Pulsed vs. Steady Current GMAW: Which Is Louder?

Measurements show sound levels for pulsed current are nearly the same as those for short-circuit and globular transfer GMAW

BY HARVEY R. CASTNER AND RAJENDRA SINGH

Welders and welding operators work under diverse conditions that may expose them to potentially hazardous substances and situations (Ref. 1). The nature of these hazards depends on the process and materials used, the length of exposure, and other factors in the working environment. Some hazards, involving machinery, equipment, tooling, and material handling, are similar to those encountered in other manufacturing operations. Other hazards may be unique to welding. Arc welding may involve hazards due to fumes and gases, visible and ultraviolet radiation, sparks and molten metal, electrical shock and noise.

Noise is defined as loud or disagreeable sound. Excessive noise levels can cause hearing damage and may have other effects on workers. For these reasons, the Occupational Safety and Health Administration (OSHA) has established a permissible exposure level (PEL) for sound of 90 dBA for workers. The PEL is defined as an 8-h time-weighted average (TWA) sound level. Sound pressure level is measured with the logarithmic decibel (dB) scale. The "A-weighted" decibel scale (dBA) simulates human hearing response to sound over the audible frequency range of from 20 to 20,000 Hz.

Noise Control Requirements

Employers are required to control noise exposure of employees to less than the PEL through administrative or engineering controls. If it is not feasible to reduce noise levels with these controls, employees must be provided with hearing protection to reduce noise levels to below the PEL. Employers also must administer a hearing conservation program whenever employee noise exposure is equal to or above the 8-h TWA action level of 85 dBA. The American Conference of Governmental Industrial Hygienists recommends that worker exposure be less than an 8-h TWA threshold limit value (TLV) of 85 dBA. Table 1 gives typical sound levels for a number of common activities, to serve as a point of reference.

Table 1 — Sound Levels of Common Activities (Source: Ref. 2)

Activity	Sound Level Decibels (dBA)
Jet Engine	160
Air Raid Siren	140
Jet Aircraft Take Off	130
Pneumatic Hammer, Stamping Press	110
Gasoline Chain Saw	100
Drilling Concrete, Air Compressor	90
Vacuum Cleaner, Busy Office	80
Traffic	70
Normal Conversation	60
Home or Office	50
Whisper	40
Quiet Sound Studio	20
Hearing Threshold For Young Adult (1000–4000 Hz)	0

HARVEY R. CASTNER is with Edison Welding Institute, Columbus, Ohio. RAJENDRA SINGH is with The Ohio State University, Columbus, Ohio.

Singh_092

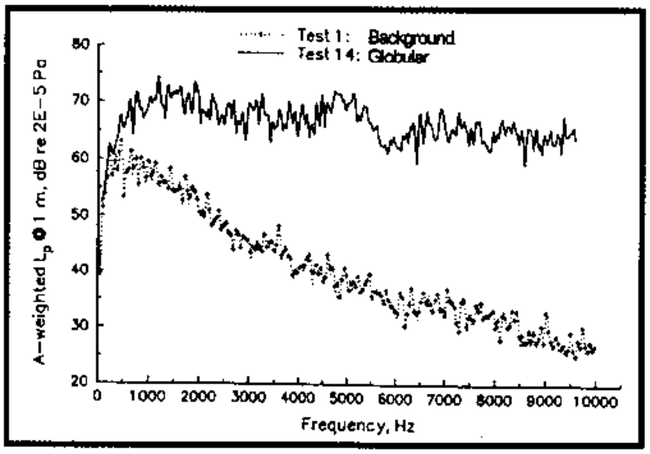

Fig. 1 — Narrow band spectra of arc welding sound from steady current GMAW with globular transfer (Test No. 14, sound pressure level = 90 dBA) and background sound signals (Test No. 1, sound pressure level = 73 dBA). Refer to Table 3 for details.

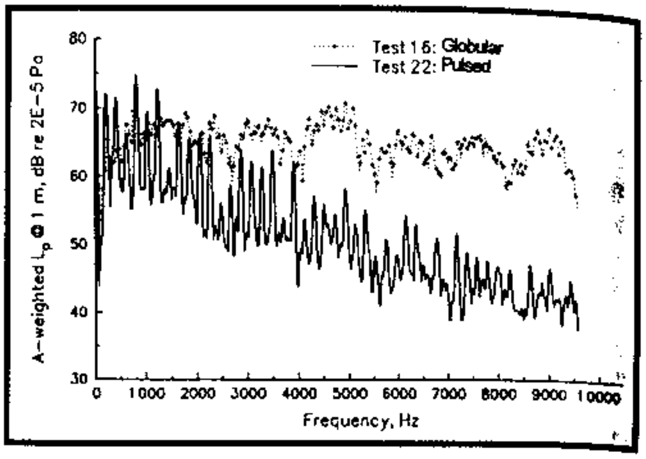

Fig. 2 — Frequency spectra of steady current GMAW with globular transfer (Test No. 16, sound pressure level = 88 dBA) and pulsed current (Test No. 22, sound pressure level = 82 dBA). Refer to Tables 3 and 4.

Table 2—Published Data on Sound Levels for Arc Welding and Fabrication Processes

Process	Sound Level dBA 1 m from the Arc (Ref. 3)	Sound Level dBA at Welder's Ear (Ref. 3)	Sound Level dBA 300–500 mm from the Arc (Refs. 4 and 6)	Sound Level dBA 400 mm from the Arc (Ref. 5)
SMAW, 150 A, AC				103
SMAW	71–74	76–77	75–77	—
GMAW, spray transfer	71–75	82		97
GMAW, globular	72–75	81	87–94	—
GMAW, CO_2, short circuit			80–87	91–95
GMAW, pulsed current, 300 A				95
GTAW, DC	50–54	57–59	79–83	65
GTAW, 60 A, AC				74
Air carbon arc gouging	99–111		105–114	>103
Grinding			108–112	105
Needle hammer			100–105	103

The available data on sound from arc welding and related processes are summarized in Table 2 (Refs. 3–6). These data indicate that gas tungsten arc welding (GTAW) produces the least sound. Grinding, needle hammer slag removal, and air carbon arc gouging produce higher sound levels than arc welding. It is difficult to draw conclusions on differences in the other processes shown. Comparison is complicated by the fact that sound was measured at a different distance from the arc in each study. The U.S. standard (Ref. 7) for measurement of sound from welding processes specifies measurement at 1 m (39.37 in.) from the arc. Eichbauer (Ref. 4) and Hermanns (Ref. 5) measured sound at between 300 and 500 mm from the arc. Hermanns states that the average distance from the arc to a welder's ear is between 380–550 mm (15–21.6 in.).

Many efforts are under way to reduce the potential hazards associated with the use of arc welding processes. Research (Refs. 8, 9) shows that fume generation of gas metal arc welding (GMAW) can be reduced by using pulsed welding current. However, there is some concern that pulsed current may increase the noise level compared to steady current welding. This concern, and the lack of definitive data on the subject, stimulated this investigation. Sound levels were measured for both pulsed current and steady current GMAW using welding parameters that produce low fume generation rates.

Equipment and Parameters for Measuring Sound

On-site measurements of GMAW process sound were conducted as described in AWS standard F6.1 (Ref. 7). This standard, which prescribes methods for measuring sound levels of arc welding processes, recommends measurement at a radial distance of one meter (1 m) from the arc. While the standard prefers off-site sound measurements in a free-field acoustic environment, on-site measurements in a manufacturing plant or laboratory are permitted provided proper techniques are used. The on-site measurement techniques for this study follow the accepted practices used in the noise control and acoustic community (Ref. 10). Instrumentation included a precision integrating-type sound level meter and calibration sound sources. All data were recorded on a digital tape recorder and processed with a dynamic signal analyzer and a computer. Sound pressure levels measured on-site also were correlated with off-site calculations to confirm the measurement methodology.

Sound from the GMAW process was measured for both steady current and pulsed current using two pulsed current welding power sources:

- Power source "B" is a constant voltage inverter, with a 100% duty cycle rating of 350 A at 34 V.
- Power source "D" is a constant voltage/constant current inverter, with a 100% duty cycle rating of 450 A at 38 V.

Welds were made on 0.5-in.-thick A-36 steel plate using 0.045-in.-diameter ER70S-3 welding wire and 85% Ar-15% CO_2 shielding gas. Tables 3 and 4 list the welding parameters used for these sound measurements. Pulsed current welding parameters (voltage and wire feed speed) were selected from those found by previous work to produce minimum welding fume generation rates. These parameters cover a range of wire feed speeds from 110 mm/s (260 in./min) to 212 mm/s (500 in./min). Sound measurements using steady current GMAW were then made at the same wire feed speeds and welding voltages that were used with the pulsed current. In addition, steady current welds were made at a wire feed speed of 76 mm/s (180 in./min) to provide data on short circuit metal transfer.

Table 3—Sound Measurements of GMAW Using Steady Current

Test No.	Power Source	Transfer Mode	Wire Feed Speed mm/s (in./min)	Welding Voltage (V)	Welding Current (A)	Fume Generation Rate (g/min)	Overall Sound Power Level (dBA)	Subjective Sound Quality
11	B	Short Circuit	76(180)	16	130	0.1	86	Loud
12		Short Circuit	76(180)	18	140	0.17	88	Loud
13		Short Circuit	76(180)	20	145	0.2	87	Loud
14		Globular	127(300)	24	205	—	90	Very loud
15		Spray	127(300)	26	220	—	73	Quiet
16	B	Globular	110(260)	24	190	0.3–0.4	88	Loud
17		Spray	110(260)	26	210	0.2–0.3	71	Very quiet
18		Spray	110(260)	28	220	0.2–0.4	71	Very quiet
19		Globular	174(410)	28	290	0.35–0.45	88	Loud
20		Spray	174(410)	30	300	0.22	75	Quiet
21		Spray	174(410)	32	315	0.27	75	Quiet
30	D	Globular[a]	212(500)	28	290	0.36–0.43	89	Loud
31		Globular[a]	212(500)	30	310	0.3	88	Loud
32		Spray	212(500)	34	320	0.4	72	Quiet

(a) Axially-directed globular.

Table 4—Sound Measurements of GMAW Using Pulsed Current

Test No.	Power Source	Wire Feed Speed mm/s (in./min)	Welding Voltage (V)	Welding Current (A)	Pulse Frequency (Hz)	Fume Generation Rate (g/min)	Overall Sound Power Level (dBA)	Subjective Sound Quality
22	B with standard pulse parameters	110(260)	24	180	180	0.04–0.09	82	Loud/Pulsating
23		110(260)	26	195	220	0.1	83	Loud/Pulsating
24		110(260)	28	210	260	0.2–0.4	83	Loud–Tonal
25		174(410)	28	280	300	0.25	85	Very Loud
26		174(410)	30	300	340	0.5–0.6	86	Screaming
27		174(410)	32	315	380	0.9	88	Screaming
33	D with standard pulse parameters	110(260)	28	185	179	0.2	88	Loud-Tonal
34		110(260)	30	190	194	0.2	90	Loud-Tonal
35		174(410)	30	248	150	0.16	85	Tonal
36		174(410)	32	255	160	0.3	86	Tonal
37		212(500)	30	278	146	0.15	84	Loud Tonal
38		212(500)	32	280	153	0.25	85	Tonal
39		212(500)	34	300	170	0.28	86	Tonal
40	D with alternative pulse parameters	106(250)	28	176	163	0.16	88	Loud Tonal
41		106(250)	30	184	180	0.2	89	Loud Tonal
42		169(400)	30	239	244	0.18	90	Loud Tonal
43		169(400)	32	246	262	0.22	89	Loud Tonal
44		212(500)	32	275	309	0.18	89	Intense Tones
45		212(500)	34	298	338	0.22	87	Loud Tonal

The sound measurements for steady current GMAW, therefore, cover short circuit, globular, and spray metal transfer modes. Pulse parameters used during these tests are the pre-programmed parameters provided by the power source manufacturers. Sound levels were measured using two different sets of pulse parameters for power source D. The first are the standard pulse parameters previously used for fume generation rate tests (Refs. 8, 9). The second is an alternative set of pulse parameters.

Prior to beginning each series of tests, the sound pickup was located at a radial distance of 1 m from the arc and the sound level meter was calibrated using one of the two available calibration sources. Background sound was measured at six locations around the welding table and analyzed to characterize the acoustic environment. Sound spectra also were recorded using a standard source of known sound power that was placed on the welding table. This analysis comprised Tests 1 through 10 and Test 29. The background sound level was 73 dBA (Test 10) for the first series of tests and 66 dBA (Test 29) for the second series of tests. Analysis revealed the background sound to be broad-band in nature (up to approximately 12,000 Hz) with most of the energy at frequencies below 2000 Hz.

Generating the Data

Tables 3 and 4 present the results of on-site sound level measurements of the GMAW process at 1 m from the arc. Results include data for two power sources over a range of steady and pulsed current. All sound power levels are given in A-weighted decibels (dBA) with a reference pressure of 20 μPa. Sound power levels are indicative of mean-square pressure over the entire audible range. Given the precision of the instruments, all decimal values have been rounded off to the nearest dB. Measurement uncertainty is estimated to be ±2 dBA because of the on-site nature of the measurements. The subjective sound quality of each test was noted by the investigator and these results are listed in Tables 3 and 4.

A detailed spectral analysis determined all measurements to be repeatable and consistent. Sound pressure levels were cor-

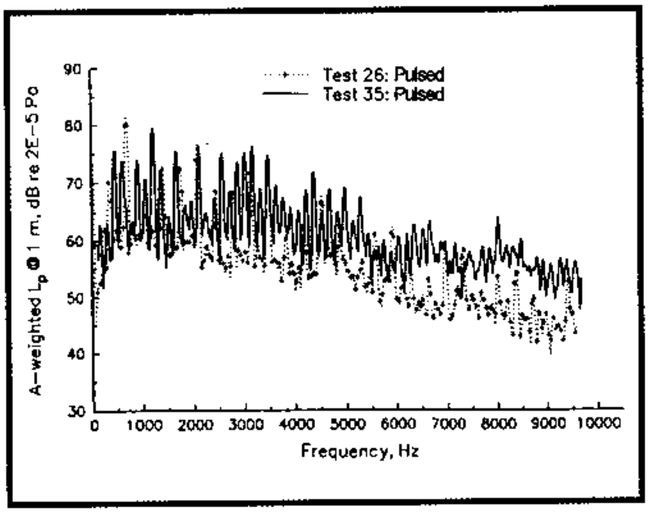

Fig. 3 — Comparison between pulsed current welding modes of power source B (Test No. 26, sound pressure level = 86 dBA) and power source D (Test No. 35, sound pressure level = 85 dBA). Refer to Table 4.

rected for the ambient sound when the difference between the welding process and background sound was 7 dB or less. In a few cases, the background sound was of the same order of magnitude as the welding process sound but their frequency contents were different. For example, the high-frequency sound radiated by the arc is at higher power levels than the background sound.

Graphs of the narrow band spectra were generated for all tests. Spectral values are in terms of the power spectrum of the pressure signal. Sound pressure levels in dBA were plotted as functions of frequency with a frequency resolution of 25 Hz.

Comparing Sound Signatures

Figure 1 compares a typical steady current GMAW sound signature with the background sound. Observe that both are broad band signals but the welding sound has significantly more energy over the higher frequencies. Figure 2 depicts sound spectra of steady current globular transfer (Test No.16) and pulse current welding (Test No. 22) modes at 110 mm/s (260 in./min) wire feed speed and 24 V. Note that for this condition, steady current produces more sound than pulsed current. Pulsed current welding modes for Power Sources B and D are compared in Fig. 3 at 174 mm/s (410 in./min) wire feed speed and 30 V. Two very different spectra are seen because of apparent differences in pulse current waveforms. Figure 3 shows the effect of the A-weighted decibel scale. The high sound levels at low frequencies for Test No. 26 result in a higher weighted sound pressure level, even though Test No. 35 appears to have higher valves at high frequencies. Finally, Fig. 4 shows the differences in sound spectra corresponding to steady and pulsed current welding modes for the case when the overall sound pressure levels are numerically identical.

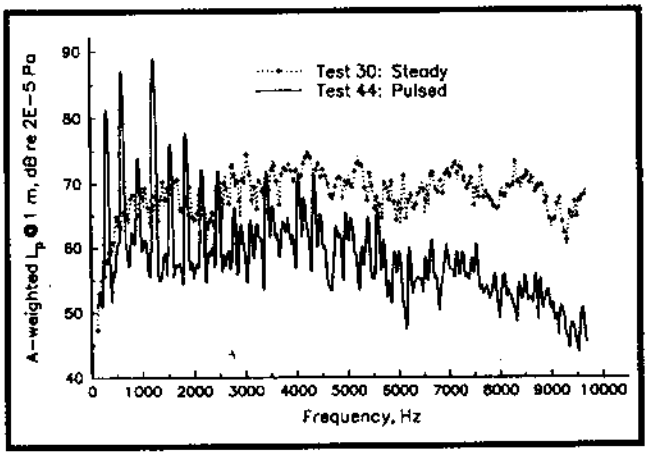

Fig. 4 — Narrow band spectra for steady current GMAW (Test No. 30, sound pressure level = 89 dBA) and pulsed welding modes (Test No. 44, sound pressure level = 89 dBA).

Figure 5 compares average sound levels for steady current with pulsed current. Steady current data are plotted for short circuit, globular, and spray metal transfer. Pulsed current data are plotted for power source B and for power source D with both standard and alternative pulse parameters. Figure 5 shows that power source B produced the lowest average sound levels for pulsed current welding. Power Source B was not tested at a wire feed speed of 212 mm/s (500 in./min) because previous data (Ref. 7) shows this power source does not reduce fume generation at this wire feed speed. The alternative pulse parameters used by power source D increased the average sound level slightly compared to the standard pulse parameters.

Understanding the Test Results

This study shows that GMAW generates sound over a wide range of frequencies, including the audible range. Steady current GMAW in the spray transfer mode produced the least sound, which was measured at 71–75 dBA at 1 m from the arc. Short circuit transfer, globular transfer, and pulsed current GMAW produced significantly higher sound levels. Short circuit transfer sounds ranged from 86 to 88 dBA, while globular transfer sounds ranged from 88 to 90 dBA. Sound levels for pulsed current GMAW were nearly the same as those for short circuit or globular transfer. Pulsed current sound levels ranged from 82 to 88 dBA for power source B, and 84 to 90 dBA for power source D using standard pulse parameters, and 87 to 90 dBA for power source D with the alternative pulse parameters.

The sounds generated by a welding arc are due to movement of the air molecules around the arc that result from changes in the size or shape of the arc. Manz (Ref. 11) described the sources of many of these sounds and a number of investigators have studied arc sounds for process monitoring and control (Refs. 12–17). There are many dynamic changes in the size and shape of the arc during GMAW. In the short circuit transfer mode, the arc is extinguished and reestablished many times per second. Steady current welding in the spray transfer mode is characterized by a stable arc that produces little sound. The sounds during globular transfer are due to the transfer of filler metal droplets through the arc, intermittent short circuits, and the explosion of molten spatter particles. Sounds during pulsed current GMAW result from rapid changes in arc power as voltage and current alternate between background and peak levels at regular frequencies.

Figures 2–4 show the periodic nature of the sound from pulsed current GMAW compared to the more random sound from steady current GMAW. The sound frequency peaks of pulsed current GMAW correspond to the pulse frequencies of the welding parameters listed in Table 4. These pulse frequencies range from 146 to 380 Hz and are quite distinguishable to the human ear. The base frequencies and harmonics of these frequencies make sound from pulsed current GMAW seem louder to the human ear than the random sound produced by steady current GMAW even at similar sound levels. This is shown by the subjective sound quality evaluations listed in Tables 3 and 4. These subjective evaluations were recorded by the sound engineer taking the measurements. All pulsed current GMAW sounds are characterized as "tonal" sounds and judged

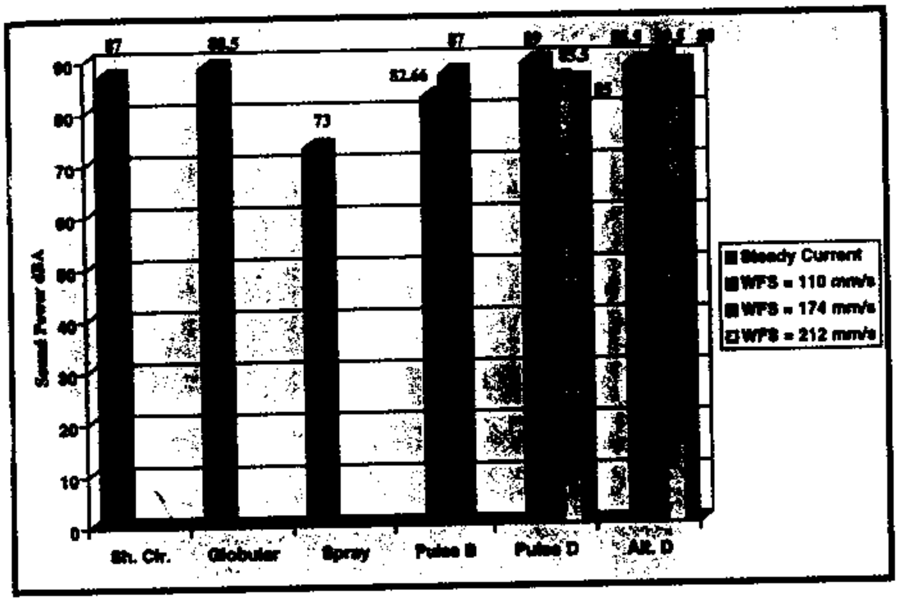

Fig. 5 — Comparison of average sound levels for steady and pulsed current.

to be more unpleasant than the more random sounds from "noisy" steady current GMAW welding conditions.

Kaskinen and Mueller (Ref. 18) found the sound intensity of a pulsed current arc to be proportional to the instantaneous rate of change of arc power, or the rate of change of current and voltage. The increased sound levels during welding with power source D are probably due to the higher rate of change in current per unit time. The peak current levels of power source D are higher than power source B. The time intervals for the current to rise from the background level to the peak level and fall back to the background level are shorter for power source D than for power source B. The current rise and fall time for power source D is approximately 0.5 ms, while the current rise time for power source B is approximately 0.9 ms and the fall time is approximately 0.6 ms. This reasoning also explains the increase in sound level for power source D using the alternative pulse parameters. While the current rise/fall time for the alternative parameters are the same as the standard parameters, the rate of current change is greater since the alternative parameters use a higher peak current level. In addition, the current waveform for power source D momentarily reaches a level that is even higher that the average peak current level. This short spike of current at the beginning of each peak pulse determines the rate of change of current for this power source. Venkat, *et al.* (Ref. 19), reported that modification of a pulse waveform to remove this type of spike can reduce arc sound. The influence of pulse current waveform on arc sound suggests that optimization of pulse current parameters could minimize both fume generation and arc sound. ◆

Conclusions

On-site measurements of sound pressure levels for pulsed current and steady current GMAW range from 71 to 90 dBA at a distance of 1 m from the arc. Sound levels depend on the mode of metal transfer, use of pulsed current, pulse parameters, welding voltage, and welding current levels. Steady current GMAW in the spray transfer mode produced the lowest sound levels (average 73 dBA) of the conditions tested.

The sound produced during pulse current GMAW is nearly the same as that for steady current GMAW using globular or short circuit transfer. However, the tonal quality of the pulsed current sound may make it more objectional to the human ear. Further study would be necessary to determine if pulse current parameters can be optimized to minimize both fume generation and arc sound.

References

1. *The Welding Environment.* 1973. American Welding Society, Miami, Fla.

2. Berger, E. H. 1993. What fab shops must know about hearing protection. *Welding Design And Fabrication*, February, pg. 48–53.

3. *Arc Welding and Cutting Noise* F6.1-78. A research report on one aspect of the welding environment, Ed., Y. Speight and H. C Campbell, American Welding Society, Miami, Fla.

4. Eichbauer, H., and Schmidt, R. 1982. Noise and fume nuisance affecting the welder. *Schweissen und Schneiden*, 34 (11): 535–539.

5. Hermanns, I. Noise problems when welding — causes, effects, and prevention, *Schweissen und Schneiden*, 34(2): 107–108.

6. Rodgers, L. 1993. Hearing conservation in fabrication shops. *Welding & Metal Fabrication*, November/December, p. 417–422.

7. *Method For Sound Level Measurements of Manual Arc Welding and Cutting Processes* AWS F6.1-78, American Welding Society, Miami, Fla.

8. Castner, H. R. 1995. Gas metal arc welding fume generation using pulsed current. *Welding Journal* 74(2): 59-s to 68-s.

9. Castner, H. R. 1996. Fume generation rates for stainless steel, nickel and aluminum alloys. *Welding Journal* 75(12): 393-s to 401-s.

10. *Noise and Vibration Control.* 1988. Ed., Beranek, revised edition, Institute of Noise Control Engineering, ISBM 0-9622072-0-9.

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

12. Arata, Y., Inque, K., Futamata, M., and Toh, T. 1979. Investigation on welding arc sound (report 1) — effect of welding method and welding condition on welding arc sound. *Transactions of JWRI*, Vol. 8, No. 1.

13. Arata, Y., Ingue, K., Futamata, M., and Toh, T. 1979, Investigation on Welding Arc Sound (Report 11) — Evaluation of hearing acuity and some characteristics of welding arc sound. *Transactions of JWRI*, Vol. 8, No. 2.

14. Futamata, M., Toh, T., Inoue, K., Maruo, H., and Arata, Y. 1986, Investigation on welding arc sound (report 6) — permissible time of arc sound exposure from viewpoint of conversation of hearing acuity. International Institute of Welding, IIW Doc. VIII-1337-86

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

16. Johnson, J., Carlson, N., and Smartt, H. 1989. Detection of metal-transfer mode in GMAW. *Proceedings 2nd International Conference on Trends in Welding Research*, Gatlinburg, Tenn., ASM International, Materials Park, Ohio, pp. 377–381.

17. Matteson, M., Morris, R., and Raines, D. 1992. An optimal artificial network for GMAW arc acoustic classification. *Proceedings 3rd International Conference on Trends In Welding Research*, Gatlinburg, Tenn. ASM International, Materials Park, Ohio, pp. 1031–1035.

18. Kaskinen, P., and Mueller, G. J. 1986. Acoustic Arc Length Control. *Proceedings International Conference on Welding Science*, Gatlinburg, Tenn., ASM International, Materials Park, Ohio, pp. 763–765.

19. Venkat, S., Sommerville, J. Trees, D., Holverson, T., Dickinson, D., and Kos, D. 1993. Predictive suppression of audible arc noise in inverter pulsed GMAW. *Proceedings North American Conference*, Edison Welding Institute, Columbus, Ohio.