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A STOCHASTIC EVALUATION METHOD ON THE LEVEL CROSSING OF WAVE FORM FOR THE ROAD TRAFFIC NOISE

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ABSTRACT:

In this paper, after introducing a fundamental theory for the acuity of arbitrary fluctuating random waves, and some new trials of evaluating statistically and hierarchically the random noise and vibration wave forms of arbitrary non-Gaussian type distribution are proposed, especially by employing the multivariate joint probability density function of series expansion type. First, the counting number that two wave curves contact each other in lower and/or higher order differential forms is estimated and explicit expression of probability distribution on the instantaneous amplitude, velocity and successive higher order differential type physical quantities of the actual random waves can be concretely derived. Especially for the stationary random wave of arbitrary distribution type, a trial toward the statistical evaluation on the locations of level crossing is considered in more detail as a special case, in close connection with the above differential type physical state variables. Finally, the effectiveness of the proposed method has been experimentally confirmed by applying it to complicated fluctuation wave forms of the actual road traffic noise wave.

1.INTRODUCTION

As is well-known, the wave form of random noise and vibration appearing in our actual environment shows usually the variety and the complexity in its fluctuation pattern. Here, several variates characterizing the states of fluctuating acuity show the statistical property. Until now, the statistical methods of analyzing and evaluating the above random wave form were studied by S.O.Rice [1], D.Middleton [2], and other many researchers [3,4], from the viewpoint of signal analysis. However, almost of these methods were linked with the state variables of lower order statistics of fluctuating random waves, such as those of displacement, velocity and acceleration in close relation to physical dynamics, and they often were individually discussed. Furthermore, even if any analytical research were found, it was very often that many of related researches were restricted to the standardized form of Gaussian process. But, in the actual environment of noise and vibration showing the variety and the complexity, it is usual that the objective random processes show actually various types of non-Gaussian property.

From the above viewpoint, in this paper, we have proposed some fundamental theory to estimate quantitatively the acuity of arbitrary fluctuating random waves, and some new trials of evaluating statistically and hierarchically these fluctuating random noise and vibration wave forms of non-Gaussian type distribution, especially by employing the multivariate joint probability density function of series expansion type. Concretely, we have first estimated the counting number that two random wave curves contact each other in lower and/or higher order differential forms, and then derived the explicit expression of probability distribution on the instantaneous amplitude, velocity and successive higher order differential type physical quantities of the actual random waves. Here, the linear and/or non-linear correlation informations of fluctuating waves have been hierarchically reflected in each expansion coefficient of probability expression. More concretely, especially for the stationary random wave of arbitrary distribution type, a trial toward the different type statistical evaluation on the level crossing has been considered in more detail as a special case, in close connection with the above differential type physical state variables.

Finally, the practical effectiveness of the proposed method has been experimentally confirmed too by applying it to complicated fluctuation wave forms of the actual road traffic noise observed in the suburb of a large city.

2. THEORETICAL CONSIDERATION

2.1 THE NUMBER OF TIMES CONTACTING BETWEEN TWO SIGNAL WAVES (the case of contacting with the differential coefficient of order n)

Let us consider the number of times contacting with the differential coefficient of order n between arbitrary two signal waves. As is well-known, when two continuously curved lines $x = X(t)$ and $x = C(t)$ contact each other at a time $t = \tau$, the mathematical condition of contact with the differential coefficient of order n can be given by the following expressions:

$$X(\tau) = C(\tau),\ \frac{d}{dt}X(t)\bigg|_{t=\tau} = \frac{d}{dt}C(t)\bigg|_{t=\tau},\ \cdots,\ \frac{d^n}{dt^n}X(t)\bigg|_{t=\tau} = \frac{d^n}{dt^n}C(t)\bigg|_{t=\tau},$$
$$\frac{d^{n+1}}{dt^{n+1}}X(t)\bigg|_{t=\tau} \neq \frac{d^{n+1}}{dt^{n+1}}C(t)\bigg|_{t=\tau}. \qquad (1)$$

Now, let us evaluate the number of times $E_n(t_1,t_2)$ that the stochastic process $X(t)$, which is continuous and continuously differentiable for $(n+1)$-times on t, comes in contact with the arbitrary type of continuously curved line $C(t)$ on the differential coefficient of order n in the time interval $(t_1,t_2]$. Hereupon, let us take notice of the fundamental properties related to Dirac's delta function. One of them is that an integral value of $\delta(x-x_0)$ brings uppon an increment at every time when x goes once across x_0. That is, the objective number of times of contact $E_n(t_1,t_2)$ can be directly expressed in the following equation:

$$E_n(t_1,t_2) = \int_{X^{(n)}(t_1)}^{X^{(n)}(t_2)} \int_{X^{(n-1)}(t_1)}^{X^{(n-1)}(t_2)} \int \cdots \int_{\dot{X}(t_1)}^{\dot{X}(t_2)} \int_{X(t_1)}^{X(t_2)} \delta\big(X(t)-C(t)\big)\cdot\delta\big(\dot{X}(t)-\dot{C}(t)\big)\cdots$$
$$\cdot\delta\big(X^{(n-1)}(t)-C^{(n-1)}(t)\big)\cdot\delta\big(X^{(n)}(t)-C^{(n)}(t)\big)\,dX(t)$$
$$\cdot d\dot{X}(t)\cdots dX^{(n-1)}(t)dX^{(n)}(t)\ , \qquad (2)$$

where $\dot{X}(t) \equiv dX(t)/dt$, $X^{(i)}(t) \equiv d^i X(t)/dt^i$.

In Eq.(2), especially when n equals to 0, two curved lines are of course in contact situation with the differential coefficient of order 0. At this time , $E_0(t_1,t_2)$ shows the number of crossing between $X(t)$ and $C(t)$ in the time interval $(t_1,t_2]$. Furthermore, when n equals to 1 and so these two curves are contacted with the order 1, $E_1(t_1,t_2)$ can show the number of extremum that $X(t)$ exists on the specific contact level $C(t)=\xi$.

2.2 THE NUMBER OF CROSSING ON ANY SET LEVEL (The case of contacting with the differential coefficient of order 0)

The number of times that $X(t)$ goes across any set level ξ in the time interval $(t_1,t_2]$ can be expressed by substituting n=0 and $C(t)=\xi$ into Eq.(2), as follows:

$$E_0(t_1,t_2) = \int_{X(t_1)}^{X(t_2)} \delta\big(X(t)-\xi\big)dX(t)$$

$$= \int_{t_1}^{t_2} \left|\dot{X}(t)\right| \cdot \delta\big(X(t)-\xi\big)dt \ . \tag{3}$$

In Eq.(3), the absolute operation of $\dot{X}(t)$ corresponds to count of the crossing with both positive and negative slopes, the mean number of crossing can be directly found by the operation of averaging: $E[\bullet]$ for Eq.(3), as follows:

$$E[E_0(t_1,t_2)] = \int_{t_1}^{t_2} E\Big[\left|\dot{X}(t)\right| \cdot \delta\big(X(t)-\xi\big)\Big]dt \ . \tag{4}$$

Therefore, when $N(\xi,t)$ is defined as the random number of crossing per unit time on any set level: ξ, Eq.(4) can be of course expressed as:

$$E[E_0(t_1,t_2)] = \int_{t_1}^{t_2} E[N(\xi,t)]dt \ , \tag{5}$$

where $E[N(\xi,t)]$ is the mean number of crossing per unit time. Now, if the stochastic process $X(t)$ can be assumed as an ergodic random process and the joint probability density function (abbr. p.d.f.) $p_{X\dot{X}}(x,\dot{x};t)$ of the instantaneous value $X(t)$ and the first order differential value: $\dot{X}(t)$ at the time t can be introduced, so $E[N(\xi,t)]$ can be expressed from Eqs.(4) and (5), as the following well-known expression:

$$E[N(\xi,t)] = \int_{-\infty}^{+\infty} |\dot{x}|\, p_{X\dot{X}}(\xi,\dot{x};t)d\dot{x} \ . \tag{6}$$

Accordingly, the total number of crossing $E[N_T(t)]$, after scanning the value of set level ξ within the possible level range of fluctuation, is given from Eq.(6), as follows:

$$E[N_T(t)] = \int_{-\infty}^{+\infty} E[N(x,t)]dx = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} |\dot{x}|\, p_{X\dot{X}}(x,\dot{x};t)dxd\dot{x} \ . \tag{7}$$

Therefore, the p.d.f. of crossing number $P_N(\xi,t)$ (where $X(t)$ is across the specific value of level ξ) is easily defined as the ratio of the mean number of crossing on the specific value ξ to the total number of crossing:

$$P_N(\xi,t) = \frac{E[N(\xi,t)]}{E[N_T(\xi)]} = \frac{\int_{-\infty}^{+\infty} |\dot{x}|\, p_{X\dot{X}}(\xi,\dot{x};t)d\dot{x}}{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} |\dot{x}|\, p_{X\dot{X}}(x,\dot{x};t)dxd\dot{x}} \tag{8}$$

2.3 LEVEL CROSSING PROBABILITY FOR ARBITRARY FLUCTUATING STOCHASTIC FORM

As aforesaid, various types of statistics like mean number of crossing, extremum, etc., reflecting the acuity of the arbitrary random wave form, have fundamental relationship to the complicated condition of contact between the objective wave form and a set level line. Accordingly, as we can understand from Eq.(8), these statistics and related probability distribution are to be immediately linked with the joint p.d.f. of each-order differential coefficients in the fluctuating wave form. Therefore, in order to evaluate the statistics universally applicable for the acuity of wave, first, we have to introduce some unified expression of the joint p.d.f. concerned with each-order differential coefficients especially for arbitrarily fluctuating random waves.

Now, it is effective to introduce in advance the following statistical orthonormal expansion type expression for the joint p.d.f. with K-variates:

$$p(x_1,x_2,\cdots,x_K) = P_1(x_1)P_2(x_2)\cdots P_K(x_K) \cdot \sum_{n_1=0}^{\infty}\sum_{n_2=0}^{\infty}\cdots\sum_{n_K=0}^{\infty} A_{n_1n_2\cdots n_K}\varphi_{n_1}^{(1)}(x_1)\varphi_{n_2}^{(2)}(x_2)\cdots\varphi_{n_K}^{(K)}(x_K) \tag{9}$$

with $$A_{n_1n_2\cdots n_K} \equiv \left\langle \varphi_{n_1}^{(1)}(x_1)\varphi_{n_2}^{(2)}(x_2)\cdots\varphi_{n_K}^{(K)}(x_K)\right\rangle , \tag{10}$$

where $\langle\bullet\rangle$ denotes an averaging operation and $\{\varphi_{n_i}^{(i)}(x_i)\}$ denote the orthonormal polynomials of degree n_i with weighting function $P_i(x_i)$ in the interval $[a_i , b_i]$. Here, $\{\varphi_{n_i}^{(i)}(x_i)\}$ satisfy the following orthonormal integral condition:

$$\int_{a_i}^{b_i} P_i(x_i)\varphi_m^{(i)}(x_i)\varphi_n^{(i)}(x_i)dx_i = \delta_{mn} , \tag{11}$$

where δ_{mn} is Kronecker's delta. Moreover, $P_i(x_i)$ taken as the first term of expansion series is the mainstay of objective distribution and denotes the dominant part of probability distribution form. In this place, it has to be noticed that random variables x_i are defined as follows $x_i \equiv d^{i-1}x/dt^{i-1}$ $(i=1,2,\cdots,K)$.

On the other hand, we already know that Eq.(9) can uniformly deal with various types of fluctuating distribution. For instance, for the usual random distribution fluctuating in the level interval $(-\infty,+\infty)$, the statistical Hermite polynomial expansion type expression (e.g., Gram-Charlier A-type series expansion expression is a kind of it.) taking a Gaussian distribution as the basis of arbitrary distribution can be widely employed. For an arbitrary random distribution fluctuating only in non-negative level interval $[0,+\infty)$ (e.g., the distribution of envelope amplitude or physical energy), the statistical Laguerre polynomial expansion type expression taking a Gamma distribution as the basis of arbitrary distribution can be widely employed. From this point of view, here, let us take the following two points into consideration:

i) The above basic distribution $P_0(x_i)$ can be selected artificially and commonly for each $P_i(x_i)$ especially from the convenience of series expansion expression.

ii) For practical type stationary random waves fluctuating within positive and/or negative regions, the differential coefficients of 1-order and more order x_i can fluctuate in both of positive and negative region.

Now, let us consider a stational random wave and adopt the Gaussian distribution concretely as the above basis $P_i(x_i)$. After employing Eqs.(9) and (10) with 2-variates, the p.d.f. of level crossing in the foregoing section: Eq.(8) can be rewritten as follows:

$$P_N(\xi) = P_1(\xi)\left\{1 + \sum_{n_1=1}^{\infty} \frac{A_{n_1}}{A_0} \varphi_{n_1}^{(1)}(\xi)\right\} \tag{12}$$

with
$$\left.\begin{aligned} A_{n_1} &= \sum_{n_2=0}^{\infty} A_{n_1 n_2} I_{n_2} \quad , \\ A_{n_1 n_2} &= \left\langle \varphi_{n_1}^{(1)}(x)\varphi_{n_2}^{(2)}(x)\right\rangle \quad , \\ I_{n_2} &= \int_{-\infty}^{+\infty} |\dot{x}| P_2(\dot{x})\varphi_{n_2}^{(2)}(\dot{x}) d\dot{x} \quad . \end{aligned}\right\} \tag{13}$$

For the stational fluctuating random signal waves of arbitrary non-Gaussian type, not only the instantaneous amplitude but also each of successive order differential coefficient x_i, are usually fluctuating in both positive and negative regions within the interval $(-\infty, +\infty)$. For adopting the well-known Gaussian distribution as the basic distribution $P_0(x_i)$, the well-known Hermite polynomials with a weighting function $P_0(x_i)$ can be selected as $\left\{\varphi_{n_i}^{(i)}(x_i)\right\}$ and we directly have the following expression:

$$P_N(\xi) = \frac{1}{\sqrt{2\pi}\sigma_{X_1}} exp\left\{-\frac{1}{2}\left(\frac{\xi-\mu_1}{\sigma_{X_1}}\right)^2\right\}\left\{1 + \sum_{n_1=1}^{\infty}\frac{A_{n_1}}{A_0}\frac{1}{\sqrt{n_1!}}H_{n_1}\left(\frac{\xi-\mu_1}{\sigma_{X_1}}\right)\right\} \tag{14}$$

with
$$\left.\begin{aligned} A_{n_1} &= \sum_{n_2=0}^{\infty} A_{n_1 n_2} I_{n_2} \quad , \quad A_{n_1 n_2} = \left\langle \frac{1}{\sqrt{n_1!}} H_{n_1}\left(\frac{x-\mu_1}{\sigma_{X_1}}\right) \frac{1}{\sqrt{n_2!}} H_{n_2}\left(\frac{\dot{x}}{\sigma_{X_2}}\right)\right\rangle \quad , \\ I_{n_2} &= \int_{-\infty}^{+\infty} |\dot{x}| \frac{1}{\sqrt{2\pi}\sigma_{X_2}} exp\left\{-\frac{1}{2}\left(\frac{\dot{x}}{\sigma_{X_2}}\right)^2\right\} \frac{1}{\sqrt{n_2!}} H_{n_2}\left(\frac{\dot{x}}{\sigma_{X_2}}\right) d\dot{x} \\ &= \begin{cases} \sigma_{X_2}\sqrt{2/\pi} & (n_2 = 0) \\ \sigma_{X_2}\sqrt{2/\pi}(-1)^{\frac{n_2-2}{2}}(n_2-3)!!/\sqrt{n_2!} & (n_2 = even) \\ 0 & (n_2 = odd) \end{cases} \quad , \\ \mu_1 &= \langle x \rangle , \quad \sigma_{X_1}^2 = \left\langle (x-\mu_1)^2 \right\rangle , \quad \sigma_{X_2}^2 = \left\langle \dot{x}^2 \right\rangle \quad . \end{aligned}\right\} \tag{15}$$

Here, the mean of velocity $\langle \dot{x} \rangle$ equals to 0 in Eq.(15) based on the fact that the frequencies of positive slope and negative slope become in average half and half each other for a stational random wave of arbitrary type.

3. EXPERIMENTAL CONSIDERRATION

In order to confirm a part of the practical effectiveness of proposed method, let us apply it to the actual road traffic noise wave which fluctuate on a large scale affected by various type of environmental factors. Concretely, as an example of experimental data, we employed the discrete data of road traffic noise with an A-weighted sound pressure level observed actually at a suburb of large city. As the sampling time interval of data, four kinds of the following: 0.1, 0.3, 0.5 and 1.0 seconds have been employed and the number of data were 5000.

3.1 EVALUATION OF VELOCITY AND CORRELATION INFORMATION

In the special case when confirming the validity of distribution expression of the level crossing Eq.(14), in advance, we had to evaluate each of the linear and/or non-linear correlation information $A_{n_1n_2}$ included in the expansion coefficient. It is necessary for the concrete evaluation of $A_{n_1n_2}$ to employ both data of the instantaneous level x and its velocity $\dot{x}$ of the fluctuating wave form. So, we have executed the differential operation to evaluate the velocity on the basis of the observed discrete data x_t by using the following formula of Rutledge's numerical differential:

$$\dot{x}_t = \left(x_{t-2} - 8x_{t-1} + 8x_{t+1} - x_{t+2}\right)/12 \quad . \tag{16}$$

For the evaluation of correlation information $A_{n_1n_2}$, we have considered about the following two cases:

(case 1) $A_{n_1n_2} = 0\left(n_2 > 2\right)$: the case with use of $A_{n_1n_2}$ reflecting at least minimum of non-linear correlation information.

(case 2) $A_{n_1n_2} = 0\left(n_2 > 4\right)$: the case with use of $A_{n_1n_2}$ reflecting more information than in case 1.

3.2 EXRERIMENTAL RESULTS

In the stochastic analysis of sound and vibration, the cumulative distribution function(abbr. c.d.f.) that immediately concerned with the statistics like a mean, variance, (100-*x*%) percentile level L_x , and others, becomes often more important than the probability density function expression. Therefore, the c.d.f. $Q_N(Y)$ of the level crossing has been derived from Eq.(14), as follows:

$$Q_N(Y) = \int_{-\infty}^{Y} P_N(\xi)d\xi$$

$$= \int_{-\infty}^{Y} \frac{1}{\sqrt{2\pi}\sigma_{X_1}} exp\left\{-\frac{1}{2}\left(\frac{\xi-\mu_1}{\sigma_{X_1}}\right)^2\right\}\left\{1+\sum_{n_1=1}^{\infty}\frac{A_{n_1}}{A_0}\frac{1}{\sqrt{n_1!}}H_{n_1}\left(\frac{\xi-\mu_1}{\sigma_{X_1}}\right)\right\}d\xi . \tag{17}$$

Figure 1 shows a comparison between the theoretically estimated curves by using proposed method and the experimentally sampled points in the expression form of c.d.f. for case 1 with every 0.3 second sampling. Here, in this figure, "Instantaneous level" denotes the c.d.f. of instantaneous sound pressure level, "the 1st term" denotes the first term of Eq.(17), and "the *n*-th approx." denotes the sum up to the *n*-th expansion term of it, and the same in the succeeding Figures And Table. Figure 2 shows the difference between the theoretical curves/experimental points and the level distribution curve of original wave.

The difference denotes a deviation from the level distribution and indicates the effectiveness of expansion term. That is, the difference $\varepsilon_N(Y)$ is defined as follows:

$$\varepsilon_N(Y) = \int_{-\infty}^{Y} \{P_N(\xi) - P(\xi)\}d\xi$$

$$= \sum_{n_1=1}^{\infty}\left(\frac{A_{n_1}}{A_0} - A_{n_1 0}\right)\cdot\int_{-\infty}^{Y}\frac{1}{\sqrt{2\pi}\sigma_{X_1}} exp\left\{-\frac{1}{2}\left(\frac{\xi-\mu_1}{\sigma_{X_1}}\right)^2\right\}\frac{1}{\sqrt{n_1!}}H_{n_1}\left(\frac{\xi-\mu_1}{\sigma_{X_1}}\right)d\xi . \tag{18}$$

Here, the distribution of level $P(\xi)$ have been provided by the following expression:

$$P(\xi)=\frac{1}{\sqrt{2\pi}\sigma_{X_1}}exp\left\{-\frac{1}{2}\left(\frac{\xi-\mu_1}{\sigma_{X_1}}\right)^2\right\}\left\{1+\sum_{n_1=1}^{\infty}A_{n_1 0}\frac{1}{\sqrt{n_1 !}}H_{n_1}\left(\frac{\xi-\mu_1}{\sigma_{X_1}}\right)\right\} \quad . \tag{19}$$

From Figures 1 and 2, it can be found that the theoretical curves get nearer to the experimental points according as the expansion term increases. Figures 3 and 4 show the results of estimating for case 2 corresponding to Figures 1 and 2 respectively. As shown in these figures, the estimated results by using the proposed method are in good agreement with the experimental values. And, in comparison the results of case 1 with that of case 2, the latter shows slightly better effectiveness than the former. From these results, in the proposed method, even if the distribution is constructed with a few information as in case 1, the effectiveness can be confirmed enough. Table 1 shows the estimated noise evaluation indexes: (100-x%) percentile level L_x , with the same sampling interval. In this table, (•) denotes the error of L_x between the experimental value and the theoretical value. From this table, we also can find numerically the trend getting nearer to the experimental value according as the expansion term increases.

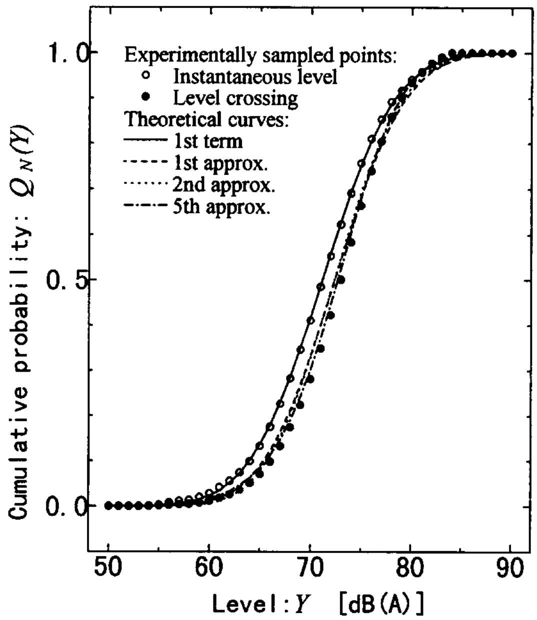

Fig.1 A comparison of distribution between the theoretically estimated curves and the experimentally sampled points for case 1 with every 0.3 second sampling.

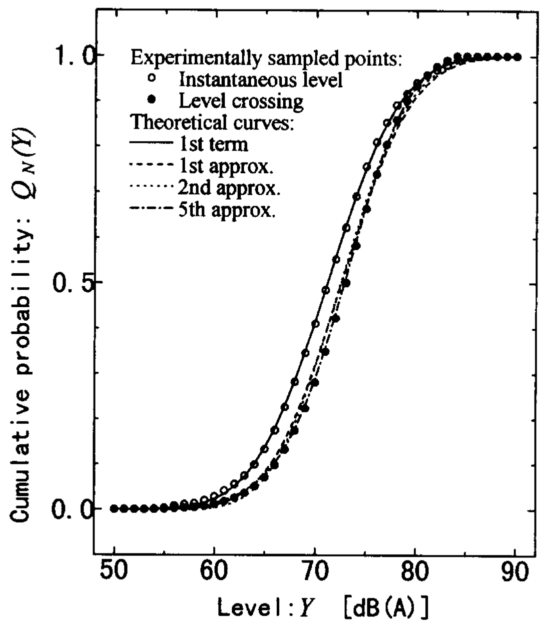

Fig.3 A comparison of distribution between the theoretically estimated curves and the experimentally sampled points for case 2 with every 0.3 second sampling.

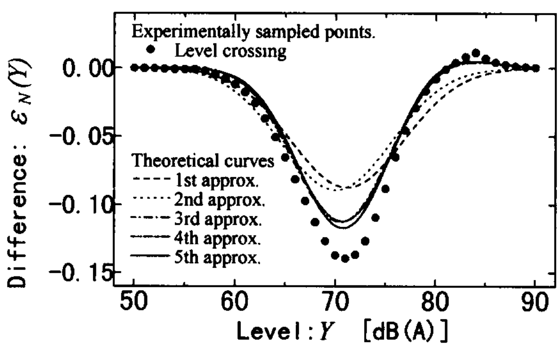

Fig.2 A difference between the theoretically estimated curves and the experimentally sampled points for case 1 with every 0.3 second sampling.

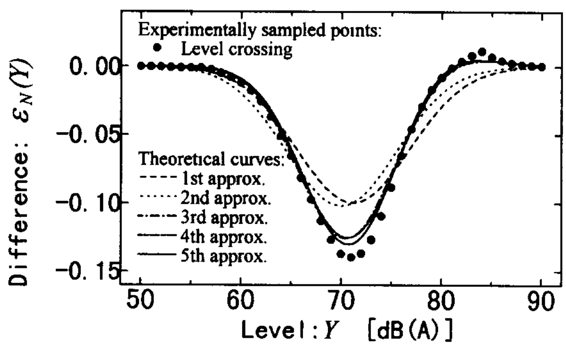

Fig.4 A difference between the theoretically estimated curves and the experimentally sampled points for case 2 with every 0.3 second sampling.

Table 1 Experimental results for L_x with every 0.3 second sampling (dB(A))

Percentile level: L_x		L_5	L_{10}	L_{50}	L_{90}	L_{95}
Experimental value		80.7	79.0	73.0	66.1	63.9
Case 1	1st term	80.5(-0.2)	78.4(-0.6)	71.2(-1.8)	63.9(-2.2)	61.9(-2.0)
	1st approx.	81.5(+0.8)	79.5(+0.5)	72.4(-0.6)	65.3(-0.8)	63.4(-0.5)
	2nd approx.	81.2(+0.5)	79.2(+0.2)	72.3(-0.7)	65.7(-0.4)	63.9(0.0)
	3rd approx.	80.7(0.0)	78.9(-0.1)	72.6(-0.4)	65.7(-0.4)	63.4(-0.5)
	4th approx.	80.7(0.0)	79.0(0.0)	72.6(-0.4)	65.6(-0.5)	63.4(-0.5)
	5th approx.	80.6(-0.1)	78.9(-0.1)	72.7(-0.3)	65.6(-0.5)	63.2(-0.7)
Case 2	1st term	80.5(-0.2)	78.4(-0.6)	71.2(-1.8)	63.9(-2.2)	61.9(-2.0)
	1st approx.	81.6(+0.9)	79.6(+0.6)	72.5(-0.5)	65.6(-0.5)	63.6(-0.3)
	2nd approx.	81.2(+0.5)	79.3(+0.3)	72.5(-0.5)	66.0(-0.1)	64.2(+0.3)
	3rd approx.	80.7(0.0)	79.0(0.0)	72.8(-0.2)	66.0(-0.1)	63.9(0.0)
	4th approx.	80.7(0.0)	79.0(0.0)	72.8(-0.2)	66.0(-0.1)	63.8(-0.1)
	5th approx.	80.6(-0.1)	79.0(0.0)	72.8(-0.2)	65.9(-0.2)	63.6(-0.3)

4. CONCLUSION

In this paper, we have considered the arbitrarily fluctuating random waves with various type characteristics of probability distribution form and linear and /or non-linear correlations. Concretely, we have proposed some new statistical evaluation method by using the universal expression form for the acuity of those fluctuation waves. Specifically, the series expansion type level crossing expansion with variety of distribution form and each sort of correlation information has been proposed for the arbitrary wave form of the random noise and vibration. The effectiveness of the proposed method has been experimentally confirmed by applying it to fluctuation waves of the actual road traffic noise.

Finally, there still remain many problems and future researches to be solved such as: i) to evaluate successively quantitatively the effect of higher order information for the acuity of wave in close connection with fluctuating physical quantities like the higher order differential information besides the level crossing (for example, extremal value (peak and trough), point of inflection, and/or others), ii) to apply the proposed method to various kinds of data in many other actual fields, iii) to correlate concretely the proposed theory for the acuity of wave with the physical response to engineering system (like destructive phenomenon) or the psychological response to human and to make clear their mutual relationship, and so on.

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