人体に対する非定常振動の測定及び評価に関する研究

平成４～６年度　特別研究報告書

労働省産業医学総合研究所

人体に対する非定常振動の
測定及び評価に関する研究
特別研究報告書

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PROCEEDINGS

The 1994 International Congress on Noise Control Engineering

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more difficult and tiring when operating with smaller draughts. Current procedures may be inadequate for predicting the effects of the motions of ships and floating platforms on the performance of manual tasks, and further research is necessary to establish more appropriate procedures to evaluate such motions.

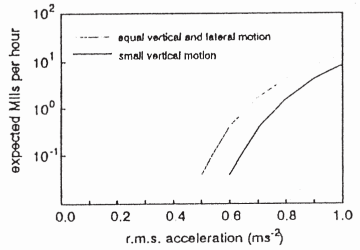

Figure 3 The number of MIIs expected in each hour of operations as a function of lateral r.m.s. acceleration.

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Table 1. Satisfactory magnitudes for 1 Hz horizontal motion specified by ISO 6897

Type of Structure	Horizontal acceleration at 1 Hz
A. Buildings used for General Purposes	0.026 ms^{-2} r.m.s
B. Fixed Offshore Structures	0.156 ms^{-2} r.m.s

Table 2. Horizontal accelerations at the drill floor, frequency weighted for equivalence to the criteria specified by ISO 6897 at 1 Hz

Direction of motion	Weighted r.m.s. acceleration		
	Minimum (all draughts)	Maximum (all draughts)	Mean (draught = 20.4 m)
Longitudinal (x-axis motion)	0.012 ms^{-2}	0.054 ms^{-2}	0.029 ms^{-2}
Lateral (y-axis motion)	0.037 ms^{-2}	0.087 ms^{-2}	0.061 ms^{-2}

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HUMAN RESPONSES TO SHORT REPEATED VIBRATION

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49.1

INTRODUCTION

There have been various types of vibration in the working places. These vibrations are divided into periodic, random, non-periodic and repeated shock type vibrations in ISO standard (ISO 5349)[1), although there are no clear classification. With respect to measurement of vibration, measurement methods have been developed to determine vibration amplitude values for the steady-state vibrations such as periodic or random vibrations as introduced in ISO standard and Japanese Industrial Standard (JIS). These standards define the r.m.s. acceleration as a measurement for stationary sinusoidal vibrations.
For the non steady-state vibrations like shock type vibration or repeated vibration, the ISO 5349 allows also provisional application of the method based on this r.m.s. value for the repeated shock type vibrations. The evaluation of single shocks, however, is problematic Schenk[2) pointed out because r.m.s. value can only be defined sensible for stationary signals. The outlines of the JIS B 4900[3) provides the equivalent continuous acceleration like Leq value in acoustics for not only stationary but also non-stationary vibration as a measurement of the hand-transmitted vibration. This Leq also is based on r.m.s. value. In addition to the Leq, peak acceleration is adopted as a measurement value of the shocks in the JIS. Therefor, some shocks are measured by Leq method, other shocks are measured by peak acceleration method depending on length of the on-time and off-time of the shocks or repeated vibration. Maeda[4) pointed out discrepancy between the both methods. At the present time, there has not been a precise measurement method for the shock type vibrations or repeated vibrations.
We tried to find a correct measurement quantity which suits to human response to repeated vibration with short duration by a method of point of subjective equality. Results of this experiment were compared with calculated r.m.s. value, r.m.q. for shocks or vibrations with short duration proposed by Griffin[5) and other quantity.

APPARATUS

Vibration was produced by an electrodynamic vibrator(Model AST-11V, AKASHI Co. Japan). Each subject sat on a seat beside the vibrator in a relaxed posture and his left palm pressed lightly on the vibration table with three sheets of paper to keep the hand warm. The subject held the control dial of a potentiometer box in his right hand to control the amplitude of the matching vibration (sinusoidal continuous vibration of 31.5 Hz and 100 Hz). The acceleration of the vibration table was measured with a vibration meter (Model VM-80,RION Co. Japan). This vibration meter measures rms acceleration and this value is expressed in terms of both an rms, in m/s^2 and a vibration acceleration level, in decibels relative to 10^{-5} m/s^2 rms.

VIBRATION STIMULI

In the experiment , vibration was in the vertical Z axis. Repeated vibrations with short duration were used as stimuli in the experiment. Frequencies of the vibration were 31.5 Hz and 100 Hz. Acceleration magnitudes of the repeated vibrations of on time were 3.15 m/s^2 rms or 110 dB for 31.5 Hz and 10 m/s^2 rms or 120 dB for 100 Hz.
On-time and off-time of the repeated vibrations were shown in the Table 1.
These on and off-time were changed from 1 wave to 200 or 500 waves depending on the frequencies.

Table 1. On-time and off-time of the repeated vibration

	(31.5 Hz ; 3.15 m/s^2 or 110 dB)
On-time	31.5 ms 63 95 160 315 630 1.0 sec 1.6
Off-time	31.5 ms 63 160 315 630 1.0 sec 1.6 6.3

	(100 Hz ; 3.15 m/s^2 or 110 dB)
On-time	10 ms 20 50 100 200 500 1.0 sec 2 5
Off-time	10 ms 20 50 100 200 500 1.0 sec 2 5

SUBJECT AND PROCEDURE

Eight male students, aged 18 to 22 years, served as subjects in the present study.
They received pay for participation in the experiments.
Each subject was required to match his perception of the intensity of each the short repeated vibration stimuli by adjusting the matching sinusoidal vibration with the same frequency of the repeated short vibration until he considered that its intensity matched the intensity of the repeated short vibration he had experienced (Point of Subjective Equality ; PSE). Each match involved a ten second exposure to the repeated vibration and subsequent ten second exposure to the matching vibration and this was repeated vibration until matching was completed. This lasted two or three minutes depending on the individual.
Each session had eight or nine matches which lasted twenty or thirty minutes and each subject had ten sessions a day including trial judgments.

RESULTS AND DISCUSSION

Observed values of the subjective judgment were compared with calculated values

of r.m.s., r.m.q. and r.m.c. of the repeated vibrations. These formula are as follows, r.m.s. ; root mean square , r.m.q. ; root mean quad , r.m.c. ; root mean cube,

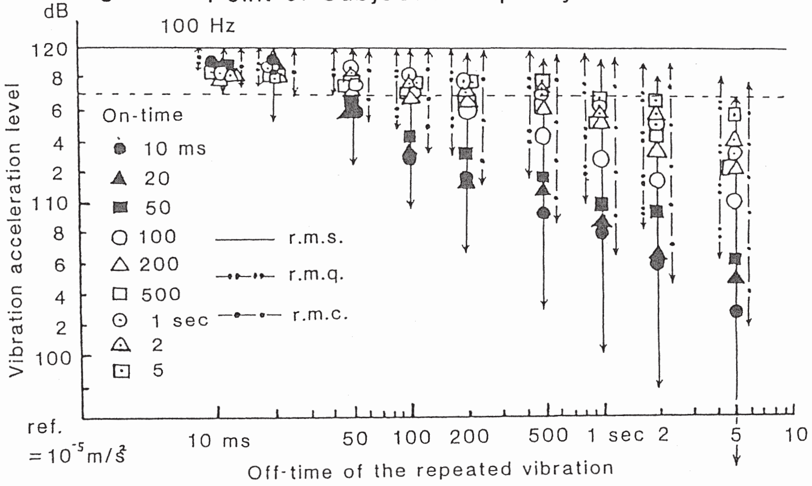
$$\text{r.m.s.} = [1/T \int_{t_1}^{t_2} a^2(t)dt]^{1/2}, \quad \text{r.m.q.} = [1/T \int_{t_1}^{t_2} a^4(t)dt]^{1/4},$$

where : $T = t_2 - t_1 = 10$ sec ,

$$\text{r.m.c.} = [1/T\left|\int_{t_1}^{t_2} a^3(t)dt\right|]^{1/3}, \quad a(t) \text{ is an acceleration value in } m/s^2.$$

Figure 1 shows observed subjective values of the matched vibration (100 Hz) against off-time of the repeated vibration as a parameter of on-time. Calculated values of r.m.s. ,r.m.q. and r.m.c. of the repeated values are also shown as ranges of lines. In the case of 31.5 Hz, the results are not shown in this text because the tendency is nearly the same as that of 100 Hz.

Fig.1 Point of Subjective Equality



Subjective magnitude of the matched vibrations decreased with increase of off-time and with decrease of on-time of the repeated vibration as shown in Figure 1.
In the case where a ratio between on-time and off-time (on-time /off-time) is less than about 1/2, calculated r.m.s. values underestimated the short repeated vibration compared with the observed values. This tendency was clearly observed in the longer off-time and in the shorter on-time of the repeated vibration. The repeated vibration with long off-time and short on-time becomes shock type vibrations. Namely, from this results, it is predicted that there are large differences between calculated r.m.s. values and human responses in shock type vibrations.
This r.m.s. value corresponds to the equivalent continuous acceleration in sinusoidal signal (like Leq value in the acoustics) based on the energy rule. The equivalent continuous acceleration level is used as a measurement value of hand-arm vibration in Japan as described in Japanese Industrial Standard.
Therefor, the measurement method of the equivalent continuous acceleration level in JIS is not suitable for the shock type vibration.
In the case where the ratio (on-time/off-time) is more than 1/2, the calculated r.m.s.

values overestimated the repeated vibration in all cases. However, values of the overestimation is not larger than values of the underestimation in the case where the ratio is less than 1/2.

It is clear that peak value of the repeated vibration with short duration in JIS is also not suitable.The r.m.q. and the vibration dose value (V.D.V.) have been proposed by Griffin[5] for measurement of the shock type vibration. Definition of the r.m.q. is described above and the V.D.V. is the r.m.q. value multiplied by the fourth root of the duration. The ratio between the repeated vibration signals and the continuous vibration signals {(r.m.q.(repeated;10sec))/r.m.q.(continuous;10sec)} is used for an indicator in comparison with human subjective value in the present study. This ratio of the r.m.q. is the same value as the ratio of the V.D.V. Therefor, the r.m.q. is only used in this text.

Calculated r.m.q. values overestimated the repeated vibration compared with observed subjective values in all cases in the experiment. This overestimation of the repeated vibration with short on-time is larger than that of the vibration with long on-time. However, from the results that difference between the r.m.q. value and subjective value is smaller than that of the r.m.s. , the r.m.q. is more suitable for measurement of the repeated vibration or shock type vibration.

We tried to calculate the root mean cube (r.m.c.) of the repeated vibration with short duration because there are the observed subjective values between r.m.s. and r.m.q. values, especially in the case of the repeated vibration with shorter on-time duration as shown in Figure 1 , although the physical meaning of the r.m.c. is not clarified. The calculated r.m.c. values are suited to the subjective values as predicted. Therefor, we propose that the r.m.c. is most suitable for a measurement quantity of the repeated vibration with short duration or shock type vibration from the results of the present experiment.

CONCLUSIONS

In consideration of the results of the subjective judgment of the repeated vibration with short duration in this experiment, root mean cubic (r.m.c.) is the most suitable measurement quantity of that vibration, although physical meaning of the r.m.c. is not clarified. And r.m.s. is not a suitable measurement quantity for short repeated vibration.

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RESEARCH ON ACOUSTICAL ENVIRONMENT PLANNING OF THE CITIES *

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1 INTRODUCTION

The rapid development of the economic construction and the transportation in the cities of this country has resulted into various kinds of noise sources which increase daily. Hence, community noise level has increased accordingly. Under certain conditions, the above situation provides us with an opportunity to make acoustical environment planning for the cities which could be implemented gradually in order to minimize the interference of the community noise.

In this paper, we will analyze simply the factors that cause the increase of noise in the cities and then examine critically some of the conditions that we could use for doing acoustical zone areas in a city or make an acoustical environment planning, and some principles of city planning for ensuring acoustical environment quality will be recommended. Finally, we will give the conclusions.

2 THE GENERAL STATE OF THE INCREASE IN NOISE LEVEL OF THE CITIES

With the development of the economic construction and the transportation in the cities, various kinds of noise have been increased daily. In Nanjing city (see Fig. 1), the total number of various types of vehicles rose from 30000 in 1984 to 130000 in 1994; among them, the bus number in the urban area rose from 970 in 1984 to 4500 in 1994. Due to there is no perfect road network of the city, people have to ride the bicycles on the pavement of the road. According to the measurement, the noise pollution area account for more than 60% of the whole urban area; the noise level that exceed the limited level is 4–8 dB separately. The total number of vehicles per hour and the noise levels listed in Table 1 show the changes between 1976 and 1993 on the Changjiang River Bridge in Nanjing city. From a comparison of measurements between 1976 and 1993, we can see that, owing to the increase in trafic flow, the L_{50} noise level rose on average by 1 dB per year. Besides traffic noise, there are total 152 industrial sources sited in the urban area that have significant interference.

Lianyungang is a harbourcity (see Fig. 1), it consists of the urban area, port area and operational regions in the port area, and the various traffic and transportation systems for joining together. we made measurements in the urban area of this city in 1990, the results of the measurements are shown in Fig. 2. It can be seen that in comparison with the $L_D = 55$ dB(A) that stipulated by the city authority, the measurement positions that exceed the limited level account for about 50%. In the components of urban noise, the traffic noise is the main part, the second is the industry noise. There are a total of 1344 industrial noise sources in this city, the distributions of

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POINT OF SUBJECTIVE EQUALITY BETWEEN CONTINUOUS VIBRATION AND REPEATED VIBRATION WITH SHORT DURATION

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Abstract

Points of subjective equality between continuous vibration and repeated vibration were examined in hand-transmitted vibration to find a tendency of human response to repeated vibration with short duration. On time and off time of the repeated vibrations were changed from 10 msec to 5 sec. Each adjustment involved a 10 second exposure to the repeated vibration and subsequent 10 second exposure to the continuous vibration. Frequencies of the vibrations were 31.5 Hz and 100 Hz. Subjective magnitude of the repeated vibrations decreased with increase of off-time and with decrease of on-time of the repeated vibrations. Results of this experiment were compared with calculated r.m.s. values and r.m.q. values. R.m.s. values underestimated the repeated vibration and r.m.q. values overestimated the vibration compared with human responses.

1. Introduction

There have been various types of vibration in the working places. These vibrations are divided into periodic, random, non-periodic and repeated shock type vibrations in ISO standard (ISO 5349)[1], although there are no clear classification. With respect to measurement of vibration, measurement methods have been developed to determine vibration amplitude values for the steady-state vibrations such as periodic or random vibrations as introduced in ISO standard and Japanese Industrial Standard (JIS). These standards define the r.m.s. acceleration as a measurement for stationary sinusoidal vibrations.

Paper presented at the Japan Informal Meeting on Human Response to Vibration held at National Institute of Industrial Health, 21-1, 6 chome, Nagao, Tama-ku, Kawasaki, 214 Japan, 1 st to 3 rd July 1994.

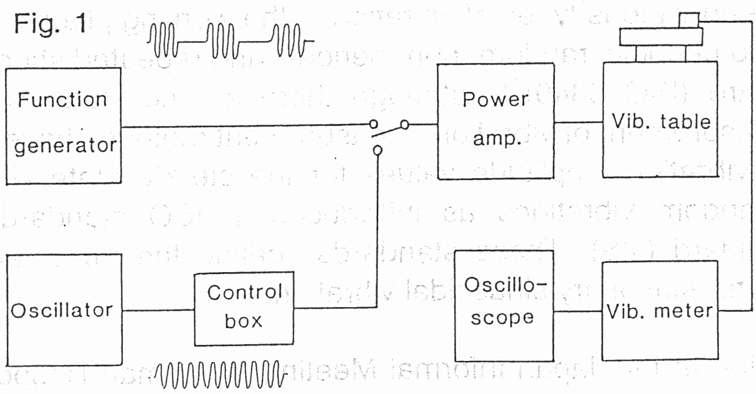
For the non steady–state vibrations like shock type vibration or repeated vibration, the ISO 5349 allows also provisional application of the method based on this r.m.s. value for the repeated shock type vibrations. The evaluation of single shocks, however, is problematic Schenk[2] pointed out because r.m.s. value can only be defined sensible for stationary signals. The outlines of the JIS B 4900[3] provides the equivalent continuous acceleration like Leq value in acoustics for not only stationary but also non–stationary vibration as a measurement of the hand–transmitted vibration. This Leq also is based on r.m.s. value. In addition to the Leq, peak acceleration is adopted as a measurement value of the shocks in the JIS. Therefor, some shocks are measured by Leq method, other shocks are measured by peak acceleration method depending on length of the on–time and off–time of the shocks or repeated vibration. Maeda[4] pointed out discrepancy between the both methods. At the present time, there has not been a precise measurement method for the shock type vibrations or repeated vibrations.

We tried to find a correct measurement quantity which suits to human response to repeated vibration with short duration by a method of point of subjective equality. Results of this experiment were compared with calculated r.m.s. value, r.m.q. for shocks or vibrations with short duration proposed by Griffin[5] and other quantity.

2. Apparatus

Vibration was produced by an electrodynamic vibrator(Model AST–11V, AKASHI Co. Japan). Each subject sat on a seat beside the vibrator in a relaxed posture and his left palm pressed lightly on the vibration table with three sheets of paper to keep the hand warm. The subject held the control dial of a potentiometer box in his right hand to control the amplitude of the matching vibration (sinusoidal continuous vibration of 31.5 Hz and 100 Hz). The acceleration of the vibration table was measured with a vibration meter (Model VM–80,RION Co. Japan). This vibration meter measures rms acceleration and this value is expressed in terms of both an rms, in m/s^2 and a vibration acceleration level, in decibels relative to 10^{-5} m/s^2 rms.(Figure 1)

Fig. 1



Block Schema of the Apparatus

3. Vibration Stimuli

In the experiment , vibration was in the vertical Z axis. Repeated vibrations with short duration were used as stimuli in the experiment. Frequencies of the vibration were 31.5 Hz and 100 Hz. Acceleration magnitudes of the repeated vibrations of on time were 3.15 m/s^2 rms or 110 dB for 31.5 Hz and 10 m/s^2 rms or 120 dB for 100 Hz.
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(31.5 Hz ; 3.15 m/s^2 or 110 dB)

On–time	31.5 ms	63	95	160	315	630	1.0 sec	1.6
Off–time	31.5 ms	63	160	315	630	1.0 sec	1.6	6.3

(100 Hz ; 3.15 m/s^2 or 110 dB)

On–time	10 ms	20	50	100	200	500	1.0 sec	2	5
Off–time	10 ms	20	50	100	200	500	1.0 sec	2	5

4. Subject and procedure

Eight male students, aged 18 to 22 years, served as subjects in the present study. They received pay for participation in the experiments.
Each subject was required to match his perception of the intensity of each the short repeated vibration stimuli by adjusting the matching continuous sinusoidal vibration with the same frequency until he considered that its intensity matched the intensity of the repeated short vibration he had experienced (Point of Subjective Equality ; PSE). Each match involved a ten second exposure to the repeated vibration and subsequent ten second exposure to the matching vibration and this was repeated until matching was completed. This lasted two or three minutes depending on the individual.
Each session had eight or nine matches which lasted twenty or thirty minutes and each subject had ten sessions a day including trial judgments.

5. Results and discussion

Observed values of the subjective judgment were compared with calculated values of r.m.s., r.m.q. and r.m.c. of the repeated vibrations. These formula are as follows, r.m.s. ; root mean square , r.m.q. ; root mean quad , r.m.c. ; root mean cube,

$$\text{r.m.s.} = [1/T \int a^2(t)dt]^{1/2}, \qquad \text{r.m.q.} = [1/T \int a^4(t)dt]^{1/4},$$

$$\text{or} \quad = [1/N \Sigma a^2(i)]^{1/2} \qquad \text{or} \quad = [1/N \Sigma a^4(i)]^{1/4}$$

$$\text{r.m.c.} = [1/T \int |a^3(t)|dt]^{1/3}, \qquad \text{or} \quad = [1/N \Sigma |a^3(i)|]^{1/3}$$

where : $T = t_2 - t_1 = 10$ sec ,
$a(t)$ = an acceleration value in m/s^2.
N = Total number of sampling,
$a(i)$ = an acceleration value in sampling number i.

Figure 2-a,b show observed subjective values of the matched vibration (31.5 Hz and 100 Hz) against off-time of the repeated vibration as a parameter of on-time. Calculated values of r.m.s. ,r.m.q. and r.m.c. of the repeated values are also shown as ranges of lines.

Fig. 2a Point of Subjective Equality

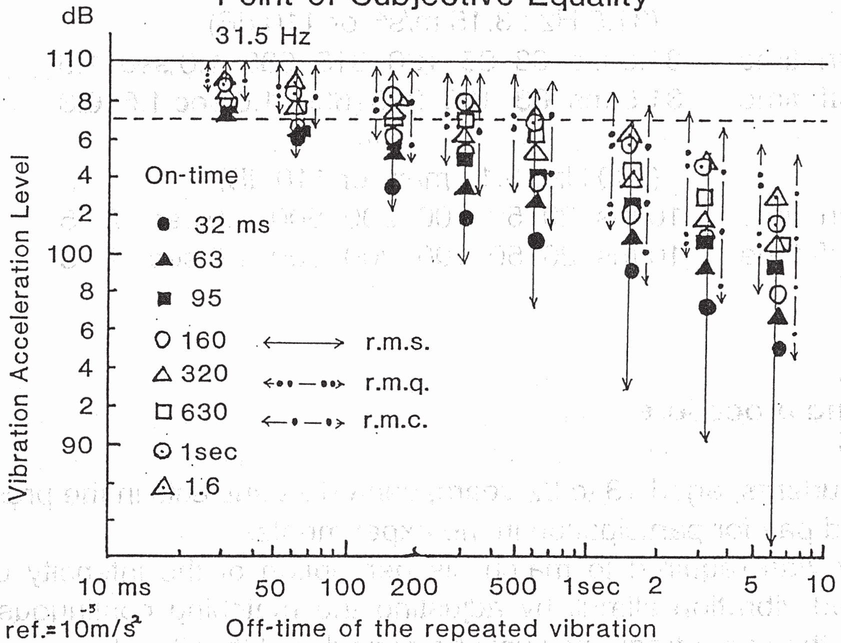
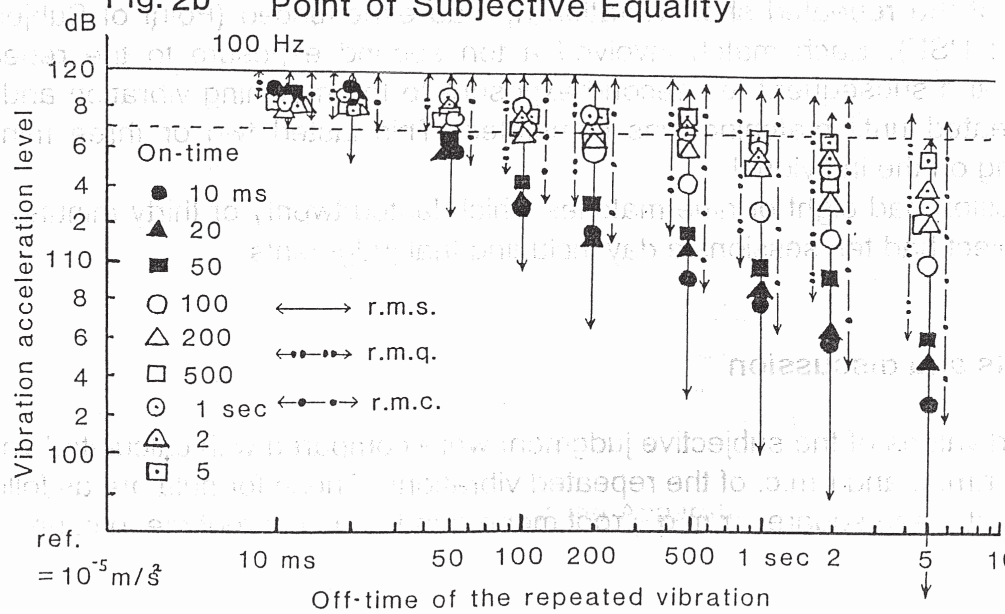


Fig. 2b Point of Subjective Equality



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This r.m.s. value corresponds to the equivalent continuous acceleration in sinusoidal signal (like Leq value in the acoustics) based on the energy rule. The equivalent continuous acceleration level is used as a measurement value of hand-arm vibration in Japan as described in Japanese Industrial Standard.
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In the case where the ratio (on-time/off-time) is more than 1/2, the calculated r.m.s. values overestimated the repeated vibration in all cases. However, values of the overestimation is not larger than values of the underestimation in the case where the ratio is less than 1/2. It is clear that peak value of the repeated vibration with short duration in JIS is also not suitable.

The r.m.q. and the vibration dose value (V.D.V.) have been proposed by Griffin[5] for measurement of the shock type vibration. Definition of the r.m.q. is described above and the V.D.V. is the r.m.q. value multiplied by the fourth root of the duration. The ratio between the repeated vibration signals and the continuous vibration signals {(r.m.q.(repeated;10sec))/r.m.q.(continuous;10sec)} is used for an indicator in comparison with human subjective value in the present study. This ratio of the r.m.q. is the same value as the ratio of the V.D.V. Therefor, the r.m.q. is only used in this text.

Calculated r.m.q. values overestimated the repeated vibration compared with observed subjective values in all cases in the experiment. This overestimation of the repeated vibration with short on-time is larger than that of the vibration with long on-time. However, from the results that difference between the r.m.q. value and subjective value is smaller than that of the r.m.s. , the r.m.q. is more suitable for measurement of the repeated vibration or shock type vibration.

We tried to calculate the root mean cube (r.m.c.) of the repeated vibration with short duration because there are the observed subjective values between r.m.s. and r.m.q. values, especially in the case of the repeated vibration with shorter on-time duration as shown in Figure 2-a,b, although the physical meaning of the r.m.c. is not clarified. The calculated r.m.c. values are suited to the subjective values as predicted. Therefor, we propose that the r.m.c. is most suitable for a measurement quantity of the repeated vibration with short duration or shock type vibration from the results of the present experiment.

6. Conclusion

In consideration of the results of the subjective judgment of the repeated vibration with short duration in this experiment, root mean cubic (r.m.c.) is the most suitable measurement quantity of that vibration, although physical meaning of the r.m.c. is not clarified. And r.m.s. is not a suitable measurement quantity for short repeated vibration.

7. Reference

1) ISO 5349 " Mechanical vibration – Guidelines for the measurement and the assessment of human exposure to hand–transmitted vibration " (1986).
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Japan
Informal Group on

HUMAN RESPONSE TO VIBRATION

VIBRATION

Yufuin, 1995

Department of Environmental Medicine
Kurume University School of Medicine

15 to 16 July 1995

MEASUREMENT AND ANALYSIS OF SHOCK-TYPE VIBRATION

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Abstract

Measurements and analysis of vibrations generated from hand-held tools were made to investigate their frequency characteristic in the laboratory. Some of the percussive tools, especially, the tools without anti-vibration protector have shock-type vibration or high frequency vibrations over 1 kHz and their crest factors are over 15 in VAL(un-weighted acceleration) and over 10 in VL(weighted acceleration). VAL values with a wide band filter(4Hz-3.2kHz) showed larger levels by about 10 dB than that with a narrow band filter(8Hz-I.25 kHz). Shocks or high frequency vibrations are to be reconsidered to affect one of the vibration factors on human body such as neurological disturbance, although it is not difficult to reduce the high frequency vibration levels with simple protector. Weighting curves are also to be reconsider to have a relevant dose-response relationship between the vibration diseases and vibrations with high frequency.

Key words ; High frequency vibration, shock, percussive tools, crest factor, vibration measurement, vibration analysis, weighting curve.

1. Introduction

It is to be considered that percussive tools, such as impact wrenches, scalers, and jack hammers have impulsive and high frequency vibration(above 1 kHz). These percussive tools may have detrimental effect on man comparing with non-percussive ones. Using these percussive tools cause relatively high preferences of vascular and neurological disturbances. Gemne[1] pointed out that a current weighting curve is based on the perception responses of human body, and that, physiologically, the subjective reaction dose not reflect the functional disturbance in vibration-induced white finger. However, application of the present ISO 5349[2] and JIS C 1511[3] of frequency range is from 8 Hz to 1kHz(center frequency) and the weighting curve shows that high frequency vibrations relatively contributes less effective to evaluate the vibrations comparing to low frequency ones.

Paper presented at the Japan Informal Meeting on Human Response to Vibration held Kurume University School of Medicine, 67 Asahi-machi, kurume, 830, Japan, 15th to 16th July 1995.

We tried to show the frequency components of the hand-held tools using in Japan, especially, percussive tools and difference of acceleration levels between frequency band width such as bands of 1/3 octave, a band of SO 5349 and more wide range.

2. Hand-held tools

Hand-held power tools used in the present study were impact wrenches, rock drills of leg type, concrete breakers which were selected as typical tools generating more shock-type vibrations and a grinder generating more steady-state vibrations. Both impact wrenches A and B have no protection handle, the wrench A is for 6 mm bolts and the wrench B is for 9 mm bolts, drills with and without protector and breakers with and without protectors and a grinder shown in Table.1.

Table 1

Hand-held tools

impact wrench A
impact wrench B
leg drill (without protector)
leg drill (with protector)
breaker (without protector)
breaker (with protector)
grinder

3. Measurement and analysis

1) Measurement

Measurement instruments of vibration acceleration were a vibration transducer(PV-93, 21 * 27 * 16mm^3,28gr) which can measure in three directions simultaneously, and a vibration meter (VM-19A,RION Co. Japan). This vibration meter measures r.m.s. acceleration and this value is expressed in terms of a vibration acceleration level(VAL; without frequency weighting) and vibration level(VL; with frequency weighting[3)]) in decibels relative to 10^{-5} m/s^2 r.m.s. A data recorder DAT type(RD-101T,TEAC Co.Japan) also is used to store vibration signals of vibration acceleration shown in Figure1-a. The transducer was mounted firmly with hose clamps on a handle of the hand-held tool. Time of operation of the tools varies 1 min. to 1 min. and 20 seconds depending on types of tools and work condition. Measurements of vibrations at the handle of impact wrenches and a grinder were followed by ISO-8662[4)]. For breakers, measurements were made on the normal work condition using a concrete block(3 * 2 * 1m^3) and for the leg drill using a granite stone(1m^3).

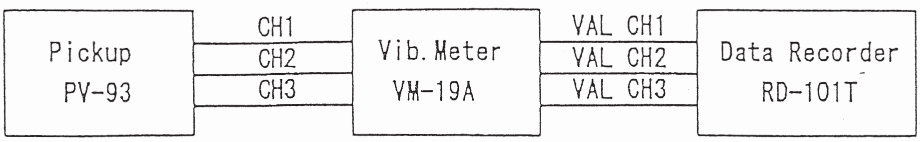


Figure. 1-a

Schematic Diagram for Measurement

2) Analysis

The vibration acceleration signals were analyzed with the data recorder, vibration meter and an analyzer. The vibration meter used as a DC amplifier and as a filter with frequency weighting (VL) and the analyzer (HP3566A,HEWLETT PACKARD) in Figure1–b. Time of analysis of the signals with the analyzer was 60 seconds over the operation time of the tools.

A power spectrum analysis was performed from 4 Hz to 3.2 kHz as a frequency analysis. In order to compare overall values of vibration spectrum components of the tools, we tried to use three frequency ranges, an 1/3 octave band (JIS C 1511: center frequencies; 8 –1.25 kHz), 8 –1.4kHz (JIS C 1511)and 4 –3.2 kHz (maximum range of the analyzer). Crest factors of signals of all tools were calculated.

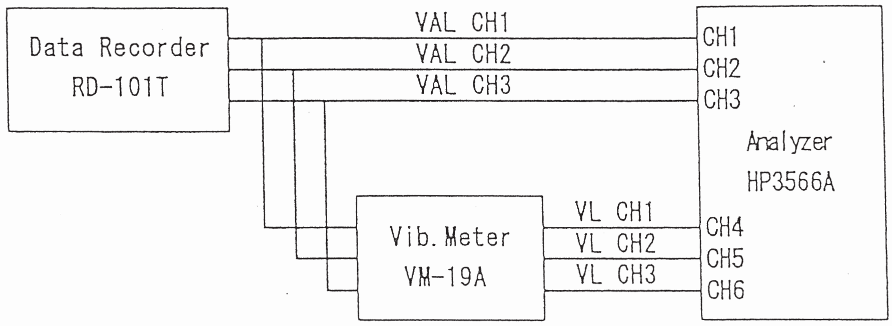


Figure 1–b

Schematic Diagram for Analysis

4. Results

1) Wave form

Acceleration time histories are shown as examples of the vibration tools in Figure 2–a,b. In the figures, the top wave form shows X direction and the middle, the bottom ones show Y and Z direction, respectively. In the impact wrench A(without protector) and breaker (without protector), shock–type waves are seen in three directions, while the grinder has less shock waves, mainly steady–state waves. In case of the breaker (with protector), it has shock–type waves in X and Z axes and has more steady vibration in Y direction.

2) Frequency component

Figure 3–a,b shows power spectrum of vibration of the hand–held tools in this study. In the figures, the top spectrum shows X direction and the middle, the bottom ones show Y and Z direction, respectively. The dominant frequency range of the vibration are between 1 kHz and 2.5 kHz in the impact wrench A, although the dominant frequency are different between axes. In case of the grinder, the fundamental and dominant frequency is 100 Hz and it has less components over 1 kHz in Figure 3–a. The fundamental frequency of the breaker(without protector) is about 17 Hz in three directions and this frequency is also the dominant in Z axis. The dominant frequency range is 500 Hz to 2 kHz in X and Y axes. However, as shown in the Figure 3–b, it includes components over 3 kHz in X direction. In the breaker (with

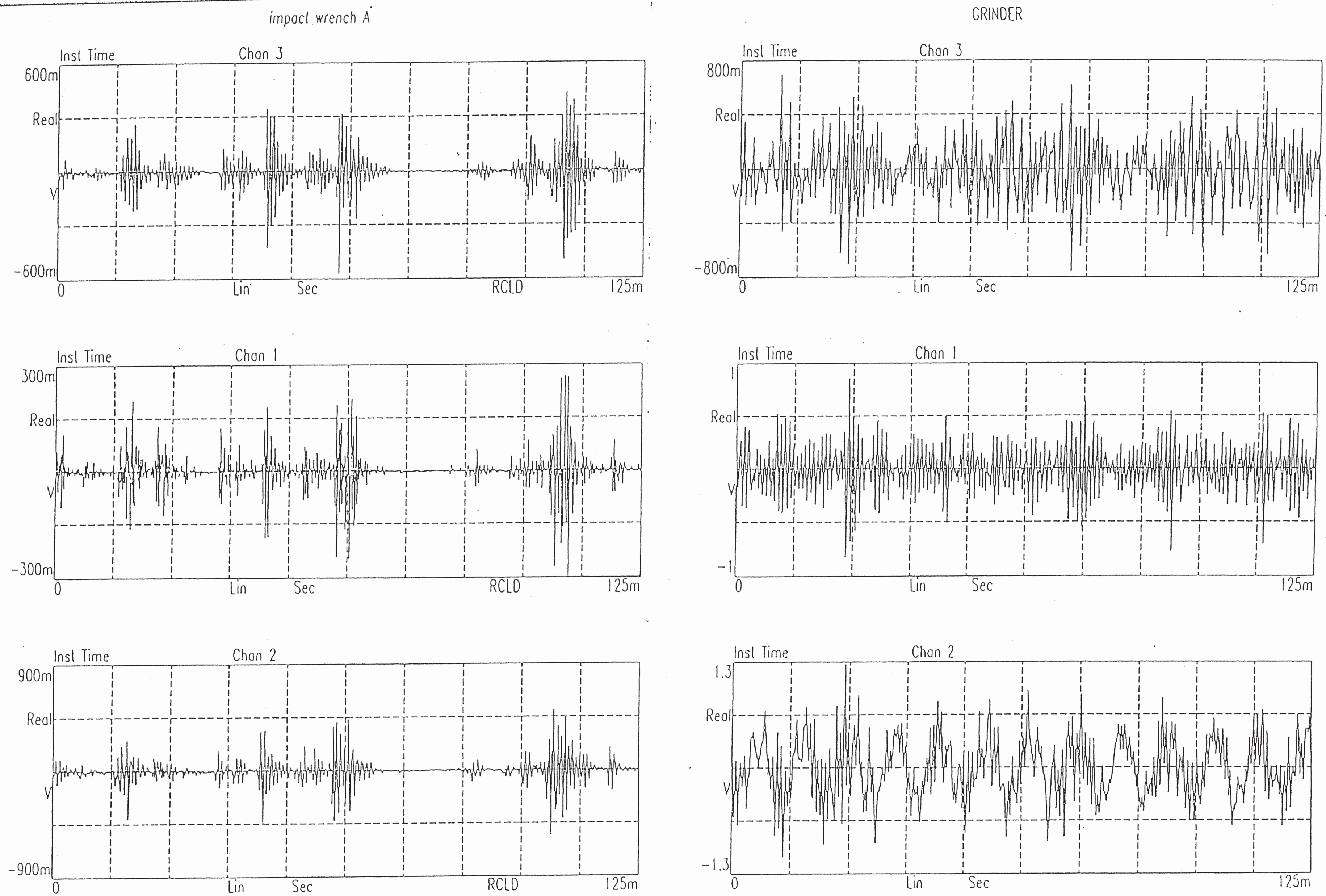
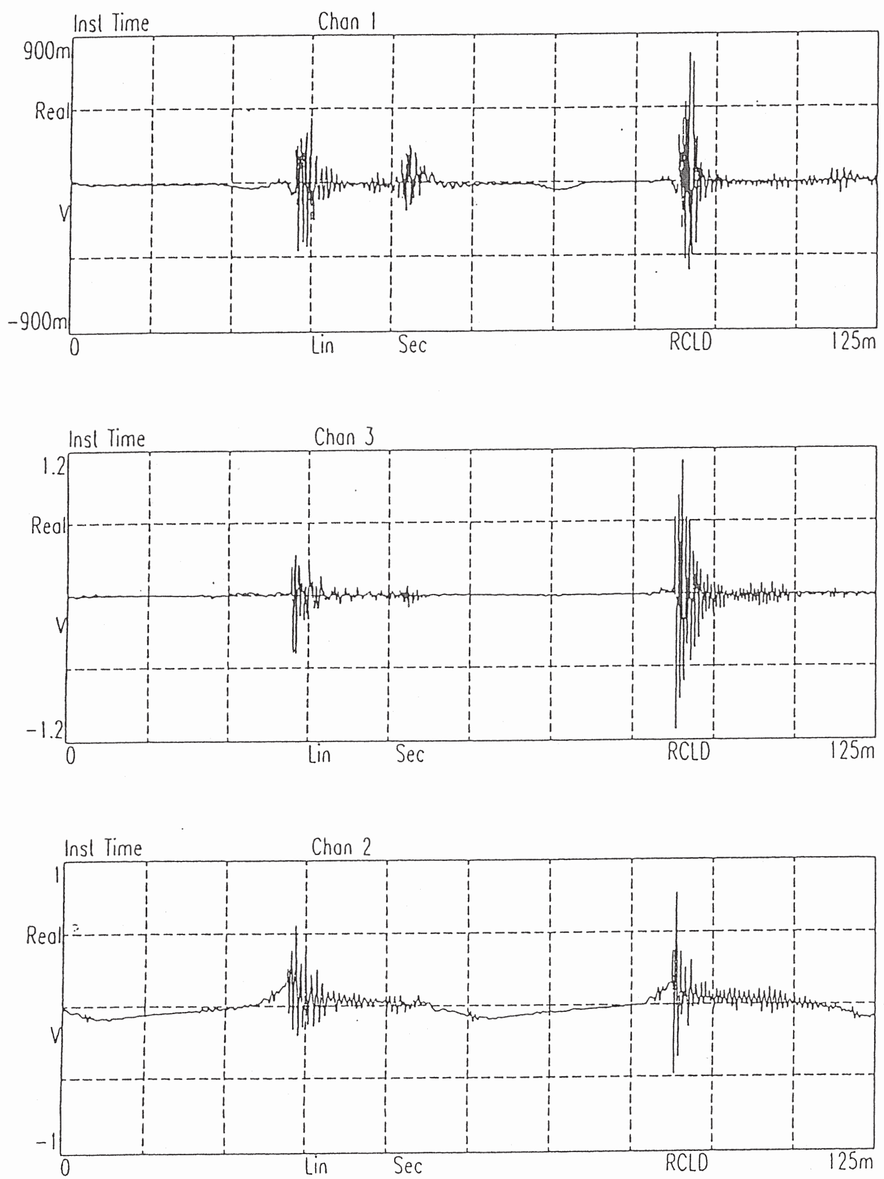
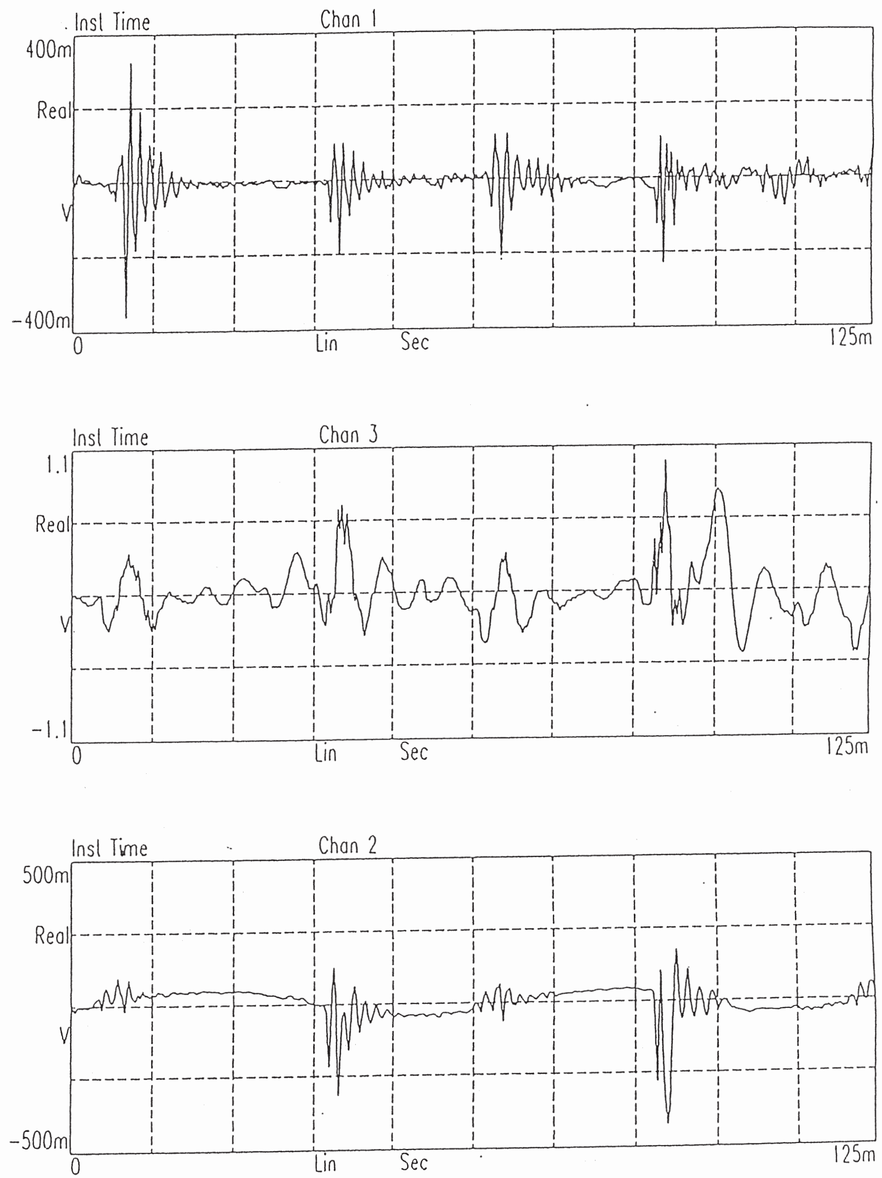


Figure 2-a Acceleration time histories of the tools

breaker (without protector)



breaker (with protector)



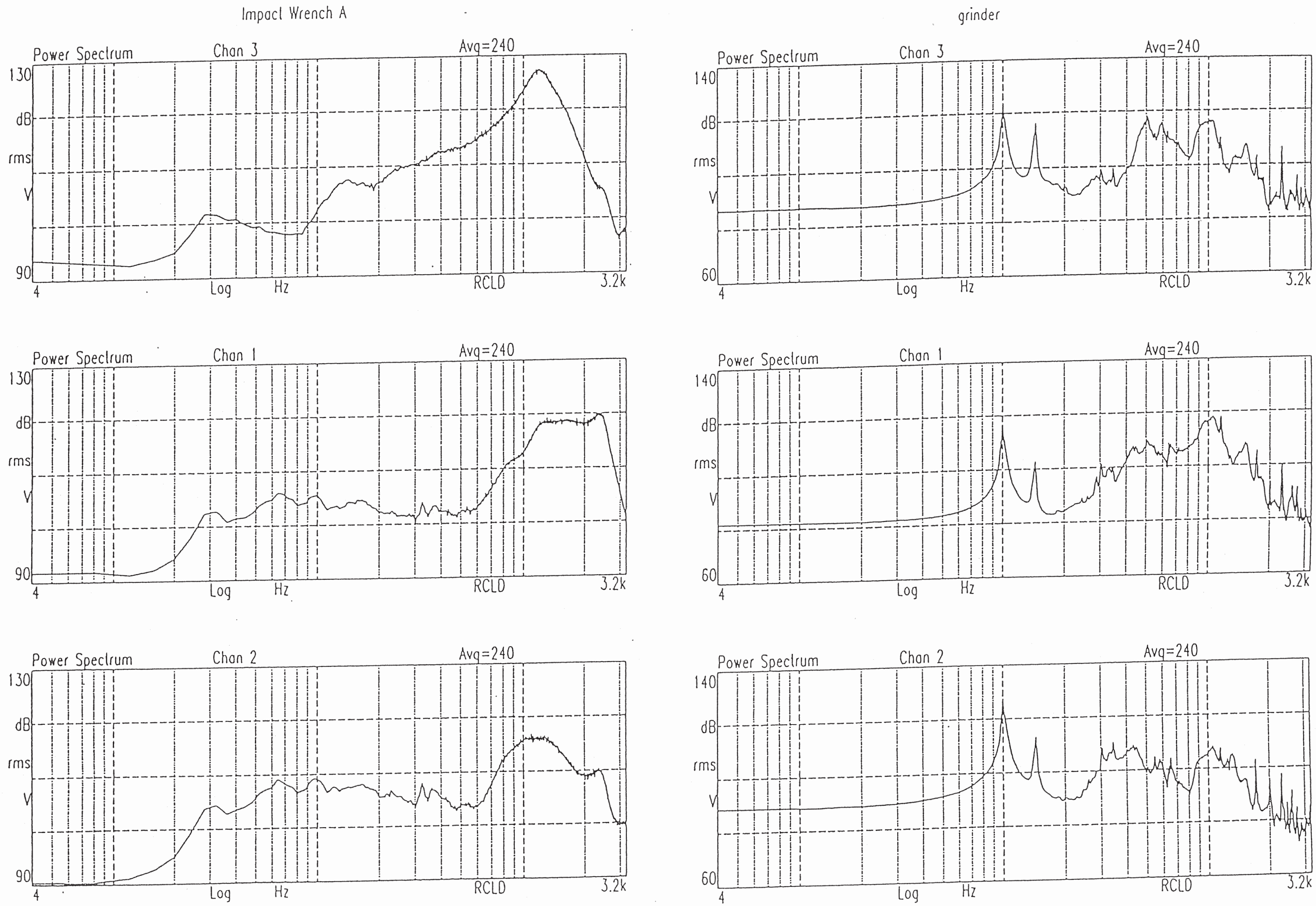


Figure 3–a Power spectrum of vibrations of the tools

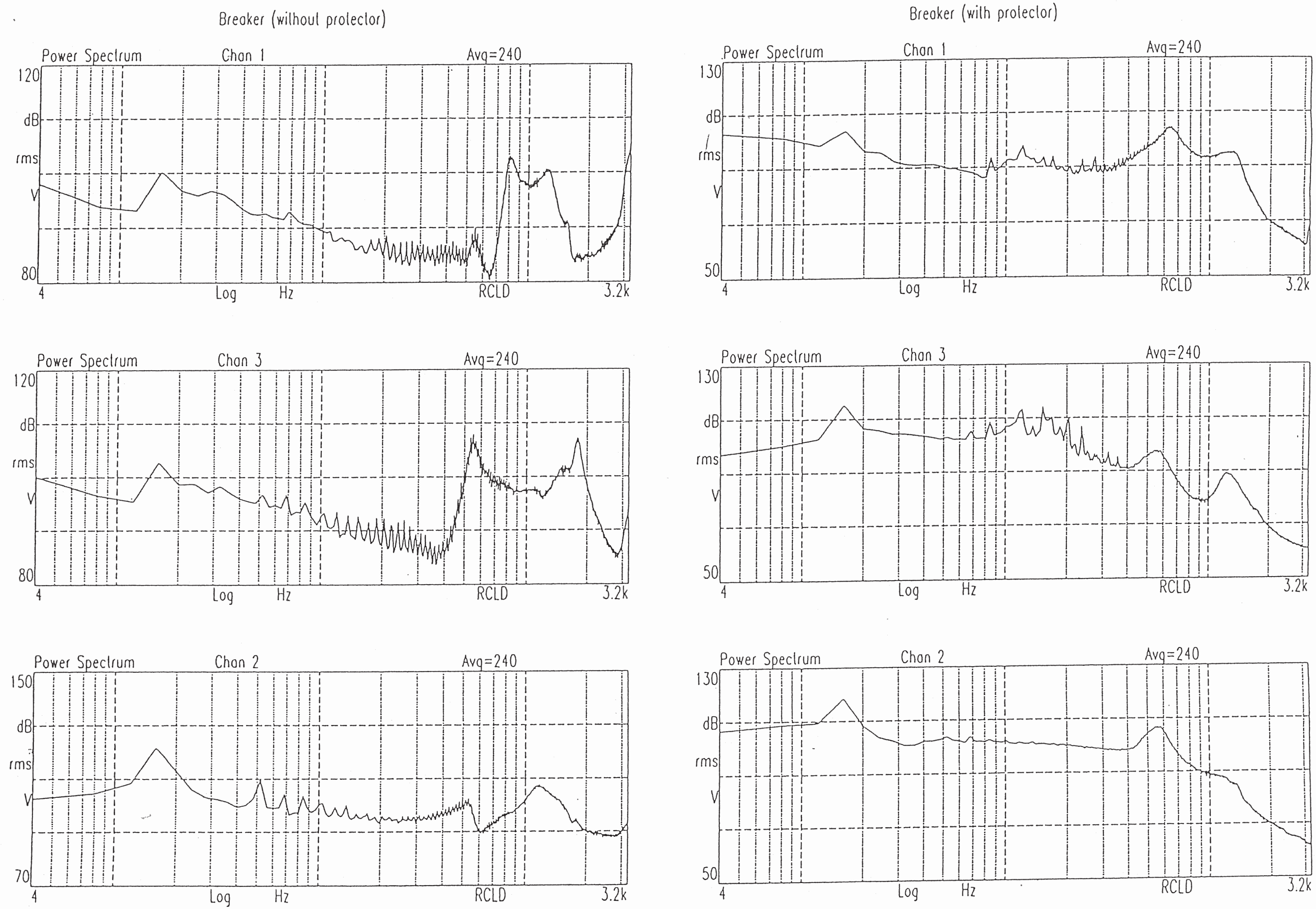


Figure 3-b Power spectrum of vibrations of the tools

protector), components of higher frequency reduced and also the fundamental and the dominant frequency is about 17 Hz in three directions.

3) Frequency characteristic of the vibration meter

Frequency characteristic of the VAL(without weighting) of the vibration meter in the study shows almost a flat line and the characteristic of the VL(with weighting) satisfied tolerance range of the response in Figure 4.

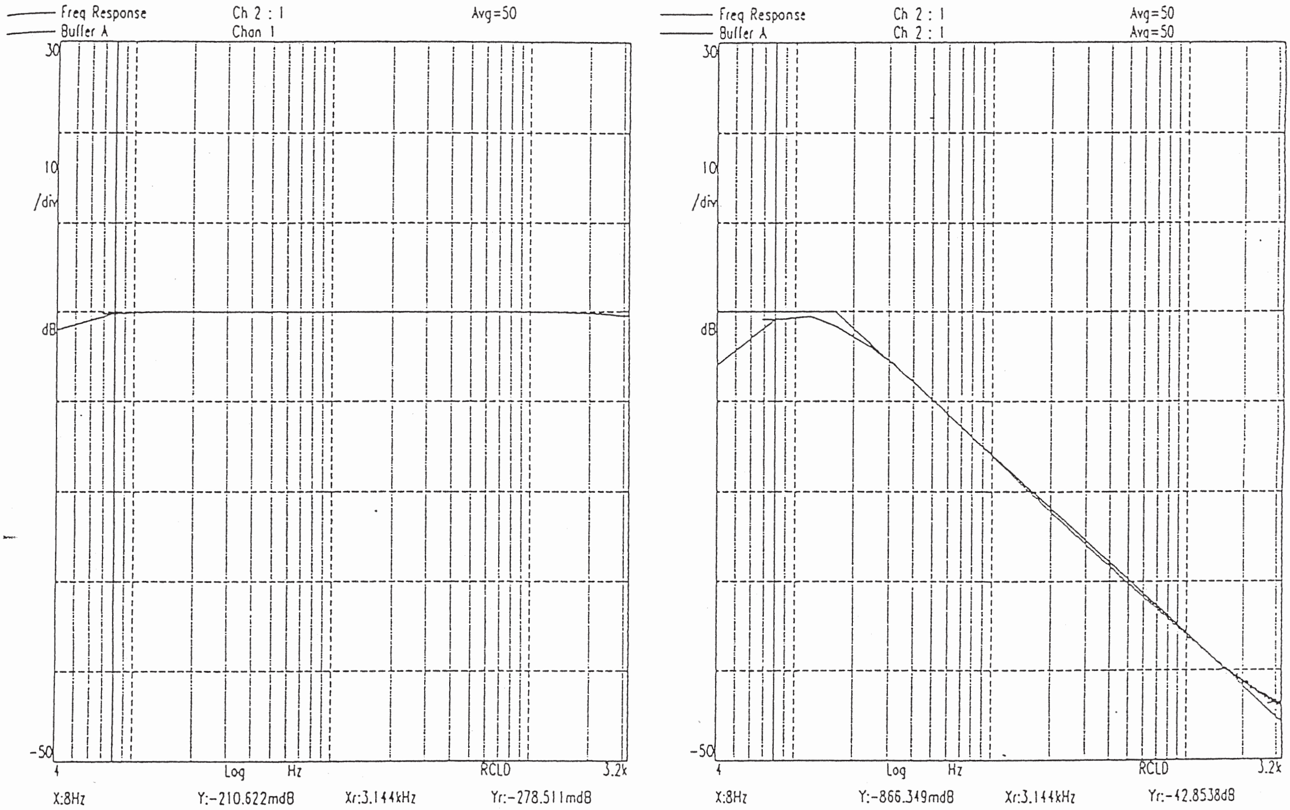
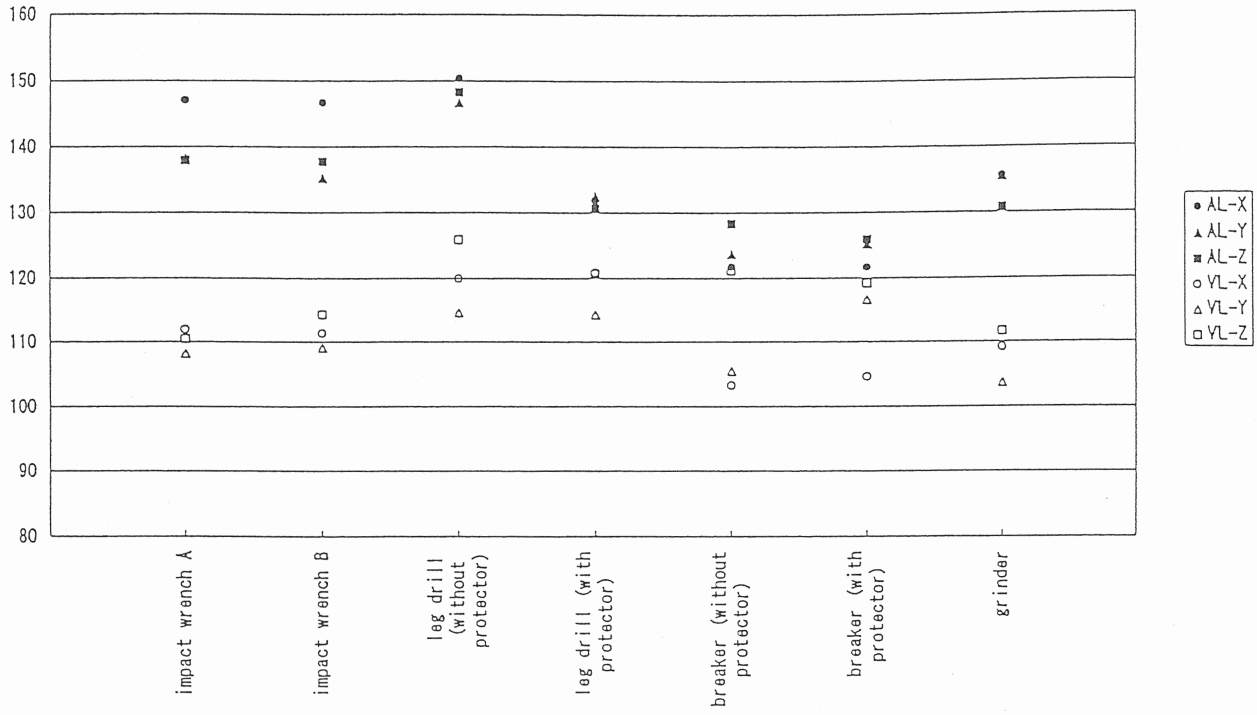


Figure 4 Frequency characteristic of the vibration meter

4) Vibration acceleration level (VAL;unweighted value) and vibration level(VL;frequency weighted value)

Observed VALs and VLs of the vibration tools in the study are shown in Figure 5. VAL values of the two impact wrenches are about 137 dB in Y and Z directions, while VAL value is about 147 dB in X direction. Ten dB difference comes from that the direction of X is the same as the direction of the force vector of the wrench. It is clear that hand-held tools without protector generate larger VAL than that of tools with protector. The protector reduced about 20 dB in VAL value in the leg drill ,while VL values are not so much different between with protector and without protector. From the results of the leg drills, they have high components of frequency. The VAL value of the leg drill has maximum value around 150 dB among the tools in this study. In case of the breaker, there are not quite difference VAL and VL values between with protector and without protector. In detail, however, the VL value in X and Y directions reduced more than 10 dB, while the value of Z direction is no difference. The fact implies the protector of the breaker is not effective. Both VAL values of the grinder are larger than that of the breaker even if without protector.

Figure 5 VAL and VL values of the tools



5) **Effect of frequency band on the VAL and VL values**

In this study, we used three frequency bands to analyze frequency components, a 1/3 octave band(8–1.25kHz), 8–1.4kHz and 4–3.2kHz. VL values of all tools used here are not affected by the frequency band. However, VAL values of the wide band(4–3.2kHz) show more large values from 2 to 9 dB depending on vibration direction than that of the narrow band in the impact wrenches and the breaker without protector. It implies that these tools have components of higher frequency in Table 2. We tried to analyzed VAL values with the level recorder(RION, Japan) and the band pass filter(8–1.4kHz and 4–3.2kHz). Signals of vibration acceleration are given into the level recorder through the band pass filter. Figure 6 shows the results of the VAL values of the impact wrench, Y direction. Results of wide bands(without BPF and 4–3.2kHz) are nearly same each other, while in the narrow band (8–1.4kHz), the value shows about 9 dB reduction as shown in Table 2.

6) **Crest factor**

Crest factors of the vibrations were calculated. Table 3 shows crest factors of both weighted and unweighted signals of vibration acceleration of the hand-held tools. In case of VAL of the tools, crest factors of all tools except the leg drill(with protector) and the grinder have over 9 value which means border value of the signals between steady-state vibration and shock-type vibration in whole-body vibration. The crest factor shows over 9 value, even if the VL value in the impact wrench and the breaker(without protector).

Table 2 VAL and VL values in different band width

		AL-X(dB)	AL-Y(dB)	AL-Z(dB)	VL-X(dB)	VL-Y(dB)	VL-Z(dB)
impact wrench A	1/3oct	146.9	138.3	137.9	111.9	108.2	110.4
	8-1.4kHz	147.0	138.3	137.9	111.9	108.2	110.4
	4-3.2kHz	148.0	144.7	139.9	112.2	109.0	110.5
impact wrench B	1/3oct	146.5	135.3	137.8	111.3	109.1	114.3
	8-1.4kHz	146.6	135.2	137.7	111.3	109.1	114.3
	4-3.2kHz	148.3	144.1	142.8	111.9	109.7	114.5
leg drill	1/3oct	150.1	146.5	148.1	119.9	114.6	126.2
(without protector)	8-1.4kHz	150.3	146.7	148.2	119.9	114.6	125.9
	4-3.2kHz	150.9	146.9	148.6	120.0	114.7	125.9
leg drill	1/3oct	131.8	132.4	130.6	121.0	114.3	120.7
(with protector)	8-1.4kHz	131.8	132.5	130.6	120.9	114.3	120.6
	4-3.2kHz	131.8	132.5	130.6	120.9	114.4	120.7
breaker	1/3oct	121.6	123.6	128.2	102.7	105.2	121.1
(without protector)	8-1.4kHz	121.7	123.7	128.3	103.2	105.5	121.1
	4-3.2kHz	124.7	127.6	129.0	104.0	106.2	121.2
breaker	1/3oct	121.5	125.1	125.9	104.3	116.7	119.1
(with protector)	8-1.4kHz	121.6	125.2	125.9	104.6	116.6	119.1
	4-3.2kHz	122.0	125.2	126.0	104.9	116.6	119.3
grinder	1/3oct	135.3	135.4	130.7	109.1	103.6	111.6
	8-1.4kHz	135.5	135.5	130.7	109.1	103.7	111.6
	4-3.2kHz	135.7	135.8	130.9	109.1	103.8	111.6

Figure 6 Values of level recorder in different band width

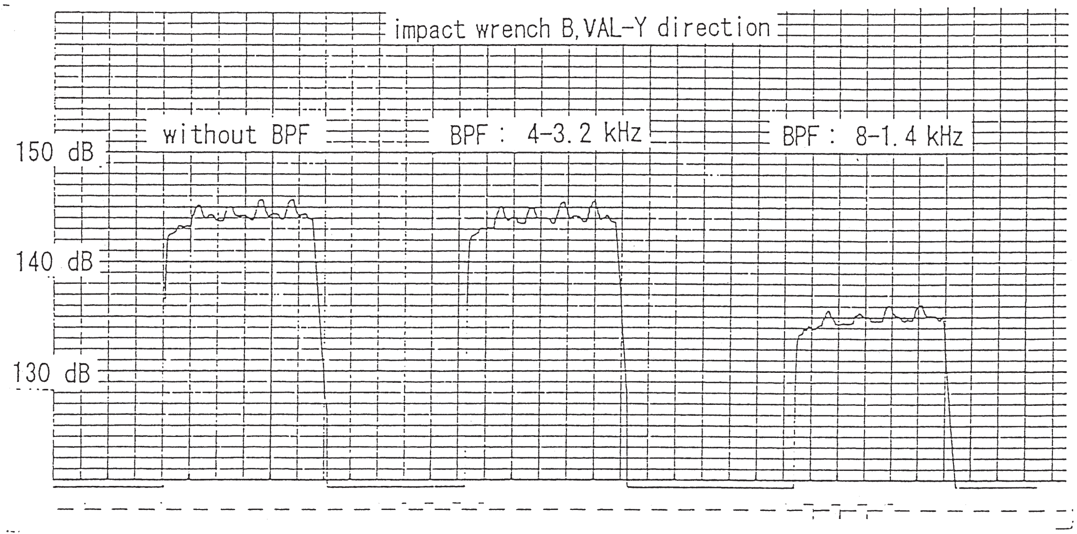


Table 3 Crest factors of vibrations of the tools

	protector	AL-X	AL-Y	AL-Z	VL-X	VL-Y	VL-Z
impact wrench A	without	17.1	22.9	13.4	13.4	10.9	8.5
impact wrench B	without	13.5	12.8	13.1	10.4	6.9	6.4
leg drill	without	14.0	9.9	9.7	8.5	8.3	4.8
leg drill	with	6.1	6.9	5.4	3.9	5.7	4.5
breaker	without	19.6	31.8	23.6	16.3	8.6	4.9
breaker	with	20.2	11.7	27.2	5.8	5.2	3.0
grinder	without	5.4	6.1	4.5	3.4	4.5	2.1

5. Discussion

Vibration acceleration of seven hand-held tools were measured and analyzed here. The tools were selected to be thought to contain shock-type vibration or high frequency vibration. Only a grinder was selected as an example of the tools which does not contain the high-frequency vibration. Measurement of shock has problems as Griffin[5)] pointed out that d.c. shifts are excited and use of a mechanical filter to isolate the transducer from high magnitude high frequency may be essential. Although the measurement of the vibrations was made without the mechanical filter here, the d.c. shifts and any distortion of the time histories of the vibration were not found during the measurements in this study.

From the results of the measurement and analysis of the study, it was found the fact that there are tools containing high-frequency vibrations as predicted.

Gemne introduced in his literature review[1)] that neurological deficiency was observed in the hand of a group of dentists and symptoms indicated injury to nerve fibers. The vibration from drills used by dentists and dental technicians contain ultra-high frequencies(up to 40 kHz). Gemne also introduced Louda's paper that separate frequency-weighting curves must be developed for various types of vibration exposure with particular consideration of impulse vibration and high frequency.

As these papers pointed out that high frequency vibration is an important factor in consideration of hand-arm vibration disease and from the present results which there are hand-held tools with high frequency components, we need to reconsider these high frequency vibration from view points of measurement, effects on human body and evaluation of vibrations. Also revision of weighting curve of present ISO should be one of the purposes to develop a relevant dose-response relation ships based on not vibration perception but on the functional disturbance in vibration induced white finger as pointed out by Gemne.

Although from vibration control it is not difficult to reduce vibration acceleration level in high frequency over 1 kHz, it is important to know that there are tools with high frequency vibration and impulse vibration. In addition to this, the effects of the impulsive vibration on man should be investigated to establish the relevant evaluation method.

6. Conclusion

1) There are hand-held tools which have high frequency vibrations above 1 kHz, especially percussive tools such as impact wrenches and breakers without anti-vibration protectors.
2) Some percussive tools have crest factors over 15 in VAL(unweighted acceleration) and over 10 in VL(weighted acceleration).
3) VAL values with a wide band filter(4Hz-3.2kHz) showed larger levels by about 10 dB than that with a narrow band filter(8Hz-I.25 kHz).
4) It must be reconsidered shocks and vibrations with high frequency to find the functional disturbance caused by these vibrations and to establish the relevant weighting curves and a evaluation method of these vibrations.

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日本労働衛生工学会第35回学会

講　演　抄　録　集

１　９　９　５

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120　　間欠振動の実効値と心理反応との比較

○米川善晴，金田一男，高橋幸雄（産業医学総合研究所）

1．はじめに

振動の分野で、人と係わる振動の場合は手腕振動と全身振動に分けて取扱っている。作業環境において全身振動も脊柱への影響との関連で問題であるが、国内では主に手腕振動が問題とされている。ここでもこの手腕振動について検討する。この振動においては測定器、測定方法はJIS規格がつくられている。評価基準は国内では現在無いのでISOの基準を使っている（チェンソーは別）。これらの測定法、規格、基準は主に定常的な振動を対象としている。現場に存在する衝撃的な振動に対する測定、評価法は検討されているが、未だ定められていない。今回、衝撃振動に近い間欠振動に対する人体の心理的な反応を求め、定常振動に使われている振動の測定量である実効値（r.m.s.）と比較してその相違を示し、実効値の有用性を検討した。

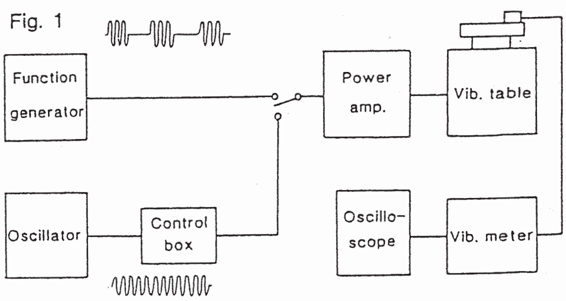
2．実験方法

間欠振動は正弦振動を断続して作り、断続の間隔を各々一定とした。この振動の元の周波数は8, 16, 31.5, 100 Hzの４種類を使った。断続のon timeは１波長から最長500波長（５秒, 100Hz）まで、off timeは１波長から最長200波長（6.3秒, 31.5Hz）で両者の種々の組合わせた振動を使った。この間欠振動の大きさは断続の onの状態の振幅が 8, 16Hzでは実効値で1.6m/s²、31.5Hzでは3.15m/s²、100Hzでは10m/s²のように手腕振動の周波数荷重特性に合わせた値を採用した（表１）。振動は垂直方向について検討した。

Table 1
On-time and off-time of the repeated vibration

(8 Hz ; 1.6 m/s² or 104 dB)									
On-time	125 ms	250	625	1.25 sec	2.5	6.25			
Off-time	125 ms	250	625	1.25 sec	2.5	6.25			
	1	2	5	10	20	50			
(16 Hz ; 1.6 m/s² or 104dB)									
On-time	62.5 ms	125	313	625	1.25 sec	3.13	6.25		
Off-time	62.5 ms	125	313	625	1.25 sec	3.13	6.25		
	1	2	5	10	20	50	100		
(31.5 Hz ; 3.15 m/s² or 110 dB)									
On-time	31.5 ms	63	95	160	315	630	1.0 sec	1.6	
Off-time	31.5 ms	63	160	315	630	1.0 sec	1.6	6.3	
	1	2	5	10	20	31.5	50	100	
(100 Hz ; 10 m/s² or 120 dB)									
On-time	10 ms	20	50	100	200	500	1.0 sec	2	5
Off-time	10 ms	20	50	100	200	500	1.0 sec	2	5

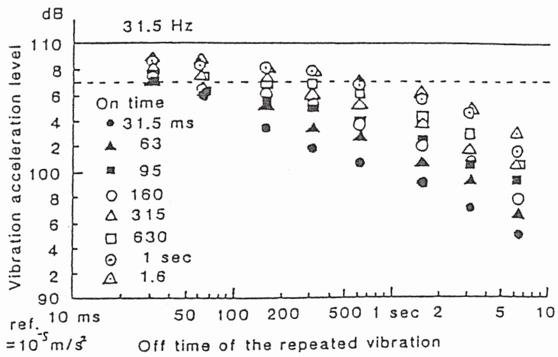
方法は被験者が振動台脇のイスにリラックスした姿勢で座り左手掌を軽く振動台に載せる。間欠振動を基準にして、同周波数の連続振動の感覚的大きさが等しくなる点（主観的等価点, PSE）を求めた。その方法は被験者自身が右手で抵抗減衰器を使い振動台の振幅（大きさ）を変えて求めた。間欠と連続振動が10秒毎交互に等価値が得られるまで与えられた（図１）。十分練習した後実験が行われた。一つの判定は約2, 3分間要し、一回の拘束が30分間以内とした。被験者は男子学生７名が実験に参加した。振動台は明石製の動電型振動台（AST11V）、刺激の電気信号発生器は NFの



Block Schema of the Apparatus

function synthesizer(1731,1732)、振動計はRIONの汎用振動計(VM-80)を使用した。実験室の室温はほぼ23℃に維持した。

Fig.2　Point of Subjective Equality



3．結果と討論

図2に代表的に31.5Hzの結果を示した。onの時間をパラメータにして横軸にoffの時間を縦軸に間欠振動に感覚的に等価した連続振動の振動加速度を示している。全般的にonの時間が短く、offの時間が長くなるに従い、等価値が小さくなる。この結果は推測された。間欠振動の休止(off)時間が長くなれば当然その振動の感覚的大きさが小さくなる。その減少率は一定でなく、onが長くoffが短い場合の方が逆の場合よりも減少率が小さい、即ち最小の減少率ではoff時間が2倍になっても1dB以下で逆の場合ではoff時間が2倍で約2dBの減少が観られた。

Fig.3　Point of Subjective Equality

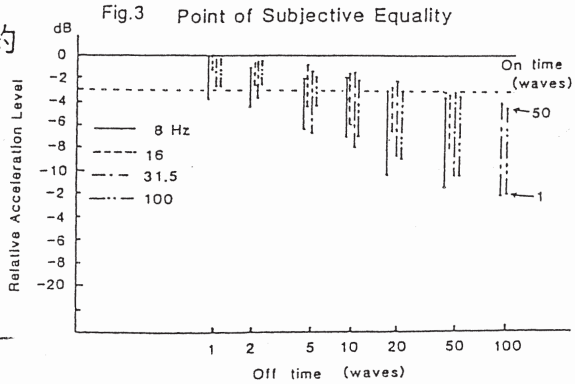


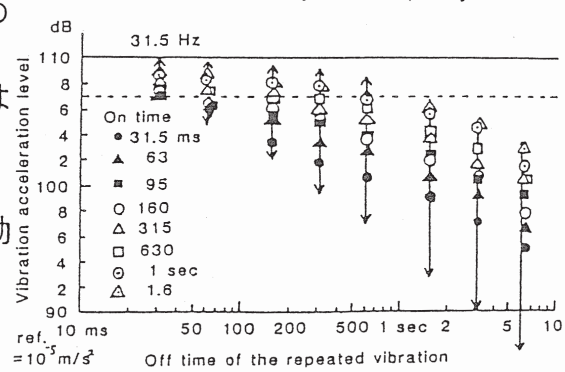
図3に他の周波数の結果を示した。ここでは横軸にoffの時間でなく波数を、縦軸は相対加速度をとった。結果は7名の平均値の範囲を示している。8Hzが少しバラツキが大きいが結果のレンジ、減少率は各々の周波数でそほど大きな差がみられなかった。従ってこの反応は周波数依存性がないと考えられる。

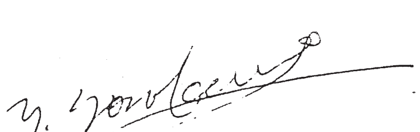
式1に示すように現在用いられている振動の測定量は実効値(r.m.s.)である。この量は現在定常振動には適用されているが、間欠振動に適用した場合、31.5Hzの結果例を図4に示す。観測値は図2と同じで、計算値は定義通りに実効値を計算し、その結果のレンジを実線で示した。offが短い場合は計算値は大きめになっているが、実験結果との差異が小さかった。他方offが長くonが長い場合では両者はほぼ一致しているが、onが短い場合計算値が可なり小さく過少評価していることが解る。この事はonが短くoffが長い場合即ち衝撃振動に近い程計算した実効値と差が大きくなることが解った。振動台上での実際の振動を使っても同様の結果であった。従って人の特性に適合する測定量を考えると、この実効値(r.m.s.)は衝撃的振動には良い量とはいえないと考えられる。

$$r.m.s. = [1/T \int a^2(t)dt]^{1/2} \quad \text{-----} \quad (1)$$

$$T = 10\ \text{sec}$$

Fig.4　Point of Subjective Equality





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HUMAN RESPONSE TO SHOCK-TYPE VIBRATION ON HAND

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SUMMARY

Points of subjective equality between continuous vibration and shock-type vibration (repeated vibration) were examined in hand-transmitted vibration to find a tendency of human response to shock-type vibration (repeated vibration with short duration). On time and off time of the repeated vibrations were changed from 10 ms to 5s. Each adjustment involved a 10 second exposure to the repeated vibration and subsequent 10 second exposure to the continuous vibration. Frequencies of the vibrations were 8, 16, 31.5 and 100 Hz. Subjective magnitude of the shock-type vibrations (repeated vibrations) decreased with increase of off-time and with decrease of on-time of the repeated vibrations. Results of this experiment were compared with calculated r.m.s. values, r.m.q.values and other quantity. R.m.s. values underestimated the repeated vibration and r.m.q. values overestimated the vibration compared with human responses.

Key words: shock type vibration, hand vibration

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INTRODUCTION

There have been various types of vibration at the working places. These vibrations are divided into periodic, random, non-periodic and repeated shock type vibrations in ISO standard (ISO 5349) (1), although there are no clear classifications. With respect to measurement of vibration, measurement methods have been developed to determine vibration amplitude values for the steady-state vibrations such as periodic or random vibrations as introduced in ISO standard and Japanese Industrial Standard (JIS). These standards define the r. m. s. acceleration as a measurement for stationary sinusoidal vibrations.

For the non steady-state vibrations like shock-type vibration or repeated vibration, the ISO 5349 allows also provisional application of the method based on this r. m. s. value for the repeated shock type vibrations. The evaluation of single shock, however, is problematic as Schenk (2) pointed out because r.m.s. value can only be defined sensible for stationary signals. The outlines of the JIS B 4900 (3) provides the equivalent continuous acceleration like Leq value in acoustics for not only stationary but also non-stationary vibration as a measurement of the hand-transmitted vibration. This Leq also is based on r. m. s. value. In addition to the Leq, peak acceleration is adopted as a measurement value of the shock in the JIS. Therefore, some shocks are measured by Leq method, other shocks are measured by peak acceleration method depending on length of the on-time and off-time of the shocks or repeated vibration. At the present time, there has not been a precise measurement method for the shock type vibrations or repeated vibrations.

We tried to find a correct measurement quantity which suits to human response to repeated vibration with short duration by a method of point of subjective equality. Results of this experiment were compared with calculated r. m. s. value, r.m.q. for shocks or vibrations with short duration proposed by Griffin (4) and other quantity.

APPARATUS

Vibration was produced by an electrodynamic vibrator (Model AST-11V, AKASHI Co. Japan). Each subject sat on a seat beside the vibrator in a relaxed posture and his left palm pressed lightly on the vibration table with three sheets of paper to keep the hand warm. The subject held the control dial of a potentiometer box in his right hand to control the amplitude of the matching vibration (sinusoidal continuous vibration of 8, 16, 31.5 and 100 Hz). The acceleration of the vibration table was measured with a vibration meter (Model VM-80, RION Co. Japan). This vibration meter measures r. m. s. acceleration and this value is expressed in terms of both an r.m.s, in m/s^2 and a vibration acceleration level, in decibels relative to $10^{-5} m/s^2$ r.m.s.

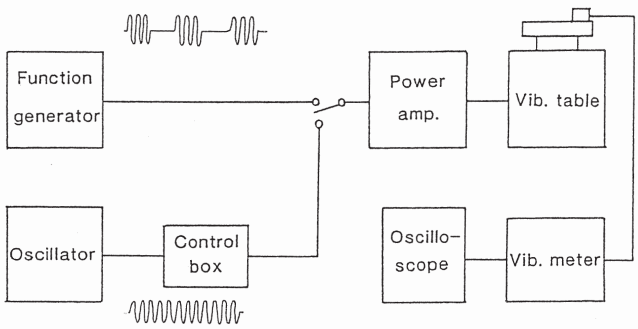

Fig. 1. Block scheme of the apparatus of present experiment.

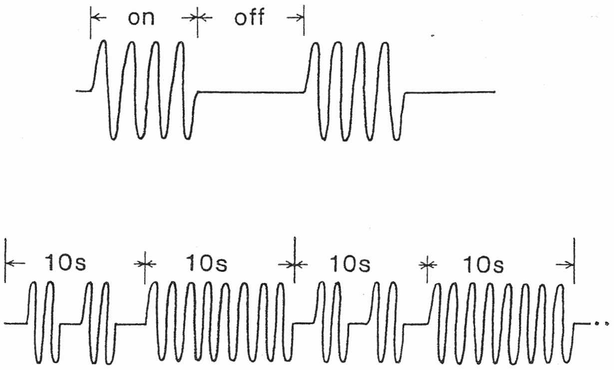

Fig. 2. Signal patterns and their sequence of the repeated vibrations.

Figure 1 shows block schema of the apparatus and an example of the vibration signal and its sequence of the signal are shown in Fig. 2.

VIBRATION STIMULI

In the experiment, vibration was in the vertical Z axis. Repeated vibrations with short duration were used as stimuli in the experiment. Frequencies of the vibration were 8, 16,

Table 1. On-time and off-time of the repeated vibration

	(8 Hz; 1.6 m/s^2 or 104 dB)
On-time	125 ms 250 625 1.25 s 2.5 6.25
Off-time	125 ms 250 625 1.25 s 2.5 6.25
	(16 Hz; 1.6 m/s^2 or 104 dB)
On-time	62.5 ms 125 313 625 1.25 s 3.13 6.25
Off-time	62.5 ms 125 313 625 1.25 s 3.13 6.25
	(31.5 Hz; 3.15 m/s^2 or 110 dB)
On-time	31.5 ms 63 95 160 315 630 1.0 s 1.6
Off-time	31.5 ms 63 160 315 630 1.0 s 1.6 6.3
On-time	(100 Hz; 10 m/s^2 or 120 dB)
Off-time	10 ms 20 50 100 200 500 1.0 s 2 5
	10 ms 20 50 100 200 500 1.0 s 2 5

31.5 and 100 Hz. Acceleration magnitudes of the repeated vibrations of on time were 1.6 m/s^2 r.m.s. or 104 dB for 8 and 16 Hz 3.15 m/s^2 r.m.s. or 110 dB for 31.5 Hz and 10 m/s^2 r.m.s. or 120 dB for 100 Hz.

On-time and off-time of the repated vibrations were shown in Table 1.

These on- and off-times were changed from 1 wave to 500 waves depending on the frequencies.

SUBJECT AND PROCEDURE

Eight male students, aged 18 to 22 years, served as subjects in the present study. They received pay for participation in the experiments.

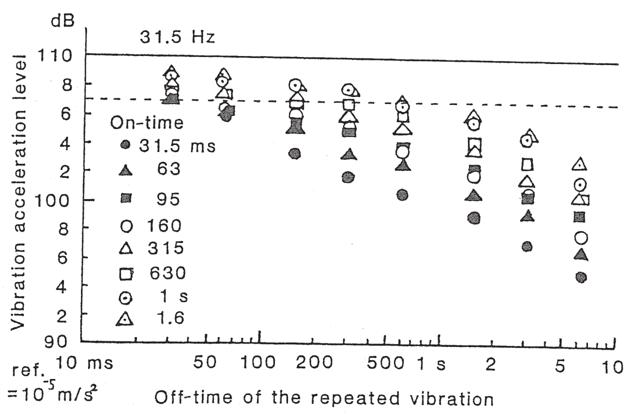

Fig. 3a Results of point of subjective equalities of the present study - frequency of vibration 31.5 Hz.

Each subject was required to match his perception of the intensity of each the short repeated vibration stimuli by adjusting the matching continuous sinusoidal vibration with the same frequency until he considered that its intensity matched the intensity of the repeated short vibration he had experienced (Point of Subjective Equality; PSE). Each match involved a ten second exposure to the repeated vibration and subsequent ten second exposure to the matching vibration and this was repeated until matching was completed. This lasted two or three minutes depending on the individual.

Each session had eight or nine matches which lasted twenty or thirty minutes and each subject had ten sessions a day including trial judgements.

RESULTS AND DISCUSSION

Figures 3a, b show typical observed subjective values of the matched vibration (31.5 Hz and 100 Hz) against off-time of the repeated vibration as a parameter of on-time. Each point of the figures shows mean value of eight subjects.

Subjective magnitude of the matched vibrations decreased with increase of off-time and with decrease of on-time of the repeated vibration.

Observed values of four frequencies are shown in Fig. 4. It is not observed that results of this experiments are dependent on frequency.

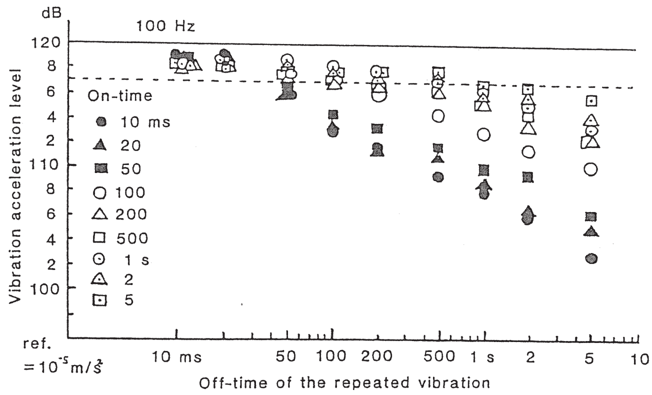

Fig. 3b Results of point of subjective equalities of the present study - frequency of vibration 100 Hz.

Observed values of the subjective judgement were compared with calculated values of r.m.s., r.m.q. and r.m.c. of the repeated vibrations as shown in Fig. 5a-b. Calculated values of r.m.s., r.m.q. and r.m.c. of the repeated values are also shown as range of lines.

These formula are as follows: r.m.s; root mean square, r.m.q.; root mean quad, r.m.c.; root mean cube,

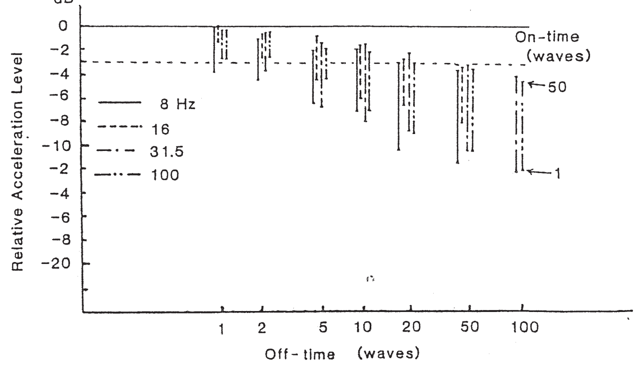

Fig. 4. All results of the experiment: 8, 16, 31.5 and 100 Hz.

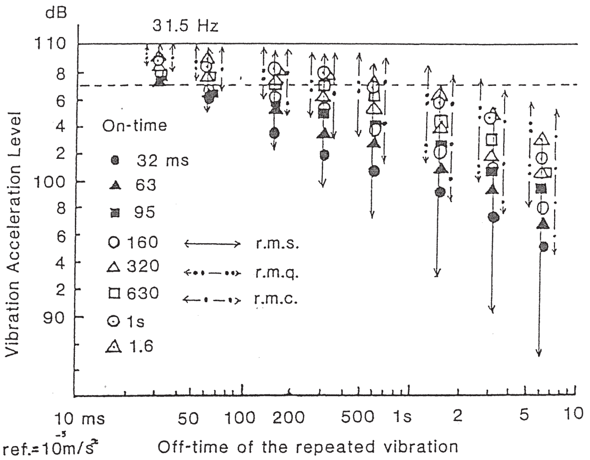

Fig. 5a. Observed values of point of subjective equalities and calculated values of the r.m.s., r.m.q and r.m.c. of repeated vibrations - frequency of vibration 31.5 Hz.

$$\text{r.m.s.} = [1/T \int a^2(t)dt]^{1/2}$$
$$\text{or} \quad = [1/N \, \Sigma \, a^2(i)]^{1/2},$$

$$\text{r.m.q.} = [1/T \int a^4(t)dt]^{1/4}$$
$$\text{or} \quad = [1/N \, \Sigma \, a^4(i)]^{1/4},$$

$$\text{r.m.c.} = [1/T \int |a^3(t)|dt]^{1/3}$$
$$\text{or} \quad = [1/N \, \Sigma \, |a^3(i)|]^{1/3},$$

where: $T = t_2 - t_1 = 10$ s, a(t) = an acceleration value in m/s^2, N = total number of sampling, a(i) = an acceleration value in sampling number i.

In the case where a ratio between on-time and off-time (on-time/off-time) is less than about 1/2, calculated r.m.s. values underestimated the short repeated vibration compared

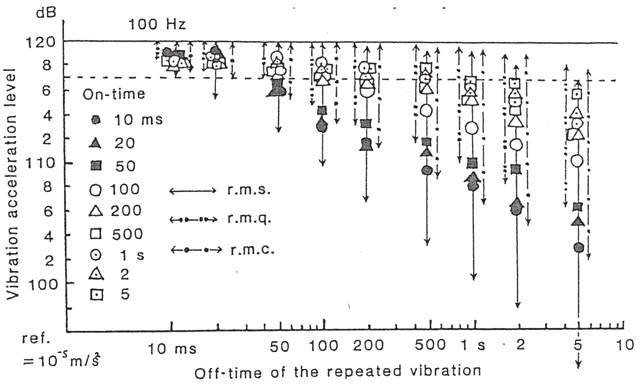

Fig. 5b Observed values of point of subjective equalities and calculated values of the r. m. s., r. m. q. and r. m. c. of repeated vibrations - frequency of vibration 100 Hz.

with the observed values. This tendency was clearly observed in the longer off-time and in the shorter on-time of the repeated vibration. The repeated vibration with long off-time and short on-time becomes shock-type vibrations.

Namely, from this results, it is predicted that there are large differences between calculated r.m.s. values and human responses in shock-type vibrations.

This r. m. s. value corresponds to the equivalent continuous acceleration in sinusoidal signal (like Leq value in the acoustics) based on the energy rule. The equivalent continuous acceleration level is used as a measurement value of hand-arm vibration in Japan as described in Japanese Industrial Standard. Therefore, the measurement method of the equivalent continuous acceleration level in JIS is not suitable for the shock type vibration.

In case where the ratio (on-time/off-time) is more than 1/2, the calculated r.m.s. values overestimated the repeated vibration in all cases. However, values of the overestimation are not larger than values of the underestimation in the case where the ratio is less than 1/2. It is clear that peak value of the repeated vibration with short duration in JIS is also not suitable.

The r. m. q. and the vibration dose value (V. D. V.) have been proposed by Griffin (4) for measurement of the shock type vibration. Definition of the r.m.q. is described above and the V. D. V. is the r. m. q. value multiplied by the fourth root of the duration. The ratio between the repeated vibration signals and the continuous vibration signals {(r.m.q. (repeated; 10s)/r. m. q. (continuous; 10s)} is used for and indicator in comparison with human subjective value in the present study. This ratio of the r.m.q. is the same value as the ratio of the V. D. V. Therefore, the r.m.q. is only used in this text.

Calculated r.m.q. values overestimated the repeated vibration compared with observed subjective values in all cases in the experiment. This overestimation of the repeated vibration with short on-time is larger than that of the vibration with long on-time. However, from the results that difference between the r.m.q. value and subjective value is smaller than that of the r.m.s., the r.m.q. is more suitable for measurement of the repeated vibration or shock type vibration.

We tried to calculate the root mean cube (r.m.c.) of the repeated vibration with short duration as shown in Fig. 5-a, b, although the physical meaning of the r.m.c. is not clarified. The calculated r.m.c. values are suited to the subjective values as predicted. Therefore, we propose that the r.m.c. is most suitable for a measurement quantity of the repeated vibration with short duration or shock type vibration from the results of the present experiment.

CONCLUSION

In consideration of the results of the subjective judgement of the repeated vibration with short duration in this experiment, r. m. s. is not a suitable measurement quantity for short repeated vibration. And root mean cubic (r. m. c.) is the most suitable measurement quantity of that vibration, although physical meaning of the r.m.c. is not clarified.

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Table 3. Number of years of exposure for the onset of vibration-induced white finger (VWF) in various percentages of forestry workers according to the vibration exposure levels of the Directive for physical agents proposed by the Commission of the European Union (EUC). Daily exposure to hand-transmitted vibration is expressed in terms of 8 h frequency-weighted energy-equivalent acceleration [A(8)]. (Fig. 1. shows the estimated regression equation)

EUC level	A(8) (m.s^{-2}r. m. s)	Percentage of forestry workers affected with VWF				
		10	20	30	40	50
Threshold	1	22.5	42.9	> 45.0	> 45.0	> 45.0
Action	2.5	9.2	17.5	25.5	33.3	41.1
Increased risk	3.5*	6.6	12.6	18.3	24.0	29.5
Exposure limit value	5	4.6	8.9	12.9	16.9	20.8

**Approximated A(8) value for a short-term exposure (~15 min) to equivalent acceleration of 20 m.s^{-2}*

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811　断続振動の回復時間

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1．はじめに

断続振動を人の手に与えた時の振動感覚の一時的域値移動（TTS)を実験的に求め、断続のon, offの時間間隔を系統的に変えて振動覚回復の程度を検討した。更に、この結果を以前別の条件で求めて得られたTTSの予測式[1)]に当てはめ、一般化の検討を試みた。

2．実験方法

断続振動は31.5Hzの正弦振動を断続して暴露振動として使った。　この振動の大きさは断続のon状態の振幅が10 m/s^2 で垂直方向について検討した。断続のon timeは1, 2, 5 minでoff time は1, 2, 5, 10 minとし、繰り返しは上記のon, offの組み合わせの一部を試みた。域値の実験は試験振動として63Hzの正弦振動を使い被験者は男子大学生７名、座位で左手の手掌を軽く振動台に載せ右手で減衰器を使い振動台の振幅を変えて域値を求めた。

予測式を求めた実験条件は暴露振動が125Hzの１オクターブのランダム振動（125dB）で模擬ハンドルを把持して暴露された。域値は校正された振動感覚計（リオン, UA-02A)を使い、125Hzの正弦振動で指先で測定された。被験者は男子大学生１０名であった。

3．実験結果と考察

このTTSの予測式を使った値と上記の結果を比較した例を図１（a, b)に示した。図１aはonが5min、offが1minの場合、１bは各々5min, 5minで５回の繰り返しの場合で、１回暴露によるTTSの増加、更に繰り返しによる増加も殆ど一致している。回復の場合は実験結果よりも予測値のほうが幾分大きかった、特にoff timeが短く繰り返し回数が少ない場合この傾向は強かった、が数回等の繰り返しを対象にすれば大きな差がないので利用出来ると考えた。

実験では出来なかったon が10min、off が2, 5, 10minについてこの予測式を使いTTSを求めた（図２a, b, c)。休止時間が短い場合は、振動感覚が暴露前の状態に回復されず、長くなると回復する。これらの結果からoff/onの値が１以上で暴露前までに回復することが判る。

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日本経営工学会誌, p336-342, Vol. 40, No. 5(1989).

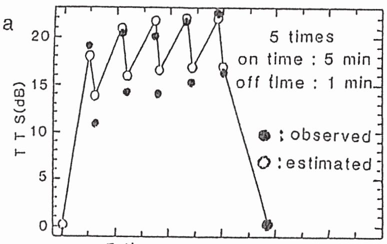
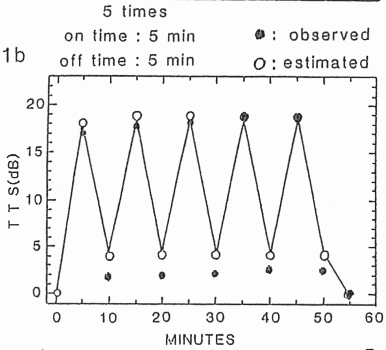
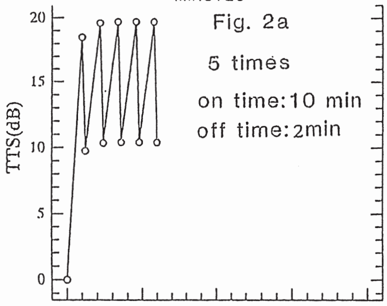
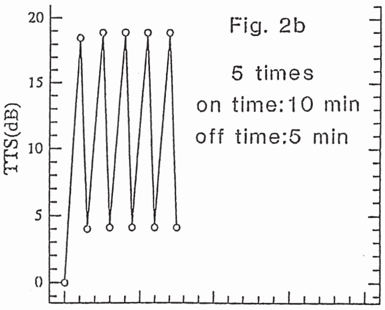
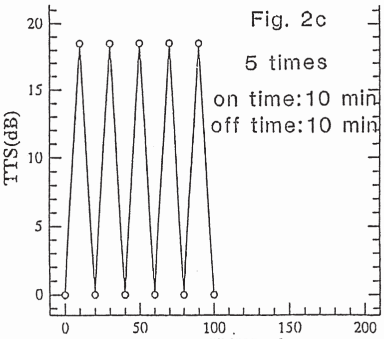
Fig. 1a


Fig. 1b








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Prediction of TTS for Hand Intermittent Vibration

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Abstract: Temporary Threshold Shift (TTS) is often used as an indicator of the effect of hand-transmitted vibration on the human body. An experiment for the prediction of TTS in exposure to intermittent vibration was conducted in the present study to examine the exposure equivalent rule, as well as the equations for growth and recovery TTS. It was found that the prediction of TTS obtained here was in good agreement with measured TTS. This estimation procedure for predicting TTS was compared with the notification of the Labor Ministry in Japan, in which control of the operation time and the rest time for hand-vibrating tools was described. The results suggest that the rest time of five minutes for a continuous exposure time of 30 minutes with low-level of vibration tools should be extended to 10 minutes of rest time.

Key words: TTS, Hand-transmitted vibration, Intermittent vibration, Vibration perception

Introduction

A great deal of research involving the subjective response to vibration of the hand and fingers has been conducted in the area of determination of thresholds. The applications suggested for threshold measurement include the measurement of temporary threshold shifts (TTS)[1] produced by vibration as an indication of the relative response to different vibration stimuli. TTS is defined as a different threshold value before and after disturbed vibration exposure, is often used as an indicator of the effect of vibration on the human body[2,3]. It would be a proper means of predicting the effects of intermittent vibration exposure by measuring the TTS values.

At the work place, workers using hand-held tools such as impact wrenches and breakers are exposed daily to the vibrations generated by these tools. Some research has been carried out on TTS of hand-transmitted vibration by the single exposure of sinusoidal vibrations[4–6]. However, workers do not use these tools throughout the entire day, but are exposed to vibration intermittently during the day. Therefore, the results of these single- exposure studies could not be applied intermittent vibrations in the work place because if the rest time between vibration exposures is short, recovery of the TTS of the first exposure will not yet be completed (residual TTS), and this residual effect increases the second TTS value. It is also predicted that many frequency components from the vibrations of hand-held tools produce larger TTS values than that of sinusoidal vibrations due to the critical band effect[7,8].

Interruptions in vibration exposure have a beneficial effect on health (1). In one of the clauses in the notification concerning the prevention of vibration disorders issued by the Labor Ministry of Japan[9], control items for operating time are specified as follows: 1) The work plan should be established so as to limit the work to two hours per day. 2) When work is being performed continuously, the work should

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be limited to ten minutes, and a rest of more than five minutes should be taken when chipping hammer, riveter or impact tools are being used. For other tools such as a grinder, one continuous work period should be limited to 30 min, and more than five minutes rest should be taken following 30 min of work. As described in the second section of the notification, we could not find any scientific results or evidence to support the description in the second section. In this time we attempted to obtain TTS following exposure to the intermittent vibrations of hand-held tools, in order to establish prediction equations of TTS for vibrations in the work place, and to apply these equations to the experimental simulation of actual field conditions. It was also examined whether notify the Labor Ministry is proper through comparison with the results of these equations.

Experiment

In work places in which hand-held tools are used, workers are normally intermittently exposed to vibrations from the tools. In the case of intermittent exposure to vibrations, rest breaks in intermittent exposure to vibration are effective in reducing exposure to vibrations.

Experimental apparatus and experimental methods

The present study used the experimental apparatus shown in Figure 1. Vibrations applied to human hands were generated by a vibration exciter with an amplifier through an electric signal oscillator and a one-octave band filter. An oscillator with a filter can generate random signals. Vibration acceleration levels were measured using a vibration meter through the vibration acceleration transducer setting on the model handle of the vibration exciter. Gripping force was also measured using a static pressure meter to maintain constant pressure as a monitor during the experiment. Vibration perceptional thresholds were measured using a vibrotactile measurement system (RION type AU-02A). The experimental conditions are shown in Table 1.

Stimuli

Primarily, the vibrations of two types of hand-held tools (tools A and B) were used as stimuli to examine TTS when human subjects were intermittently exposed to vibrations with different exposure times, rest times and vibration acceleration levels, as shown in Figure 2 and Table 1. Eight kinds of vibrations and were used, and they were applied to subjects in a random sequence, is shown in Figure 2. The total exposure time was six minutes.

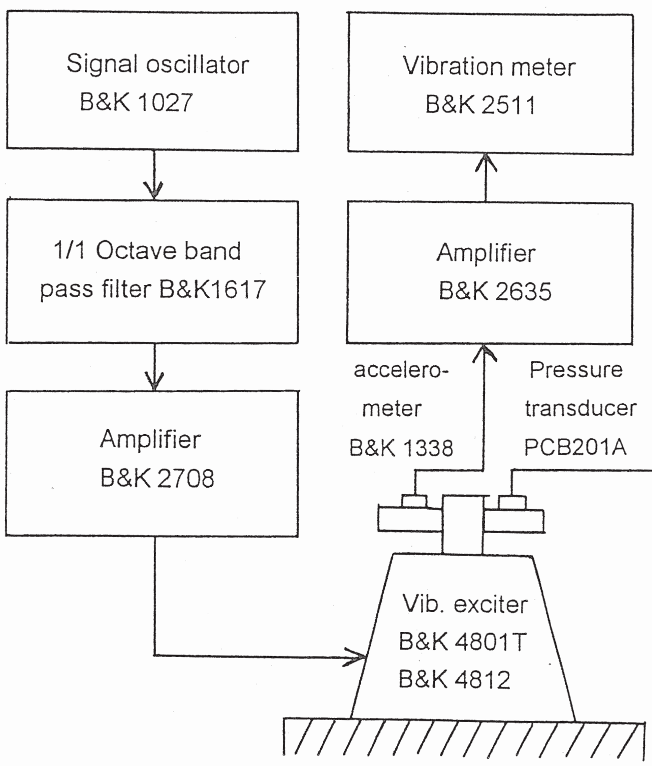

Fig. 1. Experimental apparatus

Prior to the present experiment, a preliminary experiment[10] was conducted using sinusoidal intermittent vibrations with a constant acceleration level, exposure time, and rest time. The TTS was observed under the condition of five repetitive vibrations. The exposed vibration frequency was 31.5 Hz at 120 dB, and the test frequency was 63 Hz for the preliminary experiment. The seven subjects were all healthy male students between the age of 19 and 25 years.

Subjects

Four subjects participated in the present study. Their mean age was 22.5 years. All subjects were healthy male University students with no history of neuromuscular or vascular disorders. None of the subjects had any occupational experience operating hand-held tools nor had ever suffered any injuries to the upper extremities.

Table 1. Experimental conditions

Exposure time	1, 2 min
Exposure vibration	Electric grinder A, Electric grinder B
Repetitive times	4 times
Test frequency	125 Hz
Vibration acceleration. Level*	97, 108 dB
Gripping force	0.5 Kg
Room temperature	25°C

*($dB=20 \log_{10} a/a_0$; $a_0=10^{-5} m/s^2$)

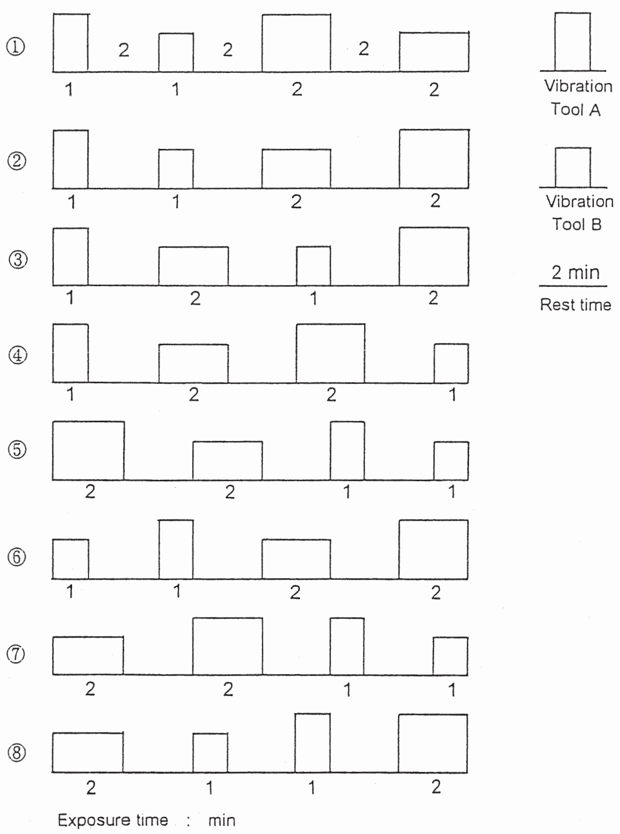

Fig. 2. Pattern of hand-transmitted intermittent vibration exposure

Procedure

In order to study the TTS in fingertip vibratory sensation, the vibratory sensation threshold was measured just before and after exposure to hand-transmitted intermittent vibration. The measurement time itself was less than 30 sec. The experiment was carried out in a soundproof room. The room temperature was maintained at approximately 25°C. Vibration was applied to the right hand through a handle. The subjects were instructed to clasp the handle tightly and constantly with the palm in a relaxed posture. The static pressure of the gripping force was to maintain 0.5 Kg by watching the monitor of the pressure meter. The threshold of 125 Hz vibratory sensation was measured at the tip of the right index finger. Vibration thresholds were determined through the use of the vibrotactile sensation meter. Vibrotactile thresholds were determined according to the adjustment method. In this method, the measurement was performed three times. Thresholds were calculated based on the mean values of three measurements. The TTS was defined as the difference (in decibels) between the vibrotactile thresholds determined before and after vibration exposure. The noise level during the vibration experiment was 55 dB(A).

Estimation Equations of TTS for Growth and Recovery

It is necessary to establish an estimation equation to calculate TTS for random exposure and rest time of intermittent vibrations in the working field. Previous experiments[11] calculated equations to estimate the growth and recovery of TTS at 125 Hz of the test frequency, as follows:

for the growth of TTS,
$$TTS = -11.76 - 8.59 \log_{10} T + 0.16\ V + 0.2\ V \log_{10} T \quad (1)$$

where T is the exposure time (in min) and V is the vibration acceleration level (in dB).

For the recovery of TTS,
$$TTSi = TTS\,(1 - 0.7836 \log_{10} (i/0.5)) \quad (2)$$

where TTSi is the TTS at after i time (in min) and TTS is growth of the TTS.

Exposure equivalent rule

To predict TTS following the exposure to intermittent vibrations, the exposure equivalent rule established by the authors was used. It is a rule that a residual TTS (dB) converts into exposure time (min). After the first t_1 minutes of vibration exposure, the TTS_1 will be A dB according to equation (1), and at the end of the t_2 (rest time), residual TTS_2 will be B dB from equation (2), although there is little recovery, as shown in Figure 3. This residual TTS_2 (B dB) could be converted into exposure time t_i using equation (1). This t_i is an equivalent exposure time. Then, TTS_3 after the next t_3 minutes of vibration exposure when be C dB using exposure time T ($T=t_i + t_3$) and equation (1) are used.

Algorithm of estimation TTS for intermittent vibrations

After the first vibration exposure to intermittent vibrations, TTS_1 (A dB) of the first exposure time t_1 could be calculated using equation (1) and after t_2 minutes, TTS_2 (B dB) could be calculated using the equation (2), and if TTS_2 becomes 0, TTS_3 of the second exposure can be obtained using equation (1). In addition, if TTS_2 is not 0, TTS_2 could be converted into the equivalent exposure time (t_i) using the exposure equivalent rule and equation (1). Following the second vibration exposure, TTS_3 will be calculated using exposure time T ($t_3 + t_i$) and equation (1). These procedures will then be continued until the vibration exposure of the intermittent vibrations is complete.

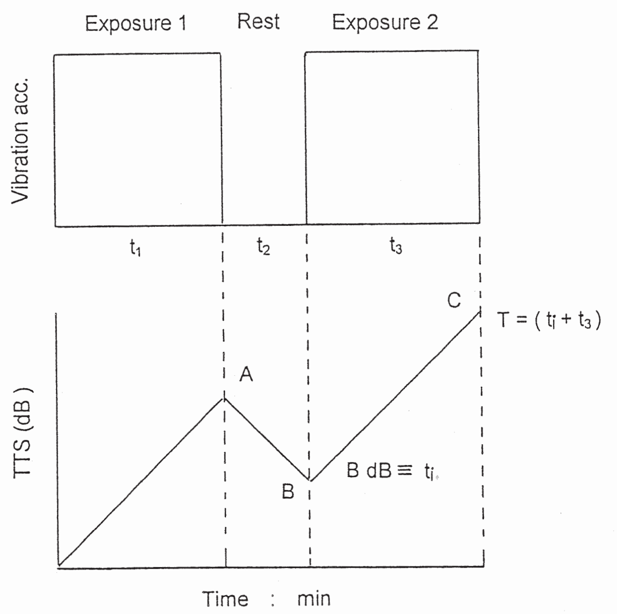

Fig. 3. The form of the exposure equivalent rule

Results and Discussion

Preliminary experiment

Figures 4-a, b show the results of the preliminary experiment. It was found that repeated exposure made a growth of TTS and an increment of residual TTS gradually from the first exposure to the fifth exposure with repetitive times, under the conditions of five minutes for the exposure time and one minute for rest time. An extended period was required for the TTS to recover under these experimental conditions. It resulted in an increase in TTS growth and residual TTS along with the vibration acceleration level. These results clarify that intermittent vibrations accumulate physiological effects in terms of TTS in the human body in the case of a longer exposure time compared to a rest time for the vibrations, as shown in Figure 4-a.

To recover the TTS, five minutes was adopted as one of rest times for the intermittent vibrations. The results show that an extended rest time reduced the of residual TTS from approximately 15 dB to 2 dB and TTS value reached to saturate promptly. This five-minute increase in the rest time,

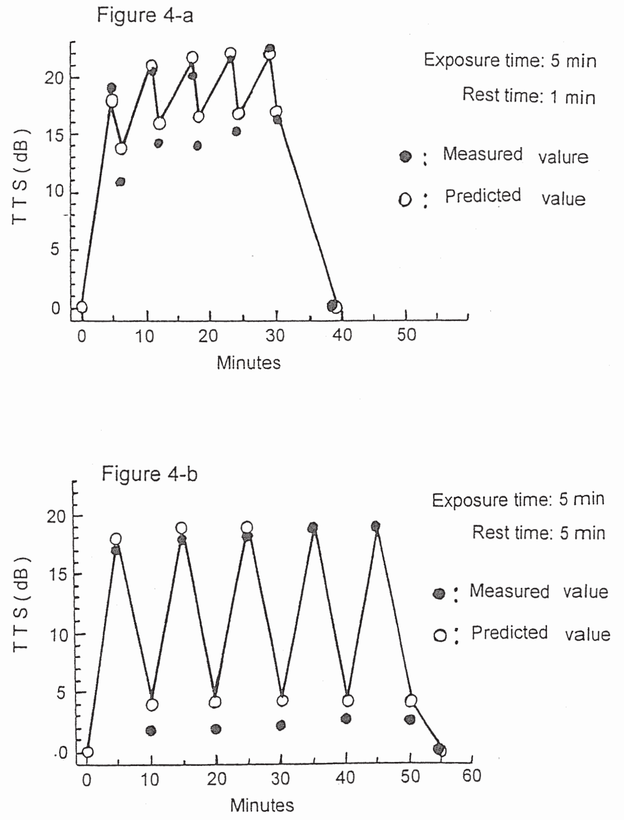

Fig. 4. Results of preliminary experiment using sinusoid and predicted values

however, did not result in the TTS recovering completely to reach a measured value of zero dB, shown in Figure 4-b.

The estimated TTS values were plotted in Figure 4. It was found that the estimated values of growth TTS were in good agreement with the measured values, although the test frequency differed between the preliminary experiment (63 Hz) and the present experiment (125 Hz). This prediction, however, overestimated the estimated residual TTS compared with the measured values in the cases in which the rest time was one minute and five minutes. This overestimation may due to the use of sinusoidal vibrations and a difference in test frequency.

Present experiment

Figures 5-a–d show four results among eight experimental results as examples, as the tendencies of the results are very similar. As shown in Figure 4, we could obtain an increase in growth TTS and residual TTS values under conditions of an extended exposure time, high magnitude of acceleration level, and the short rest time in this experiment. There was a remarkable agreement between the estimated TTS values and the measured values in each result shown in Figure 5. From these results, it is clear that the TTS following exposure to intermittent vibrations in the work place could be predicted according to the exposure equivalent rule, the growth equation, and the equation for the recovery process of TTS.

We attempted to apply this procedure for estimation TTS in the present study to notification of the Labor Ministry in Japan, which recommended a rest time of more than five minutes for a continuous exposure time of 10 min with large vibration, from tools, and of 30 min with small vibrations from tools. Factors in the estimation of TTS the exposure times of 10 min and 30 min, the rest time of 5 min, a vibration acceleration level of 110 dB, and the total net exposure time of 120 min. The results are shown in Figures 6-a, b. Repetitive exposure contributed to increase TTS only in the first and second exposures among the five time exposures, and to maintain a constant TTS thereafter. There was still residual TTS in with a rest time of five minutes. This indicates that five minutes is insufficient for the TTS to recover at the exposure time described in the notification above.

Then next trial was conducted to estimate sufficient rest time the TTS to recover completely at an exposure time of the 10 min and 30 min according to the exposure equivalent

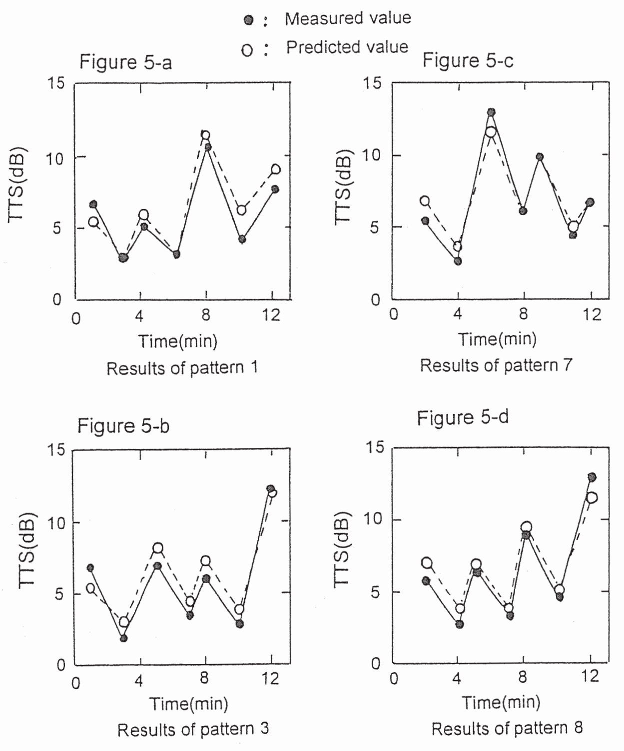

Fig. 5. Results of present experiment using vibration of hand-held tools and predicted Values

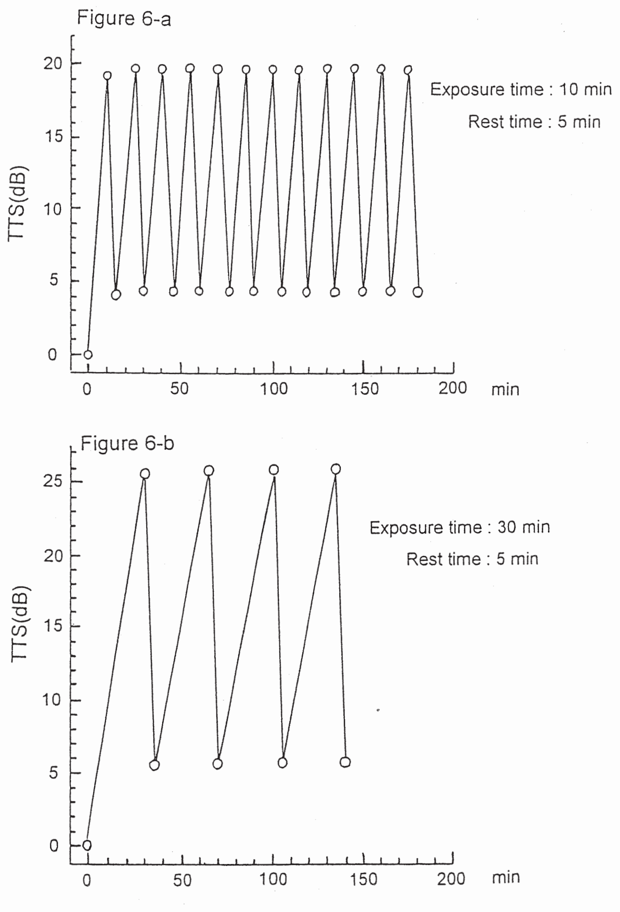

Fig. 6. Prediction TTS values for short rest time

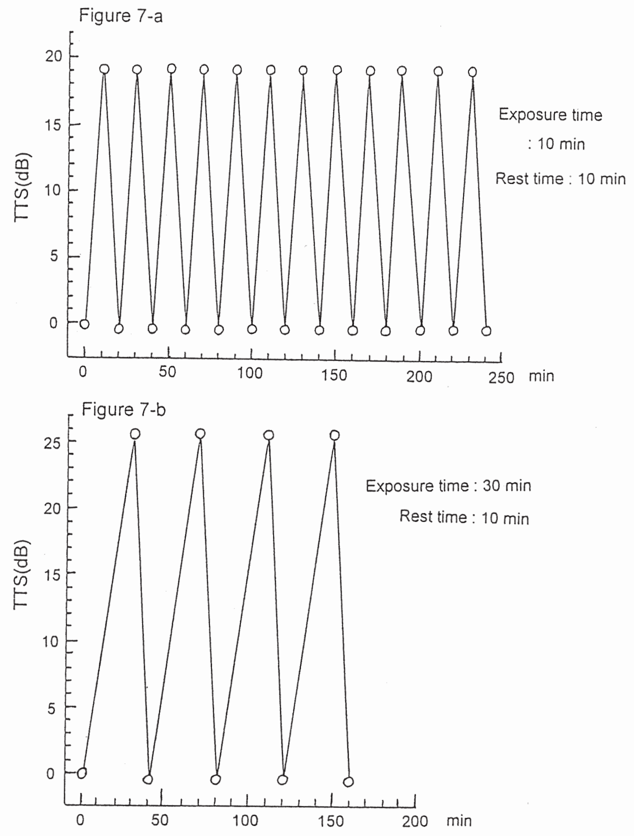

Fig. 7. Prediction TTS values for long rest time

rule and the equations. The results were plotted in Figures 7-a, b. These results suggest to the notification of the Labor Ministry that it is better to change the rest time of five minutes to 10 min for exposure times of both 10 min and 30 min in the continuous operation of hand-held tools.

In the case of continuous exposure of 30 min, it is noticeable that TTS values at 30 min are larger by approximately 6 dB than those at 10 min. From these results, it may be undesirable to maintain vibration exposure of 30 min in one continuous exposure.

Conclusion

1) The estimation procedure for predicting TTS following exposure to intermittent vibrations in the work place has been developed according to the exposure equivalent rule and the equations for both growth and recovery TTS.

2) It was found that this prediction TTS value was in good agreement with the measured value even in cases in which random intermittent vibrations from hand-held tools were used as stimuli, as in the workplace.

3) It was suggested that it is preferable to change the rest time of five minutes to 10 min for exposure times of 10 min and 30 min in the notification to the Labor Ministry in Japan.

4) It may be undesirable to maintain vibration exposure for 30 min in one continuous exposure.

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Field Report

Vibration Acceleration Magnitudes of Hand-Held Tools and Workpieces

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Abstract: The magnitudes of the hand-transmitted vibration, 297 hand-held tools and workpieces were measured at workplaces. The tools were used mainly in construction and manufacturing industries. The current standard for the measurement of hand-transmitted vibration has been based on the frequency-weighted acceleration of dominant axis method[1,2]. According to the proposal of ISO/CD5349-1[3], the results of measurements (462 points) were recalculated by the method of the frequency-weighted acceleration sum. There is 32% of difference in average value between the acceleration sum and the dominant axis method.

Key words: Hand-transmitted vibration, Hand-held tool, Frequency-weighted acceleration, Dominant axis method, Frequency-weighted acceleration sum

Introduction

For the purpose of controlling the exposure levels and assessing the risk of occupational hand-transmitted vibration diseases, 297 tools and workpieces were measured at workplaces from 1989 to 1996. The kind of tools were percussive tools, internal combustion engine powered tools, grinders, drills, woodworking tools, concrete vibrators and vibrating workpieces which were used mainly in construction and manufacturing industries. The current standard for the measurement of hand-transmitted vibration has been based on dominant axis method which is represented by the largest single component of three orthogonal axes of the frequency-weighted acceleration[1,2]. According to the committee draft of ISO/CD5349-1[3], the results of measurements (462 points) were recalculated by the method of the frequency-weighted acceleration sum (root-sum-of-squares of the three orthogonal axes).

Method (Measurement and Analysis)

Measuring instruments of vibration acceleration were a vibration pickup (triaxes piezoelectric type, 29.3 gr., PV-93T, RION Co. Japan), a vibration meter (3 ch. VM-19A, RION)[4] and a data recorder (4 ch. DAT type, RD-120T, TEAC Co. Japan). The pickup was mounted firmly with pair steel belts (width; 6.4 mm * thickness; 0.5 mm) and a fitting base on a handle of the object tools (1 point or more measured per tool).

The vibration acceleration signals of three axes were measured simultaneously, and the recorded data were analyzed with a one-third octave band real-time analyzer (SA-27, RION). The frequency-weighted energy equivalent acceleration levels in r.m.s. were obtained by the system. The averaging time varies from 30 sec to 90 sec depending on types of tools and work conditions[5]. Acceleration magnitudes of the tools were determined by ISO 5349 method[1] and Japanese standard JIS B 4900[2]. The frequency-weighted acceleration sum is a combined value of three orthogonal axes defined in the following equation.

$$a_{hws} = (a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2)^{1/2}$$

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