declaration values of the tools and for exporting tools to European countries..

## 4.2 Field Measurements (Workplace Measurement) (Vibration measurement in accordance with ISO 5349-2)

When "the vibration total value of frequency-weighted r.m.s. acceleration" can't be measured by the test protocols, the measurement, computation of "the vibration total value of frequency-weighted r.m.s. acceleration" of the vibration tool in the field or actual working situation is necessary.

When conducting field tests, measuring methods defined in ISO 5349-2, vibration measurement shall be conducted in accordance with ISO 5349-2:2004 "Hand-transmitted Vibration - Part 2: Practical Guidance for Measurement at the Workplace". When presenting the manufacturers' declared value in an instruction manual or on a website, items specified in "9. Information to be Reported" in ISO 5349-2004 shall be stated clearly.

In field measurements, three processes should be utilized ([PLAN], [DO], [SEE]) as shown in the Figure 3.

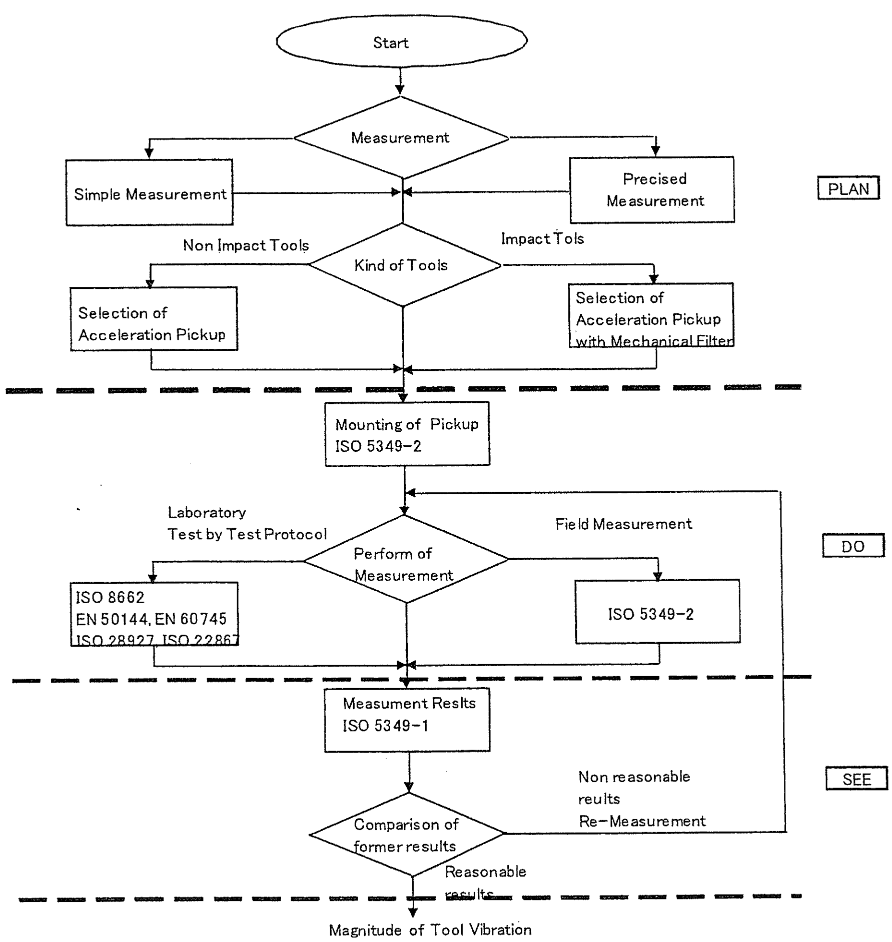


Figure 3 Measurement Procedure of Hand-Arm Vibration

## 5. Conclusions

The Machinery Directive 89/37/EC has been revised to 2006/42/EC. EU countries were required to revise their laws to conform to the latest Machinery Directive for preventing Hand-Arm Vibration Syndrome. The MSD of the EU Directive has had a great influence on Japanese tool manufacturers. It is generally recognized that the introduction of the EU Directive to Japan has been very useful in helping decrease the 400 new cases of vibration injuries that have generally occurred in Japan each year.
This paper provided a short introduction for the implementation and application of the MSD of 2006/2/EC to Japanese Tool manufacturers for preventing Hand-Arm Vibration Syndrome.

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# Validation of frequency weightings of hand-transmitted vibration for evaluating comfort

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## ABSTRACT

The purpose of this research is to establish a suitable frequency-weighting curve for comfort evaluation with regard to hand-arm vibration using the category judgment method. Experiments were conducted using random signals as stimuli. These stimuli consisted of three types of signal, namely designated stimulus F, with flat PSD ranging from 1 to 1000Hz, stimulus H with PSD, which became 20dB higher at 1000Hz than at 1Hz, and stimulus L that had a PSD 20dB lower at 1000Hz. The signal levels were varied over a range of five steps to create 15 kinds of individual stimuli. The subjects were exposed to vertical vibrations before being asked to choose a numerical category to best indicate their perceived level of comfort (or otherwise) during each stimulus. The creation of this assessment scale, including the aforementioned categories, enabled not only clarification of the relationship between the vibration stimuli and the degree of comfort but also the discovery of the connection between the frequency-weighted r.m.s. acceleration and the corresponding categories representing each degree of comfort. From the current results, it was found that the current ISO 5349-1 Frequency-Weighting curve and the Palm-Wrist & Hand back Frequency Weighting Curves from the Biodynamic Response data are suitable frequency-weighting to evaluate the comfort of the hand-transmitted vibration.
Keywords: Frequency-weighting, Hand-arm, Vibration

## 1. INTRODUCTION

In the ISO/TC108/SC4/WG3, the new frequency-weighting curve is considering to revise the ISO 5349-1 standard [1] as PWI 18570: HAV frequency weighting. Moreover, many frequency-weighting curves based on the biodynamic responses or on the epidemiological data of the hand-arm vibration experiments are proposed by many researchers. It is not clear whether which frequency-weighting curve is better to evaluate the hand-arm vibration comfort in comparing with the frequency-weighting curve of the ISO 5349-1 standard. In this study, the effectiveness of the different frequency-weighting curve is investigated by the psychological experiment [2].

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The purpose of this research is to establish a suitable frequency-weighting curve for comfort evaluation with regard to hand-arm vibration using the category judgment method. The subjects were exposed to vertical vibrations before being asked to choose a numerical category to indicate their best perceived level of comfort (or otherwise) during each stimulus. The creation of this assessment scale, including the aforementioned categories, enabled not only the clarification of the relationship between the vibration stimuli and the degree of comfort but also the discovery of the connection between the frequency-weighted r.m.s. acceleration according to the alternative frequency weighting curves as shown in Figure 1 and the corresponding categories representing each degree of comfort.

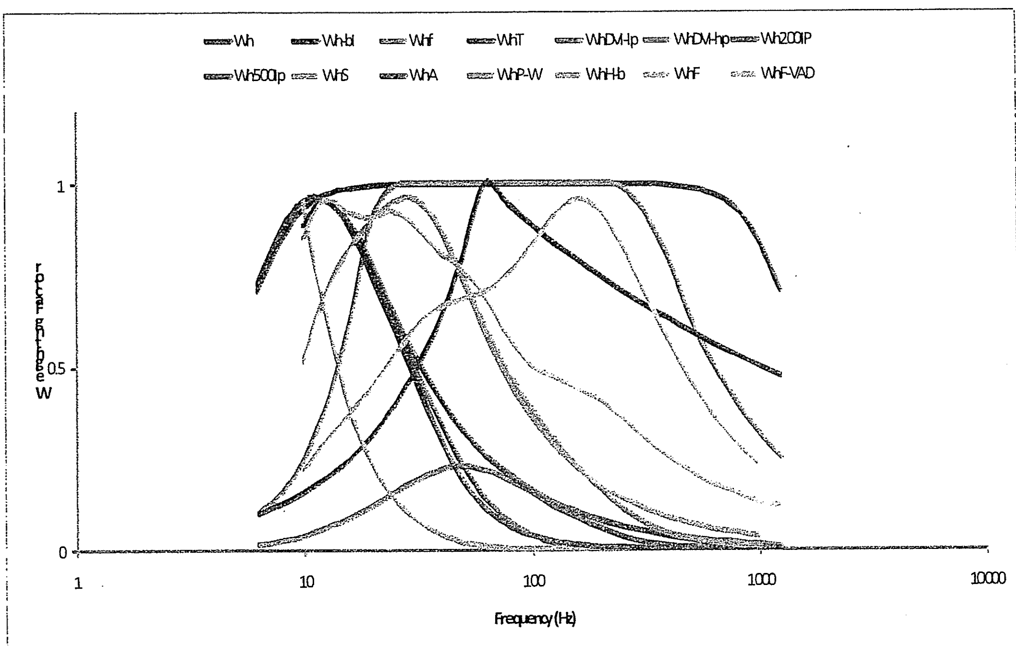


Figure 1 – Comparison of frequency weighting curves

The candidate frequency weighting curves as shown in Figure 1 are:

| | |
|---|---|
| Wh: | The frequency-weighting specified in ISO 5349-1 [1] |
| Wh-bl: | The band-limiting component of Wh [1] |
| Whf: | A frequency weighting based on finger vibration power absorption [3] |
| WhT: | A frequency weighting based on epidemiological data of incidence of vascular injury [4] |
| WhVDI-lp: | The Wh weighting with an additional 24dB/octave low-pass filter at 50 Hz [5] |
| WhVDI-hp: | The Wh weighting with an additional 24dB/octave high-pass filter at 50 Hz [5] |
| Wh200lP: | The Wh weighting with an additional 24dB/octave low-pass filter at 200 Hz [5] |
| Wh500lP: | The Wh weighting with an additional 24dB/octave low-pass filter at 500 Hz [5] |
| WhS: | A frequency weighting based on biodynamic response at Shoulder [6] |
| WhA: | A frequency weighting based on biodynamic response at Arm [6] |
| WhP-W: | A frequency weighting based on biodynamic response at Palm-Wrist [6] |
| WhH-b: | A frequency weighting based on biodynamic response at Hand-Back [6] |
| WhF: | A frequency weighting based on biodynamic response at Finger [6] |
| WhF-VAD: | A frequency weighting based on biodynamic response at Finger from Vibration Absorbed Density [6] |

## 2. APPARATUS AND METHOD

### 2.1 Apparatus

A shaker with a power amplifier (VA-ST-03, IMV corporation) and signal processing unit (F2 SPU, IMV corporation) were used in the experiments. All vibration stimuli were generated on the handle and the frequency-weighted r.m.s. vibration acceleration feedback controlled by F2 SPU controller and the computer.

### 2.2 Method

A series of 15 vibration stimuli (three times for five levels of vibration stimuli, respectively), each of which was ordered randomly, were applied in the $X_h$ axis to the right hand of each subject, seated relaxed posture in a chair. All vibration stimuli had a duration time of five seconds with a two-second pause between them as shown Figure 2. The vibration load was applied in the direction of the $X_h$ axis with a predetermined stimuli program input into the vibrator, then applied to the subject grasping on the vibration handle. The grasping force was about 2-3 N. The diameter of handle was 0.03 m and the length was 0.12 m. The subjects were issued verbal responses to each vibration stimulus, selecting from the five evaluation categories, using the designated numeric value (1 to 5) for each category as shown in Table 1. The experiments were conducted using random signals for the stimuli over a frequency range of 1-1000 Hz, similar to the ISO 5349-1 standard evaluation range.

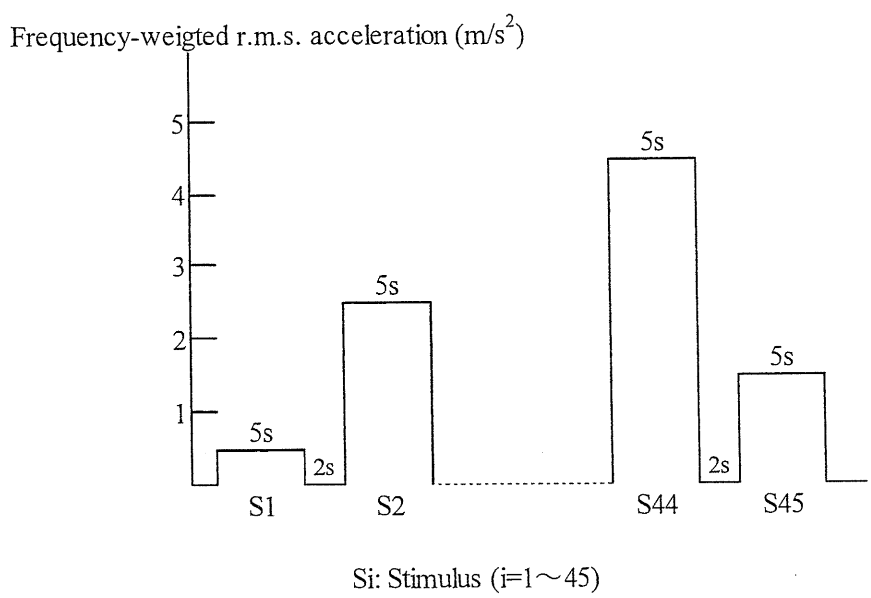


Figure 2 - Series of stimuli

Table 1 - Categories used in this experiment

1. Not uncomfortable
2. A little uncomfortable
3. Fairly uncomfortable
4. Uncomfortable
5. Very uncomfortable

In addition, in order to clarify the individual characteristics of the different spectrums with varying degrees of high and low frequency components were used. The stimuli consisted of three kinds of signals, namely designated stimulus F, with a flat PSD from 1 to 1000 Hz, stimulus H with a PSD, which became 20 dB higher at 1000 Hz than at 1 Hz and stimulus L with a PSD 20 dB lower at 1000Hz and the spectra of these signals as shown in Figure 3. The signals were modified using a frequency weighting of Wh based on the ISO 5349-1 standard, and the frequency-weighted r.m.s. acceleration were adjusted to be equal. Furthermore, the levels of the signals were varied over a range of five steps to make 15 kinds of stimuli. In order to enable the comparison of the ISO 5349-1 standard values with accelerations of 0.28, 0.56, 1.12, 2.48 and 4.48 $m/s^2$ r.m.s. were used for the five steps. These stimuli were selected from the specific vibration magnitudes of the hand-held vibration tools. Each one of these signals was used for three times, comprising a total of 45 stimulus applied in random order, each applied for a duration of five seconds with a two-second pause between stimuli for each subject in the experiment as shown in Figure 3. This meant that each subject was exposed to a total of 225 seconds of vibration, which even when the exposure time is considered, is in the acceptable range for the ISO 5439-1 standard.

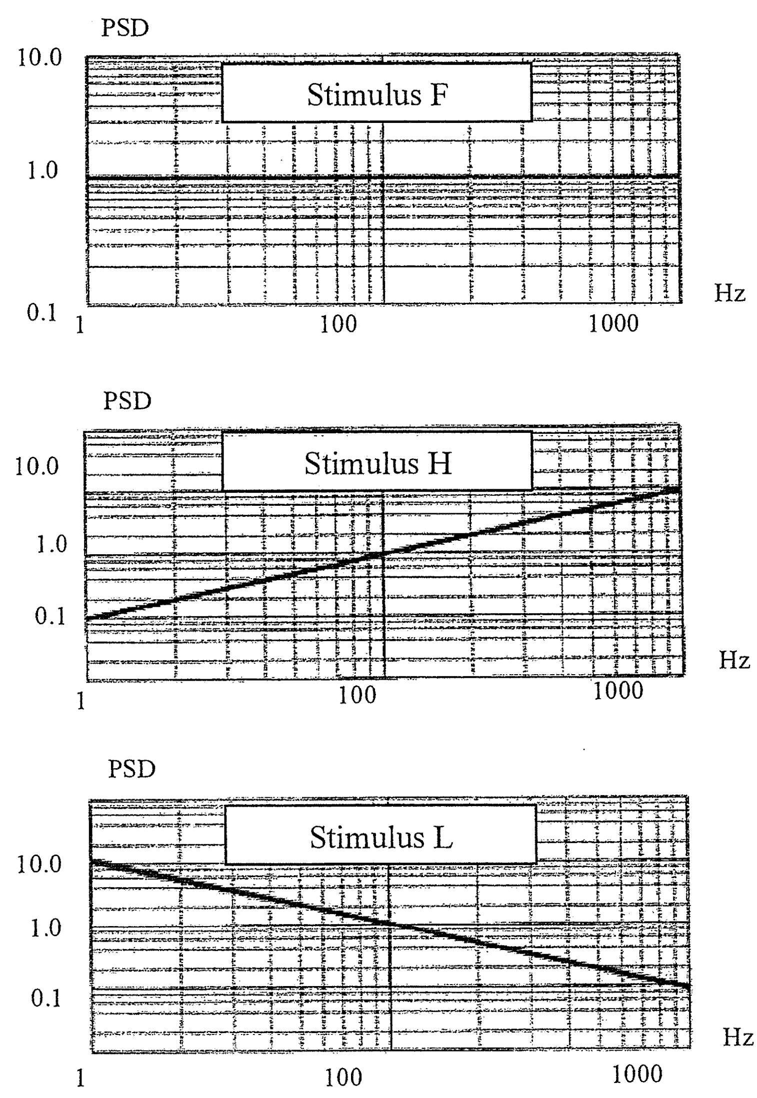


Figure 3 - Spectrum of stimuli used in the experiment

## 2.3 Subjects

The experiments were performed with totally twelve healthy subjects in twenties, six males and females with mean ages of 23.2 and 24.5, respectively. All the subjects were non-smokers. None of the subjects have been exposed to high levels or long periods of HAV occupationally or in their leisure time activities. The experiments were approved by the Research Ethics Committee of Japan National Institute of Occupational Safety and Health. All the subjects underwent an explanation of the test procedure and gave their written informed consent to participate in this study.

# 3. RESULTS

In this research, using the category judgment method, a subjective scale for evaluation of comfort, namely an order scale with unequal intervals, was established to associate physical values by using the different frequency weighting curves as show in Figure 1 with psychologically continuous categories. In order to clarify the effectiveness of the different frequency-weighting curve for evaluating the hand-arm vibration comfort, the effectiveness was quantified in terms of the square root of the sum of the squared differences between the category results and the experimental data (i.e., R.M.S. errors) [7] as shown in Table 2.

Table 2 - The R.M.S. errors obtained from different frequency-weighting curves

| Frequency-weighting curve names | R.M.S. errors |
|---|---|
| Wh (ISO 5349-1) | 1.963 |
| Wh-bl(band-limiting component of Wh) | 6.167 |
| Whf(Finger vibration power absorption) | 5.441 |
| WhT(Epideiological data) | 5.775 |
| WhVDI-lp(Wh with 24dB/Oct low-pass filter at 50 Hz | 2.680 |
| WhVDI-hp(Wh with 24dB/Oct high-pass filter at 50 Hz) | 2.925 |
| Wh200lP(VDI 2057 200 Hz) | 2.245 |
| Wh500lp(VDI 2057 500 Hz) | 2.017 |
| WhS(Biodynamic Response of Shoulder) | 3.599 |
| WhA(Biodynamic Response of Arm) | 2.729 |
| WhP-W(Biodynamic Response of Palm and Wrist) | 1.966 |
| WhH-b(Biodynamic Response of Hand back) | 1.945 |
| WhF(Biodynamic Response of Finger) | 5.426 |
| WhF-VAD(Finger of Vibration Absorption Density) | 2.979 |

## 4. DISCUSSION

From the results of R.M.S. errors of Table 1, the suitable frequency-weighting curves for evaluating the hand-arm vibration comfort are WhH-b, Wh, and WhP-W.

From Fig.1, the shapes of weighting of WhH-b, Wh, and WhP-W are almost same. But, the weighting factors of WhH-b and WhP-W are different with the ISO 5349-1 standard weighting factors from Fig.1.

Although the frequency-weighting curves of Wh-bl, Whf, and WhT for evaluating the HAVS are suitable curves, the R.M.S. errors of the frequency- weighting curves of Wh-bl, Whf and WhT are very high number. Therefore, these weighting curves are not suitable for evaluating the hand-transmitted vibration comfort. From this experiment, it was clear that the frequency-weighting curve of Current standard ISO 5349-1 is suitable for evaluating the hand-transmitted vibration comfort.

## 5. CONCLUSIONS

The purpose of this research is to establish a suitable frequency-weighting curve for comfort evaluation with regard to hand-arm vibration using the category judgment method. From the point of comfort evaluation, it was found that the current ISO 5349-1 Frequency-Weighting curve and the Palm-Wrist & Hand back Frequency Weighting Curves from the Biodynamic Response data are suitable frequency-weighting to evaluate the comfort of the hand-transmitted vibration.

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