Measurement of Whole Body Vibration of the Seated Operator of Off-Highway Work Machines — SAE J1013 JAN80

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SAE Recommended Practice

Report of the Tractor Technical Committee and Construction and Industrial Machinery Technical Committee, approved August 1973, completely revised by the Off-Road Machinery Technical Committee and Agricultural Tractor Technical Committee January 1980, editorial change January 1980.

1. Purpose—This recommendation defines a method for the measurement
ed. of the whole body vibration to which the seated operator of off-highway self-propelled work machines is exposed while performing an actual or simulated operation. It applies to vibration transmitted to the operator through the seat.

2. Scope—In the main body of this recommendation, conditions are defined for measuring and recording whole body vibration of the seated
ed. operator of off-highway self-propelled work machines. The specification of instruments, analytic methods, and description of site and operating conditions allows the measurements to be made and reported with an acceptable precision. The procedure includes means of weighting the vibration level at different frequencies as specified in ISO 2631 (Ref. 1). A standard format for reporting spectral data is recommended.

The definitions, instruments, and analytic methods also apply to simulated tests for operator vibration as performed in laboratories.

This procedure is a measuring method only and is not intended for the evaluation or selection of seating systems.

3. Definitions

3.1 **Letter Symbols**

a	—	instantaneous acceleration
a_f	—	rms value of 1/3 octave acceleration having center frequency f
a_w	—	frequency weighted acceleration signal
a_{wf}	—	weighted rms acceleration calculated as described in paragraph 5.4.1, 5.4.2, or 5.4.3
ed. B_e	—	resolution bandwidth of a frequency analysis, Hz
f	—	frequency
rms	—	root-mean-square
T	—	analysis time duration, seconds
m/s^2	—	acceleration units, meters per second squared
Hz	—	hertz, standard notation for frequency, cycles per second
W_f	—	frequency dependent, dimensionless weighting factor
G	—	acceleration of gravity, by international agreement equal to 9.80665 m/s^2 at sea level
PSD	—	Power Spectral Density expressed as mean square acceleration per unit bandwidth $(m/s^2)^2/Hz$

3.2 **Whole Body Vibration**—As used in this recommendation, this term means vibration transmitted to the body as a whole through the buttocks of a seated operator.

3.3 **Operator Seat**—Specifically for the purposes of this recommendation, that portion of the machine provided for the purpose of supporting the buttocks of the seated operator, including the seat suspension system.

3.4 **Frequency Analysis**—Process of arriving at a quantitative description of the amplitude of a vibration as a function of frequency.

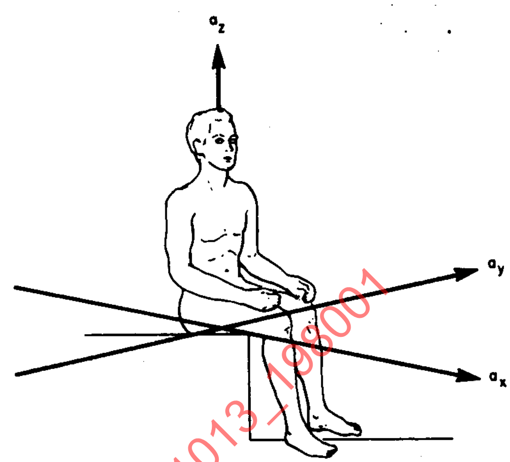
3.5 **Ride Meter**—A vibration instrument of the type described in SAE J1225, Development of a Frequency Weighted Portable Ride Meter.

3.6 **Measuring Period**—The time duration in which vibration data for analysis is obtained.

3.7 **Average Ground Speed**—Ratio of the distance traveled during the test period to the time period.

3.8 Other terminology used in this recommendation is in accordance with ANSI S1.1 and ISO 2041 (Refs. 3 and 4).

4. Vibration Measurement Axes—The vibration shall be measured along three mutually perpendicular axes, passing through a point on the interface between the operator and the seat. These axes are substantially vertical, longitudinal, and lateral (a_z, a_x, and a_y) with respect to the orientation of the seated operator and are defined in Fig. 1. The operator should sit in a typical upright position and should keep both hands in a normal position for operating the controls as suggested by Fig. 1. The seat shall be adjusted per manufacturer's instructions.



a_x, a_y, a_z = ACCELERATION IN THE DIRECTIONS OF THE x, y, z, AXIS
x-axis = DIRECTION OF THE BACK-TO-CHEST
y-axis = RIGHT-TO-LEFT SIDE
z-axis = BUTTOCKS-TO-HEAD

FIG. 1—MEASUREMENT AXES

5. Instruments

5.1 **Acceleration Transducers**—Vibration shall be sensed by acceleration transducers (accelerometers) in the mounting device described in paragraph 5.2.1. The accelerometers, together with their associated amplifiers, shall be capable of measuring rms acceleration levels ranging from 0.1 m/s^2—10 m/s^2 with a crest factor as great as 3. During the test the accelerometer and amplifier, with proper calibration for the test, shall have an accuracy of at least ±2.5% of the actual rms vibration levels in the frequency range from 0.3—40 Hz and at least ±6% of the actual rms vibration *ed.* levels in the frequency range from 40—80 Hz as calculated from the instrument specifications and the actual test conditions. See paragraph 5.5 for accuracy and frequency response requirements during calibration. The resonant frequency of the accelerometers shall be greater than 300 Hz. The accelerometers shall sustain instantaneous acceleration levels up to 100 m/s^2 without damage. Accelerometers in the mounting device (paragraph 5.2.1) and on the seat mounting base (paragraph 5.2.2) should be of similar type or model, with similar signal to noise ratios.

5.2 **Transducer Mounting**

5.2.1 Vibration Transmitted to the Operator—The accelerometers for sensing vibration transmitted to the operator shall be attached near the center of a thin disc 200 ± 5 mm in diameter placed between the operator and the seat cushion. The primary requirements for the disc are that it should provide a suitable mounting for the accelerometers, shall not adversely affect operator comfort, and shall not significantly distort the buttock-cushion load distribution. Either a rigid or semi-rigid disc may be used; however, the semi-rigid disc is recommended especially for soft or highly contoured cushions. Suggested disc designs are shown in Figs. 2 and 3. Either disc shall be placed on the seat so that the accelerometers are located midway between the ischial tuberosities and are aligned parallel to the measurement axes (Fig. 1). The disc should be taped or similarly attached to the cushion to maintain its location.

5.2.2 Vibration at the Seat Mounting Base—The vibration of the machine at the base of the seat shall be sensed by accelerometers attached to a rigid portion of the machine or seat mounting base. The accelerometers shall be located within the vertical projection of the seat cushion, not more than 100 mm from the vertical, longitudinal plane through the center of the seat, and shall be aligned parallel to the measurement axes (Fig. 1).

5.3 **Magnetic Tape Recorder**—The electrical signals generated by the

The ϕ symbol is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. If the symbol is next to the report title, it indicates a complete revision of the report.

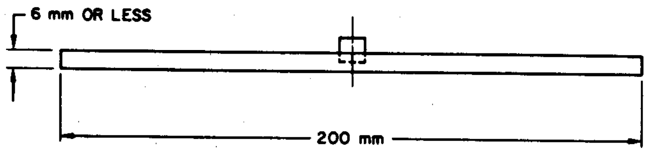


FIG. 2—SUGGESTED DESIGN FOR RIGID DISC WITH ACCELEROMETER ASSEMBLY BONDED AT CENTER

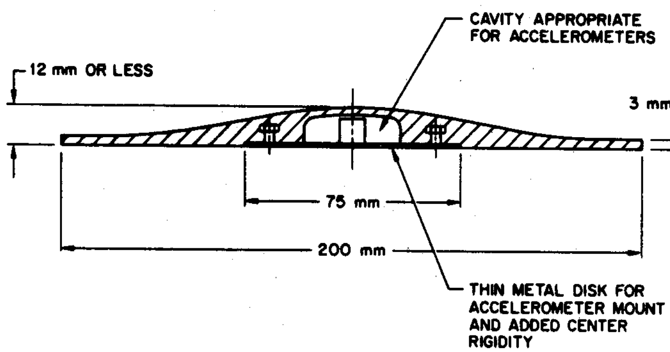


FIG. 3—SUGGESTED DESIGN FOR SEMI-RIGID DISC OF APPROXIMATELY 80-90 DUROMETER (A-SCALE) MOLDED RUBBER, PLASTIC, ETC.

transducers may be recorded on magnetic tape for later analysis. The magnetic tape recorder, with proper calibration for the test, shall be capable of a replay accuracy of at least ±3% of the rms value of the total signal within the frequency range from 0–80 Hz, as calculated from the instrument specifications and the actual test conditions. The tape recorder should
ed. meet current standards for alignment and distortion characteristics (Ref. 10).

5.4 **Frequency Weighting**—Frequency weighting may be achieved in any of three ways: by digital analysis of the acceleration into constant bandwidth levels, weighting the levels in individual bands and recombination; by analysis of the acceleration into 1/3 octave band levels, weighting the levels in individual bands and recombination; or by direct use of electrical filters in a frequency weighting *ride meter*. The three methods are described below in decreasing order of accuracy (accuracy as resulting from practical considerations of analysis equipment).

5.4.1 Constant Bandwidth Method—Each vibration tape recording, or vibration signal where a tape recorder is not used, shall be analyzed into constant bandwidth acceleration levels over the frequency range from 1–80 Hz by appropriate digital methods. The sampling time, T (in seconds),
ed. and resolution bandwidth, B_e (in Hz), shall satisfy the following:

ed. $$2 B_e T > 140 \qquad B_e < 0.3 \text{ Hz}$$

The mean square value of the digitized time data (time domain) should be compared to the mean square value of the spectral estimate (frequency domain). If these values differ, then the analysis procedure should be reviewed and corrected as necessary for possible errors such as improper scaling, wrong correction factor for the data time window (sampling window), or program errors.

The constant bandwidth rms levels shall each be multiplied by weighting factors calculated for each center frequency from Fig. 4 for a_z (vertical) vibration, or Fig. 5 for a_x or a_y (horizontal) vibration. A weighted acceleration value, a_{wf}, shall be calculated as the square root of the sum of the squares of the weighted constant bandwidth levels over the range 1–80 Hz.

5.4.2 One-Third Octave Bandwidth Method—Each vibration tape recording, or vibration signal where a tape recorder is not used, shall be analyzed into 1/3 octave component accelerations for the center frequencies of Table 1. The rms value of each component, a_f, shall be averaged over the duration specified for the measurement. The 1/3 octave values shall each be multiplied by the weighting factors, W_f, listed in Table 1, and a weighted acceleration, a_{wf}, value calculated for each recording as follows:

$$a_{wf} = \left[\sum_{f=1}^{80} W_f^2 \; a_f^2 \right]^{1/2}$$

To satisfy the following,

$$2 B_e T > 140$$ ed.

the minimum sampling time, T, is 300 s to insure sufficient statistical precision.

5.4.3 Frequency Weighting Ride Meter—The *ride meter*, if employed for direct indication of the weighted vibration, shall consist of an electronic weighting network incorporated between the transducer and a time integration stage. The weighting network shall have an insertion loss conforming to the curve in Fig. 4 for a_z (vertical) vibration, or Fig. 5 for a_x or a_y (horizontal) vibration. The loss shall not deviate from the curve by more than ±1 dB for frequencies between 1.1 and 10 Hz, and ±2 dB at any other fre- ed.
quency. The integration stage shall be capable of indicating the integral of the square of weighted acceleration, a_w, for the time period of the test run T. That is,

$$(a_{wf})^2 = \frac{1}{T} \int_{t=o}^{T} a_w^2 \; dt$$

Where conditions permit, a minimum sampling time of 300 s shall be used.

Note: The sampling time (methods of paragraphs 5.4.1, 5.4.2, and 5.4.3) when testing on a specific test track shall be the time required to traverse the track.

5.5 **Calibration**

5.5.1 General—Operating manuals or other literature furnished by the instrument manufacturer should be reviewed for both recommended operation of the instrument and precautions to be observed. The entire measurement and analysis system should be regularly calibrated by technically trained instrumentation personnel following manufacturer's recommendations for the adjustment and application of individual components.

Acceleration transducers should be calibrated in accordance with a suitable recognized calibration method such as outlined in ANSI S2.2-1959 (Ref. 6). In particular, the calibration procedures should ensure that the accelerometer sensitivity ($V/(m/s^2)$) varies less than ±2.5% of a mean value ed.
over the frequency range of 0–40 Hz and less than ±6% of a mean value ed.
over the frequency range of 0–80 Hz.

The effects of ambient temperature and humidity on the performance of all instruments shall be known. Instruments shall be operated within the temperature limits at which the required accuracy can be expected.

Field instrumentation should be protected from dust, moisture, excessive shock and vibration, etc.

5.5.2 For Tests—It is strongly recommended that technically trained personnel select the instrumentation for the actual test conditions and that the tests be conducted only by qualified persons trained in the current techniques of vibration measurement and analysis.

Multi-instrument measurement systems shall be checked for proper signal levels, terminating impedances, and cable lengths.

The general procedures described in the tilting support method (ANSI S2.2-1959) for static calibration of acceleration transducers should be used to obtain overall system acceleration sensitivity for each of the data channels. Tilting the sensitive axis of each transducer from the vertical through an angle of 180 deg in the field of gravity provides a peak-to-peak change in the output representing a 19.61 m/s^2 (2 G) change in input acceleration. The sensitive axis of each accelerometer should be independently aligned with the vertical and the 180 deg inverted position to within ±4 deg, and the peak-to-peak change in output voltage should be measured to within ±0.5%. This calibration should be made and recorded before ed.
and after each test series and at reasonable intervals during any extended test series. Each such calibration shall be compared to the internal electronic calibration of the overall instrument system.

The transducers used to measure the vibration transmitted to the operator need not be removed from the mounting disc (paragraph 5.2.1) provided

TABLE 1—VIBRATION WEIGHTING FACTORS

1/3 Octave Center Frequency, f	Weighting Factor, W_f		1/3 Octave Center Frequency, f	Weighting Factor, W_f	
	Vertical Vibration	Horizontal Vibration		Vertical Vibration	Horizontal Vibration
1.0	0.50	1.00	10.0	0.80	0.20
1.25	0.56	1.00	12.5	0.63	0.16
1.6	0.63	1.00	16.0	0.50	0.125
2.0	0.71	1.00	20.0	0.40	0.100
2.5	0.80	0.80	25.0	0.315	0.080
3.15	0.89	0.63	31.5	0.25	0.063
4.0	1.00	0.50	40.0	0.20	0.050
5.0	1.00	0.40	50.0	0.16	0.040
6.3	1.00	0.315	63.0	0.125	0.0315
8.0	1.00	0.25	80.0	0.10	0.025

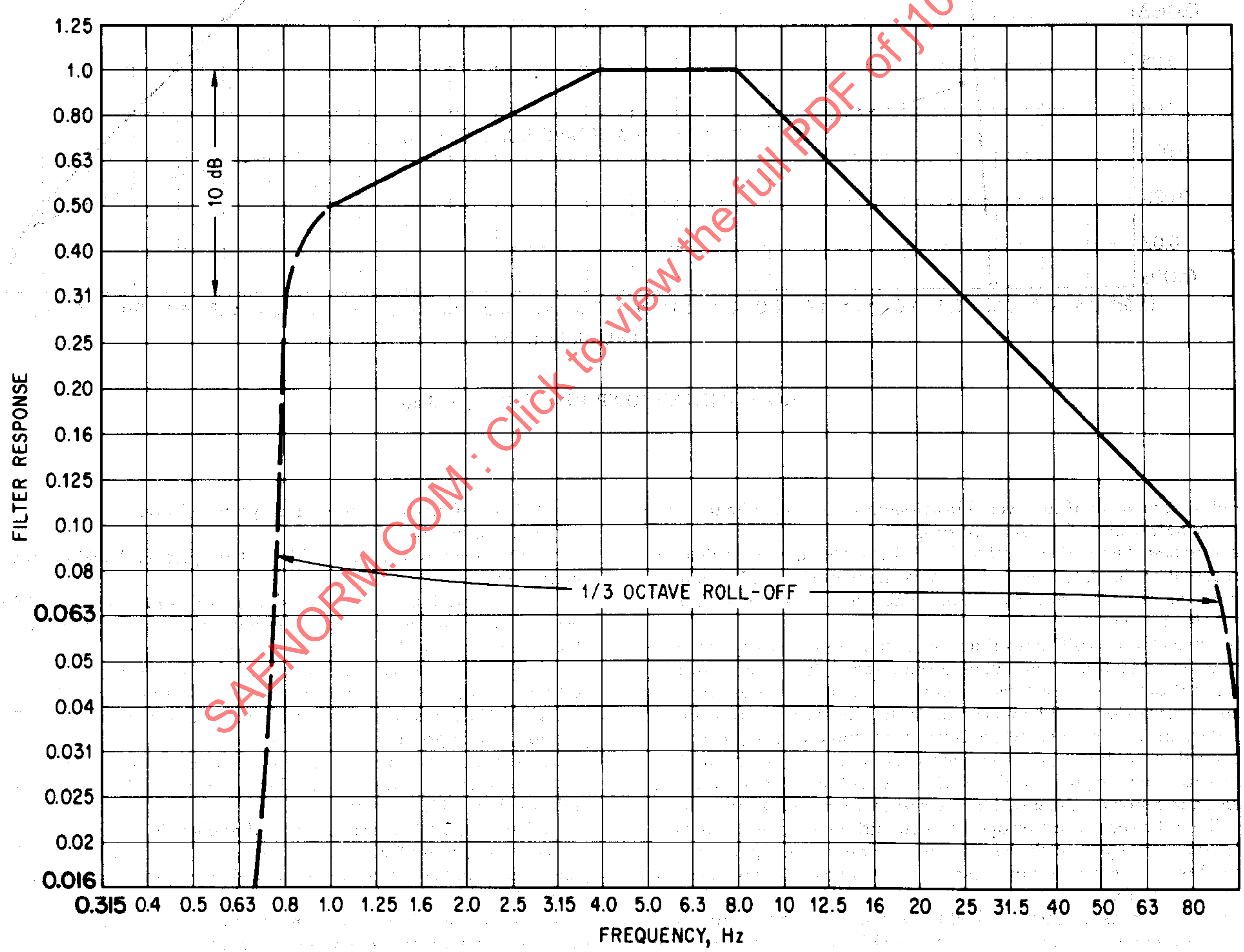


FIG. 4—FILTER RESPONSE IN VERTICAL MODE, a_z

the sensitive axis of each transducer can be located within the prescribed tolerance. Zero frequency response of the instrumentation system is required for this calibration procedure.

An internal electronic calibration of the overall instrument system shall be recorded immediately before and after each test run, and corrections made as necessary to maintain the required test accuracy.

The output from each accelerometer amplifier shall be nulled by proper balancing and zeroing techniques while the accelerometers are in test position between the seat and the seated operator and on the seat mounting base or test stand.

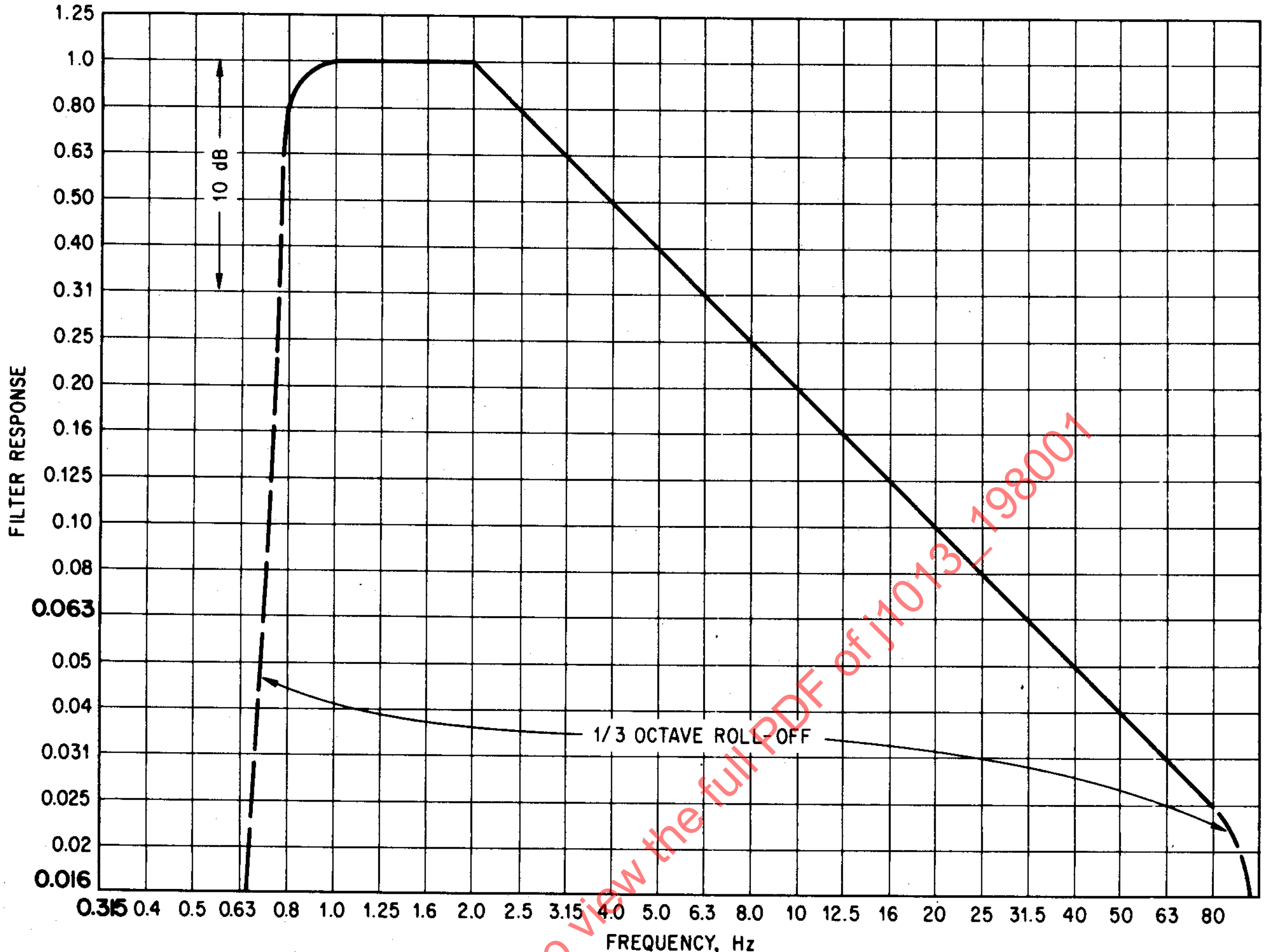


FIG. 5—FILTER RESPONSE FOR a_x and a_y

The null or zero value of the overall instrument system shall be recorded immediately before and after each test run.

6. Measurement Site and Operating Conditions—Measurements shall be made on actual or simulated work sites. Measurement sites and operating conditions shall be appropriate for the machine whose vibration characteristics are being measured.

Ground speed has a significant influence on vibration intensity. Where appropriate for agricultural equipment, ground speed shall be kept relatively constant throughout each measuring period and average ground speed during the period shall be reported. If the vibration test is being conducted during a work cycle which involves several operating speeds and/or operating conditions, then a separate measuring period should be devoted to each such segment of the work cycle and the corresponding results shall be so reported along with a description of the work cycle involved. Where the speeds and/or operating conditions are constantly varying during the work cycle, such that discrete separate cycle segments are extremely short in duration or non-existent, the work cycle can be measured on a continuous basis. *ed.*

In all cases, the measuring period shall be as long as is required to obtain vibration measurements representative of the machine and operating conditions. The minimum measuring period is stated in paragraph 5.4. If the vibration test is conducted during a work cycle which involves several discrete separate segments, the minimum measuring period shall be applied to each such segment. The minimum measuring period may be obtained by combining like segments during either the actual test or the data analysis. *ed.*

The operating conditions shall be recorded in detail, including general condition of the site (soil characteristics, grades, etc.).

7. Machine Description—The following details should be reported:

a) Machinery manufacturer.
b) Model designation.
c) Type of machine suspension system, if any.
d) Serial number.
e) Other equipment on machine—that is, ripper, backhoe, towed implements, etc.
f) Total machine weight (mass) and front and rear axle weights. If the test is conducted during transport conditions, front and rear axle weights shall be reported in the transport position. *ed.*
g) For wheeled machines—tire manufacturer, tire construction (radial or bias ply), tire code designation per SAE J711c for agricultural machines or SAE J751c for earthmoving machines, tire size, ply rating, inflation pressure, and approximate state of wear.
h) For track-type machines—type of shoe, number of grousers per shoe.
i) Type and amount of ballasting, such as wheel and frame weights, and/or ballast added to tires.
j) Tread and wheel base spacing, if applicable.
k) Description of seat and seat suspension system, if any. If seat suspension system has a variable spring or damping rate, the setting should be reported.

Also any known deviations from the machinery manufacturer specifications and recommendations should be reported.

8. Operator—Operator height and weight shall be reported.

9. Reported Vibration Levels—The weighted vibration level in each of the three directions shall be reported separately, to the nearest 0.1 m/s^2. If the 1/3 octave analysis method has been employed, the weighted and/or unweighted rms in each 1/3 octave band may be presented graphically, preferably on log-log scales. For engineering uses, constant bandwidth data presented as unweighted power spectral density plots on linear scales is preferred.

In all cases, the time duration, T, of the data should be reported. Power spectral density plots should be labeled with the resolution bandwidth, the