ACQUISITION OF PROCESS IRREGULARITIES BY MEANS OF ACOUSTIC DISTORTION PARAMETERS DURING GMA WELDING PROCESSES

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In GMAW, process irregularities often result in weld defects and have, thus, negative effect on the weld quality. Currently, the online detection of these irregularities in industrial production is mainly based on the analysis of current path and voltage time curves. Arc length control, which, for example, is used in modern welding machines, evaluats the relative changes of electric process parameters (welding current and voltage) for detection of variations of the arc length. Superimposing interferences are, however, complicating the unambiguous acquisition of arc length via electric parameters. Within the scope of research project, which has been carried out in the Welding and Joining Institute, this problem has been solved by establishing the unambiguous link between length of the arc and acoustic distortion parameters, which are the result of using an arc as a sound converter. For the detection of process irregularities, defined modulation of welding current has been carried out, the changes of which during welding have been acquired and analysed. Similar as in real audio loudspeaker, distortions during reproduction are developing, which are acquired by a directional microphone and subsequently evaluated. The parameters THD (Total Harmony Distortion) and SINAD (Signal-to-Interference Ratio including Noise and Distortion) have turned out to be the most reliable electro-acoustic parameters. Changes of arc geometry exert unambiguous and reproducible effects on these parameters. Vice versa, it is proceeded from the assumption that, in the case of persistence of parameters within a certain corridor, the arc has not been deformed. For the acquisition of arc length, the modulation of arc and acoustic acquisition and evaluation offer thus an unambiguous alternative and/or completion to the method, which has been used so far and is based on the electric parameters. The measuring set-up and test results of this novel measuring method will be specified in detail in this paper. 10 Ref., 6 Figures.

Keywords: *GMA welding, quality control, acoustic emission, arc length control, audisignal distortion parameters, power sources*

In GMAW, process irregularities often result in weld defects and have negative impact on the weld quality. The online detection of these irregularities in industrial production is, nowadays, mainly based on the analysis of current path and voltage time curves. Arc length control, which is used in modern welding equipment, evaluates, for example, the relative changes of electric process parameters (welding current and voltage) with regard to a target value for the acquisition of arc length variations. Superimposing disturbances impair, however, the unambiguous acquisition of the arc length via the electric parameters. Functionality of the arc sensor system is, moreover, based on the analysis of these process parameters [1–4].

Since, however, the quality of welding result is directly or indirectly dependent on temporal behaviour of the arc, determination of the effective arc properties during GMAW is of utmost importance [5, 6]. The weld geometry is, thus, with high degree influenced by the type of material transfer, heat input, arc pressure, which is exerted on the molten pool, and flow conditions in the molten pool, which are resulting thereof. Moreover, type of material transfer and resulting droplet properties, as well as burn-off of alloying elements from the droplet, is determined by plasma-physical conditions in the anode region of wire electrode, plasma column temperature and plasma composition and/or by the distance covered within the arc column. Welding defects such as undercuts, lack of sidewall fusion and lack of inter-run fusion are, moreover, caused by unfavourable arc attachment on the workpiece [7].

The model approach which has been used so far, i.e. the assumed proportionality of one-dimensional geometrical arc length to arc voltage, is insufficient, as depicted in Figure 1. At almost the same arc length a strongly different voltage is setting. In the present case, the 4 % reduction of the one-dimensional geometrical arc length is accompanied by 6 % increase of the voltage, that is clearly contrary to the currently applied model idea of proportionality of voltage and length of

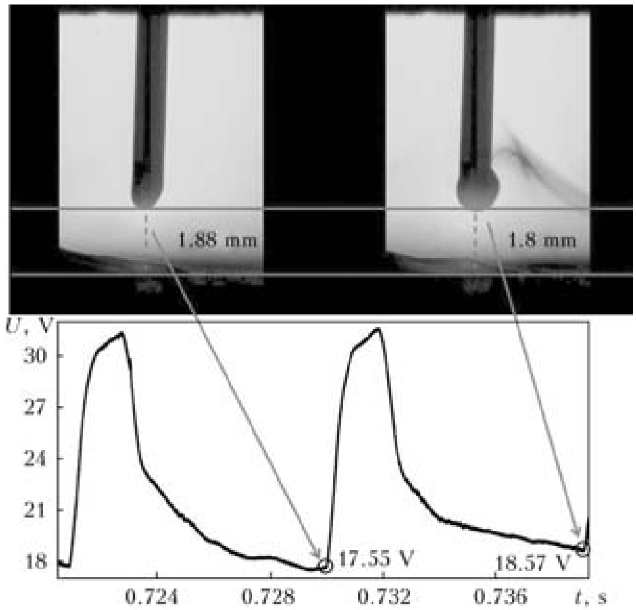

Figure 1. Non-proportionality of geometrical arc length and welding voltage

the arc. Against this background it is essential to add another fundamental process parameter, which is capable to provide further information on length and shaping of the arc.

Acoustic measurements of the arc. Ever since the «singing arc lamp» has been discovered at the Erlangen University in 1897 it has been documented that the arc is, basically, usable as a loudspeaker. It is capable to transmit frequencies within the range of 16 Hz up to range, which is no longer audible for human beings. This is basically possible in a very high quality, that is proven by the fact that in very pricy audio loudspeakers, which are on the market, the arc is used as sound converter for the tweeter range [8].

Applied to the welding technique it is, therefore, obvious to couple low-frequency audiosignals into welding power source and to evaluate the resulting sound signals. It was, therefore, required to test the hypothesis whether the geometrical shape of the arc exerts direct influence on acoustic parameters, which are capable to quantify the «transmitter system welding process». It stands to reason that, here in particularly, the acoustic parameters are to be considered, specified the non-linear distortion of the signal, to which the signal is subjected on the path from sound generation to the arc.

Figure 2 shows overall electric system, which consists of contact tube, wire, arc and workpiece. It is obvious that each subsidiary system exerts great influence on the electric behaviour. Analysis of the individual influences on resulting electric temporal behaviour is extremely complex. However, proceeding from the assumption that evaporation processes at anode, cathode and droplet, and also that the developing plasma and shielding gas flow dynamics do not cause noticeable acoustic emissions, it is only the arc system, which can be assumed to be a sound transducing subsidiary system.

In preliminary tests with TIG welding equipment, the proof has been delivered that the welding machine is, basically, capable to clearly reproduce coupled test sounds despite clearly audible process noise. Figure 3 shows spectrum of triad of three equally loud sounds of the 2, 5 and 7 kHz frequencies which have been modulated on an inverter power source. Besides the process and background noise, the low-pass behaviour of used transmission system is clearly recognizable.

In preliminary tests, the THD (Total Harmony Distortion) and SINAD (Signal-to-Interference Ratio including Noise and Distortion) parameters have proven to be the most reliable electroacoustic parameters. Herewith, changes of the arc geometry had unambiguous and reproducible effects.

THD parameter is supposed to be an important quality criterion in the generation and transmission of signals. Just as every quadripole,

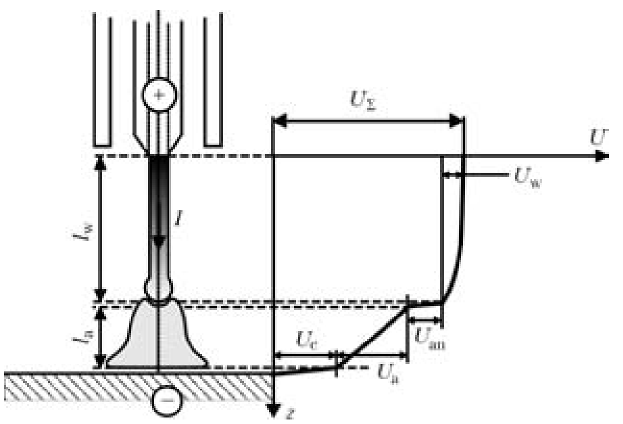

Figure 2. Operative path of arc welding process with idealised potential curves

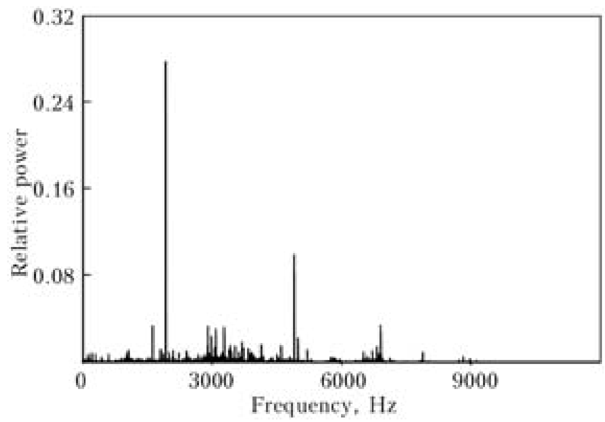

Figure 3. Spectrum of triad coupled into inverter power source

which is made of non-linear components, welding process also represents a non-linear system. If a sinusoidal signal is applied to the non-ideal characteristics of the process, inevitably harmonics are developing, which are found at the integral multiple frequencies of the base frequency (harmonic). The THD quantifies the frequency components of this harmonic, which is, as the rule, unwanted. For the calculation, a relation is established between the sum of effective value of harmonics and the sum of effective values of fundamental wave plus harmonics:

$$\mathrm{THD} = \left(\frac{\overline{U_2^2} + \overline{U_3^2} + \ldots}{\overline{U_1^2} + \overline{U_2^2} + \overline{U_3^2} + \ldots}\right)^{1/2}.$$

The THD is dimensionless, and is expressed alternatively in % or, logarithmical, in dB [9].

SINAD parameter is the ratio of root-mean-square signal amplitude to mean value of the root-sum-square of all other spectral components, including harmonics, but excluding DC-parts of the signal. SINAD is the good indication of the overall dynamic performance of system because it includes all components, which make up noise and distortion. Assuming signal S, noise N and distortion D are measured with the same input signal amplitude and frequency, SINAD is calculated as follows and is expressed in dB [10]:

$$\mathrm{SINAD} = 20 \log \left(\frac{\mathrm{S}}{\mathrm{N} + \mathrm{D}}\right).$$

In-situ-measurement during welding. For the test set-up, welding power source Cloos Quinto II with wire feeder has been used. Since welding power sources are switched, the external supply of sinusoidal signal is impeded considerably. In order to circumvent this problem in the test set-up, welding current supply signal of the Quinto II has been tapped and coupled with a function generator via an summer circuit. The resulting mixed signal is, subsequently, amplified with longitudinally controlled transistor power source ELMA 800, which is, in this case, used as fast and inverter-ripple free power section and supplied to the welding process (Figure 4).

Deposition tests using the spray arc with the contact–tube–distance of 18 mm have been carried out. Shielding gas of M21 class in accordance with DIN EN ISO 14175 with 18 % CO_2 was used.

After short settling time, quasi-stationary welding process was set. Now, sinusoidal signal, which has been generated by the function generator, was coupled into the process. The sound, which, thereupon, emitted by the spray arc, was acquired via directional microphone with a distance of 1 m, digitalised and analysed online with PC.

The tests had, in the first step, been carried out in the audible range in order to guarantee the immediate acoustic control of coupled sig-

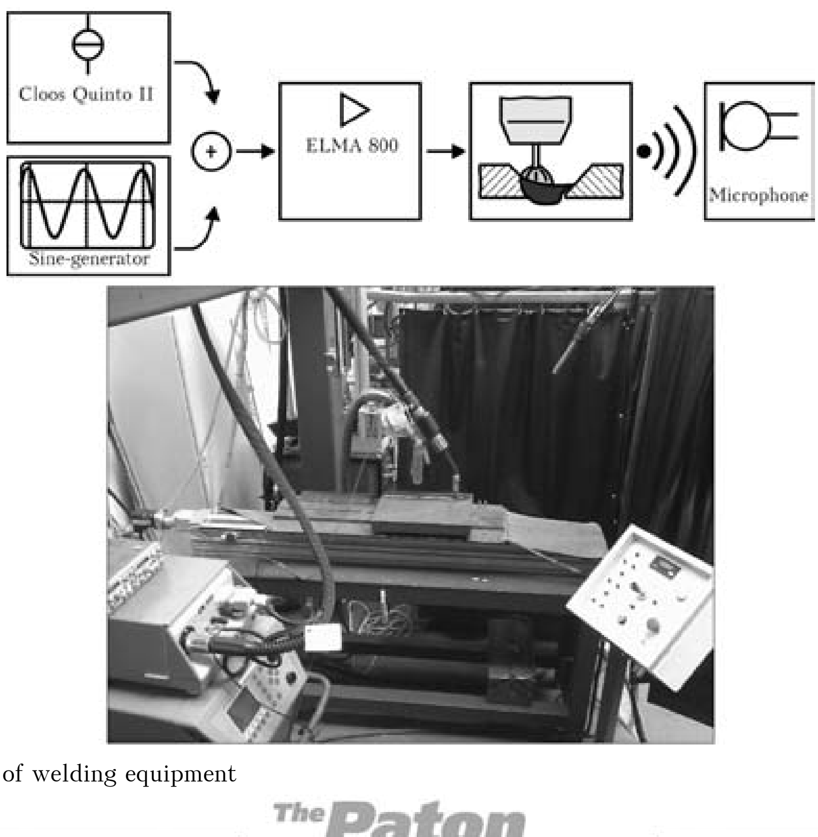

Figure 4. Test set-up of welding equipment

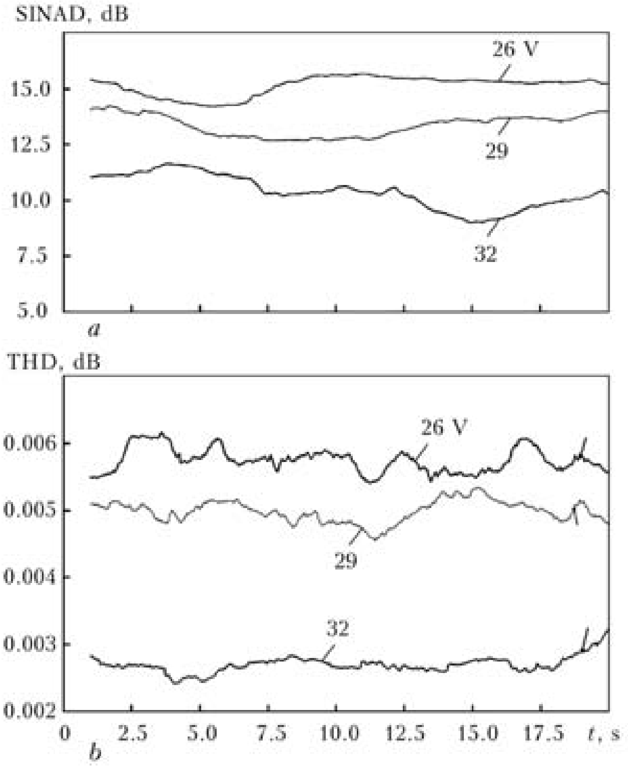

Figure 5. Chronological sequence of SINAD (*a*) and THD at welding voltage of 26, 29 and 32 V

nals. Tests made with frequency analysers showed, however, clearly that measurements also in the range, which is no longer perceivable for human beings (18–20 kHz) will be possible in the future.

Since length and shape of the arc column are in direct connection with the wire feed rate and welding voltage, a series of measurements with variations of voltage in the range 20–40 V have been carried out in order to achieve different geometrical shapes of the arc column at the constant wire feed rate.

Results. The variation of welding voltage has immediate effects on the arc, namely with increasing voltage the arc length is also increasing and extends thus the surface, that is effective for sound generation.

The tests have established that the SINAD and THD parameters are decreasing with longer arc length. Figure 5, *a* shows, by way of example, chronological sequence of SINAD depending on welding voltage. Here, wire feed rate had been constantly 10 m/min, welding current was modulated with the 12 kHz sinusoidal signal. Figure 5, *b* depicts chronological sequence of THD at various welding voltage and constant wire feed rate of 10 m/min. The frequency of the coupled sinusoidal signal was also within the range of 12 kHz.

Figure 6 shows variation of the arc length via the change of wire feed rate. Welding voltage was constantly 30 V, coupled sinusoidal oscillation had the frequency of 12 kHz. In line with the Figures above, here also the trend of decreasing distortion parameters (THD and SINAD) with increasing arc length is observed.

Summary and perspectives. The use of arc as a sound converter and the measurement of welding process distortion parameters, became useful

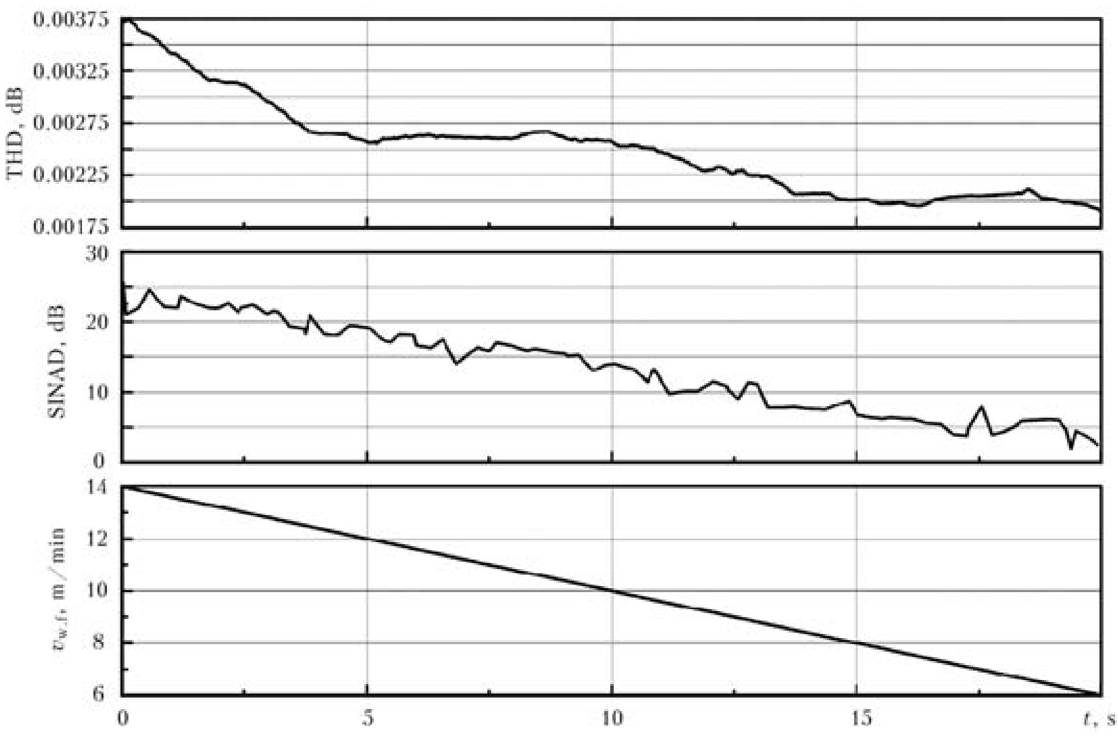

Figure 7. THD and SINAD versus wire feed rate

addition to existing characterisation of arc with regard to the arc length, which is based on analyses of the transient current and voltage signal. The most reliable parameters have proven to be the THD and SINAD, and changes of the arc geometry take unambiguous and reproducible effects.

In-situ measurement of the process with comparatively low technical expenditure is possible. Just the coupling of external signals is problematic in welding power sources due to their low inverter pulse frequency. The next generation of welding power sources will, however, be most likely equipped with increased inverter pulse frequencies since this is required for adhering to the Nyquist Shannon sampling theorem.

The tests have been carried out in the form of metal deposition using the spray arc. Further tests are planned with the inclusion of all other welding processes in order to verify the relevancy to practice and the robustness of method.

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1. Platz, J. (1986) *Beitrag zur Verbesserung eines lichtbogengesteuerten Schweisskopffuhrungssystems*: Diss. Aachen: RWTH.
2. Duan, Y., Jin, H. (1999) Digital controller design for switchmode power converters. In: *14th APEC Proc.*, Vol. 2, 967–973.
3. Nowak, S., Jaeschke, B. (2002) *Moderne Konzepte digitaler Schweissmaschinen, Fachtagung Elektrische Energiewandlungssysteme*. Magdeburg: Otto-von-Guericke-Universitat.
4. Jaeschke, B. (2003) *Digital gesteuerte Stromquellen fur das Lichtbogenschweissen*: Diss. Magdeburg: Otto-von-Guericke-Universitat.
5. Tessmar, V., Koppe, K. (2007) *Die Vielfalt des MSG-Verfahrens gewinnbringend nutzen*: Blech Inform 1. Munchen: Carl Hanser Verlag.
6. Matthes, K.-J., Richter, E. (2002) *Schweissen von metallischen Konstruktionswerkstoffen*. Fachbuchverlag Leipzig im Carl Hanser Verlag.
7. Dilthey, U. (2006) *Schweisstechnische Fertigungsverfahren I*. Springer.
8. URL. *http*://www.lansche-audio.de/eng/start.html. Abgerufen am 26.06.2013.
9. Weinzierl, S. (2008) *Handbuch der Audiotechnik*. Springer.
10. Kestler, W. (2009) Understand SINAD, ENOB, SNR, THD, THD + N, and SFDR. In: *Analog Devices Proceedings MT-003*.

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