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Sound Power Level Measurements of Work Machines— Static and In-Place Dynamic Methods

1. **Scope**—This SAE Standard is used to determine the exterior A-weighted equivalent sound power level of static and in-place dynamic machines (dozer, loader, excavator, and backhoe) similar to the sound power obtained in ISO 6393 static and ISO 6395 dynamic sound power test procedures. Additional machine types, specifically sweepers and scrubbers, covered by SAE J2130 have been added, and other work machine types covered by SAE J1116 may be added with appropriate cycle descriptions and machine preparation. The recommended test procedures include conventional integrating sound pressure level methods or the sound intensity method using paired microphones. The sound intensity methodology provides a practical indoor alternative and permits measurement in the factory environment. The procedures in this document assume that the dominant sources are not highly sensitive to load (i.e., cooling fan, engine, track system). This test can be used as a substitute for the ISO 6393 static and ISO 6395 dynamic sound power tests for many machine types.

The requirements for the machine setup and operation, and the microphone array and hemispherical measurement surface are given in this document. This document shall be used in conjunction with instrumentation manufacturer's recommendations and SAE J/ISO 9614-1. The accompanying sound intensity procedure clarification is provided pending more widespread understanding of sound intensity.

2. References

- 2.1 **Applicable Publications**—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

- 2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J184 NOV1998—Qualifying a Sound Data Acquisition System

SAE J1116 MAR1999—Categories of Off-Road Self-Propelled Work Machines

SAE J2101/ISO 4872-1978—Acoustics—Measurement of Airborne Noise Emitted by Construction Equipment Intended for Outdoor Use—Method for Determining Compliance with Noise Limits

SAE J2130 OCT1997—Self-Propelled Sweepers and Cleaning Equipment

SAE J/ISO 9614-1:1993—Acoustics—Determination of sound power levels of noise sources using sound intensity—Part 1: Measurement at discrete points

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2.1.2 ANSI AND ISO PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ANSI S1.4-1983 (R1997) (1997)—Specifications for Sound Level Meters ANSI S 1.4A-1985—Amendment to ANSI S 1.4-1983

ANSI S 1.40 (1984)—Specification for Acoustic Calibrators

ISO 6165-1997—Earth-Moving Machinery—Basic Types—Vocabulary

ISO 6393:1998—Acoustics—Measurement of exterior noise emitted by earth-moving machinery—Stationary test conditions

ISO 6395:1996—Acoustics—Measurement of exterior noise emitted by earth-moving machinery—Dynamic test conditions (includes Amend.1:1996)

2.1.3 IEC PUBLICATIONS—Available from International Electrotechnical Commission, 3 rue de Verambe, P.O. Box 131, 1211 Geneva 20, Switzerland.

IEC Publication 60651 (1979)—Sound Level Meters

IEC 60942 (1997)—Sound Calibrators

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

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1057 SEP88—Identification Terminology of Earthmoving Machines

SAE J1349 JAN90—Engine Power Test Code—Spark Ignition and Compression Ignition—Net Power Rating

SAE J/ISO 9614-2:1993—Acoustics—Determination of sound power levels of noise sources using sound intensity—Part 2: Measurement by scanning

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

2.2.2 ISO PUBLICATION—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO 1585-1992—Road Vehicles—Engine Test Code—Net Power

ISO 3744:1994—Acoustics—Determination of sound power levels of noise sources using sound pressure—Engineering method in an essentially free field over a reflecting plane

2.2.3 IEC PUBLICATION—Available from International Electrotechnical Commission, 3 rue de Verambe, P.O. Box 131, 1211 Geneva 20, Switzerland.

IEC Publication 60804 (1985)—Integrating—Averaging Sound Level Meters, plus amendments

3. Instrumentation

3.1 The integrating sound pressure level system is used in conjunction with a free field over a reflecting plane (4.1.1).

3.1.1 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.

3.1.2 Any alternate system in place of a meter must perform the same functions required in 3.1.1.

3.1.3 The components of the measuring instrumentation system shall meet the Type 1 requirements given in the relevant clauses of IEC Publication 60651 (1979) and ANSI S1.4-1983 (R1997). Systems shall be qualified according to SAE J184 for the frequency range of interest.

3.1.4 The acoustic calibrator used for calibration prior to and after the test sequence shall have an accuracy within ± 0.5 dB and meet the requirements of ANSI S1.40-1984 or IEC 60942 (1997).

3.1.5 A microphone windscreen shall 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.

3.2 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 (R1997) or of SAE J184 NOV1998 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 interim information only:

3.2.1 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.

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

TABLE 1—USABLE FREQUENCY RANGE FOR MICROPHONE SPACING

Usable Frequency Range with Phase Mismatch Microphone Spacing	Usable Frequency Range with Phase Mismatch 0.1 degree	Usable Frequency Range with Phase Mismatch 0.3 degree
6 mm	50 - 10 000 Hz	200 - 10 000 Hz
12 mm	40 - 5000 Hz	125 - 5000 Hz
20 mm	30 - 3500 Hz	100 - 3500 Hz
50 mm	10 - 1250 Hz	31 -1250 Hz

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

3.2.3.1 *Phase Matched Instrumentation*—The phase error between the two channels shall be less than 0.5 degree (dependent on frequency—see B&K Technical Review No. 4—1985).

3.2.3.2 *Channel Switching*—Electrically or physically switching channels halfway through each measurement.

3.2.3.3 *On-Site Phase Calibration*—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.

3.2.3.4 A combination of 3.2.3.1 and 3.2.3.2 or 3.2.3.3.

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

- 3.3 The anemometer or other device used in measurement of ambient wind speed and direction shall be accurate within $\pm 10\%$ at 20 km/h.
- 3.4 The engine speed indicator shall be accurate within $\pm 2\%$ of the indicated reading.
- 3.5 The ambient temperature measurement shall be accurate within $\pm 1^\circ\text{C}$.

4. Procedure

4.1 Test Site—A nonabsorbing reflecting plane is required.

- 4.1.1 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.
- 4.1.2 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 shall be inside the measurement surface. This system permits measurements in most factory environments.

4.2 Measurement Surface—Size and shape depend on the instrumentation selected and the machine dimensions:

- 4.2.1 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 to the basic length (ℓ).

TABLE 2—HEMISPHERE RADIUS RECOMMENDATION

Basic Length (ℓ) of the Machine	Radius (r) of Hemispherical Measurement Surface
$\ell \leq 1.5\text{ m}$	4 m
$1.5\text{ m} < \ell \leq 4\text{ m}$	10 m
$\ell > 4\text{ m}$	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.

- 4.2.2 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 semicylindrical surface with hemispherical ends has proven satisfactory for long machines.

4.3 Measurement Surface and Microphone Positioning

4.3.1 For sound pressure level instrument systems, the measurement surface shall be a hemisphere of radius (r) given in Table 2. Location coordinates of the microphone positions are given in Table 3 and Figure 1.

TABLE 3—COORDINATES OF THE MICROPHONE LOCATION POINTS

Location No.	Figure No.	X/r ⁽¹⁾	Y/r	Z/r	Z
1	2	0.70	0.70	—	1.5 m
2	4	-0.70	0.70	—	1.5 m
3	6	-0.70	-0.70	—	1.5 m
4	8	0.70	-0.70	—	1.5 m
5	10	-0.27	0.65	0.71	—
6	12	0.27	-0.65	0.71	—

1. The positive X axis is the machine primary direction of travel.

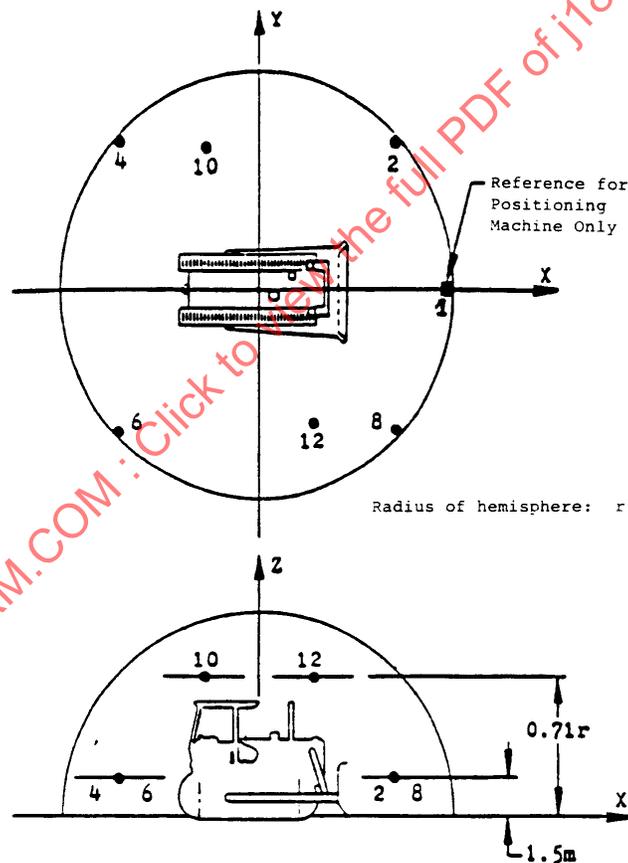


FIGURE 1—HEMISPHERE MEASUREMENT SURFACE FOR SOUND PRESSURE

4.3.2 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 must be further from the machine which results in lost detail, but simply and accurately determines 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 (at least 20 positions shall be used on a close enclosing hemisphere to ensure accuracy). The area is obtained by multiplying the hemisphere radius squared by the microphone location segment area factor given in Table 4 and illustrated in Figure 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.

TABLE 4—MICROPHONE LOCATION SEGMENT AREA FACTORS

Segments per Layer	Elevation Vertical Angle	Counterclockwise Angle Relative to Front	Segment Area Factor Multiply by (r) Squared
Bottom - 12	75 degree	Start @ 0, inc. 30 degree	0.270
Middle - 8	45 degree	Start @ 0, inc. 45 degree	0.248
Upper - 4	15 degree	Start @ 45, inc. 90 degree	0.263

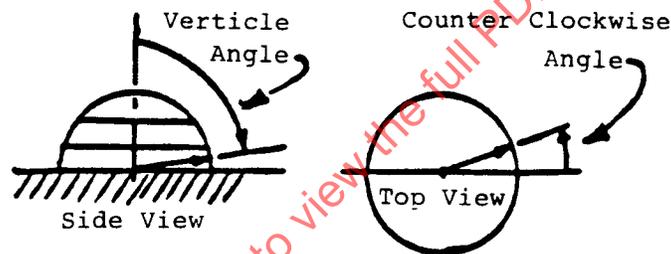


FIGURE 2—ORIENTATION OF VERTICAL AND CLOCKWISE ANGLES

4.4 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 for front buckets or blades) except when attachment motion is required during the cycle. When specified, the machine shall be elevated to obtain clearance between the ground and the wheels or tracks to permit operation of the power train without machine travel.

- 4.4.1 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. 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.
- 4.4.2 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 to 50 mm clearance between the track chain and track rollers. The skid surface height shall not exceed 100 mm above the reflecting plane. Graphite or grease may be used to lubricate the hardwood skin 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.

4.4.3 Wheeled and tracked excavator machines shall be in contact with the reflecting plane or protecting rubber belting or any other nonabsorptive material.

4.5 Machine Operation—The machine shall be operated at a stabilized running temperature for the prevailing ambient condition. All engines on a multiengined machine shall be operated concurrently. Sound data on the machine shall be measured under the two operating conditions as follows:

4.5.1 **STATIC CONDITION**—The machine will be operated at the manufacturer's specified rated engine speed under no-load condition with the transmission in neutral.

4.5.2 **IN-PLACE DYNAMIC CONDITION**—Machine operations are described in Appendices A through E. For machine types not listed use the dynamic cycle in the EU Sound directive or devise a cycle to characterize machine work and describe the cycle along with the data.

4.6 Climatic Conditions—Ambient wind and temperature shall be measured at a height of 2 m 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 or above $+50^{\circ}\text{C}$ or if the wind velocity exceeds 8 m/s.

4.7 Measurements

4.7.1 Criteria for A-weighted background noise measured at the microphone positions shall be as follows:

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

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

4.7.2 **INTEGRATION PERIOD**—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 to 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 \bar{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 \bar{L}_{pAeq} .

4.7.3 **NUMBER OF DYNAMIC CYCLES**—Three dynamic cycles shall be carried out resulting in three measurements to be taken at each of the six microphone positions. Calculate the three sets of data obtained at all microphone positions. If two of the three values so obtained do not differ by more than 1 dB, further measurements are not necessary. If this is not the case, continue taking measurements until two values within 1 dB of each other are obtained. Report, as the value of the A-weighted sound power level, the arithmetic mean of the two highest values that are within 1 dB of each other.

4.8 Calculations

- 4.8.1 For sound pressure level systems, the surface energy average sound pressure level L_{pAeq} shall be calculated from each set of measured values of the energy average A-weighted equivalent continuous sound pressure level from all six 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.

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

where:

S is the area of the measurement surface in square meters.

Ref: $S_0 = 1 \text{ m}$. ($S = 2 \pi r^2$ for a hemispherical measurement surface.)

(See Table 5.)

TABLE 5—AREA FACTOR FOR STANDARD RADIUS HEMISPHERES

Radius	10 Log(S/S ₀)
4 m	20 dB
10 m	28 dB
16 m	32 dB

Annex A of SAE J2101/ISO 4872-1978 shall be used to determine the environmental factor K or to determine if the reflecting plane is suitable. 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.

- 4.8.2 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.

4.9 Information to be Recorded

- 4.9.1 **MACHINERY UNDER TEST**—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.
- 4.9.2 **INSTRUMENTATION**—State the instruments used during the tests to include name, type, manufacturer, and serial number.
- 4.9.3 **ACOUSTICAL DATA**—The measurement surface radius, microphone placement, average background sound pressure level, machine energy averaged sound pressure level or energy average sound intensity, and calculated sound power level, in A-weighted decibels, for the static and in-place dynamic test conditions.

4.10 Information to be Reported

- 4.10.1 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.
- 4.10.2 The sound power level in A-weighted decibels for both the static and in-place dynamic test conditions rounded to the nearest decibel.

5. General Comments

- 5.1 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.
- 5.2 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.
- 5.2.1 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.
- 5.2.2 Proper signal levels, terminating impedances, and cable lengths on multi-instrument measurement systems must be known.
- 5.2.3 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.
- 5.2.4 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 4.1.
- 5.3 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.

6. Notes

- 6.1 **Marginal Indicia**—The change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

APPENDIX A

EXCAVATORS (HYDRAULIC OR ROPE OPERATED)

Preface—(This appendix forms an integral part of the document.)

A.1 Definition (in Accordance with ISO 6165)—A self-propelled crawler or wheeled machine with an upper structure capable of a minimum of 360-degree rotation, which excavates, elevates, swings, and dumps material by the action of a bucket fitted to the boom and arm or telescoping boom, without moving the chassis or undercarriage during any one cycle of the machine.

A.2 Safety and Operation—All relevant safety precautions and the manufacturer's operating instructions shall be followed during the test.

Any signal devices, such as forward warning horn or backup alarm, shall not be activated during the test.

A.3 Setting-Up of the Machine—The excavator shall be equipped with the bucket, such as hoe, shovel, grab type, or dragline, designated for the manufacturer's production version. Engine and hydraulic systems shall be warmed to normal operating conditions for the prevailing ambient temperature. The engine governor control shall be set to the maximum position (high idle). All actuating movements shall be carried out at maximum velocity but without activating relief valves or contacting end-of-travel mechanical barriers. The excavator shall be located on a hard reflecting plane as specified in 4.1.

A.4 Operation of the Machine

A.4.1 Basic Machine Cycle—The dynamic cycle, without moving material, as described in A.4.2 to A.4.5, comprises three 90-degree swings to the left of the operator and back, with the machine positioned so the center of rotation of the upper structure of the excavator (which is defined as the machine center for the purpose of locating the machine) shall coincide with the center of the hemisphere shown in Figure 1. The longitudinal axis of the machine shall coincide with the x-axis and the front of the machine shall face position 1.

Each swing shall be from the x-axis to the y-axis, and back to the x-axis. A single cycle consists of three continuous 90-degree swings to the left and back while moving the front end attachment through a complete sequence for each 90-degree swing and back.

A.4.2 Hoe Attachment—The aim of the dynamic cycle is to simulate trench excavation and dumping the material adjacent to the trench. At the beginning of the cycle, the boom and arm shall be adjusted to place the bucket at 75% of the maximum reach with the bucket 0.5 m above the ground surface. The cutting edge of the bucket in the rolled forward position shall be at an angle of 60 degrees to the test site measurement surface.

First raise the boom and simultaneously retract the arm so that the bucket remains 0.5 m above the test site for 50% of the remaining boom and arm travel distance. Then roll back or curl the bucket. Lift the bucket by raising the boom and continue to retract the arm to simulate the adequate clearance (30% of maximum bucket lift height) needed to swing across the edge of the trench. Execute a 90-degree swing to the left of the operator. Raise the boom during the swing and extend the arm until the bucket has reached 60% of maximum boom lift height. Then uncurl the arm until it is 75% extended. Roll forward or uncurl the bucket until the cutting edge is vertical. Execute a return swing to the starting position with the boom being lowered and bucket being curled.

Repeat the sequence of events two more consecutive times in order to complete a single dynamic cycle.

NOTE—The single dynamic cycle is repeated three times to meet the requirements of three dynamic cycles as defined in 4.7.3.

A.4.3 Shovel Bucket Attachment—The aim of the work cycle is to simulate excavation at the height of a high wall. At the beginning of the cycle, with the bucket cutting edge parallel to the ground, the bucket shall be 0.5 m above the test site in the 75% retracted position.

First extend the bucket 75% of travel while maintaining the original bucket orientation. Then roll back or curl the bucket and raise it to 75% of maximum lift height and 75% of dipper arm extension. Execute a 90-degree swing to the left of the operator and at the end of the swing actuate the bucket dump mechanism. Execute a return swing to the starting position with the bucket 0.5 m above the test site in the 75% retracted position.

Repeat the sequence of events two more consecutive times in order to complete a single dynamic cycle.

NOTE—The single dynamic cycle is repeated three times to meet the requirements of three dynamic cycles as defined in 4.7.3.

A.4.4 Grab Type Attachment—The aim of the work cycle is to simulate excavation of a pit. At the beginning of the cycle, the grab shall be open and 0.5 m above the test site.

First close the grab. Then raise the grab to half of the maximum lift height. Execute a 90-degree swing to the left of the operator. Open the grab. Execute a return swing while lowering the attachment to the starting position.

Repeat the sequence of events two more consecutive times in order to complete a single dynamic cycle.

NOTE—The single dynamic cycle is repeated three times to meet the requirements of three dynamic cycles as defined in 4.7.3.

A.4.5 Dragline Attachment—The aim of the work cycle is to simulate excavation of a layer in a trench and dumping of the material adjacent to the trench. For the duration of the cycle, the boom shall be positioned at an angle of 40 degrees. The bucket shall hang vertically under the end of the boom and 0.5 m above the test site with drag chains not touching the ground.

First retract the bucket to bring it as close as possible to the machine while maintaining the distance of 0.5 m above the test site. When the bucket has been retracted, execute a 90-degree swing to the left of the operator. Simultaneously, raise the bucket to 75% of maximum lift height and extend to maximum reach in the loaded bucket position. Execute a return swing. Simultaneously, actuate the bucket dump and retract the bucket to the starting position.

Repeat the sequence of events two more consecutive times in order to complete a single dynamic cycle.

NOTE—The single dynamic cycle is repeated three times to meet the requirements of three dynamic cycles as defined in 4.7.3.

APPENDIX B

TRACTORS WITH DOZER EQUIPMENT

Preface—(This appendix forms an integral part of the document.)

B.1 Definition (in Accordance with ISO 6165)—A self-propelled crawler or wheeled machine used to exert a push or pull force through mounted equipment.

B.2 Safety and Operation—All relevant safety precautions and the manufacturer's operating instructions shall be followed during the test.

Any signal devices, such as forward warning horn or backup alarm, shall not be activated during the test.

B.3 Setting-Up of the Machine—The tractor shall be equipped with the dozer designated for the manufacturer's production version. Engine and hydraulic systems shall be warmed to normal operating conditions for the prevailing ambient temperature.

B.4 Operation of the Machine

B.4.1 The machine shall be positioned and elevated at the center of the hemisphere as defined in 4.4.

The machine shall be operated with the dozer in a lowered carry position $0.3 \text{ m} \pm 0.05 \text{ m}$ above the ground plane of the hemisphere. The machine shall be operated at maximum governed engine speed (high idle) in a constant simulated forward and reverse travel mode. The simulated forward travel velocity shall be close to but not exceeding 4 km/h for crawler and steel-wheeled machines and 8 km/h for rubber-tired wheeled machines. The matching gear ratio shall be used in the reverse travel mode, regardless of the velocity. For the majority of machines, this will be first forward and first reverse. Hydrostatic drive machines may use a range of 3.5 to 4 km/h (crawler or steel-wheeled) and 7 to 8 km/h (rubber-tired) because of difficulty in setting ground speed controls for exact travel speeds.

These modes of operation are nonstop with no movement of the dozer equipment. If the lowest gear results in a velocity higher than the specified velocity, it shall be used with the engine operating at maximum governed speed (high idle). For hydrostatic drive machines with the engine at maximum governed engine speed (high idle), the ground speed control shall be set to match to specified velocities stated.

NOTE— Three separate forward and reverse cycles should be carried out to meet the requirements of three dynamic cycles as defined in 4.7.3.

B.4.2 Calculation for Combined Simulated Forward and Reverse Travel Mode Cycles—Since the forward and reverse modes of operation are two distinct modes, both the time and sound pressure level shall be measured as separate entities for each travel direction. The formula to be used for the calculation of the equivalent continuous A-weighted sound pressure level, $L_{pAeq,T}$, in decibels, for the combined dozer cycle is given by the following:

$$L_{pAeq,T} = 10 \log \frac{V_1 V_2}{V_1 + V_2} \left[\left(\frac{1}{V_1} \times 10^{0.1 L_{pAeq,1}} \right) + \left(\frac{1}{V_2} \times 10^{0.1 L_{pAeq,2}} \right) \right] \quad (\text{Eq. B1})$$

where:

V_1 is the velocity for the simulated forward travel mode.

V_2 is the velocity for the simulated reverse travel mode.

$L_{pAeq,1}$ and $L_{pAeq,2}$ are the quantities determined during the measurements at V_1 and V_2 velocities.

Use $1/V$ (where V represents velocity) for the in-place dynamic test instead of time used for the moving test to proportion the duration of forward and reverse travel.

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APPENDIX C

LOADERS

Preface—(This appendix forms an integral part of the document.)

C.1 Definition (in Accordance with ISO 6165)—A self-propelled crawler or wheeled machine with an integral front-mounted bucket-supporting structure and linkage, which loads or excavates through forward motion of the machine, and lifts, transports, and discharges material.

C.2 Safety and Operation—All relevant safety precautions and the manufacturer's operating instructions shall be followed during the test.

Any signal devices, such as forward warning horn or backup alarm, shall not be activated during the test.

C.3 Setting-Up of the Machine—The loader shall be equipped with the bucket designated for the manufacturer's production version. Engine and hydraulic systems shall be warmed to normal operating conditions for the prevailing ambient temperature.

All activating movements shall be carried out at maximum velocity but without relief valves or contacting end-of-travel mechanical barriers.

C.4 Operation of the Machine

C.4.1 The machine shall be positioned and elevated at the center of the hemisphere, on a stand, as defined in 4.4.

The machine shall be operated with an empty bucket in a lowered carry position $0.3 \text{ m} \pm 0.05 \text{ m}$ above the ground plane of the hemisphere. The machine shall be operated at maximum governed engine speed (high idle) in a constant simulated forward and reverse travel mode. The simulated forward travel velocity shall be close to but not exceeding 4 km/h for crawler machines and 8 km/h for wheeled machines. The matching gear ratio shall be used in the reverse travel mode, regardless of the velocity. For the majority of machines, this will be first forward and first reverse. Hydrostatic drive machines may use a range of 3.5 to 4 km/h (crawler) and 7 to 8 km/h (rubber-tired) because of difficulty in setting ground speed controls for exact travel speeds.

These modes of operation are with no movement of the bucket. If the lowest gear results in a velocity higher than the specified velocity, it shall be used with the engine operating at maximum governed speed (high idle). For hydrostatic drive machines with the engine at maximum governed engine speed (high idle), the ground speed control shall be set to match the specified velocities stated.

NOTE—Three separate forward and reverse cycles should be carried out to meet the requirements of three dynamic cycles as described in 4.7.3.

C.4.2 Calculation for Simulated Travel Modes—Since the simulated forward and reverse modes of operation are two distinct modes, both the time and sound pressure level shall be measured as separate entities for each travel direction. The formula to be used for the calculation of the equivalent continuous A-weighted sound pressure level, $L_{pAeq,3}$, in decibels, for the combined loader travel cycle is given by the following:

$$L_{pAeq,3} = 10 \log \frac{V_1 V_2}{V_1 + V_2} \left[\left(\frac{1}{V_1} \times 10^{0.1 L_{pAeq,1}} \right) + \left(\frac{1}{V_2} \times 10^{0.1 L_{pAeq,2}} \right) \right] \quad (\text{Eq. C1})$$

where:

V_1 is the velocity for the simulated forward travel mode.

V_2 is the velocity for the simulated reverse travel mode.

$L_{pAeq,1}$ and $L_{pAeq,2}$ are the quantities determined during the measurements at V_1 and V_2 velocities.

Use $1/V$ (where V represents velocity) for the in-place dynamic test instead of time used for the moving test to proportion the duration of forward and reverse travel.

C.4.3 Stationary Hydraulic Mode—The engine shall be operated at its maximum governed speed (high idle). The transmission control shall be set to neutral. Raise the bucket from the carry position to 75% of maximum lift height and then return to carry position three times. This sequence of events is considered to be a single cycle for the stationary hydraulic mode.

NOTE—The single cycle is repeated three times to meet the requirements of three dynamic cycles as defined in 4.7.3 $L_{pAeq,4}$ is the energy average L_{eq} .

C.4.4 Calculation for Combined Cycles in Travel and Stationary Hydraulic Modes—Calculate the combined equivalent continuous A-weighted sound pressure level, $L_{pAeq,T}$, in decibels, for a total loader cycle using the following equation:

$$L_{pAeq,T} = 10 \log [0.5 \times 10^{0.1 L_{pAeq,3}} + 0.5 \times 10^{0.1 L_{pAeq,4}}] \quad (\text{Eq. C2})$$

where:

$L_{pAeq,3}$ is the quantity determined in the travel mode over the specified travel path.

$L_{pAeq,4}$ is the quantity determined with the loader in the stationary hydraulic mode.

APPENDIX D

BACKHOE LOADERS

Preface—(This appendix forms an integral part of the document.)

D.1 Definition—A self-propelled wheeled machine with a main structural support designed to carry both a front-mounted bucket loading mechanism and a rear-mounted backhoe. When used in the backhoe mode, the machine normally digs below ground level with bucket motion towards the machine. The backhoe lifts, swings, and discharges material while the machine is stationary. When used in the loader mode, the machine loads or excavates through forward motion of the machine, and lifts, transports, and discharges material.

D.2 Safety and Operation—All relevant safety precautions and the manufacturer's operating instructions shall be followed during the test.

Any signal devices, such as forward warning horn or backup alarm, shall not be activated during the test.

D.3 Setting-Up of the Machine—The backhoe loader shall be equipped with the backhoe and bucket designated for the manufacturer's production version. Engine and hydraulic systems shall be warmed to normal operating conditions for the prevailing ambient temperature.

For backhoe operation, the engine governor control shall be set to the maximum position (high idle) or to the position specified for use by the manufacturer. All actuating movements shall be carried out at maximum velocity but without activating relief valves or contacting end-of-travel mechanical barriers.

D.4 Operation of the Machine

D.4.1 Test Site Measurement Surface—For all operating modes of backhoe loaders the test site measurement surface shall be a hard reflecting plane, as specified in 4.1.

D.4.2 Backhoe Operation of the Machine—Carry out backhoe mode of operation of the machine in accordance with the procedures specified in A.4.1 and A.4.2, except substitute 45 degrees for each 90-degree angle specified in these subclauses.

D.4.3 Loader Operation of the Machine—Carry out this operation in accordance with the procedure specified in Section C.4 and with the bucket of the backhoe in a carry position.

D.4.4 Calculation for Combined Cycles in Backhoe and Loader Modes of Operation—Calculate the combined equivalent A-weighted sound pressure level, $L_{pAeq,T}$, in decibels, for a total backhoe loader cycle using the following equation:

$$L_{pAeq,T} = 10 \log [0.8 \times 10^{0.1 L_{pAeq, backhoe}} + 0.2 \times 10^{0.1 L_{pAeq, loader}}] \quad (\text{Eq. D1})$$

where:

$L_{pAeq,backhoe}$ is the quantity determined in the backhoe mode of operation.

$L_{pAeq,loader}$ is the quantity determined in the loader mode of operation.