An Investigation of Gas Metal Arc Welding Sound Signature for On-Line Quality Control

High-speed signal data acquisition and computer-aided analysis of sound signature may reveal conditions that generate weld defects

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ABSTRACT. On-line quality control in automated welding operations is an important factor contributing to higher productivity, lower costs and greater reliability of the welded components. However, the development of on-line inspection techniques and feedback control is still in its infancy.

Sound signature produced by GMAW contains information about the behavior of the arc column, the molten metal and the metal transfer mode. Manual welders rely on sound signature as important feedback for production of good welds. High-speed data acquisition and computer-aided analysis of the sound signature may indicate conditions that generate weld defects. This paper presents an experimental investigation that attempts to establish correlations between sound signature, welding parameters and weld transfer mode with a view toward detection of weld defects. The results indicate that the sound signature is a usable, practical information source for process-linked quality control of welds.

Introduction

In recent years, gas metal arc welding (GMAW) and its variants have been extensively used in robotic welding operations employed for mass production of welded components. Considerable effort has been directed toward the development of on-line sensing (joint tracking) and correction of the welding path by using feedback and adaptive control. Significant progress has been made in applying this technology reasonably in production environments. However, on-line sensing and control of weld quality is in its infancy and a great deal of research will be required before its development is sufficient for use in production operations (Ref. 1), with the ultimate aim to achieve good quality welds with high productivity. Different control methods for automated welding (Refs. 2–4) have been employed to reach this objective, but a lack of direct information on weld quality has hindered these approaches. The harsh environment, temperature and dynamic conditions of the arc welding process and the different types of weld discontinuities produced simultaneously create difficulties for real-time quality control. Techniques such as ultrasonics (Refs. 5, 6), radiography (Refs. 7, 8), through-the-arc sensing (Refs. 9–11) and infrared sensing (Refs. 12, 13) have been proposed for on-line inspection and quality control of welding operations. However, the problems of sensor mounting, sensor movement as the weld progresses and interpretation of complex waveform signals have obstructed the successful application of the ultrasonic technique for on-line quality control of welding operations. The radiography technique for weld quality control requires high-speed data acquisition and fast processing of information to extract information that will be useful in feedback to adjust welding conditions so as to maintain weld quality. This technique, however, suffers the drawback of time delay in extracting feedback information on the weld, resulting in some weld areas having unsatisfactory penetration (Ref. 7). Through-the-arc sensing relies on the statistical and numerical analysis of the welding current and voltage transient response for monitoring the metal transfer mode, which influences the process stability, and, thus, the resultant weld quality. This technique — though a simple and nonintrusive method of sensing — requires a relatively longer period for classification of metal transfer modes in the GMAW operation, compared to visual methods (Refs. 9, 10).

The sound signature generated by arc welding contains information about the behavior of the arc column, the molten metal and the metal transfer mode (Refs. 14, 15). High-speed signal data acquisition and computer-aided analysis of the sound signature may reveal conditions that generate weld defects.

The sound produced by arc welding has provided important feedback to manual welders for the production of good welds (Ref. 16). Although the relationship between arc sound, voltage, current, arc length and anode material was demonstrated as early as 1944 (Ref. 17), investigations of arc sound for monitoring and diagnosis of the welding process only began in the late 1970s (Refs. 15, 18–20). Since then, a number of attempts have been made to use sound for sensing the arc and for controlling the welding process in automated welding operations (Refs. 21–24, 26, 27). However, little attention was paid to fundamental aspects, including feature extraction from the welding arc sound and the behavior of the sound parameters as the weld quality deteriorates. This paper presents a study of the sound generated in GMAW, undertaken to assess its feasibility for on-line weld quality monitoring and adaptive control.

Sound Generation in GMAW

In GMA welding, sound is generated from three sources: the arc, gas shielding and welding equipment. In previous literature concerning GMAW airborne acoustics, no mention was made of the influence of gas shielding and welding equipment sound on the sound signature of the arc column. However, preliminary tests done by the authors indicate that the

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magnitude of sound signal from the shielding gas and welding equipment is very small compared to the arc sound and thus is unlikely to influence the character of arc sound signal collected in the experiments — an observation also made by Schiebeck (Ref. 25).

Various investigations have attempted to quantify sound generation based on arc characteristics such as voltage, current, arc length, etc. (Refs. 21, 22). Manz (Ref. 16) argued that an electrical arc generates sound when the energy level of the arc changes. He stated that for every pulse of electrical energy put into an arc, a pulse of sound is created. Kaskinen and Mueller (Ref. 21) reported that in GMAW, sound is generated when the volume of plasma is changed. When the volume of the plasma is proportional to the power of the arc, the sound pressure generated by the arc (Ref. 21) can be expressed as follows:

$$S = k\frac{d(VI)}{dt} \tag{1}$$

$$S = K\left(I\frac{dV}{dt} + V\frac{dI}{dt}\right) \tag{2}$$

where:

VI = Power of the arc
V = Voltage across the arc
I = Current across the arc
k, K = Constants
S = Sound pressure

Thus, sound is produced by an arc whenever the energy level of the arc is changed. Power supply, transfer mode and transfer rate are the three factors that affect the arc's change in energy level.

Experimental Setup

A schematic arrangement of the experimental setup is shown in Fig. 1. In order to achieve reproducible results, the welding torch was mounted on a fixed arm, permitting both angular and height adjustment of the torch relative to the workpiece. Mild steel specimens were clamped on a motor-driven carriage with a variable speed in the range of 100 to 500 mm/min.

Sound signals of about 15-s duration were collected for short circuiting and spray transfer mode of GMA welding. A contact tip-to-job distance of 13 mm was set for all welds. The welding head was angled back at 22 deg. The microphone was placed vertically above the welding head contact tip and at a distance of 380 mm from the work surface. The workpiece was traversed under the torch at a speed of 350 mm/min. Other settings such as voltage, current and wire feed rate are detailed in Table 1.

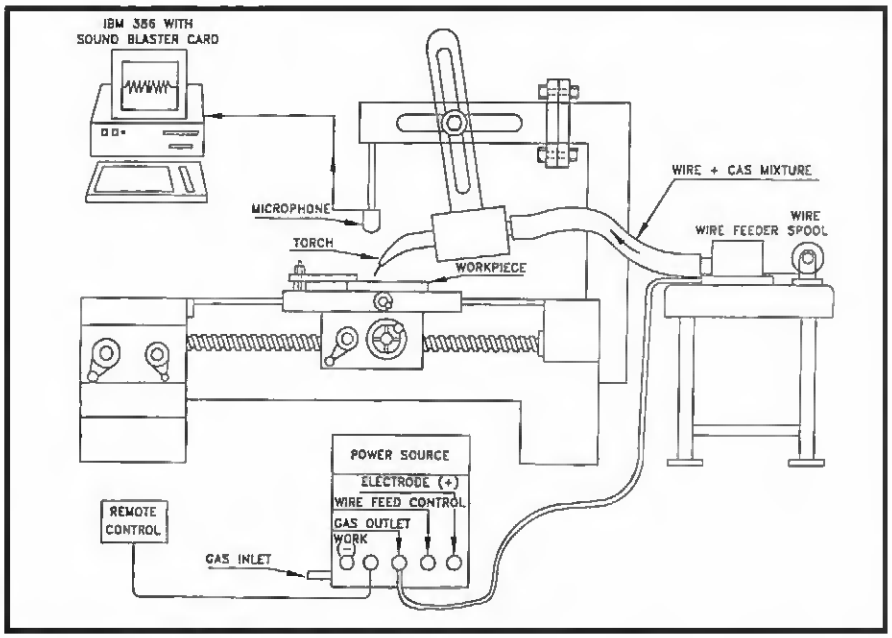

Fig. 1— Schematic arrangement of the experimental setup.

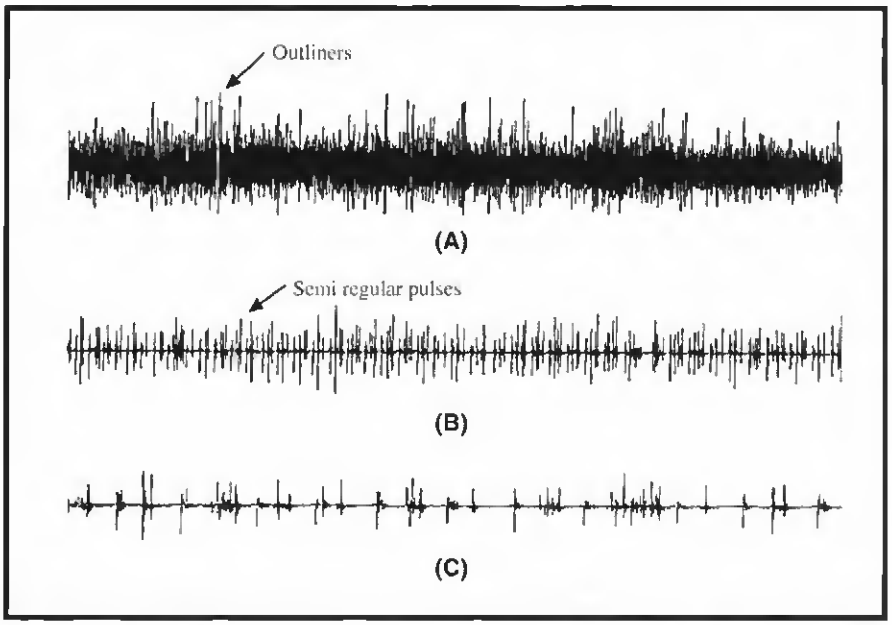

Fig. 2 — Sound signal of GMAW in short circuiting transfer mode: A — 0.0–9.64 s of WELD31.WAV; B — 0.0–1.00 s of WELD31.WAV; C — 0.0–0.20 s of WELD31.WAV.

The sound signals generated by the GMAW process were collected by an omnidirectional microphone (50 Hz to 18 kHz frequency response), and then stored on the hard disk of an IBM 386 computer, after 15-bit A/D conversion carried out by a sound card (Sound Blaster 16ASP MCD) installed within the computer. The sampling of the sound signal was done at a frequency of 44.1 kHz.

Arc Sound Analysis and Results

Analysis of the stored sound signal was carried out in two steps:

1) Qualitative Analysis — A visual analysis of the sound using COOL–EXE,

2) Quantitative Analysis — Using specially written C Programs to extract numerical parameters of the sound signal.

Visual Examination of Sound

COOL–EXE was used for production of sound graphs. The other graphing programs, such as EXCEL, could not be used as the number of data points contained in the sound file far exceed EXCEL's capability. Figures 2A and 3A show about 10 s

Table 1 — Welding Parameters for the Two Sound Recordings

File Name	Wire diameter (mm)	Wire Feed (RPM)	Wire Feed (m/min)	Voltage (V)	Current (Amp)	Transfer Mode
WELD31.WAV	1.2	75	7.07	19	280	short circuiting
SP4.WAV	1.2	80	7.54	31	300	spray

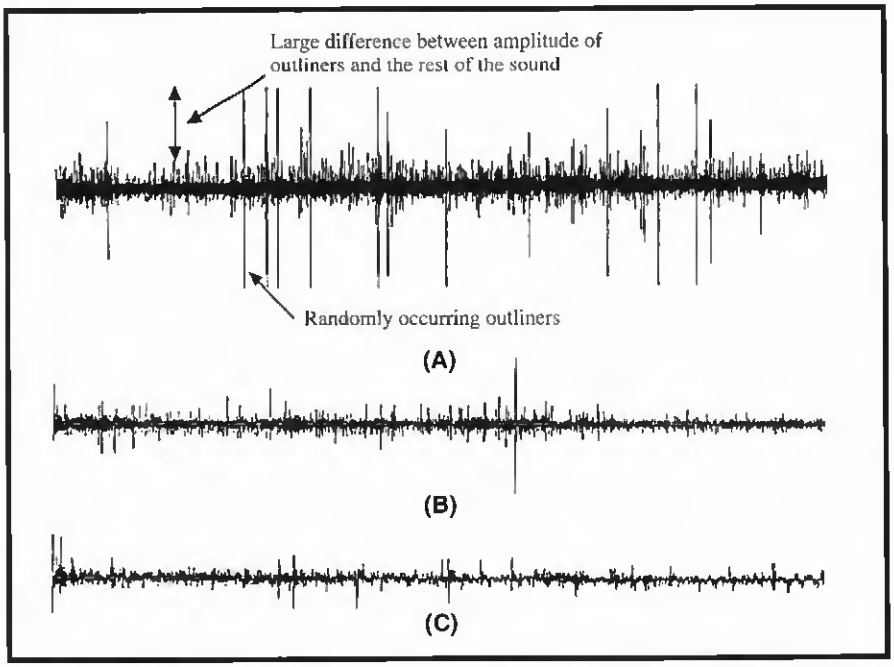

Fig. 3 — Sound signal of GMAW in spray transfer mode: A — 0.0–8.70 s of SP4.WAV; B — 0.0–1.00 s of SP4.WAV, C — 0.0–0.20 s of SP4.WAV.

sound of GMA welding in short circuiting and spray transfer mode. Zoom-ins on a small sector of sound signals are presented in Figs. 2B, 2C, 3B and 3C.

An examination of Figs. 2 and 3 indicates that spray transfer is much quieter than short circuiting transfer. The sound produced during short circuiting transfer is a series of very loud "cracks" that occur with a regular pattern. Spray transfer, on the other hand, is a much quieter (sometimes silent) hushing sound with occasional crackles possibly caused by the filler wire dipping into the weld pool.

By comparing Fig. 2A to Fig. 3A, it can be seen that sound produced by short circuiting transfer mode GMA welding (WELD31.WAV) has a larger number of randomly occurring outliers, as opposed to the sound generated by spray transfer mode GMA welding (SP4.WAV), which has fewer randomly occurring outliers. Also note that the difference between the amplitude of the outliers compared to the rest of the sound is larger in SP4.WAV than WELD31.WAV indicating, as expected, that spray transfer welding has periods of quiet noise with occasional loud cracks. Comparing Fig. 2B and Fig. 3B, the difference between WELD31.WAV and SP4.WAV becomes more apparent. Figure 2B shows that WELD31.WAV contains numerous irregular pulses that occur quite periodically. Figure 3B shows that SP4.WAV produces a more continuous sound, more regular than WELD31.WAV.

Comparing Fig. 2C to Fig. 3C, it can be seen once again that WELD31.WAV is made up of a series of pulses and that SP4.WAV contains a continuous uninterrupted sound. The most important piece of information from this visual examination of the two sounds is that the sound produced by short circuiting transfer welding contains regular pulses. The term "pulse" is hard to define. In this paper a pulse is referred to as a segment of sound separated by a period of relative silence. Hence, Fig. 2C contains approximately 19 pulses (a pulse rate of 95 Hz). The frequency of the short circuiting transfer cycle is in the order of this frequency.

Time Domain Analysis of the Arc Sounds

Dimensional and dimensionless time domain parameters detailed below were extracted from arc sounds related to two metal transfer modes. Dimensional parameters change as the power of the signal changes, while dimensionless parameters alter as the shape of the time varying signal changes. C programs specifically written by the authors were employed for the estimation of time domain factors. Greater details of these factors can be found in Ref. 28.

Time Domain Dimensional Parameters

If $u(t)$ is a continuous signal (in this case sound) that is to be sampled, *i.e.*,

$$u[n] = u(nT) \tag{3}$$

where:

T = sample period = 1/fs
= 1/sample frequency
n = (0, 1, 2 ..., N–1)
N = window length

The following parameters can be then extracted from a segment of sound.

Average amplitude

$$\bar{u} = \frac{1}{N}\sum_{n=0}^{N-1}\left|u[n]\right| \tag{4}$$

Root amplitude

$$u_r = \left[\frac{1}{N}\sum_{n=0}^{N-1}\sqrt{\left|u[n]\right|}\right]^2 \tag{5}$$

RMS amplitude

$$u_{RMS} = \left[\frac{1}{N}\sum_{n=0}^{N-1}u^2[n]\right]^{1/2} \tag{6}$$

Absolute peak value

$$\hat{u} = \max\left|u[n]\right| \quad n = 0,1,2,\ldots,N-1 \tag{7}$$

Zero crossing rate

$$Z = \frac{f_s}{N}\sum_{n=0}^{N-1}\left|\mathrm{sgn}\left(u[n]\right) - \mathrm{sgn}\left(u[n-1]\right)\right| \tag{8}$$

$sgn\ (n)$ = 0, if sgn $(n) < 0$
$sgn\ (n)$ = 1, if sign $(n) \geq 0$
f_s = the sampling rate of the signal in Hz

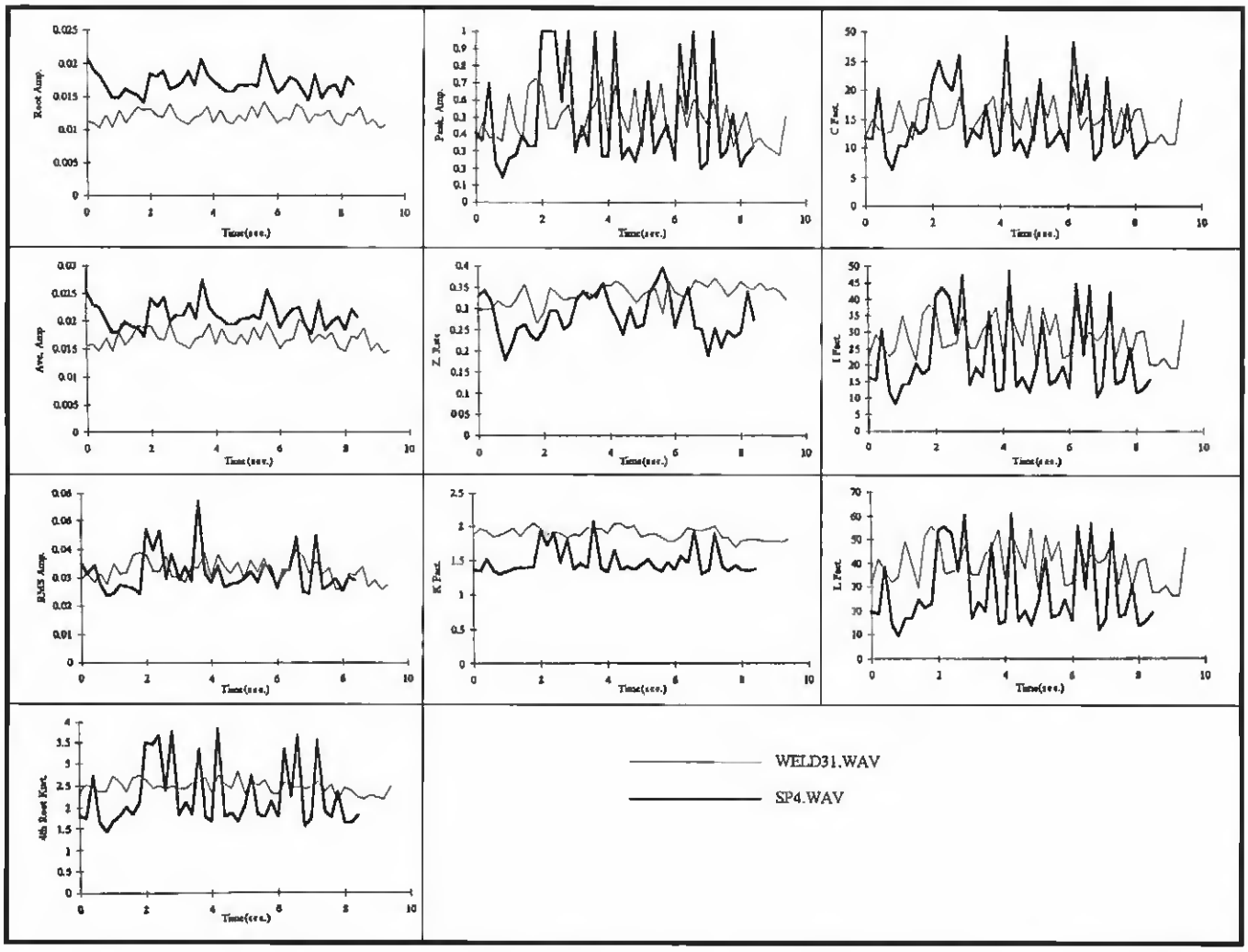

Fig. 4 — WELD31.WAV and SP4.WAV analyzed by TDOMAIN.EXE; window length = 8820 sample points (0.20 s).

Time Domain Dimensionless Parameters

Shape factor, crest factor, impulse factor, clearance factor and the fourth root of Kurtosis are dimensionless parameters used to describe the amplitude spread of a stochastic process, and can be used to classify different sounds. These parameters can be computed as follows:

Shape factor $$K = \frac{u_{RMS}}{\bar{u}} \quad (9)$$

Crest factor $$C = \frac{\hat{u}}{u_{RMS}} \quad (10)$$

Clearance factor $$L = \frac{\hat{u}}{u_r} \quad (11)$$

Impulse factor $$I = \frac{\hat{u}}{\bar{u}} \quad (12)$$

Fourth root of Kurtosis

$$\beta^{0.25} = \frac{\left[\frac{1}{N}\sum_{m=0}^{m=N-1} u^4[n]\right]^{1/4}}{u_{RMS}} \quad (13)$$

Signal Segmenting and Analysis

Segmenting was carried out to split the signal into smaller segments or window lengths (up to 16,000 data points). Various parameters were calculated from each segment and relevant graphs generated. The length of the segment is an important factor: the longer the segment, the less responsive the parameters are to changes in the sound; the shorter the segment length, the higher the variation in parameters. Thus, segment length is a trade-off between parameter variation and parameter sensitivity to change.

Due to limitations of space, detailed results for all parameters investigated will not be presented here. Figure 4 shows variation of selected time domain parameters for 0.2 s of GMA welding in short circuiting and spray transfer modes. An examination of Fig. 4 clearly indicates that some parameters such as clearance factor (C. Fact.), the impulse factor (I. Fact.), peak amplitude, and the clearance factor (L. Fact.) all vary too much during stable welding, and therefore fail the basic requirement of low variability during stable welding. These parameters are all dependent upon the peak value within the segment of sound, and are hence all affected greatly by any extreme outliers within the sound that do not provide a general representation of the sound signal. Figure 5, however, shows that parameters such as root amplitude, average amplitude, RMS amplitude, K factor and fourth root Kurtosis do not vary much and fit the basic requirement of a parameter for monitoring arc welding sound.

As window length increases, the variance of each parameter is expected to decrease, giving a better statistical repre-

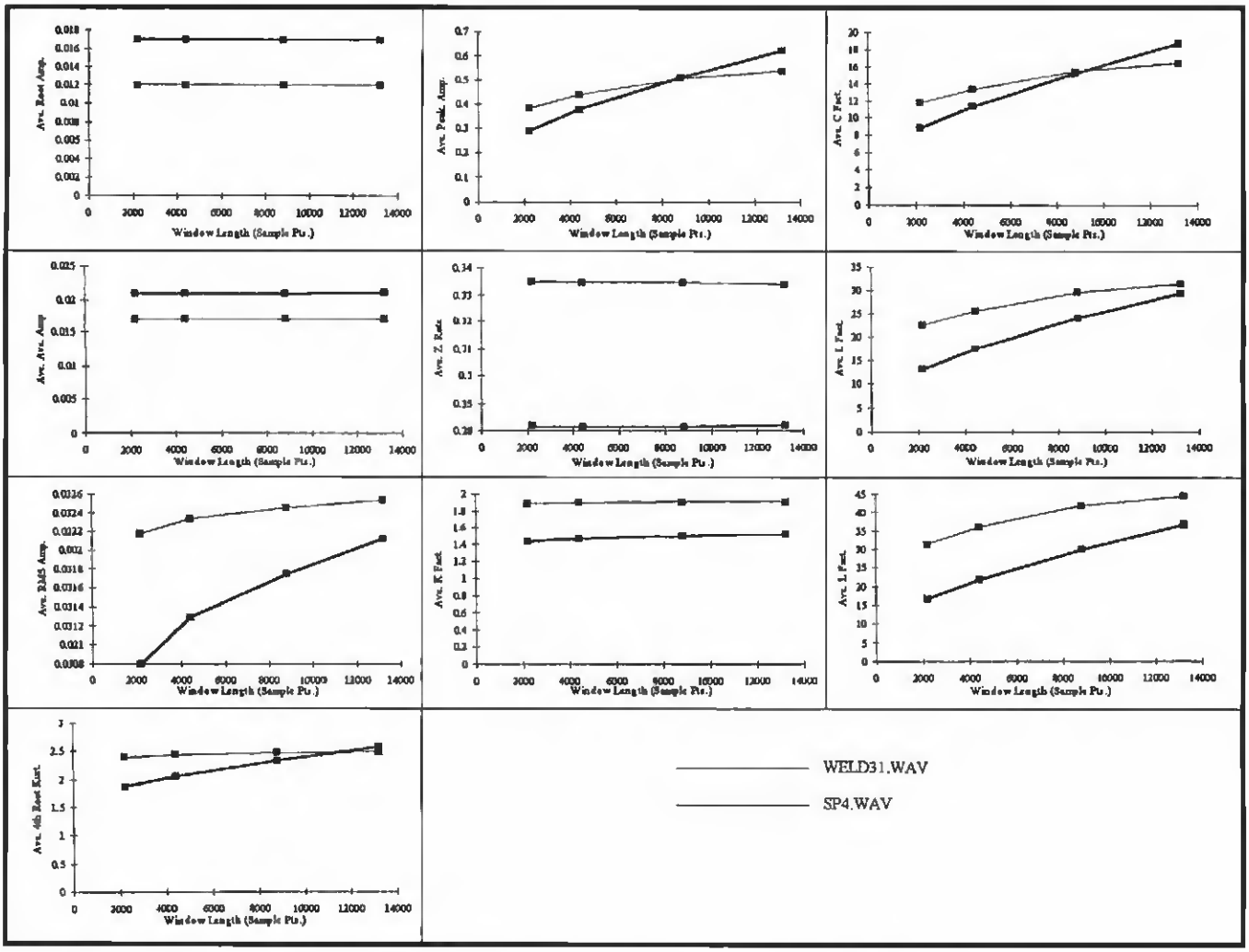

Fig. 5 — Overall averages of WELD31.WAV and SP4.WAV analyzed by TDOMAIN.EXE against window length.

sentation of the sound being analyzed. Figure 6, however, showed that this is not the case with all parameters. The variance of parameters such as peak amplitude, crest factor (C. Fact.), 4th Root Kurtosis, impulse factor (I. Fact.), and clearance factor (L Fact.) increased considerably for SP4.WAV and increased to a lesser extent for WELD31.WAV. It cannot be explained why this happened. The time domain parameters — root amplitude, average amplitude, RMS amplitude, zero crossing rate (Z. rate), and the shape factor (K. Fact.) — did show the expected behavior of decreasing variance as window length increased.

From Fig. 6 it can be seen that a window length of 8820 samples or 0.2 s seems to be a good compromise between low variance and high responsiveness.

From Fig. 6 it can also be seen that the variance of the parameters during SP4.WAV was much higher than for WELD31.WAV. This indicates that the parameters varied more during the length of SP4.WAV than for WELD31.WAV, (also clearly visible in Fig. 4), probably due to the large difference between the amplitude of the outliers and the rest of the sound — Fig. 4. This problem could be solved by filtering out the random outliers contained in the sound.

Figures 5 and 6 show that the sounds generated by short circuiting transfer (WELD31.WAV) and spray transfer (SP4.WAV) mode of GMA welding result in significantly dissimilar but stable zero-crossing rate (Z. Rate) and shape factor (K. Fact.), indicating that these parameters are capable of detecting changes in the sound.

Frequency Domain Analysis of Arc Sounds

In order to examine any relationship between the GMA welding process and the sound signature generated, a frequency domain analysis of the arc sounds was also carried out. A frequency resolution using 256 point FFT was found to be high enough to determine trends in the frequency spectrum.

Figure 7 shows the variation of four frequency domain parameters for the short circuiting and spray metal transfer mode in GMA welding. As with the time domain parameters, the variation of the frequency domain parameters is greater for SP4.WAV than for WELD31.WAV. Once again this variation could be reduced by filtering out the outliers in the sound. Figure 7 shows that all of the frequency domain parameters are quite stable for WELD31.WAV, indicating that all of the frequency domain parameters satisfy the basic requirement of a sound parameter. Figure 7 also shows that there is an obvious difference between the frequency domain parameters (particularly the frequency average) for SP4.WAV and WELD31.WAV, indicating that they will

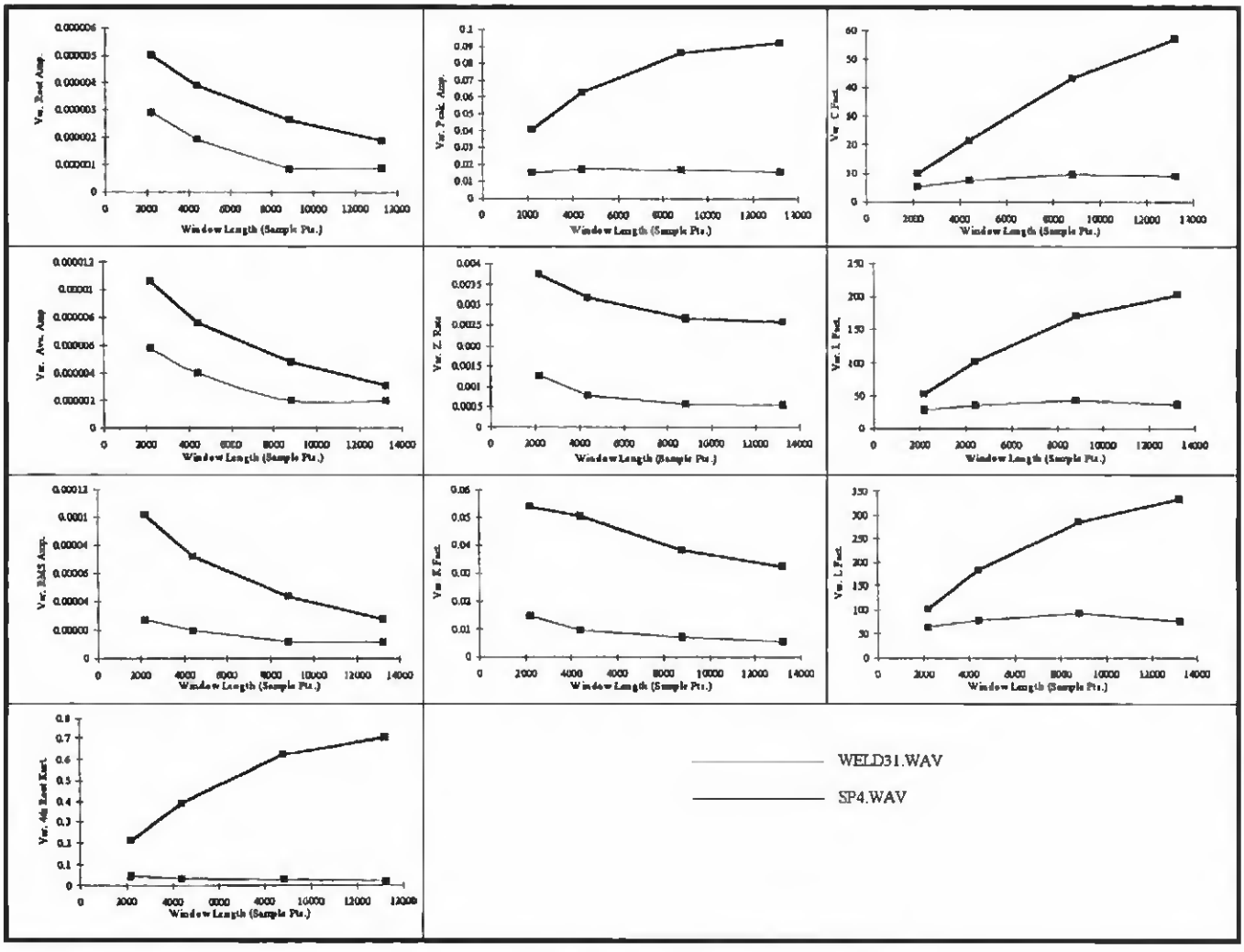

Fig. 6 — Overall variance of WELD31.WAV and SP4.WAV analyzed by TDOMAIN.EXE against window length.

likely satisfy the second requirement of sound parameters.

Figure 8 shows an average overall normalized power spectrum for the short circuiting and spray transfer welds. The frequency range of the sound produced by both welds is between 0 and 17 kHz. This range is probably limited by the frequency response range of the microphone. The overall frequency spectrum of spray transfer weld appears to be very different to that of the short circuiting transfer weld. The frequency spectrum of short circuiting transfer weld sound is distributed at the higher end of the frequency range compared to the spray transfer weld.

Figure 8 also shows that both welds have dominant peaks in similar positions — approximately 11 kHz and 13 kHz. Other smaller, less dominant peaks that occur at similar positions lie at 2000, 4300 and 5200 Hz. The source of these peaks is unknown and is under current investigation by the authors. Dominant peaks also occur at 6600 Hz and 9290 Hz for WELD31.WAV and 360 Hz, 1970 Hz and 3930 Hz for SP4.WAV.

Figures 9 and 10 show the frequency spectrum changes during the time span of the welds. The frequency of the short circuiting transfer mode GMA welding sound appears quite stable during the weld run — Fig. 9. However, the frequency spectrum of the spray transfer mode GMA welding sound is less stable compared to that of short circuiting transfer weld sound — Fig. 10. These changes are probably due to the large difference between the amplitudes of the outliers and the rest of the sound.

Conclusions

Sounds generated from gas metal arc welding in two metal transfer modes were collected and investigated for possible application in on-line quality control of automated welding operations. The investigation included the use of a number of new parameters that can be extracted from the time domain and frequency domain of sound. These parameters listed below, though used in other areas of research, have not been previously used for general sound analysis:

- Pulse rate
- Fourth root Kurtosis
- Zero-crossing rate
- Shape factor
- Crest factor
- Impulse factor
- Clearance factor

The following conclusions can be drawn from the present research:

1) Monitoring of time domain parameters including zero-crossing rate, root amplitude, and shape factor allows detection of changes in the arc weld sound and enables the detection of deviations from ideal arc behavior during GMAW.

2) The time domain parameters — impulse factor, peak amplitude, clearance factor and crest factor — do not show much promise, as they are dependent upon the peak value of the sound within the segment.

3) Frequency domain parameters

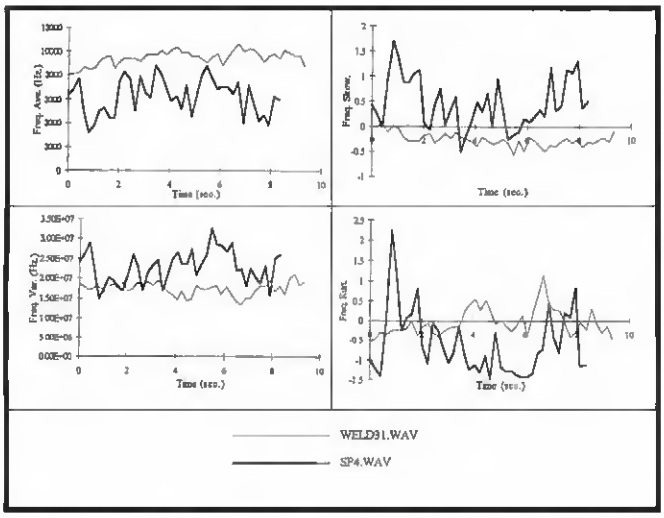

Fig. 7 — Frequency domain parameters of WELD31.WAV and SP4.WAV; m = 35 and N = 256.

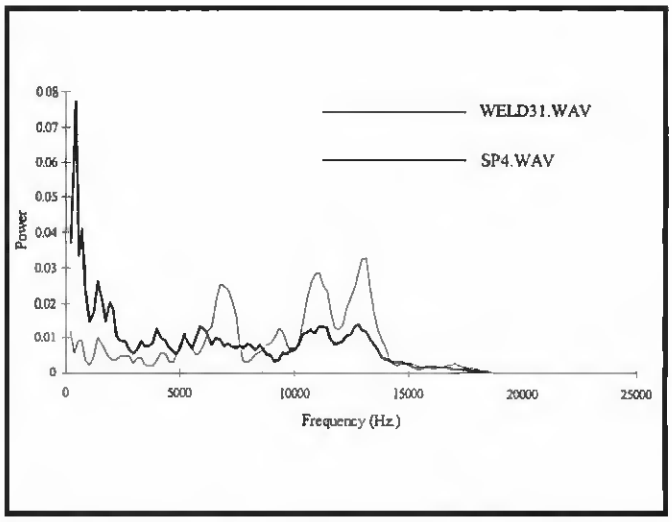

Fig. 8 — Overall average frequency spectrum of WELD31.WAV and SP4.WAV.

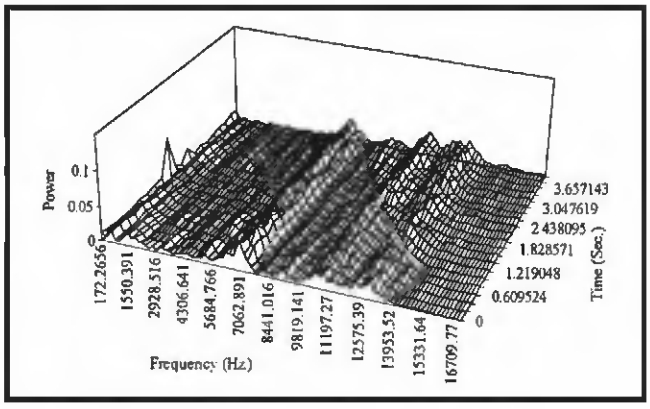

Fig. 9 — Frequency domain graph of frequency against time against power for WELD31.WAV (Spectrum limited to 17054.3 Hz).

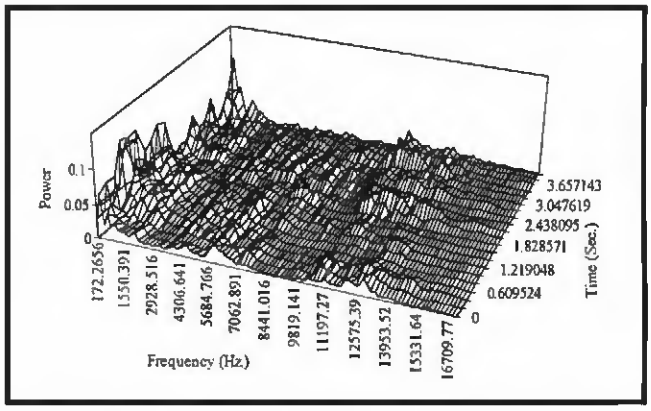

Fig. 10 — Frequency domain graph of frequency against time against power for SP4.WAV (spectrum limited to 17054.3 Hz).

offer some promise for detection of metal transfer mode. However, the data processing speed needs to be significantly enhanced before any application for feedback quality control.

4) Outliers in the sound should be filtered out, as they greatly affect the stability of the sound parameters.

5) A window length of approximately 0.2 s for the calculation of all sound parameters provides a good compromise between low variance and high responsiveness.

6) These results were obtained in a quiet environment. However, practical applications of sound monitoring would require attention to ambient noise and possible differential detection technique.

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References

1. Cook, G., Andersen, K., and Barrett, R. 1990. Keynote Address: Feedback and Adaptive Control in Welding. *Recent Trends in Welding Science and Technology*, pp. 891–903. ASM International, Materials Park, Ohio.

2. Madigan, R. B., Renwick, R. J., Farson, D. F., and Richardson, R. W. 1986. Computer-based control of full penetration GTA welding using pool oscillation sensing. *Proc. 1st International Conference on Computer Technology in Welding*, pp. 103–112. London, U.K.

3. Siewert, T., Madigan, B., Quinn, T., and Mornis, M. November, 1992. Through-the-arc sensing for measuring gas metal arc weld quality in real time. *Materials Evaluation:* 1314–1318.

4. Kaihara, S., Kouketsu, M., Saitoh, T., and Murayama, T. 1993. Development of in process assurance welding system. *Journal of Ship Production* 9(2): 107–112.

5. Fehn, R. 1985. Ultrasonic monitoring and control during arc welding. *Welding Journal* 64(9): 18–22.

6. Carlson, N., Johnson, J., Lott, L., and Kunerth, D. November 1992. Ultrasonic NDT methods for welding sensing. *Materials Evaluation:* 1338–1343.

7. Rokhlin, S. I., Cho, K., and Guu, A. C. 1989. Closed loop control of weld penetration using real time radiography. *Materials Evaluation 47:* 350–369.

8. Guu, A. C., and Rokhlin, S. I. November 1992. Arc weld process control using radiographic sensing. *Materials Evaluation:* 1344–1348.

9. Johnson, J. A., Carlson, N. M., Smart, H. B., and Clark, D. E. 1991. Process control of GMAW: Sensing of metal transfer mode. *Welding Journal, 70(4):* 91-s to 99-s.

10. Wang, W., Liu, S., and Jones, J. E. 1995. Flux cored arc welding: arc signals, processing and metal transfer characteriza-

tion. *Welding Journal, 74(11)*: 369-s to 377-s.

11. Ogunbiyi, B., and Norrish, J. 1997. Monitoring indices for metal transfer in the GMAW process. *Science and Technology of Welding and Joining* 2(1): 33–35.

12. Chen, W. H., Banerjee, P., and Chin, B. A. May, 1989. Study of Penetration Variations in Gas Tungsten Arc Welding. *2nd International Conf. on Trends in Welding Research*, Gatlinburg, Tenn., ASM International, Materials Park, Ohio.

13. Nagarajan, S., Banerjee, P., Chen, W. H., and Chin, B. A. 1992. Control of the welding process using infrared sensors. *Robotics and Automation* 8(1): 86–93.

14. Matteson, A., Morris, R., and Tate, R. 1993. Real time GMAW quality classification using an artificial neural network with airborne acoustic signals as inputs. *OMAE* 3 (Part A): 273–278.

15. Arata, Y., Inoue, K., Futamata, M., and Toh, T. 1979. Investigation on welding arc sound (Report I). *Transactions of JWRI* 8(1): 25–31.

16. Manz, A. May 1981. Welding arc sounds. *Welding Journal, 60(5)*: 23–27.

17. Schluge, H., and Finkelburg, W. 1944. On the hissing of the homogeneous carbon arc. *Zeitzchrift für Physik* (122): 714–739.

18. Arata, Y., Inoue, K., Futamata, M., and Toh, T. 1979. Investigation on welding arc sound (Report II). *Transactions of JWRI* 8(2): 33–38.

19. Futamata, M., Takahashi, Y., Inoue, K., Maruo, and Arata, Y. 1983. Application of arc sound to detection of welding processes. *Quarterly J. of the Japan Welding Society* 1 (3): 305–310.

20. Schlebeck, E. 1983. Acoustic process diagnosis in flash and fusion welding processes. *Schweisstechnik* 33(8): 340–343.

21. Kaskinen, P., and Mueller, G. 1986. Acoustic arc length control. *Advances in Welding Science and Technology, Proceedings of an International Conference on Trends in Welding Research*, Gatlinburg, Tenn., ASM, pp. 763–765.

22. Chawla, K. S., and Norrish, J. June 1992. Real time quality monitoring using analysis of the arc sound. *Proc. 4th International Conference on Computer Technology in Welding, Cambridge, U.K.*, Paper 17.

23. Rostek, W. 1990. Investigations on the connection between the welding process and airborne noise emission in gas shielded metal arc welding. *Schweiben und Schneiden* 42(6): 96–98 and 289–292.

24. Budde, L. 1991. Analysis and evaluation of sound emission in the welding and cutting technology. *ASME* 51: 245–250.

25. Schiebeck, E. 1991. Audible range acoustic diagnosis of the MAG welding arc. *Welding International* 5(7): 572–576.

26. Inoue, K., Takahashi, Y., and Zhang, J. 1993. Measurement of arc sound with burnthrough in MAG welding. *Welding International* 7(10): 770–775.

27. Futamata, M. 1991. Welding process monitoring by arc sound. *Technical Commission on Welding Processes*, Japan Welding Society, pp. 139–142.

28. Cempel, C. 1991. *Vibroacoustic Condition Monitoring*, Ellis Horwood, New York.

Call for Papers for 1999 United Thermal Spray Conference

ASM International has announced a call for papers for "Coating in Practice," the 1999 United Thermal Spray Conference & Exposition (UTSC'99). The conference is sponsored by the ASM Thermal Spray Society and the German Welding Society (DVS) and will be held March 17–19, 1999, in Dusseldorf, Germany.

Conference organizers are requesting abstracts of no more than 200 words in German or English on the following subjects:

Application technology and solutions to problems
Pretreatment and posttreatment
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Health and safety at work and environmental protection
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Plasma transferred-arc surfacing (PTA)

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