INTERNATIONAL STANDARD

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Mechanical vibration and shock — Free, mechanical impedance of the human hand-arm system at the driving point

Vibrations et chocs mécaniques — Impédance mécanique libre du système main-bras au point d'entrée

Reference number
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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 10068 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 4, *Human exposure to mechanical vibration and shock*.

Annex A is an integral part of this International Standard. Annexes B to F are for information only.

Introduction

The mechanical impedance of the human hand and arm describes the motion of the hand-arm system in response to an oscillatory force impressed upon the hand. Such oscillatory forces occur, for example, during operation of a vibrating, hand-held power tool. The mechanical impedance of the hand-arm system is required for the design and development of

a) vibration-reducing and protective devices;

b) test rigs with which to measure the handle vibration of power tools.

Knowledge of this impedance permits the mechanical power transmitted to the hands to be estimated, and assists in the description of the biodynamic properties of the hand-arm system. The establishment of standardized values for human hand-arm impedance will foster the development of effective vibration-reducing and protective devices, and meaningful test procedures.

The response of the hand-arm system when the hand grasps a vibrating object depends on several factors. The most important of these are:

— the direction of vibration with respect to the hand-arm system;

— the geometry of the object grasped;

— the forces exerted by the hand on the object;

— posture;

— muscle tone;

— anthropometric characteristics.

The forces exerted by the hand are usually described in terms of the grip force and feed force. The latter is often called the “thrust”, “push” or “press” force.

In this International Standard, the free, mechanical impedance at the driving point is employed to describe the dynamic response of the human hand-arm system to forced motion of the hand, as a function of frequency. The values of free impedance have been derived from the results of impedance measurements performed on groups of live, male subjects, by different investigators. Insufficient data are available from independent sources to specify hand-arm impedances for females.

The unexplained differences between the mean values of impedance reported in studies conducted independently, under nominally equivalent conditions, has dictated the form in which the standardized male hand-arm impedance is presented. A synthesis of measured values has been performed (see annex F). The most probable values of impedance modulus and phase are defined, as a function of frequency, by upper and lower envelopes, which encompass the mean values of all accepted data sets at each frequency. The envelopes have been constructed from segmental cubic spline functions, and define, at each frequency, the range of accepted values of the male hand-arm impedance. The weighted mean of the accepted data sets, and standard deviation of the mean, are defined as a function of frequency, and represent the target values for all applications of this International Standard.

No impedance modulus or phase presented as a function of frequency in this International Standard corresponds precisely to the mean value measured in a single investigation involving human subjects, at all frequencies.

Mechanical vibration and shock — Free, mechanical impedance of the human hand-arm system at the driving point

1 Scope

This International Standard describes the free, mechanical impedance of the human male hand-arm system at the driving point. Values of the free impedance, expressed as modulus and phase, are provided for three orthogonal, translatory directions of excitation that correspond to the x_h, y_h and z_h axes of the basicentric coordinate system for the hand defined in ISO 5349 and ISO 8727. The x_h, y_h and z_h components of free impedance are defined as a function of frequency, from 10 Hz to 500 Hz, for specified arm positions, grip and feed forces, handle diameters, and intensities of excitation. The components of free impedance in the three directions are treated as being independent (see annex F).

This International Standard may be used to define typical values of the free, mechanical impedance of the hand-arm system at the driving point, applicable to males under the circumstances specified. For each impedance component, the free impedance is defined at each frequency by three values, to reflect the range of values measured on male hands. The upper and lower values define the range of most probable values of impedance. The middle value represents an overall mean of the human data, and defines the target value for all applications. This International Standard may be provisionally applied to females.

Reference values of the free, mechanical impedance at the driving point are provided as a function of frequency for a specified grip and feed force in annex A. These impedance values are intended for the determination of the transmissibility of resilient materials, when loaded by the hand-arm system.

Mathematical representations of the hand-arm system that model the values of free impedance are also provided in annexes C to E.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 5349:1986, *Mechanical vibration — Guidelines for the measurement and the assessment of human exposure to hand-transmitted vibration*

ISO 8727:1997, *Mechanical vibration and shock — Human exposure — Biodynamic coordinate systems*

3 Definition

For the purposes of this International Standard, the following definition applies.

3.1
free impedance
complex ratio of the applied periodic excitation force at frequency f, $F(f)$, to the resulting vibration velocity at that frequency, $v(f)$, with all other connection points to the system "free", that is, having zero externally applied force (see also ISO 2041)

$$Z(f) = F(f)/v(f)$$

NOTE 1 The free impedance is generally complex, that is, it possesses real and imaginary parts, which may be expressed as modulus and phase.

NOTE 2 This International Standard is based on measurements in which both force and velocity were measured at the same point, this being the point of introduction of vibration to the hand-arm system.

NOTE 3 The hand and arm are treated as a system in which translatory vibrations in the three mutually perpendicular directions are independent.

NOTE 4 Alternative descriptions of the dynamic response of the human hand-arm system have been used in the scientific literature (e.g. apparent mass).

4 Free, mechanical impedance of the hand-arm system at the driving point

The modulus and phase of the free, mechanical impedance of the hand-arm system at the driving point are given in tables 1 to 3 and (for illustration) in figures 1 to 3 as a function of frequency, for three orthogonal directions of excitation. The directions correspond to the x_h, y_h and z_h axes of the basicentric coordinate system according to ISO 5349 and ISO 8727. Each table and diagram contains three values of modulus and phase at each frequency, for each direction of motion. Numerical values are quoted up to three significant figures for the purposes of calculation, and do not reflect the precision of knowledge of the hand-arm impedance. Linear interpolation is permitted to obtain impedance values at frequencies other than those listed in tables 1 to 3. Impedance values for one-third-octave band centre frequencies are given in annex B.

The upper and lower limiting values at each frequency encompass the mean values of all data sets selected, and are shown by bold continuous curves in figures 1 to 3. The central value at each frequency, shown by dotted curves in figures 1 to 3, provides an estimate of the weighted mean of all data sets selected, and forms the target value for all applications. The standard deviation of the mean (target) values are also listed in tables 1 to 3.

Applications that generate/employ values of impedance between the upper and lower limits at any frequency satisfy the requirements of this International Standard, and represent the male hand-arm mechanical impedance at that frequency, or frequencies.

If an application only satisfies the requirements of this International Standard at certain frequencies, then those frequencies should be stated in any description of the application.

Table 1 — Values of the free, mechanical impedance of the hand-arm system at the driving point in the x_h direction

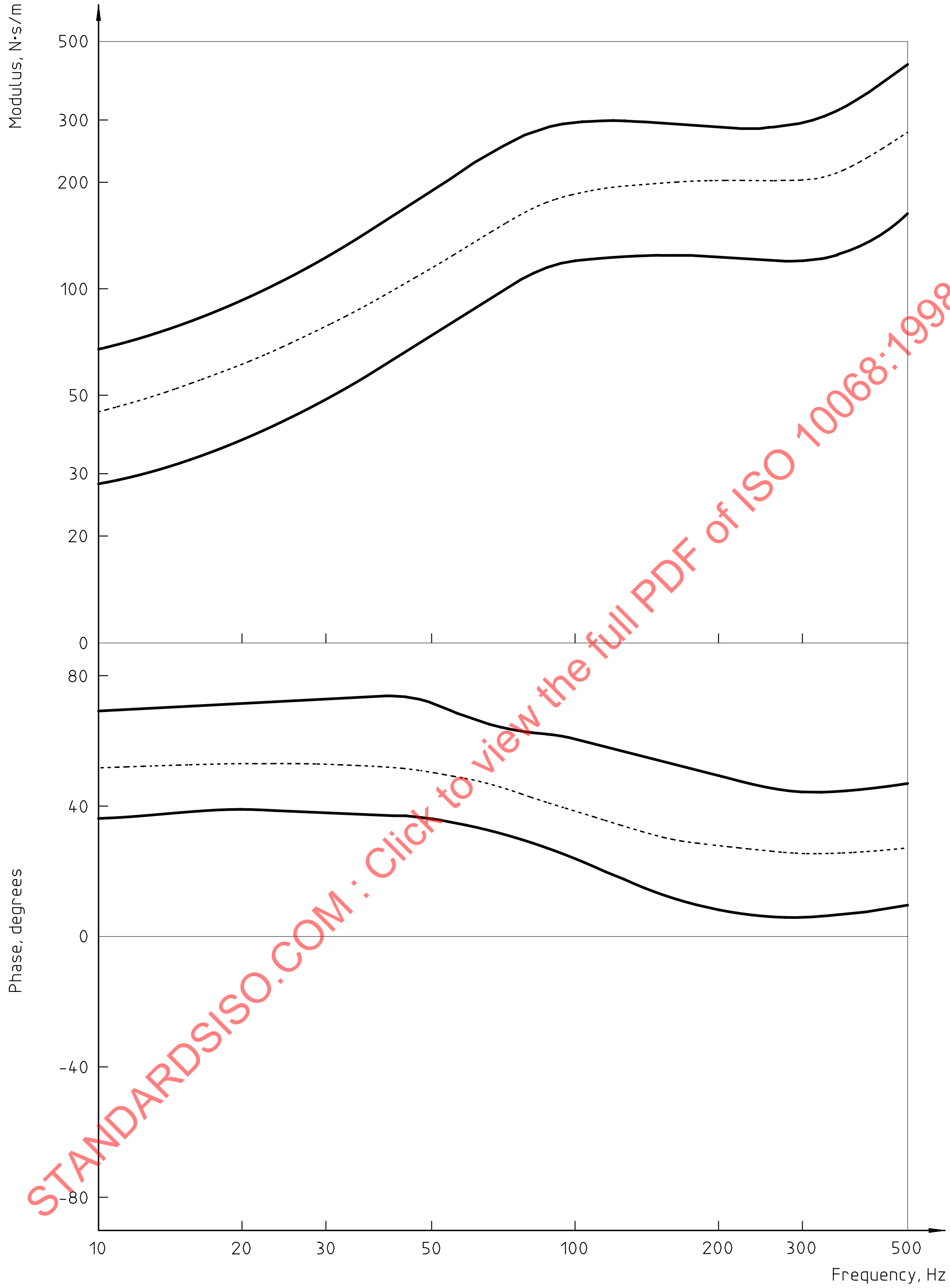
Frequency Hz	Modulus N·s/m				Phase degrees			
	Lower limit	Mean	Standard deviation	Upper limit	Lower limit	Mean	Standard deviation	Upper limit
10	24	38	13	59	36	53	14	68
15	33	50	12	69	38	53	8	70
20	36	64	14	84	38	54	8	71
25	43	72	19	104	38	57	12	72
30	49	81	22	120	38	55	12	73
35	55	88	25	137	37	53	12	73
40	62	95	28	154	37	53	10	73
45	68	104	29	171	37	52	10	72
50	74	112	31	189	36	51	10	70
60	86	132	38	223	34	50	10	67
70	98	153	46	255	32	46	10	64
80	109	172	54	280	29	43	11	63
90	115	186	54	291	26	40	11	62
100	120	199	56	300	23	37	11	60
125	124	211	58	302	18	31	10	57
150	124	219	61	297	13	27	11	54
175	122	217	59	291	10	25	14	50
200	120	208	50	287	7	23	14	48
250	119	189	44	287	6	24	13	45
300	119	187	54	297	6	25	13	44
350	124	203	51	321	6	25	13	44
400	134	224	55	360	8	26	12	45
450	150	265	90	405	9	27	12	46
500	168	292	111	442	10	29	12	47

Table 2 — Values of the free, mechanical impedance of the hand-arm system at the driving point in the y_h direction

Frequency Hz	Modulus N·s/m				Phase degrees			
	Lower limit	Mean	Standard deviation	Upper limit	Lower limit	Mean	Standard deviation	Upper limit
10	21	55	28	80	20	39	12	55
15	26	62	23	105	11	32	17	52
20	30	86	27	119	6	31	15	49
25	35	96	34	128	1	23	15	44
30	39	101	36	132	− 3	15	15	39
35	43	103	33	134	− 7	11	15	35
40	48	102	29	135	− 12	7	15	30
45	51	102	26	133	− 15	3	13	26
50	55	101	23	130	− 18	− 1	12	22
60	60	93	16	119	− 21	− 4	11	17
70	63	89	14	110	− 22	− 5	10	13
80	64	86	12	106	− 23	− 5	10	10
90	64	86	13	106	− 24	− 7	11	9
100	63	86	15	106	− 23	− 9	11	7
125	60	80	16	106	− 22	− 11	10	6
150	55	76	17	107	− 20	− 10	7	6
175	51	73	18	107	− 17	− 8	7	7
200	49	71	20	108	− 16	− 6	7	9
250	45	67	23	110	− 11	0	7	17
300	44	66	24	113	− 8	7	12	27
350	46	69	22	115	− 5	12	14	37
400	51	71	19	118	− 4	16	15	45
450	58	75	19	125	− 2	20	18	52
500	66	79	20	134	1	22	20	56

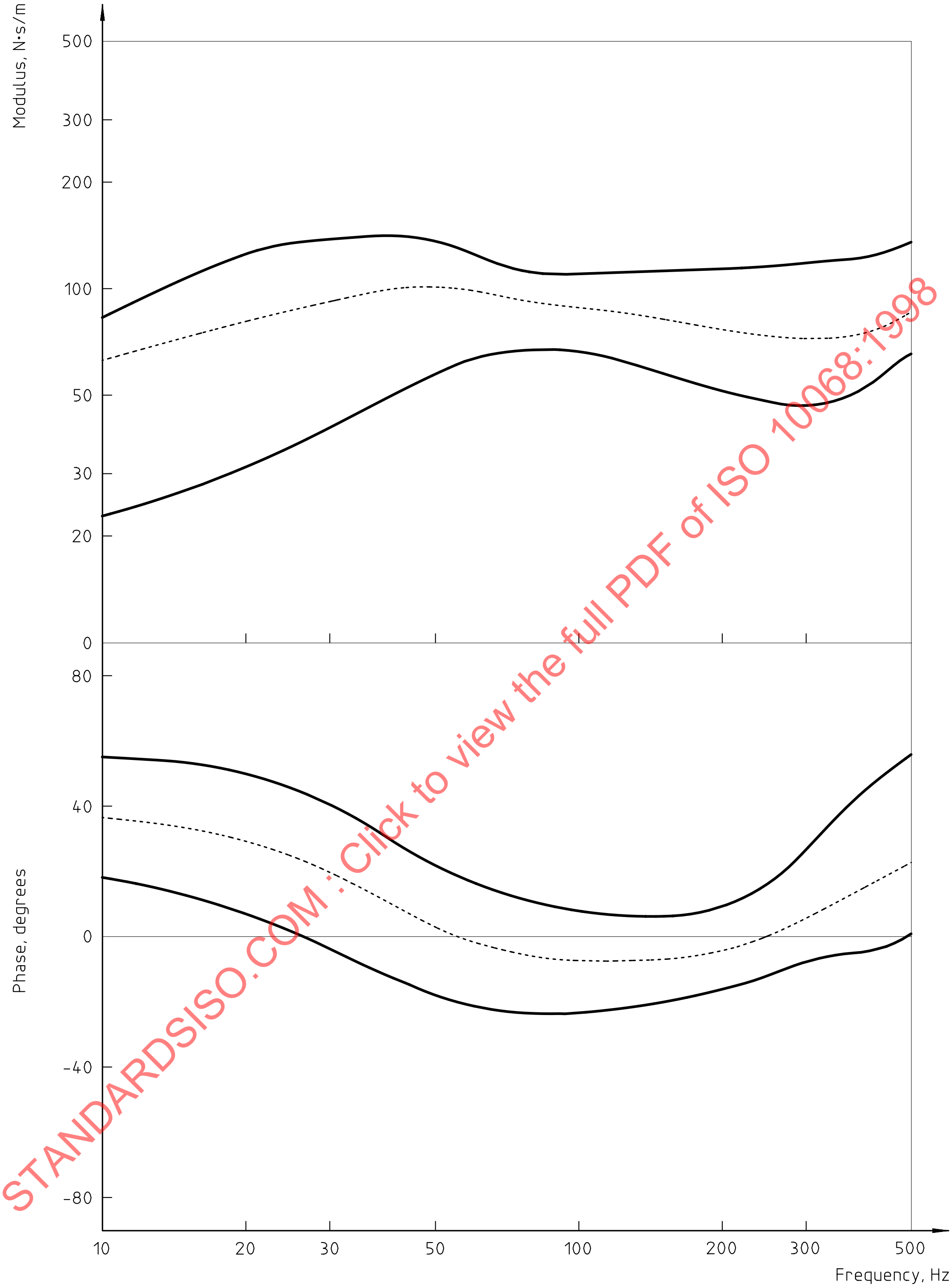
Table 3 — Values of the free, mechanical impedance of the hand-arm system at the driving point in the z_h direction

Frequency Hz	Modulus N·s/m				Phase degrees			
	Lower limit	Mean	Standard deviation	Upper limit	Lower limit	Mean	Standard deviation	Upper limit
10	100	153	34	200	15	30	10	44
15	107	175	60	235	2	25	12	41
20	112	190	70	260	− 4	19	22	38
25	116	200	70	275	− 11	15	22	34
30	120	212	75	295	− 16	10	18	31
35	122	219	79	304	− 21	5	16	28
40	125	220	80	305	− 26	1	16	27
45	126	215	72	299	− 30	− 1	17	25
50	126	207	61	288	− 33	− 4	18	25
60	123	186	40	257	− 38	− 6	23	25
70	117	169	28	230	− 37	− 5	24	26
80	109	160	30	219	− 31	− 3	22	28
90	106	160	37	219	− 26	0	19	29
100	105	160	47	227	− 21	2	15	30
125	110	175	65	257	− 10	8	11	31
150	117	181	85	288	− 2	13	10	31
175	124	190	89	310	2	16	8	31
200	130	200	84	325	6	18	7	32
250	146	216	65	345	8	19	5	33
300	157	229	68	353	7	20	7	35
350	163	238	67	359	6	20	12	39
400	169	246	63	365	5	20	14	43
450	175	255	63	370	6	21	13	47
500	183	265	64	377	7	23	13	49



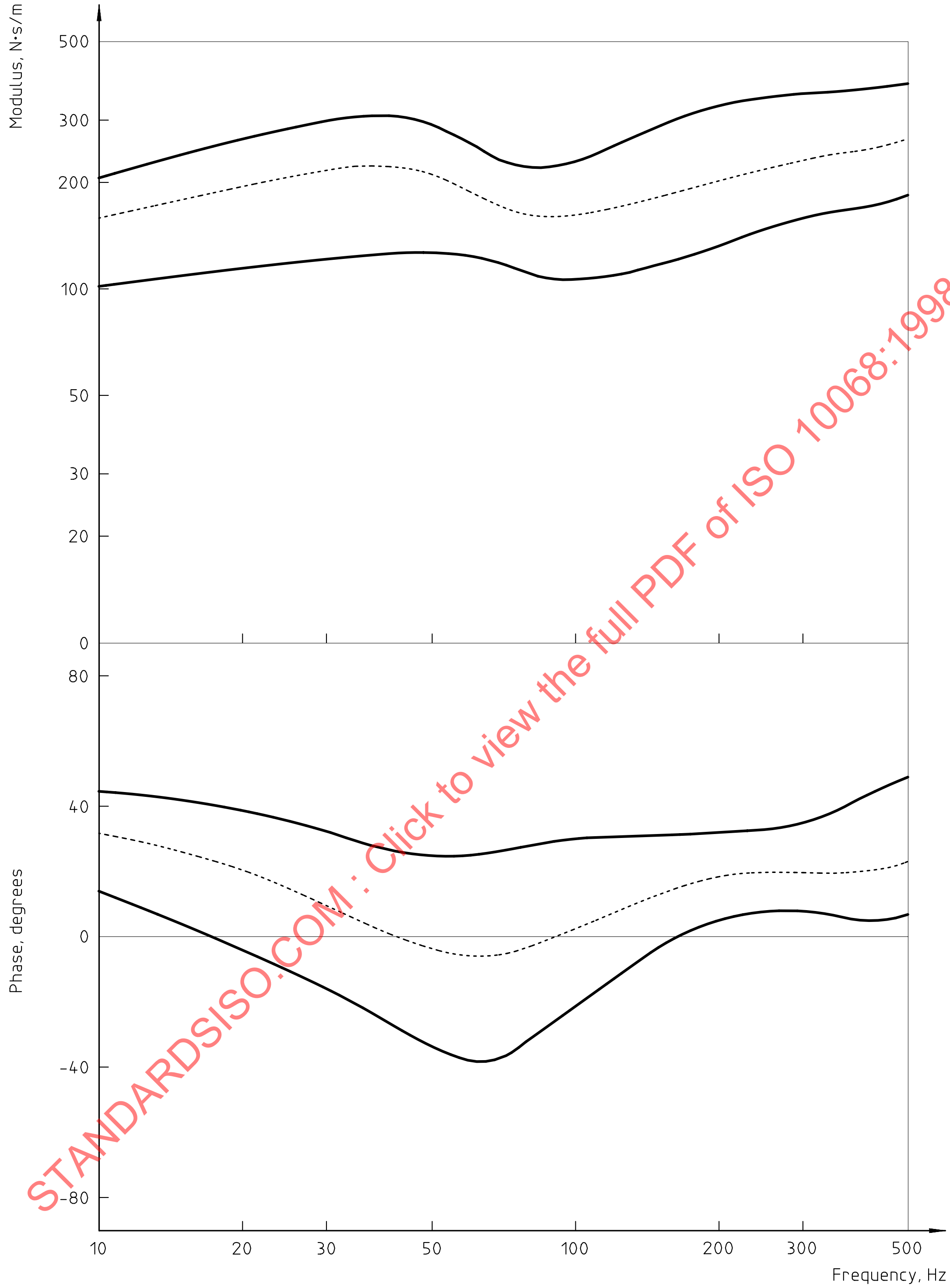
NOTE For an explanation of the lines, see clause 4.

Figure 1 — Values of the free, mechanical impedance of the hand-arm system at the driving point in the x_h direction



NOTE For an explanation of the lines, see clause 4.

Figure 2 — Values of the free, mechanical impedance of the hand-arm system at the driving point in the y_h direction



NOTE For an explanation of the lines, see clause 4.

Figure 3 — Values of the free, mechanical impedance of the hand-arm system at the driving point in the z_h direction

5 Applicability of values of impedance

The values of free impedance are applicable to human males under the following conditions, all of which shall be met. The limits of applicability approximately correspond to the range of measurement conditions over which data were obtained.

a) The position of the arm relative to the torso falls within the ranges defined in figure 4.

b) The wrist is in the neutral position, that is, the position involving no flexion or extension (tolerance ±15°), as shown in figure 5.

c) The hand grasps a handle which is between 19 mm and 45 mm in diameter. The values of free impedance are applicable to handles with non-circular cross-sections, provided that the largest and smallest cross-section dimensions are between 19 mm and 45 mm.

d) The hand grip force is between 25 N and 50 N. The feed force applied by the hand is not greater than 50 N.

NOTE 1 The impedance values are mainly based on data obtained from the right hand, and may be provisionally applied to the left hand.

NOTE 2 The impedance values may be provisionally applied to females. Research has shown the modulus of impedance for females to be up to 20 % less than the corresponding value for males.

NOTE 3 An increase in grip force has been reported to result in an increase in impedance modulus, especially at frequencies in excess of about 50 Hz.

NOTE 4 The impedance modulus and phase do not appear to be substantially influenced by feed force at frequencies above 100 Hz. An increase in impedance modulus with increased feed force has been reported at lower frequencies. The values may be expected to change by less than 10 % for feed forces of up to 150 N.

NOTE 5 The impedance may be influenced by the magnitude of the acceleration of the handle. The values in this International Standard are believed to be applicable to accelerations of up to 50 m/s^2.

6 Applications

6.1 Evaluation of the transmissibility of resilient materials when loaded by the hand-arm system

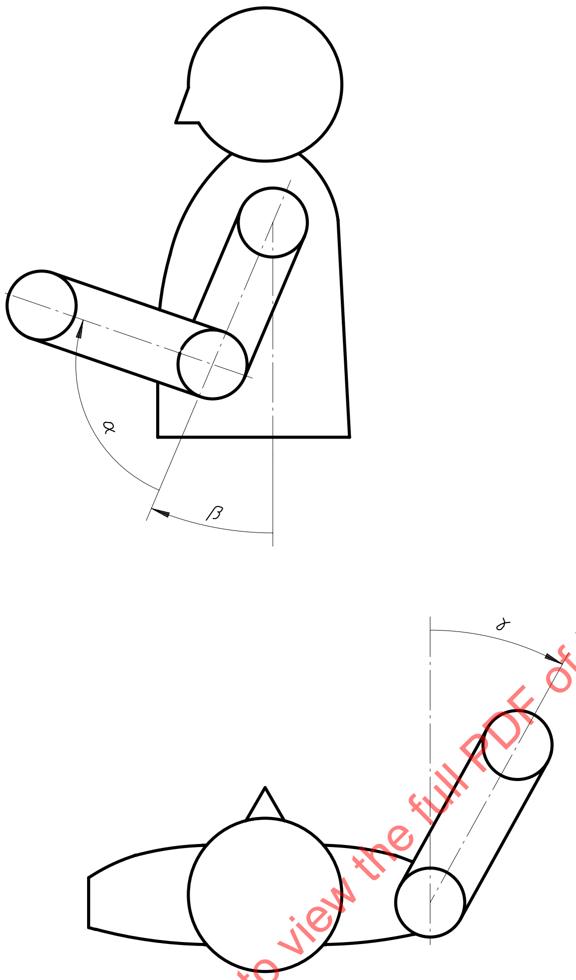
Reference values for the x_h and z_h components of the free, mechanical impedance at the driving point are given in annex A as a function of frequency for a grip force of 30 N, a feed force of 50 N, and an elbow angle of 90°. These impedance values are provided for evaluating the transmissibility of resilient materials, when loaded by the hand-arm system (details are given in ISO 13753).

6.2 Models of the hand-arm system

Models of the hand-arm system that comply with the provisions of this International Standard are provided in annexes C to E. The models possess varying degrees of complexity. These annexes are provided to facilitate mathematical modelling, and the construction of mechanical analogues of the hand-arm system for use in test rigs.

6.3 Estimation of power absorbed in the hand-arm system

The mechanical power transmitted to the hand when grasping a vibrating object may be calculated from a knowledge of the source internal impedance and motion, and the free, mechanical impedance of the hand-arm system at the driving point. If calculations use the impedance values in this International Standard, then the value calculated will represent only an approximate estimate of the power transmitted to the hand-arm system, even for postures satisfying the requirements of clause 5.



$15° < \alpha < 120°$; $-15° < \beta < 75°$; $-15° < \gamma < 15°$; $\alpha + \beta < 120°$

NOTE Angles are positive in sign when measured in a clockwise direction.

Figure 4 — Ranges of allowable arm positions

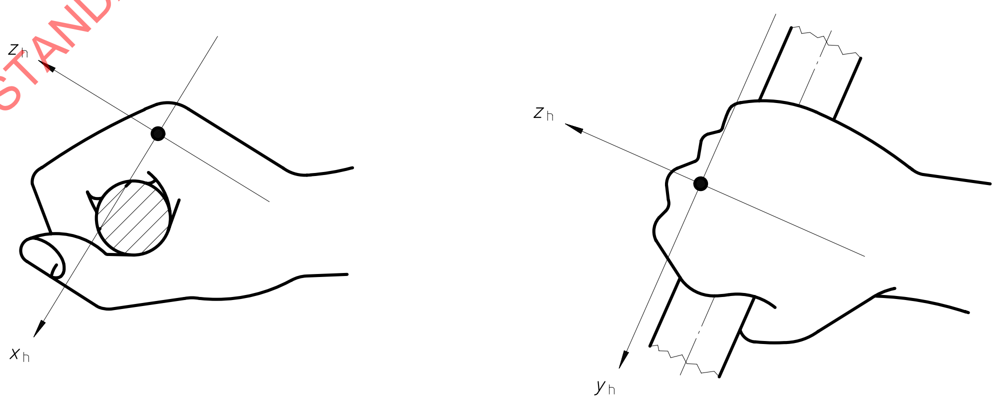


Figure 5 — Wrist position

Annex A
(normative)

Reference values for the x_h and z_h components of the free, mechanical impedance of the hand-arm system at the driving point

Reference values for the x_h and z_h components of the free, mechanical impedance are given in table A.1 as a function of frequency, from 10 Hz to 500 Hz. The values have been derived from impedance measurements conducted on human male subjects, and are intended for evaluating the transmissibility of resilient materials, when loaded by the hand-arm system (details are given in ISO 13753). Linear interpolation is permitted to obtain impedance values at frequencies other than those listed in table A.1.

The reference values of free impedance are applicable to human males under the following conditions, all of which shall be met.

a) The elbow angle is 90° (tolerance ±15°), so that the position of the arm relative to the torso falls within the ranges defined in figure 4, when:

$75° < \alpha < 105°$; $-15° < \beta < 15°$; $-15° < \gamma < 15°$

b) The wrist is in the neutral position (tolerance ±15°), as shown in figure 5.

c) The hand grasps a handle which is between 19 mm and 45 mm in diameter. The reference values are applicable to handles with non-circular cross-sections, provided the largest and smallest cross-section dimensions are between 19 mm and 45 mm.

d) The grip force is 30 N ± 5 N and the feed force is 50 N ± 8 N.

NOTE Hand-arm impedance may be influenced by the magnitude of the acceleration of the surface in contact with the hand.

Table A.1 — Reference values of the free, mechanical impedance of the hand-arm system at the driving point in the x_h and z_h directions, at one-third-octave band centre frequencies

Frequency	x_h direction		z_h direction	
	Modulus	Phase	Modulus	Phase
Hz	N·s/m	degrees	N·s/m	degrees
10	40	53	156	30
12,5	51	53	170	28
16	57	53	185	24
20	67	54	198	19
25	76	57	210	15
31,5	87	53	225	8
40	98	53	228	1
50	114	51	210	− 4
63	140	47	181	− 6
80	173	43	161	− 3
100	204	37	165	2
125	216	31	180	8
160	215	29	190	14
200	213	23	205	18
250	194	24	221	19
315	208	25	236	20
400	229	26	251	20
500	297	29	270	23

Annex B
(informative)

Tabulation of hand-arm impedance values at one-third-octave band centre frequencies

For explanations of the terms “Lower limit”, “Mean”, and “Upper limit”, see clause 4.

Table B.1 — Values of the free, mechanical impedance of the hand-arm system at the driving point in the x_h direction, at one-third-octave band centre frequencies

Frequency Hz	Modulus N·s/m			Phase degrees		
	Lower limit	Mean	Upper limit	Lower limit	Mean	Upper limit
10	24	38	59	36	53	68
12,5	30	49	71	38	53	69
16	33	54	80	38	53	70
20	36	64	84	38	54	71
25	43	72	104	38	57	72
31,5	51	80	125	38	53	73
40	62	95	154	37	53	73
50	74	112	189	36	51	70
63	90	140	233	33	47	66
80	109	172	280	29	43	63
100	120	199	300	23	37	60
125	124	211	302	18	31	57
160	123	210	294	11	29	52
200	120	208	287	7	23	48
250	119	189	287	6	24	45
315	120	207	302	6	25	44
400	134	224	360	8	26	45
500	168	292	442	10	29	47

Table B.2 — Values of the free, mechanical impedance of the hand-arm system at the driving point in the y_h direction, at one-third-octave band centre frequencies

Frequency Hz	Modulus N·s/m			Phase degrees		
	Lower limit	Mean	Upper limit	Lower limit	Mean	Upper limit
10	21	55	80	20	39	55
12,5	23	62	90	15	35	54
16	26	70	106	11	32	52
20	30	86	119	6	31	49
25	35	96	128	1	23	44
31,5	40	88	132	− 6	18	39
40	48	102	135	− 12	7	30
50	55	101	130	− 18	− 1	22
63	61	93	117	− 22	− 2	16
80	64	86	106	− 23	− 5	10
100	63	86	106	− 23	− 9	7
125	60	80	106	− 22	− 11	6
160	54	77	107	− 19	− 7	7
200	49	71	108	− 16	− 6	9
250	45	67	110	− 11	0	17
315	45	69	113	− 7	8	30
400	51	71	118	− 4	16	45
500	66	79	134	1	22	56

Table B.3 — Values of the free, mechanical impedance of the hand-arm system at the driving point in the z_h direction, at one-third-octave band centre frequencies

Frequency Hz	Modulus N·s/m			Phase degrees		
	Lower limit	Mean	Upper limit	Lower limit	Mean	Upper limit
10	100	153	200	15	30	44
12,5	104	165	220	10	28	42
16	108	180	241	2	24	40
20	112	190	260	− 4	19	38
25	116	200	275	− 11	15	34
31,5	121	215	297	− 18	8	30
40	125	220	305	− 26	1	27
50	126	207	288	− 33	− 4	25
63	122	181	247	− 38	− 6	25
80	109	160	219	− 31	− 3	28
100	105	160	227	− 21	2	30
125	110	175	257	− 10	8	31
160	120	185	298	0	14	31
200	130	200	325	6	18	32
250	146	216	345	8	19	33
315	160	231	355	7	20	36
400	169	246	365	5	20	43
500	183	265	377	7	23	49

Annex C
(informative)

Model 1

This model employs the same general configuration for each of the three directions (figure C.1). Different values of model parameters, listed in table C.1, are used for each direction to obtain the values of impedance shown in figures C.2 to C.4.

In this three-degrees-of-freedom model, masses, springs and dampers do not correspond to physiological structures within the hand-arm system. Smaller model masses occur closer to the point of introduction of motion to the model (F in figure C.1), which is taken to be at the hand.

Table C.1 — Values for model parameters

Parameter	Unit	Direction of vibration		
		x_h	y_h	z_h
m_1	kg	0,026 7	0,008 6	0,029 9
m_2	kg	0,486	0,356 5	0,662 3
m_3	kg	3,095 2	3,246 2	2,902 3
k_1	N/m	4 368	$2,709 \times 10^4$	5 335
k_2	N/m	132,0	300,0	$2,994 \times 10^5$
k_3	N/m	1 565	6 415	2 495
c_1	N·s/m	207,5	68,00	227,5
c_2	N·s/m	18,93	51,75	380,6
c_3	N·s/m	9,10	30,78	30,30

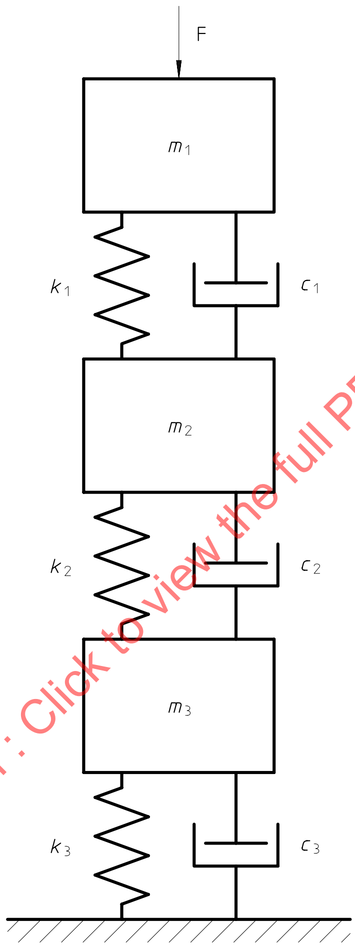
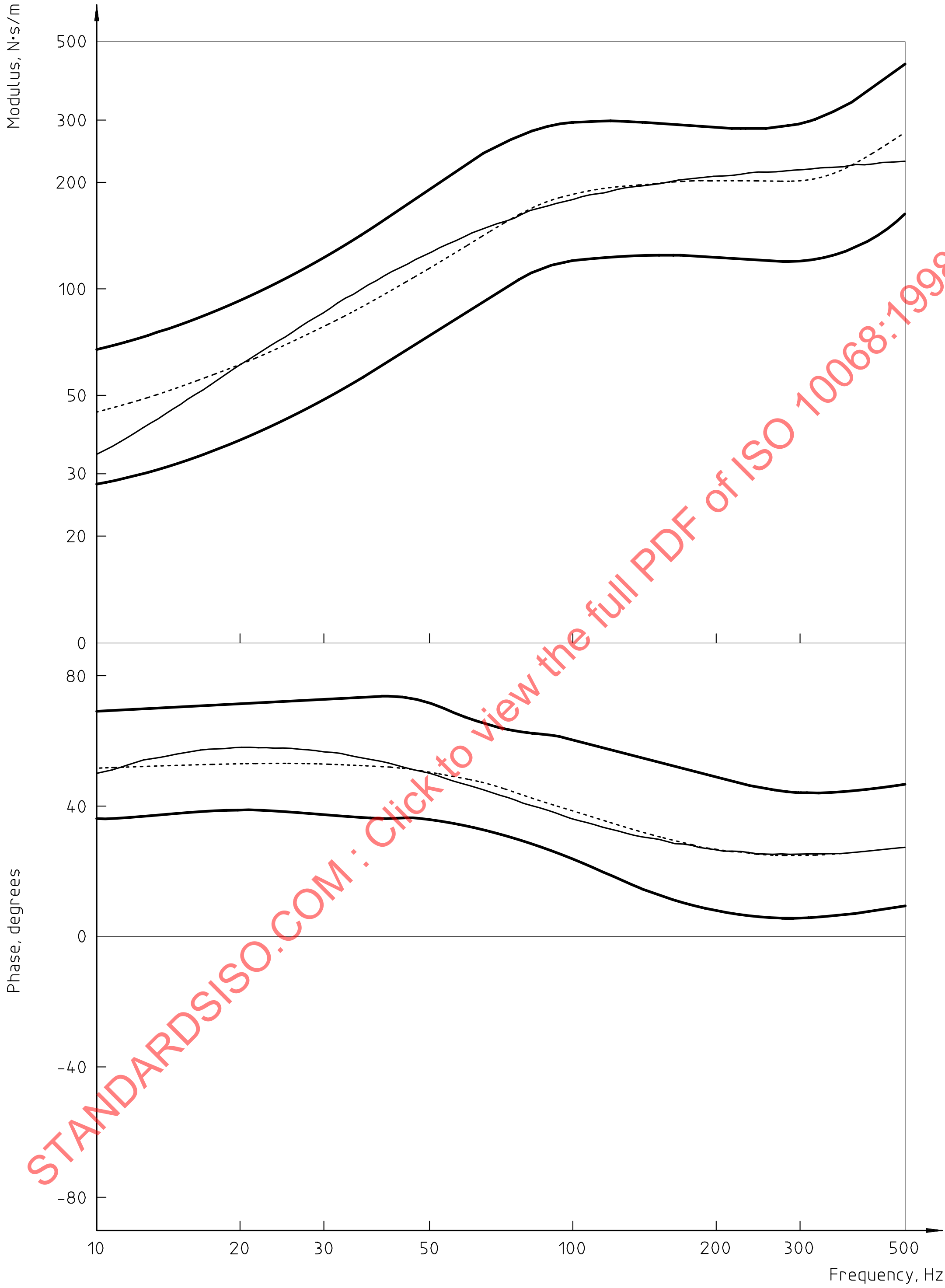
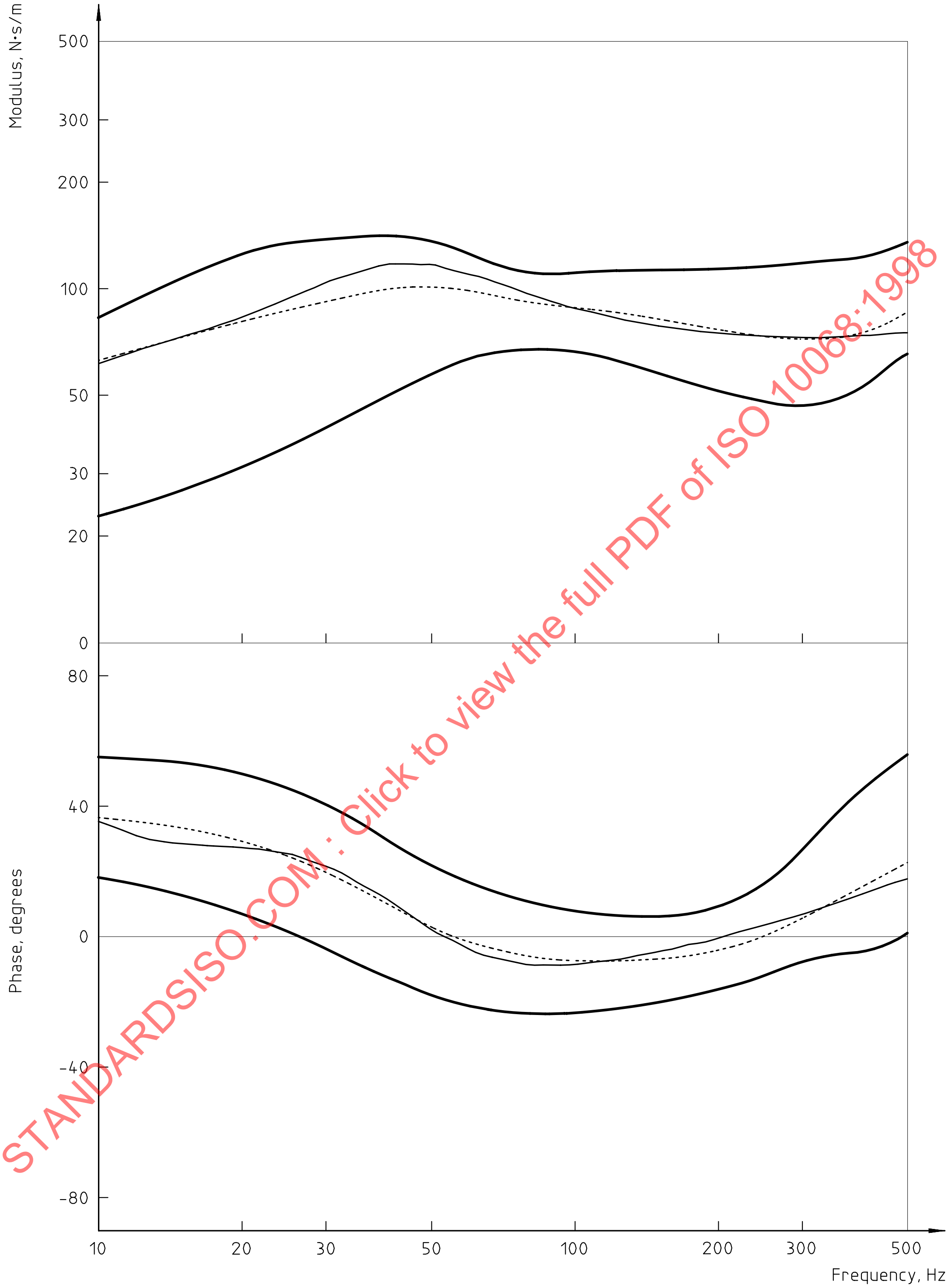


Figure C.1 — Model for the free impedance of the human hand-arm system



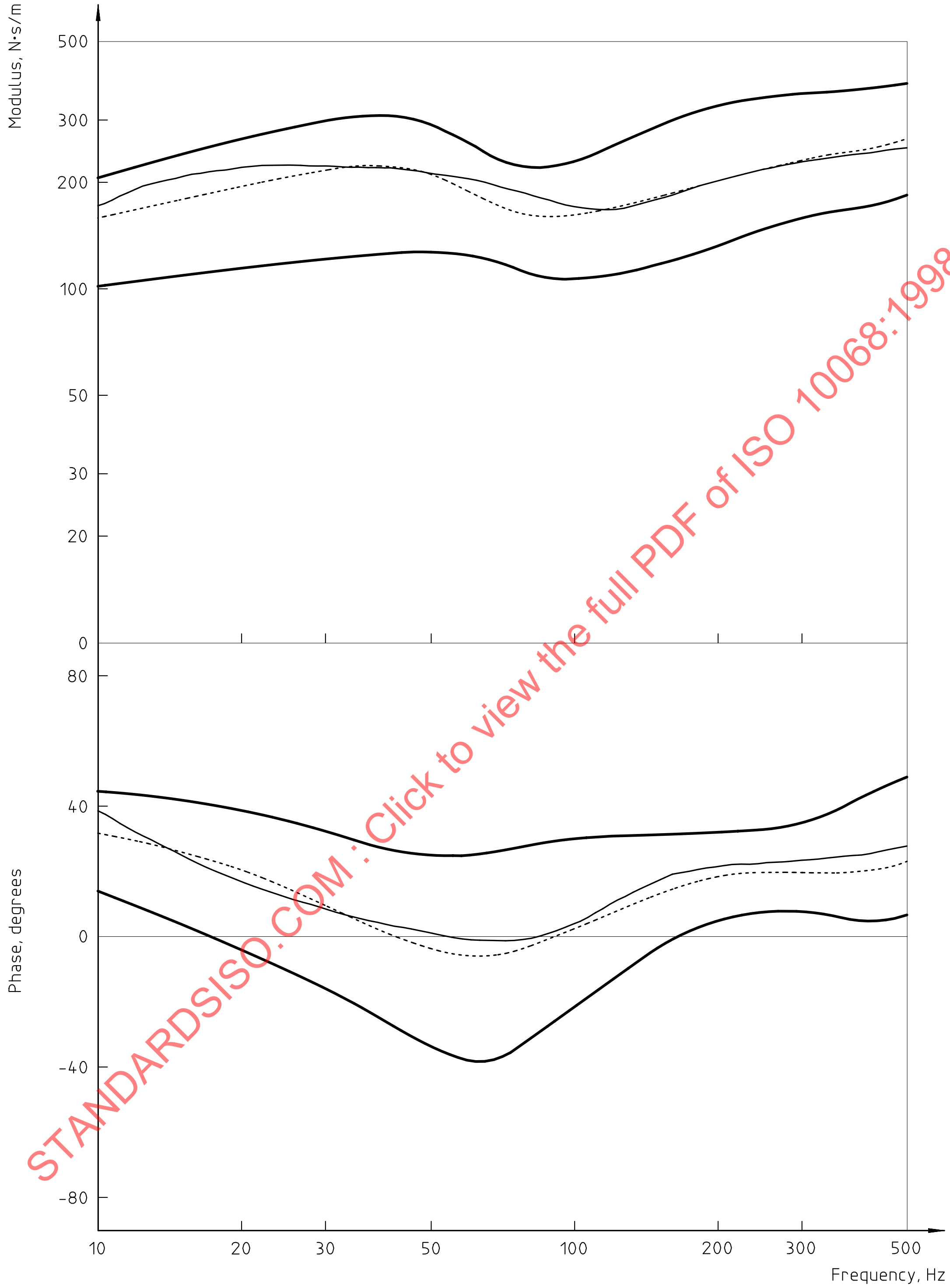
NOTE For an explanation of the lines, see clause 4.

Figure C.2 — Comparison between model (fine line) and values of the free impedance of the human hand-arm system in the x_h direction



NOTE For an explanation of the lines, see clause 4.

Figure C.3 — Comparison between model (fine line) and values of the free impedance of the human hand-arm system in the y_h direction



NOTE For an explanation of the lines, see clause 4.

Figure C.4 — Comparison between model (fine line) and values of the free impedance of the human hand-arm system in the z_h direction

Annex D
(informative)

Model 2

This model employs the same general configuration for each of the three directions (figure D.1). Different values of model parameters, listed in table D.1, are used for each direction to obtain the values of impedance shown in figures D.2 to D.4.

In this four-degrees-of-freedom model, which is a further development of the type of model in annex C, masses, springs and dampers do not correspond to physiological structures within the hand-arm system. Smaller model masses occur closer to the point of introduction of motion to the model (F in figure D.1), which is taken to be at the hand.

Table D.1 — Values for model parameters

Parameter	Unit	Direction of vibration		
		x_h	y_h	z_h
m_1	kg	$4,30 \times 10^{-3}$	$9,10 \times 10^{-3}$	$1,90 \times 10^{-2}$
m_2	kg	$1,05 \times 10^{-1}$	$5,44 \times 10^{-2}$	$9,47 \times 10^{-2}$
m_3	kg	$5,66 \times 10^{-1}$	1,42	$6,55 \times 10^{-1}$
m_4	kg	4,304	3,62	4,29
k_1	N/m	$8,88 \times 10^{4}$	6 50	$3,00 \times 10^{5}$
k_2	N/m	$1,50 \times 10^{3}$	$1,93 \times 10^{5}$	$6,80 \times 10^{4}$
k_3	N/m	100	650	199
k_4	N/m	$3,99 \times 10^{3}$	$1,00 \times 10^{3}$	$2,04 \times 10^{3}$
c_1	N·s/m	678	115	591
c_2	N·s/m	185	147	203
c_3	N·s/m	23,9	8,00	199
c_4	N·s/m	34,9	$1,00 \times 10^{3}$	239

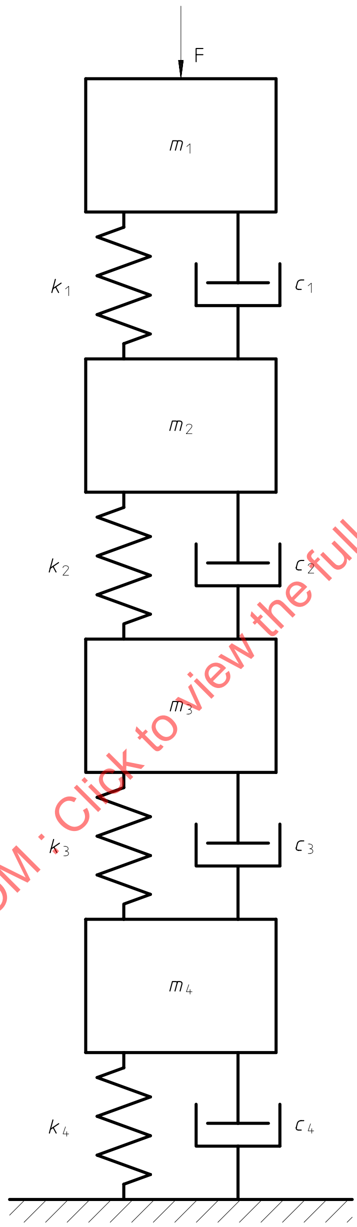
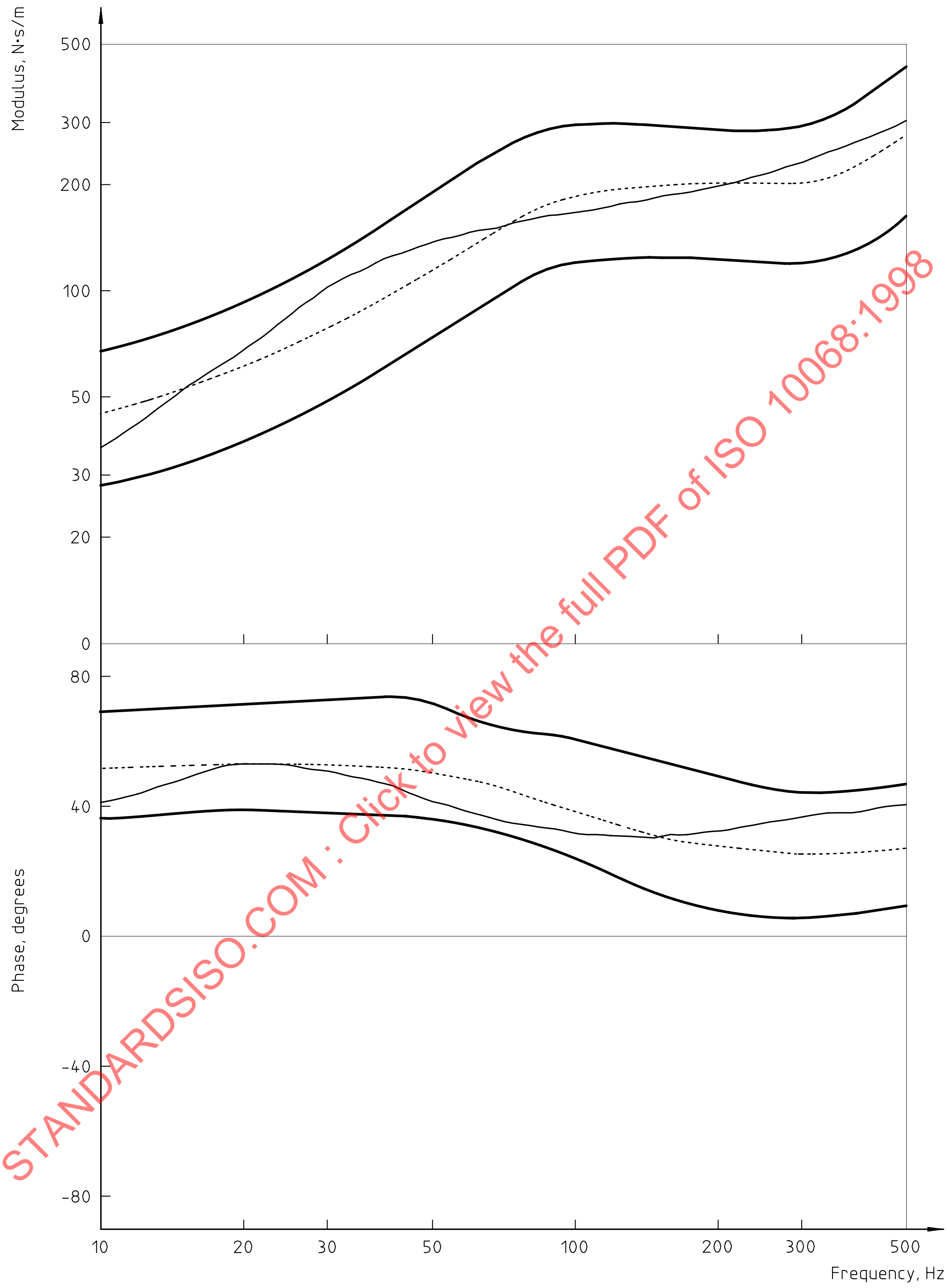
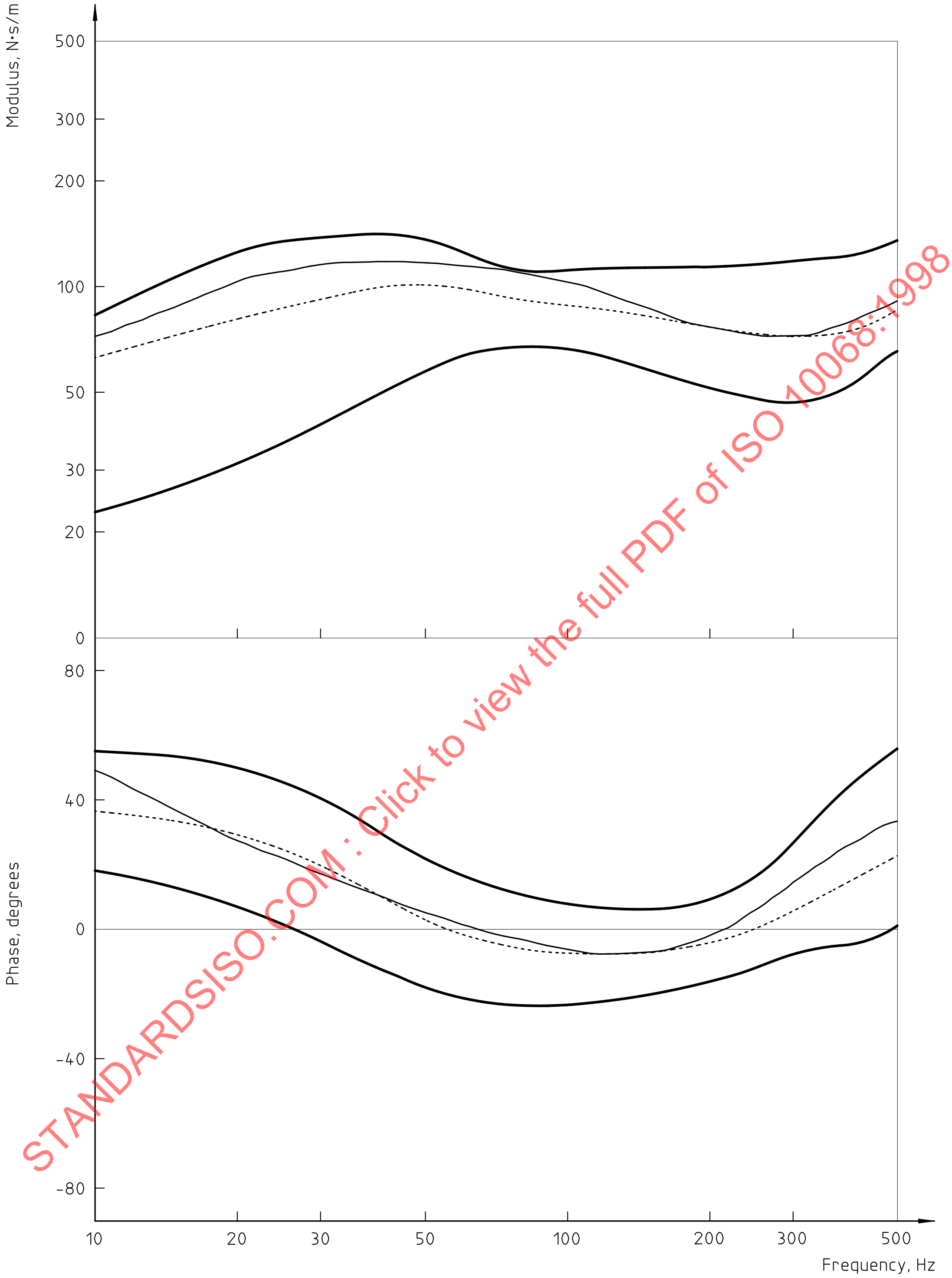


Figure D.1 — Model for the free impedance of the human hand-arm system



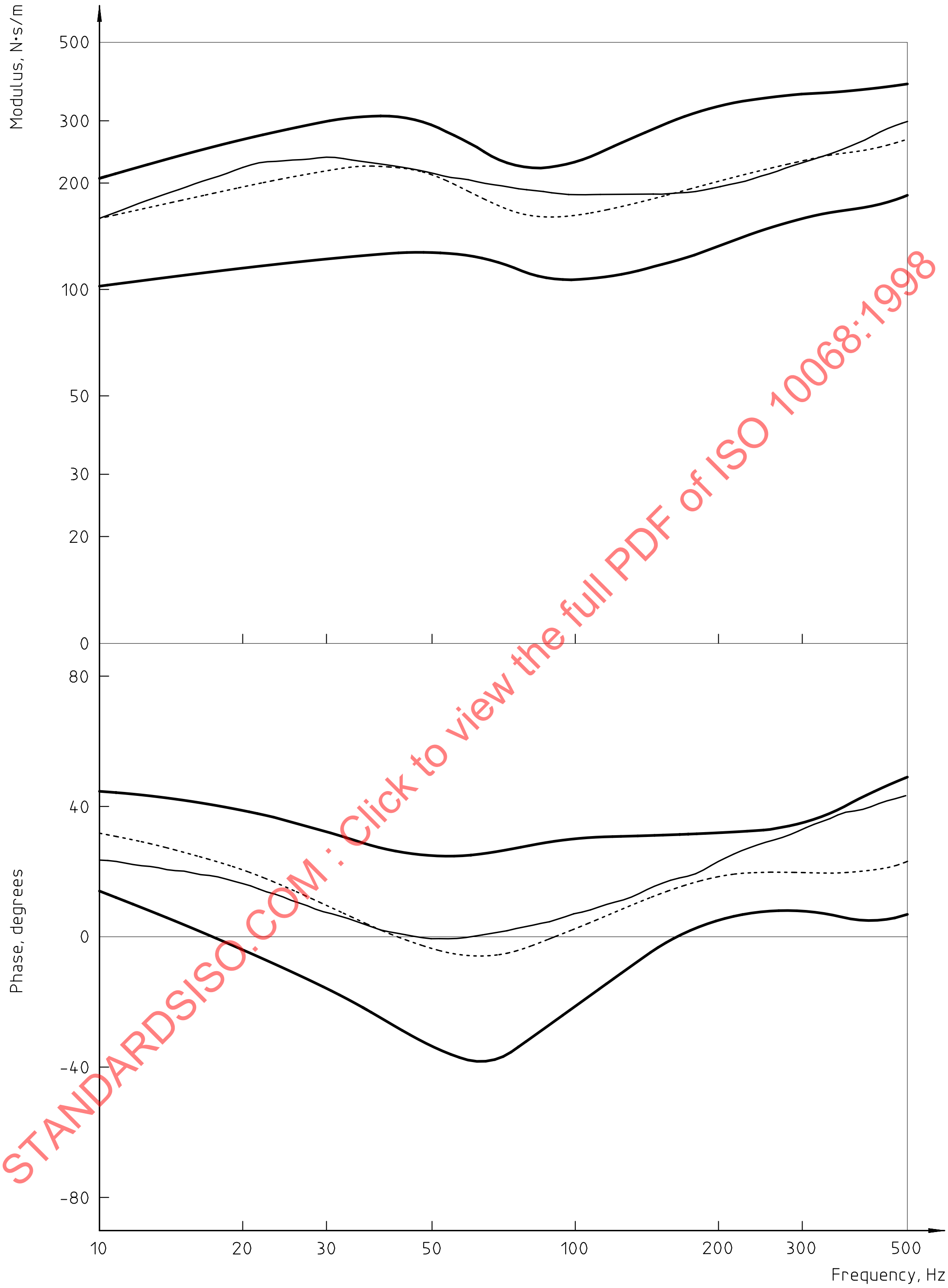
NOTE For an explanation of the lines, see clause 4.

Figure D.2 — Comparison between model (fine line) and values of the free impedance of the human hand-arm system in the x_h direction



NOTE For an explanation of the lines, see clause 4.

Figure D.3 — Comparison between model (fine line) and values of the free impedance of the human hand-arm system in the y_h direction



NOTE For an explanation of the lines, see clause 4.

Figure D.4 — Comparison between model (fine line) and values of the free impedance of the human hand-arm system in the z_h direction

Annex E
(informative)

Model 3

This model employs the same general configuration for each of the three directions (figure E.1). Different values of model parameters, listed in table E.1, are used for each direction to obtain the values of impedance shown in figures E.2 to E.4.

Masses, lever arms, springs and dampers do not correspond to physiological structures within the hand-arm system.

NOTE When adjusting the model parameters to correspond to the values of the modulus of hand-arm impedance, the phase received limited consideration.

Table E.1 — Values for model parameters

Parameter	Unit	Direction of vibration		
		x_h	y_h	z_h
m	kg	2,378	5,767	5,316
r	m	0,061 3	0,038 6	0,043 1
l_1	m	0,191 8	0,383 8	0,258 3
l_2	m	− 0,487 8	− 0,475 5	$3,301 \times 10^{-3}$
l_3	m	− 0,285 7	− 0,461 5	− 0,139 5
k_1*	N/m	$1,114 \times 10^{6}$	$0,289\,4 \times 10^{6}$	$2,773 \times 10^{9}$
k_2*	N/m	$2,161 \times 10^{-6}$	$24,98 \times 10^{-9}$	$51,50 \times 10^{-9}$
k_3*	N/m	$4,715 \times 10^{6}$	$72,07 \times 10^{6}$	$6,207 \times 10^{6}$
k_1	N/m	$0,506\,9 \times 10^{-6}$	$24,98 \times 10^{-9}$	$50,16 \times 10^{3}$
k_2	N/m	$0,307\,9 \times 10^{6}$	$1,636 \times 10^{6}$	4 185
k_3	N/m	$0,483\,4 \times 10^{-6}$	$51,50 \times 10^{-9}$	$89,73 \times 10^{-3}$
c_1	N·s/m	485,6	140,9	107,0
c_2	N·s/m	$51,50 \times 10^{-9}$	$24,98 \times 10^{-9}$	$0,645\,0 \times 10^{-3}$
c_3	N·s/m	$18,97 \times 10^{3}$	7 234	257,7