Evaluation of Nonlinear Vibration Characteristics of a Piping System with a Gap by Stationary Random Vibration

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ABSTRACT

This paper deals with evaluation of nonlinear vibration specific characteristics of a continuous body with a gap by stationary random input waves and making out analytical model for the evaluation of the nonlinear vibration characteristics. The vibration model in experiment is fixed beam with a mass on the center of the beam and with a gap between a mass and a plate fixed the both end. The vibration model on shaking table is shook by stationary random noise. Accelerations of the mass on the beam and the shaking table are measured and used to experimentally evaluate the transfer function. The shapes of the transfer functions by the simulations considered the nonlinear spring have tendencies to be like that by the experiments. So we think that the plates have the characteristic of the nonlinear spring after the collision. We make out the analytical model for the estimation of the nonlinear spring constants of the plate and estimate the nonlinear spring constants.

1 INTRODUCTION

Piping systems in nuclear power plant are supported by pipe support systems. The piping system with a gap between the pipe and the support have characteristics of nonlinear vibration after collision by earthquake. The characteristics of the nonlinear vibration by the earthquakes or the random noise are very complex and difficult, but a matter of great importance to seismic design. The spring characteristic of the plate fixed the both end has three dimension equation after the collision of a mass (Sato et al. 1985). The cantilever beam with a mass at the top has the spring characteristic of the three dimension equation after the collision to the plates and the equivalent damping ratios of the transfer functions in the experiments are evaluated about 20 % by the curve fitting of linear transfer function (Shintani et al. 1990). So we think that the plates have the characteristics of the nonlinear spring after the collision. We make out the analytical model for the estimation of the nonlinear spring constant of the plate and the beam.

This paper deals with the evaluation of the nonlinear vibration chracteristics of the fixed beam with a mass on the center of the beam and with a gap between a mass and a plate fixed the both end by the stationary random noise and making out the analytical model for the evaluation of the nonlinear vibration characteristics.

2 EXPERIMENT

Figure 1 shows a experimental model. The model is a fixed beam that has a mass at the center of the beam. The vibration model has the plates on either side of the mass with a gap. The plates are fixed at the both end. The diameter of the beam is 7 mm, the length is 1200 mm. The diameter of the mass is 50 mm, the length is 100 mm, the weight is 2 kg. The length of the plates is 60 mm, the width is 31 mm, the thicknesses are 0.5, 0.6, 1.0 and 1.6 mm. The material of the beam, the mass and the plates are steels. The gap between the mass and the plate is 0.5 mm. The first natural frequency of the beam with the mass is 6.13 Hz by the experiment and 6.19 Hz by FEM. The

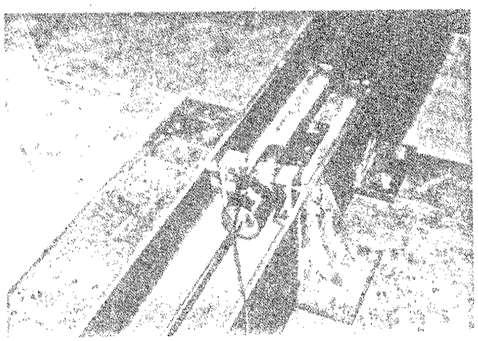

Fig. 1 Experimental model

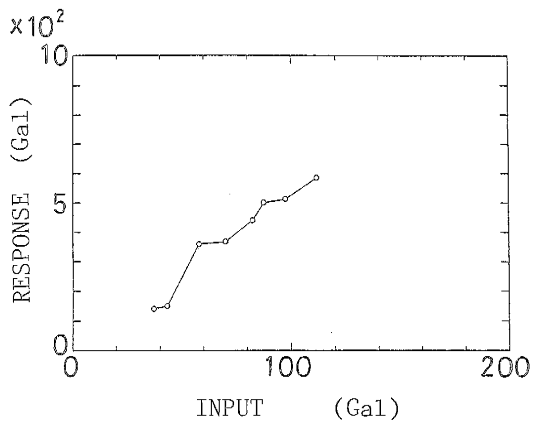

Fig. 2 Relation between standard deviation of acceleration on mass with plate 0.5 mm and on shaking table

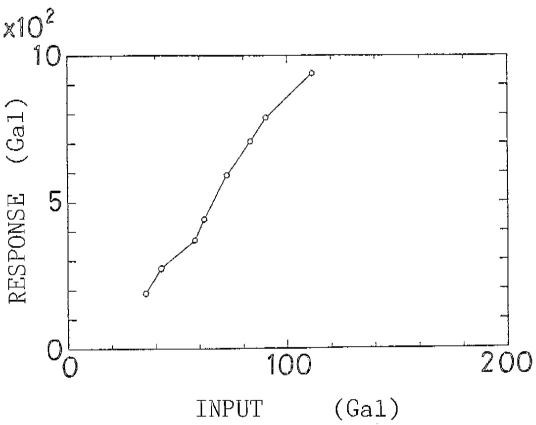

Fig. 3 Relation between standard deviation of acceleration on mass with plate 1.0 mm and on shaking table

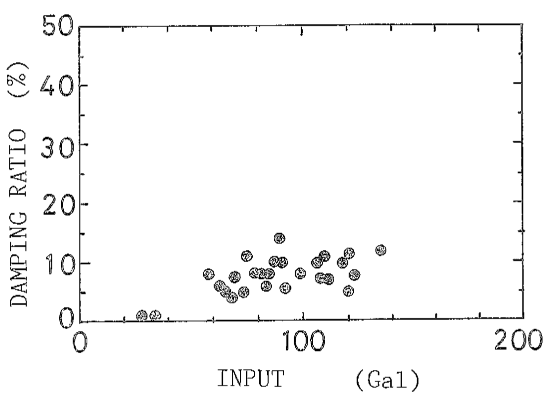

Fig. 4 Equivalent damping ratios (Plate 0.5 mm)

vibration model on shaking table is shook by the stationary random noise. Accelerations of the mass at the center of the beam and the shaking table are measured and used to experimentally evaluate of the transfer function. Strain of the plate is measured. It is estimated to evaluate the displacement of the mass on the beam in the relation to the strain at the plate.

Figures 2 and 3 show the relation between the standard deviation of the acceleration on the mass with the plates and on the shaking table. From Figs. 2 to 3, we think that the standard deviation of the acceleration on the mass is proportional to the standard deviation of the input waves. The inclination with the plates 1.0 mm is larger than the one with the plates 0.5 mm. The equivalent damping ratios are calculated by the curve fitting to the linear transfer function. Figure 4 shows the equivalent damping ratios of the plate of the thickness 0.5 mm. The equivalent damping ratios are constant to about 9 % in spite of the level of the input waves over the

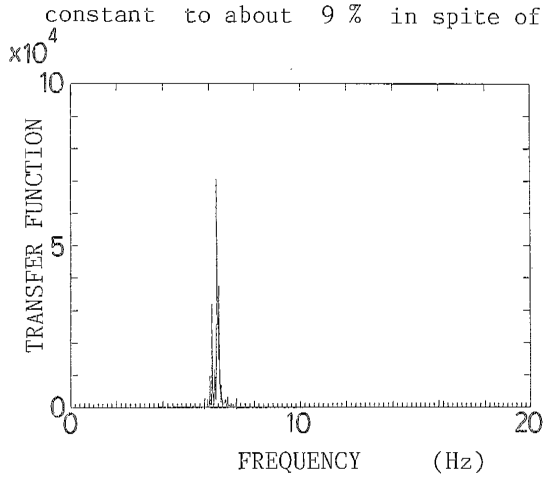

Fig. 5 Transfer function by experiments (Input level 42.6 Gal, plate 0.5 mm)

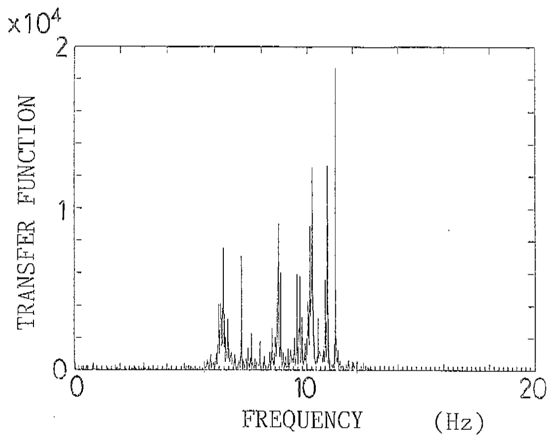

Fig. 6 Transfer function by experiments (Input level 72.8 Gal, plate 0.5 mm)

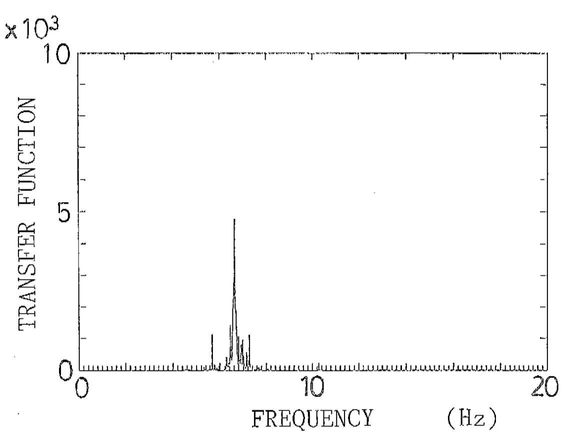

Fig. 7 Transfer function by experiments (Input level 32.4 Gal, plate 0.6 mm)

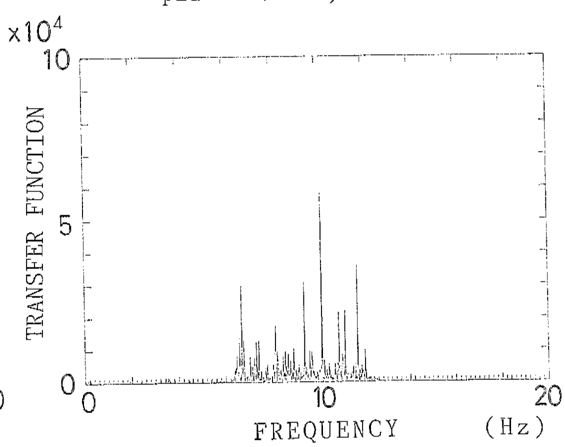

Fig. 8 Transfer function by experiments (Input level 70.0 Gal, plate 0.6 mm)

input level 60 Gal.

The transfer functions by the experiments are showed from Fig. 5 to Fig. 10. From Figs. 5 to 8 the frequencies of the transfer functions with the plates 0.5 mm or 0.6 mm come together around 6 Hz or from 6 Hz to 12 Hz. From Figs. 9 and 10 the frequencies of the transfer functions with the plates 1.0 mm spread from 0 Hz to 20 Hz and the transfer functions have many peaks. The ranges from the smallest frequency (f_S) to the largest frequency (f_L) of the transfer function are showed Figs. 11 and 12. From Fig. 11 the smallest frequency (f_S) is the first natural frequency of the vibration model. The largest frequency (f_L) is proportional to the input level. From Fig. 12 the smallest frequencies (f_S) is 0 Hz over the input level 60 Gal.

We think that the characteristics of these vibration phenomena are two types. One is the spring characteristic of the nonlinear spring like to Duffing's equation. The other is the typical collision phenomena. The criterion of the two types is considered to vary the first mode shape by the

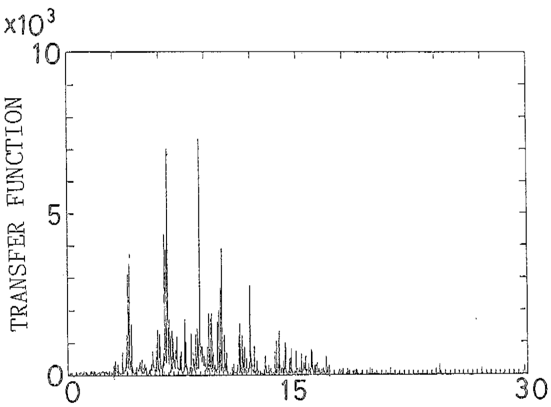

Fig. 9 Transfer function by experiments (Input level 59.7 Gal, plate 1.0 mm)

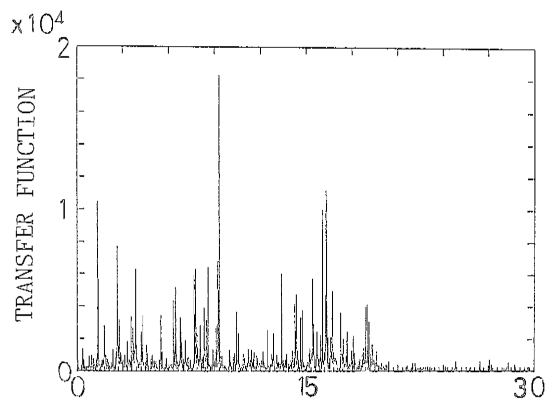

Fig. 10 Transfer function by experiments (Input level 71.1 Gal, plate 1.0 mm)

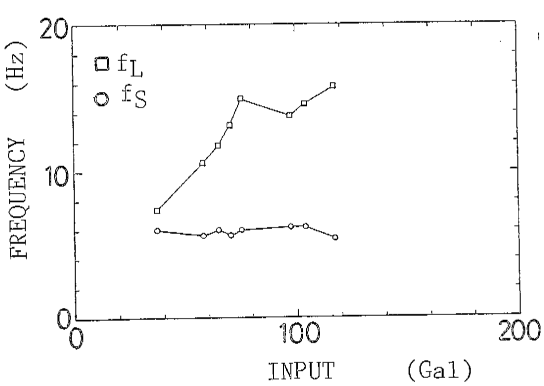

Fig. 11 Range from smallest frequency to largest frequency of transfer function (Plate 0.5 mm)

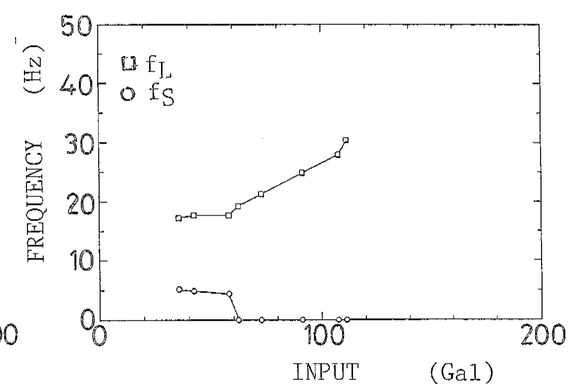

Fig. 12 Range from smallest frequency to largest frequency of transfer function (Plate 1.0 mm)

thickness of the plate. The first and second natural frequencies of the beam put together the plates of the thickness 0.5 mm by FEM are 36.1 Hz and 48.6 Hz. The first natural frequency put together the plates of the thickness 1.0 mm are 48.6 Hz. The second natural frequency of the beam with the mass only is 48.6 Hz. The mode shape of the first natural frequency 48.6 Hz with the plates 1.0 mm is the same as the second mode of the beam with the mass only. As this, the vibration system put together the plates of 1.0 mm hasn't the first mode shape of the beam with the mass only. We think that the spring characteristics have two types by the criterion.

3 SIMULATION

Here we think that the spring characteristic of the nonlinear vibration is replaced by the nonlinear spring of the three dimension equation. Equation (1) is considered the nonlinear vibration of our vibration model system.

$$\ddot{x} + 2\zeta\omega_0\dot{x} + \omega_0{}^2(x + \beta x^3) = -\alpha(t) \tag{1}$$

here, βx^3 is the term of the nonlinearity, the parameter β is the coefficient of the nonlinearity, x is the displacement of the mass, ζ is the damping ratio, ω_0 is the first natural angular frequency of the beam with the mass, and $\alpha(t)$ is the acceleration of the input wave. The input waves are used to the waves of the experiments and are used to the stationary white noises by Monte Calro method. Equation (1) is calculated by the Runge-Kutta-Gill method. In this calculation the number of the data in a sample is 8000 and the time interval of the data is 0.001 sec.. The transfer function by the simulations is showed Fig. 13. The shape of the transfer function is the average of the 32 samples with the plates 0.5 mm by the simulations used the parameter β=1167 [1/cm^2]. The average of the 32 samples with the plates 0.5 mm by the experiments is showed Fig. 14. The transfer functions by the simulations have a tendency to be like the results of the experiments. We think that the difference of the input levels between Fig. 13 and Fig. 14 is the difference of the power of the input waves.

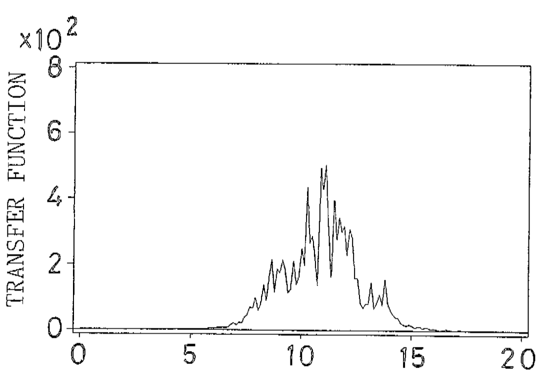

Fig. 13 Transfer function of average of 32 samples by simulations (Input level 20.0 Gal, β=1167 1/cm^2)

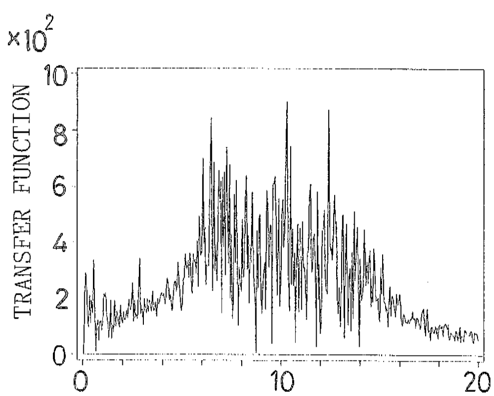

Fig. 14 Transfer function of average of 32 samples by experiments (Input level 40.0 Gal, plate 0.5 mm)

4 ESTIMATION OF COEFFICIENT β

The spring characteristic model of the fixed beam with the gaps indicates the bi-linear spring model generally. The bi-linear spring model has the two peaks with the relation to the two inclinations in the transfer function. But the average of the transfer function of 32 samples by the experiments hasn't two peaks clearly from Fig. 14. Broadly speaking the transfer function has only one peak. So we think that the spring characteristic of the nonlinear vibration has the three dimension equation. The curve is calculated by the next Equation (2).

$$y = x + \beta x^3 \quad (2)$$

The parameter β decides the shape of the curve of Eq. (2). We propose that the parameter β is decided the next two conditions. (1) The inclination of the Eq. (2) at the zero of the displacement is one. (2) The inclination of the Eq. (2) at the twice the gap of the displacement is the square of the ratio of the first natural frequencies of the beam put together the plates and the beam only. The maximum of the displacement of the plate after the collision was about the same displacement as the gap under the input levels in the experiments. When the thickness of the plate is 0.5 mm, the ratio of the first natural frequencies is about 6 and the inclination at the displacement $x=2\cdot 0.05=0.1$ cm is 36 by the condition (2). The parameter β is calculated 1167 [1/cm^2] by Eq. (2). The transfer function of Fig. 13 by the simulations used the parameter β has a tendency to be like the result of Fig. 14 by the experiments.

5 CONCLUSIONS

(1) The characteristics of the nonlinear vibration after the collision are two types by the shapes of the transfer functions. One is the characteristic of the nonlinear spring like to the three dimension equation. The other is the typical collision phenomena. (2) We propose the method of evaluating the parameter β of the nonlinear spring. (3) The shapes of the transfer functions by the simulations considered the nonlinear spring used the parameter β have tendencies to be like ones by the experiments.

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