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A stochastic approach to the arc welding data

S.C. Absi Alfaro[a], G.C. Carvalho[a], F.R. da Cunha[b]

[a]Automation and Control Group (GRACO), ENM, Brasilia University, Brasilia-DF, Brazil

[b]Vortex, ENM-FT, Brasilia University, Brasilia-DF, Brazil

This paper presents the theory of stochastic processes as applied to the analysis of gas metal arc welding data. A theoretical approach is presented and some of the commonly assumed hypothesis of process stationarity and ergodicity are verified for data collected from stable processes adjusted for short-circuiting and spray modes of metal transfer. Typical fluctuations of the welding voltage and current were calculated for both modes of metal transfer studied. The results showed a significant difference on the magnitudes of the intensity of fluctuation, pointing out that the short-circuiting mode of metal transfer is much less stable than the spray mode, in a statistical sense.

1. INTRODUCTION

It is well established that the arc welding processes produce signal that can be considered to have a stochastic behaviour. Some authors (Refs. 1, 2, 3, 4) assume that the process is ergodic and therefore, if a sufficiently large amount of data is collected it can statistically represent the process. Also, if these data are collected at different times, if the process is stationary, the statistical features can be considered to be the invariant. This assumption was used by Chawla (Ref. 3) to develop a monitoring system based on the "Windowing Technique". This was based on the collection of "windows" (fixed amount of samples) of welding data at different times during the process and on the calculation of statistical features of each window in order to characterise the time evolution of the variables from the welding process. The problem with this technique is the determination of the sampling frequency and the window length necessary for guaranteeing the independence of the data from one window to the data from a subsequent window. One of the problems with this approach is the determination of the amount of welding data necessary for statistically representing the process, without loosing information concerning frequency content of the signal.

2. STATISTICAL BACKGROUND

The first and least restrictive assumption that shall be proved from the experimental data is the assumption that the random processes *V(t)* (welding voltage) and *I(t)* (welding current) studied here are stationary in time. A stochastic process, being stationary, means that the form of the probability distribution function does not depend on a shift in the origin of time. In a sense, it is assumed that the underlying probabilistic mechanism of the process does not change with time. More precisely, it can be said that a random process, $\Phi(t,\beta)$, is stationary when the probability distributions of $\Phi(t,\beta)$ and $\Phi(t+\tau,\beta)$ are the same for any τ. (Refs. 6).
It is important to note one more property that follows from the ergodic hypothesis and the assumption of stationarity. In dealing with general random processes, there are two types of mean values that can be encountered. One is the probability average obtained by observations made on many realisations at some fixed time t, denoting this average by $\langle\Phi\rangle$, and the other is the time average made on one system as a function of time, denoting this average by, $\overline{\Phi}$. In the case of a stationary random process, both averages yield the same result. In terms of equations,

$$\langle\Phi\rangle = \int_{-\infty}^{+\infty} \phi \, f(\phi) d\phi \tag{1}$$

$$\overline{\Phi} = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} \Phi(t) dt \tag{2}$$

For the method of averaging defined in equation (2) to have any significance, it is necessary that the limit exist and that it be independent of the definition of the time *T*. For a stationary random process, these conditions are in fact satisfied. According to the ergodic hypothesis, the time average thereby obtained is the same as the probability average defined by equation (1) (i.e. $\overline{\Phi}=\langle\Phi\rangle$), provided that the function Φ is finite and continuous. Considering that Φ is a stationary stochastic process, then $\Phi = \langle\Phi\rangle + \Phi'$, where Φ' represents the random fluctuation around $\langle\Phi\rangle$. Therefore, the necessary condition for demonstrating that the ergodic hypothesis is satisfied for a stationary stochastic process is that the time average of the fluctuations must be null (i.e. $\overline{\Phi'} = 0$).

3. RESULTS AND DISCUSSIONS

The theory developed above was utilised to analyse the welding data acquired from controlled gas metal arc welding trials. The welding parameters were adjusted before acquiring the data to provide stable processes in both the dip and the spray modes of metal transfer. Several welding trials were carried out with different parameters and the welding data was acquired using an acquisition system based on the windowing technique (Refs. 3,5). The sampling frequency adopted was 4032 Hz and the sampling time, 254 milliseconds (ms). Such sampling time resulted in 1024 samples per 254 ms "window" (realisation). Before being converted to the digital form, the analogue welding signals were conditioned and filtered with an analogue eighth-order Butterworth switched capacitor filter, with cut-off frequency adjusted to 1kHz. Around fifty-five 254ms "windows" were acquired for each welding trial, from which around 47 were chosen as representative of stable processes.

According to the theory developed before, each window was considered a realisation of the stochastic process. In this work, only a small fraction of the results obtained will be shown for illustration due to limitations on the size of the paper. The welds were carried out using the BOC Argonshield 5 (93%Ar+5%CO_2+2%O_2) as the shielding gas, at 15 l/min flow rate, and the Bohler EMK 8A (BS 2901 pt. 1 Gr. A18) mild steel welding wire. The stands off were set to 12 mm in the dip transfer trials and to 20 mm in the spray transfer. The welding speed was set to 500/min in both modes of metal transfer. The welding parameters utilised during the welding trials were: (a) Dip transfer: welding voltage, V = 19.5 volts; wire feed speed, WFS=8.0 m/min; and (b) Spray transfer: V = 31.0 volts; WFS=14.5 m/min.
The short time behaviour of the process is characterised by the mean and the variance. Figure 2 shows the plots of the probability and time averages (defined in eqs. 1 and 2, respectively) of the welding voltage for the dip transfer mode process.

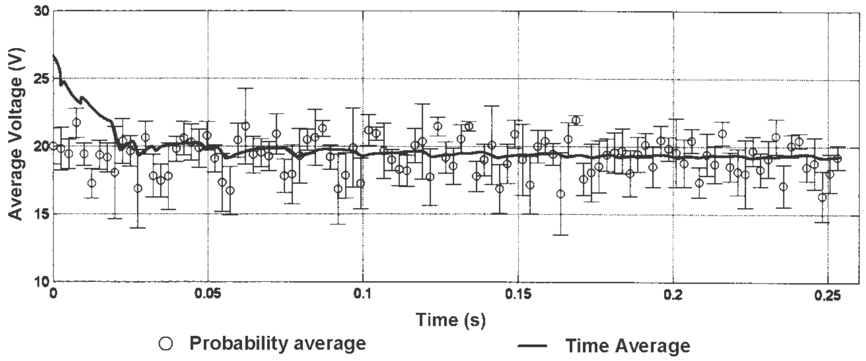

Figure 2 – Comparison between probability average and time average

Figure 3 displays the plots of the probability and time averages of the fluctuation intensity (normalised standard deviation), calculated for the process with dip mode of metal transfer. In agreement with the theoretical background of this work, it can be observed from the plots in figures 2 and 3 that the stochastic processes investigated here are statistically stationary, since neither the probability averages nor the respective fluctuation intensities present any systematic changes with time. It should be noted that in the case of a stationary process, the correlation function depends only on the time shift, τ, and not on the absolute time, t.

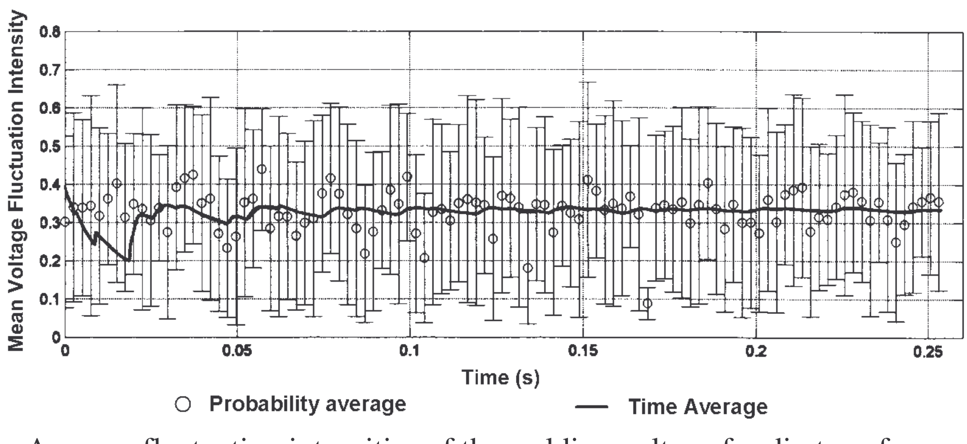

Figure 3 – Average fluctuation intensities of the welding voltage for dip transfer mode.

Generally, process instability can be quantified by the fluctuation intensity. In the investigated stochastic processes, it was observed that the dip transfer mode presents a higher fluctuation intensity (around 30% of the average voltage and current) than the spray mode (around 1% of the average voltage and current). Therefore, the already known unstable electrical characteristic of the dip mode relative to the spray mode of metal transfer was statistically quantified.

4. CONCLUSIONS

The commonly assumed hypotheses of stationarity and ergodicity were demonstrated by means of a rigorous statistical treatment of the experimental data. The analysis of the short time behaviour of the process showed that the mean welding voltage and current and their variance are, in a statistical sense, independent of the time. The analysis of the long time behaviour of the fluctuations was described by the normalised auto-correlation functions. The results revealed that this function decays exponentially with time towards zero for the welding voltage and current from the dip mode of metal transfer and for the welding voltage from the spray mode. However, an unexpected behaviour was detected in the case of the welding current from the spray mode of metal transfer. The unstable electrical characteristic of the dip mode of metal transfer was quantified relative to the spray mode, showing that the first presents fluctuation intensity about 30% higher than the latter. The density spectrum confirmed the already known characteristic frequencies of the GMAW process. In the dip transfer mode, the spectrum of welding voltage showed a concentration of energy in the low frequency range (<100Hz), whereas in the spray transfer mode, the spectrum of the same variable showed sharp peaks of energy concentrated in the fundamental frequency of 300 Hz, and in its first and second harmonics.

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