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MEASUREMENT OF IMPEDANCE OF HAND ARM SYSTEM

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INTRODUCTION

The work which is described in this paper was initiated by an interest within the International Standards Organization (I.S.O.) to develop a standard which would define typical values of the human hand arm impedance for specified conditions of measurement. A knowledge of these values for all three directions of translatory motion would be of value when calculating the loading provided by the human body when developing standardised type testing of different machines. It is also of value to have a knowledge of the impedance of the hand arm when estimating the transfer characteristics of resilient materials such as gloves and handle coverings, provided the physical characteristics of such materials are known.

Measurements of the mechanical impedance of the hand arm have not generally shown close agreement (1-7). Undoubtedly some of the differences have been due to different experimental techniques and factors such as different postures and grips adopted by the subject.

Although it is recognized that the impedance of the hand-arm will have a dependence on parameters such as the gripping force, arm position, body posture and build, magnitude of excitation and location of the measuring points, this study is not concerned with an evaluation of the importance of these factors, but rather an establishment of values of impedance which relate to a pre-determined reference situation.

From a mechanical point of view; the hand-arm system can be modelled as a set of separate elements consisting of masses, springs and viscous dampers, which taken as a whole constitute a mechanical structure whose response to an applied vibration can be described in terms of its Mechanical Impedance Z. The Mechanical Impedance describes the velocity with which the mechanical system moves when a force is applied. It is the complex ratio of the vibration force and vibration velocity. The force and velocity being measured either at the same point (driving point impedance), or at different points of the same system (transfer impedance). Generally the term refers only to linear systems. Formally, the mechanical impedance $Z(\omega)$ is defined as the ratio of the Fourier transforms of the force and velocity time functions $F(\omega)$ and $V(\omega)$.

$$Z(\omega) = \frac{F(\omega)}{V(\omega)}$$

As both $F(\omega)$ and $V(\omega)$ are complex quantities, $Z(\omega)$ is complex and has both magnitude and phase or real and imaginary parts. The real part of Z reflects the damping properties of the system, i.e. the energy dissipating properties, the imaginary part reflects the elastic properties and is associated with energy being stored in the system.

If the system is excited using harmonic forces then the magnitude of $Z(\omega)$ can be determined from the ratio of the magnitudes of the force and velocity and the phase of $Z(\omega)$ can be obtained from the phase difference between the force and velocity. This has to be done at discrete frequencies and is a time consuming process. It is also difficult to ensure that the experimental conditions remain stable across a range of test frequencies.

By exciting the system with a suitable random signal and using a twin channel Fourier analyser, the mechanical impedance can be computed directly in both magnitude and phase (or real and imaginary parts). Care has to be taken to ensure that the coherence of the system is satisfactory. In the study reported here, the impedance was measured using the latter technique for one reference situation for groups of both Males and Females.

METHOD

The reference situation, which had been suggested by ISO was to determine the driving point impedance at 1/3 octave band frequencies for the basecentric coordinate directions and X, Y and Z as specified in ISO 5349 (6) see figure 1. The grip force was to be set at 25 ± 5.0N with the arm unsupported and elbow angle at 120°. A handle is grasped by the subject, while the acceleration input to the base of the handle is maintained constant at about $0.5 m/s^2$. The force and acceleration signals measured on the handle are fed into a dual channel FFT analyser and the transfer function between them is measured. The subsequent handling of the data in order to obtain the mechanical impedance of the handle alone and hence that of the hand which is gripping the handle is performed in the computer which is interfaced to the FFT analyser.

The handle was made of wood and balanced in such a way that it behaved almost as a perfect mass over the frequency range of interest (16-500Hz). This was apparent from the fact that the transfer function between the force and acceleration revealed that the force and acceleration remained in phase over the frequency range studied. Fig 2 shows the initial values of the real part of the dynamic mass of the handle, together with the values obtained after the stem of the handle had been shortened and an attempt had been made to re-distribute the mass along the length of the handle. The peaks associated with resonances in the handle have clearly been reduced and it is the values of dynamic mass of the modified handle which have subsequently been used to determine the impedance of the handle.

The resolution of the analyser was set such that the impedance of the handle could be determined for signals with a bandwidth of 0.75Hz. An averaging time of 128 seconds was adopted. The data which related to the handle alone was stored for its subsequent use in determining the impedance of the hand-arm when a subject gripped the handle. When the handle was gripped, the transfer function between force and acceleration enabled the impedance of the handle and hand to be determined. Subsequent subtraction of the real and imaginary parts of the impedance of the handle from those of the handle plus hand gave the real and imaginary parts of the impedance of the hand alone.

A group of 10 adult Male and a group of 10 adult Female subjects, selected to encompass a range of sizes and builds were used as subjects. Each subject gripped the handle for about 2½ minutes during which time a 128 second average of the transfer function was obtained. From this information a value of impedance (magnitude and phase) of the hand-arm of each subject could be determined.

In addition to these two groups of subjects, two additional adult males each held the handle for about 6 minutes, during which time ten 32-second averages of the transfer function were obtained. In this way 10 separate estimates of the impedance of the hand-arm were made for each of these two subjects.

The whole of the above procedure was repeated for measurements done in the X, Y and Z directions.

RESULTS

The results are presented for the X direction only. The first groups of data, shown in fig 3, gives the impedance magnitude and phase for the X direction for each of the two subjects for whom ten estimates of the impedance were obtained. The graphs give the mean values of the determinations together with the associated standard deviations.

The second group of data shown in Figure 4 gives the average impedance magnitudes and phases for the X direction for the group of 10 Male and 10 Female subjects. The graphs give the mean values for each of the two groups together with the corresponding group standard deviations.

Consideration of the individual subject data first, shows that the general shape of the curves for the two subjects are similar, but there are sufficient differences to suggest that there are likely to be significant differences between the hand arm characteristics between different individuals. Figure 3 suggests that there appear to be two principal resonances in the X direction. Data for Y and Z directions (not shown here) suggest responses that also differ slightly in frequency and extent for the two subjects.

In a previous study (5), the same two subjects had had the impedance of their hand-arm measured in the X direction using a similar technique to that described here. However, on that occasion, the measurements were performed at discrete frequencies using a harmonic signal input to the handle. Also, the handle was made of steel and was about four times the mass of the handle used in the study being reported here. This impaired the accuracy with which measurements could be made - particularly at higher frequencies. Fig 5 shows the magnitudes and phases of the impedance obtained in this earlier study. The values and the general shapes of the curves are very similar to those obtained using the FFT transfer function techniques. One is encouraged, therefore, to believe that the data obtained for the remaining two axes of vibration is reliable.

When one examines, the curves in Figure 4 which relate to the groups of subjects, there are some differences which are evident. There are clearly changes in the size and position of the major resonances. The major resonances occur at lower frequencies for the group of males compared with groups of females.

A similar observation is apparent for the Z direction data. In the Y direction the resonances are less marked and the differences between the male and female groups appear to be less significant than in the X and Z directions. However, as with data obtained in the

X and Z directions, it is apparent that data for individual subjects can be markedly different from that which is obtained when data from groups of Males and/or Females is averaged. These differences highlight a difficulty associated with the original initiative for conducting the study which is being reported here, namely the need for a standardized set of values for the impedance of the hand arm. Clearly if this is to be done, data for males and females should be presented separately. A matter which may be less easy to resolve would be the question of how the hand-arm system might be modelled. The data in Table 1 illustrates the problem. Here the magnitude of the impedance in the X direction for each of the 10 Male subjects together with the associated mean and standard deviations are shown. Clearly the values for each subjects show maxima which occur at different frequencies for different subjects. The first one occurs at between about 20 and 50Hz and the second one at between about 100 and 160Hz. When this data is averaged out to give the information for the whole group shown in Figure 4, the first peak is virtually eliminated to give a curve which may well represent average values of the impedance of the hand arm, but does not represent the response of any one individual hand-arm. The problems created by this observation become even more apparent if one attempts to model the data in Figures 3 and 4.

A four degree of freedom unidirectional system which models the impedance magnitude and phase can be constructed for the data which relates to Subject 1 and Subject 2 shown in Figure 3. Although the sizes of the masses, springs and dampers which describe these models are different for the two subjects, the responses of the models do follow the same pattern as that observed on the individual subjects.

The modelling of the average data shown in Figure 4 proves to be more problematical and therefore raises the question of how one should proceed towards the establishment of a model of the human hand arm.

The present authors would suggest that models for individual subjects should be constructed and then the average value of each component part of the model be established. These average values would then be used to construct a model which would simulate the 'average' hand arm system.

CONCLUSIONS

The magnitude and phase of the impedance of the hand arm has been measured for different subjects. It proved possible to model the characteristics of individual subjects but an attempt to model the average characteristics of the hand arm has not been performed. Clearly if there is a need for a model which describes the response of the typical hand arm system, it is necessary to have a consensus view on how this model should be established. Should it be a model which attempts to predict the average response of the male and/or female arm, or should it be a model built up from the average component values of models which predict response of individual subjects? If ISO wish to pursue this particular work item, they should decide on which approach they wish to adopt. We believe that they should adopt the second of the alternative approaches which are outlined above i.e. average the component values for models of individual subjects and then construct a model which is derived from these average component values.

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REFERENCES

1. Diekmann, D. Ein mechanisches model fur das schwengungerregte hand-arm system des mesnchen. Intenant. Z. angen Physiol einschl. Arbeitsphysiol 17 (1957) 125.

2. Reynolds, D D and Soedel, W. Dynamic response of the hand arm system to a sinusoidal input, J. Sound Vib 21(3) (1972) 339-353.

3. Suggs, C W and Mishoe J W. Hand Arm Vibration: Implications drawn from lumped parameter models. In: Wasserman D E, Taylor W and Curry M G eds. Proc of the Int Occup Hand-Arm Vibration Conf. Cincinnati, OH: Dept of Health and Human Services, 1977. (NIOSH publication No.77-170): 136-141.

4. Reynolds, D D and Falkenberg R J. Three- and Four-Degrees-of-Freedom Models of the Vibration Response of the Human Hand. In: Brammer A J and Taylor W. eds. Vibration effects on the hand and arm in industry. New York: Wiley, 1982: 117-132.

5. Hempstock T I and O'Connor D E. Measurement Accuracy of the Impedance of the Hand Arm. Scand. J. Work. Environ. Health 12 (1986) 355-358.

6. ISO Guidelines for the measurement and assessment of human exposure to hand transmitted vibration (1986).

TABLE I

Male Impedance mag(Nms-1) Xdirection

Freq	1	2	3	4	5	6	7	8	9	10	Ave	Dev
16.3	68	76	46	72	85	45	51	40	69	72	63.2	13.5
20.0	88	80	44	95	100	54	58	69	86	71	74.3	18.8
25.0	92	64	64	124	93	66	47	101	104	80	83.4	22.2
32.5	102	66	66	123	71	78	70	114	89	61	84.8	20.8
40.0	77	53	57	97	53	93	80	123	83	64	78.1	21.3
50.0	85	78	76	103	72	97	90	141	86	75	91.2	19.4
62.5	110	107	113	145	111	93	122	124	94	103	110.1	14.2
80.0	163	172	179	259	188	114	124	150	148	161	165.8	37.9
100.0	272	281	242	422	293	184	203	275	237	241	265.1	61.8
125.0	267	277	215	486	364	248	166	466	325	205	314.0	56.9
162.5	364	256	212	350	317	311	196	495	363	262	312.7	83.3
200.0	275	280	191	278	248	233	163	374	265	218	244.6	55.2
250.0	271	190	180	208	186	171	152	291	244	184	207.7	43.5
315.0	256	186	181	231	173	140	154	230	241	160	157.9	38.3
400.0	252	208	170	215	158	142	176	202	276	217	200.5	40.3
500.0	228	216	184	234	182	167	219	152	348	200	203.2	49.9

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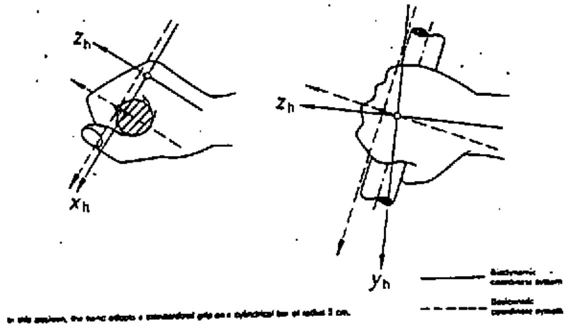


FIGURE 1

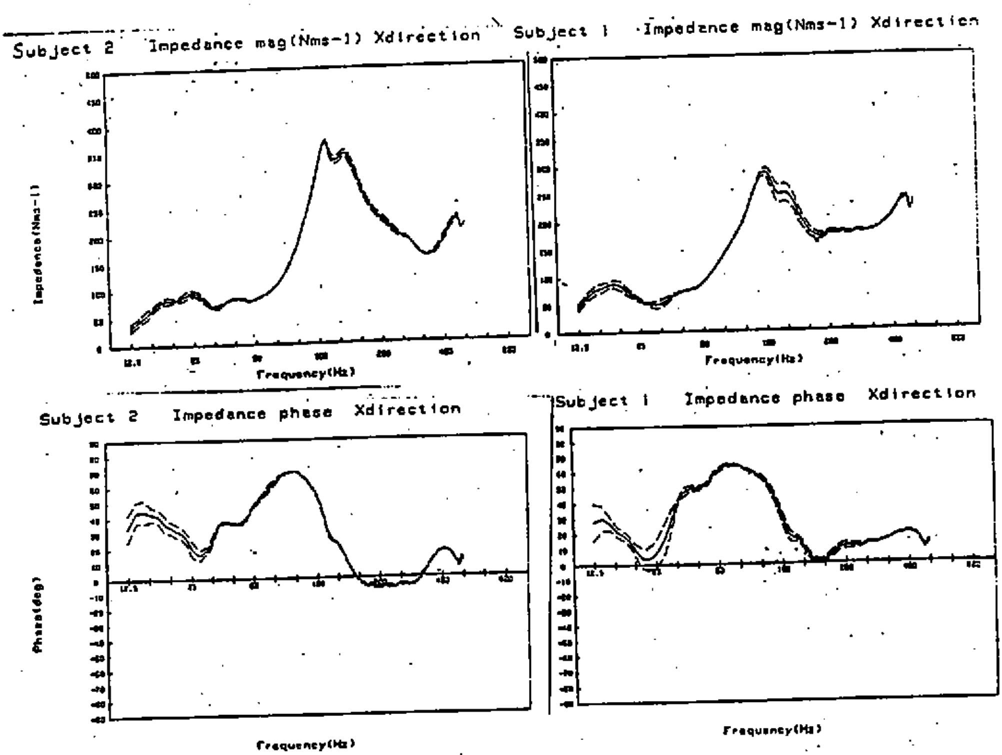


FIGURE 3

MEASUREMENT OF IMPEDANCE OF HAND ARM SYSTEM

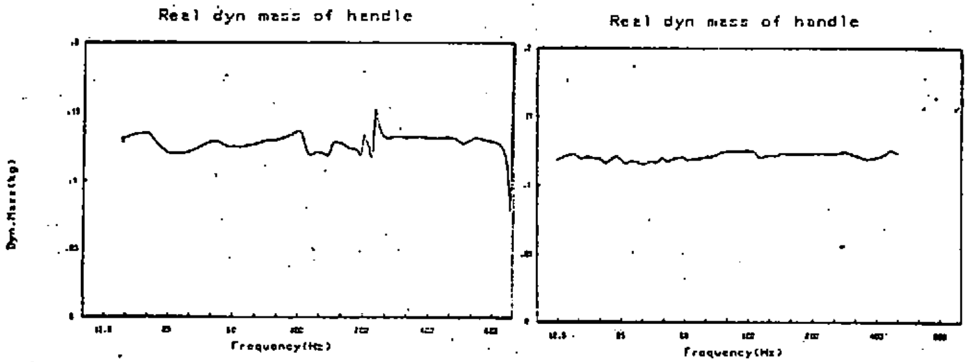


FIGURE 2

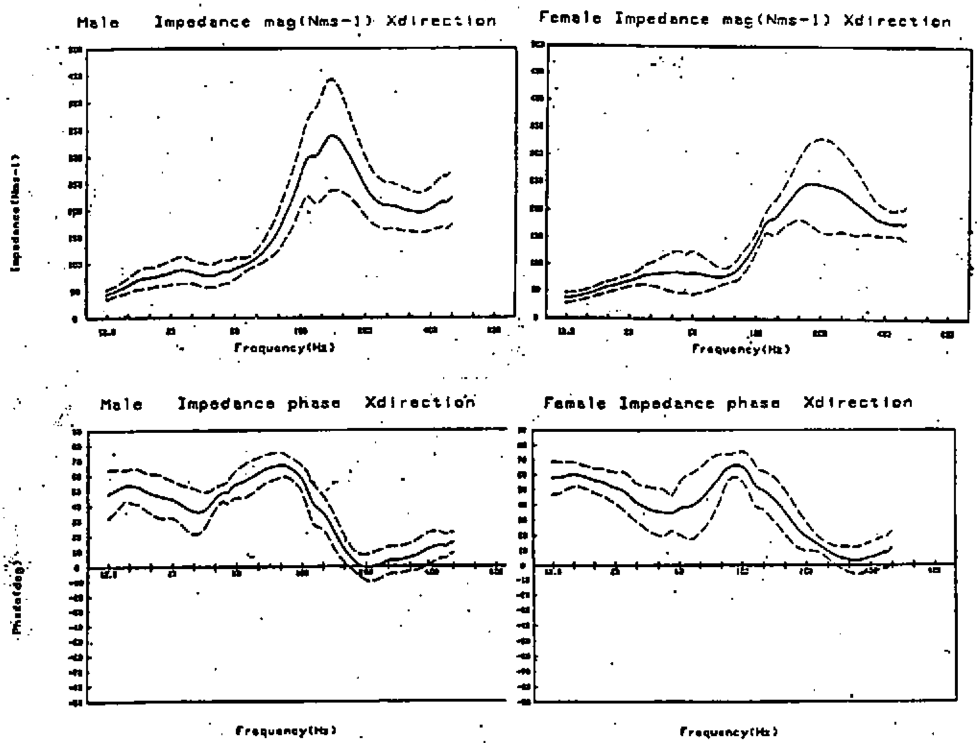
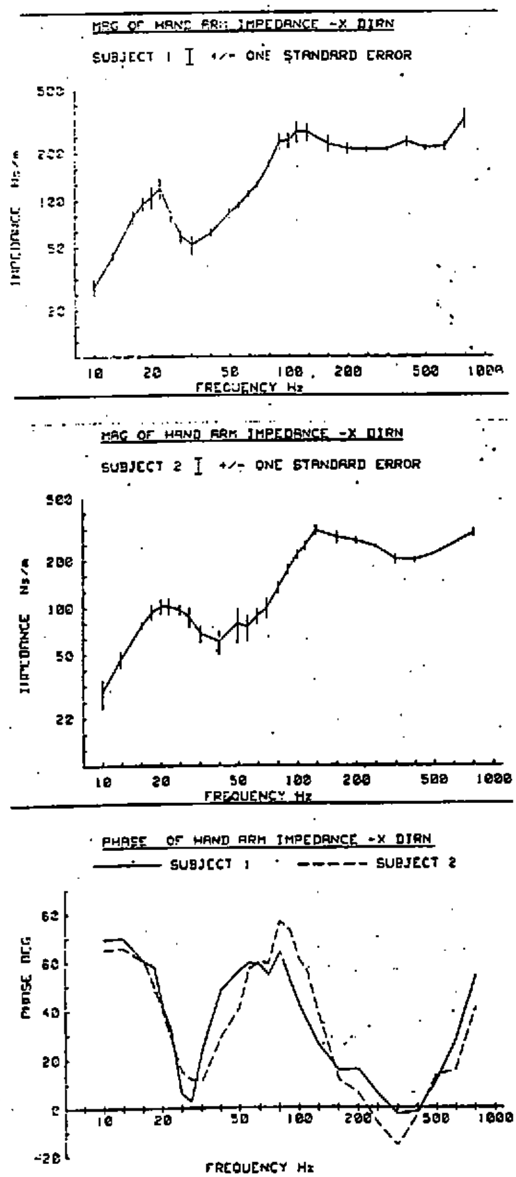


FIGURE 4

FIGURE 5


MAG OF HAND ARM IMPEDANCE -X DIRN
SUBJECT 1 +/- ONE STANDARD ERROR
IMPEDANCE Ns/m
FREQUENCY Hz
MAG OF HAND ARM IMPEDANCE -X DIRN
SUBJECT 2 +/- ONE STANDARD ERROR
500
200
100
50
22
10
20
50
100
200
500
1000
IMPEDANCE Ns/m
FREQUENCY Hz
PHASE OF HAND ARM IMPEDANCE -X DIRN
SUBJECT 1
SUBJECT 2
PHASE DEG
40
20
-20
FREQUENCY Hz

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