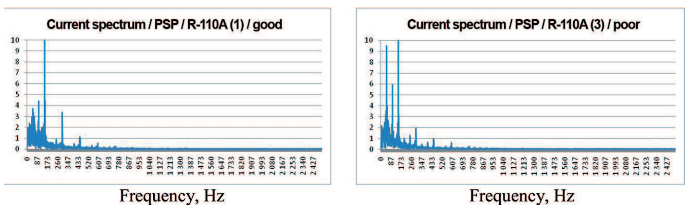

Fig. 9. a. Current spectrum. Electrode: Omnia 46 Weldability: good. Source: PSP250. Current: 110A; b. Current spectrum. Electrode: Omnia 46 Weldability: poor. Source: PSP250. Current: 110A

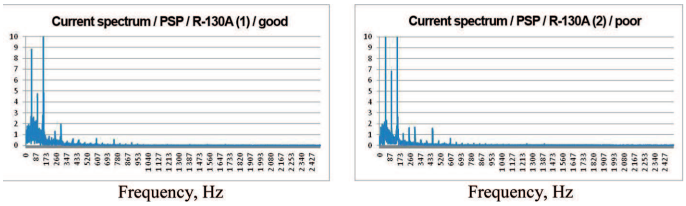

Fig. 10. a. Current spectrum. Electrode: Omnia 46 Weldability: good. Source: PSP250. Current:130A; b. Current spectrum. Electrode: Omnia 46 Weldability: poor. Source: PSP250. Current:130A

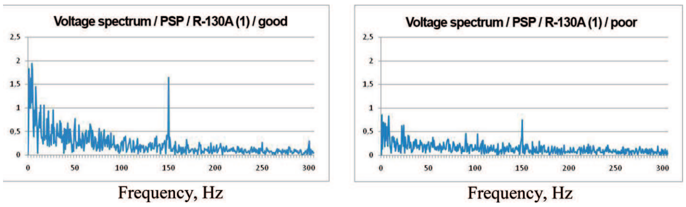

Fig. 11. a. Voltage spectrum (0-300Hz). Electrode: Omnia 46 Weldability: good. Source: PSP250. Current: 130A; b. Voltage spectrum (0-300Hz). Electrode: Omnia 46 Weldability: poor. Source: PSP250. Current: 130A

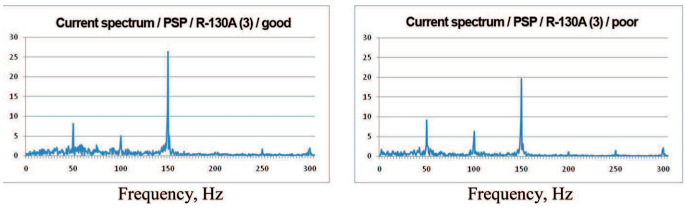

Fig. 12. a. Current spectrum (0-300Hz). Electrode: Omnia 46 Weldability: good. Source: PSP250. Current: 130A; b. Current spectrum (0-300Hz). Electrode: Omnia 46 Weldability: poor. Source: PSP250. Current: 130A

While analysis of both current and voltage spectra it can be noticed that frequency components (in the form of lines) occur in the values characteristic for the selected welding power source. Therefore:

– for conventional welding rectifier of PSP250 type the lines are in sequence of 50, 100 and 150 Hz (multiplicity of power-line frequency). This fact should be directly associated with the three-phase Graetz bridge rectifier configuration, where each of three alternating current phases of frequency 50Hz is being "elevated" over the time axis by the rectifying system (Fig. 13). At the same time it is worth stressing that evidently dominating frequency is 150Hz (the highest peaks at the histogram) what is confirmed by voltage spectra (Fig. 11a b), for which only one line is visible, precisely in the range of 150Hz.

– for inverter welding machine Faltig200 the harmonic components (frequency ones) appear decidedly on the side of higher frequencies (first line in the range of 340-380Hz, second line 830-850Hz, third line 1220-1260Hz, forth line 1670-1710Hz and the last one in the range of 2075-2080Hz). This time the characteristic feature of the sources with internal frequency conversion (inverters) which transform current of the range approximately 20 kHz is being revealed and the visible lines seem to echo the transformation frequency.

In order to interpret and describe the separate signals in the context of the worst or better weldability the analysis of the amplitudes values of the separate harmonic components should be performed. In other words to explain and understand the separate spectra the height of the particular lines not the values of harmonic frequencies should be taken into consideration.

1. The conclusions based on the spectra analysis obtained while applying inverter source Faltig200:
   – current spectrum amplitude values of electrodes of poorer weldability (Fig. 4-6b) for the third line (in the range of 1220-1260Hz) are visibly lower (0.1-0.25A) when comparing with the electrodes of good weldability, for which mean values of amplitudes reach 0.5-0.7A,
   – lines of voltage spectra (Fig. 3 a and b) for good electrodes are sharply outlined and consolidated.
2. The conclusions based on the spectra analysis obtained while applying conventional source PSP250:
   – harmonic amplitudes of 150 Hz for current spectra are higher (on the average 25A) for the electrodes of good weldability (Fig.12a) if comparing with the electrodes of poor weldability, for which the value of amplitude of 150 Hz line fail to exceed 20A (Fig.12b),
   – in voltage spectra only one component of 150Hz appears and for electrodes of good weldability (Fig.11a) is evidently higher in comparison with the amplitude of the spectrum obtained for the electrodes of poor weldbility (Fig.11b).

As each welding power source has its own characteristic spectrum signature, therefore it is possible to try to identify the type of a source basing on the frequency spectra. This would however require further research.

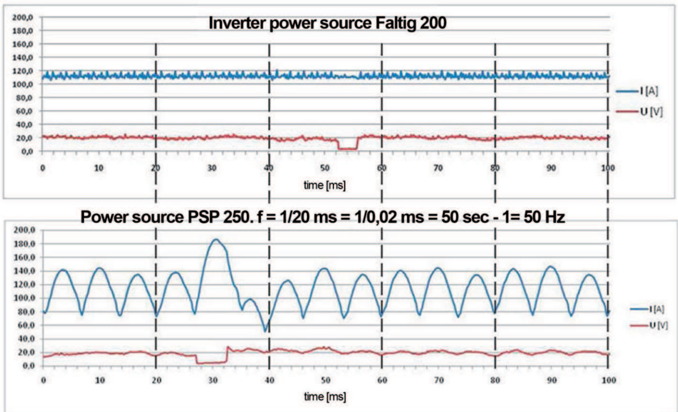

Fig. 13. Examples of real current signals (blue colour) and voltage (red colour). The current waveform for inverter power source Faltig 200 is clearly more consolidated (narrower range of variability) and characteristic harmonic lines are located on the side of higher frequencies

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