Information Circular 9363

# Vibration Environment of Instrumentation for Scrapers and Loaders

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**UNITED STATES DEPARTMENT OF THE INTERIOR**
**Bruce Babbitt, Secretary**

**BUREAU OF MINES** ___

# CONTENTS

## ILLUSTRATIONS

## TABLES

# UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

| | | | | |
|---|---|---|---|---|
| $G^2/Hz$ | square standard acceleration of gravity per hertz | | lb | pound |
| | | | m | meter |
| h | hour | | | |
| | | | $(m/s^2)^2/Hz$ | square meter per second per second per hertz |
| Hz | hertz | | | |
| kg | kilogram | | pct | percent |

# VIBRATION ENVIRONMENT OF INSTRUMENTATION FOR SCRAPERS AND LOADERS

By Walter K. Utt[1] and John C. Gagliardi[2]

## ABSTRACT

The vibration levels of the heavy machines used in surface mining are much greater than for vehicles used on highways. In order to assure the proper functioning of electronic equipment placed on the surface mining vehicles, the U.S. Bureau of Mines has conducted a program of field measurements to define their vibration environment. The information in this report is for a class of vehicle that has a blade for scraping and wheels with rubber tires. The statistical information derived from these measurements can be used as a basis for laboratory testing to qualify equipment for a surface mining vehicle of this class.

The envelope that would encompass 99 pct of the vibrations encountered in normal operations is presented for each location on the vehicle. The five locations for which data were recorded are the floor of the cab, the engine, the frame, the drive train (gear, differential, and torque converter), and the axle. Tabulated data are provided for those who wish to use a different probability level. The appropriate test profile for the laboratory testing can be determined from the information presented in this report.

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# INTRODUCTION

The vibrational environment of scrapers and loaders used in surface mining operations is determined for the use of those who design or select electronic instrumentation for these vehicles. The vibration data are for the normal operation of scrapers and loaders that have rubber tires. Graders are included in this class of vehicle. Vehicles that run on tractor treads, crawlers, have different vibrational characteristics as indicated by the vibration spectra. The crawlers are not included in this report. Although loaders exhibit a low-frequency rocking motion when moving loaded, the spectra of scrapers, loaders, and graders are qualitatively similar, with the higher acceleration levels occurring below 600 Hz. The variation in the acceleration level of a vehicle is relatively large because of operating conditions such as scraping rocks. The qualification of equipment, with respect to vibrational acceleration, can be based upon the representative data presented in this report. The equipment to be qualified may be electronic instrumentation, controls, or sensors.

The vibration levels of the heavy machines used in surface mining are much greater than for trucks used on highways. In order to assure the proper functioning of electronic equipment placed on surface mining vehicles and to improve the safety and efficiency of mining, the U.S. Bureau of Mines has conducted a program of field measurements of acceleration that has extended over several years. Several mining companies agreed to cooperate in this project to define the vibration environment. The statistical information from these measurements can be used as a basis for laboratory testing to qualify equipment for a surface mining application. The vehicles were categorized by function and feature. Haul trucks were evaluated and those results will be published in a separate report. This report pertains to the vehicles that have blades for scraping and wheels with rubber tires.

An engineer can use a laboratory test to evaluate an instrumentation package while it is in the prototype stage of development, which should reduce application problems and life-cycle costs. Dissatisfied customers and costly redesigns may be avoided. The increased reliability of the product should result in increased safety and increased customer satisfaction.

Most of the vibration testing in the United States is conducted in accordance with military standards or the standards of the Society of Automotive Engineers (SAE). Military Standard 810E (MIL-STD 810E), "Environmental Test Methods and Engineering Guidelines," presents test methods for determining the effects of natural and induced environments on equipment used in military applications (1).[3] Test methods are described for vibration, temperature, humidity, dust, etc. The vibration qualification testing consists of functional testing and endurance testing. It is recommended that test profiles based upon data for the specific type of vehicle and the expected operations should be used when available.

Common failures in electrical equipment attributed to vibration must be avoided. These common failures are described in MIL-STD-810E (1) and in SAE J1211 (2).

The qualification of equipment, with respect to vibrational acceleration, should be based upon the most representative data which are available to the designer. If sufficient data are available for the specific vehicle and the specific location, then that data should be used. However, that specific information may not be readily available. Consequently, the USBM has obtained representative data for the class of vehicle that includes scrapers and loaders with rubber tires.

Acceleration measurements were obtained for the following five different locations on the vehicles: (1) the floor of the operator's cab, (2) the engine and accessories, (3) the frame or yoke, (4) the drive train elements (gear, differential, and torque converter), and (5) the axle. The statistics from the field measurements were used to establish the vibration levels for normal operations at surface mines. An instrumentation package could be placed in any of the data source locations. However, the floor, the engine, and the frame are more likely locations for additional instrumentation. The information for the most appropriate location, in the judgment of the engineer, can be used as a basis for the vibration test level of the specific item to be installed on the vehicle.

## DATA ANALYSIS

Field measurements of acceleration were obtained for different vehicles within the category with the cooperation of four surface mining operations. Accelerometers were placed in the selected location on the vehicle in order to record vibrational accelerations in three dimensions. The data were transmitted, via telemetry, to a van with a precision tape recorder, as indicated in figure 1. The subsequent analysis of the vibration spectra was conducted in the Vibration Laboratory of the USBM at the Twin Cities Research Center.

The field measurements were taken for representative operations at surface mines. Accelerometers were mounted on blocks that were bonded to the vehicle at the

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[3]Italic numbers in parentheses refer to items in the list of references at the end of this report.
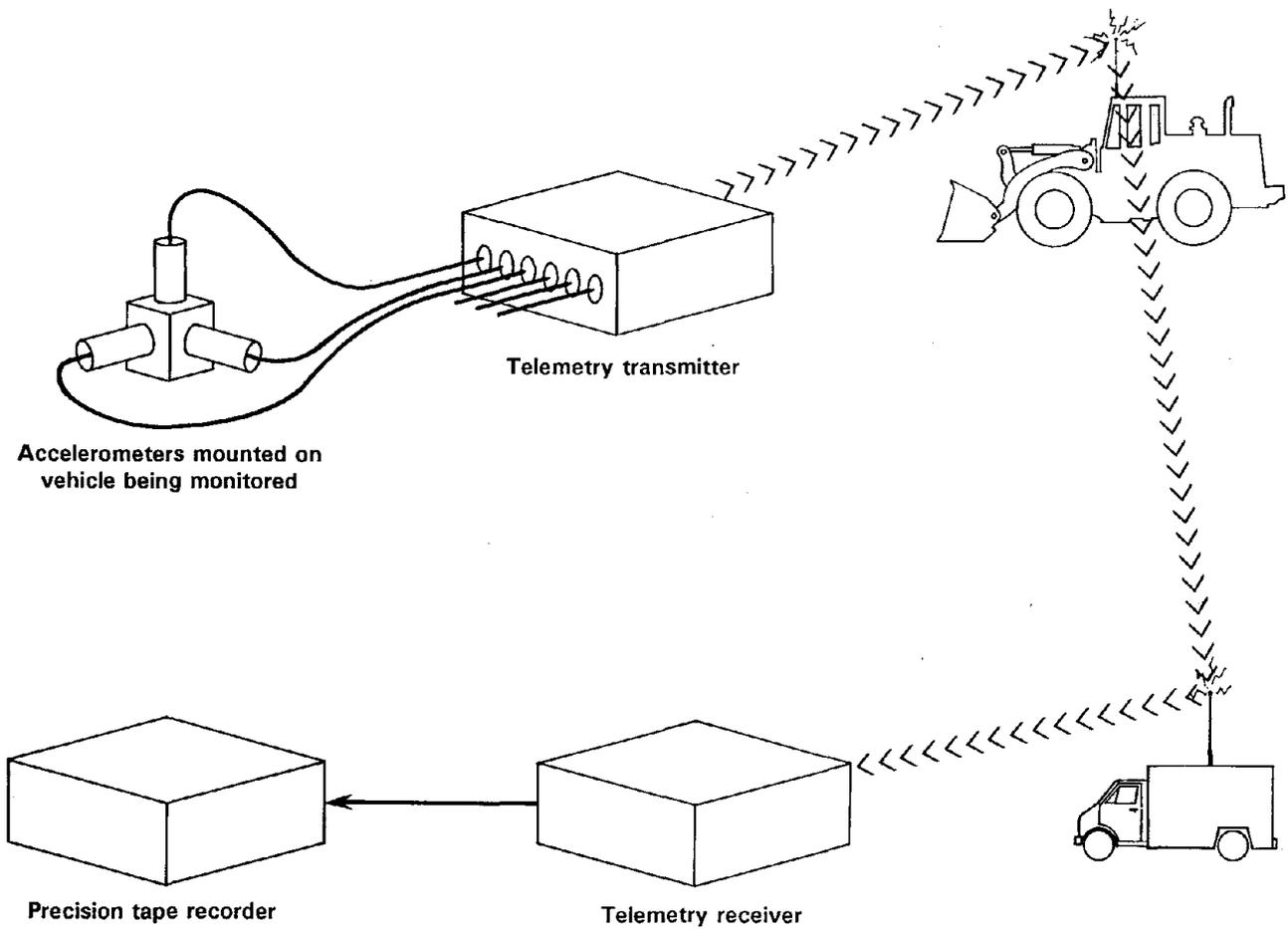
**Figure 1.—Vibration data recording setup.**

selected locations, as depicted in figure 2. The accelerometers mounted on the frame usually were mounted near the wheel. Those mounted on the engine usually were mounted on a valve cover. The accelerometers were mounted in groups of three to cover the three axes. Each accelerometer had a frequency response well above the required 2,000 Hz. Data were recorded for the vehicles engaged in normal activities such as scraping, loading, moving empty, and moving loaded. The data sources are indicated in table 1. Multiple data sets were recorded for each activity.

**Table 1.—Data sources and vehicle descriptions**

| Mine | Type | Size | |
|---|---|---|---|
| | | lb | kg |
| Midwest Aggregate Producer. | Wheel loader ........ | 58,000 | 26,310 |
| Northern Minnesota Taconite. | Grader ............ | 45,280 | 20,540 |
| Southwestern Copper | Wheel bulldozer ...... | 45,908 | 20,820 |
| Idaho ........... | Wheel tractor-scraper .. | 131,000 | 59,420 |



**Figure 2.—Accelerometers mounted on vehicle.**

4

Since vibrations in the range from 4 to 2,000 Hz were to be analyzed, the data from the tape were filtered through an anti-aliasing filter with a corner frequency of 2,000 Hz. The analog-to-digital converter had 12 bits of precision. In order to obtain good quality data, the sampling rate was 8,000 samples per second, twice the Nyquist rate. The digital signal processing consisted of obtaining the power spectral density (PSD) by means of the fast Fourier transform for each channel of acceleration data.

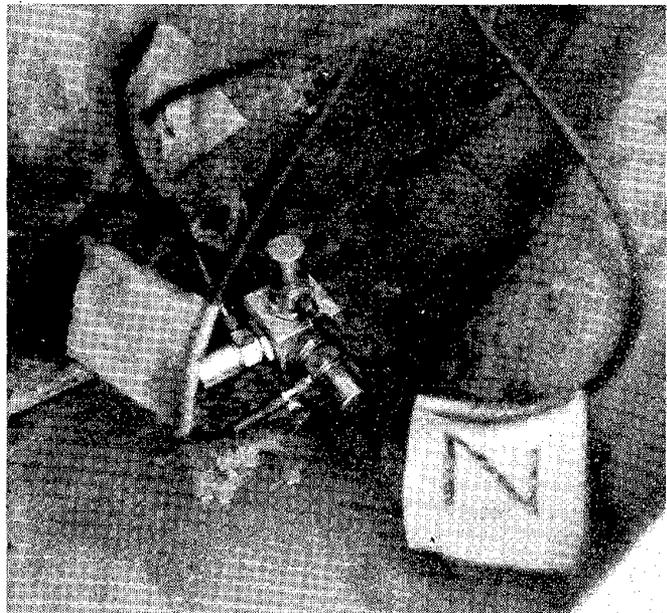The actual input disturbance is a complex combination of factors. The major sources of disturbance are (1) the engine and the drive train, which would be periodic at a constant speed, but that input is modified by gear shifting and speed changes; (2) the road, which is a random input; and (3) the shock of scraping and loading, which is an intermittent, impulsive input.

These vehicles do not have a conventional suspension; they have only the rubber tires to cushion any shocks. However, the driver's seat has a mechanical suspension that may be represented as a harmonic oscillator with damping in the vertical component (z axis). The vehicle frame can transmit disturbances without much attenuation in the forward (x axis) and the lateral (y axis) directions. A rocking (rotational) motion also may occur. The response of the vehicle is influenced by all of these factors.

A spectral analysis was conducted in order to determine the acceleration PSD variation with frequency. Random vibration spectra are defined in terms of acceleration spectral density profiles, which relate energy density levels to specific frequency bands. The data are tabulated for one-third-octave frequency bands, which provides finer resolution at the lower frequencies. The lower frequencies are of greater interest because the maximum accelerations usually are observed at the lower frequencies. The peak value within each one-third-octave frequency band was extracted for each case. The use of band peak values rather than band average values is conservative. Since equipment is the concern rather than the human operator, there was no frequency weighting. The data from several field test cases were compiled for each location on a vehicle, and the vibrational statistics were calculated. The data for all three axes were combined to determine an omnidirectional vibration environment. Consequently, designers need not be concerned about different test levels for different orientations of their electronics packages.

The acceleration mean and standard deviation are presented in tabular form so designers can construct their own envelope for the probability level they regard as appropriate. The profile for the vibration test can be based upon the envelope. A test profile is a sequence of straight

line segments that are fitted around an envelope. Sample profiles for common carriers can be found in reference 1, figure 514.4-2. An envelope that would encompass at least 99 pct of the typical vibrations was determined. The omnidirectional acceleration PSD for the 99-pct envelope is

$$a_{99} = \mu + 2.33 \cdot \sigma, \tag{1}$$

where $\mu$ = mean of the sample,

and $\sigma$ = standard deviation of the sample.

The coefficient, 2.33, from the normal curve of error corresponds to the 99th percentile. If a different probability level is of interest, one can use the appropriate coefficient in a similar equation to obtain the envelope from the tabulated data. Some designers use a 95-pct envelope, which would have a coefficient of 1.645.

The vibrational environment was determined for five different locations on a vehicle, (1) the floor of the cab, (2) the engine or hydraulic pump, (3) the frame or yoke, (4) the drive train (gear, differential, and torque converter), and (5) the axle. The number of cases in a category ranged from 18 for the axle to 51 for the floor. Each case is an average of 12 sets of data for a particular vehicle activity. Designers can select the most appropriate data envelope for testing their instrumentation packages. The nearest location or a more severe acceleration level may be selected. A test profile can be based upon the corresponding envelope and the selected test level.

Functional testing is performed to demonstrate that the equipment will function properly in the expected vibration environment. These tests are usually based upon the highest vibration levels that are expected in normal service. Although some preliminary developmental testing may include resonant search by means of a low-level, swept-sine input, broadband random vibration generally is used for the functional qualification testing. In the case of track-laying vehicles, known resonant peaks may be represented as a narrowband random superimposed on a broadband random vibration base, but that is not done in this report. The suggested test durations are presented in reference 1, table 514.4-VII. The minimum test duration for a general application is 1 h per axis.

Endurance testing is performed to assure that the equipment will continue to perform properly throughout its expected lifetime. Endurance tests usually are conducted at higher acceleration levels than the functional tests in order to reduce the test time. The fatigue relationship that is used for the test time scaling is presented

in reference 1, section I-4.7, page 514.4-46. The time scaling would be limited by the maximum allowable stress for the unit under test and possibly by the test equipment. A preliminary test may be used to demonstrate that the unit under test can tolerate the higher acceleration level. Designers may scale the appropriate envelope for endurance testing at their discretion.

The use of the military standard approach to vibration testing in underground mining machinery was evaluated in reference 3. The use of MIL-STD-810B vibration test curves for tracked vehicles was recommended for that

application. This report recommends the use of the military standard test methods, which are described in MIL-STD-810E, in conjunction with the vibration levels determined here for scrapers and loaders in a surface mining operation.

The vibration spectral analysis was conducted in a manner consistent with that described in reference 4, pp. 142-145.

The selection of vibration test levels and the use of environmental testing are discussed in references 5 and 6.

## DISCUSSION OF RESULTS

The vibration level of the floor of the cab is indicated in figure 3. The mean acceleration PSD for the 51 cases (612 data sets) in which measurements were obtained is presented as a function of frequency. A case is an average of 12 sets of data for a particular activity of a vehicle. Data for all three dimensions are averaged to yield an omnidirectional mean. The highest acceleration level is near the low-frequency end of the range. The acceleration level is high until about 600 Hz, where it begins to roll off. The acceleration decreases with increasing frequency, in an almost linear fashion, to 2,000 Hz. The standard deviation also is presented in figure 3. The deviation has the same order of magnitude as the mean. The acceleration mean and standard deviation are presented in table 2. The data are tabulated for one-third-octave frequency bands, which provides finer resolution at the lower frequencies. One can construct an envelope for any desired probability level from that tabulated information by using the appropriate coefficient in equation 1. An acceleration test profile, based upon the envelope, can be used for laboratory testing. An envelope that would encompass 99 pct of the vibrations encountered in normal operations is presented in figure 4. An example of a profile for laboratory testing is indicated by the dashed lines.

The mean vibration level of the engine is indicated in figure 5. The mean acceleration PSD is presented as a function of frequency. The spectrum of an individual case would show the engine harmonics, but the averaging of several cases with differing engine rotational speeds tends to smooth the resulting curve. There is a peak between 200 and 250 Hz. The acceleration level decreases with increasing frequency above 300 Hz. An envelope that would encompass 99 pct of the vibrations encountered in normal operations is presented in figure 6. The mean and standard deviation for the engine acceleration are presented in table 3 for the one-third-octave frequency bands.

The vibration level of the engine is more than twice as high as the vibration level of the floor of the cab. The engine compartment is a more severe vibrational environment for an instrumentation package.

The mean vibration level of the frame is indicated in figure 7. There is a peak at 300 Hz, and beyond that, a decreasing vibration level with increasing frequency. The combined effects of the operations, such as scraping, with the engine disturbance produce the resulting vibration power spectrum. The mean and standard deviation for the frame vibrations are presented in table 4. An envelope that would encompass 99 pct of the vibrations encountered in normal operations is presented in figure 8.

The mean vibration level of the gear and differential housing is indicated in figure 9. The trend is again a decreasing vibration level with increasing frequency, but there are two peaks superimposed, one at about 150 Hz and another at about 600 Hz. The mean and standard deviation for the gear and differential housing are presented in table 5. An envelope that would encompass 99 pct of the vibrations encountered in normal operations is presented in figure 10. The vibration level of the gear is a little lower than that for the engine, but higher than that for the floor of the cab. If one has a specific description of the gear meshing, a more detailed analysis of the complex gear vibrations may be conducted, but that is beyond the scope of this report.

The mean vibration level of the axle is indicated in figure 11. The trend is again a decreasing vibration level with increasing frequency, but there is a low-frequency peak. The mean and standard deviation for the axle are presented in table 6. An envelope that would encompass 99 pct of the vibrations encountered in normal operations is presented in figure 12. The vibration level of the axle is lower than that of the engine.

Figure 3.—Floor mean vibration, acceleration PSD versus frequency.



Figure 4.—Floor 99-pct vibration envelope, acceleration PSD versus frequency.

Figure 5.—Engine mean vibration, acceleration PSD versus frequency.



Figure 6.—Engine 99-pct vibration envelope, acceleration PSD versus frequency.

Figure 7.—Frame mean vibration, acceleration PSD versus frequency.



Figure 8.—Frame 99-pct vibration envelope, acceleration PSD versus frequency.

Figure 9.—Gear-differential mean vibration, acceleration PSD versus frequency.



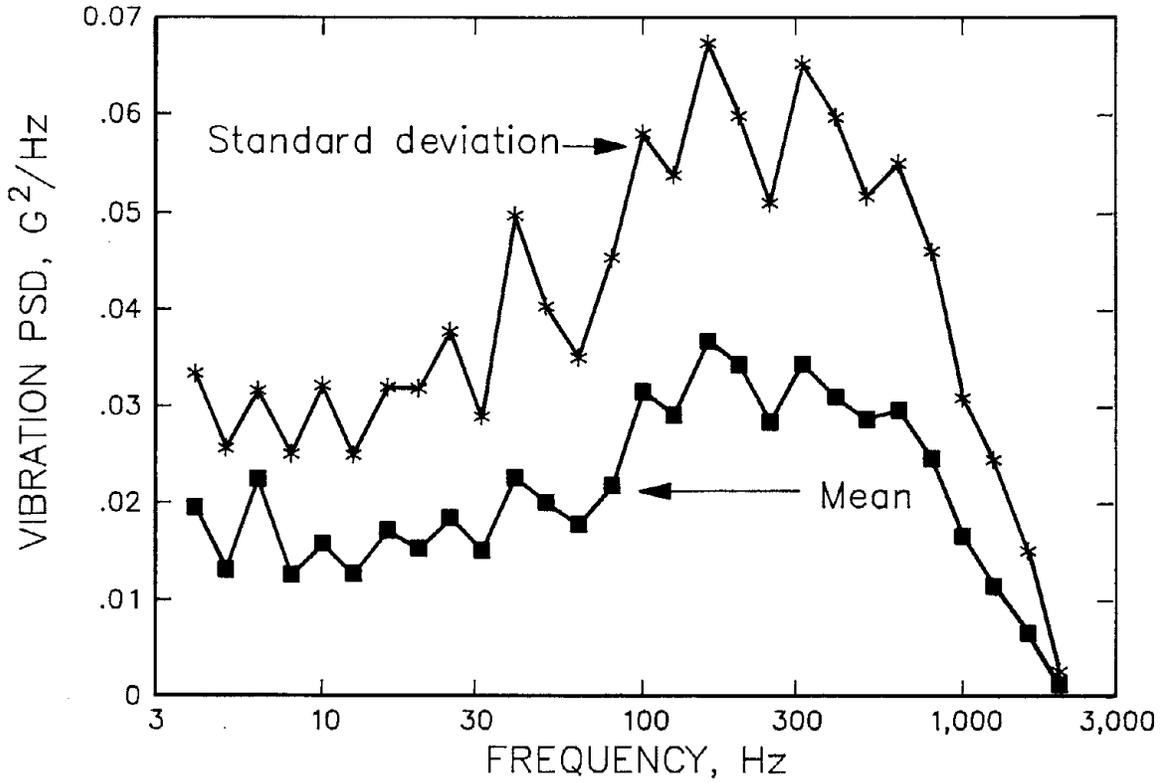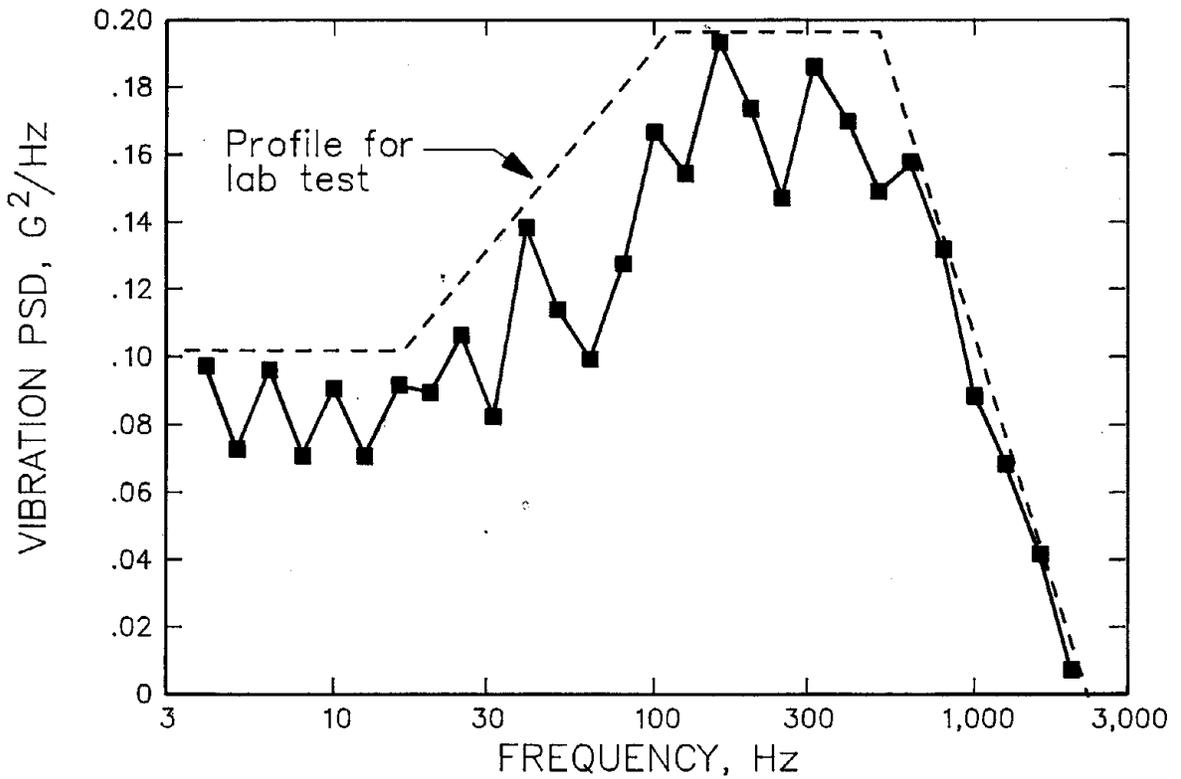Figure 10.—Gear-differential 99-pct envelope, acceleration PSD versus frequency.

Figure 11.—Axle mean vibration, acceleration PSD versus frequency.



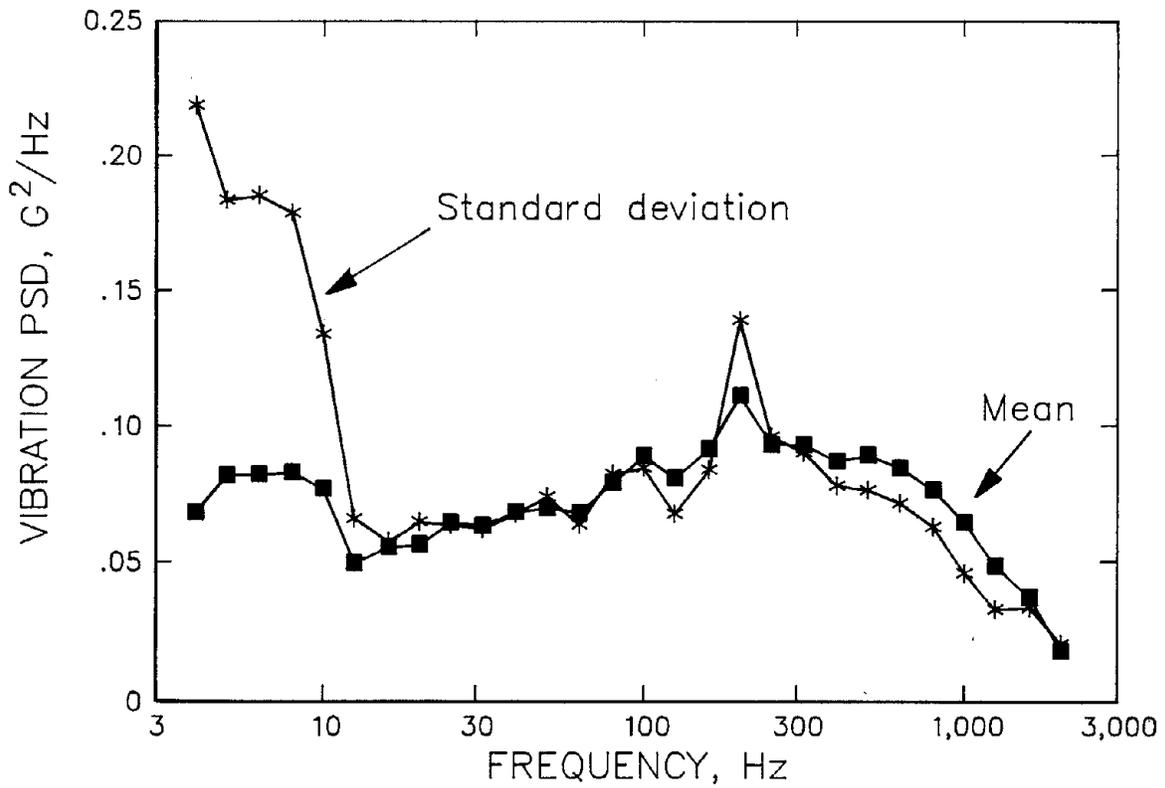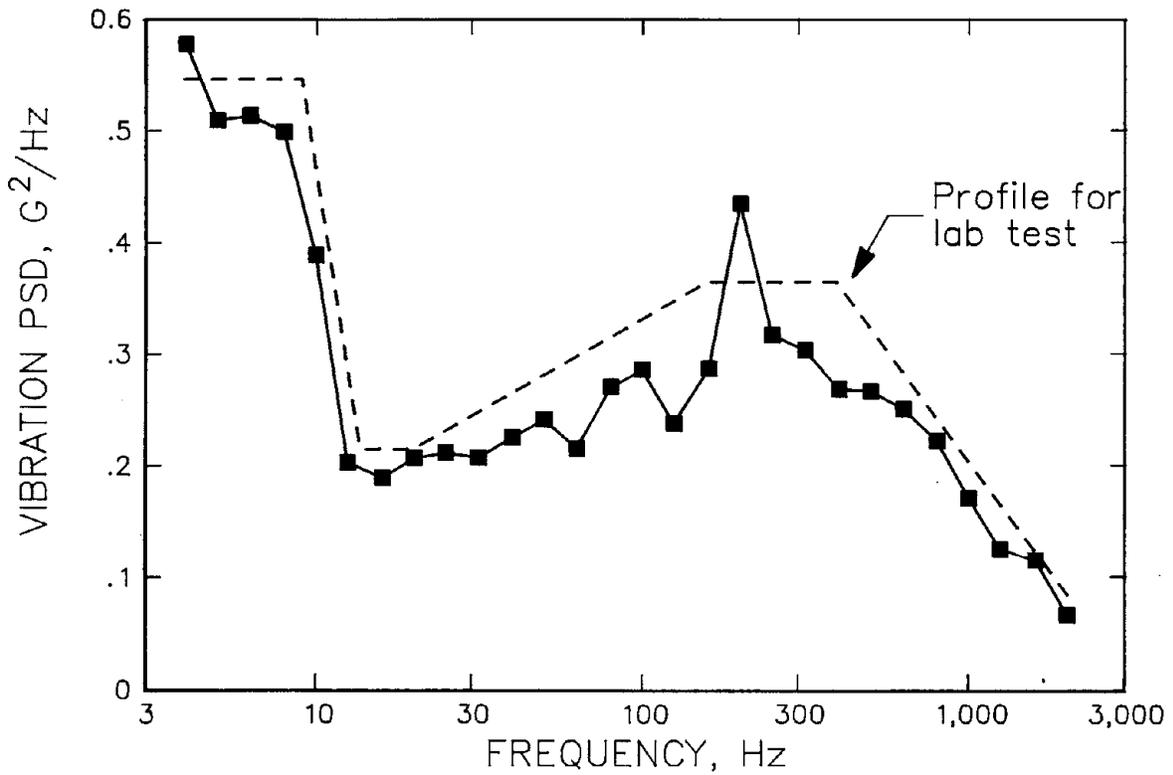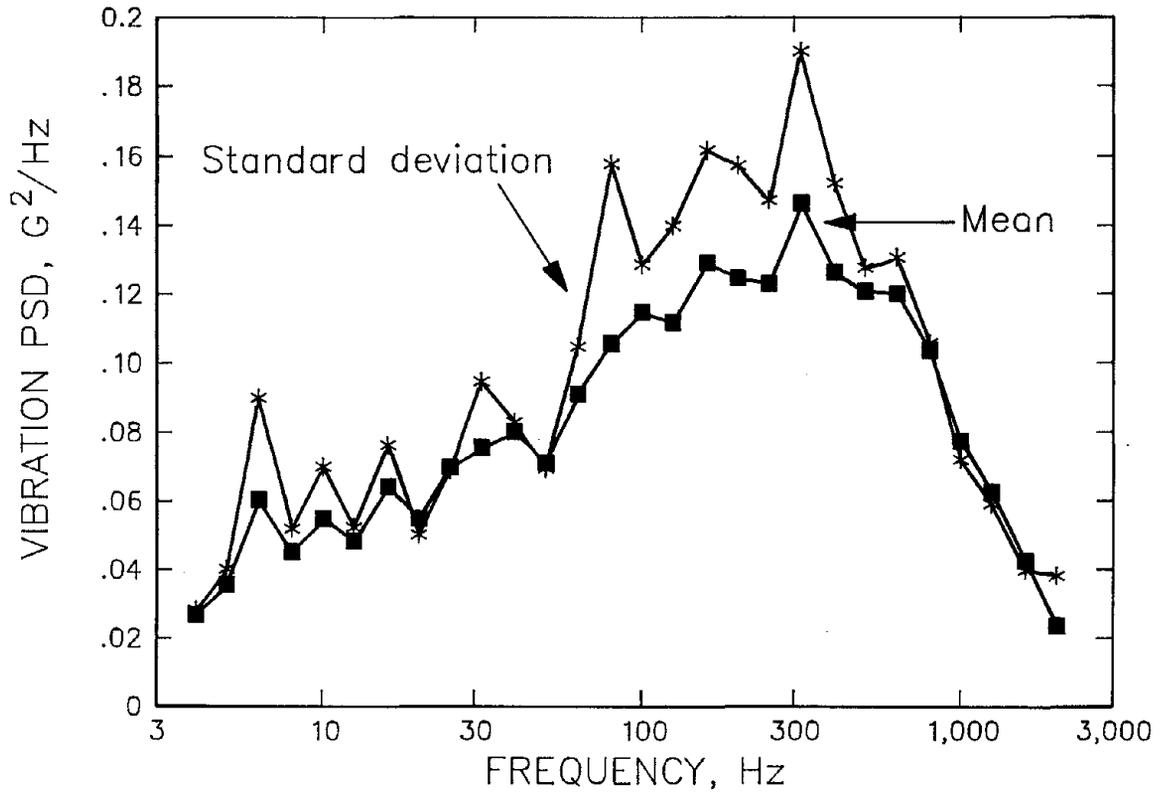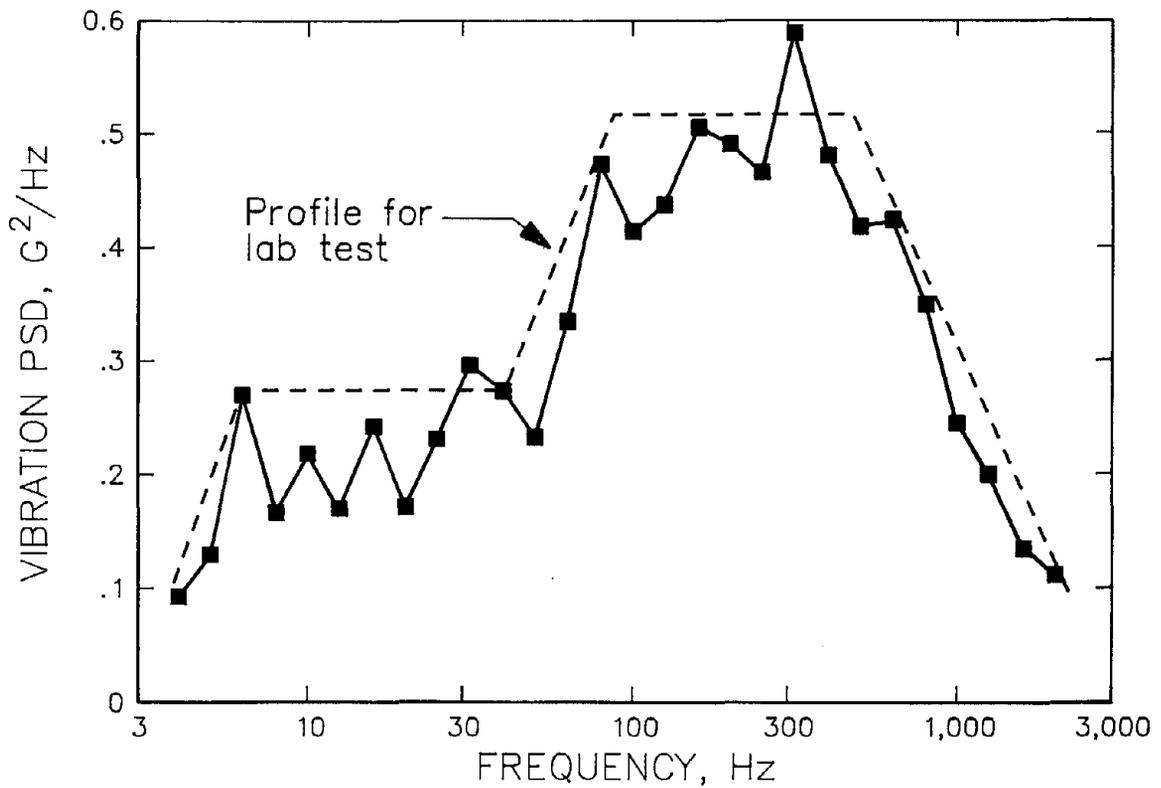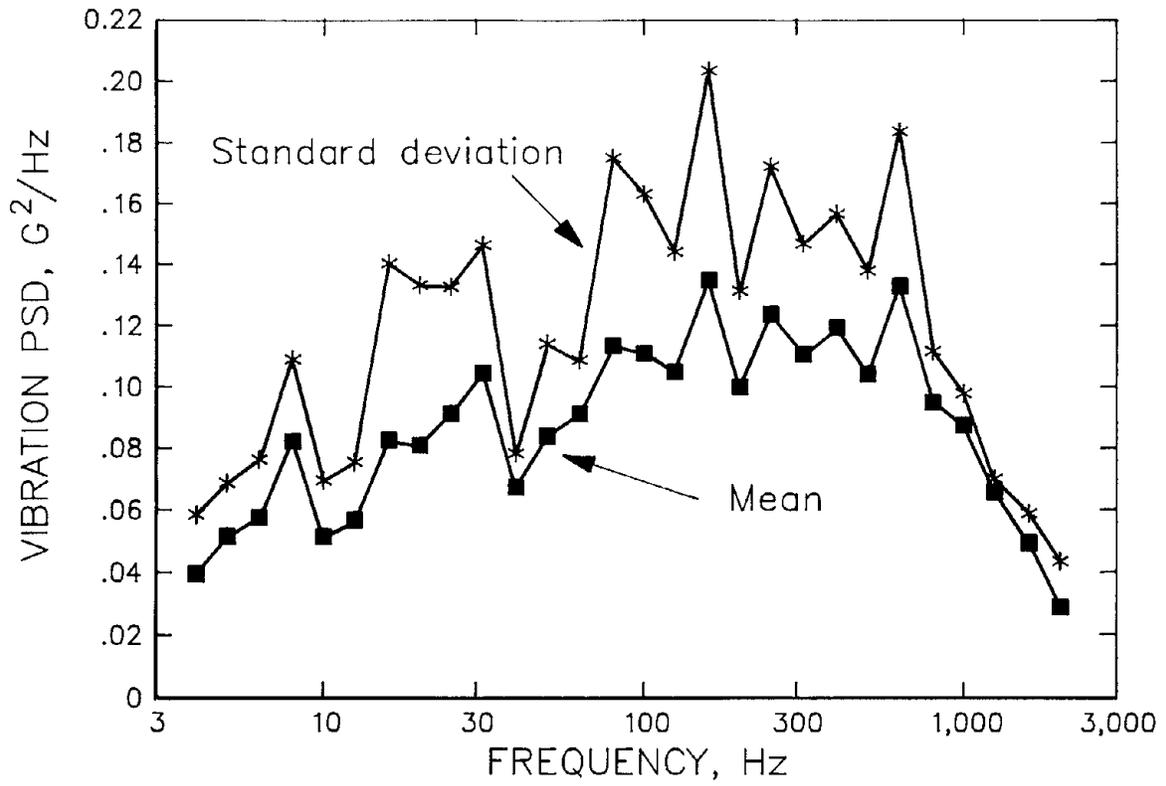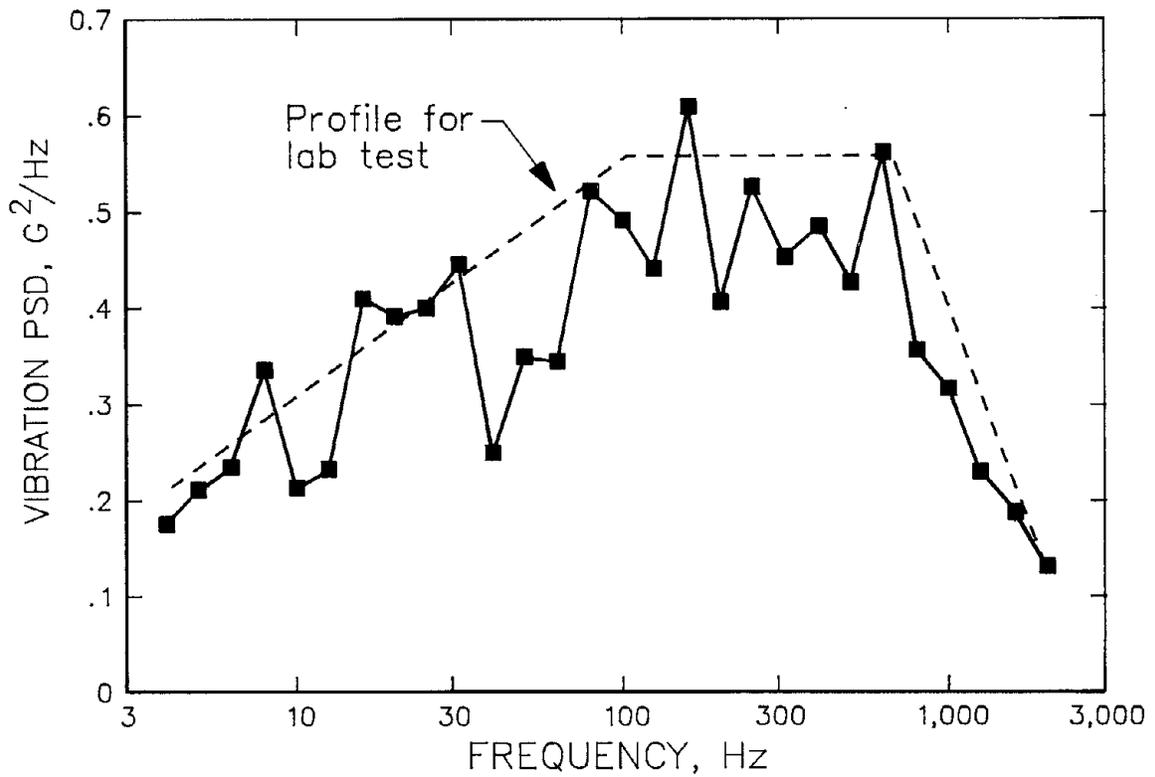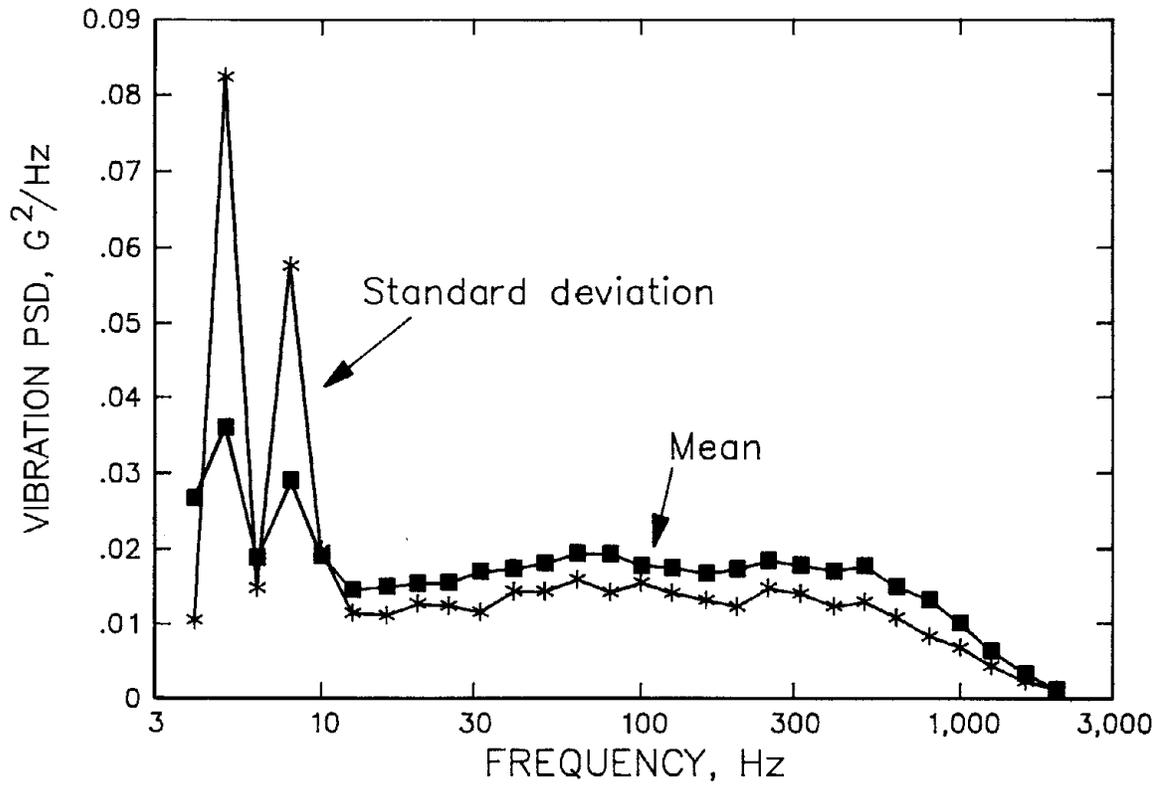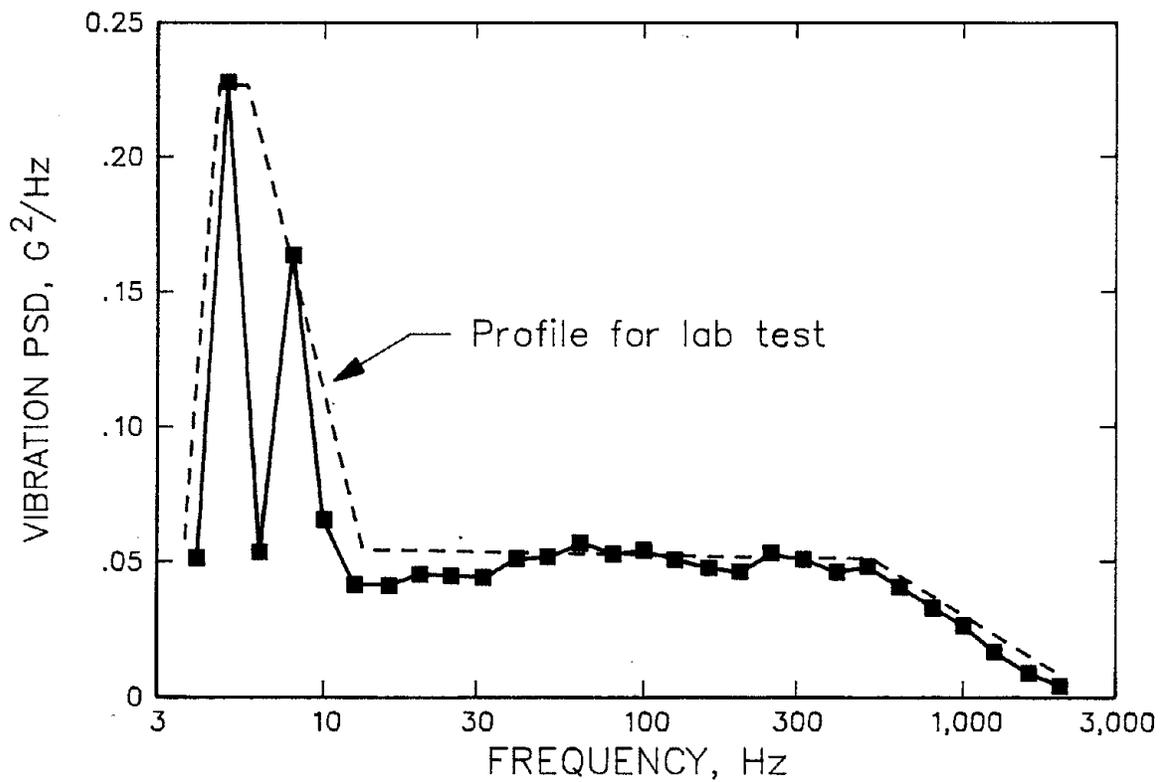Figure 12.—Axle 99-pct vibration envelope, acceleration PSD versus frequency.

Table 2.—Floor acceleration level statistics in one-third-octave band

| Band center frequency, Hz | $G^2/Hz$ | | | $(m/s^2)^2/Hz$ | | |
|---|---|---|---|---|---|---|
| | Mean | Standard deviation | 99th percentile | Mean | Standard deviation | 99th percentile |
| 4 | 0.019434 | 0.033358 | 0.097158 | 1.8688 | 3.2077 | 9.3428 |
| 5 | .013096 | .025574 | .072683 | 1.2593 | 2.4592 | 6.9892 |
| 6.3 | .022414 | .031582 | .096001 | 2.1554 | 3.0370 | 9.2315 |
| 8 | .012553 | .024976 | .070747 | 1.2071 | 2.4017 | 6.8031 |
| 10 | .015758 | .032101 | .090555 | 1.5153 | 3.0869 | 8.7078 |
| 12.5 | .012659 | .024874 | .070617 | 1.2173 | 2.3919 | 6.7906 |
| 16 | .017125 | .031954 | .091579 | 1.6468 | 3.0728 | 8.8063 |
| 20 | .015265 | .031811 | .089385 | 1.4679 | 3.0590 | 8.5953 |
| 25 | .018424 | .037699 | .106262 | 1.7717 | 3.6252 | 10.2183 |
| 31.5 | .015052 | .028872 | .082325 | 1.4474 | 2.7764 | 7.9165 |
| 40 | .022525 | .049703 | .138333 | 2.1660 | 4.7795 | 13.3022 |
| 50 | .019967 | .040298 | .113861 | 1.9200 | 3.8751 | 10.9490 |
| 63 | .017730 | .034971 | .099213 | 1.7049 | 3.3629 | 9.5404 |
| 80 | .021731 | .045383 | .127473 | 2.0897 | 4.3640 | 12.2579 |
| 100 | .031488 | .057963 | .166541 | 3.0279 | 5.5737 | 16.0147 |
| 125 | .029106 | .053742 | .154326 | 2.7989 | 5.1679 | 14.8401 |
| 160 | .036694 | .067219 | .193313 | 3.5285 | 6.4638 | 18.5892 |
| 200 | .034263 | .059773 | .173535 | 3.2948 | 5.7478 | 16.6872 |
| 250 | .028339 | .050950 | .147053 | 2.7251 | 4.8994 | 14.1407 |
| 315 | .034361 | .065048 | .185922 | 3.3042 | 6.2550 | 17.8784 |
| 400 | .030945 | .059595 | .169801 | 2.9757 | 5.7307 | 16.3282 |
| 500 | .028631 | .051649 | .148972 | 2.7532 | 4.9666 | 14.3253 |
| 630 | .029577 | .054966 | .157649 | 2.8442 | 5.2856 | 15.1596 |
| 800 | .024551 | .045996 | .131722 | 2.3608 | 4.4230 | 12.6665 |
| 1,000 | .016528 | .030846 | .088399 | 1.5893 | 2.9662 | 8.5005 |
| 1,250 | .011437 | .024417 | .068329 | 1.0998 | 2.3480 | 6.5706 |
| 1,600 | .006571 | .015018 | .041564 | .6319 | 1.4442 | 3.9968 |
| 2,000 | .001203 | .002555 | .007156 | .1156 | .2457 | .6861 |

Table 3.—Engine acceleration level statistics in one-third-octave band

| Band center frequency, Hz | $G^2/Hz$ | | | $(m/s^2)^2/Hz$ | | |
|---|---|---|---|---|---|---|
| | Mean | Standard deviation | 99th percentile | Mean | Standard deviation | 99th percentile |
| 4 | 0.068085 | 0.218615 | 0.577457 | 6.5471 | 21.0221 | 55.5287 |
| 5 | .081840 | .183411 | .509186 | 7.8698 | 17.6369 | 48.9637 |
| 6.3 | .082171 | .185215 | .513721 | 7.9016 | 17.8104 | 49.3998 |
| 8 | .082816 | .178671 | .499120 | 7.9637 | 17.1812 | 47.9958 |
| 10 | .076813 | .133780 | .388521 | 7.3864 | 12.8644 | 37.3604 |
| 12.5 | .049636 | .065686 | .202684 | 4.7731 | 6.3164 | 19.4902 |
| 16 | .055508 | .057296 | .189007 | 5.3377 | 5.5096 | 18.1751 |
| 20 | .056451 | .064615 | .207005 | 5.4284 | 6.2134 | 19.9057 |
| 25 | .064395 | .063341 | .211980 | 6.1922 | 6.0909 | 20.3842 |
| 31.5 | .063218 | .061863 | .207358 | 6.0791 | 5.9487 | 19.9397 |
| 40 | .068297 | .067633 | .225882 | 6.5675 | 6.5037 | 21.7210 |
| 50 | .069734 | .073839 | .241778 | 6.7056 | 7.1004 | 23.2496 |
| 63 | .067875 | .063525 | .215887 | 6.5269 | 6.1086 | 20.7599 |
| 80 | .079160 | .082323 | .270973 | 7.6121 | 7.9163 | 26.0570 |
| 100 | .089087 | .084552 | .286093 | 8.5666 | 8.1306 | 27.5110 |
| 125 | .080777 | .067452 | .237939 | 7.7676 | 6.4862 | 22.8804 |
| 160 | .091666 | .083906 | .287168 | 8.8147 | 8.0685 | 27.6143 |
| 200 | .111299 | .139016 | .435207 | 10.7026 | 13.3679 | 41.8498 |
| 250 | .093254 | .096026 | .316996 | 8.9674 | 9.2340 | 30.4826 |
| 315 | .093142 | .090185 | .303273 | 8.9566 | 8.6723 | 29.1630 |
| 400 | .086968 | .077857 | .268374 | 8.3629 | 7.4868 | 25.8071 |
| 500 | .089274 | .076173 | .266757 | 8.5846 | 7.3249 | 25.6516 |
| 630 | .084514 | .071368 | .250801 | 8.1270 | 6.8628 | 24.1172 |
| 800 | .076393 | .062714 | .222516 | 7.3460 | 6.0306 | 21.3973 |
| 1,000 | .064440 | .045855 | .171282 | 6.1966 | 4.4095 | 16.4706 |
| 1,250 | .048532 | .032914 | .125223 | 4.6669 | 3.1651 | 12.0415 |
| 1,600 | .037211 | .033530 | .115336 | 3.5783 | 3.2242 | 11.0908 |
| 2,000 | .018140 | .020701 | .066373 | 1.7444 | 1.9906 | 6.3825 |

**Table 4.—Frame acceleration level statistics in one-third-octave band**

| Band center frequency, Hz | G²/Hz | | | (m/s²)²/Hz | | |
|---|---|---|---|---|---|---|
| | Mean | Standard deviation | 99th percentile | Mean | Standard deviation | 99th percentile |
| 4 . . . . . . . . . | 0.026888 | 0.028186 | 0.092561 | 2.5856 | 2.7104 | 8.9007 |
| 5 . . . . . . . . . | .035675 | .040182 | .129300 | 3.4305 | 3.8640 | 12.4336 |
| 6.3 . . . . . . . . | .060350 | .089851 | .269702 | 5.8033 | 8.6401 | 25.9347 |
| 8 . . . . . . . . . | .045224 | .051826 | .165978 | 4.3488 | 4.9836 | 15.9606 |
| 10 . . . . . . . . | .054881 | .069903 | .217755 | 5.2774 | 6.7219 | 20.9395 |
| 12.5 . . . . . . . | .048306 | .052230 | .170003 | 4.6451 | 5.0225 | 16.3476 |
| 16 . . . . . . . . | .064191 | .076224 | .241794 | 6.1727 | 7.3298 | 23.2511 |
| 20 . . . . . . . . | .054940 | .050093 | .171657 | 5.2831 | 4.8170 | 16.5067 |
| 25 . . . . . . . . | .069805 | .069027 | .230637 | 6.7125 | 6.6377 | 22.1783 |
| 31.5 . . . . . . . | .075503 | .094530 | .295757 | 7.2604 | 9.0901 | 28.4402 |
| 40 . . . . . . . . | .080147 | .082818 | .273112 | 7.7070 | 7.9638 | 26.2627 |
| 50 . . . . . . . . | .071051 | .069379 | .232704 | 6.8323 | 6.6715 | 22.3770 |
| 63 . . . . . . . . | .090937 | .104583 | .334617 | 8.7446 | 10.0568 | 32.1770 |
| 80 . . . . . . . . | .105562 | .157640 | .472863 | 10.1509 | 15.1588 | 45.4709 |
| 100 . . . . . . . | .114592 | .128470 | .413927 | 11.0192 | 12.3538 | 39.8035 |
| 125 . . . . . . . | .111627 | .139787 | .437331 | 10.7342 | 13.4420 | 42.0541 |
| 160 . . . . . . . | .129076 | .161569 | .505532 | 12.4121 | 15.5366 | 48.6123 |
| 200 . . . . . . . | .124573 | .157147 | .490725 | 11.9791 | 15.1114 | 47.1885 |
| 250 . . . . . . . | .122902 | .147167 | .465802 | 11.8183 | 14.1517 | 44.7919 |
| 315 . . . . . . . | .146381 | .189805 | .588627 | 14.0761 | 18.2518 | 56.6029 |
| 400 . . . . . . . | .126216 | .152032 | .480450 | 12.1370 | 14.6195 | 46.2005 |
| 500 . . . . . . . | .120654 | .127556 | .417860 | 11.6022 | 12.2659 | 40.1817 |
| 630 . . . . . . . | .119911 | .130477 | .423923 | 11.5307 | 12.5468 | 40.7648 |
| 800 . . . . . . . | .103628 | .105568 | .349601 | 9.9650 | 10.1515 | 33.1769 |
| 1,000 . . . . . . | .077277 | .071863 | .244717 | 7.4310 | 6.9104 | 23.5322 |
| 1,250 . . . . . . | .062477 | .058988 | .199919 | 6.0078 | 5.6723 | 19.2244 |
| 1,600 . . . . . . | .042412 | .039623 | .134734 | 4.0784 | 3.8102 | 12.9562 |
| 2,000 . . . . . . | .023513 | .037988 | .112025 | 2.2610 | 3.6530 | 10.7724 |

**Table 5.—Gear-differential acceleration level statistics in one-third-octave band**

| Band center frequency, Hz | G²/Hz | | | (m/s²)²/Hz | | |
|---|---|---|---|---|---|---|
| | Mean | Standard deviation | 99th percentile | Mean | Standard deviation | 99th percentile |
| 4 . . . . . . . . . | 0.039487 | 0.058485 | 0.175758 | 3.7971 | 5.6240 | 16.9010 |
| 5 . . . . . . . . . | .051530 | .068640 | .211462 | 4.9551 | 6.6005 | 20.3343 |
| 6.3 . . . . . . . . | .057574 | .076211 | .235145 | 5.5364 | 7.3285 | 22.6117 |
| 8 . . . . . . . . . | .082168 | .108877 | .335852 | 7.9014 | 10.4697 | 32.2958 |
| 10 . . . . . . . . | .051392 | .069464 | .213242 | 4.9419 | 6.6797 | 20.5055 |
| 12.5 . . . . . . . | .056698 | .075478 | .232561 | 5.4521 | 7.2580 | 22.3632 |
| 16 . . . . . . . . | .082619 | .140200 | .409285 | 7.9447 | 13.4817 | 39.3572 |
| 20 . . . . . . . . | .080868 | .133197 | .391217 | 7.7764 | 12.8083 | 37.6198 |
| 25 . . . . . . . . | .091223 | .132472 | .399883 | 8.7721 | 12.7386 | 38.4531 |
| 31.5 . . . . . . . | .104516 | .146272 | .445330 | 10.0504 | 14.0656 | 42.8233 |
| 40 . . . . . . . . | .067258 | .078217 | .249503 | 6.4676 | 7.5214 | 23.9924 |
| 50 . . . . . . . . | .083897 | .114063 | .349664 | 8.0676 | 10.9684 | 33.6240 |
| 63 . . . . . . . . | .091139 | .108700 | .344408 | 8.7640 | 10.4526 | 33.1186 |
| 80 . . . . . . . . | .113435 | .175033 | .521262 | 10.9080 | 16.8313 | 50.1250 |
| 100 . . . . . . . | .110930 | .163195 | .491174 | 10.6671 | 15.6929 | 47.2317 |
| 125 . . . . . . . | .104846 | .144026 | .440427 | 10.0821 | 13.8496 | 42.3518 |
| 160 . . . . . . . | .134707 | .203451 | .608747 | 12.9535 | 19.5640 | 58.5376 |
| 200 . . . . . . . | .099995 | .131231 | .405763 | 9.6156 | 12.6193 | 39.0185 |
| 250 . . . . . . . | .123749 | .172328 | .525274 | 11.8998 | 16.5712 | 50.5108 |
| 315 . . . . . . . | .110612 | .146734 | .452502 | 10.6365 | 14.1100 | 43.5130 |
| 400 . . . . . . . | .119399 | .156708 | .484528 | 11.4815 | 15.0691 | 46.5926 |
| 500 . . . . . . . | .104204 | .137977 | .425691 | 10.0204 | 13.2680 | 40.9348 |
| 630 . . . . . . . | .132847 | .183738 | .560956 | 12.7747 | 17.6684 | 53.9419 |
| 800 . . . . . . . | .094936 | .111787 | .355398 | 9.1291 | 10.7495 | 34.1754 |
| 1,000 . . . . . . | .087562 | .097931 | .315742 | 8.4200 | 9.4171 | 30.3620 |
| 1,250 . . . . . . | .065672 | .070154 | .229131 | 6.3151 | 6.7461 | 22.0334 |
| 1,600 . . . . . . | .049473 | .058909 | .186732 | 4.7574 | 5.6648 | 17.9563 |
| 2,000 . . . . . . | .028978 | .043585 | .130530 | 2.7865 | 4.1911 | 12.5519 |

Table 6.—Axle acceleration level statistics in one-third-octave bands

| Band center frequency, Hz | $G^2/Hz$ | | | $(m/s^2)^2/Hz$ | | |
|---|---|---|---|---|---|---|
| | Mean | Standard deviation | 99th percentile | Mean | Standard deviation | 99th percentile |
| 4 .......... | 0.026739 | 0.010503 | 0.051211 | 2.5712 | 1.0100 | 4.9245 |
| 5 .......... | .035999 | .082323 | .227811 | 3.4617 | 7.9162 | 21.9065 |
| 6.3 ........ | .018859 | .014817 | .053383 | 1.8135 | 1.4248 | 5.1334 |
| 8 .......... | .029054 | .057628 | .163327 | 2.7939 | 5.5415 | 15.7056 |
| 10 ......... | .019070 | .019859 | .065342 | 1.8338 | 1.9097 | 6.2833 |
| 12.5 ....... | .014578 | .011460 | .041279 | 1.4018 | 1.1020 | 3.9694 |
| 16 ......... | .015033 | .011130 | .040966 | 1.4456 | 1.0703 | 3.9393 |
| 20 ......... | .015420 | .012712 | .045040 | 1.4828 | 1.2224 | 4.3311 |
| 25 ......... | .015575 | .012444 | .044568 | 1.4977 | 1.1966 | 4.2857 |
| 31.5 ....... | .017054 | .011594 | .044068 | 1.6399 | 1.1149 | 4.2376 |
| 40 ......... | .017431 | .014404 | .050992 | 1.6762 | 1.3851 | 4.9034 |
| 50 ......... | .018168 | .014384 | .051684 | 1.7471 | 1.3832 | 4.9699 |
| 63 ......... | .019471 | .016024 | .056808 | 1.8724 | 1.5409 | 5.4627 |
| 80 ......... | .019396 | .014272 | .052649 | 1.8651 | 1.3724 | 5.0628 |
| 100 ........ | .017841 | .015563 | .054104 | 1.7156 | 1.4966 | 5.2027 |
| 125 ........ | .017521 | .014168 | .050533 | 1.6848 | 1.3625 | 4.8593 |
| 160 ........ | .016799 | .013210 | .047577 | 1.6154 | 1.2702 | 4.5751 |
| 200 ........ | .017400 | .012333 | .046135 | 1.6732 | 1.1860 | 4.4364 |
| 250 ........ | .018497 | .014848 | .053092 | 1.7786 | 1.4278 | 5.1054 |
| 315 ........ | .017888 | .014066 | .050662 | 1.7201 | 1.3526 | 4.8717 |
| 400 ........ | .017087 | .012388 | .045952 | 1.6431 | 1.1913 | 4.4188 |
| 500 ........ | .017788 | .012999 | .048076 | 1.7105 | 1.2500 | 4.6230 |
| 630 ........ | .015024 | .010888 | .040395 | 1.4448 | 1.0470 | 3.8844 |
| 800 ........ | .013254 | .008372 | .032761 | 1.2746 | .8051 | 3.1503 |
| 1,000 ...... | .010140 | .006857 | .026118 | .9751 | .6594 | 2.51215 |
| 1,250 ...... | .006414 | .004387 | .016634 | .6167 | .4218 | 1.5996 |
| 1,600 ...... | .003357 | .002318 | .008759 | .3228 | .2229 | .8423 |
| 2,000 ...... | .001176 | .001214 | .004005 | .1131 | .1167 | .3851 |

## SUMMARY

The vibrational environment of scrapers and loaders that are used in surface mining operations has been determined. The data are for the normal operation of scrapers and loaders that have rubber tires. The information should be useful to those who design instrumentation for these vehicles. The qualification of equipment, with respect to vibrational acceleration, can be based upon the representative data presented in this report. Consequently, an engineer can use a laboratory test to evaluate an instrumentation package while it is in the prototype stage of development. The increased reliability of the product should result in increased safety and increased customer satisfaction.

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