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A STUDY OF DYNAMICS AND MODELLING OF HUMAN BODY EXPOSED TO MULTI-DIMENSIONAL EXCITATION

T Yoshimura & G Tamaoki

Department of Mechanical Engineering, Tokyo Metropolitan University, 1-1 Minami-osawa, Hachioji-shi, Tokyo, 192-03, Japan

1. INTRODUCTION

When the sitting human is exposed to whole body vibration, e.g., in transportation systems, it often undergoes vibration input from various directions. The vibration response occurs not only in the parallel direction to the input but also in cross (perpendicular) directions to the input due to dynamic coupling.

The purpose of this study is to understand dynamic characteristics of the sitting human body by performing multi-dimensional experiments, and to make up a three-dimensional dynamic model of the human body.

2. VIBRATIONAL EXPERIMENT ON HUMAN BODY

Equipment and Procedure

An overview of experiment is shown in Fig.1. The wooden seat having a footrest is fixed on a shaking table. A nonskid mat is laid out on it. Subject sits on the seat in an erected posture with his hands on his thighs. The subject is excited in three directions, i.e., fore-and-aft (*x*-axis), lateral (*y*-axis) and vertical (*z*-axis) one after another. The acceleration on the seat in input direction and that of the mouth and the forehead in three translational directions (*x, y, z*-axis) are measured. Transfer functions from the seat to two measurement points on the head are acquired through

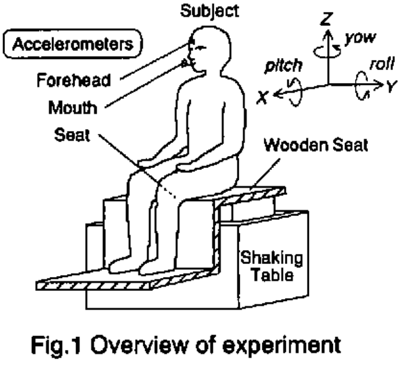


Fig.1 Overview of experiment

FFT spectrum analyzer.

The input signal is random wave from 0 to 20Hz. The magnitude of input vibration is 0.1G (about 1 m/s^2) in the rms value of acceleration on the seat surface. Motion of the mouth is measured by a set of three piezo-electric accelerometers fixed on a bite-bar (a strip of SPZ) which is settled in the mouthpiece. Motion of the forehead is measured by a set of three strain-gage-type accelerometers fixed on an aluminum plate (20×20mm, t=1mm) which is attached on the center of the forehead by adhesive tape. Weight of these measurement equipments is about 40g and 3g respectively. Since the weight is light enough comparing to that of the head, it can be assumed that the motion of the head is not influenced by the weight.

Data Analysis

Transfer functions from the seat to two measurement points on the head are acquired with respect to three translational directions. A set of nine (=3×3) transfer functions are obtained for each measurement point. As for the forehead, transfer functions are corrected geometrically since the surface of the forehead is slightly inclined from the vertical plane.

Transfer functions are cited as H^m_{Xy}, where m indicates the measurement point (m : mouth, f : forehead), y is the input direction and X is the measurement direction.

By assuming that the head is rigid, difference between transfer function of the mouth and that of the forehead is considered due to rotation of the head. Therefore rotation of the head is evaluated, i.e., as :

$$\boldsymbol{H}_{Pj} = \frac{H^f_{Xj} - H^m_{Xj}}{L} \quad (j = x, y, z), \tag{1}$$

where H_{Pj} denotes the pitch (rotation around y-axis) motion excited by the j input ($j = x, y, z$), and L is the vertical distance between two measurement locations.

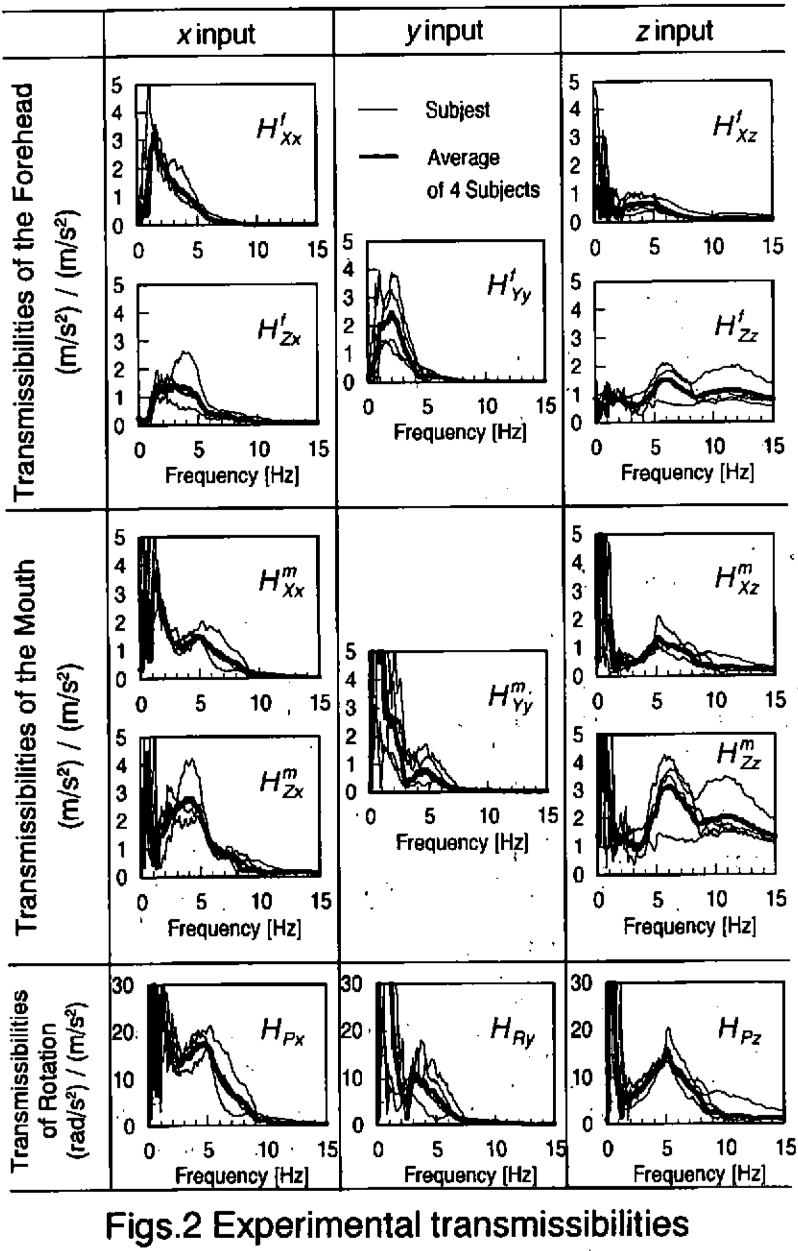
Furthermore H_{Rj} denotes the roll (rotation around x-axis) motion excited by the j input ($j = x, y, z$), which is evaluated similarly as H_{Pj}.

$$\boldsymbol{H}_{Rj} = -\frac{H^f_{Yj} - H^m_{Yj}}{L} \quad (j = x, y, z). \tag{2}$$

Results and Discussion

Figures 2 show the representative transfer functions from the all. Each figure shows the transfer functions of four subjects and the average of them. Though these figures show some variety among the subjects, some of fundamental dynamic properties are commonly observed.

In for-and-aft (x) excitation, a resonant peak is observed around 4-5Hz in H^m_{Xx} H^m_{Zx}, and also in H^f_{Zx}. In vertical (z) excitation, principal resonant peaks are commonly observed around 5-6Hz in H^m_{Zz}, H^m_{Xz} and H^f_{Zz}. These results reveal a dynamic coupling between the fore-and-aft and the vertical motion. It is supposed that this is caused by the pitch motion by the



Figs.2 Experimental transmissibilities

observation of H_{Px} and H_{Pz}. On the other hand, in lateral (y) excitation, no dynamic couplings are observed between translational directions. The second resonant peak (around 4Hz) in H^{m}_{Yy} is caused by the roll motion of the head. This is justified by the observation of H_{Ry}. The results are consistent with the past studies [1, 2].

As for the translation, H^{k}_{Yx}, H^{k}_{Xy}, H^{k}_{Zy} and H^{k}_{Yz} ($k = f, m$) are omitted to display in Figs.2. As for the rotation, H_{Rx}, H_{Py} and H_{Rz} are omitted since the magnitudes of these functions are small. For reference, those functions of the average are represented together in Fig.3.

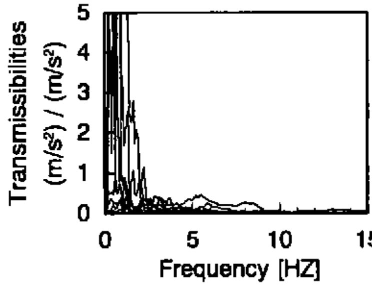


Fig.3 Remaining functions

3. MODELLING OF HUMAN BODY

Model of Human body

A three-dimensional model of sitting human body is constructed considering the results of experiment. In the model, the body and the head are regarded as rigid bodies and they are connected to each other by nine sets of translational spring and damper as shown in Fig.4. The point C is a center of rotation of the head, which can move on the vertical relative to the body. This model has totally six d.o.f. (degree-of-freedom); the body has three d.o.f. in translational directions, and the head has single d.o.f. in vertical direction and two d.o.f. in rotations, i.e., roll and pitch. The model is idealized to be linear on the assumption that every rotational angle of the head is small.

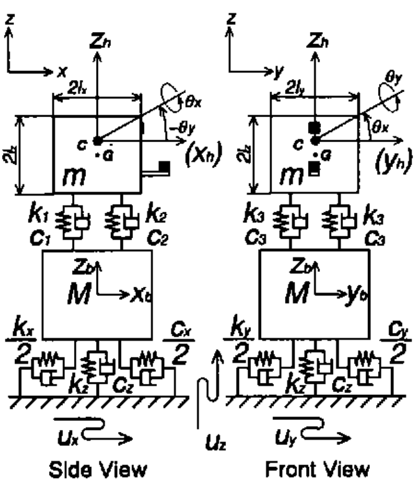


Fig.4 6-degree-of-freedom vibrational model of sitting human body

Results of Modelling and Discussion

Mass of the head and the body and other dimensions were taken by rough estimation, where the springs and dampers were unknown parameters. The unknown parameters were estimated so as to fit the transfer functions of the model to the experimental ones of the average. Figures 5 show those results. Note that the fitness of the phase as well as the magnitude around the resonance is important to evaluate the mode shape of the model.

Though it shows some discrepancies between the experiment and the model in some transfer functions, e.x., at 1-5Hz in H^{m}_{Zx} and H_{Px}, the model reflects the fundamental dynamic characteristics revealed by the experiment : resonant frequencies, fundamental modes, rotational motion and dynamic coupling between fore-and-aft and vertical motion. Dynamic coupling is realized by arranging two different sets of spring and damper in the front and the rear ($k_1 \neq k_2$ and $c_1 \neq c_2$) between the head and the body.

Comparing to many attempts to construct a human model [3, 4, 5], the model has some advantages : number of d.o.f. is small, the structure is quite simple, and it has multi-dimensional dynamic properties of the human body.

4. CONCLUSION

1. The fundamental vibrational characteristics of sitting human body exposed to multi-dimensional excitations were clarified experimentally with paying attention to the head's motion.
2. The six-degree-of-freedom linear model of sitting human was built by considering the results of experiment, and the model reflects the fundamental characteristics of human body.

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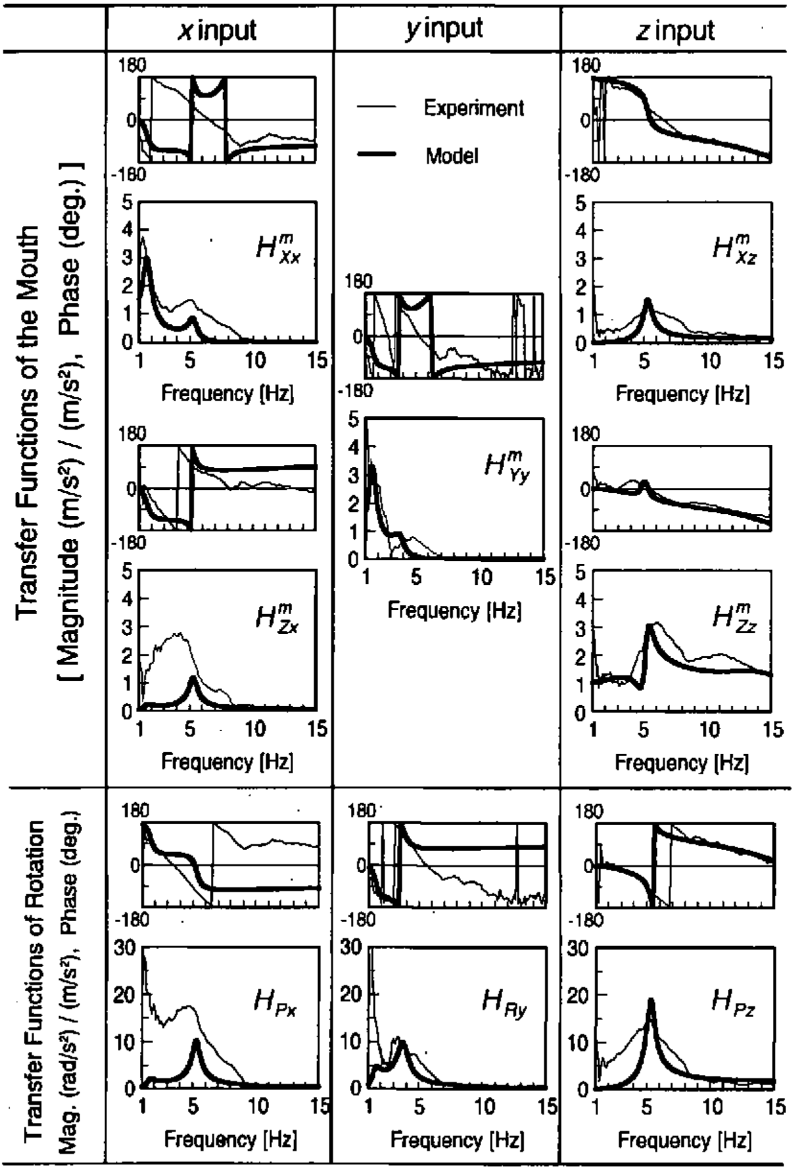

Figs.5 Results of experiment and modelling