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Vibration properties of hand-arm system while holding a grip

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ABSTRACT

Recently, many vibration tools such as concrete breakers are used in the construction site. Workers holding them may suffer from vibration disorder such as white finger. They also feel uncomfortable from them. Many studies of vibration disorder have been carried out. However, there have been few studies for evaluating the comfort. Furthermore, dynamic properties of hand-arm vibration system by vibration exposure have not been reported. Thus, the purpose of this study is to investigate the vibration properties of hand-arm system when holding a grip. In this study, a motion capture system is used to measure the responses of the hand-arm; markers are attached to the subject's arm while holding a grip. The vibration is transmitted through the grip, and the transmissibilities of hand-arm system are measured. We investigate the vibration properties of hand-arm system by conducting curve fit to the measured FRFs. The subject's seated postures and the direction of the grip are changed to see the difference and common characteristics depending on these factors. In the result, we extract four natural modes of hand-arm system. The dependencies of vibration properties to the subject's conditions are also clarified.

Keywords: Hand-Arm System, Vibration Properties, Human Vibration, Comfort Evaluation
I-INCE Classification of Subjects Number(s): 62.5

1. INTRODUCTION

Recently, many vibration tools such as concrete breakers are used in the construction site. Workers holding them may suffer from vibration disorder such as white finger because of long-time exposure. It is vascular motor nerves disorder, and the symptom of it is that fingers whiten spasmodically, called Raynaud's phenomenon. Iwata[1)] studied prevalence rates of Raynaud's phenomenon corresponding to vibration tools and related disorders and preventions for them.

In addition to vibration disorder, we feel uncomfortable when using vibration tools. However, most studies of hand-arm system vibration deal with vibration disorder and few studies are to evaluate the comfort. Moreover, the standard for evaluating the comfort has not been established. Dynamic properties of hand-arm vibration system by vibration exposure have not been reported. Murakami[2)] examined the experiment method for the vibration evaluation of hand-arm system and conducted vibration experiment to investigate the dynamic properties of hand-arm system. In the experiment, a motion capture system is used, where markers are attached to the subject's hand-arm while holding a steering wheel. The vibration is transmitted through the steering, and the transmissibilities of hand-arm system are measured. They investigated the dynamic properties of hand-arm system by conducting curve fit to measured FRFs. If we change the steering wheel to more general one such as a columnar grip, we could obtain more universal results.

The purpose of this study is to investigate the vibration properties of hand-arm system when holding a grip. Furthermore, the subject's posture and the direction of the grip are changed to see difference and common characteristics depending on these factors.

2. Vibration experiment on hand-arm system

2.1 Experimental method

As shown in Fig.1, the subject holds a columnar grip with his left arm; the grip is connected to an exciter. The markers of a motion capture system are attached on the subject's left arm. An accelerometer is attached to the grip to measure the input vibration. The vibration is transmitted through the grip and the transmissibilities of hand-arm system are measured. One healthy male subject participated in this experiment.

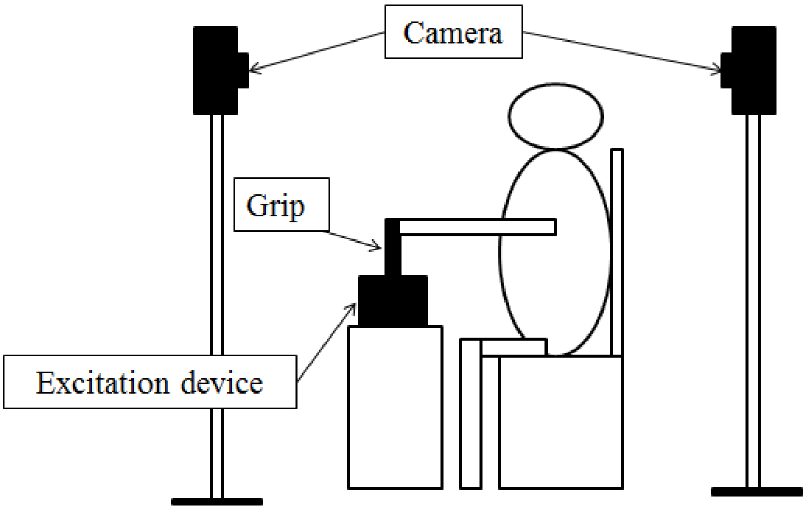


Fig.1 - Experimental posture

2.2 Measurement points on hand-arm system

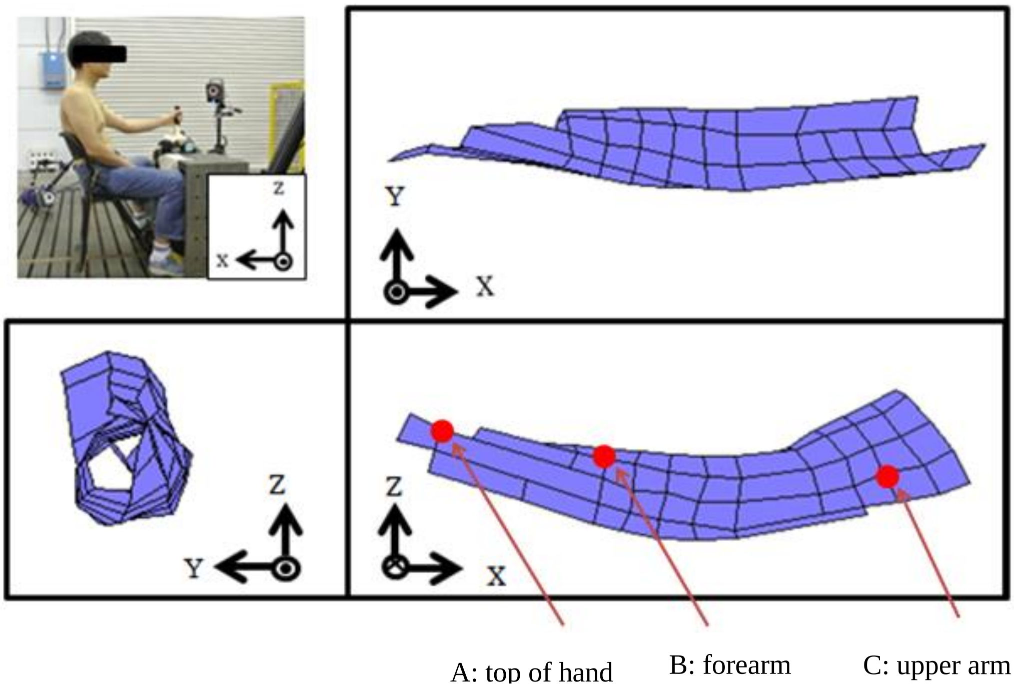
In this section, the method of setting measurement points on hand-arm system is described. The subject stands in the anatomical position as shown in Fig.2. Two longitudinal lines are drawn from the wrist to elbow: one passes through the radius, the other through the ulna. Eight transverse lines are drawn so that each longitudinal line is divided into seven equal segments; each transverse line forms a cross-sectional circle; eight points are determined on each circle so that they are evenly located. Measurement points of 64(=8x8) are set in the forearm by this way. The procedure is extended to the upper-arm in a similar manner. 40(=5x8) measurement points are located in the upper-arm.

Fig.2 – Anatomical position[3]

2.3 Representative points of hand-arm system

The number of measurement points is 110. Thus, three representative points are set for the evaluation: the first on top of hand, the second in the forearm and the third in the upper arm. Figures 3 show the model of hand-arm system made from the coordinate data captured by the system and the positions of representative points.

Representative point A is on the top of arm. It is in the center of the top of hand, and on the extension line of the middle finger. Representative point B is on the forearm. It is in the middle of the wrist and the elbow on radius. Representative point C is on the upper arm. It is on the triceps brachii muscle located on an extension line of the representative point A.



Figs.3 - Hand-arm model

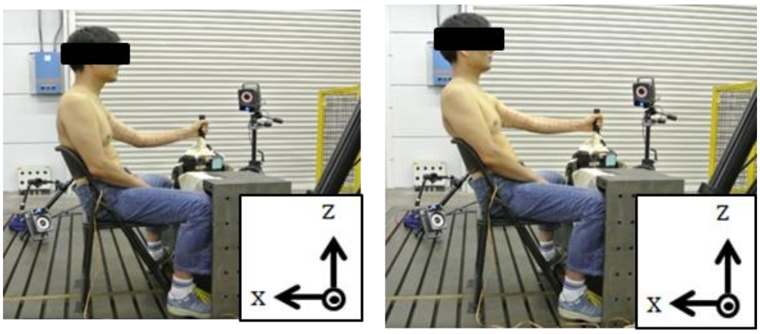
2.4 Experimental cases

In this study, the experiments were conducted in three different conditions cited as Case1, Case2 and Case3. The subject's seated posture and the direction of the grip were changed to see the difference and common characteristics depending on the conditions. Experimental cases are summarized in Table 1. Case1 is cited as a standard case; the seated posture is similar to the normal driving posture and direction of grip is vertical against the ground. In Case2, the posture is changed so that the upper-body leans back a little; the upper body is a little far away from the grip than in Case1 (Fig.4). In Case3 the direction of the grip is changed to horizontal (Figs.5). The subject holds the grip softly. Reference values of gripping force is 49.1 to 98.1[N].

Excitation wave is a random wave with the frequency range of 5 to 50[Hz]. Frequency characteristic of excitation wave is 20[db/dec], speed power spectral density is constant. The direction of excitation is vertical direction against the ground. The duration of vibration exposure for transmissibility measurement is about 60[s].

Table 1 - Experimental cases

Case No.	Seated posture	Direction of grip
1	Standard	Vertical
2	Distant	Vertical
3	Standard	Horizontal



(a) Standard (b) Distant

Figs. 4 – Seated postures

(a) Vertical (b) Horizontal

Figs.5 – Directions of the grip

2.5 Date processing

In this section, the data processing method used in this study is described. As the output (response) the displacements of hand-arm system are measured by a motion capture system; as the input, the acceleration of the grip is measured by an accelerometer. Measured accelerations are transformed to displacements. FRFs (i.e., transmissibilities) of the hand-arm system are estimated. Signal conditions for spectrum analysis are as follows; the overlap rate is 75%, the number of averages is 20, and the window function is Hanning. Modal parameters of hand-arm system are investigated by conducting Multi-reference Iterative Curve Fitting[4] to measured FRFs.

3. Results

3.1 Identification results (Case1)

Measured coherence, phase and amplitude of transmissibility of each representative point of hand-arm system in vertical direction are shown in Figs.6(a) to (c). Coherence at point C was lower than those at point A and B. It is understood that the vibration is attenuated as it is transmitted through the body. Since the upper arm is further than the hand and the lower arm from the grip, vibration is more attenuated than those parts. Especially for the upper arm, the more fat is put as well as the muscle. This would be another reason that the vibration is more attenuated than other parts. This tendency was particularly notable in high frequencies such as from 30Hz to 50Hz.

Any remarkable peak are not commonly observed among three transmissibilities (Figs.6(a)-(c)) although a mild peak is observed at around 15Hz at point B in Fig.6(b): the modes are heavily coupled and the system is highly damped. Generally speaking, it is quite difficult to identify natural modes from these data. Thus, in this study, we try to identify modal properties by applying the NLS (non-linear least squares) approach for modal parameter estimation: modal parameters are identified so as to minimize the squared error between the experimental and the synthesized data. In Figs.6(d) to (f), the synthesized transmissibilities are compared with the experimental ones. As shown in Table

2, four natural modes were extracted in the range from 5 to 30[Hz].

Figs.7 to 10 show four mode shapes: each mode consists of two figures whose phases are apart in 180 degree.. Graduations of color show the amplitude of the vibration, i.e., the deep color shows the large amplitude. The numbers in the axis show the mode amplitude in a relative sense.

As shown in Fig.7, at the 1st mode, the whole arm vibrates in the vertical direction almost in phase. At the 2nd mode in Fig.8, forearm vibrates in anti-phase with his upper-arm. The forearm vibrates in a torsional way(around x-axis) as well as in z-translation. Vibration is propagated to the upper arm with attenuation. At the 3rd mode in Fig.9, the vibration is dominant in the forearm; vibration in the forearm is more attenuated. The 4th mode shape is shown in Fig.10: the wrist vibrates largely; the forearm vibrates smaller than other modes; and the upper arm hardly vibrates. As a whole, the main part of vibration of mode shapes changes from the global motion to the local motion; the center of vibration moves near to the grip as increasing the mode order.

Table 2 - Identification results

	Case1		Case2		Case3	
	fr	ζr	fr	ζr	fr	ζr
1st	6.35	0.20	8.93	0.27	7.29	0.38
2nd	12.29	0.23	14.99	0.18	13.56	0.17
3rd	17.51	0.19	19.43	0.38	19.99	0.23
4th	27.99	0.17	29.35	0.21	30.39	0.31

fr ; damped natural frequency [Hz]

ζr ; modal damping ratio[-]

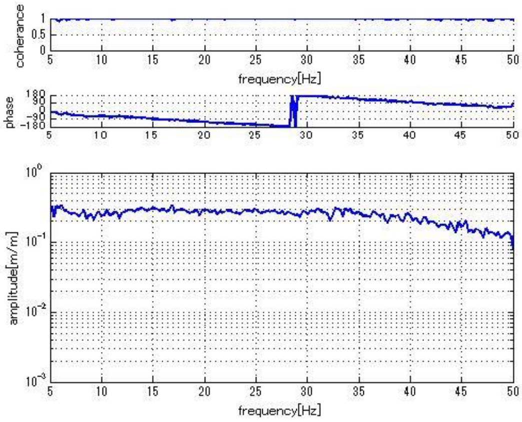


Fig.6(a) Transmissibility of A in z-direction

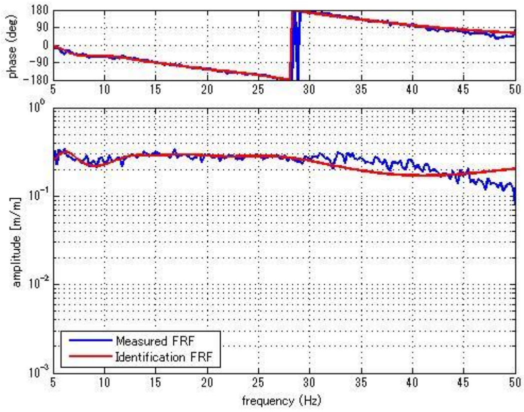


Fig.6(d) Modal identification transmissibility of A

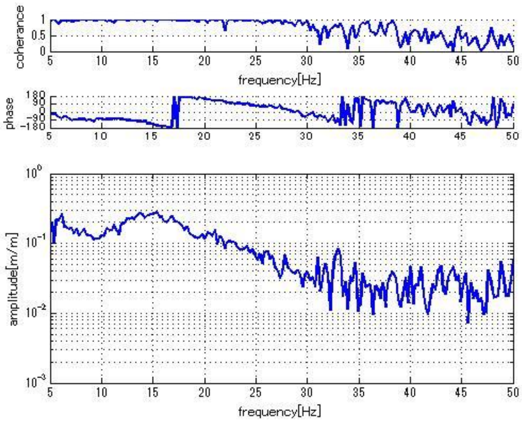


Fig.6(b) Transmissibility of B in z-direction

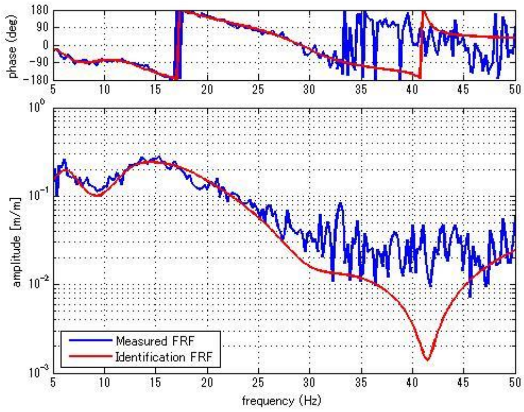


Fig.6(e) Modal identification transmissibility of B

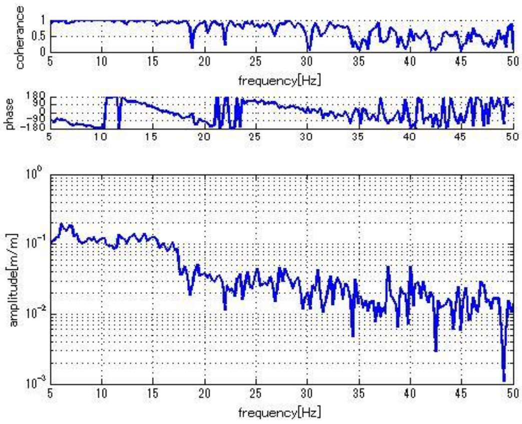


Fig.6(c) Transmissibility of C in z-direction

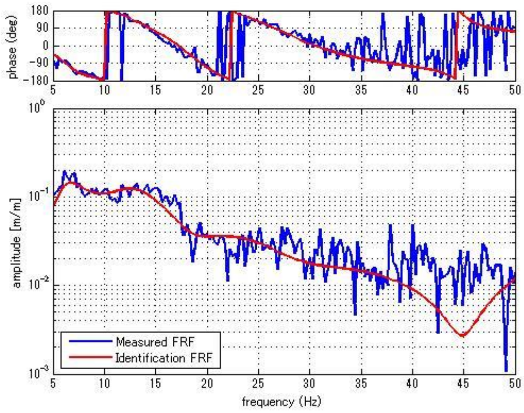


Fig.6(f) Modal identification transmissibility of C

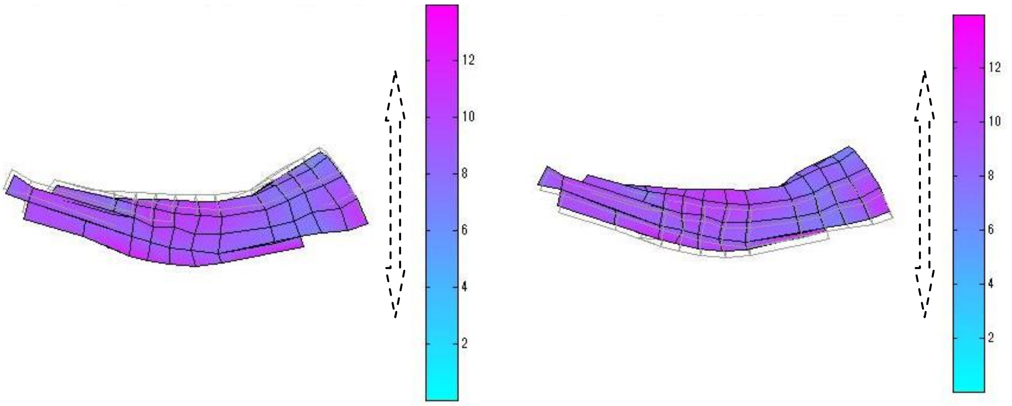


Fig.7 - 1st mode shape

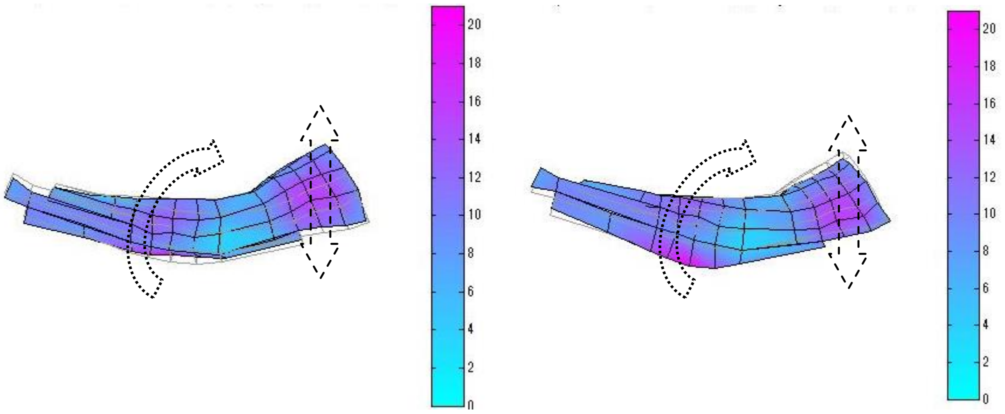


Fig.8 - 2nd mode shape

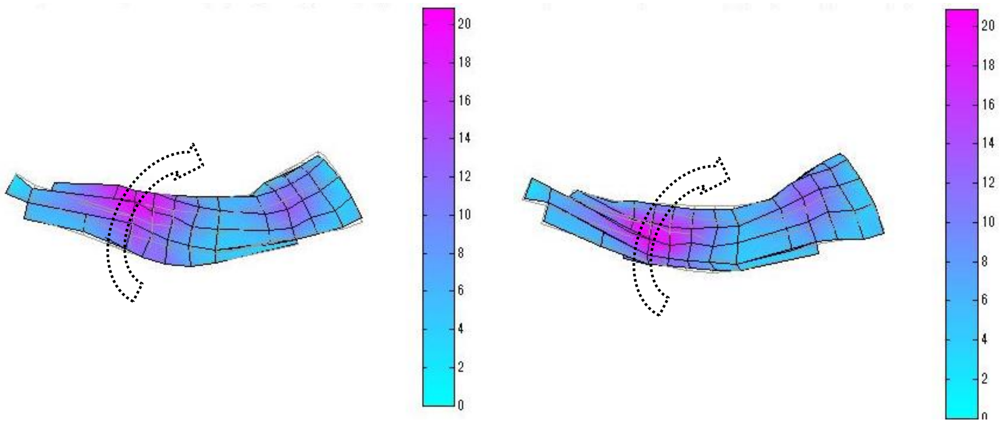


Fig.9 - 3rd mode shape

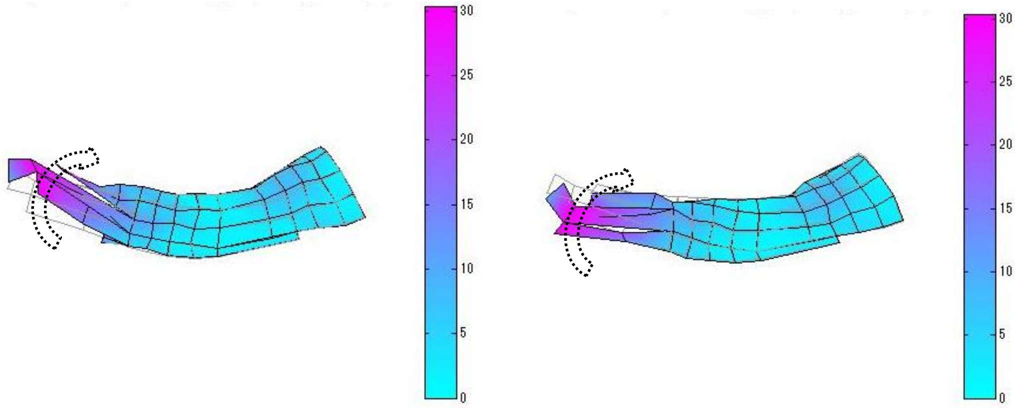


Fig.10 - 4th mode shape

3.2 Influence of seated postures

Influence of change of seated posture is examined by comparing Case1 with Case2. In Case2, The posture is changed so that the upper-body leans back a little; the upper body is a little further away from the grip than in Case1 (Fig.4). Measured coherence, phase and transmissibility of each representative point for Case1 and 2 are shown in Fig.11 to 13. Coherence of point C is lower than those of point A and B for both cases. Four natural modes were identified in the range from 5 to 30[Hz] like Case1. All damped natural frequencies of Case2 are larger than corresponding natural frequencies of Case1. Difference of mode shapes between the conditions is small; mode shapes of each order for both conditions show a similar tendency.

3.3 Influence of gripped directions

Influence of the direction of the grip is examined by comparing Case1 with Case3. In Case3 the direction of the grip is changed to horizontal (Fig.5(b)). Measured coherence, phase and transmissibility of each representative point for Case1 and 3 are shown in Fig.11 to 13. 4 Four natural modes were investigated in the range from 5 to 30[Hz] like Case1. All damped natural frequencies of Case3 are larger than corresponding natural frequencies of Case1. Difference of mode shapes between the conditions is small; mode shapes of each order for both conditions show a similar tendency.

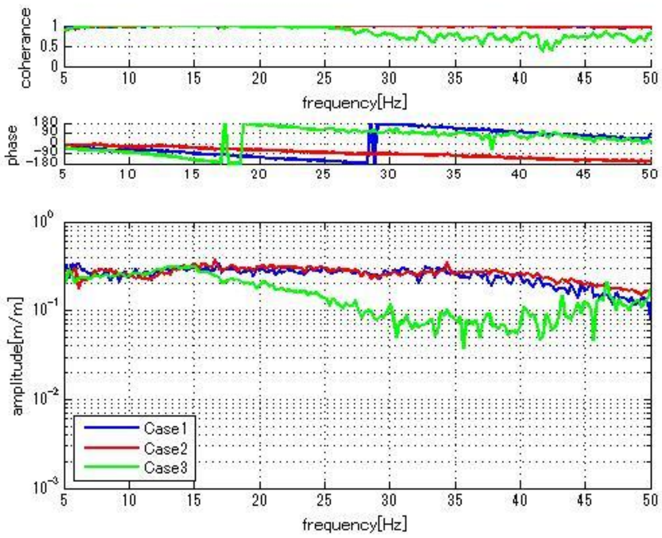


Fig.11 - Transmissibility of representative point A

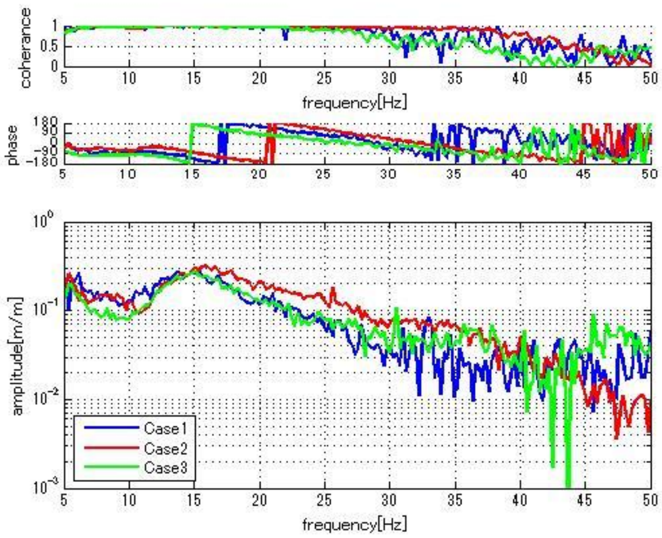


Fig.12 - Transmissibility of representative point B

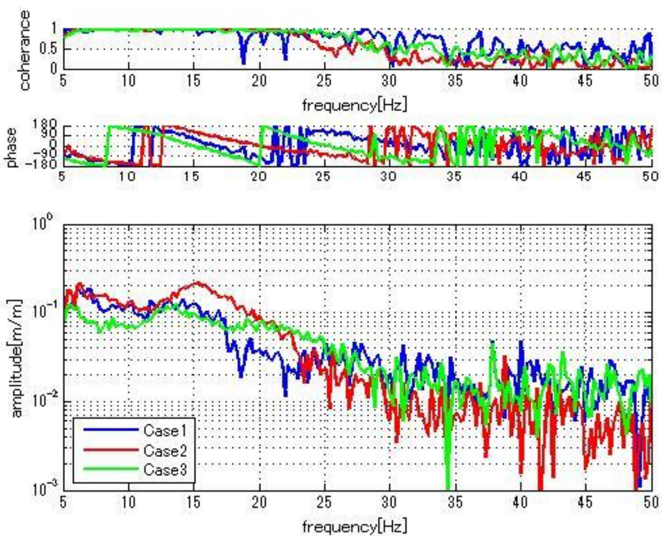


Fig.13 - Transmissibility of representative point C

4. Discussion

The results of this study show that damped natural frequencies changed depending on subject's conditions. In Case2 and Case3 the damped natural frequencies increased because the rigidity of hand-arm system increased. In Case2, the upper body leans back and the subject stretched his hands; this leads to muscles of hand-arm system tensed. Similarly, in Case3, the direction of the grip was changed to horizontal from vertical; subject twisted his hand-arm system; and this causes the muscles of hand-arm system stretched. From the above reasons, damped natural frequencies of hand-arm system changed depending on the subject's conditions.

5. Conclusion

In this study, we conducted the vibration experiment while the subject's holding a columnar grip and investigated vibration properties of the hand-arm system. As the result, four natural modes were extracted regardless of the experimental conditions; mode shapes of these modes were also described. Even though the transmissibilities do not show any noticeable resonant peaks, four natural modes are extracted by applying the NLS approach for modal parameter estimation. Natural frequencies increase in the case that seated position is farther from the grip. If the direction of grip is horizontal, the natural frequencies increase than in the case of that the direction is vertical. Difference of mode shapes between the conditions is small; mode shapes of each order for any condition show a similar tendency.

Further studies are needed to see difference depending on subjects because we examined for a single subject in this study.

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