inter•noise 83

A METHOD FOR PREDICTING THE AVERAGE STIMULUS INTENSITY FOR NON-STEADY VIBRATION BASED ON THE SUMMATION OF SUBJECTIVE MAGNITUDE

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INTRODUCTION

This study investigates the applicability of a method of predicting the point of subjective equality (PSE) for non-steady vibration. The method was proposed by one of the present authors |1| for predicting the sound pressure level of a steady noise which produces a subjective magnitude equal to that of a non-steady noise.

The theory for predicting the PSE of non-steady vibration has two assumptions. First, that Stevens' power law holds at every instance:

$$\psi = k\ a^{\alpha} \tag{1}$$

where ψ is subjective magnitude, a is rms vibration magnitude and k and α are constants. Results show the overall subjective magnitude, ψ of steady vibration of duration, T, may be expressed:

$$\Psi \propto a^{\alpha}\ T^{\beta} \tag{2}$$

where α and β constants. Figure 1 shows the time history of the subjective magnitude corresponding to the vibration magnitude.

The second assumption is that $\psi_i . T_i{}^{\beta}$ is summed over i = 1 to k. Since the total sum of $T_i{}^{\beta}$ is different from T^{β}, a correction factor C $(=T^{\beta}/\sum_i T_i{}^{\beta})$ is introduced to make the sum of the relative contribution of duration at each subjective magnitude unity. Then the effective vibration magnitude (evm) is expressed as follows:

$$\text{evm} = (\Psi/T^{\beta})^{1/\alpha} = (C\sum_i \psi_i T_i{}^{\beta}/T^{\beta})^{1/\alpha} = (\sum_i a_i{}^{\alpha} T_i{}^{\beta}/\sum_i T_i{}^{\beta})^{1/\alpha} \tag{3}$$

EXPERIMENT I

Apparatus

Whole-body vertical (z-axis) vibration was produced on an electro-dynamic vibrator. The vibration command signals were generated by a

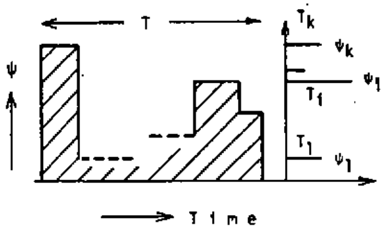

Figure 1: Time history of subjective magnitude and accumulated duration at each subjective magnitude.
$T = T_1 + T_2 \ldots + T_k$

digital computer. Subjects sat in a comfortable upright posture on a rigid flat seat.

Design and Procedure

Each subject received 25 exposures of sinusoidal 8 Hz vibration at five vibration magnitudes (0.5, 0.75, 1.11, 1.67 and 2.5 ms^{-2} rms) and five durations (2, 5, 10, 20 and 50s) in a session.

The method of magnitude estimation was used. The 25 motions were presented to each of 18 subjects in a randomized order. The interval between two successive vibrations was 10s. All subjects attended two sessions. After every motion, the subject assigned a number to the motion proportional to the discomfort he or she had perceived. They were asked to base their judgement on the total overall effect of the motion and not on the maximum vibration magnitude alone.

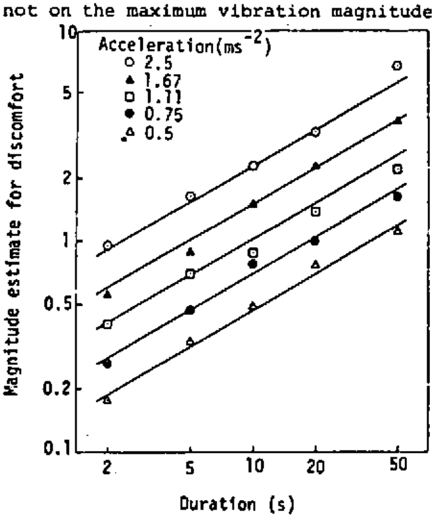

Figure 2: Average magnitude estimates for five vibration levels as a function of duration.

Before the experiment, subjects practiced magnitude estimation and magnitude production with segments of lines, sounds and vibrations.

Results

The 50 numbers assigned by each of the subjects were normalized by equalizing the geometric mean judgement of each subject. Figure 2 shows the geometric mean of the equalized judgements of the eighteen subjects. The lines were obtained by means of a multiple regression analysis and are expressed:

$$\log \Psi = 0.964 \log a + 0.563 \log t - 0.607 \quad (r = 0.995) \qquad (4)$$

where Ψ is the geometric mean of magnitude estimates, a is the rms value of vibration acceleration (ms^{-2}), t is the duration (s) and r is the correlation coefficient. The values of exponents, α and β, in Eq (2) were, therefore, 0.964 and 0.563.

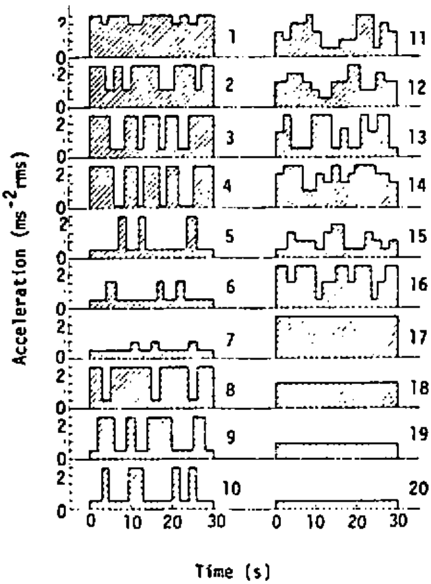

Figure 3: Time histories of root mean square vibration magnitudes.

EXPERIMENT II

Design and Procedure

Every subject received 20 exposures to 30 second periods of sinusoidal 8 Hz vibration in a session. The time histories of the rms vibration magnitude of the 8 Hz motions used in the experiment are indicated in Figure 3. Motions from No. 1 to No. 4, (type A motions) investigated how discomfort changed when the lower of the two vibration magnitudes was varied. Motions No. 3, No. 5 and No. 8 to No. 10 (type C motions) investigated the effect of the proportion of time at the higher vibration magnitudes while both the higher and the lower magnitudes were fixed. Motions from No. 11 to No. 16 have various distributions of vibration magnitude. Motions from No. 17 to No. 20 were steady 8 Hz vibrations. 15 subjects from Exp. I were used.

Results and Discussion

Magnitude estimates of the subjects were calculated in the same way as for the results of Experiment I. The results for steady vibrations indicated that the relation between magnitude estimate and rms acceleration was given by:

$$\log \Psi = 1.203 \log a - 0.184 \quad (r = 0.998) \qquad (5)$$

The magnitude estimates given to each non-steady vibration was converted into the equivalent vibration magnitude (PSE) of a steady vibration by means of this equation.

The value of the exponent for the acceleration obtained in this experiment was 1.203 - larger than for the same 15 Ss in Exp. I. It is assumed in this paper that the value of exponent for duration also increased by about 22 percent (1.20/0.98 = 1.22), holding the proportion between the values of the two exponents constant. Thus the values of 1.20 and 0.72 (= 0.59*1.22) for α and β are used in the calculation

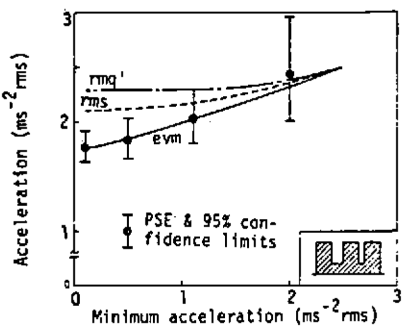

Figure 4: Predicted stimuli intensities for type A vibrations and points of subjective equality.

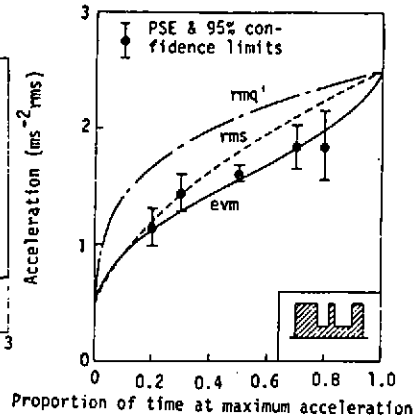

Figure 5: Predicted stimuli intensities for type C vibrations and points of subjective equality.

of effective vibration magnitude.

Figure 4 shows, for type A motions, how rms, rmq and evm change with the minimum vibration magnitude. The PSE and confidence limits are also shown.

In Figure 5, rmq, rms, evm and PSE of the type C motions are shown as functions of the proportion of time at the higher vibration magnitude. Both Figures 4 and 5 show the effective vibration magnitude (evm) provides a good fit to the PSE value. Although they are not shown in this paper, PSEs of motions No. 6, No. 7 and from No. 11 to No. 16 are also in good agreement with the evm.

From the results of Experiment II it appears that the theory to predict PSE can also be applied to vibration. However, the number and type of vibrations used in this experiment was restricted and further investigations are needed to confirm the validity of the procedure for calculating effective vibration magnitude.

REFERENCE

|1| K. Hiramatsu et al, "A procedure for rating fluctuating noise on the basis of the additivity of annoyance", J. Acoust. Soc. Jpn., 34 (11), 650-658, (1978).