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Weld transference modes identification through sound pressure level in GMAW process

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ABSTRACT

Purpose: One of the most used processes in the industry is GMAW, in this welding process there is physical phenomena such as the temperature, electromagnetic field, luminosity and sound pressure. It is known that GMAW weld specialized techinicisian combine visual and sound at the work to garantee the process stability. It is important to improve the final weld quality; therefore, the quantification of electrical and acoustical behaviour - within the audible bands, offer an information that is important to comprehend his impirical rules.
Design/methodology/approach: With these he can identify the transfer mode, instabilities in the process, determine defects and evaluate the weld quality along the weld bead. The sound signal is captured simultaneously with the arc voltage and current signals. Was proved that first derived from the instantaneous power of the electrical arc presents a behaviour similar to the acoustical with a delay, because the measured sound is airborne.
Findings: This relation was corroborated by the comparison between the sound pressure level calculated by electrical signals and by acoustical signals. This relation presented a similarity between the calculated signals greater than that between the sound and the power first derived.
Practical implications: Besides that, with the sound pressure level it is possible to identify process instabilities that is not so trivial to realize with the sound pressure signal. In spite of it, the identification of instabilities for the globular and spray tranfer modes displays greater difficulty than that for the short circuit transfer mode. It was shown that the acoustical weld sensing offers information about the behaviour of the tranfer mode and the process stability.
Originality/value: The sound quantification would be applied as a control variable for the weld process. Thus, it would be possible to develop similar control strategies as those applied by specialized workers.
Keywords: GMAW; Sound pressure; Weld quality; Airborne; Acoustic sensing

1. Introduction

The welding process is the most used in manufacture and metallic construction. The final process resulting evaluation, the weld, determines if it presents or not acceptable quality levels to fulfil market requirements. The quality control in the welding process is something very researched, mainly those that relate to the suitable election of the process parameters. In process GMAW the union of the pieces is produced by a fusion produced by the electric arc that also is known by metallic transference. The GMAW process classically presents three modes of metallic transference: (a) Short Circuit, (b) Droplet, (c) Spray Modenesi et al [15]. During GMAW process, many physical phenomena appear, such as voltage and current of the arc, luminosity, magnetic field, temperature, sound pressure and others. Each metallic transfer mode produces a variation of characteristic pressure of sound that makes possible the identification between the modes. It is known that expert technicians in welding use a visual-acoustics combination for monitoring and control of

GMAW process, Kralj, [1]. The airborne acoustics emitted by a welding arc are an indirect indicator of the arc stability and metal transfer characteristics. The knowledge of the behaviour of the sound pressure and its correlation with the parameters of the process, to obtain beads of better quality, offers a good alternative for automatization and optimization of the weld process.

The investigation objectives are to find a relation between the electric and acoustic behaviour for each transfer mode and to evaluate if it is a good indicator for the weld quality. It is based on the measurement of the sound wave produced by the arc, which is shown to depend on the rate of change of the electrical power fed to the arc column Druet et al and Mansor et al [2, 4]. In essence, it is the combination of arc stability and regulation of the rate and mode of 'metal transfer' that dictates the quality of the final weld. These properties are the integration of many interdependent aspects of the process, thus making GMA welding a fully coupled, highly non-linear multivariable process. Doumanidis et al [5] have identified three dominant qualities that need to be controlled, albeit indirectly: fusion zone geometry, heat affected zone properties, and thermally induced deflections and residual stress. Due to the challenges inherently presented by GMA welding control, 4 attempts at classical modelling and control techniques have met with little success Hellinga *et al* and Doumanidis et al [6, 7]. This method here is no electrical connection to the arc circuit, then the errors usually caused by the voltages, induced by the arc dI/dt and ohmic drops in the arc electrodes are avoided. Chawla et al [8] successfully demonstrated online identification of 'good' and 'poor' fluxcored arc welding (FCAW) wire using sound data. Kaskinen et al [9] pursued acoustic arc length control by converting the measured sound pressure to an equivalent arc voltage for feedback into the original controller. The resulting system was reported to be competitive at any reasonable arc length and superior to the original signal at very short lengths. Arc-sound signals have also been utilized by Murugesan et al [10] in monitoring and controlling the deposition thickness in an electric arc-spraying process.

The sound is known as the disturbance that becomes on a body and generates a mechanical wave that is transmitted through an elastic material. The sound waves are perceptive to human being between 20 Hz and 20 kHz. The sound propagation can be expressed by the linearized wave equation in function of the sound pressure; one can assume that the waves are longitudinal (ie. x axis), and equation 1 can be expressed as:

$$\frac{\partial^2 p}{\partial x^2} = \frac{1}{v_s^2}\frac{\partial^2 p}{\partial t^2} \tag{1}$$

In which $\nabla^2 p$ is the pressure Laplacian operator, p the acoustic pressure, v_s the sound propagation speed and t the time.

$$S_a(t) = \frac{d(k.V(t).I(t))}{dt} \tag{2}$$

$$k = \alpha\frac{(\gamma - 1)}{c^2} \tag{3}$$

In which $S_a(t)$ is the sound signal, *V(t)* the arc voltage, *I(t)* the arc current, k is a geometrical factor, γ the adiabatic expansion coefficient of air and c the sound speed in the arc. The equivalent continuous sound pressure level (also called time average-sound level), Leq, is defined as twenty times the logarithm in base ten of the ratio of a toot-mean – square sound pressure during a time interval to the reference sound pressure. That equivalent continuous sound level, Leq, is expressed in decibels (dB) and is given by [11]; the Bruel and Kjaer, type 2250, sound-level meter with a 4189 microphone linear was employed, it has 50mV/Pa of sensibility. Equation 4 express the sensibility function.

$$L_{eq} = 20.Log\left[\sqrt{\frac{1}{\Delta t}\int_t^{t+\Delta t} P^2(\xi)d\xi}\Big/ p_o\right] \tag{4}$$

$$L_{eq} = 20.Log\left[\sqrt{\frac{1}{\Delta t}\int_t^{t+\Delta t}\left(\frac{S(\xi)}{50E-3}\right)^2 d\xi}\Big/ p_o\right] \tag{5}$$

Relating Equations 2 and 5 results:

$$L_{eq} = 20.Log\left[20\sqrt{\frac{1}{\Delta t}\int_t^{t+\Delta t}\left(\frac{d(k*V(\xi)*I(\xi))}{d\xi}\right)^2 d\xi}\Big/ p_o\right] \tag{6}$$

In which Leq is the sound pressure level, V the arc voltage, I the arc current, K the geometrical factor, Po the reference sound pressure (20 uPa), ξ is a dummy variable of time integration over the mean time interval, t the start time of the measurement, Δt the averaging time interval, S the sound signal. Drouet et al, [2] who originally established the relationship, capitalized upon its usefulness in applications to arc furnaces and currently hold a patent to the use of the technique of acoustic voltage measurement. In 1979 and 1980, Arata et al. [12, 13] made measurements confirming the strong relationship between sound pressure level (SPL) and electrical characteristics and also revealing the influence of sound on the molten weld pool. They also discovered that there is synchronization between sound impulses and short circuit transfer, confirming what expert human welders have claimed, but never proven.

2. Experimental procedure

The major advantages of using PC based systems, indicated by Lucas et al [14], are low-cost, customizability and upgradeability. During the experiments we simultaneously acquired the arc voltage signal, welding current and sound pressure. In order to do the acquisition process, we implemented the Labview 8.2 virtual instrumentation software (VI's).

In Tables 1 and 2 we detailed the experiment's variables magnitudes and restrictions. Table 1 shows the electrical parameters, the execution time, the transfer mode, the tip speed and the protection gas flux. This set of experiments covered all three transfer modes. Table 2 shows the constraints for the second experiment set, which were applied to the short circuit transfer mode and the globular transfer mode.

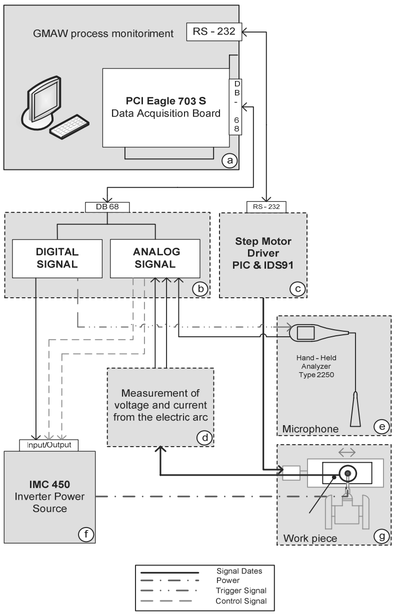


Fig. 1. Experimental set-up

a. Variables control, monitoriment and measurement from welding process. It is a personal computer with a data acquisition board - PCI Eagle 703S and a RS-232 port.
b. Hybrid system connection to analog and digital signals.
c. Local and remote system for the work piece displacement control. The remote communication is made by the computer - port RS-232.
d. Measurement system of voltage and current that comes from the weld process.
e. Measurement system of sound pressure level intensity. It is a hand–held decibelimeter analyzer, type 2250, 4189 prepolarized free-field ½" microphone, preamplifying microphone ZC 0032. Sensitivity 50 mV/Pa.
f. Power source - Inversal 450.
g. Mechanical system responsible for the work piece displacement and weld torch fixation.

3. Results and discussions

3.1. General remarks

The sound signal was captured simultaneously with the arc voltage and current signals; it was sampling with a 20 KHz rate. Studies in psychoacoustic determined that while the acoustic signal from GMAW process does not go longer then at 400 ms, this will be a good indicator of the behaviour from welding process. In diverses works of weld acoustic monitoring, each author put the microphone into different distances from the weld pool; 85 mm Druet et al [3], 1 m Sanches et al [17], 200 mm Warinsiriruk et al [18], 35 mm Čudina et al [20]. The Figure 2 shows as were located the microphone for the acoustical measurement from GMAW process taking into account the protection of the microphone against the spatters from weld and the excess thermal radiation that can alter the stability, repeatability and time response from microphone.

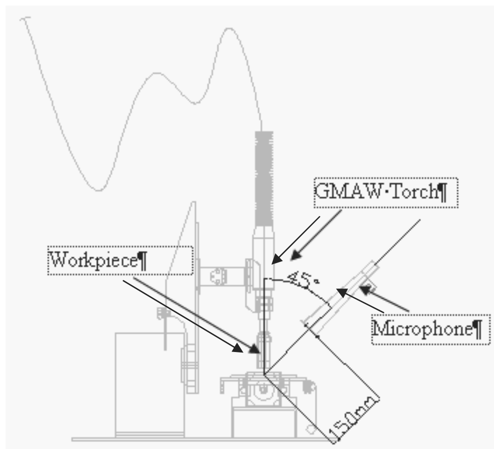


Fig. 2. Microphone positioning

Table 1.
Electrical parameters for tests group 1

Test	Time (s)	Voltage (V)	Sped Wire (m/s)	Mode	Stand Off (mm)	Gas (lt/min)
1	20	20.0	6.0	sc	16	16.25
2	20	19.0	3.5	sc	16	16.25
3	20	18.0	4.5	sc	16	16.25
4	20	25.0	3.5	gb	18	16.25
5	20	27.0	3.5	gb	18	16.25
6	20	24.0	3.0	gb	18	16.25
7	20	32.0	6.0	sp	20	17.00
8	20	33.5	6.5	sp	20	17.00
9	20	35.0	7.0	sp	20	17.00

sc: short circuit mode – gb: globular mode; - sp: spray mode

Table 2.
Electrical parameters for tests group 2 (Constant Current)

Test	Voltage (V)	Current (A)	Mode	Stand Off (mm)	Gas (lt/min)
10	20	90	sc	16	16.25
11	24	120	gb	16	16.25

sc: short circuit – gb: globular

3.2. Scope

Materials and properties

These tests were made with a wire electrode AWS A5.18 ER70S-6 with 1 mm diameter. The different metallic transfer modes tests were made on steel work piece AISI 1020 of 6.50 mm. The shielding gas used was a mixture of argon and carbonic gas M21 (ATAL 5A/Ar 82% + CO_2 18%).

Methodology of research

Studies in psychoacoustic indicate that the human ear is only able to distinguish between two frequencies when the relation among them is the double or half. This frequency band is denominated octave frequencies. Each transfer mode has a characteristic sound and the difference between ones and the others are the component frequencies, the harmonics and the SPL. In the present work we acquired sound pressure, voltage arc and current weld signals. The SPL signal (see Figure 3(e)) is calculated from the pressure sound signal measured (see Figure 3(d)). With the objective to calculate the SPL from the relation found by Druet et al [3], first we calculated the acoustical signal from process from the voltage arc and weld current (Equation (2)). After this, from acoustical signal obtained and the Equation (6) we obtain the SPL as function of the electrical signals from process (see Figure 3(f)), these calculations confirm the narrow relation between electrical and acoustic signals on GMAW process.

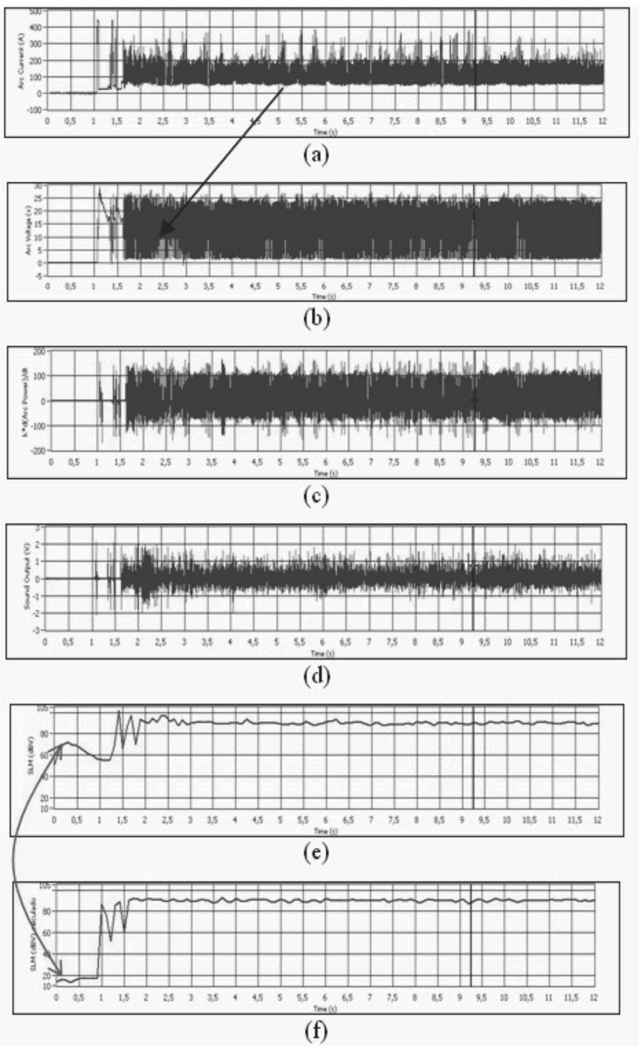


Fig. 3. Oscilogram from signals for short circuit tranfer mode

The measured signal shown in Figure 3(e), presents an initial threshold measured, but the calculated signal by Equation (6) do not present this initial threshold (Figure 3(f)). The one that appears in the measured signal is due to the shielding gas liberation. This fact has not an electrical nature, thus it is not possible to calculate it by Equation (6). Figure 4(a) and (b) shows the measured signals for short circuit and droplet transfer modes. One can notice the behaviour of sound pressure signal and sound pressure level between the two transfer modes (Figure 4(b)). From that difference we can identify between a transfer mode and another one. For the identification of the transfer modes, we will use statistical descriptors (Arithmetic Mean, Most Frequent Value, Range, Standard Deviation and Variance) since these signals have stochastic behaviour, Sadek et al [16]; previous investigations demonstrated that FFT analysis for acoustic signals from GMAW process, are not too much reliable by their instability, Warinsiriruk et al [18], whereas the analysis of SPL turns more stable Cayo et al [19].

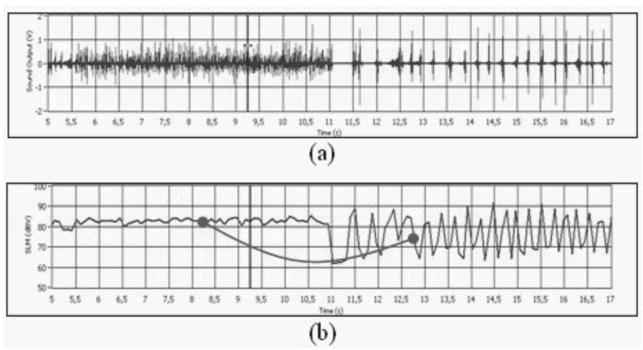


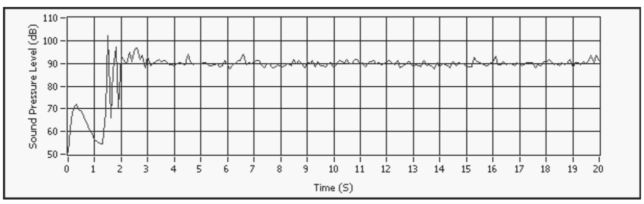
Fig. 4. Oscilogram of short circuit and droplet transfer modes signals

Analysis and modelling

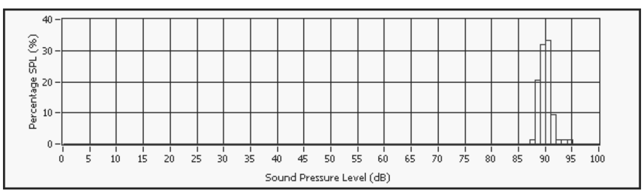
After having acquired the on-line process signals, we made an off-line analysis of them using VI's. Figures 5(a), 6(a) and 7(a) have the SPL's for the tests 3, 6 and 9 of the Table 1 that represents the transfer modes short-circuit, globular and spray respectively. In these graphs we can notice that the SPL behaviour in globular and spray modes varies dramatically in comparison with the short circuit mode. For differentiate between a tranfer mode and another one, we make a component distribution of the percentage of SPL for each transfer mode. The SPL distributions are shown in the Figures 5(b), 6(b) and 7(b). Also we determined the statistical descriptors for each transfer mode that are showed in Tables 5, 6 and 7. In the Figures 5(a), 6(a) and 7(a) it is possible to be noticed that exists a variation initial on the signal is due to the start of the process. And the first fluctuation is related to the beginning of the shielding gas flow. These perturbations also can be observed on the all transfer modes. After this unstable and chaotic behaviour, it is possible to see that each transfer mode presents a characteristic stationary behaviour in the SPL. Table 3 shows the statistical indicators of the sound level pressure behaviour from GMAW process, in the short circuit transfer mode.

According to the statistical descriptors obtained, we noticed that in the short circuit mode, the SPL distribution concentrates around an average of 89.9719 dB within a small range of the variation and standard desviation. This behaviour of the SPL distribution is characteristic in the short circuit transfer mode. Its continuous behaviour during the weld execution indicates that the SPL can be a good indicator of the weld process stability.

We can notice that the SPL behaviour for the globular and spray transfer mode are similar, nevertheless, their statistical distribution show differences. In addition to it, the statistical descriptors display results with different tendencies as the average, variation range and standard desviation. Also we noticed that both transfer modes present great amplitude of range, standard deviation and variance, reason why its use for the evaluation of the stability from GMAW process in the globular and spray modes would be little reliable.

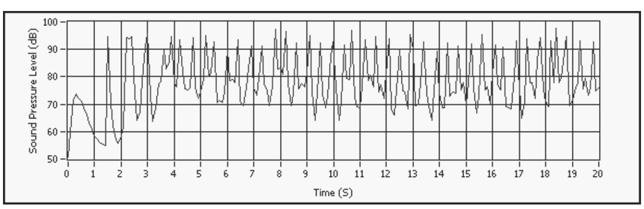


(a)

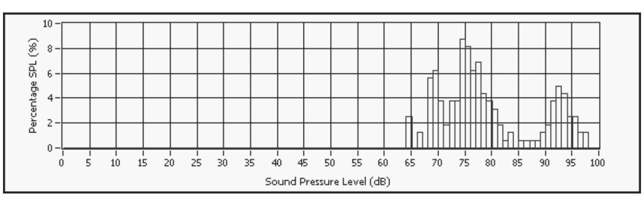


(b)

Fig. 5. Sound pressure level measure for short circuit transfer mode

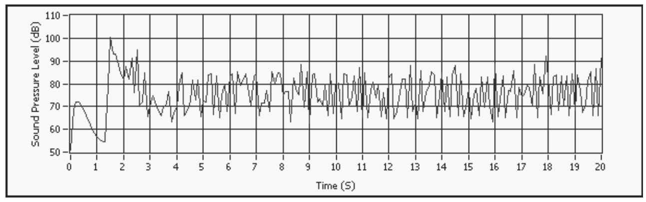


(a)

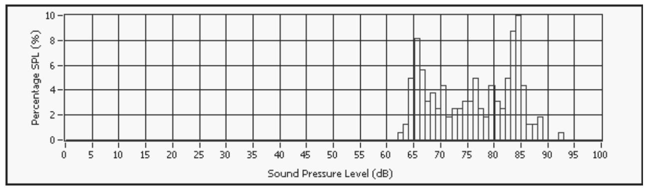


(b)

Fig. 6. Sound pressure level measure for globular transfer mode



(a)



(b)

Fig. 7. Sound pressure level measure for spray transfer mode

Table 3.
Measurement of central tendency and dispersion for short circuit transfer mode

Statistical Indicators	Values
Arithmetic Mean	89.9719 dB
Most Frequent Value	89.5000 dB
Range	6.3000 dB
Standard Deviation	1.2814
Variance	1.6421

Table 4.
Measurement of central tendency and dispersion for globular transfer mode

Statistical Indicators	Values
Arithmetic Mean	79.1975 dB
Most Frequent Value	75.9280 dB
Range	33.6000 dB
Standard Deviation	8.97886
Variance	80.6200

Table 5.
Measurement of central tendency and dispersion for spray transfer mode

Statistical Indicators	Values
Arithmetic Mean	75.9313 dB
Most Frequent Value	65.3075 dB
Range	29.5000 dB
Standard Deviation	7.75137
Variance	60.0837

In Figure 8, the comparative graph displays, for each mode, the number of acoustic pulses per second since the fourth second of the weld process. The difference is very noticeable for each mode. On the other hand, in Tables 3, 4 and 5, note that the SPL average arithmetic decreases for the short circuit, globular and spray modes respectively. In each transfer mode, the number of pulses per second influences in the continuity characteristic of the SPL. It is why for the short circuit mode the SPL remains almost constant due to the high frequency of pulses per second. Whereas the globular and spray mode have little frequency of pulses and therefore the SPL will stay less stable.

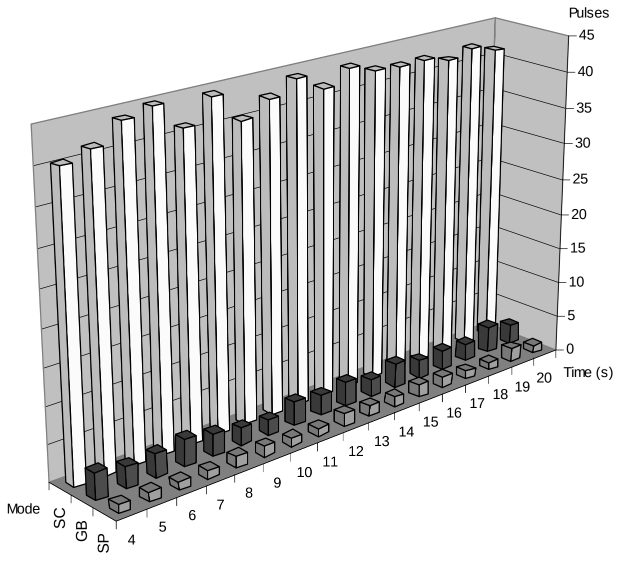


Fig. 8. Pulses for each transference mode in GMAW process; SC: short circuit mode – GB: globular mode; - SP: spray mode

4. Conclusions

The sound from weld process is a consequence of the amplitude modulation of the arc voltage by weld current, its behaviour is an indicator of the weld process and its suitable measure and quantification, can offer information of the process in real time.

An analysis of SPL from GMAW process offers more reliable information about the continuity of the weld process that the acoustical signal in time domain.

The continuity characteristic that presents the SPL in the short circuit transfer mode is due to the fact that the metallic transference takes place with a great amount of the followed short circuits. Whereas in the globular mode is noticed that in average three drops to weld pool are transferred per second; in the spray transfer mode in average a drop per second. Therefore it is possible to be affirmed that the SLM is a very good indicator of the stability on the GMAW process for short circuit mode.

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