MECHANIKA
CZASOPISMO TECHNICZNE
TECHNICAL TRANSACTIONS
MECHANICS
WYDAWNICTWO POLITECHNIKI KRAKOWSKIEJ
1-M/2011
ZESZYT 2
ROK 108
ISSUE 2
YEAR 108

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IMPEDANCES AND APPARENT MASSES OF ACTIVE HUMAN BODY MODELS–SEAT SYSTEMS

IMPEDANCJE I MASY WIRTUALNE UKŁADU SIEDZISKO–AKTYWNY MODEL CIAŁA CZŁOWIEKA

A b s t r a c t

In the paper the driving point impedances and apparent masses of two active human seated body models in posture back-off and back-on were calculated. It was shown what are the mutual relations between the impedances and transfer functions of the seated human body models obtained from the experimental measurements and theoretical modeling. The influence of impedances of passive seats on total impedances and apparent masses of human body–seat systems was numerically calculated. The graphically shown comparison of the analytical expressions of the impedances and apparent masses of the considered models were presented.

Keywords: *human body models–seat systems, impedances, apparent masses*

S t r e s z c z e n i e

W artykule przedstawiono impedancje mechaniczne oraz masy wirtualne dwóch aktywnych modeli człowieka siedzącego w pozycjach z oparciem i bez oparcia. Impedancje i odpowiadające im masy wirtualne porównano z całkowitymi impedancjami i masami wirtualnymi obliczonymi dla układu siedzisko–człowiek dla siedziska sztywnego i siedziska biernego stanowiącego układ Kelvina-Voigta. Pokazano również zależności analityczne pomiędzy impedancjami a funkcjami przejścia rozważanego układu. Wpływ struktury i parametrów siedziska na całkowitą impedancję i masę wirtualną układu człowiek–siedzisko został przedstawiony za pomocą odpowiednich wzorów analitycznych oraz obliczeń numerycznych w postaci wykresów Bode.

Słowa kluczowe: *modele biomechaniczne ciała człowieka, impedancja mechaniczna, masa wirtualna układu człowiek–siedzisko*

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1. Introduction

At the present time the notions of impedance and apparent mass are applied very frequently in analysis of human body vibration [3–5, 7–9, 21–23, 29]. These notions are very useful in theoretical and experimental investigations of the dynamic properties of human body–seat systems.

The active models of seated human operator body used in the presented paper were obtained for the first time in [11] and then in [12, 13]. In the bibliography they were the first active models of the seated human body for two back-off and back-on posture, with the same external frame structure of 2DOF. The active models of the seated human body used in the paper have been also several times shown in the different configurations and applications in [14–16]. In the presented paper the impedances and apparent masses of the models themselves and the impedances and apparent masses of the systems composed of these models and some chosen structures of seats were analytically and numerically calculated. Such approach allows easier estimation of influence of different structures of seat systems on quality of potential suspensions.

2. Models of active human body back-off and back-on positions

2.1. Models description

The two active biomechanical models (AHBM) of the sitting human-body were synthesized [11] from two mathematical transmissibility functions, for “back-off” and “back-on” positions, identified on the basis of experimental data. The common structure of the active biomechanical (“back-off” and “back-on”) models is shown in Fig. 1. Corresponding numerical parameters of AHBM are given after [17] in Table 1.

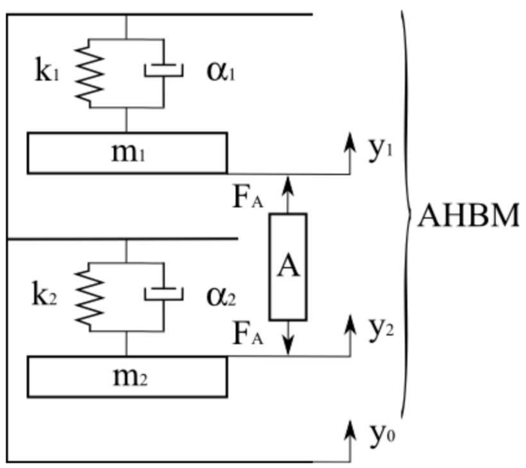

Fig. 1. Positions back-off and back-on of sitting human body

Rys. 1. Pozycje człowieka siedzącego bez oparcia i z oparciem

Table 1

Parameters of back-off and back-on models

Model parameters	"back-off" (z = 3, p = 4), $m_1 + m_2$ = 70.8 [kg]	Model parameters	"back-on" (z = 3, p = 4), $m_1 + m_2$ = 70.8 [kg]
m_1 [kg]	9.1	m_1 [kg]	66
k_1 [N/m]	11972.5557	k_1 [N/m]	51189.32
α_1 [Ns/m]	3251.9783	α_1 [Ns/m]	1704.17
m_2 [kg]	61.7	m_2 [kg]	4.8
k_2 [N/m]	22456.7485	k_2 [N/m]	63335.50
α_2 [Ns/m]	519.0440	α_2 [Ns/m]	1262.59
k_{11} [N/m]	97323.2354	k_{11} [N/m]	123251.32
k_{12} [Ns/m]	–2226.0653	k_{12} [Ns/m]	–1781.04
k_{13} [N/m]	–1960.5176	k_{13} [N/m]	–104227.69
k_{14} [Ns/m]	1164.3525	k_{14} [Ns/m]	759.69

The control forces for back-off and back-on models are correspondingly expressed, after [13] and [17], by the formulae (1) and (2)

$$F_{\text{Aback-off}} = -k_{11}(y_1 - y_0) - k_{12}(\dot{y}_1 - \dot{y}_0) - k_{13}(y_2 + y_0) - k_{14}(\dot{y}_2 + \dot{y}_0) \tag{1}$$

$$F_{\text{Aback-on}} = -k_{11}(y_1 + y_0) - k_{12}(\dot{y}_1 - \dot{y}_0) - k_{13}(y_2 + y_0) - k_{14}(\dot{y}_2 - \dot{y}_0) \tag{2}$$

2.2. Relations between driving point impedance and transmissibility functions of the models

In [11–13] was shown that the general expression for the transmissibility function H1(s) for back-off and back-on models can be presented in the form (3), where $s = j\omega$.

$$H_1(s) = H_{\frac{y_1}{y_0}} = \frac{n_3 s^3 + n_2 s^2 + n_1 s + n_0}{d_4 s^4 + d_3 s^3 + d_2 s^2 + d_1 s + d_0} \tag{3}$$

Writing the differential equations of the models one can show that their driving point impedance may be expressed as follows.

$$Z(s) = \frac{F_T(s)}{\dot{y}_0(s)} = s\left\{ \begin{array}{l} m_1 H_1(s) + \\ + m_2 \dfrac{(m_1 s^2 + \alpha_1 s + k_1)H_1(s) - ((\alpha_1 + \alpha_2)s + (k_1 + k_2))}{-(m_2 s^2 + \alpha_2 s + k_2)} \end{array} \right\} \tag{4}$$

Substituting (3) into (4) we obtain

$$Z(s) = \frac{F_T(s)}{\dot{y}_0(s)} = s m_1 \frac{(n_3 s^3 + n_2 s^2 + n_1 s + n_0)(m_2 s^2 + \alpha_2 s + k_2)}{(d_4 s^4 + d_3 s^3 + d_2 s^2 + d_1 s + d_0)(m_2 s^2 + \alpha_2 s + k_2)} +$$

$$+ s m_2 \frac{-(m_1 s^2 + \alpha_1 s + k_1)(n_3 s^3 + n_2 s^2 + n_1 s + n_0) + ((\alpha_1 + \alpha_2)s + (k_1 + k_2))(d_4 s^4 + d_3 s^3 + d_2 s^2 + d_1 s + d_0)}{(m_2 s^2 + \alpha_2 s + k_2)(d_4 s^4 + d_3 s^3 + d_2 s^2 + d_1 s + d_0)} \tag{5}$$

The parameters n_i (i = 0, 1, 2, 3) and d_j (j = 0, 1, 2, 3, 4) in expression (5) are different for the models back-off and back-on. For back-off model with active force F_A given by (1) the parameters describing transmissibility function (3) take the form shown by (6) and (8).

$$\begin{aligned}
n_{13} &= m_2\alpha_1 + m_2 k_{12} - m_2 k_{14} \\
n_{12} &= \alpha_2 k_{12} - 2k_{14}\alpha_2 - \alpha_1 k_{14} + \alpha_1\alpha_2 + k_{11}m_2 + k_1 m_2 - k_{13}m_2 \\
n_{11} &= k_2 k_{12} - k_1 k_{14} - \alpha_1 k_{13} - 2k_{14}k_2 - 2k_{13}\alpha_2 + k_{11}\alpha_2 + \alpha_1 k_2 + k_1\alpha_2 \\
n_{10} &= -k_1 k_{13} + k_1 k_2 + k_{11}k_2 - 2k_{13}k_2
\end{aligned} \tag{6}$$

For back-on model the active force F_A takes the form shown in (2) and the corresponding parameters describing transfer function (3) are expressed by relations (7) and (8).

$$\begin{aligned}
n_{23} &= m_2(k_{14} + \alpha_1 + k_{12}) \\
n_{22} &= (-k_{14} + \alpha_2)(k_{14} + \alpha_1 + k_{12}) + m_2(k_1 - k_{13} - k_{11}) - (-k_{14} + \alpha_2 - k_{12})k_{14} \\
n_{21} &= (-k_{13} + k_2)(k_{14} + \alpha_1 + k_{12}) + (-k_{14} + \alpha_2)(k_1 - k_{13} - k_{11}) - (k_{11} + k_2 + k_{13})k_{14} + \\
&\quad - (-k_{14} + \alpha_2 - k_{12})k_{13} \\
n_{20} &= (-k_{13} + k_2)(k_1 - k_{13} - k_{11}) - (k_{11} + k_2 + k_{13})k_{13}
\end{aligned} \tag{7}$$

$$\begin{aligned}
d_4 &= m_1 m_2 \\
d_3 &= (\alpha_1 + k_{12})m_2 + m_1(-k_{14} + \alpha_2) \\
d_2 &= k_{12}k_{14} + (k_{11} + k_1)m_2 + (\alpha_1 + k_{12})(-k_{14} + \alpha_2) + m_1(-k_{13} + k_2) \\
d_1 &= k_{11}k_{14} + k_{12}k_{13} + (k_{11} + k_1)(-k_{14} + \alpha_2) + (\alpha_1 + k_{12})(-k_{13} + k_2) \\
d_0 &= (k_{11} + k_1)(-k_{13} + k_2) + k_{13}k_{11}
\end{aligned} \tag{8}$$

3. Impendances of HBM-SEAT models

In this paragraph the impedances and apparent masses were calculated for whole AHBM – SEAT models. Two cases shown in Figs. 2a and 2b were taken into account: Fig. 2a shows active human body (AHBM) with rigid seat of mass m_0, Fig. 2b shows active human body (AHBM) with passive seat, considered as vibration isolation system (VIS) [5], composed of mass m_0, damper α and spring c.

3.1. Impedance of active human body models and passive models of the seat

It can be shown, that the impedance of the system composed of active human body model (AHBM) with rigid seat of mass m_0 presented in Fig. 2a can be calculated from the relation (9).

$$Z_{\mathrm{mod}+m_0}(s) = Z_{\mathrm{mod}}(s) + Z_{m_0}(s) \tag{9}$$

For the system composed of active human body model with passive seat presented in Fig. 2b, the impedance is calculated from the relation (10)

$$\frac{1}{Z_{\mathrm{mod}+m_0+\alpha,c}(s)} = \frac{1}{Z_{\mathrm{mod}+m_0}(s)} + \frac{1}{Z_{\alpha,c}(s)} \tag{10}$$

or relation (11)

$$Z_{\text{mod}+m_0+\alpha,c}(s) = \frac{Z_{\text{mod}+m_0}(s)\,Z_{\alpha,c}(s)}{Z_{\text{mod}+m_0}(s) + Z_{\alpha,c}(s)} \tag{11}$$

where the index "mod" denotes alternatively back-off or back-on AHBM. The impedances of considered types of passive seats are correspondingly given by the formulae (12) and (13).

$$Z_{m_0} = m_0 s \tag{12}$$

$$Z_{m_0,\alpha,c}(s) = \frac{m_0 s(\alpha s + c)}{m_0 s^2 + \alpha s + c} \tag{13}$$

The relation between mechanical impedance and apparent mass is expressed by the formula (14).

$$M_{m_0,\alpha,c}(s) = \frac{Z_{m_0,\alpha,c}(s)}{s} \tag{14}$$

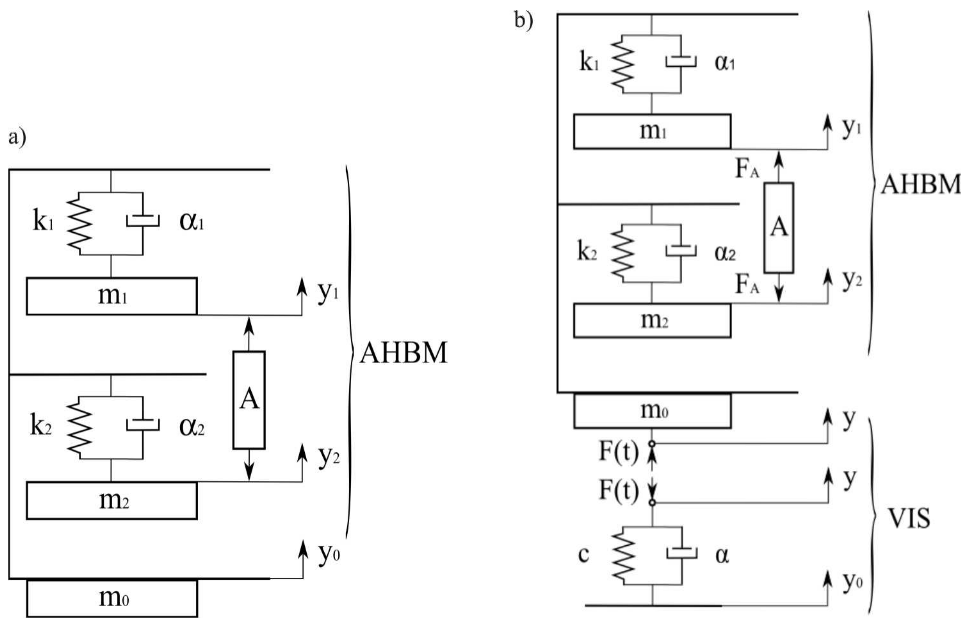

Fig. 2. The common structure of active human body models for back-off and back-on positions

Rys. 2. Struktura aktywnych modeli ciała człowieka dla pozycji bez oparcia i z oparciem

3.1.1. Impedance of active human body models and passive models of the seat for back-off position

The formula for the total impedance in case of back-off AHBM – passive vibration isolation system takes the form

$$
Zofftotal = NumZoffTotal\,/\,DenZoffTotal \tag{15}
$$

where expressions of the numerator and denominator are given by (16) and (17) as follows.

$$
\begin{aligned}
&NumZoffTotal = (\alpha s + c)(-m_0 m_1 m_2 s^4 + (m_0 m_1 k_{14} - m_0 m_2 k_{12} - m_1 m_2 \alpha_1 - m_0 m_2 \alpha_1 - m_1 m_2 \alpha_2 - m_0 m_1 \alpha_2)s^3 \\
&+(-m_2 \alpha_1 \alpha_2 + m_1 \alpha_1 k_{14} - m_0 k_{11} m_2 - m_2 \alpha_1 k_{14} - m_2 k_{12} \alpha_2 - m_0 k_1 m_2 - m_0 k_{12} \alpha_2 - m_0 m_1 k_2 + \\
&+m_0 m_1 k_{13} + m_0 \alpha_1 k_{14} - m_1 k_1 m_2 - m_1 \alpha_1 \alpha_2 - m_0 \alpha_1 \alpha_2 - m_1 k_{12} \alpha_2 + 2 m_1 \alpha_2 k_{14} - m_2 m_1 k_2)s^2 + \\
&+(m_0 \alpha_1 k_{13} - m_2 k_{11} \alpha_2 - m_0 k_{11} \alpha_2 - m_2 k_{12} k_2 - m_2 \alpha_1 k_2 - m_0 k_1 \alpha_2 - m_2 k_1 k_{14} + \\
&+m_0 k_1 k_{14} - m_2 \alpha_1 k_{13} - m_1 k_1 \alpha_2 - m_0 k_{12} k_2 - m_2 k_1 \alpha_2 - m_0 \alpha_1 k_2 + m_1 k_1 k_{14} + 2 m_1 \alpha_2 k_{13} + \\
&+2 m_1 k_2 k_{14} - m_1 k_{12} k_2 - m_1 \alpha_1 k_2 + m_1 \alpha_1 k_{13} - m_1 k_{11} \alpha_2)s + 2 m_1 k_2 k_{13} + m_0 k_1 k_{13} - m_0 k_{11} k_2 - \\
&m_2 k_1 k_2 - m_2 k_{11} k_2 - m_0 k_1 k_2 - m_2 k_1 k_{13} - m_1 k_1 k_2 + m_1 k_1 k_{13} - m_1 k_{11} k_2)s
\end{aligned} \tag{16}
$$

$$
\begin{aligned}
&DenZoffTotal = (-m_0 m_1 m_2 s^6 + (-m_0 m_1 \alpha_2 - m_1 m_2 \alpha_2 - m_1 m_2 \alpha - m_1 m_2 \alpha_1 + m_0 m_1 k_{14} - m_0 k_{12} m_2 - m_0 \alpha_1 m_2)s^5 \\
&+(-\alpha k_{12} m_2 + 2 m_1 \alpha_2 k_{14} + m_1 \alpha_1 k_{14} - c m_1 m_2 - m_0 k_{11} m_2 - m_2 k_{12} \alpha_2 - m_0 k_1 m_2 - m_1 k_1 m_2 - m_1 k_{12} \alpha_2 + \\
&+m_0 \alpha_1 k_{14} - m_1 \alpha_1 \alpha_2 - m_0 m_1 k_2 - m_0 k_{12} \alpha_2 - m_2 \alpha_1 k_{14} + m_0 m_1 k_{13} - m_1 m_2 k_2 - m_2 \alpha_1 \alpha_2 - m_2 \alpha \alpha_1 - m_1 \alpha \alpha_2 + \\
&+\alpha m_1 k_{14} - m_0 \alpha_1 \alpha_2)s^4 + (-\alpha k_1 m_2 - m_2 \alpha_1 k_2 - \alpha m_1 k_2 + \alpha m_1 k_{13} - m_2 \alpha_1 k_{13} - m_2 k_{11} \alpha_2 - m_2 k_1 k_{14} - \\
&m_2 k_1 \alpha_2 - m_2 k_{12} k_2 - m_0 \alpha_1 k_2 + m_0 \alpha_1 k_{13} - m_0 k_{11} \alpha_2 + m_0 k_1 k_{14} - m_0 k_1 \alpha_2 - m_0 k_{12} k_2 - m_1 \alpha_1 k_2 + \\
&+m_1 \alpha_1 k_{13} - m_1 k_{11} \alpha_2 - m_1 k_1 \alpha_2 + 2 m_1 \alpha_2 k_{13} + 2 m_1 k_2 k_{14} - m_1 k_{12} k_2 + m_1 k_1 k_{14} - c m_1 \alpha_2 - c k_{12} m_2 - c \alpha_1 m_2 + \\
&+c m_1 k_{14} - \alpha \alpha_1 \alpha_2 - \alpha k_{11} m_2 + \alpha \alpha_1 k_{14} - \alpha k_{12} \alpha_2)s^3 + (-m_2 k_1 k_2 - m_2 k_1 k_{13} - \alpha k_{11} \alpha_2 - c k_{11} m_2 - \\
&c k_{12} \alpha_2 - c \alpha_1 \alpha_2 + c m_1 k_{13} - m_2 k_{11} k_2 + \alpha \alpha_1 k_{13} - c m_1 k_2 + m_1 k_1 k_{13} - m_1 k_1 k_2 - c k_1 m_2 - \\
&\alpha \alpha_1 k_2 - \alpha k_{12} k_2 + c \alpha_1 k_{14} + 2 m_1 k_2 k_{13} - m_0 k_{11} k_2 - \alpha k_1 \alpha_2 + \alpha k_1 k_{14} - m_0 k_1 k_2 + m_0 k_1 k_{13} - m_1 k_{11} k_2)s^2 + \\
&+(-c k_1 \alpha_2 - c k_{11} \alpha_2 - c \alpha_1 k_2 + c \alpha_1 k_{13} + \alpha k_1 k_{13} - c k_{12} k_2 - \alpha k_1 k_2 + c k_1 k_{14} - \alpha k_{11} k_2)s - c k_1 k_2 + \\
&+c k_1 k_{13} - c k_{11} k_2)
\end{aligned} \tag{17}
$$

3.1.2. Impedance of active human body models and passive models of the seat for back-on position

The formula for the total impedance in case of back on AHBM – passive vibration isolation system takes the form (18)

$$
Zontotal = NumZonTotal\,/\,DenZonTotal \tag{18}
$$

where the expressions of the numerator and denominator are expressed by the formulae (19) and (20).

$$
\begin{aligned}
&NumZonTotal = \\
&(\alpha s + c)(m_0 m_1 m_2 s^4 + (m_1 m_2 \alpha_1 - m_0 m_1 k_{14} + m_1 m_2 \alpha_2 + m_0 m_1 \alpha_2 + m_0 k_{12} m_2 + m_0 m_2 \alpha_1) s^3 + \\
&+ (m_2 \alpha_1 \alpha_2 - m_2 \alpha_1 k_{14} + m_2 k_{12} \alpha_2 + m_0 m_1 k_2 - m_0 m_1 k_{13} + m_1 \alpha_1 \alpha_2 - m_1 \alpha_1 k_{14} + m_1 k_{12} \alpha_2 + \\
&+ m_1 m_2 k_1 + m_0 \alpha_1 \alpha_2 - m_0 \alpha_1 k_{14} + m_1 m_2 k_2 + m_0 k_{12} \alpha_2 + m_0 m_2 k_1 + m_0 k_{11} m_2) s^2 + (m_0 k_{12} k_2 - \\
&m_0 k_1 k_{14} + m_2 k_1 \alpha_2 + m_1 k_1 \alpha_2 - m_1 k_{11} \alpha_2 + m_1 \alpha_1 k_2 - m_0 \alpha_1 k_{13} + m_2 k_{11} \alpha_2 + m_2 \alpha_1 k_2 + m_2 \alpha_1 k_{13} + \\
&+ m_0 \alpha_1 k_2 - m_2 k_1 k_{14} + m_0 k_1 \alpha_2 + 2 m_2 k_{11} \alpha_1 - m_1 \alpha_1 k_{13} + m_0 k_{11} \alpha_2 - 2 m_1 \alpha_2 k_{13} + m_1 k_{12} k_2 - \\
&m_1 k_1 k_{14} + m_2 k_{12} k_2) s + 2 m_2 k_{11} k_1 + m_2 k_1 k_{13} + m_0 k_{11} k_2 - 2 m_1 k_2 k_{13} + m_0 k_1 k_2 - m_1 k_1 k_{13} - \\
&m_1 k_{11} k_2 + m_2 k_1 k_2 - m_0 k_1 k_{13} + m_1 k_1 k_2 + m_2 k_{11} k_2) s
\end{aligned}
\tag{19}
$$

$$
\begin{aligned}
&DenZonTotal = (m_0 m_1 m_2 s^6 + (m_0 m_1 \alpha_2 + m_1 m_2 \alpha_2 + m_1 m_2 \alpha + m_1 m_2 \alpha_1 - \\
&m_0 m_1 k_{14} + m_0 k_{12} m_2 + m_0 \alpha_1 m_2) s^5 + (\alpha k_{12} m_2 - m_1 \alpha_1 k_{14} + c m_1 m_2 + m_0 k_{11} m_2 + \\
&m_2 k_{12} \alpha_2 + m_0 k_1 m_2 + m_1 k_1 m_2 + m_1 k_{12} \alpha_2 - m_0 \alpha_1 k_{14} + m_1 \alpha_1 \alpha_2 + m_0 m_1 k_2 + \\
&+ m_0 k_{12} \alpha_2 - m_2 \alpha_1 k_{14} - m_0 m_1 k_{13} + m_1 m_2 k_2 + m_2 \alpha_1 \alpha_2 + m_2 \alpha \alpha_1 + m_1 \alpha \alpha_2 - \\
&\alpha m_1 k_{14} + m_0 \alpha_1 \alpha_2) s^4 + (\alpha k_1 m_2 + m_2 \alpha_1 k_2 + \alpha m_1 k_2 - \alpha m_1 k_{13} + m_2 \alpha_1 k_{13} + \\
&+ m_2 k_{11} \alpha_2 - m_2 k_1 k_{14} + m_2 k_1 \alpha_2 + m_2 k_{12} k_2 + m_0 \alpha_1 k_2 - m_0 \alpha_1 k_{13} + m_0 k_{11} \alpha_2 - \\
&m_0 k_1 k_{14} + m_0 k_1 \alpha_2 + m_0 k_{12} k_2 + m_1 \alpha_1 k_2 - m_1 \alpha_1 k_{13} - m_1 k_{11} \alpha_2 + m_1 k_1 1 \alpha_2 - \\
&2 m_1 \alpha_2 k_{13} + 2 m_2 k_{11} \alpha_1 + m_1 k_{12} k_2 - m_1 k_1 k_{14} + c m_1 \alpha_2 + c k_{12} m_2 + c \alpha_1 m_2 - \\
&c m_1 k_{14} + \alpha \alpha_1 \alpha_2 + \alpha k_{11} m_2 - \alpha \alpha_1 k_{14} + \alpha k_{12} \alpha_2) s^3 + (c k_1 m_2 + m_1 k_1 k_2 - m_1 k_1 k_{13} + \\
&c k_{11} m_2 + c k_{12} \alpha_2 - c m_1 k_{13} + m_2 k_{11} k_2 + m_0 k_1 k_2 - m_0 k_1 k_{13} + m_0 k_{11} k_2 - \alpha k_1 k_{14} + \\
&+ c \alpha_1 \alpha_2 - m_1 k_{11} k_2 + 2 m_2 k_{11} k_1 + \alpha k_{11} \alpha_2 + \alpha \alpha_1 k_2 + c m_1 k_2 - \alpha \alpha_1 k_{13} + \alpha k_{11} k_2 + \\
&+ m_2 k_1 k_2 + m_2 k_1 k_{13} + \alpha k_1 \alpha_2 - 2 m_1 k_2 k_{13} - c \alpha_1 k_{14}) s^2 + (\alpha k_1 k_2 + \alpha k_{11} k_2 + c \alpha_1 k_2 + \\
&c k_1 \alpha_2 + c k_{12} k_2 + c k_{11} \alpha_2 - c \alpha_1 k_{13} - \alpha k_1 k_{13} - c k_1 k_{14}) s - c k_1 k_{13} + c k_{11} k_2 + c k_1 k_2)
\end{aligned}
\tag{20}
$$

4. Examples of numerical comparison of magnitudes of impedances and apparent masses of AHBM–seat systems

In this paragraph the exemplary numerical descriptions of the AHBM–seat system were presented. The magnitudes of the impedances and apparent masses of the AHBM–SEAT systems were numerically calculated taking into account the values of parameters shown in Table 1 for two cases of the seat system: 1) case of rigid seat with mass m_0 = 35 kg, 2) case of passive seat composed of mass m_0 = 35 kg and Kelvin-Voigt VIS with spring of rigidity c = 9950 N/m and damper with damping coefficient α = 260 Ns/m.

The results of numerical calculations were graphically presented in Figs. 3–6. As was shown in these figures the impedances and apparent masses of AHBM–SEAT system depend on structure of the seat and its parameters. In Figs. 3 and 4, for the system with back-off and back-on models there are big differences between impedances in function of structure of seat. Relatively small differences are between apparent masses for the systems without seat and with rigid seat. Influence of passive seat is very significant for back-off and back-on models of human body.

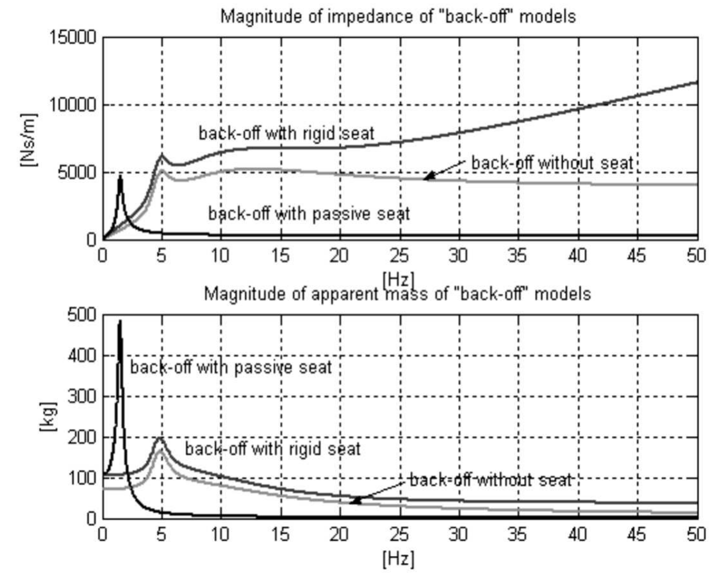

Fig. 3. Human body model and passive seats: a) AHBM and passive rigid seat,
b) AHBM and passive Voigt-Kelvin seat

Rys. 3. Model ciała człowieka i siedziska: a) aktywny model ciała wraz ze sztywnym siedziskiem,
b) aktywny model ciała wraz z pasywnym siedziskiem typu Kelvina-Voigta

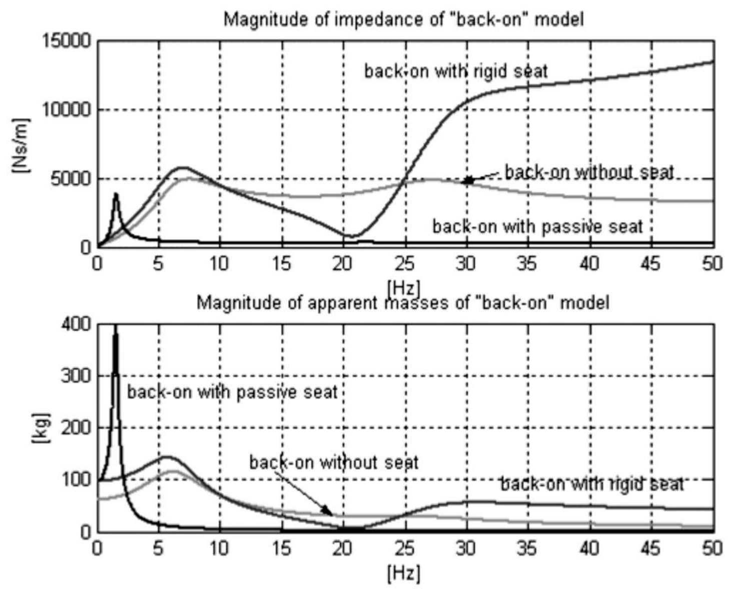

Fig. 4. Magnitudes of impedances and apparent masses of back-off models with and without seat

Rys. 4. Moduły impedancji i mas pozornych modeli bez oparcia z siedziskiem i bez siedziska

In Figs. 5 and 6 the difference between impedances and apparent masses for back-off and back-on positions of human body are shown. For the systems with passive seat both impedances and apparent masses are almost the same. It means that for the numerical values of the parameters of the passive seat chosen for calculations the influence of structure of AHBM is not so important.

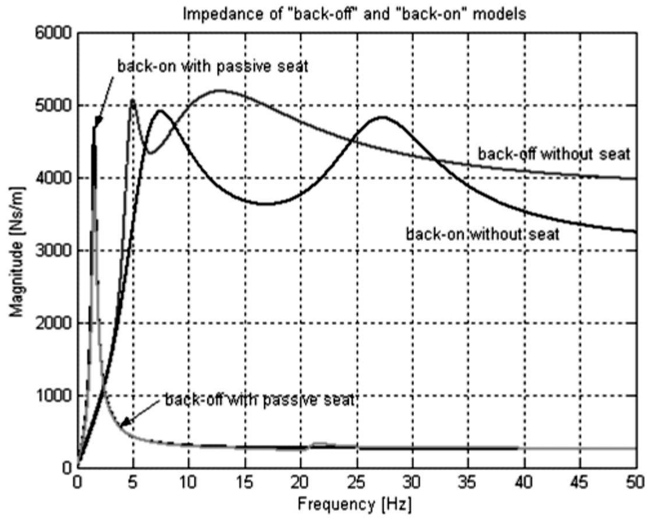

Fig. 5. Magnitudes of impedances of back-on models with and without seat

Rys. 5. Moduły impedancji modeli z oparciem z siedziskiem i bez siedziska

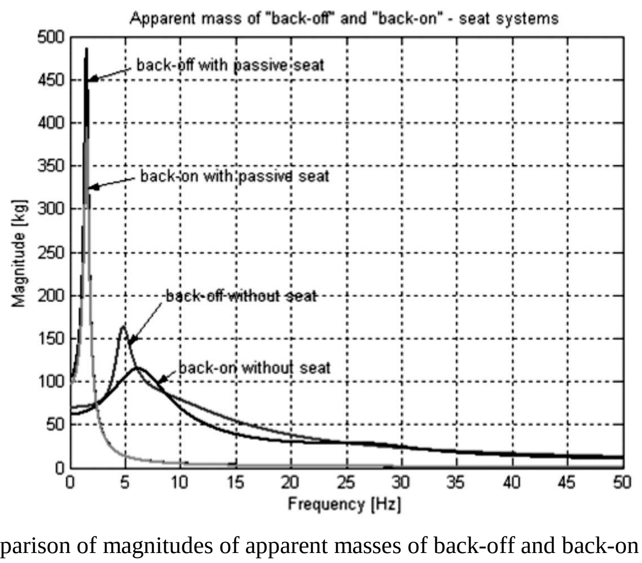

Fig. 6. Comparison of magnitudes of apparent masses of back-off and back-on models with and without seat

Rys. 6. Porównanie modułów mas pozornych modeli z oparciem i bez oparcia z siedziskiem i bez siedziska

In Figs. 7 and 8 the influence of the value of damping suspension coefficient α on the the impedance and apparent mass of the AHBM–SEAT system for back-off and back-on models was shown. This coefficient was chosen as the parameter of control of VIS commonly used in practical applications. The values of mass m_0 and spring rigidity c was assumed invariable. Their influence has not been analyzed.

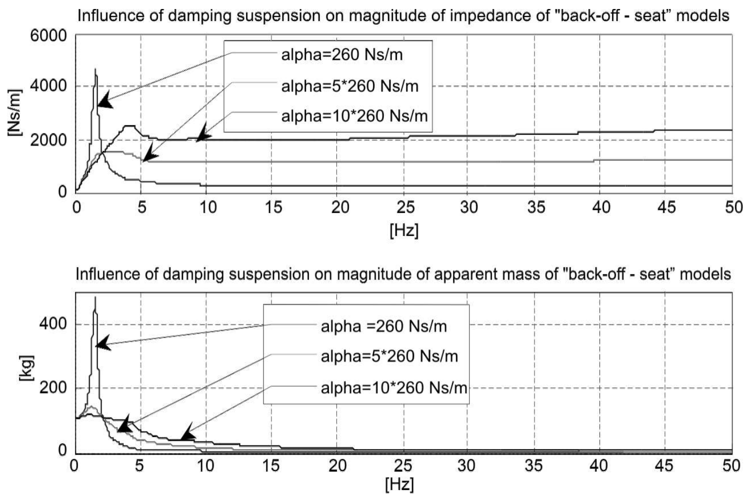

Fig. 7. Influence of the value of damping suspension coefficient α on the impedance and apparent mass of the AHBM – passive seat system for back-off model

Rys. 7. Wpływ wartości współczynnika tłumienia zawieszenia α na impedancję i masę pozorną układu aktywnego modelu ciała człowieka bez oparcia i pasywnego siedziska

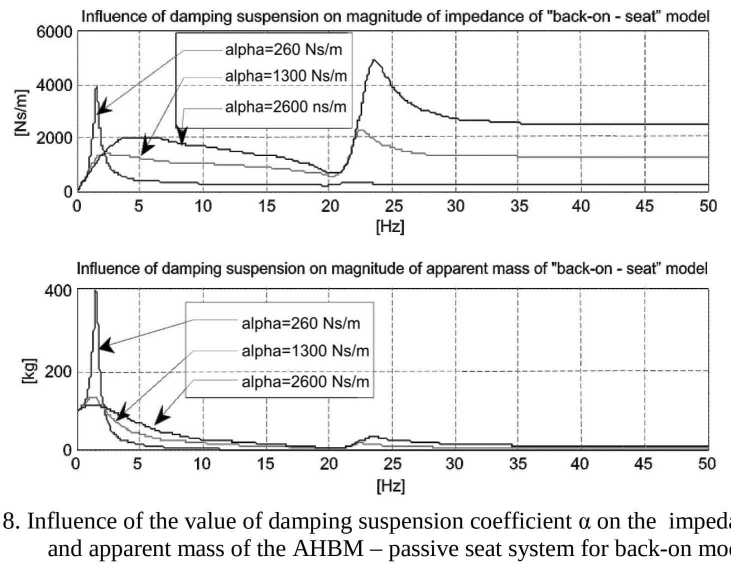

Fig. 8. Influence of the value of damping suspension coefficient α on the impedance and apparent mass of the AHBM – passive seat system for back-on model

Rys. 8. Wpływ wartości współczynnika tłumienia zawieszenia α na impedancję i masę pozorną układu aktywnego modelu ciała człowieka z oparciem i pasywnego siedziska

5. Concluding remarks

Each position of sitting human body corresponds to separate active biomechanical model.

It is possible to assume the same structure of the models for the positions back-off and back-on, however analytical structures and numerical values of the parameters of corresponding active forces (1), (2) for each of the models are different as was shown in Table 1. Total impedance of the human body–seat systems significantly depends on the structure and damping suspension coefficient of the seat.

As it was shown in Figs. 3–6 there are big quantitative differences between impedances and apparent masses of the models back-off and back-on. The magnitude of impedance of back-off model has two peaks at lower frequencies than the magnitude of impedance of back-on model. It signifies that the back-off model is relatively softer than the back-on one. The impedance and the apparent mass of seat itself depend on the value of damping coefficient α. It was verified that for the band of values of damping coefficient ($\alpha = 260 – 2600$ Ns/m) and the band of low frequencies (from 0 – to 4 Hz), the assumed constant values of mass of the seat $m_0 = 35$ kg and its rigidity $c = 9950$ N/m, both impedance and apparent mass of the AHBM–SEAT system are the biggest for the smallest value of $\alpha = 260$ Ns/m. In the zone of frequency over 4 Hz one can notify that for the bigger damping coefficients there are the bigger magnitudes of the impedance and apparent mass of the AHBM–SEAT system.

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