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Vibration Isolation of Electric Golf Cart Seat

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Abstract. The paper is focused on minimization of vibration transmitted from electric golf cart wheels to seat and seated person. This vibration appears during golf cart driving on uneven terrain of the golf court. This problem can be solved according to [2] using the elastic and damping link between cart frame and seat tightly connected to battery of electric power. For evaluation of designed solution is used mathematical calculation describing golf cart as system of masses connected with elastic and damping links. The result of mathematical description of designed solution is reference step response of golf cart seat.

Introduction

Suspension seats are used in a wide range of vehicles, especially for the purpose of protecting person's health exposed to whole-body vibration during travel, and also for comfortability increase. Driving on uneven terrain of golf court leads to high-intensity vibration of wheels which is transmitted to frame, seat and seated person. Conventional battery powered electric golf carts do not have suspension seats, for the purpose of transmitted vibration reduction to seat and seated person the elastic and damping link between chassis and frame of golf cart is being used. These links reduce transmission of vibration only partially, so the drive in golf cart can get uncomfortable.

Effects of Vibration on Comfort

Evaluation of effect of vibration on comfort of seated person during the golf cart drive was made in accordance with [1]. Result of evaluation of effect of vibration is frequency-weighted r.m.s. acceleration of measured acceleration as a function of time during the golf cart drive and comparison this acceleration value with table in [1]. Frequency-weighted r.m.s. acceleration for the one-third octave band is shown in Fig. 1.

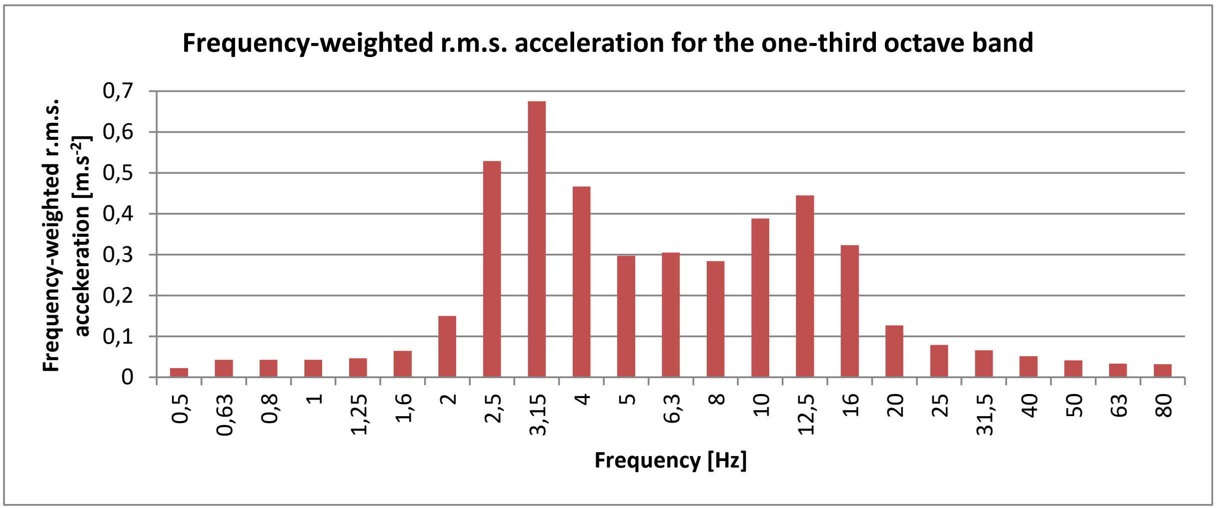

Fig.1 Frequency-weighted r.m.s. acceleration for the one-third octave band

Comparison of frequency-weighted r.m.s. acceleration with table in [1] shows that effect of vibration on comfort during golf cart drive is in interval of uncomfortable and very uncomfortable.

Minimization of Transmitted Vibration

Minimization of vibration, transmitted from golf cart wheels to seat and seated person, is based on principle described in patent application [2]. Transmitted vibration can be reduced according to [2] using the elastic and damping link between cart frame and seat tightly connected to battery of electric power. Battery of electric power tightly connected to seat increases inertial effect of mass, which reduces seat vibration. The principle is shown in Fig. 2.

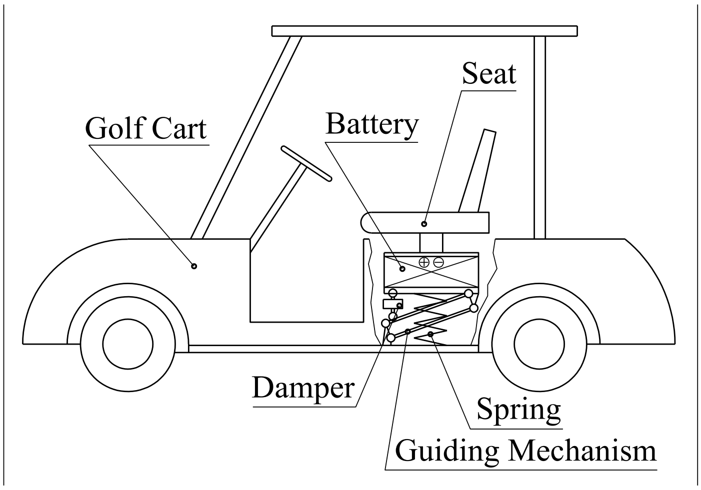

Fig.2 Principle of vibration isolation of seat

Calculation of Transmitted Vibration

The system in Fig. 2 can be described in simplified way by differential equations:

$$m_R.\ddot{x}_R+b_R.\left(\dot{x}_R-\dot{u}\right)+b_{SB}.\left(\dot{x}_R-\dot{x}_{SB}\right)+k_R.\left(x_R-u\right)+k_{SB}.\left(x_R-x_{SB}\right)=0, \tag{1}$$

$$m_{SB}.\ddot{x}_{SB}+b_{SB}.\left(\dot{x}_{SB}-\dot{x}_R\right)+k_{SB}.\left(x_{SB}-x_R\right)=0, \tag{2}$$

where m_R is mass of frame, m_{SB} mass of seat, battery and seated persons, b_R damping coefficient of chassis, b_{SB} damping coefficient between seat with battery and frame, k_R stiffness of chassis, k_{SB} stiffness between seat with battery and frame, u deflection of chassis, x_R deflection of frame and x_{SB} deflection of seat with battery.

In matrix form can be the system in simplified way described by equation:

$$\vec{q}=\left(\mathbf{K}+i.\omega.\mathbf{B}-\omega^2.\mathbf{M}\right)^{-1}.\vec{f}, \tag{3}$$

where $\vec{q}$ is vector of deflection, **K** matrix of stiffness, **B** matrix of damping, **M** matrix of mass, $\vec{f}$ vector of force substituting deflection u, ω angular frequency and i imaginary unit.

In case of using elastic and damping link between golf cart frame with tightly connected battery and seat, the differential equations are:

$$m_R.\ddot{x}_R+b_R.\left(\dot{x}_R-\dot{u}\right)+b_S.\left(\dot{x}_R-\dot{x}_S\right)+k_R.\left(x_R-u\right)+k_S.\left(x_R-x_S\right)=0, \tag{4}$$

$$m_S.\ddot{x}_S+b_S.\left(\dot{x}_S-\dot{x}_R\right)+k_S.\left(x_S-x_R\right)=0, \tag{5}$$

where m_S is mass of seat and seated persons, b_S damping coefficient between seat and frame, k_S stiffness between seat and frame and x_S deflection of seat.

Differential equations Eq. 1, Eq. 2, Eq. 4 and Eq. 5 are described in Fig. 3 on the left, equation Eq. 3 is described in Fig. 3 on the right.

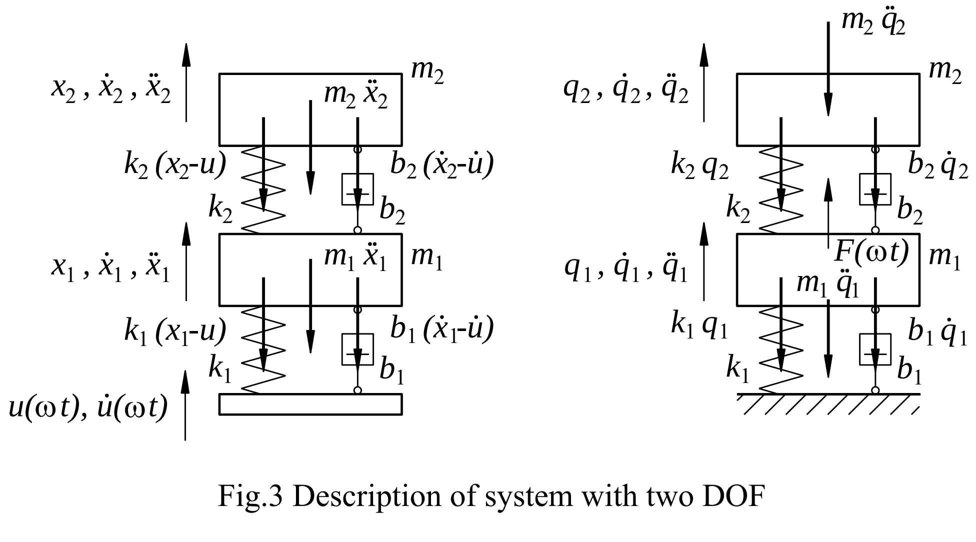

Fig.3 Description of system with two DOF

The result of solved equations Eq. 1 – Eq. 5 is amplitude-frequency response shown in Fig. 4 and reference step response of systems (Fig. 5 and Fig. 6).

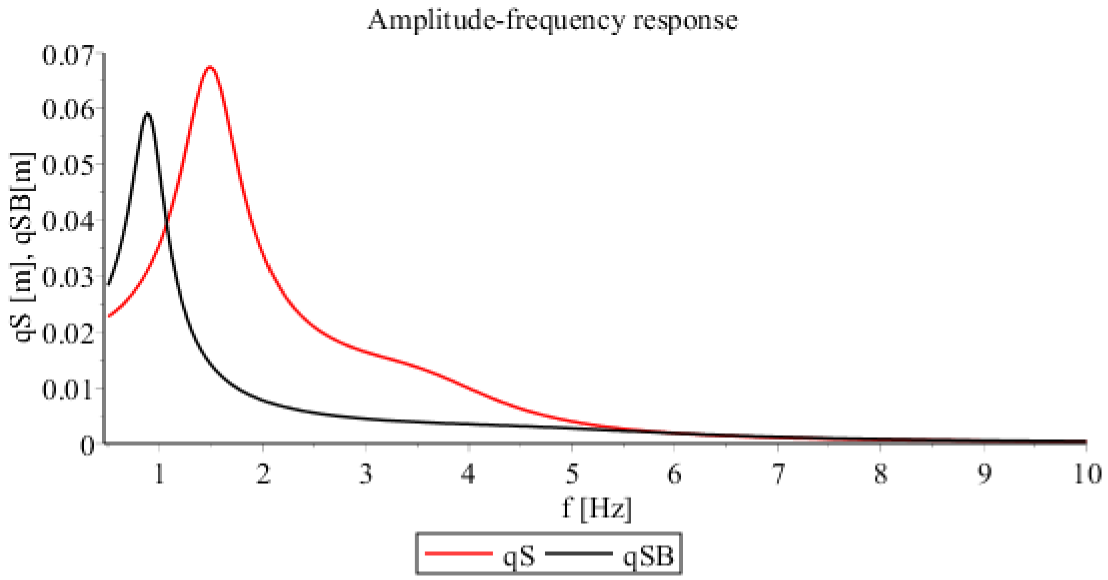

Fig.4 Amplitude-frequency response

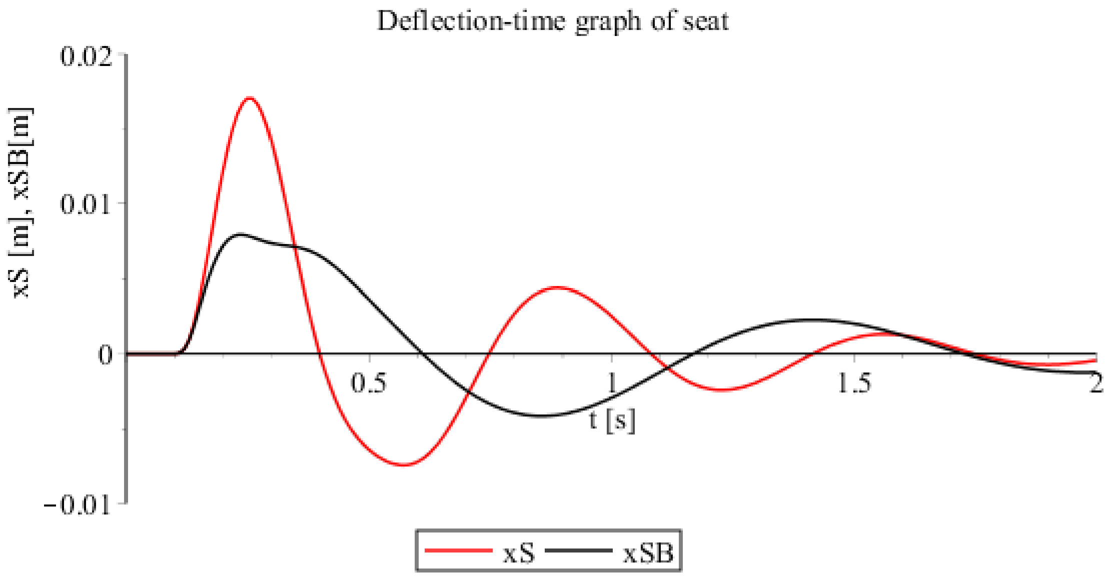

Fig.5 Step response of systems – deflection-time graph

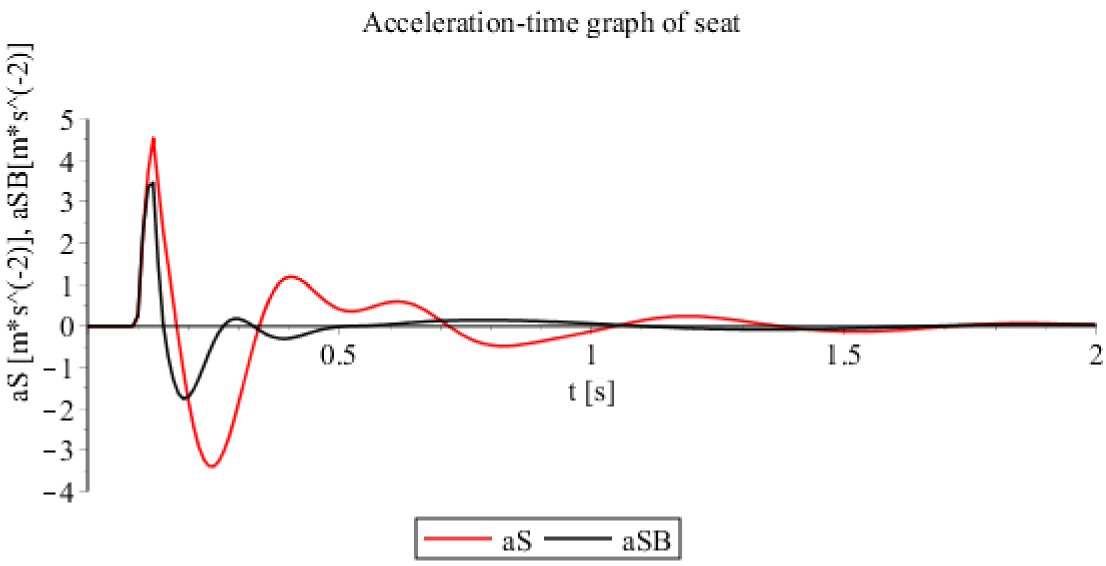

Fig.6 Step response of systems – acceleration-time graph

Driving golf cart on uneven terrain of golf court leads to non-periodic and non-harmonic vibration. In simplified way this vibration can be represented by separated step functions. The deflection u in differential equations Eq. 1, Eq. 2, Eq. 4 and Eq. 5 can be substituted by reference step signal. Decisive for evaluation of effect increasing seat inertia is reference step response of systems, amplitude-frequency response shown in Fig. 4 should be taken as additional.

For evaluation of effect of vibration on comfort in accordance with [1] is decisive acceleration-time graph of seat as reference step response (Fig. 6).

Evaluation of Transmitted Vibration

The system of electric golf cart without suspension seat can be described in simplified way by differential equation:

$$m_R.\ddot{x}_{RS}+b_R.(\dot{x}_{RS}-\dot{u})+k_R.(x_{RS}-u)=0, \quad (6)$$

where x_{RS} is deflection of frame with seat.

In Fig. 7 the differential equation Eq. 6 is described.

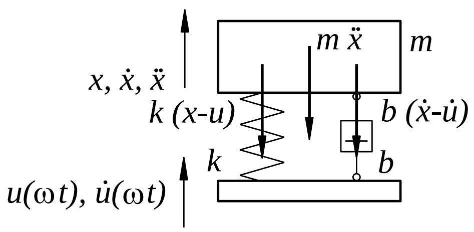

Fig.7 Description of system with one DOF

The result of solved differential equations Eq. 1, Eq. 2 and Eq. 6 is reference step response of systems. Acceleration-time graph of suspension seat and seat tightly connected to golf cart frame is shown in Fig. 8.

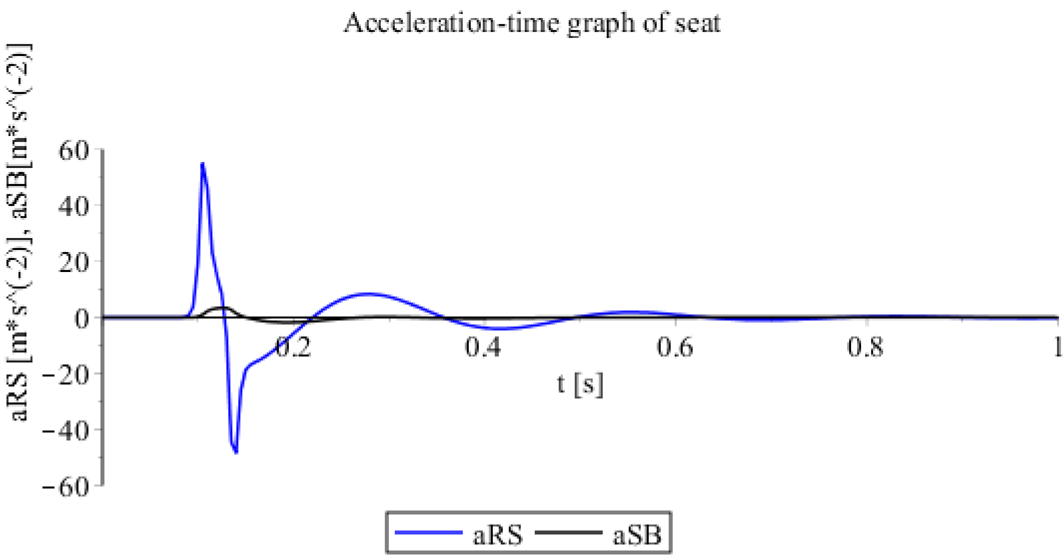

Fig.8 Step response of systems – acceleration-time graph

Conclusion

The paper deals with current issue of vibration isolation of golf cart seat. The solution uses invention idea of increase inertia of tightly connected mass to seat. This allows significantly reduce vibration transmitted from golf cart wheels to driver and passenger.

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