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Measurement Methodology and Supporting Documentation for Portable Air Compressor Noise

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National Bureau of Standards
Washington, D. C. 20234

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Final Report

Prepared for
U. S. Environmental Protection Agency
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Summary

This report presents recommendations and supporting rationale on a measurement methodology for portable air compressors. The methodology is believed to be general enough to allow determination of noise emission from other outdoor stationary noise sources. The methodology provides for the determination of A-weighted sound power level or the equivalent weighted sound pressure level at a reference distance. A-weighted level is used because of its strong, positive correlation with community response to noise from internal combustion engine noise. It is recommended, however, that the spectra associated with the regulated source be monitored in some manner to insure that the spectra remain similar to those for which A-weighted sound level retains good correlation with community response. The methodology uses weighted sound level measurements at eight positions on a curved surface surrounding the source at a distance of one metre from the surface of the machine. Data recorded at these positions are used to calculate the average A-weighted sound pressure level of the machine on the measurement surface. This is combined with the area of the measurement surface to give the sound power level of the machine. From this value, a rating sound pressure at a rating distance may be calculated by subtracting a constant value.

While a specific methodology is proposed which is believed to be consistent with achievable accuracy and precision of field measurements conducted for regulatory purposes, we believe that the flexibility inherent in regulation by use of sound power level should be exploited by permitting the use, for quality control purposes, of any measurement methodology which provides estimates of the sound power level which has demonstrable precision and accuracy consistent with the difference between the actual level radiated by the source and the regulated level.

Procedures which permit the rapid estimation of A-weighted sound level are presented in Appendix A. These are applicable for estimation of A-weighted sound level in a variety of circumstances when the sound power or equivalent sound pressure level at a reference distance is known.

Key Words: Acoustics; air compressor; internal combustion engine; noise; sound power level; sound pressure level.

1. BACKGROUND

The construction site is an omni-present fixture of present life in U. S. cities, and represents a significant source of noise to occupants and residents in nearby areas. While the noise arises from many sources within the site, the U. S. Environmental Protection Agency has identified portable air compressors as a major noise source under authority of Section 6 of the Noise Control Act of 1972. At the request of EPA, the National Bureau of Standards, with the cooperation of industry, has derived a test procedure applicable to portable air compressors. In this report we describe this measurement methodology and review the rationale behind the decisions which led to its development.

1.1 Source Description

Portable air compressors are self-powered devices which produce compressed air for the operation of other equipment. They are portable in the sense that they are mounted on trailers or truck beds, to facilitate moving from site to site. The machine consists of a driver, i.e., a gasoline or diesel engine (or possibly an electric motor), and a driven element which is a reciprocating, or rotary vane or rotating screw pump. Currently, units are available which may be described as standard and quieted (the latter category generally implys some degree of noise control treatment added to an otherwise standard unit). Also included is an air receiving tank, an automatic regulation system which matches air output to demand, and suitable performance indicating gauges such as air pressure and engine speed. The output automatic control system may be of an on-off or continuously variable type. In the former case, depending on air pressure demand from the receiving tank, the engine will be operated either at idle or rated (i.e., governed) speed. In the continuously variable case, engine speed is varied through a control loop to match compressor output to air demand. Because of the relatively fine gradation in model size (there are approximately twenty-five model sizes to span the output range from 85-2000 cubic feet per minute (cfm)) compressors tend to be selected to closely match the demand requirements for the tools which they power, and are probably operated very close to rated output nearly all of the time when they are in use. In physical size, the units vary from about 0.7 m x 1.0 m x 1.3 m with a 30 horsepower engine to approximately 3 m x 3 m x 6 m with a 650 horsepower engine. Within the range of compressors manufactured, there are logical divisions, for example, as a function of driver type and pump type. There is a less clearcut division on size. Virtually all gasoline powered units have a rated capacity below 250 cfm (424 m^3/s), while all diesel units are larger than 125 cfm (213 m^3/s) capacity. No similar categories for pump type occur, since all three types are used throughout the range of sizes produced.[1][1/]

1/ Numbers in brackets indicate literature references at the end of this report.

The predominent noise sources associated with the compressor operation are those associated with the operation of internal combustion engines (i.e., engine intake, exhaust and casing radiation plus cooling system fan) and also radiation from the compressor casing and air receiving system and associated valving. No single routine operation leads to the production of noise from warning devices or from pressure relief valves.

There does not appear to be justification for fundamental variations in the measurement methodology to accommodate the above mentioned machine parameters.

There is no typical use pattern established for portable air compressors since the requirements and site descriptions vary substantially from construction job to construction job. The site may vary from a large controlled area (such as a site for a major building or power plant), to a city street where pavement is being removed. In a typical urban site, the compressor is frequently located on or near the street where passers-by and nearby building occupants may be expected to receive substantial exposure.

1.2 Parties Affected by Noise

The two principal groups affected by compressor noise are construction workers on the job site, and the surrounding community. The nature of the effects on construction workers range from task interference and annoyance to possible hearing loss. Potential hearing loss, task interference, communication interference, and annoyance will constitute the most significant effects in the community. Construction workers presumably will be protected by occupational health and safety regulations, with the possible exception of small construction firms which do not engage in interstate commerce. The proportion of exposed workers in this latter category is unknown. For these reasons the principal concern in this methodology is to equitably assess the noise emission which contributes to community noise levels.

1.3 Present Accepted Noise Measurement Methodologies

The Compressed Air and Gas Institute and its European counterpart (CAGI/PNEUROP) have promulgated a test code for the measurement of noise from pneumatic equipment[2], including portable air compressors, which is now nationally and internationally accepted[3]. This code consists of determining the average octave band and A-weighted sound pressure level at ten positions near the ground plane (1.2-1.5 meters above the ground) at 1 and 7 meters from the surfaces of the machine. Current standardization activity includes proposed modifications to these standards which incorporate sound power level determinations[4].

The data resulting from use of the CAGI/PNEUROP methodology are not equitable measures for characterizing the noise radiated to the community for two major reasons. The first problem is that the sound pressure level (SPL) measured at a fixed distance from the surface of a machine is not simply proportional to the level at another distance from a machine, since the proportionality constant depends on machine size. Consider, for example, two machines (whose sizes represent the extremes mentioned earlier) with the same SPL at 1 meter from the surface. At 30 meters from the center of the machines the SPL from the larger machine will be about 5 dB higher; while for the same SPL at 7 meters, the difference in SPL at 30 meters will be about 2 dB with the larger machine again higher. Thus it is clear that without some allowance for machine size, the present methodology will not produce an unbiased estimate of noise in the community. A second problem arises because the CAGI/PNEUROP code provides for no measurement above the unit, so that noise radiated to upper stories of nearby buildings would not be controlled. Both of these problems have been recognized by the industry which is one reason for the present work on modification of the international standards.

Both of the above problems may be rectified by a change of determined quantity from average sound pressure level to radiated sound power or sound power level. The proposed methodology is based on this latter concept.

Present methods for determining sound power involve the calculation of average sound pressure level from measurements on large radius hemispherical surface, centered on the source which is placed on a hard reflecting plane[5], combined with an added constant which is proportional to the logarithm of the surface area of the hemisphere. An alternate procedure[6] involves the determination of average sound pressure over a surface surrounding a device at a uniform distance from the surface of that device, times a constant which is equal to the area of that measurement surface. The former method involves extensive test site requirements which make the procedure very difficult to use directly as a quality control or field enforcement test. The latter test has good possibilities for such use because it does imply the possibility of a measurement at short distances from the machine with associated easing of test site and background noise requirements. The major problem associated with this latter test is the relatively lower experience with use of the test by the acoustics community, which creates difficulties in estimating, *a priori*, how many measurement positions are required to achieve a given level of precision, or what accuracy may be expected.[7]

2. RATIONALE FOR METHODOLOGY

2.1. Introduction

Section 4 of this report consists of a detailed description of the measurement methodology for characterizing the noise from portable air compressors with respect to the resulting noise exposure in the community. In the following paragraphs of this section we review the information which led to the proposal of this methodology, and which in fact constitutes the rationale for the decisions made during its preparation. The remainder of this introduction will provide a brief overview of the methodology, while subsequent paragraphs will address the significant decisions concerning the use of sound power and weighted sound level to describe the source, the questions of accuracy and precision in the measurement, and finally a detailed discussion of the important paragraphs within the methodology itself.

The recommended methodology involves the determination of the A-weighted sound power output of the source. The sound power output is estimated from the average of eight measurements of sound pressure level (SPL) on a measurement surface which is one metre from the surface of the source, with the source placed on a hard reflecting plane.

2.2. Determination of Sound Power

The sound power output of a device is a quantity which characterizes the power radiated by that device in a manner which is, to first order, independent of the surrounding environment. There is a strong analogy between thermal and acoustical problems which may assist in visualizing this situation. In both cases power is used to characterize energy output per unit time. Temperature is the variable in the thermal case which corresponds to sound pressure in the acoustic case. Both variables are measures of the intensity of the radiation from the source at a given position. In either case, the value variable is directly related to the source strength and is also influenced by the environment. As energy propagates away from the source, it may be thought of as spreading over a surface of equal distance from the source. In the case of a small source, for example, which radiates in all directions, placed on a non-absorbing surface, the power radiated from that source is distributed over a hemispherical surface.

The acoustic power W radiated by a simple source such as a pulsating sphere is determined from the equation[5]

$$W \simeq \langle p^2 \rangle \, S/\rho c \qquad (1)$$

where ρ is the density of air, c the velocity of sound in air, $\langle p^2 \rangle$ is the space and time average sound pressure, and S is the area of the surface on which $\langle p^2 \rangle$ is determined. This equation is accurate within one decibel for complex sources when the effective radius of the measurement surface is greater than (120/f meters) where f is the center frequency of the frequency band of greatest contribution to the weighted sound level. It should be noted that this equation appears to produce an upper bound estimate of the sound power determined by other standard procedures under typical conditions[8].

Since the area of the hemispherical surface is proportional to the square of the radius, the intensity (i.e., power per unit area) is inversely proportional to the square of the distance from the source. Thus if the distance from the center of the source is doubled, the intensity is reduced by a factor of four. Since a 3 dB reduction in sound pressure level (SPL) corresponds to a halving of sound pressure, a doubling of distance in this case will produce a 6 dB reduction in SPL. The total power radiated may be determined from the mean square sound pressure averaged over a measurement surface, the area of that measurement surface, and the characteristic impedance of the ambient air.

The sound radiated from a device of complex shape spreads out on a wavefront which is always at a uniform distance from the surface of the source. Thus, in principle, the determination of sound power can be made on any measurement surface which is a uniform distance from the source surface. At large distances from any source mounted near a reflecting plane, the wavefront surface becomes nearly hemispherical in shape, and a hemispherical measurement surface is appropriate. Thus the determination of sound power output may be made on any hemisphere of any arbitrary radius greater than some appropriate minimum radius -- subject to other limitations of a practical nature which affect the accuracy or precision of the measurement. The major practical limitations are imposed by background noise, atmospheric propagation effects, the necessity of testing over reflecting plane which is larger than the test hemisphere and accuracy of microphone positioning. The first three factors all become increasingly important as distance increases, and thus minimizing the measurement radius is desirable. The last factor is more significant for smaller radii, and thus also suggests a minimum radius.

The foregoing information suggests that, in principle, it does not matter whether or not the measurements are made on a hemispherical surface whose radius is several source dimensions, or on a surface surrounding the source at a fixed, relatively small distance as long as the effective radius is greater than the minimum specified for complex sources. The same information is obtainable using either surface, but the number of measurements required to obtain information to the same degree of accuracy may differ. This is due to the fact that close to a complex source (i.e., one composed of a number of independent subsources), the sound level is a stronger function of the contribution of the nearest subsource, and thus additional measurement positions may be required to appropriately include the contributions from each subsource. The results of recent research[8] suggests, however, that for compressor noise the number of measurement positions required is nearly the same and is independent of the distance from the source (outside a region very close to the source).

2.3. Use of Weighted Sound Levels

a. Limitations of Weighted Sound Levels

A-weighted sound level has been identified by many researchers as a simple, useful measurement which correlates with human response to noise in a number of situations. It has been noted that A-weighted levels show fair correlation with speech interference and annoyance for a wide variety of sources, and, in particular, A-weighted levels are one of the better available descriptors of community response to internal combustion engine noise.[2/] These considerations strongly indicate that A-weighted level is an appropriate measure for present air compressors. It should be noted, however, that two significant factors which contribute to this fortuitous situation are that a) compressors which are currently manufactured do not radiate dominant discrete tones at mid and high frequencies and b) the spectra of energy from presently manufactured compressors are "regular" in the sense that they do not contain large amounts of low frequency (i.e., below 125 Hz) energy. We believe it is appropriate that the methodology be a suitable measure of community response not only for compressors as presently manufactured, but also for compressor designs which can reasonably be anticipated to result in response to noise emission regulation.

The lack of discrete tones at mid and high frequencies from present compressors is attributed to the fact that it is physically difficult (with the exception of poorly designed compressor air handling systems) to produce such sounds with present compressors internal combustion engines and cooling fans with a relatively small number of blades. The only anticipated mechanism for changing this situation would be the future use by the industry of other types of engines for driving the compressor, such as the gas turbine, which may generate strong high frequency tones. This is considered to be a reasonable possibility in view of the rapidly developing technology of small gas turbines. In this event, it is conceivable that a more complex descriptor such as perceived noise level may be required in order that the measured value will correlate well with community response.[9]

The other major question which must be addressed is the frequency spectra of noise from compressors which is to be expected when a internal combustion engine powered compressor is quieted to meet an A-weighted noise regulation. It should be noted that the A-weighting puts very little emphasis on low frequency sounds, and low frequency sounds are not reduced as much, and may in fact be increased, by noise control treatments which are designed to control high frequency sound. Thus there are both physical and economic grounds for expecting low frequency noise from portable air compressors to at best remain the same and potentially increase under the influence of an A-weighted noise regulation.

[2/] It was noted earlier in this report that the engine driving the compressor is the principle noise source on presently manufactured compressors.

Given the possibility that low frequency noise from compressors could increase, what might be the resulting response from the community? One major potential source for community disturbance is the vibration induced in structures by low frequency sound[3/]. Another source of complaint has been identified by one author[10] as "disturbance or unease" in the presence of noise which peaks in the 31.5 Hz octave band or lower frequencies. In particular he identifies "the indadequacy of dB(A) as a predictor of adverse reaction to sound with most of their energy at low frequencies," which he attributes to the fact that "dB(A) was originally designed for use at fairly low intensities and makes no allowance for the rapid growth of loudness with intensity which occurs in this [low frequency] region." The spectra identified as disturbing exhibited a difference between C- and A-weighted levels of 22 dB or more, and substantially exceeded the threshold of hearing (~60 dB SPL) in the 31.5 Hz octave band. A typical range of difference between C- and A-weighted level for presently manufactured portable air compressors is 5-13 dB. If we assume that A-weighted noise from compressors is reduced by 10 dB, and assuming C-weighted noise, which is determined by low frequency components of the spectrum, remains unchanged, we find that the C-minus A-weighted difference will be in the range 15-23 dB, thus creating a potential problem.

Should the need for reduction of the low frequency noise emission from a compressor be explicitly identified, then engineers can design to incorporate low frequency noise control treatments. The principle source of possible increase in low frequency noise is associated with the large surface area enclosure (large with respect to the size of the source) which is needed to contain the noise radiated by the engine and compressor. If the enclosure is directly connected to the vibrating surface of the compressor, it will produce a new, far more efficient, path for radiation of low frequency energy. This problem can be reduced or avoided by judicious selection of attachment points for the enclosure.

The proposed methodology incorporates no measure of this low frequency noise. It is recommended that some appropriate mechanism be created which permits the detection of significant increases in radiated noise in this frequency region, so that this may be regulated if it occurs. The justification for this approach is that the lack of current community response data for this low frequency noise problem makes it extremely difficult to define a suitable measure, or an appropriate limit, even though we expect, based on limited experience that A-weighted level alone will not completely describe the community response to signals containing very high proportions of low frequency energy. Additional research on community response to low frequency noise is clearly needed in order to provide a basis for regulating sources with these characteristics.

[3/] Several acoustical consultants (G. W. Kamperman, Kamperman and Assoc., R. M. Hoover, Bolt Beranek and Newman, In., F. M. Kessler, Dames and Moore, Inc.) have observed that sound levels on the order of 75-80 dB in the 31.5 Hz octave band are sufficient to rattle windows and dishes in wood frame housing.

b. Representative Noise Spectra of Portable Air Compressors

Figures 1-8 depict 1/3-octave band sound pressure level spectra for rotary vane, rotary screw, and reciprocating compressors with diesel and gas power plants, in standard and silenced configurations[11]. All spectra represent either single position or average levels at a seven metre distance from the surface of the machine in question. The data indicate, within the limitations of the analysis bandwidth, the lack of high frequency pure tones from compressors. Of the seven spectra, only the data for the 750 cfm, silenced, rotary screw compressor exhibits potential high frequency tones. In this case it was verified that the signal at 1600 Hz represented a narrow band noise radiated by the muffler shell, and not a tone *per se*. The spectra are representative in the sense that they include a diversity of machine types and manufacturers, but should not be considered as typical or indicative of the sound levels produced by any given type or model of compressor, or of the limitations of noise control treatments of machines. Additional spectral data may be found in reference 8, which further confirms these generalizations.

The presence of significant, apparently-discrete-frequency energy at low frequencies is attributed primarily to exhaust discharge at the firing frequency and its first few harmonics for the case of relatively minimal exhaust silencing.

An inverse A-weighting curve is superimposed on each spectrum in such a fashion as to identify the important spectral components for that weighting. The most important portions of the spectra are those which are within five to ten decibels of the weighting curve as plotted. It should also be noted that noise in the low frequency region below 100 Hz is such that mid frequency noise would have to decrease by 15 dB or more for this group of compressors before the low frequency noise would significantly affect the A-weighted sound level, indicating lack of positive response of the A-weighting in this low frequency region. Alternatively, this low frequency noise could increase by as much as 15 dB in some cases in the present situation without affecting A-weighted sound level.

c. Use of A-Weighted Level

One major correlative study on the use of various physical measures to describe human response to noise has identified the A-weighted sound level as "...the only measure [of motor vehicle noise] having high correlation with subjective reaction that can also be read directly on a commercially available meter having standardized performance"[12]. This conclusion is not at variance with other published studies which have considered noise produced by vehicles. However there has been little study of stationery sources. The lack of more general studies of community response to noise is unfortunate from at least two points of view. The first difficulty results from the fact that the above mentioned study was specifically concerned with the driveby situation (both uniform speed and accelerating) which is a transient event, while compressor noise is a steady state event. The second cause for concern is the change in spectrum shape (already discussed in this section) which may result when an A-weighted criterion is applied. Neither of these questions can be resolved from presently available information in the open literature.

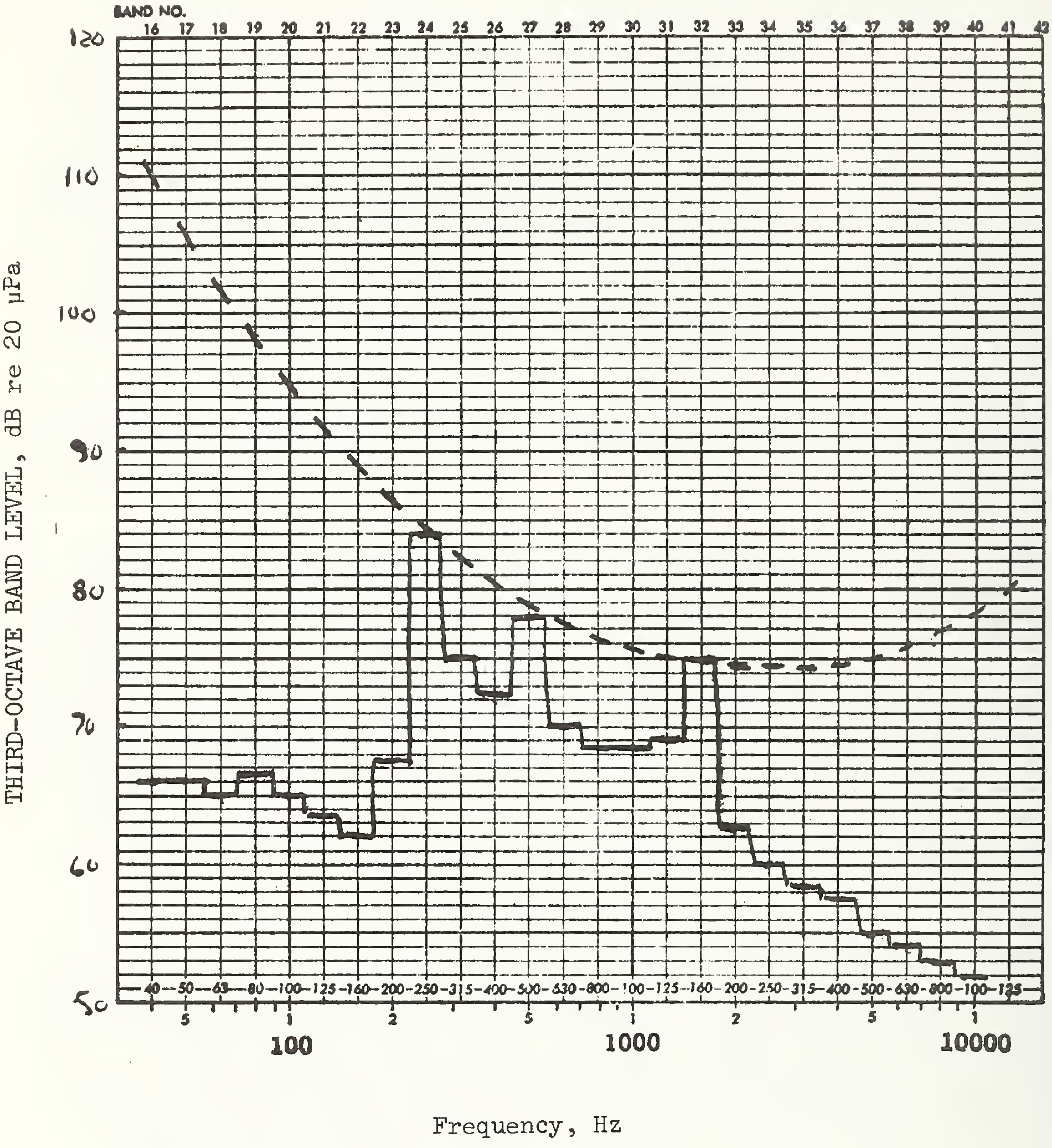


Figure 1. 85 cfm Standard, Gas Powered (2050 rpm), Rotating Vane Compressor (7 meter Measurement)[11].

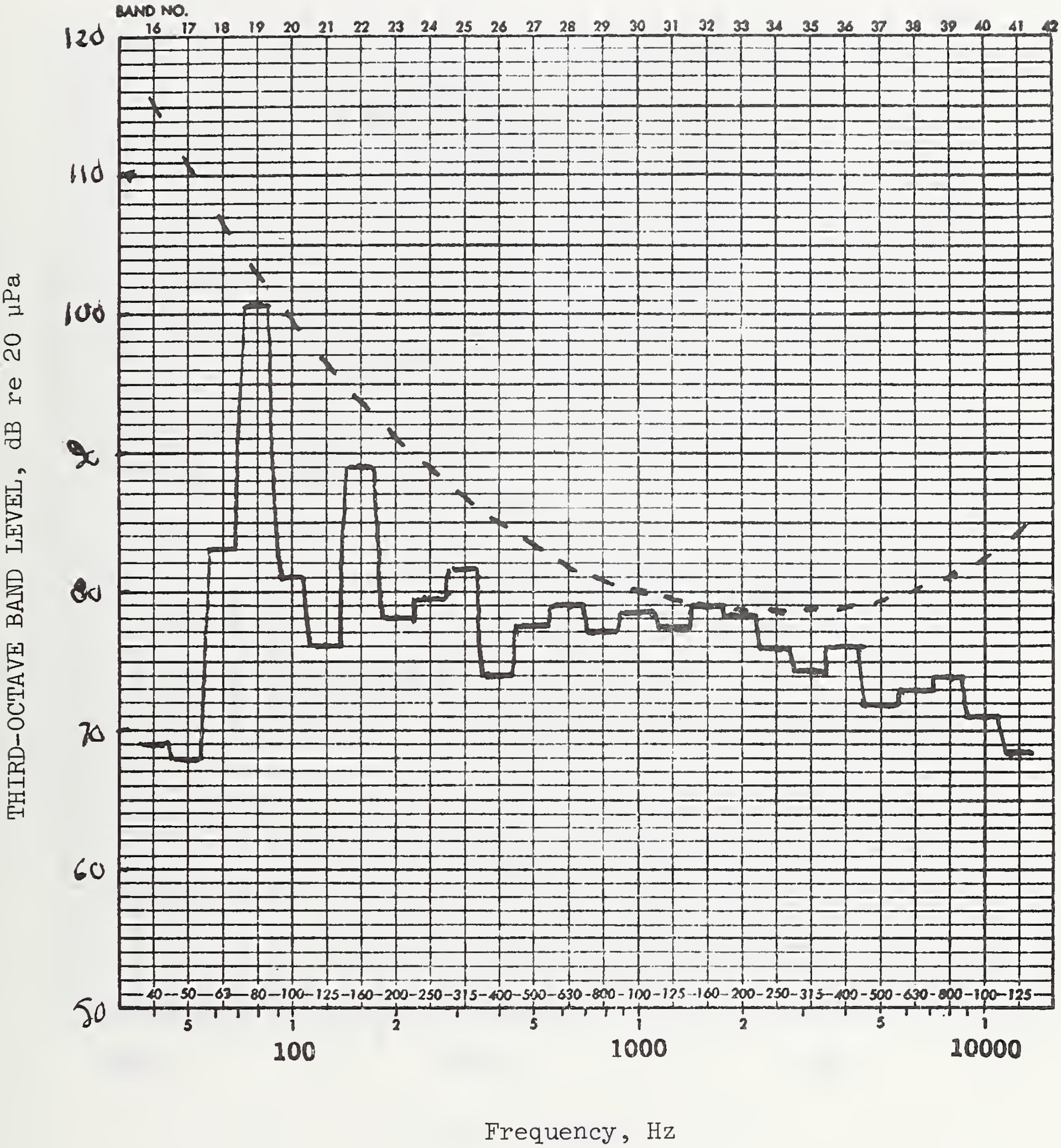


Figure 2. 175 cfm Standard, Gas Powered (2200 rpm), Rotary Screw Compressor (7 meter Measurement)[11].

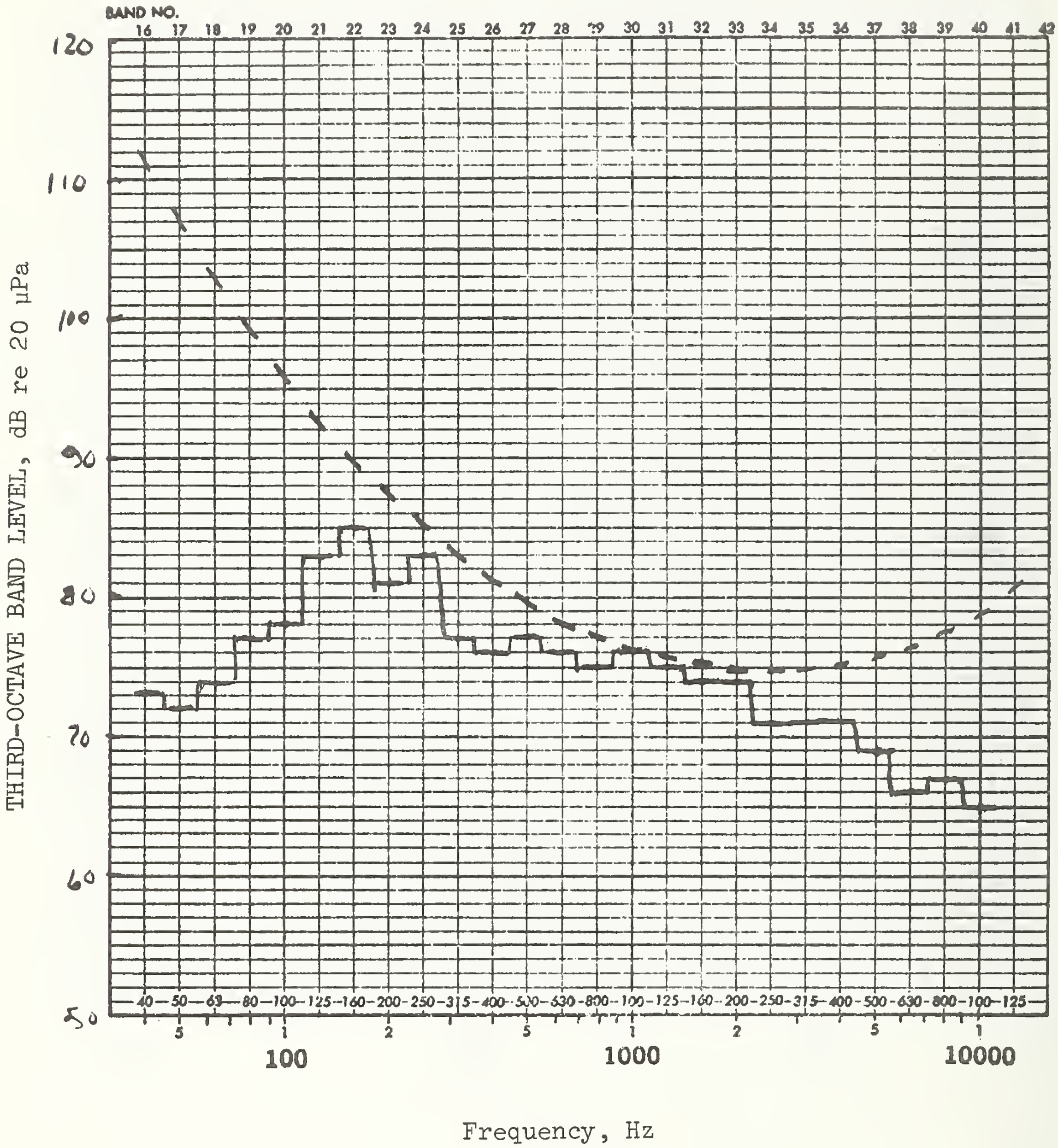


Figure 3. 330 cfm, Standard (engine unidentified), Reciprocating Compressor (7 meter Measurement)[11].

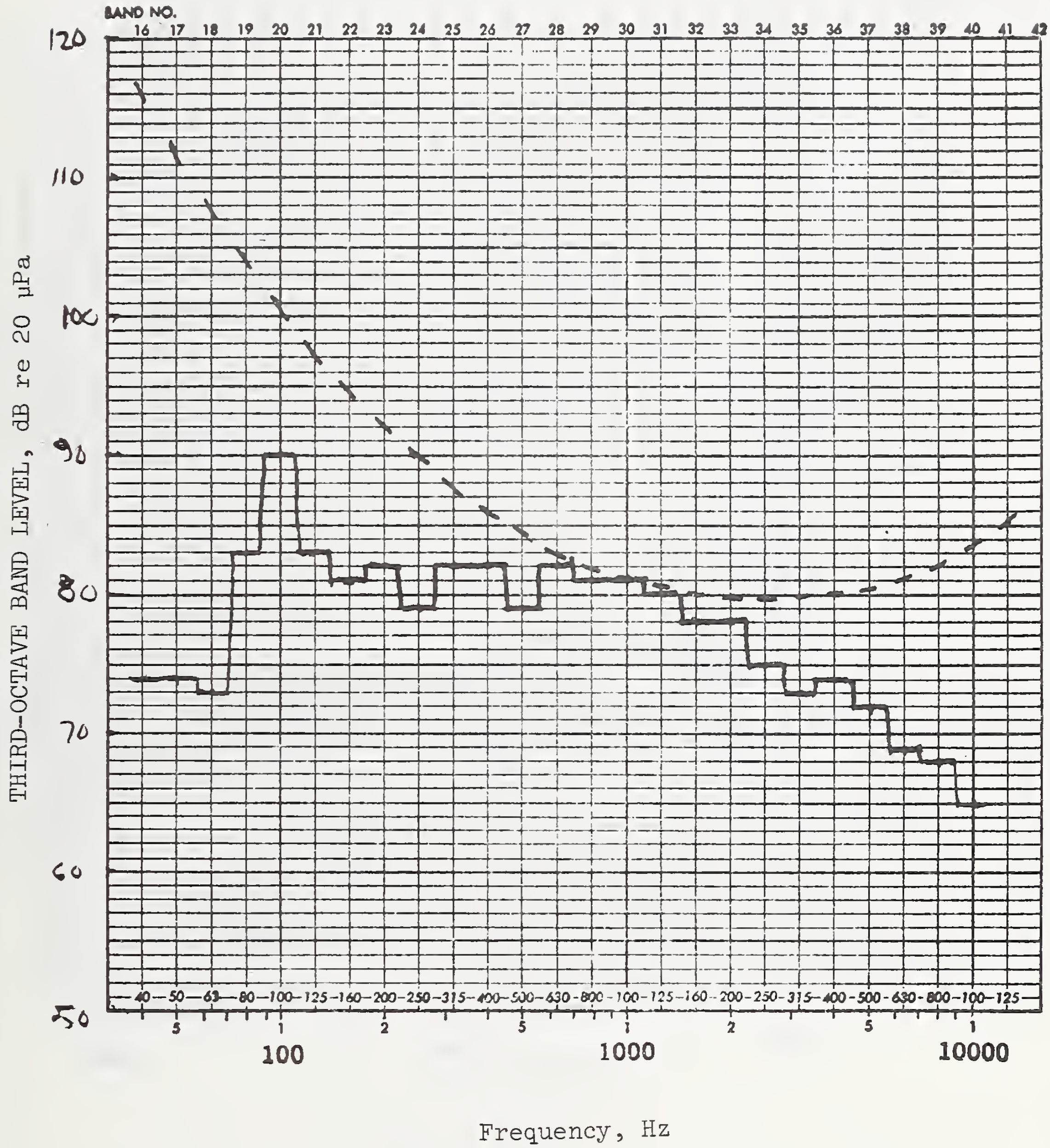


Figure 4. 700 cfm, Standard, Diesel Powered, Reciprocating Compressor (7 meter Measurement)[11].

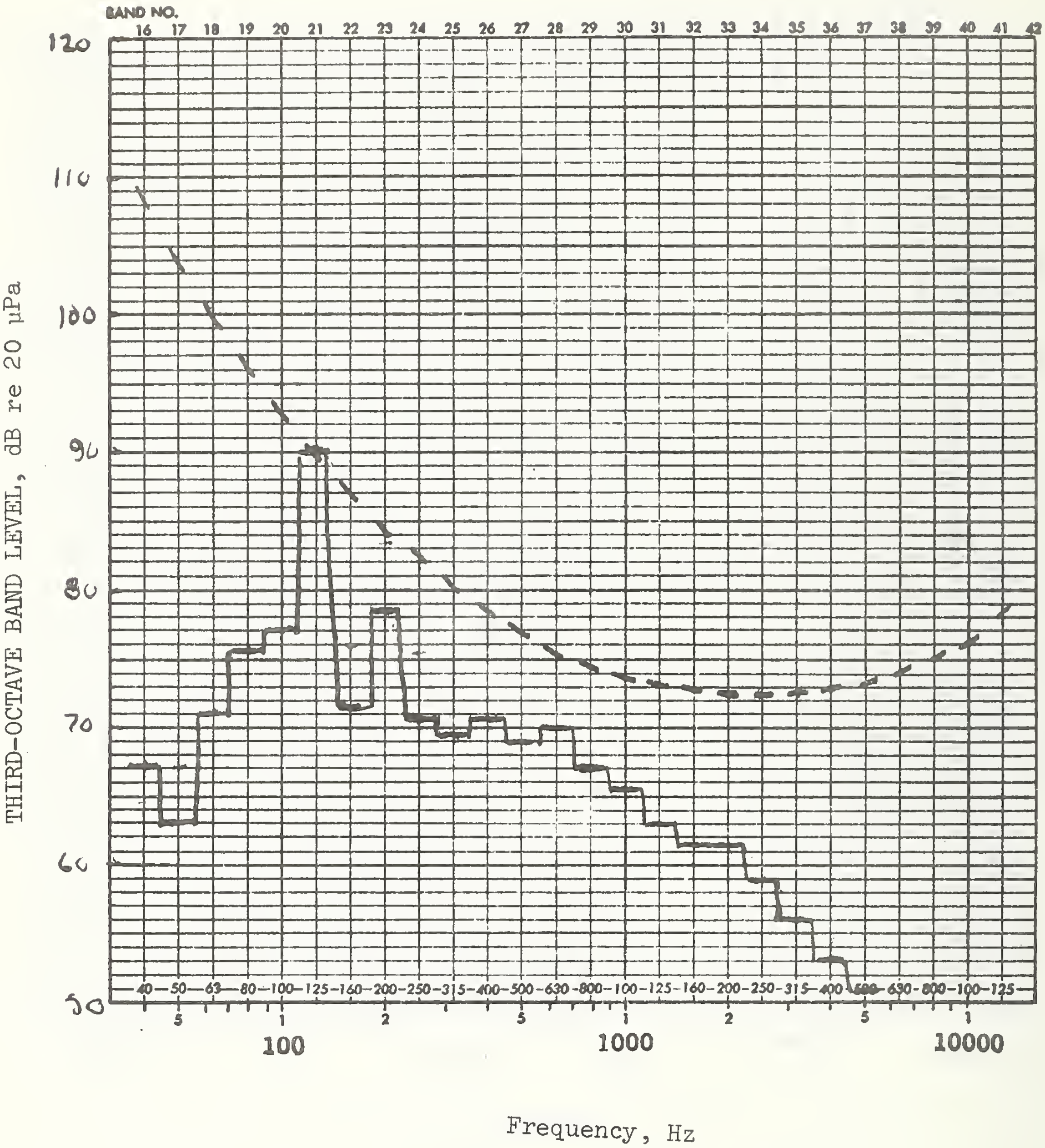


Figure 5. 185 cfm, silenced, Gas powered, Rotary Screw Compressor (7 meter Measurement)[11].

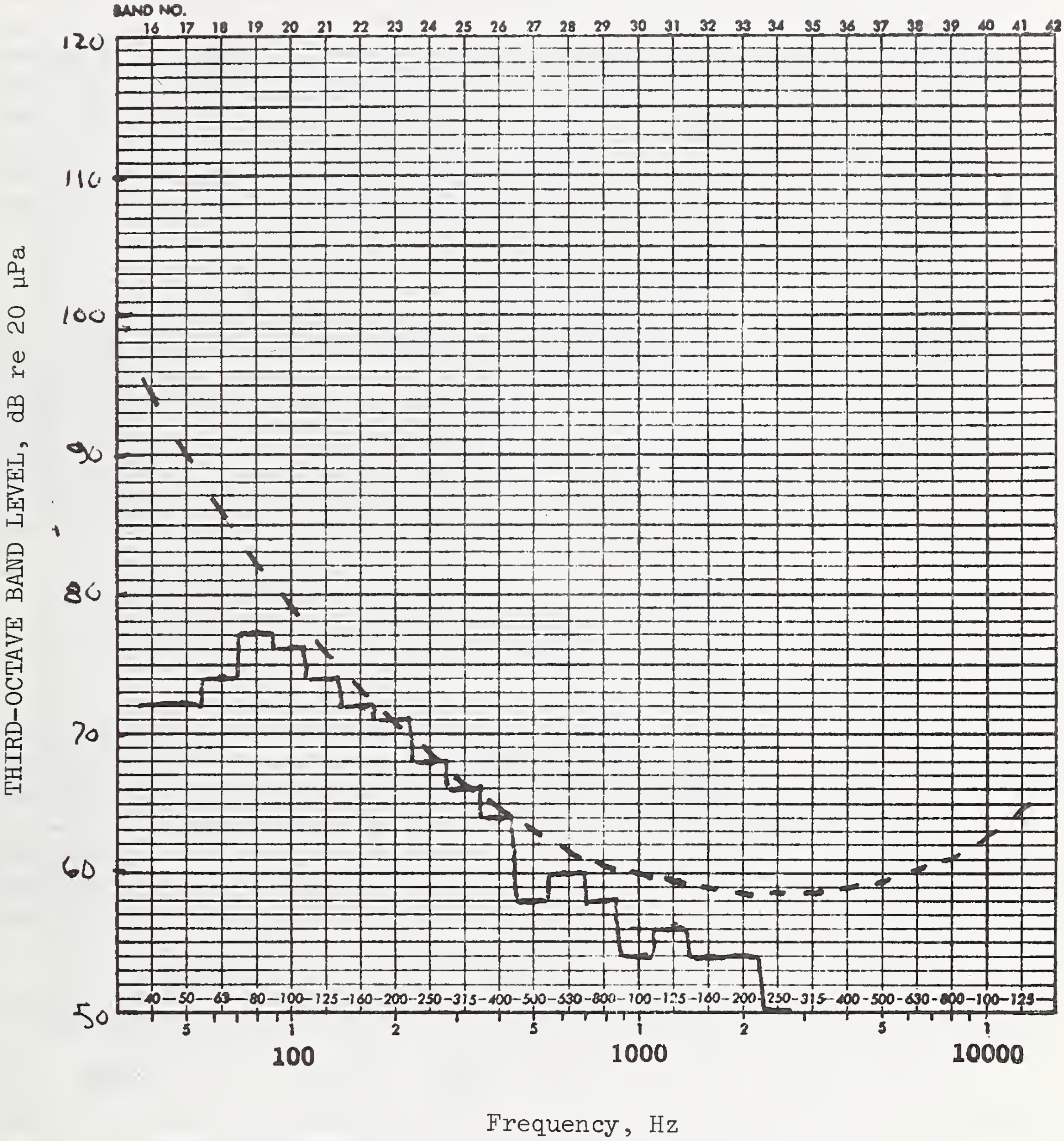
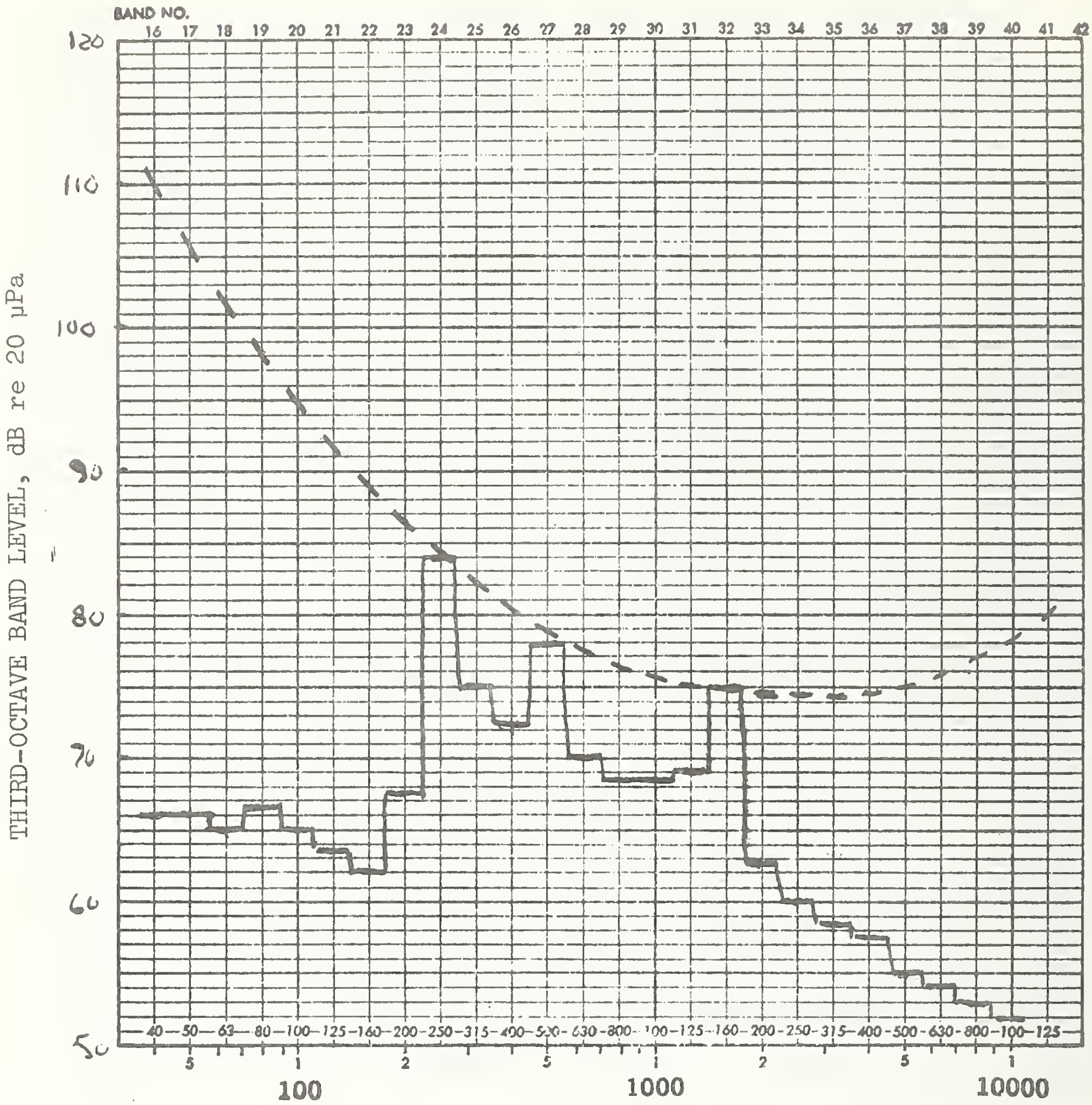


Figure 6. 330 cfm Silenced, (engine unidentified), Reciprocating Compressor (7 meter Measurement)[11].



Frequency, Hz

Figure 7. 750 cfm, Silenced, Diesel Powered, Rotary Screw Compressor (7 meter Measurement)[11].

We conclude at this point that A-weighted sound level is an adequate predictor of community noise for "regular spectra" of internal combustion engine noise, but that some additional measure of low frequency noise levels may be required in the future in order to adequately protect public welfare. C-weighted level could provide this latter measure, since it is also the only single scale which is available on standardized instruments which adequately reflects sound levels in this low frequency region. The lack of suitable correlation of community response with C-weighted level alone[12] is the reason that measurement of C-weighted level is not included at this time. Further research is required in order to quantify community response to low frequency noise and evaluate the validity of various objective measures of this noise.

2.4. Discussion of Accuracy and Precision

The proposed methodology is intended to provide a measure of A-weighted sound power radiated to the far field. The estimated precision (one standard deviation) of the measurement methodology using eight measurement positions is ±1.7 decibels with respect to A-weighted power of the same source determined under laboratory conditions utilizing a large number of measurement positions and laboratory grade equipment[8]. The principal sources of inaccuracy of the field measurement are attributed to:

(a) instrument tolerances

(b) sound field sampling error.

The instrument tolerances for American National Standard S1.4-1971 (Specification for Sound Level Meters) Type 1 precision instruments, as required by the measurement methodology, are no more than ±1 dB for measurement of A-weighted sound level at any given frequency from 50 to 4000 Hz. This uncertainty, coupled with the ±0.5 dB uncertainty for the calibrator, produced the principal sources of instrument error in the measurement, as well as the principal source of imprecision when different instrumentation systems are used.

If the measurement methodology uses five measurement positions, the overall measurement imprecision is expected to increase to about 2.4 dB.

The overall estimated standard error (one standard deviation) of the recommended methodology (i.e., reproducibility of measurement using different observers, test sites and instrumentation, but sources with the same sound power output) is estimated (on the basis of limited experience with similar measurements, assuming normal distributions of all variables and ignoring truncation error) to be on the order of 2 dB with 95% confidence[8]. (That is, 68% of the measurements on a given source are expected to be within ±2 dB of each other with a 95% level of confidence in the value 2. Similarly 95% of the measurements will lie within ±4 dB.) If the number of sample points for sound pressure level measurement is reduced to five measurement positions, the estimate of standard error of the methodology will increase to 2.7 dB (one standard deviation). (That is to say 68% of the measurements will lie within ±2.7 dB with 95% confidence.)

3. REVIEW OF METHODOLOGY

In the following paragraphs, we will discuss individual sections of the methodology in the order of their appearance in Section 4, and identify the rationale behind detailed decisions that have not been discussed under previous more general headings.

a. Acoustic Environment. Requirements for acoustic environment for the measurements are derived from presently accepted national and international measurement standards [2, 3, 5, 6]. The requirements for outdoor measurements are based on reasonable considerations of contributions from reflections in the context of the accuracy requirements outlined earlier. No indoor measurement qualification procedure is provided, since procedures presently being considered have serious defects, and no new procedure could be developed within the time constraints of this program. Such a procedure would be highly desirable, since indoor testing would eliminate weather restrictions. The outdoor site, used for tests by NBS[8], was checked using one proposed indoor site qualification procedure[6], which resulted in a calculated correction of more than 2.5 dB when in fact none was required. Because of such problems, we believe considerable further study is required before indoor testing for regulatory purposes with an environmental correction, can be considered. Since the facilities required to test indoors without a correction are much more expensive than is believed to be justifiable, this matter has not been pursued further. (The acoustic treatment alone, for one such test facility, suitable to frequencies as low as say 50 Hz, is estimated to cost in the region of $250k-500k, which is more than the estimated cost of research needed to fully clarify the correction problem.)

b. Instrumentation. The instrument specifications are derived from a minimum required performance to achieve desired accuracy. More sophisticated or faster systems involving multiple microphone arrays and/or computerized data reduction may also be implemented within this specification.

c. Source Operation. These requirements are derived from present standards for these devices, [2, 3] and are necessary to assure a reproducible measurement.

d. Measurement Procedures. The measurement procedure described here is adapted, with very minor improvements, from the currently proposed ISO Draft International Standard[6]. Based on our experimental data[8], this methodology offers the maximum precision and minimum bias for total measurement effort expended. Reducing the number of measurement positions from eight (as used here) to five as suggested for some survey class measurements significantly increases the estimated 95% confidence interval for the measurements from on the order of ±4 dB to ±5.5 dB (two standard deviations).

The modifications include small changes in the heights of the lower microphone positions to bring the microphone height closer to the center of the area it is intended to sample, thereby reducing the potential of correlation between the measurement points. The specification of the height of the upper microphone positions are changed to bring them onto the measurement surface.

No vertical traverse of the microphone at a measurement position has been incorporated, since it is believed, based on the experimental data, that the interference pattern arising from ground reflections is not as significant at small measurement distances from the source. At large distances from the source, such traversing is believed to be necessary to maintain the same level of precision with a given number of measurement positions.

The precision estimates for the methodology are based on the assumption that the variation in the sound level with position on the measurement surface will be comparable in magnitude or less than that for the sample group of compressors. The requirement for additional measurement positions has thus been added for cases where the variance is large in order to maintain the precision of the measurement. This requirement for additional positions is only expected to be significant for some large compressors, however, none of the seventeen compressors measured in a previous study[8] exceeded this requirement.

e. Information to be Recorded. The data included as line items in the tables are believed to be those which are both necessary and sufficient to insure reproducibility of a given measurement at another time within the above precision limits. Note that the tables are provided as a guide only, and are not in any way intended to be specific recording formats.

f. Calculation Procedures. The calculation procedures described are straightforward applications of the intended measurement. The included corrections for barometric pressure and temperature are not required for measurement on a standard day at altitudes below 1 km, as defined by the pressure and temperature range in section 4.9, but are included to anticipate the potential variations implicit in application of the methodology throughout the world. The reference conditions are those which produce an acoustic impedance in air (ρc) equal to 400 MKS Rayls $\pm$ 10% ($\pm$0.5 dB).

The expression used in the equation for computation of measurement surface area is exact. The following approximate expression, given in a draft ISO Standard, may be found to be computationally more convenient than the equation used

$$S' = 4(ab + ac + bc)\frac{(a + b + c)}{(a + b + c + 2r)}$$

where a, b, c and r are as defined in Table I. The expression gives a value which is always larger than the true value, by an amount which varies from 0 at $r = 0$, up to +15% (0.6 dB) at large r. The error for $r \approx$ 1 meter and a, b, c comparable with typical compressor dimensions is on the order of +8% (0.3 dB).

In view of the number of questions that have been raised concerning the potential difficulties with calculating sound power level, the following example is included.

Example computation of sound power, using the proposed methodology (Data taken from test 9 of reference 11).

A compressor is measured on a surface of one metre distance from the source.

The physical size of the compressor is 3.66 m long by 1.82 m wide by 2.14 m high. Test conditions are 25°C, 755 mm Hg. The coordinates of the measurement positions are as follows (r = 1m)

$$a = (\frac{\ell}{2} + r) = 2.8 \text{ m}, \quad \frac{a}{2} = 1.4 \text{ m}$$

$$b = (\frac{w}{2} + r) = 1.9 \text{ m}$$

$$c = (h + r) = 3.1 \text{ m}$$

$$h_1 = \frac{1}{2}(a + b - r/2) = 2.1 \text{ m}$$

$$a_1 = \frac{1}{2}(a + r/2) = 1.7 \text{ m} \quad (\text{less than } \ell/2)$$

$$b_1 = \frac{1}{2}(b + c/2) = 1.7 \text{ m} \quad (\text{less than } b)$$

The measured A-weighted sound level at the eight measurement positions were found to be (rounded to the nearest half dB):

Position	1	2	3	4	5	6	7	8
Source Sound level (dB)	79.5	78.5	76.5	78.5	79.5	77.5	76.5	79.5
Background Sound level	50	51	48	57	49	35	51	51
Mean square pressure(pascals)^2 (from Table IV)	.036	.028	.018	.028	.036	.023	.018	.036

Since the spread of the source data is less than 9 dB, only eight positions were required according to the methodology.

The background noise was found to be negligible (more than 10 dB below the measured levels). The sound levels were converted to mean square pressure using Table IV. In using Table IV, all the data were noted to be in the range 74 to 80 dB. The upper portion of Table IV shows that the mean square pressure should be in the range 0.01 to 0.04 (pascals)^2. The lower (expanded) scale permits easy, accurate interpolation to find values more precisely.

If equation 1[4/] had been used to calculate the values (very easily handled with a pocket calculator that includes log and power (x^y) functions), the calculation would go as follows:

[4/] Equation numbers refer to the equations given in Section 4.9 Calculation Procedures.

$$p(1) = 10^{(79.5/10)-9.4} = 10^{7.95-9.4} = 10^{-1.45}$$

$$= 0.0354813389$$

with similar simple calculations for the remaining values.

Averaging (adding up and dividing by eight) gives:

$$p_{avg} = \frac{p(i)}{n} = \frac{.223}{8} = .028$$

The measurement surface area is calculated from equation (3) as follows.

$$\begin{aligned} S &= 2(3.66)(2.14) + 2(1.82)(2.14) + (3.66)(1.82) \\ &\quad + \pi(1)(2(2.14) + 3.66 + 1.82) + 2\pi(1)^2 \\ &= 67.06 \text{ sq. meters.} \end{aligned}$$

The sound power is computed from equation (4). Since temperature and barometric pressure are within the acceptable range, the value of C is unity and

$$\begin{aligned} W &= 2.5\ (1)(67.06)(0.028) \\ &= 4.69 \text{ milliwatts} \end{aligned}$$

The sound power level from equation (5) is

$$\begin{aligned} L_w &= 10 \text{ Log } (4.69 + 90) \\ &= 6.74 + 90 \\ &= 97 \text{ dB} \end{aligned}$$

rounded to the nearest dB. This number is expected to be within ±4.0 dB of the true sound power with 95% confidence. An independent, more accurate measurement gave L_w equals 98.7 dB.

If the compressor rating were in terms of average sound level at ten metres from the center of the source, this could be computed using equation (6).

$$\begin{aligned} L_p(r) &= 97 - 8 - 20 \text{ Log } 10 \\ &= 97 - 8 - 20 \\ &= 69 \text{ dB.} \end{aligned}$$

4. PORTABLE AIR COMPRESSOR MEASUREMENT METHODOLOGY

4.1. Purpose and Applicability

This measurement methodology defines an acceptable procedure by which the noise from portable air compressors may be measured to ascertain whether the noise emitted is in compliance with the noise emission standards promulgated by the U. S. Environmental Protection Agency pursuant to Section 6 of the Noise Control Act of 1972 (Public Law 92-574). The method is applicable to air compressors of a portable type intended for outdoor use. The measurement method provides for the determination of the A-weighted sound power output of the device in the free-field over a reflecting plane based on A-weighted sound level (SPL) measurements determined on a measurement surface one metre from the surface of the machine.

4.2. References

The following standards are referenced within this methodology.

a. American National Standard S1.4-1971 "Specifications for Sound Level Meters".

b. International Electrotechnical Commission Publication 179, "Precision Sound Level Meters".

c. American National Standard S1.2-1962 "The Physical Measurement of Sound".

d. American National Standard S1.1-1966 "Specifications for Octave Half Octave and One-third Octave Filters".

e. American National Standard S1.13-1971 "Methods for the Measurement of Sound Pressure Levels".

4.3. Measurement Uncertainty

The achievable uncertainty for a measurement of A-weighted sound power level of a portable air compressor according to this methodology using commercially available instrumentation meeting the requirements of Section 4.5 is estimated to be a precision of 2 dB (one standard deviation with 95% level of confidence) with negligible bias.

4.4. Acoustic Environment

a. General Requirements

The test site shall be such that the compressor radiates sound into a free field over a reflecting plane. This condition may be considered fulfilled if the test site consists of an open space free of large reflecting surfaces within the distances specified below from any microphone position or equipment location (See 4.2(b)). The minimum measurement area shall consist of a circular, flat, hard surface which extends from the source at least 1 meter beyond the most distant measurement point (see Section 4.5.2, Microphone Positions).

b. Criteria for Adequacy of the Environment

1. Reflecting plane. The reflecting plane shall be flat (±0.1 meters), and of smooth concrete or sealed asphalt, or other hard material. Materials other than concrete or sealed asphalt shall have normal incidence absorption coefficient of less than 0.06 over the frequency range 20 Hz to 10 kHz.

2. Outdoor measurement. No large reflecting surface such as a signboard, building, hillside, trees, etc. shall be located within 10 meters of a microphone position or source location.

c. Ambient Noise

It is strongly preferred that the background ambient noise at the test site shall be more than ten decibels below the A-weighted sound levels of the unit under test, especially if the noise is fluctuating. In no case shall a site be used in which the maximum background ambient noise is within four decibels of the levels to be measured. The background ambient noise shall be recorded before the start of the test. In the event that the average ambient background noise is within ten decibels of the measured sound levels, the ambient background noise after the test shall be recorded, and the smaller of the before and after levels shall be included in the calculation of sound power.

See also Section 4.6.(a) for ambient noise from sources other than the compressor during compressor operation.

d. Other Ambient Factors

The temperature and barometric pressure at the time and place of the test shall be recorded for reference purposes. No measurements shall be taken when the wind speed exceeds 5 m/s (12 mph). (See paragraph 4.5(a) for windscreen requirements.)

4.5. Instrumentation

a. General Requirements

The measurement system used shall conform to the requirements of American National Standard S1.13 "Methods for the Measurement of Sound Pressure Levels", Section 5, Field Method, except that the sound level meter or equivalent instrumentation shall meet the frequency response requirements of a Type 1 meter as stated in American National Standard S1.4-1971 "Specifications for Sound Level Meters" over the frequency range 50 Hz - 10,000 Hz. A windscreen shall be used when the average wind noise is within 20 dB of the levels to be measured. The windscreen shall not affect the measured

A-weighted sound levels from the noise source in excess of ±0.5 dB. This may be experimentally evaluated by comparing the measured A-weighted sound level with and without the windscreen, at a position close enough to the source that wind noise is not a factor.

b. Additional Instrumentation Requirements

a) A sound level calibrator accurate within ±0.5 dB.

b) An anemometer or other device for measurement of ambient wind speed and direction accurate within 10% at 5 m/sec.

c) An engine speed indicator, accurate within ±2%.

d) An air pressure guage, accurate within ±5%.

e) A thermometer for measurement of ambient temperature accurate within ±1°C.

f) A barometer for measurement of ambient pressure accurate within ±1%.

4.6. Installation and Operation of the Source

a. Source Operation

The machine under test shall be operated continuously at design full speed with the compressor on load, delivering its rated airflow and pressure. The compressed air discharge should be piped clear of the test area or fed into an effective silencer. The air discharge line shall be provided with a throttling device remote from the compressor such that no significant pressure drop need be maintained at the compressor air distribution valve(s). The sound level from the compressed air discharge shall be at least 10 dB. below the machine sound level at all microphone positions. All cooling air vents in the engine/compressor enclosure shall be full open during all sound level measurements. Service doors that should be closed during normal operation (at any and all ambient temperatures) shall be closed during all sound level measurements.

All sound level measurements reported shall be obtained after the machine is operating at normal engine temperature.

b. Source Monitoring

The compressor speed and air discharge pressure shall be monitored and recorded at the beginning and at the completion of the sound level tests.

4.7. Measurement Procedure

a. Microphone Positions

The measurements are made at eight positions on a measurement surface which is a uniform distance from the reference surface. The reference surface is the smallest hypothetical rectangular box of dimensions L x W x H with top surface parallel to the reflecting plane which encloses the source. The minimum number of measurement positions shall be eight, including one near the center of each of the four sides of the source and four above the top of the source near the corners of the measurement surface. The coordinates of these positions are given in Table I. The measurement positions are shown in Figure 4.1. Note the height for positions 5 to 8 is determined by the requirement that the distance from the closest point on the reference surface to the measurement point is equal to the measurement distance r.

Accuracy of microphone positioning with respect to the reference surface shall be r ± 0.1 m. Accuracy of microphone positioning on the measurement surface shall be within 0.2 r of the position defined by the three coordinates of Table I.

The minimum allowable value for r to be used shall be 0.75 m. The preferred value of r is 1.0 m. The maximum allowable value for r shall be that value which is consistent with background noise level and test site dimension requirements given in Section 4.4.

The microphone shall be oriented with respect to the measurement surface, in the manner which it is calibrated for optimum flat frequency response assuming that the direction of sound field propagation at each measurement location is perpendicular to the measurement surface at the measurement position. Observers shall be at least one meter away from the microphone, and r + 1 meters away from the measurement surface.

The time average A-weighted sound level using the "slow" response mode of the sound level meter shall be determined to a precision of ±0.5 dB at each measurement location with the compressor operating and the compressor off.

If the range of the eight sound-level values exceeds 8 dB for the operating compressor condition, additional sound level data shall be recorded at eight additional positions. The coordinates of the additional positions shall be as given in Table IA.

4.8 Information to be Recorded

The maximum steady observed A-weighted sound level using the slow response characteristic, shall be recorded for each measurement location to the nearest 0.5 dB.[5/] The average A-weighted background noise levels shall be recorded at all locations after the measurement, if within ten decibels of the measured value.

[5/] If levels are resolved to the nearest 0.1 dB, then levels in the range x.8 to y.2, shall be recorded as y.0; values in the range x.3 to x.7 shall be recorded as x.5 (y = x + 1).

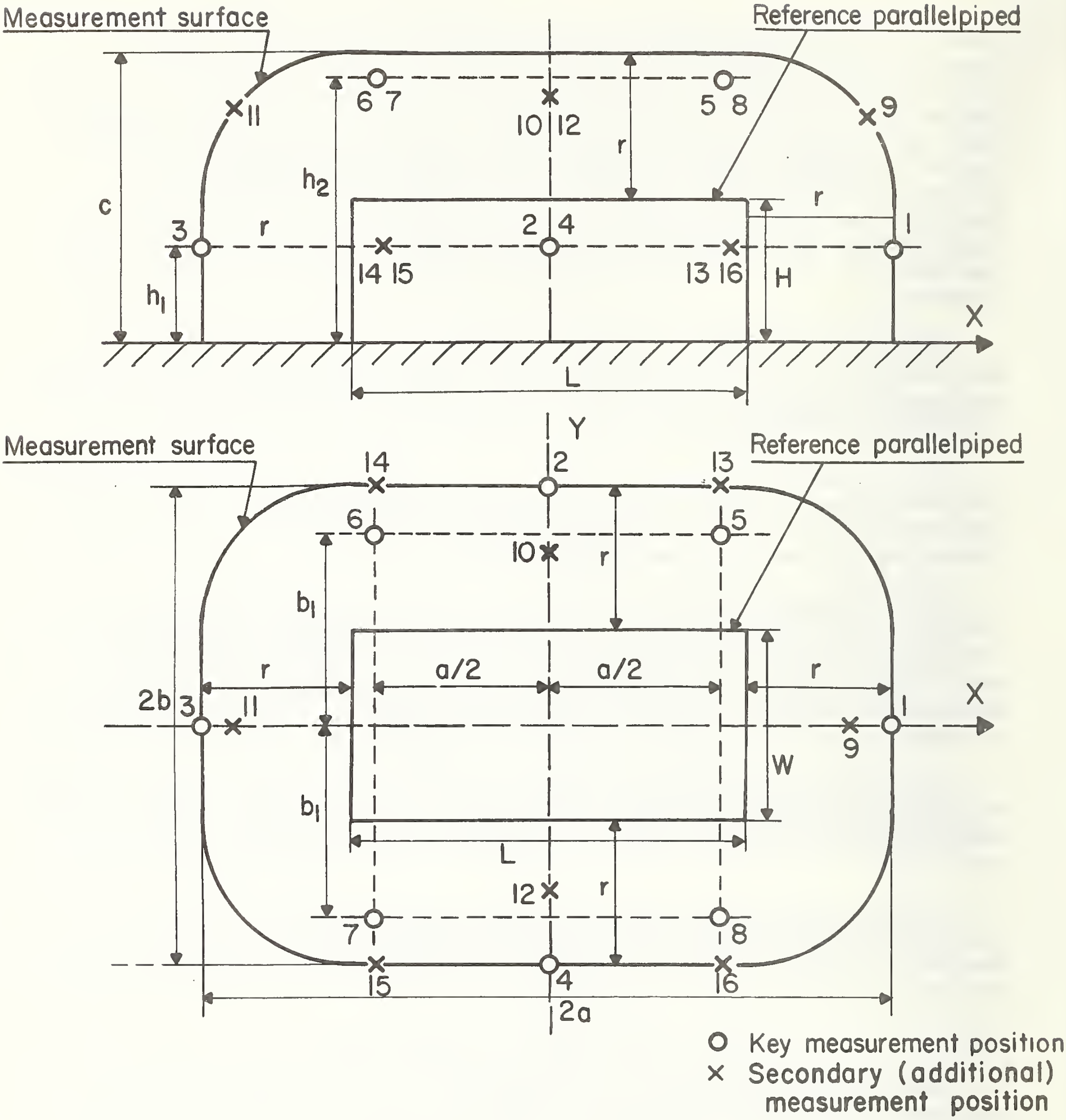


Figure 4.1. Location of measurement positions on the measurement surface.

TABLE I

Microphone Position Coordinates

Source reference surface dimensions are L, W, H.

$a = \frac{L}{2} + r$, $b = \frac{W}{2} + r$, $c = H + r$

$h_1 = \frac{1}{2}(a + b - \frac{r}{2})$, if h_1 is greater than H then take $h_1 = H$

$a_1 = \frac{1}{2}(a + \frac{r}{2})$, if a_1 is greater than $\frac{L}{2}$ then take $a_1 = L/2$

$b_1 = \frac{1}{2}(b + \frac{c}{2})$, if b_1 is greater than b then take $b_1 = b$

Position Number	X	Y	Z	Dist. from reference surface
1	a	0	h_1	r
2	0	b	h_1	r
3	-a	0	h_1	r
4	0	-b	h_1	r
5	a_1	b_1	greater than H	r
6	$-a_1$	b_1	greater than H	r
7	$-a_1$	$-b_1$	greater than H	r
8	a_1	$-b_1$	greater than H	r

Origin for the coordinate system is the point on the ground plane under the geometric center of the source.

TABLE IA

Coordinates of Additional Positions

Position Number	X	Y	Z	Distance from reference surface
9	a_2	0	greater than H	r
10	0	b_1	greater than H	r
11	$-a_2$	0	greater than H	r
12	0	$-b_1$	greater than H	r
13	a_1	b	h_1	r
14	$-a_1$	b	h_1	r
15	$-a_1$	-b	h_1	r
16	a_1	-b	h_1	r

$a_2 = \frac{1}{2}(a + \frac{c}{2})$, if a_2 is greater than a, then take $a_2 = a$

TABLE II

EXAMPLE DATA FORM FOR MEASUREMENT OF SOUND FROM PORTABLE AIR COMPRESSORS

Manufacturers Test Report No. __________ Date of Test __________

SUBJECT

Model: __________ Manufacturer: ______________ Serial No: __________
Rated Speed & Capacity: ______________________________
Description: ______________________________
Dimensions (ℓ,w,h) ______________________________

TEST CONDITIONS:

Manufacturers Test Site Identification ______________________________
Test Radius (r) for Measurement: ______________________________ meters
Distance from Observer to Microphone: ______________________________ meters
Operating Speed as Tested: (Beginning) ____rpm
(End of test) _____rpm
Reflecting Plane Composition: ______________________________
Ambient Temperature: ______°C
Ambient Maximum Wind Speed During Sound Level Measurements: _______km/h
Wind Direction (see Sketch Following Page): ______________________
Atmospheric pressure: ______________________________mmHg
Remarks: ______________________________
____

INSTRUMENTATION:

Microphone: ______________________________ Ser. No. __________
Sound Level Meter: ______________________________ Ser. No. __________
Calibrator: ______________________________ Ser. No. __________
Other: ______________________________ Ser. No. __________

SOUND LEVEL DATA

A-weighted Sound Level (dB re 2 x 10^{-5} pascal)

		Position							
		1	2	3	4	5	6	7	8
Full Load Condition	Pos 1-8								
	Pos 9-16								
Background (compressor off)	Before (pos 1-8)								
	After (pos 1-8)								

Tested by ______________________ Date ______________________

Sketch: Indicate source orientation, wind direction,

Computed Measurement Location Coordinates

$a = (L/2 + r)$ ________ meters

$b = (W/2 + r)$ ________ meters

$c = (H + r)$ ________ meters

observed value of height for positions 5-8 ________meters

observed value of height for positions 13-16 ______meters

$h_1 = (\frac{1}{2}(a + b - \frac{r}{2}))$ _____ meters (Not greater than H)

$a_1 = (\frac{1}{2}(a + \frac{r}{2}))$ ________ meters (Not greater than L/2)

$b_1 = (\frac{1}{2}(b + \frac{c}{2}))$ ________ meters (Not greater than b)

$a_2 = (\frac{1}{2}(a + \frac{c}{2}))$ ________ meters (Not greater than a)

The additional data identified in Table II shall be recorded.

A calibration history of all equipment used, meeting the requirements of American National Standard S1.13-1971, Section 5 shall be maintained.

4.9. Calculation Procedures

The average A-weighted sound level on the measurement surface, and the A-weighted sound power level shall be computed in a manner similar to that shown in Table III. Use of the specific format shown is not required.

The steps of the computation of sound power level are as follows.

(1) Determine the corrected sound pressure (or pressure level).

(2) Compute the average mean square pressure for the measurement surface.

(3) Compute the area of the measurement surface.

(4) Compute the sound power for the measurement surface from the product of the mean square pressure and the area of the surface.

(5) Compute the sound power level from the logarithm of the sound power.

The equations which may be used for this calculation are shown below.

(1) <u>Corrected sound pressure.</u>

The corrected mean square sound pressure at a measurement position may be calculated using the following equation.

$$p(i) = 10^{((L_p(i)/10)-9.4)} - 10^{((L_p'(i)/10)-9.4)} \qquad (1)$$

where $p(i)$ is the mean square pressure at position i (pascals^2)

$L_p(i)$ is the sound level of the source with background noise at position i (dB)

$L'_p(i)$ is the sound pressure level of the background noise at position i (dB).

(Table IV may be used to convert pressure level to squared pressure.)

If the background noise sound level at a position is more than ten decibels below the source sound level then the correction will be negligible.

(2) Average sound pressure.

The average mean square sound pressure (P) may be calculated from the equation

$$P = \frac{(P(1) + P(2) + \ldots + P(n))}{N}$$

(3) Measurement surface area.

The measurement surface area is calculated using the equation:

$$S = 2\,LH + 2\,WH + LW + \pi r\,(2H + L + W) + 2\pi r^2$$

where S is the area of the measurement surface (square meters)

L,W,H are the source reference surface length, width and height respectively (metres)

r is the distance from the source to the measurement surface (metres)

(4) Sound power.

The sound power is computed from the equation

$$W = 2.5 \times C \times S \times P_{avg}$$

where W is the sound power (milliwatts)

C is the value of $\frac{400}{\rho c}$.

where ρ is the density of air at the time of the test (kg/m^3) and c is

the speed of sound in the air at the time of the test (m/s). (See note below.)

S is the measurement surface area from eq. 3.

P is the average sound pressure from eq. 2.

Note: If the test temperature is in the range -15°C to 40°C and the barometric pressure at the test site is in the range 680 - 780 mm Hg the value for C shall be taken as 1.

Outside this range the following expression shall be used for C.

$$C = \frac{740}{B}\left(1 + \frac{T-20}{586}\right)$$

Where B is the barometric pressure (mm Hg)

T is the air temperature (degrees Celsius)

(5) Sound power level.

The sound power level is calculated from

$$L_w = 10 \text{ Log}_{10} W + 90$$

L_w is the sound power level (dB re 10^{-12} watt)

W is the sound power (mW), from eq. 4.

The sound power level shall be rounded to the nearest dB.

(6) Average sound level.

The average sound level at any distance from the center of the source over a reflecting plane (with no nearby vertical reflecting surfaces) may be computed from:

$$L_p(R) = L_w - 8 - 20 \text{ LogR dB}$$

R Is the distance from the center of the source (meters).

TABLE III

EXAMPLE FORM FOR SOUND POWER CALCULATION FOR NEAR FIELD MEASUREMENTS

Manufacturers Test No. ____________ Test Date ____________________

Machine Identification ____

1. Test source dimensions L ____________m

W ____________m

H ____________m

2. Test radius (r) ____________m

3. Test surface area $S = (2LH + 2\ WH + LW + \pi r\ (2H + L + W) + 2\ \pi r^2)$ ____________m^2

4. Barometric Pressure (B) ____________mmHg

5. Temperature (T) ____________C°

6. Number of measurement positions n____________

7. Average A-weighted Sound Pressure

Position	A-weighted SPL (dB)		A-weighted $(\text{Sound Pressure})^2$		Corrected $(\text{Sound Pressure})^2$
	(1) Source On	(2) Source Off	(3) Source On	(4) Source Off	(3) - (4)
1					
2					
3					
4					
5					
6					
7					
8					

8. Sum of $(\text{Sound Pressure})^2$ position 9-16 (Enclose table)

9. Sum of $(\text{Sound Pressure})^2$ (sum of table plus Line 8)

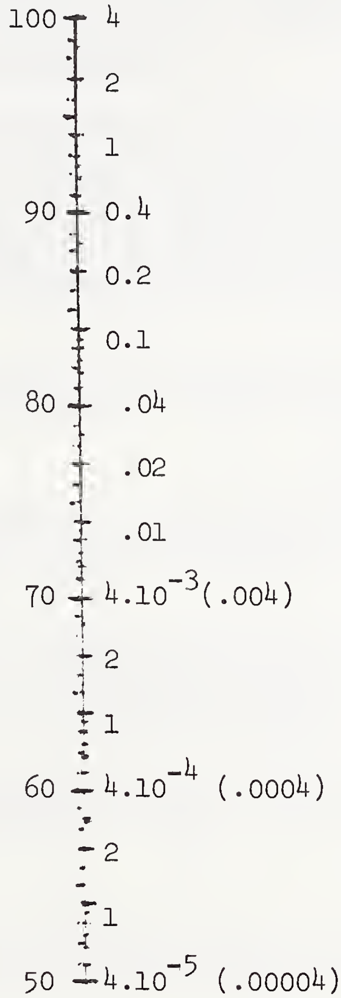
10. $\overline{P}_A^2$ = Average Sound Pressure (line 5 divided by n)

TABLE IV

CONVERSION OF WEIGHTED SOUND PRESSURE LEVEL TO SQUARED SOUND PRESSURE $(\text{pascal})^2$

A solution of the equation: $P_{avg} = 10^{(Lp/10)-9.4)} (\text{pascal})^2$

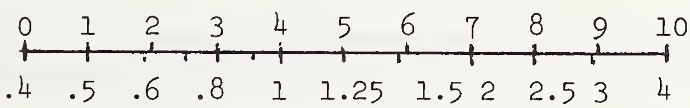
PRESSURE LEVEL (dB)



SQUARED PRESSURE $(\text{pascal})^2$

EXPANDED SCALE (TYPICAL FOR ALL 10 dB INTERVALS)

PRESSURE LEVEL



SQUARED PRESSURE

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NAME	ORGANIZATION
Mr. Harry Baker	Worthington CEI, Inc.
Mr. George M. Diehl	Ingersoll-Rand Co.
Mr. R. S. Geney	Atlas Copco, Inc.
Mr. L. T. Hayes	Schramm Inc.
Mr. F. Wm. Heckenkamp	Gardner-Denver Co.
Mr. F. M. Kessler	Dames & Moore
Mr. Richard Ostwald	Gordon Smith Co.

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[3] American National Standard Test Code for the Measurement of Sound from Pneumatic Equipment, S5.1-1971 (American National Standards Institute, New York, New York, 1971); International Organization for Standardization Recommendation for the Measurement of Airborne Noise Emitted by Compressor/Primemover Units Intended for Outdoor Use, R2151-1972 (American National Standards Institute, New York, New York, 1972).

[4] Work by International Organization for Standardization Technical Committee 43 (Acoustics)/ Subcommittee 1 (Noise)/Working Group 9 (Pneumatic Equipment).

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APPENDIX A

PROCEDURE FOR PREDICTING A-WEIGHTED SOUND LEVEL FROM A-WEIGHTED SOUND POWER

A.I. Introduction

This appendix is intended as a guide for users to estimate the A-weighted sound level to be expected from a portable air compressor in practical situations under rated operating conditions. The following applications are considered: (1) estimating the A-weighted sound level at various distances from a portable air compressor operating in a relatively open area, (2) estimating the A-weighted sound level at various distances from a portable air compressor operating in a confined space, such as in an alley or on a street between tall buildings, and (3) estimating the effective A-weighted sound level reduction due to introducing a "noise shield" or barrier wall between the portable air compressor and the observer. This appendix is only concerned with the relative A-weighted sound level contribution from one specific source. To determine the total A-weighted sound level from multiple sound sources, refer to American National Standard S1.2-1962.

A.II. Sound Level Decrease With Distance

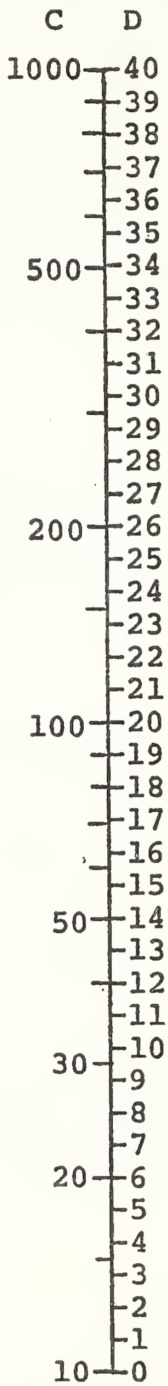
The following procedure is to be used for estimating the A-weighted sound level from the geometric center of a portable air compressor, operating under rated conditions more than ten meters (33 feet) away. For this situation it is assumed that the area including both the portable air compressor and the observer is relatively free of large sound reflecting surfaces (except the ground), such as buildings or berms, and there is a direct line of sight from the observer to the air compressor.

From the A-weighted sound power level of the source (A), determine the corresponding A-weighted sound level for the reference distance of 10 meters (B), by subtracting 28 dB from (A).	A ________ dB -28 dB B ________ dB
Measure the direct distance from the geometric center of the air compressor to the observer (in meters)	C: ________ m
Using Nomogram No. 1 read the corresponding sound level correction	D: ________ dB
Subtract the value found in Step D from that found in Step B.	X: ________ dB

The final result above assumes no excess sound attenuation due to atmospheric conditions which may affect the actual A-weighted sound level at distances greater than about 100 meters (330 feet).

NOMOGRAM NO. 1

A-WEIGHTED SOUND LEVEL DECREASE WITH DISTANCE

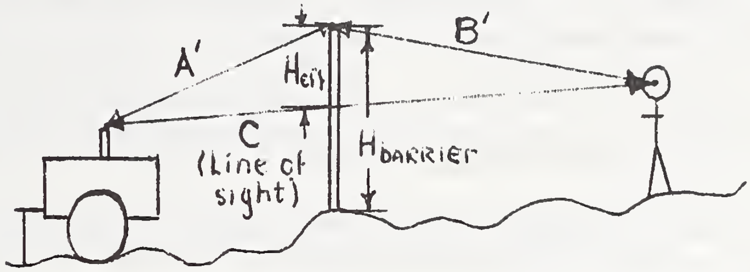


C: Distance From Center of Air Compressor in Meters

D: A-weighted Sound Level Reduction (dB)

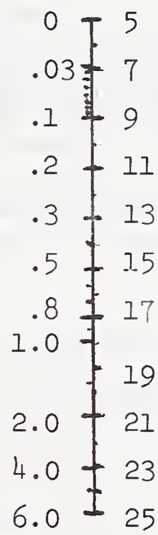
NOMOGRAM NO. 2

APPROXIMATE SOUND LEVEL ATTENUATION USING A BARRIER



P = PATH LENGTH DIFFERENCE) = A' + B' - C (Meters)

P. PATH LENGTH DIFFERENCE (METERS) (MULTIPLY BY 3.3 TO OBTAIN P IN FEET)



G. A-WEIGHTED SOUND LEVEL DECREASE DUE TO BARRIER ATTENUATION (dB).

PRACTICAL LIMIT OF BARRIER ATTENUATION

A.III. Sound Level Reduction From Barriers

The following procedure can be used for estimating the minimum attenuation due to a barrier, or the height of a barrier to be constructed, or the distance the portable air compressor or observer must be from a barrier to achieve a specified A-weighted sound level reduction. (The A-weighted spectrum of the operating compressor is assumed to have maximum energy near or above 500 Hz for this noise reduction estimating procedure.) The length of the barrier is assumed to be at least two times the barrier height or two times the largest compressor (source) dimension, whichever is greater.

A. To determine the attenuation for a given barrier height and compressor location, we must determine the effective path length for sound propagation over the barrier.

The effective height of the barrier is the height of the top of the barrier above the line of sight from the top of the compressor to the observer. The barrier changes the sound level by blocking the sound and forcing the sound to "bend around" the top of the barrier. The amount of bending is measured by the "path length difference" (P) between the direct path (if there was no barrier) and the distance along the shortest path over the top of the barrier. If the compressor and the observer have approximately the same elevation, then a rough estimate of the path length difference is calculated by:

Measuring the height of the barrier above the top of the compressor H________m

Determining the longer of the distance from the barrier to the compressor or barrier to the observer R________m

Calculate $P = H \times H/R$ P________m

If the compressor and observer are on significantly different elevations, then the simplest method is to make a scale sketch of a section showing the top of the compressor, top of the barrier and the observer, and measuring the dimensions A', B', and C indicated in the nomogram. P is simply computed from these dimensions.

With the value of P, the nomogram is entered to find the A-weighted level difference (G). The sound level with the barrier is then

A-weighted sound level at observer = X - G = ______ dB

Note that the barrier provides some attenuation even if it just meets the line of sight (but this attenuation reduces rapidly toward zero within a short distance above the barrier).

B. To determine the height of a barrier to be constructed to achieve a given A-weighted sound level reduction:

Measure the compressor to barrier distance in meters or the observer to barrier distance and enter whichever is larger __________m

Note the desired A-weighted reduction ________dB

Note the path length difference indicated for the desired level reduction P________m

Enter the line of sight distance C________m

Estimate the effective height of the barrier Heff = C x P/2 Heff ________m

Estimate the elevation of the line of site (H_{ls}) above the ground at the proposed barrier site. (Use scale sketch if necessary) H_{es}________m

The total height of the barrier is $H_{eff} + H_{ls}$ = ________m

This is the total barrier height necessary to achieve the desired "A-weighted reduction" assuming no other large sound reflecting surfaces in the vicinity of the compressor.

The value of H_{eff} is the approximate maximum height required if the barrier is midway between the compressor and observer. To check the result, perform the calculation described in A above.

The above procedure for predicting noise reduction effectiveness of a barrier placed near a compressor assumes that both the compressor and the observer are in a relatively open, level area. In many practical situations this is not the case and the effectiveness of the barrier will be somewhat reduced because of sound reflecting off of other surfaces. Also, if the A-weighted sound level reaching the observer before installation of a barrier is determined by low frequencies (such as the fundamental firing rate of the engine) due to an inadequate or poorly maintained compressor engine muffler the barrier will provide less A-weighted reduction.

A.IV. Summary

This appendix is a simplified application guide for estimating noise level from sound power rated portable air compressors. The guide can prove very useful for determining whether the sound level of the compressor is in compliance with local or state noise control regulations. Alternately, the guide may be used to determine what techniques are available to the user of a portable air compressor for reducing the compressor sound level exposure at specific locations of interest.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)* This report presents recommendations and supporting rationale on a measurement methodology for portable air compressors. The methodology provides for the determination of A-weighted sound power level or the equivalent weighted sound pressure level at a reference distance. A-weighted level is used because of its correlation with community response to noise from internal combustion engine noise. It is recommended, however, that the spectra associated with the regulated source be monitored in some manner to insure that the spectra remain similar to those for which A-weighted sound level retains good correlation with community response. The methodology uses weighted sound level measurements at eight positions on a curved surface surrounding the source at a distance of one metre from the surface of the machine. Data recorded at these positions are used to calculate the average weighted sound pressure level of the machine on the measurement surface. This is combined with the area of the measurement surface. This is combined with the area of the measurement surface to give the sound power level of the machine. From this value, a rating sound pressure at a rating distance may be calculated by subtracting a constant value. Procedures which permit the rapid estimation of A-weighted sound level are included. These are applicable for estimation of A-weighted sound level in a variety of circumstances when the sound power or equivalent sound pressure level at a reference distance is known.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*
Acoustics; air compressor; internal combustion engine; noise; sound power level; sound pressure level.

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