# SIMPLIFYING THE MEASUREMENT OF HAND-TRANSMITTED VIBRATION

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## INTRODUCTION

British Standard BS 6842:1987 [1] provides information for the design of a hand-transmitted vibration frequency weighting filter. Such a filter unit allows the construction of a simple, single number, single axis, hand-transmitted vibration meter.

A proposed British Standard "Specification for instrumentation for the measurement of vibration exposure of human beings parts 1 and 2 (draft 4"), [2,3], defines a series of electronic tests for hand-transmitted vibration meters.

This report describes the results from two projects, both making use of a simplified vibration meter. One assesses the practicality of the conformity tests given in the proposed hand-transmitted vibration meter specification [3]. The other compares vibration measurement results obtained by a variety of measurement techniques including two using simple vibration meters.

## SIMPLIFIED VIBRATION METER

The simplified vibration meter was based around a Bruel and Kjaer (B&K) type 2231 Modular Precision Integrating Sound Level Meter. The ISLM was used in the all-pass linear mode (2Hz to 70kHz) with Leq as the displayed output parameter. Input to the ISLM was taken, via a dummy microphone, from a frequency weighting filter. The input to the filter was either an electronic test signal or the output from an accelerometer, via a charge amplifier.

Figure 1 shows the circuit diagram of the hand-transmitted vibration frequency weighting filter unit. The design is based on equations given in BS 6842:1987. Figure 2 compares the theoretical frequency response function with that obtained for the practical frequency weighting filter.

## TEST OF PROPOSED BRITISH STANDARD SPECIFICATIONS

In these tests measurements were made of the electronic characteristics of the vibration meter; that is: linearity, frequency weighting, time averaging and pulse range. No tests were made that required input from a vibration transducer.

### Proposed British Standard test procedures

The proposed British Standard [3] provides basic guidelines for performing specification tests on hand-transmitted vibration instrumentation and the allowed tolerances for each test. The following briefly summarises the requirements of the four tests, as stipulated in the proposed British Standard, performed in this project:

<u>Linearity</u>: The complete instrument shall be tested using steady sinusoidal signals. A tolerance of ±8% is allowed over a 1:316 (50dB) range for all frequencies from 8 to 80Hz.

<u>Frequency weighting</u>: The instrument shall be tested using steady sinusoidal

signals. The frequency weighting characteristics and tolerances are specified in 1/3rd octave increments from 0.8Hz to 10kHz, see Table 1.
Time averaging: A reference sinusoidal 80Hz signal, 10dB above the lower limit of the linearity range, is defined. The meter should be tested using a regular sequence of four-cycle 80Hz signal bursts, such that the calculated average level is identical to that of the reference signal. The allowed tolerances are: ±6%, for tone burst duty factors of 0.1 (4 cycles on, 36 cycles off) and 0.01 (4 cycles on, 396 cycles off) and ±12%, for a 0.001 duty factor (4 cycles on, 3996 cycles off).
Pulse range: During a 60 second integration period 12.5Hz signal burst of 0.4s and 4s duration should be applied, superimposed on a continuous sinusoidal signal at a level corresponding to the lower limit of the linearity range. The signal burst and the continuous background signal should be in phase. The pulse range of the instrument is given by the range of signal burst levels over which there is less than 20% difference between the indicated and calculated rms weighted vibration levels. The pulse range should meet or exceed 1:447 (53dB).

Results of the specification tests

The 'vibration meter' proved to be well within the suggested specifications for linearity and pulse range; with a linearity range found to be greater than 1:500 (54dB) at 8, 25 and 80Hz, and a pulse range greater than 1:1000 (60dB).

Table 1 shows the results of the frequency response tests. It can be seen that the weighting filter is generally within the required tolerances. However, at low frequencies the measured weighting factor is a little outside the specified tolerances. It is believed that the weighting factor accuracy could be improved by careful selection of the electronic components used in the filter unit.

The time averaging tests gave errors of +16% for duty factors of 0.1 and 0.01 and +17% for the 0.001 duty factor. These results are well outside the proposed tolerances.

It was discovered while performing the time averaging test that the 80Hz tone burst signal excited a low-frequency resonance of the filter network. This excitation characteristic of the weighting filter can clearly be seen in the decay of the impulse response function, shown in Figure 3.

Clearly any test signal which excites the weighting filter resonance will produce measurement results higher than those calculated for the same signal. Therefore, to avoid exciting the filter resonance (at approximately 16Hz) the time averaging tests were repeated using 12.5Hz tone bursts.

The repeated time averaging tests, at 12.5Hz, produced very small errors (less than 1%) for all duty factors.

COMPARISON OF VIBRATION MEASUREMENT METHODS

For this experiment a series of different vibration signals were generated on a vibration exciter system. The input signals were chosen to provide a wide range of signal types and included two based on high-quality recordings of the vibrations on real tool handles. Figure 4 shows the unweighted acceleration time histories of the six test inputs.

A B&K type 4382 transducer was used to monitor the acceleration of the vibration exciter. Signals from the transducer were processed using a D J Birchall CA/04 charge amplifier, giving a 10mv/g output voltage. From the charge amplifier the vibration signal was distributed to a series of different vibration analysis systems.

Weighted vibration measurement techniques

Six different methods for measuring the weighted acceleration were used during these experiments:

1. Computer narrow-band analysis of the unweighted acceleration, and application of two frequency weighting functions: the theoretical response function of the frequency weighting filter and the asymptotic (straight line) approximation.
2. Computer narrow-band analysis of the frequency weighted acceleration from the output of the hand-transmitted vibration frequency weighting filter unit.
3. Measurement of frequency weighted acceleration Leq using the 'simple vibration meter'.
4. Measurement of one minute frequency weighted acceleration Leq using the B&K type 2513 Integrating Vibration Meter with its own transducer (B&K type 4384) and weighting filter network.
5. Octave and 1/3rd octave band analyses using a B&K type 2131 Digital Frequency Analyser and application of the appropriate weighting factors given in BS 6842: 1987 [1] (and ISO/DIS 5349: 1984 [4]).
6. Recording of the acceleration signal on two tracks of a data recorder (one track covering the frequency range from d.c. to 200Hz, the other from d.c. to 1625Hz, with independent amplification for each) then obtaining a full frequency range analysis by octave band analysis using the B&K type 2131 Digital Frequency Analyser. The weighting factors given in BS 6842: 1987 [1] are then applied to the octave band data.

Method 6 above is normally used by the Noise and Vibration Section of the Health and Safety Executive for the recording and measurement of triaxial hand-transmitted vibration in field investigations.

Results of the comparison tests

BS 6842: 1987 specifies that the application of the frequency weighted function defined in that standard is the preferred method for achieving frequency weighted hand-transmitted vibration measurements. For the purpose of these tests the preferred measurement method was taken to be the application of the theoretical, BS 6842: 1987, weighting function to be unweighted computed narrow-band spectra.

In Table 2 the results have been summarised in terms of their percentage difference from the frequency weighted acceleration values given by the preferred method. The results have been normalised such that the frequency weighted calibration level is correct, rather than the unweighted calibration level.

Generally the results from the frequency weighted acceleration measurements covered a range of ±10%.

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The simplest measurement methods were the vibration meter systems. These proved to give results which agreed well with the computed theoretical frequency weighted accelerations.

Measurement of the weighted vibration level using octave and 1/3rd octave band analysis can be seen to be, predictably, imprecise with large errors possible where the input has dominant pure tone components.

The comparison of the different computed weighted accelerations showed that the results obtained by applying the asymptotic approximation to the unweighted vibration signal do not agree well with those given by applying the theoretical weighting function.

## DISCUSSION AND CONCLUSIONS

The tests carried out here have shown that it is feasible to construct a vibration meter which will satisfy the requirements of the proposed British standard [2,3]. It is clear, however, that the proposed conformity tests [3] need to be altered to make allowances for the impulse response characteristic of the frequency weighting filter.

Any practical weighting filter constructed to produce the frequency response required by BS 6842: 1987 [1] must have an impulse response function similar to those shown in Figure 3. The 60ms decay characteristic of the filter will cause misleading results during meter tests using tone bursts of frequencies above 16Hz (1/60ms). Therefore any tests requiring short duration tone bursts should use signals with frequencies lower than 16Hz.

The tests here show that it is possible to perform an effective time averaging test using a tone burst frequency of 12.5Hz (the frequency specified for use in the pulse range tests).

A simple vibration meter has been shown to be capable of providing accurate measurements of frequency weighted vibration dose. It should be noted, however, that the simple, single number, hand-transmitted vibration exposure meter provides no means of checking the validity of any measurement made.

In situations where measurement transducers are shaken loose, or are knocked against machinery the acceleration time histories often show clearly where the fault occurred. Also in high impulsive vibration environments where dc shift [1] might be present, the validity of the vibration measurement can normally be assessed by estimating the displacement corresponding to the vibration magnitude in a particular frequency band.

The ability to check the acceleration signal and its spectral content is, to a large extent, lost with a simple meter. Care must be taken to avoid erroneous results. It is important therefore that simple hand-transmitted vibration meters include adequate overload indication systems.

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REFERENCES

[1] British Standards Institution "The measurement and evaluation of human exposure to vibration transmitted to the hand" BS 6842 (1987).

[2] Proposal for a British Standard specification for instrumentation for the measurement of vibration exposure of human beings. Part 1. General requirements, Draft 4 (March 1987).

[3] Proposal for a British Standard specification for instrumentation for the measurement of vibration exposure of human beings. Part 2. Hand-transmitted vibration exposure, Draft 4 (March 1987).

[4] International Organization for Standardization "Guidelines for the measurement and the assessment of human exposure to hand-transmitted vibration" ISO/DIS 5349.2 (1984)

Table 1 Frequency response test results and tolerances

| Frequency (Hz) | Measured weighting factor | BS 6842: 1987 Weighting factor | Error (%) | Tolerance (%) |
|---|---|---|---|---|
| 2.5 | 0.102 | 0.078 | 31 | +20,-inf |
| 3.15 | 0.168 | 0.163 | 3 | +20,-inf |
| 4 | 0.275 | 0.329 | -16 | +20,-inf |
| 5 | 0.427 | 0.550 | -22 | +15,-inf |
| 6.3 | 0.631 | 0.748 | -15 | +10,-10 |
| 8 | 0.832 | 0.870 | -4 | +10,-10 |
| 10 | 0.902 | 0.907 | -1 | +10,-10 |
| 12.5 | 0.881 | 0.877 | 1 | +10,-10 |
| 16 | 0.785 | 0.804 | -2 | +10,-10 |
| 20 | 0.684 | 0.705 | -3 | +15,-15 |
| 25 | 0.582 | 0.597 | -3 | +15,-15 |
| 31.5 | 0.484 | 0.492 | -2 | +15,-15 |
| 40 | 0.394 | 0.399 | -1 | +15,-15 |
| 50 | 0.324 | 0.321 | 1 | +15,-15 |
| 63 | 0.257 | 0.257 | 0 | +15,-15 |
| 80 | 0.204 | 0.205 | 0* | +15,-15 |
| 100 | 0.164 | 0.163 | 0 | +15,-15 |
| 125 | 0.132 | 0.130 | 2 | +15,-15 |
| 160 | 0.104 | 0.103 | 1 | +15,-15 |
| 200 | 0.083 | 0.0819 | 1 | +15,-15 |
| 250 | 0.067 | 0.0650 | 3 | +15,-15 |
| 315 | 0.053 | 0.0516 | 3 | +15,-15 |
| 400 | 0.042 | 0.0409 | 3 | +15,-15 |
| 500 | 0.033 | 0.0323 | 2 | +20,-20 |
| 630 | 0.026 | 0.0252 | 3 | +20,-20 |
| 800 | 0.019 | 0.0191 | -1 | +20,-20 |
| 1000 | 0.014 | 0.0138 | 1 | +20,-20 |
| 1250 | 0.009 | 0.00916 | 1 | +20,-inf |
| 1600 | 0.005 | 0.00547 | -4 | +20,-inf |
| 2000 | 0.003 | 0.00300 | -3 | +20,-inf |

* Reference attenuation at 80Hz

Table 2 Comparison of the vibration measurements expressed as percentage differences from the results given by the 'preferred' method

| | 160Hz calibration Linear (%) | Frequency weighted (%) | Impulse (%) | Random noise (%) | Decaying 80Hz sine (%) | Chipping hammer (%) | Disc sander (%) |
|---|---|---|---|---|---|---|---|
| Computed (theoretical)* | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Computed (asymptotic) | 3 | 0 | 12 | 3 | 3 | 11 | 0 |
| Filtered (computed) | 11 | 0 | -1 | 0 | 0 | -12 | 1 |
| B&K2231 (simple meter) | 6 | 0 | -6 | -2 | -2 | -9 | 10 |
| B&K2513 | 4 | 0 | 3 | 0 | 0 | -14 | 17 |
| 1/3rd octave | 2 | 0 | 15 | 4 | 4 | 0 | 12 |
| 1/1 octave | 5 | 25** | 9 | 13 | 13 | 2 | -1 |
| Multitrack rec. (1/1 octave) | 3 | 25** | 11 | 14 | 14 | 9 | 0 |

* Reference ('preferred') method.
** +25% difference due to 160Hz calibration signal falling in the 125Hz octave band and so having a weighting factor of 0.125 applied to it rather than 0.1.

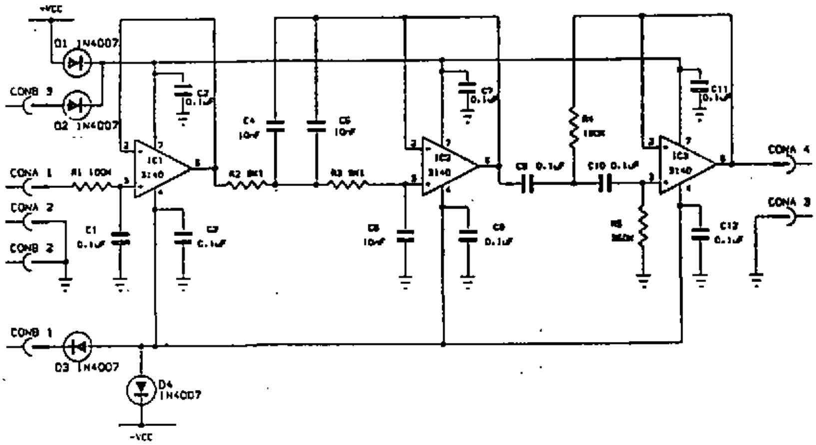


Figure 1 Circuit diagram of the hand-transmitted vibration frequency weighting filter unit.

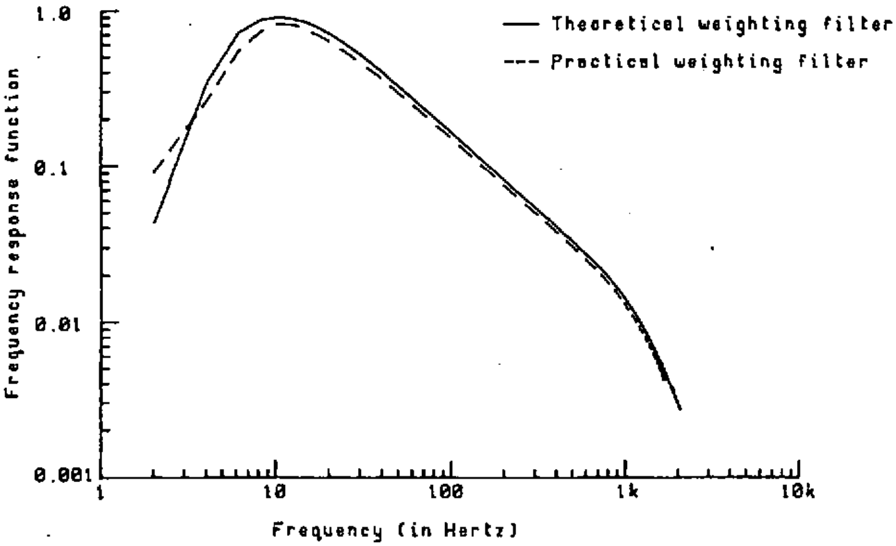


Figure 2 Frequency response functions of the theoretical and practical frequency weighting filters.

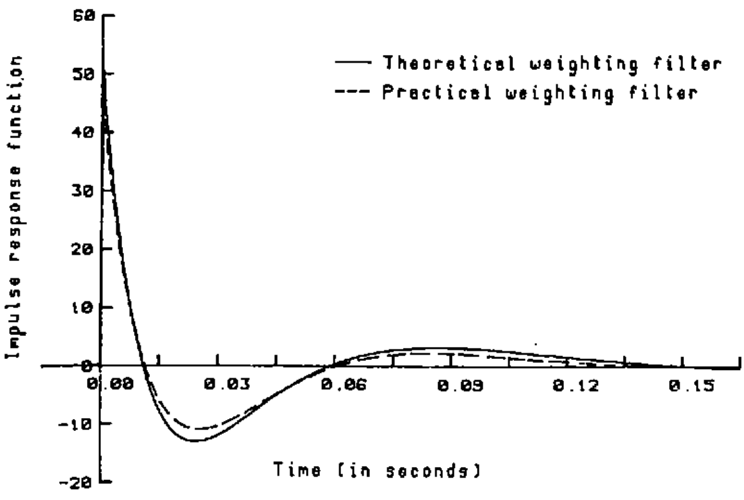


Figure 3 Impulse response functions of the theoretical and practical frequency weighting filters.

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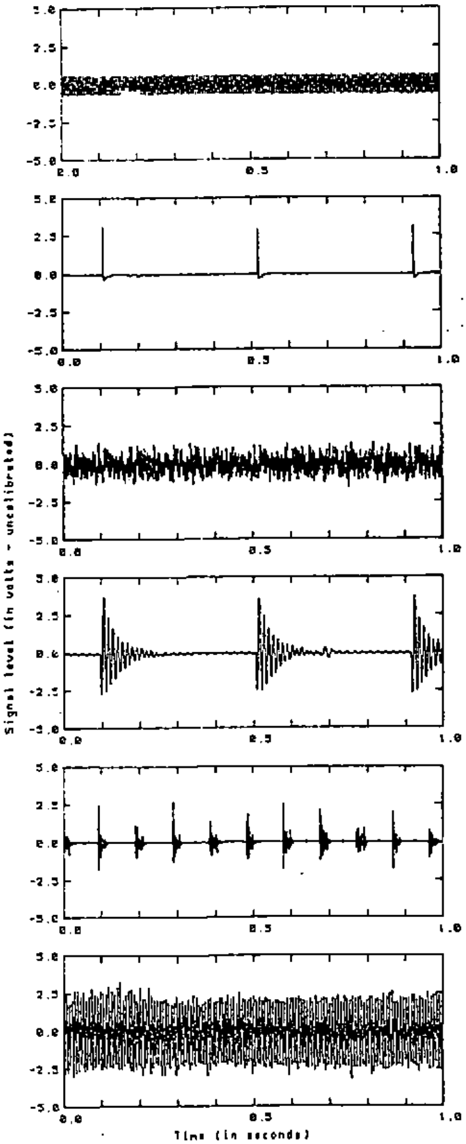


160 Hz calibration signal

Impulse

Gausian random noise

Decaying 80 Hz sine wave

Chipping hammer handle

Disc sander handle



Figure 4 Unweighted test signals used in comparison tests.