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Laboratory measurements of air carbon arcing sound power levels

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Investigative field reports show that air carbon arcing generates sound levels between 108 dB(A) and 120 dB(A) at the operator's ear. Sound levels above 115 dB(A) are in excess of the Mine Safety and Health Administration (MSHA) compliance limit, potentially resulting in hearing loss from short-term exposure. The National Institute for Occupational Safety and Health (NIOSH) is conducting research to understand the effects of air carbon arcing parameters on the noise produced, specifically to reduce hearing loss in the mining industry. Repeatable laboratory experiments have been conducted in an accredited reverberation chamber to measure the sound power levels generated by air carbon arcing. To reduce variability between gouges, air carbon arcing was performed using an automated machine with consistent sample material. Typical electrodes, 1.27 cm (1/2 in) and 0.95 cm (3/8 in) in diameter, were investigated. Amperage, air pressure, and gouging speed were measured. This paper will describe the measurement procedures and document the results obtained. The implications in terms of how the parameters affect the generated sound power will be discussed. The largest effects were seen by altering the amperage and air pressure settings. The highest sound power level measured was 130 dB(A), when gouging with a 1.27-cm electrode. The lowest sound power level observed was 116 dB(A), using a 0.95-cm electrode. Lowering current to the minimum effective setting had a larger effect than lowering the air pressure. However, lowering both current and air pressure to the minimum effective settings produced the lowest observed sound power levels.

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1 INTRODUCTION

To reduce noise-induced hearing loss (NIHL) from air carbon arcing in mining, the National Institute for Occupational Safety and Health (NIOSH) is conducting research to understand the effects of the air carbon arcing process parameters on the noise generated. Mine Safety and Health Administration (MSHA) field studies conducted between 1999 and 2008 show that air carbon arcing can produce sound levels (sound pressure) between 108 dB(A) and 120 dB(A) at the operator's ear¹⁻³. Sound levels (sound pressure) above 115 dB(A) are in excess of the MSHA compliance limit, potentially resulting in NIHL from short-term exposure⁴. Other published studies on sound level measurements for air carbon arcing show similar results⁵⁻⁷. Noise-induced hearing loss is the most common occupational illness in the United States, with 30 million workers exposed to excessive noise levels⁸. Mining has the highest prevalence of hazardous noise exposure of any major industry sector and is second only to the railroad industry in prevalence of workers reporting NIHL^{9,10}.

Air carbon arcing is used in the mining industry for both cutting (ACAC) and for gouging (ACAG). Air carbon arcing was originally designed and introduced to welders primarily for ship repairs in 1948 by Myron Stepath¹¹, and has since been used by welders in almost every industry. Carbon arcing with air removal of the slag was being done as a two-person process for decades prior. However, the advancement of incorporating an air jet into the electrode holder enabled one welder to gouge as much as two welders could previously, and the process became known as air carbon arcing. In the mining industry, it is used to cut or prepare work pieces for welds or surfacing and to fix and remove cracked welds. Air carbon arcing is a valuable process because it is fast, inputs minimal heat to the surrounding area of the work piece, and it can be used on virtually any conductive material. The process has remained a mainstay of metalworking.

As the electric arc melts the metal, molten drops of metal are blown away from the work piece by the air stream. Figure 1 shows a process diagram and typical electrode holder¹² and Fig. 2 shows the ACAG process¹². Some of the most significant parameters are the electric current, the operating air pressure, and the electrode diameter. The electrode holder is connected with a conductive air hose to a welding power supply capable of producing at least 25 volts and 500 amps. Compressed air is forced onto the area being cut or gouged through two to four jets located within the electrode holder. The carbon electrodes are usually copper coated. The electrode is touched to the base metal and an electric arc is struck. Through this process, the work piece can be cut or gouged, with temperatures reaching 5000 °C (9000 °F) where the metal is melted. The air jets blow the molten metal away as it is formed, making the detrimental heat transfer (heat input) to the base metal minimal.

Previous research on other welding processes such as arc welding has shown that noise production from an arc is not only a function of the amplitude of the arc current, but is also a function of the rate of change of the arc current¹³. Significant reduction of noise from arc welding is achieved by lowering the current or by switching from abrupt direct current arc changes to a smoothed alternating current supply¹⁴. For air carbon arcing, MSHA has shown during field studies that a combination of reducing the amplitude of the arc current and reducing the air pressure to the minimum effective settings can reduce air carbon arcing sound levels by up to 6 dB(A)¹. MSHA also observed that the highest sound pressure levels for air carbon arcing are generated by abrupt changes in the arc length, due to the operators hand movement of the electrode holder, resulting in a crackling sound^{2,6} and that switching to a constant voltage power supply resulted in a significant noise reduction³. Additionally, previous research has shown that in a limited number of situations welding processes can be performed inside a sound absorbing box^{7,15}, and that in limited situations ACAG can be performed inside of a movable box¹⁶.

2 DESIGN OF EXPERIMENTS

Of the many possible sound measurements, sound power level was chosen because it measures the total sound energy from a machine or process. It is independent of the orientation of the machine or process within the test chamber. Changes can be made to the experimental apparatus without concern for altering the results by changes to the orientation of the apparatus or by blocking a sound path.

To measure sound power levels, NIOSH maintains a National Voluntary Laboratory Accreditation Program (NVLAP) accredited reverberation chamber for measurements per ISO 3741/ANSI S12.51¹⁷. Sound power level measurements are conducted per ISO 3743-2. At least three tests are conducted per test condition (as an ACAG example, lowered operating air pressure) and the results are averaged. The chamber is a 1286-m³ room with treated hard walls and monitored humidity to ensure a highly diffuse sound field. It is equipped with assorted sensors to document the test environment. Room temperature, relative humidity, and barometric pressure are monitored during sound power level testing. The reverberation chamber is equipped with fifteen microphones sampled by a Bruel & Kjaer Pulse system and the data are linked into an Excel spreadsheet.

By studying all of the inputs and outputs of the air carbon arcing process, the process parameters and settings were identified. Each component of the air carbon arcing process can be represented as parameters, with constant or variable settings. The components of the air carbon arc process, as shown in Fig. 2, that may affect sound levels are the material being cut or gouged, the electrode holder, the air jets, the electrode, and the arc (electricity). Some of the parameters are the following: arc current, arc voltage, shape of the electrode, size and composition of the electrode, humidity, air velocity, speed of gouging, angle of attack of the electrode holder, arc length, condition of the material, and percentages of elements in the material. An example of a process parameter setting is 500 amps for the arc current.

For this research, electrode composition and shape, speed of gouging, angle of attack, and the work piece material were held constant in the laboratory because they vary with unpredictable field conditions and operator technique. Varying these parameters could confuse results produced by other more significant parameters. For this reason, air carbon arcing was performed using an automated gouger on consistent sample material with typically used round gouging electrodes. Common SAE 1018 low carbon steel (1.27 cm thick, 15.24 cm wide, and 122 cm long) was chosen as the sample material because it is representative of the majority of mild steel metal gouged in the field. Round copper-coated carbon electrodes were chosen because they are the most common type used. The angle of attack of the electrode was set at 30 degrees from the horizontal (30 to 45 degrees is the usual range). The welding power supply was chosen to match the capacity of the automated gouger (Miller Dimension Series 652). The arc voltage was maintained at 40 volts by the gouging machine electrode feeder. The gouging speed was 76 cm per minute (the upper limit of human gouging speed). Each gouging test was at least 15 seconds in duration. Figure 3 shows the arc and slag spray made by the C.H. Symington automated gouger during one of the experiments.

Three main parameters of the air carbon arcing process (Table 1) were tested in these experiments because they were believed to be the most significant and readily controlled in the laboratory. The ranges and electrode sizes in Table 1 are representative of process settings typically used in the field for these parameters.

The constant current settings varied from 810 amps down to 500 amps for 1.27-cm (1/2-in) round electrodes and from 500 amps down to 250 amps for 0.95-cm (3/8-in) round electrodes, at

approximately 50 amp increments. The current in the welding cable was measured by an amperage clamp, and the average current per test varied by no more than +/- 18 amps from the nominal. For example, while the nominal current for one of the tests was 550 amps, the measured average current over the test was 532 amps. The operating air pressure settings varied from 827 kPa (120 psi) down to 414 kPa (60 psi) at 138-kPa (20-psi) increments for 1.27-cm electrodes and down to 276 kPa (40 psi) for 0.95-cm electrodes. More air flow was necessary for the 1.27-cm electrodes to keep them from overheating at high current settings. The pressure was measured by a pressure sensor in the supply line during flow, and the average air pressure varied by no more than +/- 28 kPa (4 psi) from the nominal. Two sizes of electrodes were tested: 1.27-cm and 0.95-cm.

3 RESULTS AND DISCUSSION

The sound power testing program consisted of 127 air carbon arcing tests performed in the NIOSH reverberation chamber. Figures 4, 5, and 6 show samples of the measured sound power levels. For each set of three sound power levels per combination of current and air pressure, the measurements were within +/- 1.0 decibels.

Differences in sound power levels may be caused by different interactions between the arc, the air jets, and the electrode. The mechanisms of interactions between the arc, the air jets, and the electrode and the effects on arc stability are not yet understood. The data displayed in Figs. 4 and 5 are easily considered assuming linearity of the dataset for comparison purposes. Steeper line slopes are seen in Fig. 4 than in Fig. 5. Similarly, the lines in Fig. 6 fit the data more closely as curves than as straight lines.

From Figs. 4-6, it is clear that the two major inputs of energy to air carbon arcing are the current and the compressed air. The largest effect seen from lowering the current was for 0.95-cm electrodes at 827 kPa as shown in Fig. 4. The sound power levels were reduced by 9 dB, from 128 dB(A) down to 119 dB(A). The largest effects seen from lowering the air pressure was for 1.27-cm electrodes at 810 amps, as shown in Fig. 5, and for 0.95-cm electrodes at 450 amps, as shown in Fig. 6. The sound power levels were reduced by 4 dB. Lowering both current and air pressure at the same time produced the lowest observed sound power levels. The lowest sound power level observed was 116 dB(A) using a 0.95-cm round electrode at 250 amps and 276 kPa, as shown in Fig. 6.

Electrode diameter also makes a significant difference in the noise produced. At 500 amps, both 0.95-cm and 1.27-cm round electrodes were tested to determine what effect diameter has (see Figs. 4 and 5). Increasing the electrode diameter reduced the sound power levels by up to 3 decibels, as much as cutting the air pressure in half (from 827 kPa to 414 kPa) at 500 amps. One hypothesis is that the larger cross-sectional area makes for more potential pathways for the electricity from the end of the electrode to the work piece. It has been observed in the literature that as arc stability increases, the noise produced decreases^{2,6}.

One-third octave band plots of the sound power level data were produced to show where the sound energy is concentrated and to target those frequencies for noise reduction. Targeting frequencies where sound energy is concentrated leads to effective noise controls. Figure 7 shows two representative tests at the process extremes. Depending on the process settings, 65 to 75 percent of the sound energy is between 3150 and 8000 Hertz.

4 CONCLUSIONS

From the results of the laboratory experiments conducted, three conclusions can be drawn.

First, to reduce noise, welders should use the lowest settings for current and air pressure that still maintain cutting and gouging effectiveness. Secondly, for a given set of current and air pressure settings, welders should utilize a larger electrode size whenever feasible. Lastly, the majority of the sound energy measured was at frequencies between 3150 and 8000 Hertz. Why the majority of the sound energy is in these frequencies is as yet undetermined, although there may be a correlation between these frequencies and arc instabilities or structure borne noise. One approach to be investigated in the next phase of work is the use of a constant voltage power supply and control of current variations to evaluate the ability to reduce noise in this important frequency range. In future work, measurements will also be made with a laser vibrometer to test for contributions to the noise from structure borne paths.

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Table 1 - Air carbon arcing parameters varied and process setting ranges.

Electrode Diameter (cm)	Operating Air Pressure (kPa)	Constant Current (amps)
0.95	276 kPa to 827 kPa	250 amps to 500 amps
1.27	414 kPa to 827 kPa	500 amps to 810 amps

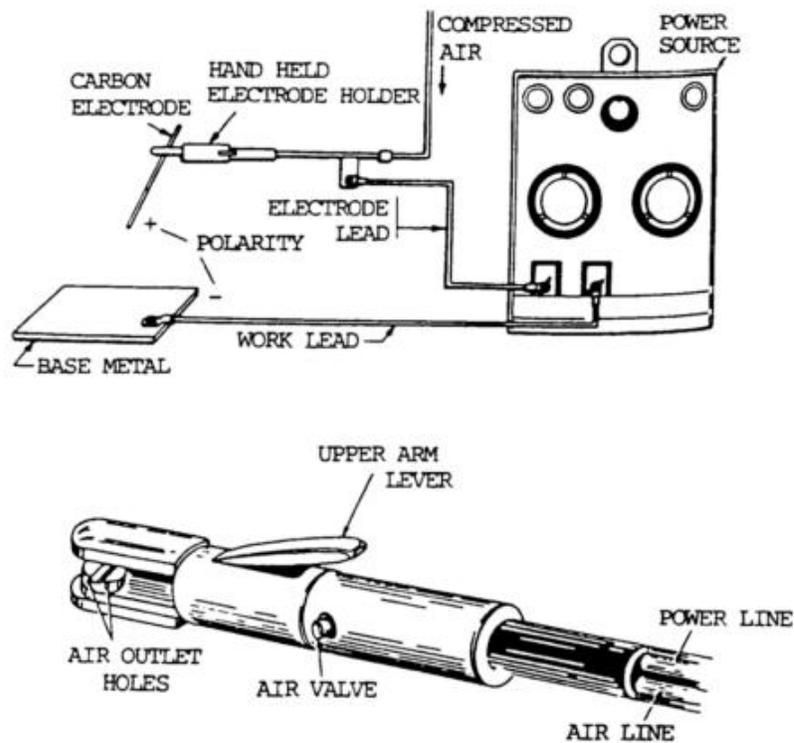


Fig. 1 - ACAC/ACAG diagram and electrode holder¹².

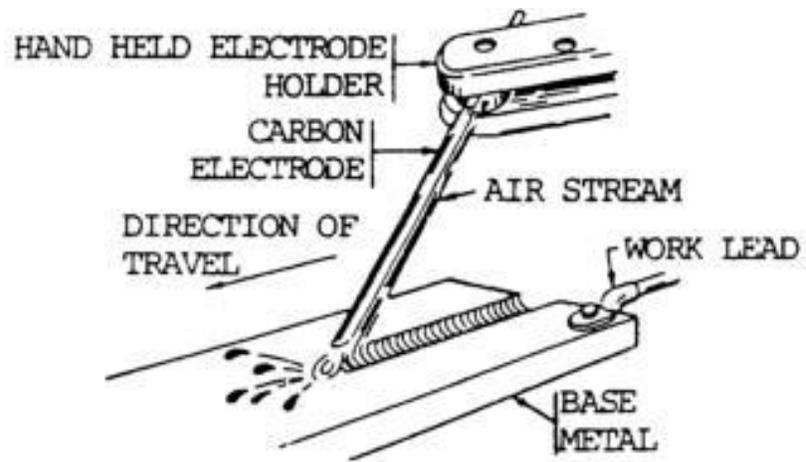


Fig. 2 - ACAG process¹².

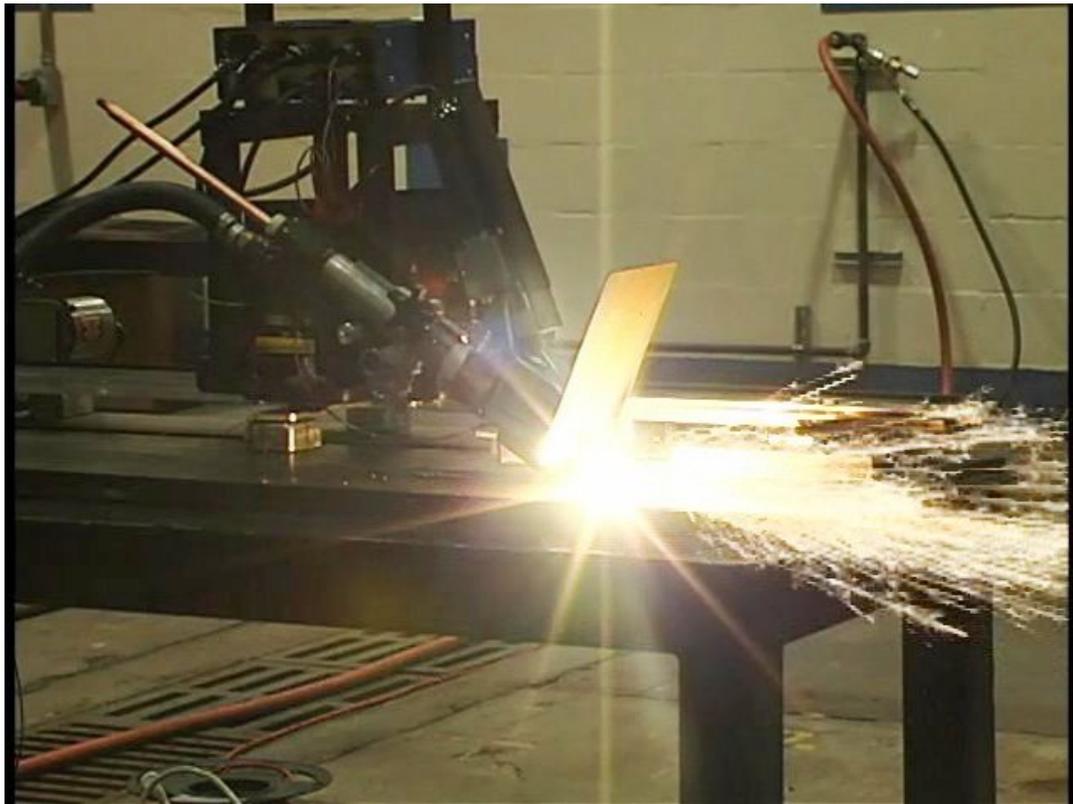


Fig. 3 – Arc and slag spray made by the C.H. Symington automated gouging machine.

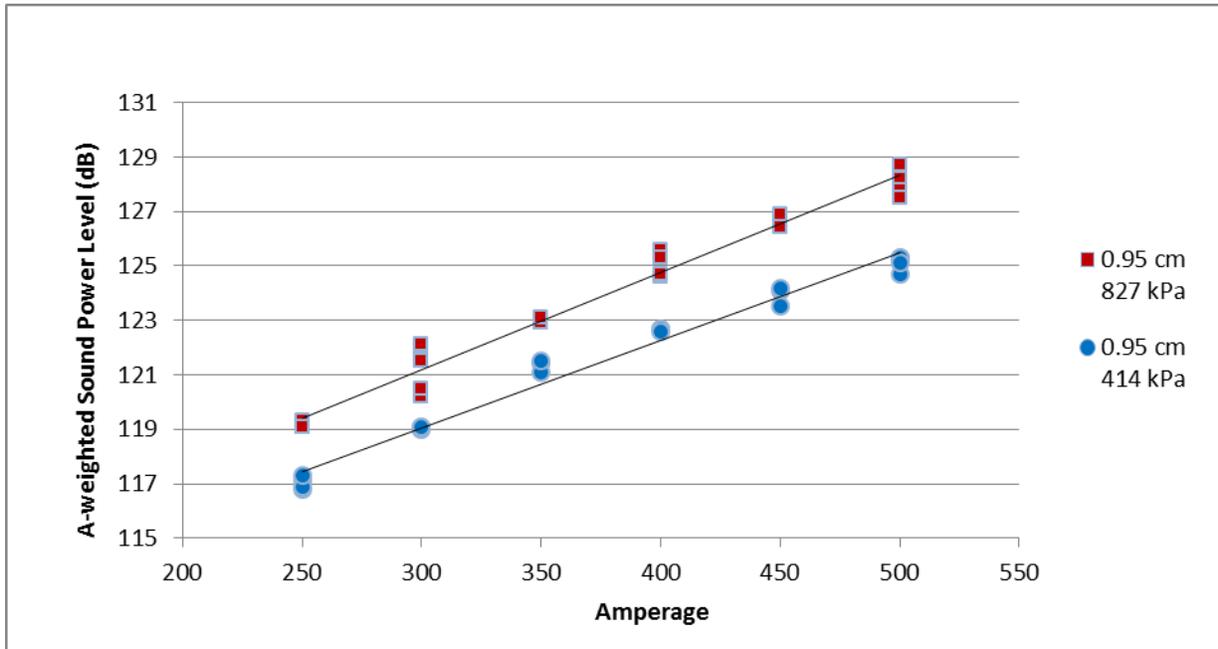


Fig. 4 - Effect of current on sound power levels for 0.95-cm electrodes and 414- and 827-kPa operating air pressures.

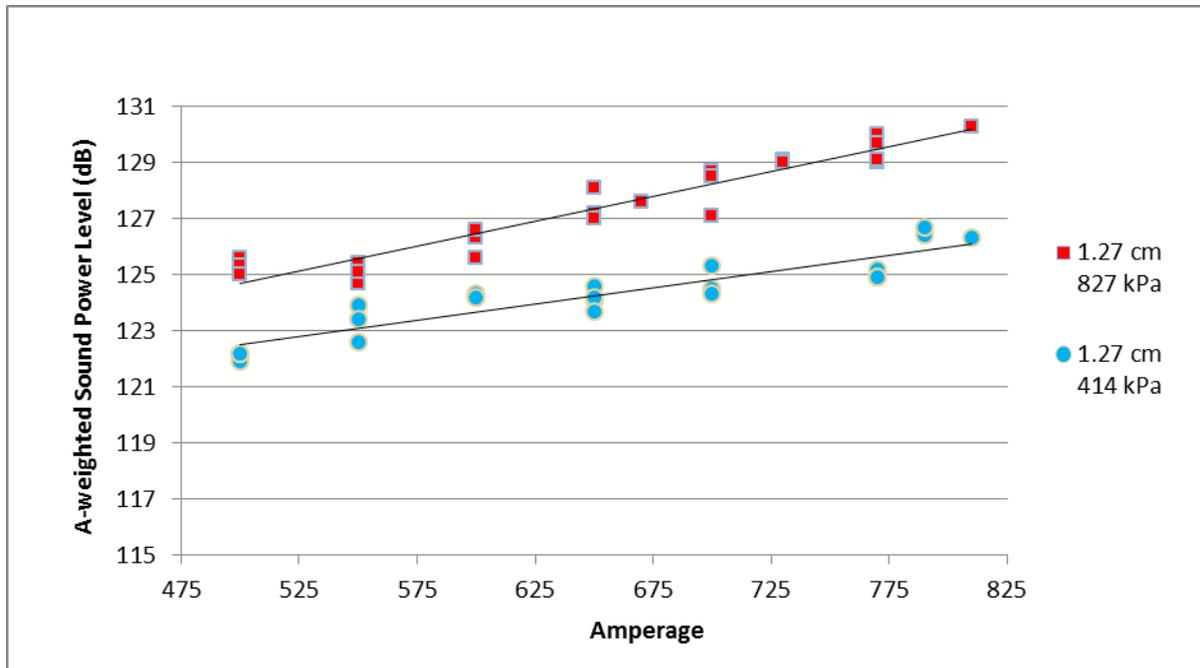


Fig. 5 - Effect of current on sound power levels for 1.27-cm electrodes and 414- and 827-kPa operating air pressures.

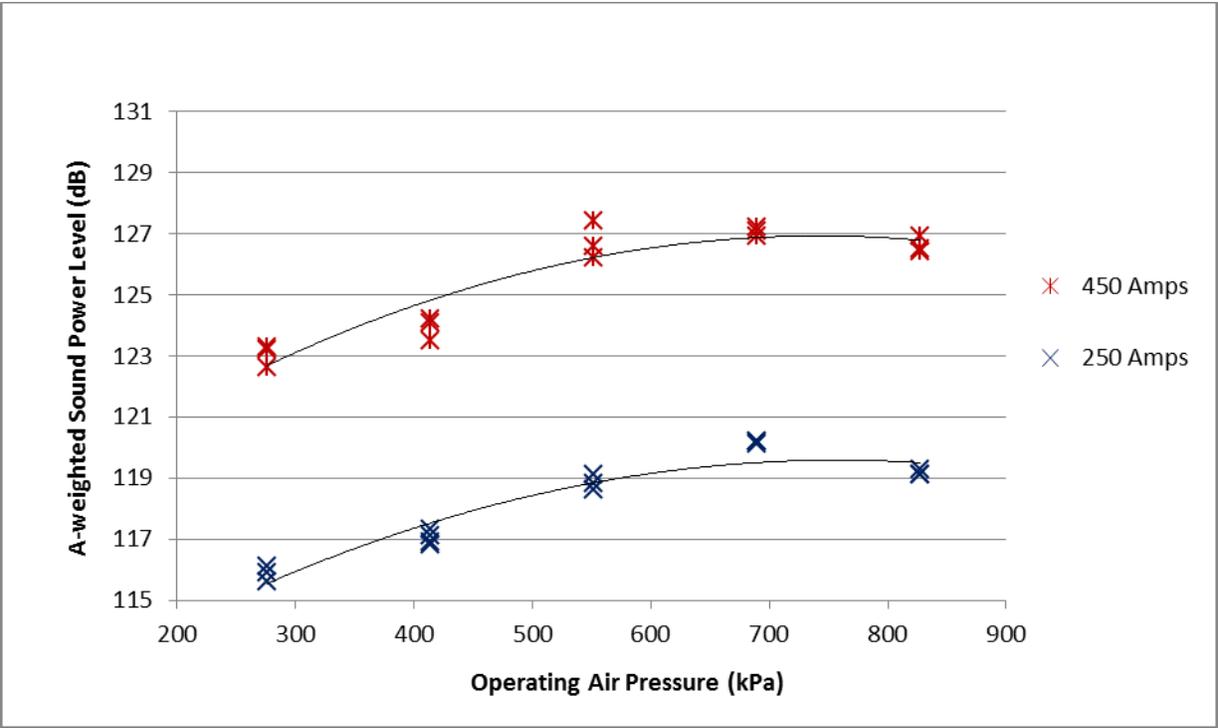


Fig. 6 - Effect of air pressure on sound power levels for 0.95-cm electrodes at 250 and 450 amps.

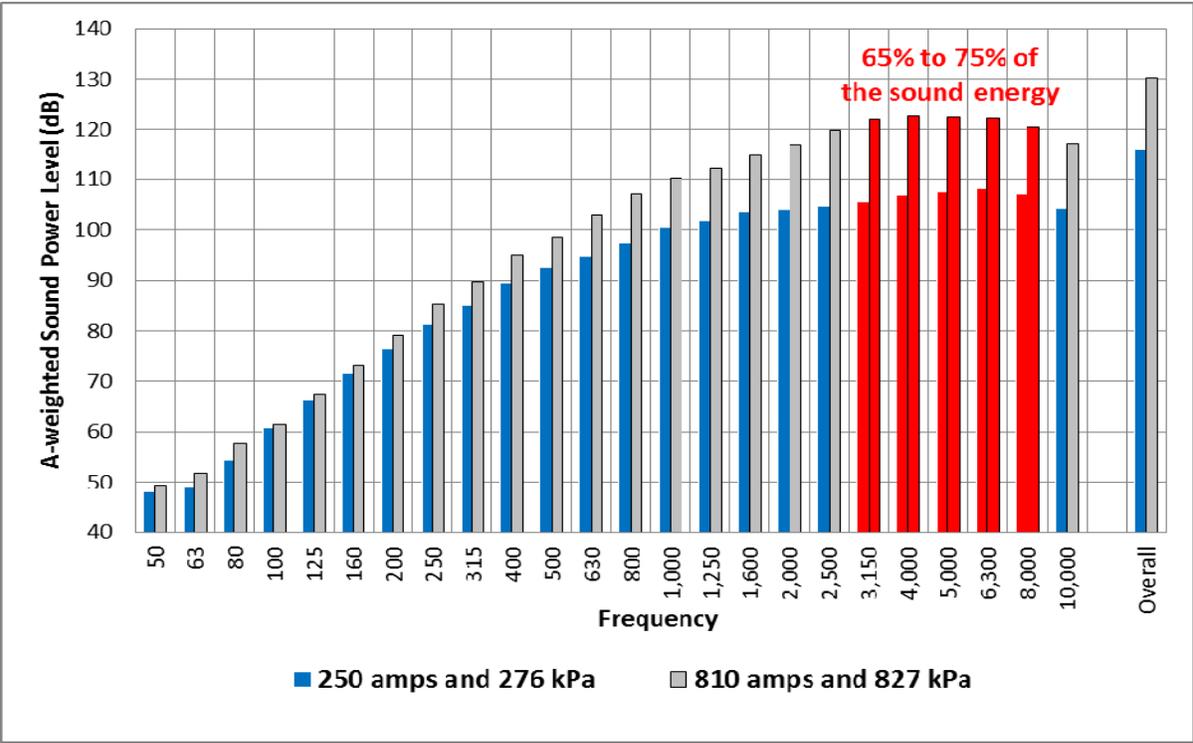


Fig. 7 - Concentration of sound energy shown by 1/3-octave bands.