The Engineering Society For Advancing Mobility Land Sea Air and Space®

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SAE J1805 APR87

Sound Power Level Measurements — Earthmoving Machinery (Dozer, Loader, Excavator, and Backhoe) — In Place Dynamic — Sound Pressure Level or Sound Intensity Method

SAE Recommended Practice
Issued April 1987

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
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OFF-HIGHWAY MACHINERY PRACTICE

SAE J1805

Issued April 1987

SOUND POWER LEVEL MEASUREMENTS - EARTHMOVING MACHINERY (DOZER, LOADER, EXCAVATOR, AND BACKHOE) - IN PLACE DYNAMIC - SOUND PRESSURE LEVEL OR SOUND INTENSITY METHOD

1. PURPOSE AND SCOPE:

1.1 Purpose: This draft procedure is to be used to determine the exterior A-weighted equivalent sound power level of static and in-place dynamic machines (dozer, loader, excavator, & backhoe) similar to the sound power obtained of unloaded moving machines described in ISO 6393 (static) and ISO/DIS 6395 (dynamic) sound power test procedures. Test instrumentation recommended includes conventional integrating sound pressure level methods or the two (paired) microphones sound intensity method (which permits measurement in the factory environment). This methodology provides a practical indoor alternative to the ISO procedures better suited to high volume conformance testing for machines powered by piston type internal combustion engines. This procedure assumes that the dominate sources are not highly sensitive to load (cooling fan, engine and track system). This test can be used as a substitute for the ISO 6393 (static) and ISO/DIS 6395 (dynamic) sound power tests for many machine types and at least a more repeatable measure for the remainder. The SAE J1372 JUN83, Sound Power Determination - Earthmoving Machinery - Static Condition test remains valid for only a static test, but it is not necessary to run SAE J1372 in addition to SAE J1805.

1.2 Scope: The requirements for setting up and operating the machinery, the microphone array and hemispherical measurement surface are given in this document. This document shall be used in conjunction with manufacturer's recommendations pending finalization of ANSI documents on the subject of sound intensity procedures. The accompanying sound intensity procedure clarification is provided pending more widespread understanding of sound intensity.

2. INSTRUMENTATION:

2.1 The integrating sound pressure level system is to be used with a free field over reflecting plane (paragraph 3.1.1).

2.1.1 The integrating sound level meter must permit the determination of the value of the A-weighted sound pressure level, energy averaged, over a time period dependent on the machine test cycle.

2.1.2 Any alternate system in place of a meter must perform the same functions required in paragraph 2.1.1.

2.1.3 Whatever the type of instrumentation used, appropriate components of the measuring instrumentation system shall meet the Type 1 requirements given in the relevant clauses of IEC Publication 651-1979 and ANSI S1.4-1983 (R1985). Systems shall be qualified according to SAE J184 FEB87 for the frequency range of interest.

2.1.4 An acoustical calibrator for use in calibration prior to and after the test sequence (accuracy within ±0.5 dB(A) (paragraph 4.2.3).

2.1.5 A microphone windscreen should not be used except when it is required to reduce wind induced noise that is within 15 dB of the sound level of the source being measured. When a windscreen is used, it shall not affect the sound level of the source being measured by more than ±0.5 dB(A) under zero wind speed conditions.

2.2 The sound intensity measurement system (frequency response, linearity, A-weighting, and crest factor specifications) shall conform to the Type 1 requirements of ANSI S1.4-1983 (R1985) or of SAE J184 FEB87 for the frequency range of interest. (Until completion of the ANSI document, literature and software support from the major acoustic instrumentation manufacturers will aid in effective implementation of a sound intensity system.) The following is provided as only interim information.

2.2.1 A sound intensity system usually employs two closely spaced (paired) microphones, appropriate signal conditioning components and a computerized analysis system. The sound intensity probe has a measurement axis that passes through the diaphragm center of both microphones (whether positioned side-by-side or end-to-end).

The intensity measurement interprets the phase information from each channel to determine the cosine value of the sound intensity vector relative to the probe axis. Sound energy passing through each surface segment is then the product of the intensity vector and the measurement surface segment perpendicular to the probe axis.

The total sound power is the summation of the surface segments times their respective intensity vectors.

2.2.2 Microphone spacing determines the useful frequency range of interest. A nominal spacing of 20 mm (0.8 in) is suggested, but can be modified to better match the frequency characteristics of the machine being measured. (see Table 1).

Table 1 - Useable Frequency Range for Microphone Spacing

Microphone Spacing	Useable Frequency Range with Phase Mismatch 0.1 deg	0.3 deg
6 mm	50 Hz - 10000 Hz	200 Hz - 10000 Hz
12 mm	40 Hz - 5000 Hz	125 Hz - 5000 Hz
20 mm	30 Hz - 3500 Hz	100 Hz - 3500 Hz
50 mm	10 Hz - 1250 Hz	31 Hz - 1250 Hz

2.2.3 Low frequency bias errors caused by phase-mismatching of the two microphones may be reduced by:

2.2.3.1 <u>Phase Matched Instrumentation</u>: The phase error between the two channels shall be less than 0.5 deg (dependent on frequency - see B&K Technical Review No. 4 - 1985).

2.2.3.2 <u>Channel Switching</u>: Electrically or physically switching channels halfway through each measurement.

2.2.3.3 <u>On-Site Phase Calibration</u>: Apply a random noise signal in a close coupled chamber or standing wave tube (refer to manufacturers' recommendations) simultaneously to both channels. The intensity program then calculates the phase mismatch between channels and applies a correction to the data.

2.2.3.4 A combination of the above - paragraphs 2.2.4.1 and 2.2.4.2 or 2.2.4.3.

2.2.4 A-weighting for a sound intensity system shall be simply accomplished digitally on the calculated intensity vector frequency spectrum for data within the accuracy of standard industrial practice.

2.3 An anemometer or other device for use in measurement of ambient wind speed and direction [accuracy within ±10% at 20 km/h (12 mph)].

2.4 Power source (engine) speed indicator (accuracy within ±2% of the indicated reading).

2.5 A thermometer for measurement of ambient temperature [accuracy within ±1°C (±2°F)].

3. PROCEDURE:

3.1 Test Site: A non-absorbing reflecting plane is required.

3.1.1 For sound pressure level instrumentation, a free field is required above the reflecting plane. There shall be no sound reflecting obstacles within a distance from the source equal to three times the radius of the measuring hemisphere.

3.1.2 For sound intensity instrumentation the presence of reflecting objects is less critical, but no absorbing object or additional noise source other than the machine being measured will be inside the measurement surface. This system permits measurements in most factory environments.

3.2 Measurement Surface Size and Shape: Depends on the instrumentation selected and the machine dimensions.

3.2.1 For sound pressure level instrument systems the measurement surface is a hemisphere with the radius determined by the length of the main body of the basic machine structure, excluding major attachments such as dozer blades, buckets and booms. The radius (r) of the measurement hemisphere surface is given in Table 2 according the basic length(ℓ). Refer to SAE J1372 JUN83.

Table 2 - Hemisphere Radius Recommendation

Basic Length ℓ of the Machine	Radius of Hemispherical Measurement Surface
$\ell \leq 1.5$ m	4 m
1.5 m $< \ell \leq 4$ m	10 m
$\ell > 4$ m	16 m

As a guideline for larger machines, over 6.5 m, the hemisphere radius should be 2.5 times the length of the basic machine not including attachments.

3.2.2 For sound intensity systems rectangular and spherical surfaces are convenient for calculating surface segments and reproducibility. Though not required by this document, a hemispherical measurement surface is described to show the process and demonstrate the factors to be considered: perpendicular orientation of probe axis and the minimum number of surface segments. The measurement hemisphere radius should be large enough to enclose the machine and its moving attachments. A semi-cylindrical surface with hemispherical ends has proven satisfactory for long machines.

3.3 Measurement Surface and Microphone Positioning:

3.3.1 For sound pressure level instrument systems the measurement surface given as alternative B in paragraph 7.2.3 of ISO 4872-1978 shall be used. Only microphone locations 2, 4, 6, 8, 10, and 12 shall be used in this measurement procedure. The location and the coordinates of the microphone positions on a hemispherical measurement surface of radius (r) are given in Table 3 and Fig. 1 as shown:

Table 3 - Coordinates of the Microphone Location Points

No.	X/r	Y/r	Z/r	Z
2	0.71	0.71	--	1.5 m
4	-0.71	0.71	--	1.5 m
6	-0.71	-0.71	--	1.5 m
8	0.71	-0.71	--	1.5 m
10	-0.27	0.65	0.71	--
12	0.27	-0.65	0.71	--

3.3.2 For sound intensity systems the microphone probe axis shall be held perpendicular to the measurement surface. Two general methods are currently in use with their respective merits. Close scanning or area scanning will provide more information than just sound power, but is more complex and labor intensive. Though not excluded, close scanning will not be detailed further. Fixed microphone locations at a sufficient number of representative surface segments, should be further from the machine and, therefore, loses detail, while simply and accurately determining sound power. A hemispherical measurement surface is easily understood and implemented. Microphone positioning is most easily accomplished by a quarter arc boom pivoted to rotate above the hemisphere center. The arc boom provides the correct orientation of the microphone probe toward the hemisphere center located on the reflecting plane. Microphone repositioning becomes the simple horizontal rotation of the supporting arc boom to the next position (until the microphone probe must be moved higher along the arc boom for the upper layers). The suggested 24 microphone position array is described below (at least 20 positions shall be used on a close enclosing hemisphere to insure accuracy). The area is obtained by multiplying the hemisphere radius squared by the microphone location area factor given in Table 4 and illustrated in Fig. 2. To qualify the number of surface segments necessary for a different measurement surface shape, continue doubling the number of surface segments until the change with each increase is less than 0.5 dB sound power.

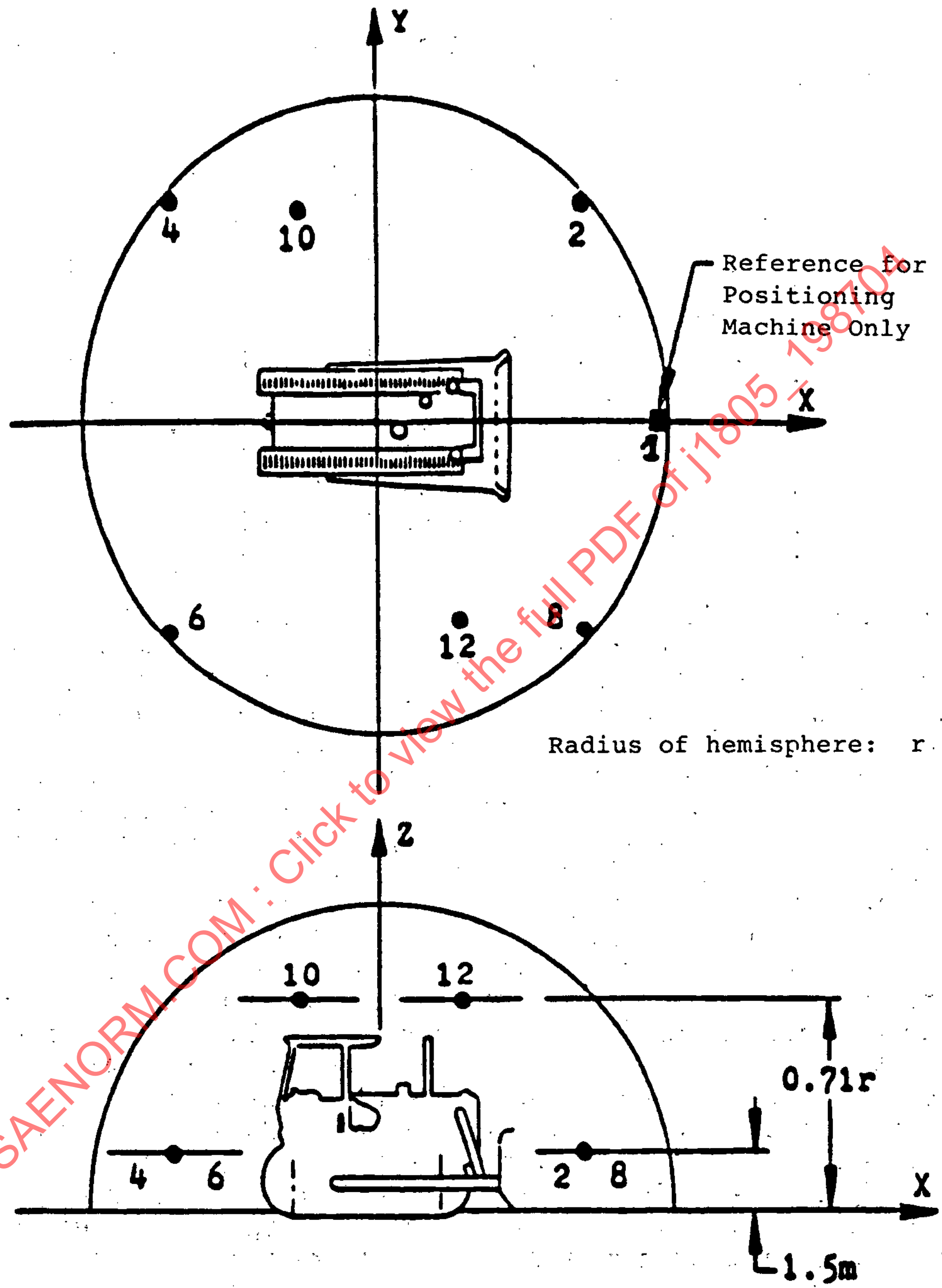

FIG. 1 - HEMISPHERE MEASUREMENT SURFACE FOR SOUND PRESSURE

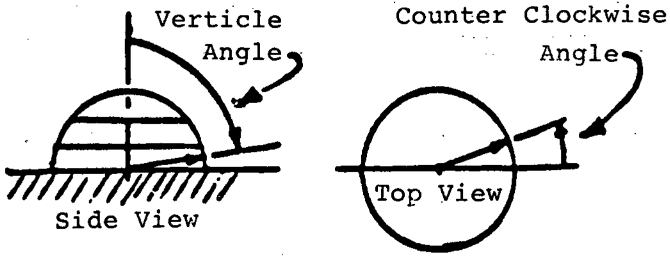

FIG. 2

Table 4 - Microphone Location Area Factors

Segments per Layer	Elevation Vertical Angle	Counter Clockwise Angle Relative to Front	Segment Area Factor Multiply by Radius Sqd
Bottom - 12	75 deg	Start @ 0, inc. 30 deg	0.270
Middle - 8	45 deg	Start @ 0, inc. 45 deg	0.248
Upper - 4	15 deg	Start @ 45, inc. 90 deg	0.263

3.4 Machine Location: The basic machine structure will be centered over the hemisphere center and the front pointed toward position No. 1. Attachments will be installed and operable. The attachment will be carried at travel height (normally 0.3 m (1 ft) for front buckets or blades) except when attachment motion is required during the cycle. Clearance shall be maintained so that the power train may be operated without machine travel.

3.4.1 Wheeled Machines (except Excavators and Backhoes) shall be mounted on stands allowing the powered wheels to turn freely without touching the ground. Ground clearance shall not exceed 75 mm (3 in). Backhoe-Loaders in the backhoe mode will have the bucket and stabilizers in the fully down position on high friction material such as rubber belting.

3.4.2 Tracked Machines (except Excavators) shall be mounted on stands above a hardwood (or similar material) skid surface allowing the tracks to slide freely without moving the machine. Stand height shall be adjusted to allow a suggested 25-50 mm (1-2 in) clearance between the track chain and track rollers. The skid surface height shall not exceed 100 mm (4 in) above the reflecting plane. Graphite or grease may be used to lubricate the hardwood skid surface. Note: Supporting track weight on the skid allows realistic tensioning of the upper track spans since tension affects noise; any other method of controlling track tension while maintaining the same sound characteristics is allowed. The hardwood skid may be permanent or installed on a plate for temporary use. Proper care in making the plate and shimming it on the reflecting plane will reduce plate noise contribution to insignificance.

3.4.3 Wheeled and Tracked Excavator Machines shall be in contact with the reflecting plane or protecting rubber belting or any other non-absorptive material.

3.5 <u>Machine Operation</u>: The machine shall be operated at a stabilized running temperature for the prevailing ambient condition. All engines on a multi-engined machine shall be operated concurrently. The machine shall then be measured under two operating conditions:

3.5.1 For the static condition, the machine will be operated at the manufacturer's specified rated speed under no-load condition and with the transmission in neutral.

3.5.2 For the in-place dynamic condition, operate crawler loaders and tractors per Appendix A, wheel loaders and tractors per Appendix B, excavators per Appendix C, and backhoe loaders per Appendix D.

3.6 <u>Climatic Conditions</u>: Ambient wind and temperature shall be measured at a height of 2 mm (6.6 ft) above the ground and recorded. Measurements shall not be conducted outdoors when precipitation is falling or when the test surface is covered with snow or temperature is below -10°C (14°F) or above +50°C (122°F) or if the wind velocity exceeds 8 m/s (17.9 mph).

3.7 <u>Measurements</u>:

3.7.1 Criterion for A-weighted Background Noise measured at the microphone positions shall be:

3.7.1.1 For sound pressure level instruments, background noise should be at least 10 dB below the measured level of the machine under test.

3.7.1.2 For sound intensity systems, background noise can be equal that of the machine as long as no other noise source is within the measurement hemisphere. If significant background noise (within 5 dB of the vector measurement) is present, it should be constant within 2 dB during the measurement and during the entire data accumulation.

3.7.2 <u>Integration Period</u>: Shall be the duration of one cycle unless the event being simulated is a drive-through or static rated speed test, in which case, a single integration period of 20-30 s at each microphone location is recommended. It is recommended that three correctly executed cycles be measured at each microphone location. The surface segment measurements will be used to obtain the surface energy average sound pressure level $\overline{L}_{pAeq}$. The measurements from each surface segment will be energy averaged together for comparison. The average of the highest two (within 2 dB of each other) will be used to obtain the surface energy average sound pressure level $\overline{L}_{pAeq}$.

3.8 <u>Calculations</u>:

3.8.1 For sound pressure level systems, the surface energy average sound pressure level $\overline{L}_{pAeq}$ shall be calculated from each set of measured values of the energy average A-weighted equivalent continuous sound pressure level from all 6 microphone locations based on an energy average. The sound power level is obtained by adding an area factor, 10 log (S/S_0), and the environmental factor (K).

$$L_{WAeq} = \overline{L}_{pAeq} + 10 \log (S/S_0) - K \quad \text{decibels Ref: 1pW} \quad (1)$$

S is the area of the measurement surface in square meters. Ref: $S_0 = 1m$. ($S=2\pi r^2$ for a hemispherical measurement surface.)

Radius	10 Log(S/S_0)
4 m	20 dB
10 m	28 dB
16 m	32 dB

Annex A of ISO 4872-1978 must be used to determine the environmental factor K or to determine if the reflecting plane satisfies the specifics of Section 4. For test sites which consist of a hard, flat, surface such as asphalt or concrete and with no sound reflecting obstacles within a distance from the source equal to three times the greatest distance from the source center to the lower measurement points, it may be assumed that the environmental correction factor K is less than or equal to 0.5 dB and is, therefore, negligible.

3.8.2 For sound intensity systems, the products of the sound intensity vectors times the represented perpendicular surface segments are summed. The surface correction factor K may be ignored if less than 0.5 dB. The total is sound power in decibels.

3.8.3 The reported value for static and dynamic sound power, whether determined by sound pressure or sound intensity methods, will be expressed in Bels (decibels/10).

3.9 <u>Information to be Recorded</u>:

3.9.1 <u>Machinery Under Test</u>: The machine manufacturer, model number, arrangement, major attachments, engine speed at rated speed no-load condition, and maximum governed engine speed (during the in-place dynamic test only) shall be recorded. The machine operation will be specified either as a base mode operation under the appendix, or detailed to include gear selection, attachment operation, engine speeds, and if tracked, the track tension adjustment.

3.9.2 <u>Instrumentation</u>: State the instruments used during the tests to include name, type, manufacturer, and serial number.

3.9.3 Acoustical Data: The measurement surface radius, microphone placement, average background sound pressure level, machine energy average sound pressure level or energy average sound intensity, and calculated sound power level, in Bels, for the static and in-place dynamic test conditions.

3.10 Information to be Reported:

3.10.1 The machine manufacturer, model number, arrangement, major attachments, engine speed at rated speed no-load condition for the static test, and maximum governed engine speed for the in-place dynamic test shall be recorded. For tracked machines, the track tension adjustment will be reported. The machine operation will be specified either as a base mode operation under the appendix, or detailed to include gear selection, attachment operation, and engine speeds.

3.10.2 The sound power level in Bels for both the static and in-place dynamic test conditions rounded to the nearest 0.1 Bels.

4. GENERAL COMMENTS:

4.1 It is recommended that persons trained and experienced in the current techniques of sound measurements select the instrumentation and conduct the tests. Attention to detail and a thorough understanding of the machine and test instrumentation operational requirements shall be prerequisites of all personnel attached to the evaluation program.

4.2 Proper use of all test instrumentation is essential to obtain valid measurements. Operating Manuals or other literature furnished by the instrument manufacturer should be referred to for both recommended operation of the instrument and precautions to be observed.

4.2.1 The effects of ambient weather conditions on the performance of all instruments (for example: temperature, humidity, barometric pressure, and stray magnetic fields) must be known. Instrumentation can be influenced by low or high temperature, and caution should be exercised.

4.2.2 Proper signal levels, terminating impedances, and cable lengths on multi-instrument measurement systems must be known.

4.2.3 Proper acoustical calibration procedure, to include the influence of extension cables, etc., should be performed. Field acoustical calibration shall be made immediately before and after the testing of each piece of earthmoving machinery. The calibration before and after shall not vary by more than ±0.5 dB for tests to be valid.

4.2.4 The overall effect due to an alternate test environment on the sound level measurement shall not exceed ±1.0 dB(A) from the sound power measurement made at the test site described in paragraph 3.1.

4.3 It should be recognized that variations in measured sound levels may occur due to variations in test site, ambient weather differences (temperature, wind, and their gradients), test equipment differences, and inherent differences between nominally identical machines.

5. COMMENTS ON REPORTING IN BELS: If the A-weighted sound power level of the machine is 112.3 dB, the sound power level L_{WAeq} according to paragraph 3.8.3 shall be reported as described by appropriate paragraphs of ANSI S1.23-1976:

Equivalent A-Weighted Sound Power Level = 11.2 Bels

or L_{WAeq} = 11.2 Bels

6. REFERENCE MATERIAL:

6.1 SAE J184 FEB87, Qualifying a Sound Data Acquisition System

6.2 SAE J1057 JUN81, Identification Terminology of Earthmoving Machines

6.3 SAE J1349 JUN85, Engine Power Test Code - Spark Ignition and Diesel

6.4 SAE J1372 JUN83, Sound Power - Determination - Earthmoving Machinery - Static Condition

6.5 SAE Technical Paper 850991 - In-Place Dynamic Sound Power Test Method

6.6 ANSI S1.1-1960 (R1976), Acoustical Terminology

6.7 ANSI S1.13-1971 (R1976), Methods for the Measurement of Sound Pressure Levels

6.8 ANSI S1.23-1976, Method for the Designation of Sound Power Emitted by Machinery and Equipment

6.9 ANSI S1.4-1983 (R1985), Specification for Sound Level Meters

6.10 ISO 1585-1974, Road Vehicles - Engine Test Code - Net Power

6.11 ISO 4872-1978, Acoustics - Measurement of Airborne Noise Emitted by Construction Equipment Intended for Outdoor Use - Method for Determining Compliance with Noise Limits

6.12 ISO 6165-1978, Earthmoving Machinery - Basic Types - Vocabulary

6.13 ISO 6393-1985, Acoustics - Measurement of Airborne Noise Emitted by Earthmoving Machinery - Method for Determining Compliance with Limits for Exterior Test Condition - Stationary Test Condition

6.14 ISO/DIS6395, Acoustics - Measurement of Airborne Noise Emitted by Earthmoving Machinery - Method for Determining Compliance with Limits for Exterior Noise - Simulated Work Cycle Test Conditions

6.15 IEC Publication 651-1979, Type 1, Precision Sound Level Meters

6.16 B&K Technical Review No. 4-1985, Validity of Intensity Measurements in Partially Diffuse Sound Fields, Svend Grand, M.Sc.

The ANSI and ISO Documents are available from: American National Standards Institute, 1430 Broadway, New York, NY 10018.

APPENDIX A
CRAWLERS LOADERS AND TRACTORS - SIMULATED DYNAMIC CYCLE

The stationary elevated machine shall be operated with an empty bucket or unloaded dozer at maximum governed engine speed (high idle) in a transmission mode that results in a simulated forward and reverse travel velocity close to but not to exceed 4.5 km/h (2.8 mph) (hydrostatic drive machines may use a range of 4-4.5 km/h (2.5-2.8 mph) because of difficulty in setting ground speed controls for precise simulated travel speeds). If the lowest transmission selection should result in a velocity higher than the specified simulated velocity, it shall be used. A separate set of sound power level data will be obtained for both forward and reverse travel. The cycle sound power shall consist of the two direction sound power levels energy averaged in inverse proportion to speed.

$$L_{WAeq} = 10 \log \frac{1}{(Tf + Tr)} (Tf * 10^{0.1 L_{WAeq(f)}} + Tr * 10^{0.1 L_{WAeq(r)}}) \quad (2)$$

Where Tf is the inverse (1/Vf) of Vf, the simulated velocity of forward travel and $L_{WAeq(f)}$ is the corresponding forward sound power level. Tr, Vr and $L_{WAeq(r)}$ represent the corresponding values in reverse.

APPENDIX B
WHEEL LOADERS AND TRACTORS - SIMULATED DYNAMIC CYCLE

The stationary elevated machine shall be operated with an empty bucket or unloaded dozer at maximum governed engine speed (high idle) in a transmission mode that results in a simulated forward and reverse travel velocity close to but not to exceed 9 km/h (5.6 mph) (hydrostatic drive machines may use a range of 8-9 km/h (5-5.6 mph) because of difficulty in setting ground speed controls for precise simulated travel speeds). If the lowest transmission selection should result in a velocity higher than the specified simulated velocity, it shall be used. A separate set of sound power level data will be obtained for both forward and reverse travel. The cycle sound power shall consist of the two direction sound power levels energy averaged in inverse proportion to speed.

$$L_{WAeq} = 10 \log \frac{1}{(Tf + Tr)} \left(Tf * 10^{0.1\, L_{WAeq(f)}} + Tr * 10^{0.1\, L_{WAeq(r)}}\right) \quad (2)$$

Where Tf is the inverse (1/Vf) of Vf, the simulated velocity of forward travel and $L_{WAeq(f)}$ is the corresponding forward sound power level. Tr, Vr and $L_{WAeq(r)}$ represent the corresponding values in reverse.

APPENDIX C
EXCAVATORS - SIMULATED DYNAMIC CYCLE

The machine shall be positioned directly on the reflecting plane or tracks on rubber belting or any other non-absorptive, high friction material. At the beginning of the test sequence, the arm and bucket shall be in the fully retracted and tucked under position with the lowest portion being 0.3 m (12 in) above the test surface. During the test cycle, the engine shall be operated at maximum governed engine speed (high idle) unless the manufacturer's specifications state otherwise. The machine shall be run through three complete simulated sequences to complete the test cycle. Conduct the test at as rapid a pace as possible for safe operating conditions at the test site.

C1. Raise the boom to sufficient height to permit the arm to come to a vertical position with the bucket in a horizontal position resting on the reflecting plane (or appropriate pad).

C2. Operate the appropriate hydraulic circuits that will result in downward pressure on the bucket and as the basic machine starts to raise off the test site reflecting plane, the machine shall be held in this position for 10 seconds.

C3. Once the 10 s loading cycle is completed, then return the boom and arm to the initial lowered tucked bucket position and repeat the cycle two more times.

APPENDIX D
BACKHOE LOADERS - SIMULATED DYNAMIC CYCLE

This machine will be tested during two complete independent simulated work cycles. First it shall be tested as a wheel loader and then as a backhoe.

D1. Loader Dynamic Test: Appendix B

D2. Backhoe Dynamic Test:

D2.1 Machine Set Up: The outriggers shall be in the fully extended position and shall carry the weight of the machine. It is recommended that the outrigger pads be on rubber belting or any other non-absorptive, high friction material to reduce sliding during boom rotation and floor damage. The wheels should be approximately 50-75 mm (2-3 in) off the reflecting plane. Position the backhoe with the stock fully retracted, bucket curled, and boom partially lowered to position the backhoe bucket 1 m (3 ft) above the floor or the distance necessary to safely clear the outriggers. Set the manufacturer's recommended engine speed for backhoe operation, or if not specified set the engine at 85% of the manufacturer's stated rated speed.

D2.2 Machine Test Operation: Operate only the swing control at 2/3 to full valve stroke to move the boom back and forth 45 deg from both sides of center. The movement should be continuous, making swift direction changes at the end of the prescribed travel arc to reduce excessive bucket rattles. Maintain the continuous operation for 20-30 s or longer for the sound power determination.

D3. Reported Data: The final report shall include two separately identified sound power levels for the dynamic test.

850991

In-Place-Dynamic Sound Power Test Method

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ABSTRACT

ISO and SAE static sound power test methods are currently used for construction machinery. The European Economic Community sound committee has been developing a drive-by or simulated work cycle test method using a hemispherical array of microphones. The EEC method is inconsistent due to the changing test surface (moist sand) and the variables of outdoor testing: temperature, wind, and precipitation. The in-place-dynamic test method described provides a disciplined way to evaluate machines with moving track or wheels and operating hydraulic systems. The machine is slightly elevated, resting on stands, so that the wheels are off the ground or the tractor weight is off the track chain. Data obtained from track-type tractor, track-type loader, and wheel loader machines supports the validity of using an indoor, in-place-dynamic test instead of a moving, outdoor test. Results also show that using sound intensity instrumentation permits the option of testing in an untreated, indoor facility.

RATED-SPEED SOUND POWER TESTS for some classes of construction machines are a widely accepted static procedure in Europe. The EEC is developing a dynamic (moving) test over moist sand. Manufacturers are concerned about problems related to a sand site: availability during and after inclement weather; maintenance of a smooth, level, and moist surface; and consistency under different weather conditions.

Tests were conducted to compare: machine sound power determined over sand with that over concrete; outdoor results with indoor; in-place-dynamic testing (previously studied in Japan) to moving (1)*. Alternative instrumentation that can determine the machine sound power at least as accurately as conventional instruments was evaluated. The test results demonstrate a more useful dynamic test site and an in-place-dynamic alternative that can be an effective option to the current proposed moving test. Also an alternative to conventional sound level instrumentation systems was found to permit tests in a factory environment.(2)

*Numbers in parentheses designate references at the end of the paper.

EEC/ISO DYNAMIC TEST SPECIFICATIONS

GENERAL DESCRIPTION - Test methods and test sites specified by ISO/DP 6395 include a basic measurement hemisphere of six stationary microphone locations. The 10 meter radius hemisphere was chosen for this study to facilitate comparison of indoor with outdoor results (previous CTCo. studies showed no significant difference between sound power results using 16 and 10 meter radius hemispheres). Three microphones are located on each side of the tractor (one at 7 meters height and two at 1.5 meters). The ISO ground surface is 2 mm or finer smooth, level, moist sand, see Fig. 1. The sound power is determined by obtaining the energy average of all six microphones as the machine operates through a measuring zone within the hemisphere.

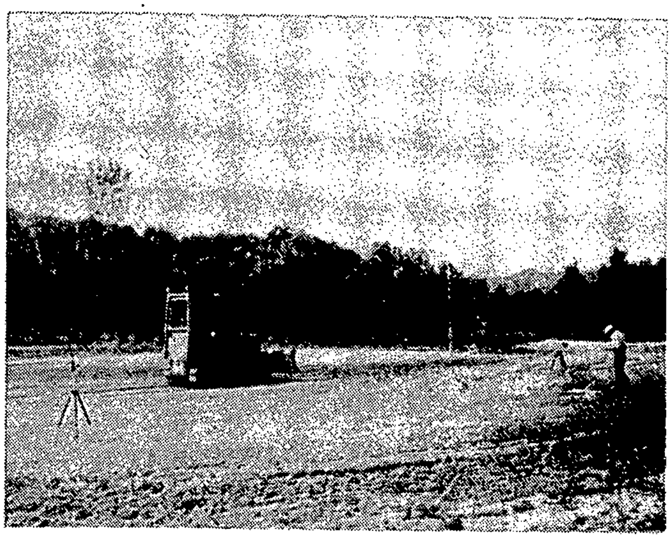

Fig. 1 Track-type tractor on sand test site.

TEST SITE

SAND TEST SITE - Many problems have been observed during the three years that the sand site has been maintained at Caterpillar's Peoria Proving Ground. Footprint deformation of the surface is unavoidable. Track and particularly wheel deformation of the drive-by area is extensive, as shown in Fig. 2. Sand is too dry, or else, excessively wet for many days following a heavy rain. Sand washes away in heavy rains. Moist sand is totally unusable during the winter.

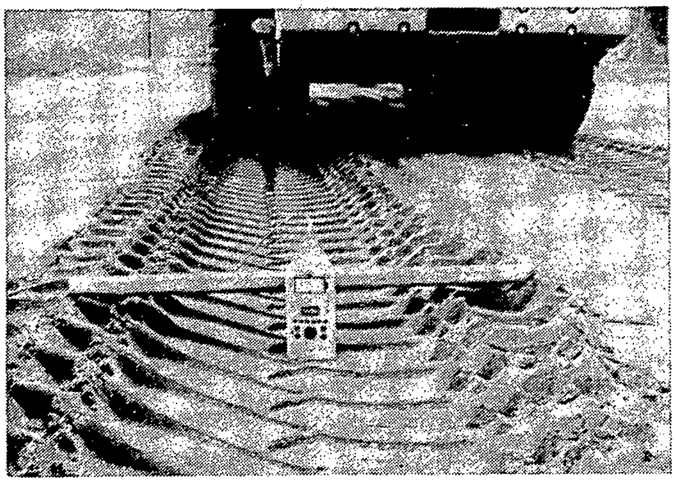

Fig. 2 Sand deformed by a large wheel loader.

ALTERNATE TEST SITES

OUTDOOR CONCRETE - The 41 by 50 meter level, sealed concrete test site, see Fig. 3, has an adjacent gravelly material drive-by strip for tracked machines, see Fig. 4. There has been no problem maintaining this site; the pad is swept and the drive-by strip dressed up occasionally. During the winter its usefulness is diminished by surrounding mud, or ice on the concrete. It is useable approximately three times as many days as the sand site; but, also being outdoors, is often no properly available for weeks at a time.

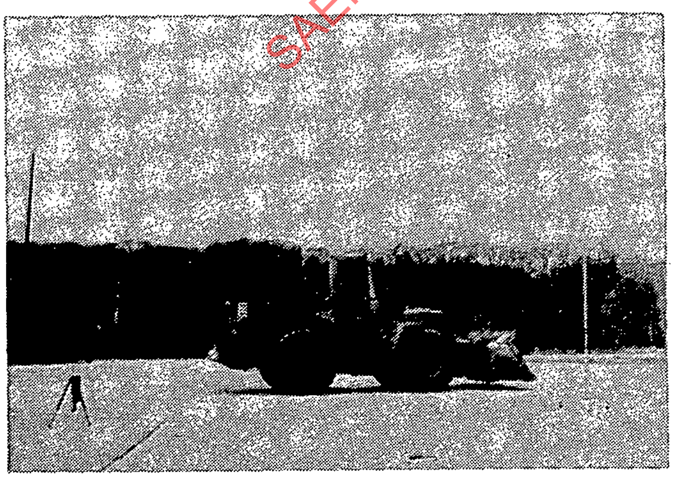

Fig. 3 Concrete sound test site.

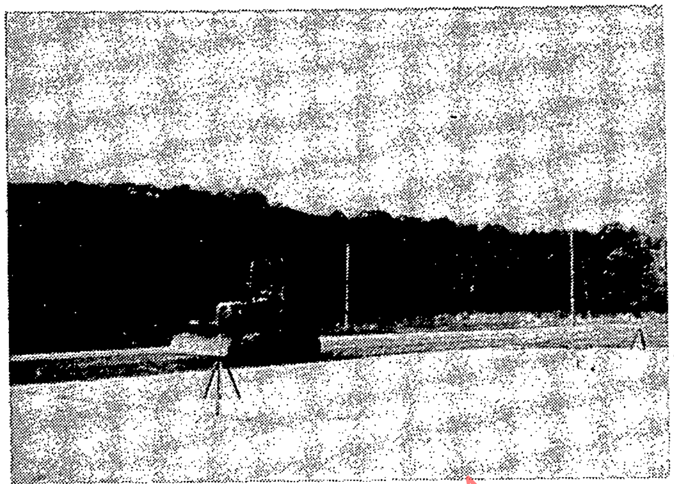

Fig. 4 The adjacent drive-by strip for tracks.

HEMIANECHOIC - The 32.2 by 24.4 meter hemianechoic building with 8.4 meter ceiling is lined with 500 mm Polyether Urethane foam wedges and has a smooth, troweled, heavy duty wearing coarse concrete floor. An exhaust fumes extractor and large capacity heaters provide repeatable temperatures throughout the year, see Fig. 5. This indoor facility eliminates the effects of wind, rain, snow, ice, and temperature gradients; thus providing a consistent, year-round test site.

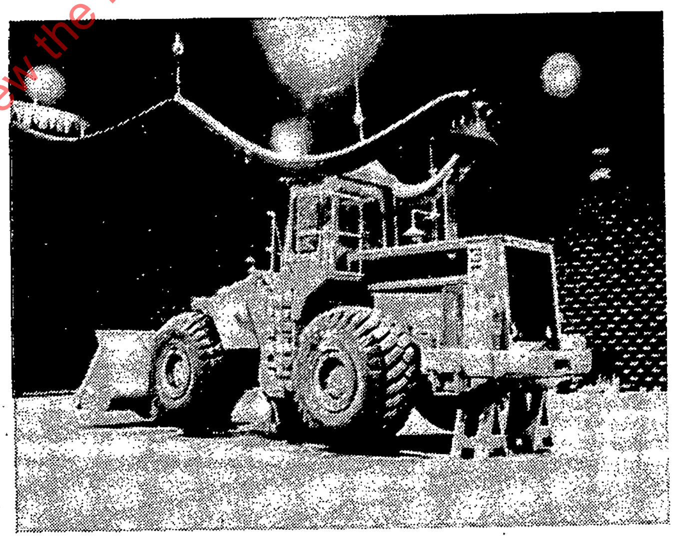

Fig. 5 Wheeled machine in hemianechoic site.

TEST CYCLES

TEST CYCLE SPECIFICATIONS - Test Cycles are specified by Draft 2 ISO/DP 6395.

Track-Type Tractor - Sound power of track-type tractors is calculated from two elements as prescribed in the document: forward travel and reverse travel at low speed (4.0 km/h) or low gear through the hemispherical array.

Track-Type Loader - Sound power of track-type loaders is determined from the energy average equivalent level obtained in a continuous manner while accelerating forward in low gear to a stopping point; then, in low gear reverse while raising the bucket until the machine passes the starting point.

Wheel Loader - Sound power of wheel loaders is measured during a cycle similar to the track-type loader except in a gear producing 13 km/h.

ALTERNATE TEST CYCLE METHODS EVALUATED

TRACK-TYPE MACHINES - In-place-dynamic testing of track-type machines is accomplished on stands, Fig. 6, with the track shoes sliding on lubricated oak skids to allow proper control of upper track span tension (past experience has shown that neither the ground interface nor the track sliding on wood significantly influences noise, but that track tension can influence noise as much as 2.5 dB). The tractor is raised only enough to provide a track-link-to-track-roller clearance of 25 to 50 mm. The track-type tractor can be run in forward and in reverse for separate energy averages to be combined as prescribed in the ISO procedure and the track-type loader can be operated in the prescribed test cycle. The updated test description in ISO/DIS 6395 includes higher speeds in reverse for track type machines.

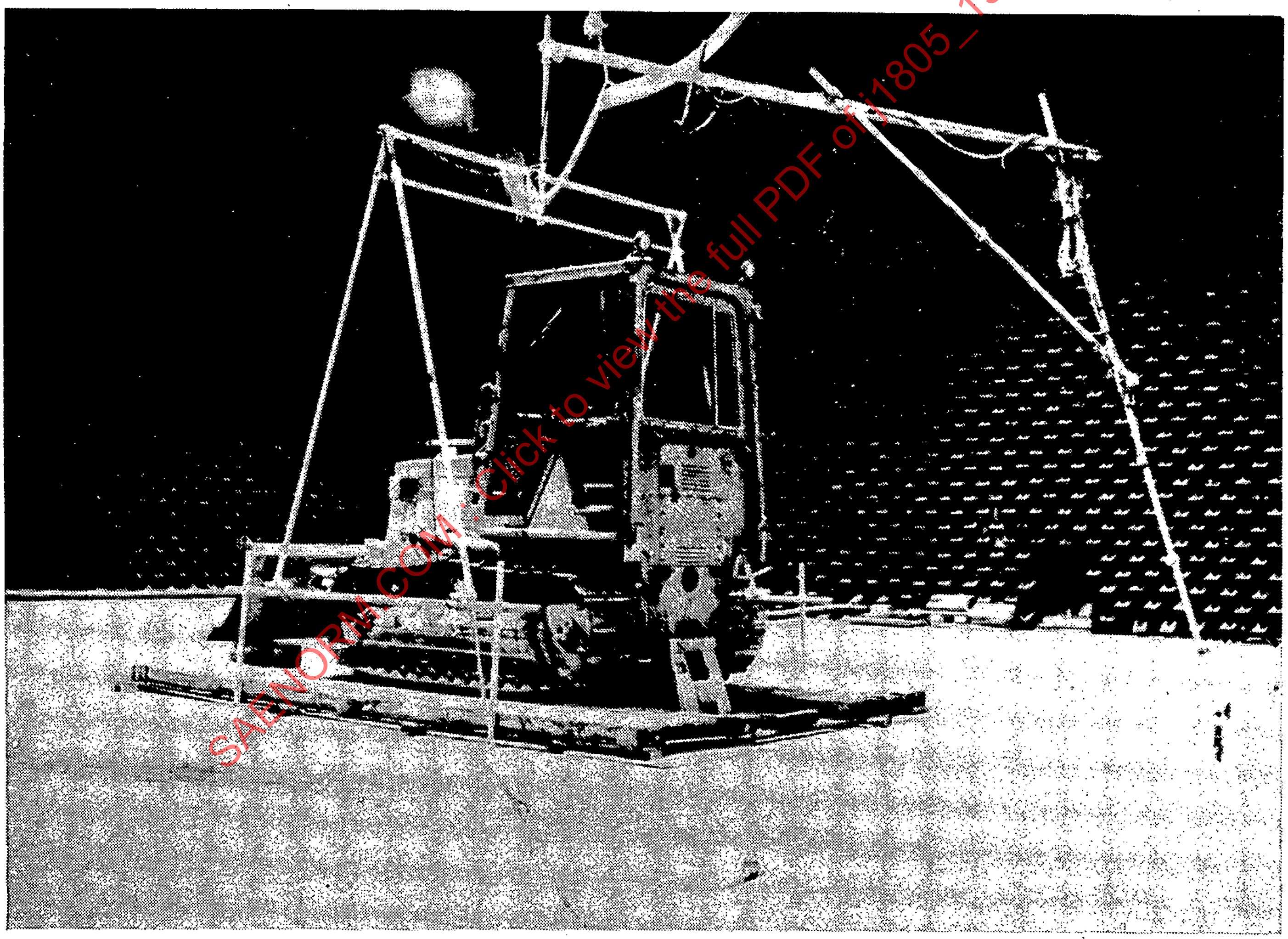

Fig. 6 Track-type machine on stands; wood skid supports the track chain only. The rotating microphone support is used to orient the microphone pair of the sound intensity sytem.

WHEEL LOADERS - In-place-dynamic testing of wheeled machines is done on stands so the wheels are free of the ground plane. The in-place-dynamic test consists of running for similar time duration and operation as the moving test including raising the bucket during reverse.

INSTRUMENTATION

The EEC draft method specifies instruments that determine the energy average sound pressure level at each microphone location.

ALTERNATE INSTRUMENTATION EVALUATED

SOUND INTENSITY - Sound intensity instrumentation has been evaluated relative to its use in the measurement of construction equipment (3), and reported previously by various authors to be equivalent to conventional methods. This method determines the sound intensity normal to a measurement surface by processing signals from two closely spaced microphones oriented in-line with a normal to the surface. The microphone support used is in the form of a rotating arc which positions the microphones. The microphone support mechanism, Fig. 6, accurately orients the microphone pair toward the hemisphere's center. A 4 meter radius hemisphere consisting of three layers of microphone positions (4 upper, 8 middle, and 12 lower) was selected. The sound intensity system would permit sound power determination within the factory environment as in Fig. 7.

Fig. 7 Track Loader set up for sound intensity measurements in the factory environment.

RESULTS

Data was obtained from specific test machines to evaluate the test methods:

TTT <150 kW Track-Type Tractor less than 150 kW
TTT >250 kW Track-Type Tractor 250 to 375 kW
TTL <150 kW Track-Type Loader less than 150 kW
WL <150 kW Wheel Loader less than 250 kW
WL >150 kW Wheel Loader 150 to 250 kW

Comparison of raw data from three successive runs of any given dynamic test showed the following sequential repeatability: wheel loaders 0.2 dB; track-type machines 0.5 dB. Sequential repeatability for all static tests was within 0.2 dB.

Results of comparisons are summarized below for each test site or instrumentation method.

ALTERNATE CONCRETE SITE - Concrete Reflecting Plane (Table 1) sound power data results are compared with sand site results on the same day for each machine. It should be noted that the sand was 5 to 7% moisture on each test except for the large wheel loader which was 18% moisture and apparently as reflective as concrete. The data is very uniform indicating a trend of 1.1 dB absorbtion of sand relative to concrete during the static test for average moisture sand.

A significant amount of sand adhered to the track of the samll track-type tractor which was clean and dry before entering the sand. Mud is known to reduce track noise radiation and this data suggests that sand adhering to track shoes reduced noise. Sand did not adhere to track on subsequent days on the other machines. This demonstrates one more variable which can occur with sand that does not occur with the concrete site and gravel drive-by. A comparison with static data also suggests a uniform additional reduction due the slightly lower engine speed when the tractor is moving in the higher rolling resistance material.

Table 1
SOUND POWER OVER CONCRETE minus OVER SAND

	TTT <150kW)	TTT >250kW	TTL <150kW	WL <150kW	WL >150kW
Static	+0.9	+1.1	+1.2	+1.1	0.0
Moving	+2.4	+1.9	+1.8	+1.7	+0.8