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ABOUT THE POSSIBILITY OF THE STIFFNESS REDUCING OF A VIBROISOLATION SYSTEM

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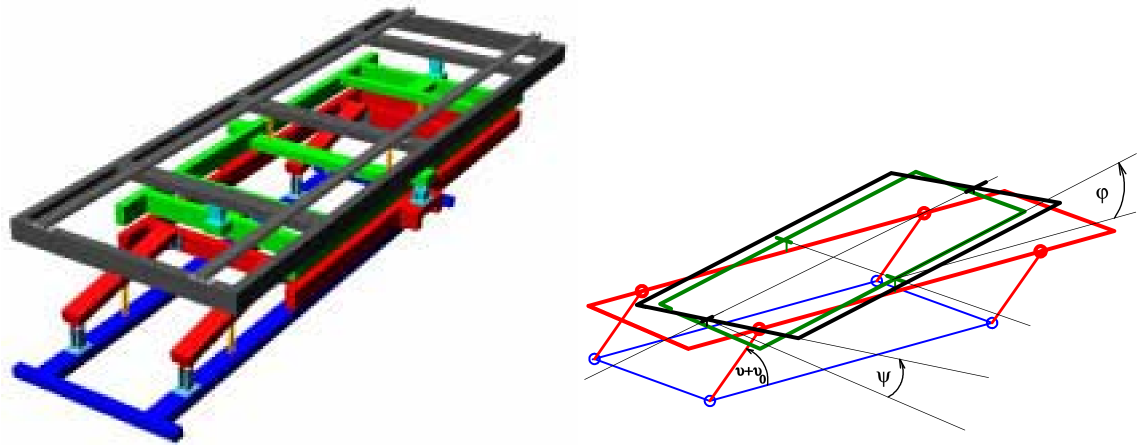
Summary: *The suspension of the ambulance couch is realized by pneumatic springs. The all natural frequencies must be less than the first natural frequency of the chassis.*

1. Introduction and preliminary considerations

Vibroisolation of sanit couch with three degrees of freedom (see Pic. 1) is described in the article [1], where its motion equations are deduced for the case of the three degrees kinematic excitation (vertical translation and rotation around both horizontal car axis). There are defined three general coordinates: ϑ (the angle of parallelogram), φ (the angle deflection of the first Cardan frame) and ψ (the angle of the second frame, on that the couch with a human body is fixed).

To have a sence of human body vibroisolation, it is necessary the all three natural frequencies must be lower, than the first natural frequency of the car undercarriage – less than 1 Hz. There is demonstrated, that the reaching of this requirment is a serious problem. Its analysis is the object of this paper; we confine to the vertical kinematic excitation and the small angle deflections around the equbrilium state.



Picture 1

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2. Preliminary consideration

According to the introduced assumption, we start from the linearised system, that we can deduce from [1]

$$\overline{A}\ddot{\vec{q}}^T + \left(\overline{B}_0 + \overline{B}_1(t)\right)\dot{\vec{q}}^T + \left(\overline{C}_0 + \overline{C}_1(t)\right)\vec{q}^T = \vec{E}_0 + \vec{E}_1(t) \tag{1}$$

where is denoted: $\vec{q}(\vartheta,\varphi,\psi)$ vector of the angle deflections, $\overline{A}$ symetrical matrix of mass, $\overline{B}_0$ diagonal matrix of damping, $\overline{C}_0$ matrix of stiffness, $\overline{B}_1(t), \overline{C}_1(t)$ matrix of parametric excitation, $\vec{E}_1(t)$ vector of external excitation, $\vec{E}_0(t)$ vector of stationary moment of gravity and pneumatic springs.

The members of the matrix $\overline{A}$ are expressed by relations

$$\begin{gathered}
A_{11} = (m_R + m_4 + m_5 + m_6)R^2 + 4J_{Ry} \\
A_{12} = R[m_5(-x_{T5}\cos\vartheta_0 - z_{T5}\sin\vartheta_0) + m_6((-x_{T6} - x_{56})\cos\vartheta_0 + (-z_{T6} - z_{56})\sin\vartheta_0)] \\
A_{13} = m_6 R\cos\vartheta_0 y_{T6} \\
A_{22} = J_{5y} + J_{6y} + m_6(x_{56}^2 + z_{56}^2 + 2x_{56}x_{T6} + 2z_{56}z_{T6}) \\
A_{23} = -D_{6xy} - m_6 x_{56} y_{T6} \\
A_{33} = J_{6x} \\
A_{21} = A_{12}, \quad A_{32} = A_{23}, \quad A_{31} = A_{13}
\end{gathered} \tag{2}$$

It is obvious, that the general distribution of the masses is respected (mass of the upper base of the parallelogram m_4, of the first Cardan frame m_5, of the second frame m_6, its inertia moments $J_{5x}, J_{5y}, J_{5z}, J_{6x}, J_{6y}, J_{6z}$). The general position of the patient on the couch (production moments D_{6x}, D_{6y}, D_{6z}) and the coordinates of the mass centres and frame centres ($x_{T5}, y_{T5}, z_{T5}, x_{T6}, y_{6T}, z_{T6}$, $x_{45}, y_{45}, z_{45}, x_{56}, y_{56}, z_{56}$) are also respected.

Stiffness matrix (see [1]) is derived from the components of the varying moment of pneumatic springs

$$\begin{aligned}
C_{11} &= -(2m_R + m_4 + m_5 + m_6)gR\sin\vartheta_0 - 4r_{p\vartheta}^2\left(\frac{n(p_a + p_4)S_{04}^2}{V_4} + p_4 S_{14}\right) + \\
&\quad + 4p_4 S_{04} r_{p\vartheta}\sin\vartheta_0 \\
C_{22} &= -(m_5 z_{T5} + m_6 z_{56} + m_6 z_{T6})g - r_{p\varphi 1}^2\left(\frac{n(p_a + p_{51})S_{05}^2}{V_5} + p_{51}S_{15}\right) - \\
&\quad - r_{p\varphi 2}^2\left(\frac{n(p_a + p_{52})S_{05}^2}{V_5} + p_{52}S_{14}\right) \\
C_{33} &= -m_6 g z_{T6} - r_{p\psi 1}^2\left(\frac{n(p_a + p_{61})S_{06}^2}{V_6} + p_{61}S_{16}\right) - r_{p\psi 2}^2\left(\frac{n(p_a + p_{62})S_{06}^2}{V_6} + p_{62}S_{16}\right)
\end{aligned} \tag{3}$$

Damping matrix (see [1]) is also diagonal and its members are the functions of the velocity characteristics of the dampers and their transmissions.

$$B_{11} = 4b_{1i} r_{T\vartheta i}^2 \cos^2 \vartheta_0$$

$$B_{22} = \sum_{j=1}^{2} b_{1j} r_{T\varphi j}^2 \qquad (4)$$

$$B_{33} = \sum_{j=1}^{2} b_{1j} r_{T\psi j}^2$$

3. Equilibrium state and natural frequencies of the system

This state is defined in such a way, that the static components of the gravity moment (given by null-order members in the Taylor expansion) are balanced with the help of appropriate position controlers by means of static components of pneumatic springs moments

$$\vec{E}_0 = 0 \qquad (5)$$

According to the range of human body mass (40 kg – 120 kg) and according to the design geometrie is demonstrated, that the pneumatic spring DUNLOP 2x2¾" (produced by Rubena Náchod ČR) is the most usable.

Relation (5) comes to moment equations of equibrilium

$$(m_4 + m_5 + m_6 + 2m_r) gR \cos \vartheta_0 = 4.p_4 S_{04} (r_{p\vartheta} \cos \vartheta_0)$$

$$m_6 g(x_{56} + x_{T6}) = \sum_{j=1}^{2} p_{5j} S_{05} r_{p\varphi j} \qquad (6)$$

$$m_6 g y_{T6} = \sum_{j=1}^{2} p_{6j} S_{06} r_{p\psi}$$

and forces equilibrium equations join them

$$-(m_5 + m_6) g + p_{51} S_{05} + p_{52} S_{05} = 0$$

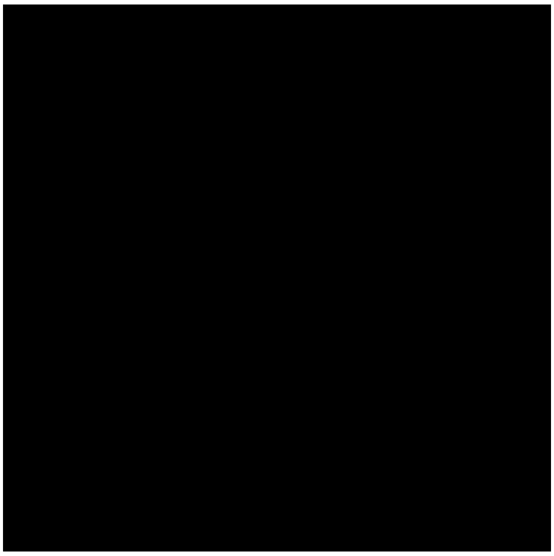
$$-m_6 g + p_{61} S_{06} + p_{62} S_{06} = 0 \qquad (7)$$

4. Natural frequencies of the undamped system

The natural frequencies are defined as imaginary parts of the eigen values of the characteristic matrix

$$\overline{A} \lambda^2 + C_0 \qquad (8)$$

The natural frequencies depend on the some parameters of the system. The dependence on the moment arm of pneumatic forces are demonstrated on the graphs (patient mass 120 kg) (see pic. 2a, 2b, 2c).



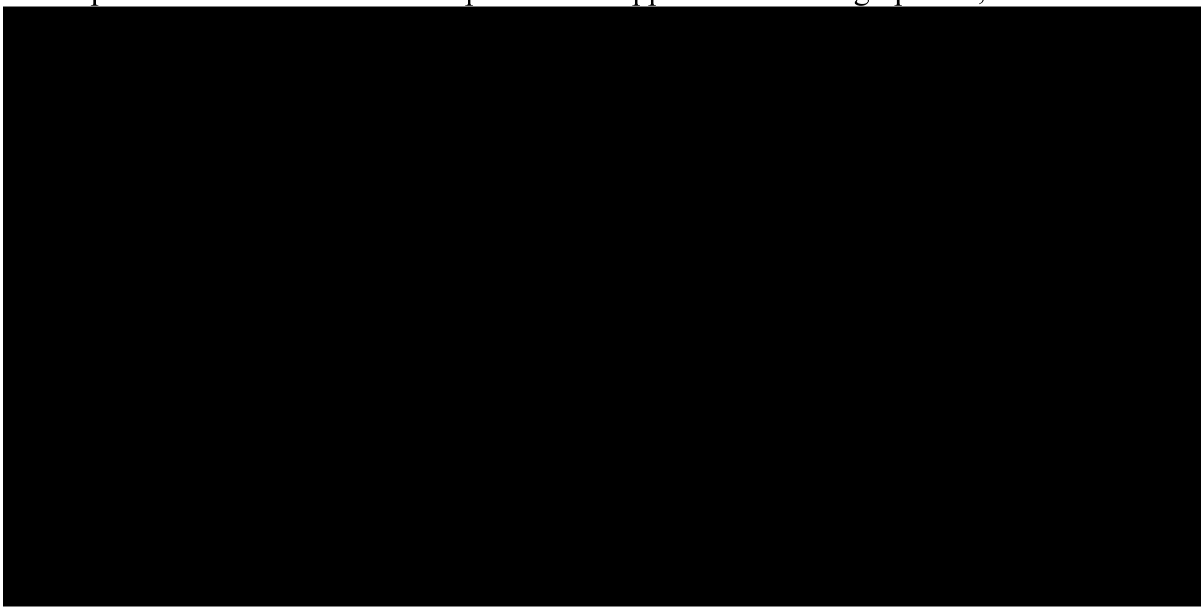
Picture 2a

Picture 2b, 2c

The pressures in the equilibrium state are demonstrated at the pictures 3a, 3b, 3c.

Picture 3a, 3b, 3c

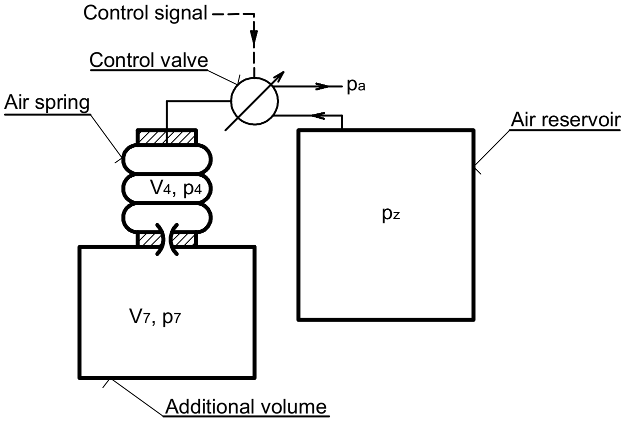
The dependence on the mass centre positions is apparent from the graphs 4a, 4b.



Picture 4a, 4b

5. Application of the additional volumes

These graphs result in: with real shortening of the moment arm we come to the natural frequencies in the interval ($2 \div 3$ Hz) which is insufficient. The last possibility is the application of the additional volumes (see pict. 5).



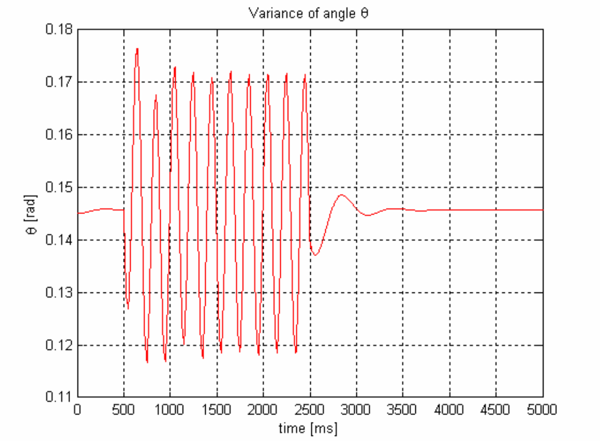
Picture 5

This means that the original system of motion equations have to be completed by mass stream equations. The pressures in additional volumes $V_7, V_8, V_9, V_{10}, V_{11}$ are designated as $p_7, p_8, p_9, p_{10}, p_{11}$. It is valied

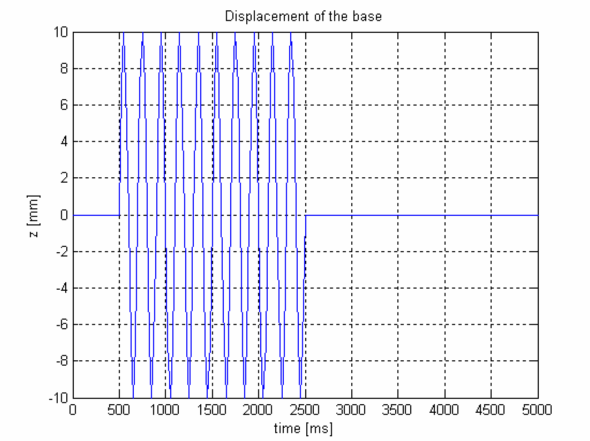
$$\frac{dp_4}{dt}V_4 + p_4\frac{dV_4}{dt} = D_{41}(p_4 - p_7)$$
$$V_7\frac{dp_7}{dt} = -D_{41}(p_4 - p_7)$$
$$V_5\frac{dp_{51}}{dt} + p_{51}Sr_{51p}\frac{d\varphi}{dt} = -D_{51}(p_{51} - p_8)$$
$$V_5\frac{dp_{52}}{dt} + p_{52}Sr_{52p}\frac{d\varphi}{dt} = -D_{52}(p_{52} - p_9)$$
$$V_8\frac{dp_8}{dt} = D_{51}(p_{51} - p_8) \qquad (9)$$
$$V_9\frac{dp_9}{dt} = D_{52}(p_{52} - p_9)$$
$$V_{10}\frac{dp_{61}}{dt} + p_{61}S.r_6\frac{d\psi}{dt} = -D_{61}(p_{61} - p_{10})$$
$$V_{11}\frac{dp_{62}}{dt} + p_{62}S.r_6\frac{d\psi}{dt} = -D_{62}(p_{62} - p_{11})$$
$$V_{10}\frac{dp_{10}}{dt} = D_{61}(p_{61} - p_{10})$$
$$V_{11}\frac{dp_{11}}{dt} = D_{62}(p_{62} - p_{11})$$

where $D_{41}, D_{51}, D_{52}, D_{61}, D_{62}$ are the resulting constriction coefficients of the mass-discharge between the spring and additional volume. At the same time it is necessary to correct the members $C_{11} \div C_{33}$ of the stiffness matrix. The natural frequencies are determined from characteristic matrix, relevant to the system of equation (1) and (5). We remark, that in first approximation it is valied: we decrease the natural frequency $\sqrt{N+1}$ time, where N is relation of the additional volume and spring volume (see [3]).

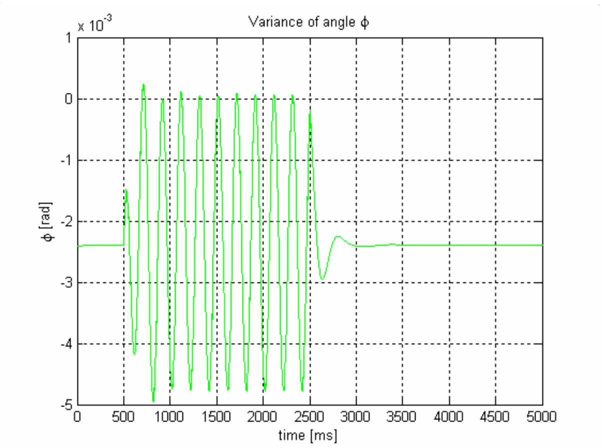
We poind out, that there is analysed an uncontrolled system (system with switched off position control). We remark, that at this time some manufactories come back to such a system (the position controll is switched on only to make the equilibrium state). But a completely tight pneumatic circuit is required.
There are forced oscilations of the analysed system (see picture 6a – 6d) in the case of the human body modelled discretly [4] and continuously.



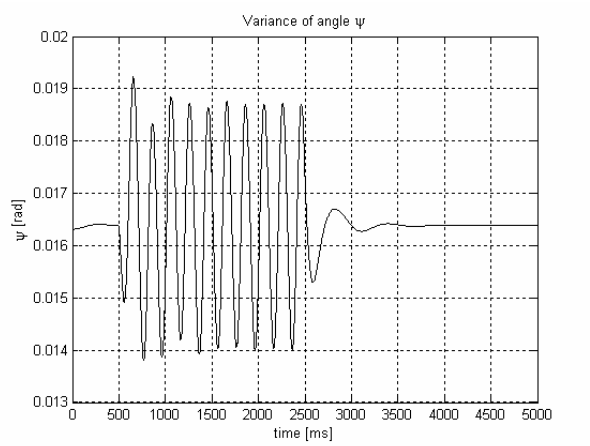
Picture 6a.



Picture 6b.



Picture 6c.



Picture 6d.

6. Conclusions

There are three possibilities:
A. The linear contraction of the spring arms (this is decreasing their transmission).
B. The forming of the piston of hose spring (it is impossible).
C. Application of the additional volume is the most effective solution (but very exciting on the design modification), teoretically there is possible to reduce the self frequencies multiply. But it is necessary to consider, that by application of the position controll the natural frequencies will be a little changed.

Acknowledgement

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