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Shaking moment cancellation of self-balanced slider–crank mechanical systems by means of optimum mass redistribution

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Abstract

This paper deals with a solution of the problem of shaking moment cancellation of self-balanced slider–crank systems. The conditions for shaking moment balancing are formulated by using the copying properties of the pantograph linkage and the method of dynamic substitution of distributed masses by concentrated point masses. The suggested solution is illustrated by a numerical example.

Keywords: Dynamics of mechanisms; Balancing; Vibration; Shaking force; Shaking moment

1. Introduction

In high-speed machines, shaking force and shaking moment, which are generated by an unbalanced mechanism bring about variable dynamic loads on the frame and, as a result, vibrations. One of the most effective means for the reduction of these vibrations is the mass balancing of moving links of mechanisms (Lowen and Berkof, 1968; Arakelian and Smith, 2005; Arakelian et al., 2000; Arakelian and Dahan, 2000; Arakelian et al., 2002; Arakelian and Dahan, 2001; Arakelian and Smith, 1999). The balancing in machines can be achieved by counterweights mounted on the movable links (Dresig, 2001), by counter-rotating masses mounted on the gears (Chiou and Tzou, 1997, 1998), by added dyads (Yu, 1988; Arakelian, 1998) or by opposite movements (Arakelian and Smith, 2005; Arakelian, 1998). The latter carried out by addition of an axially symmetric duplicate mechanism will make the new combined center of mass stationary and thus balance the shaking force.

Fig. 1 shows well-known self-balanced mechanical system, in which two identical slider–crank mechanisms execute similar but opposite movements (see Dresig, 2001). Such mechanical systems found a successful application in engines, agricultural machines, mills, and in various automatic machines.

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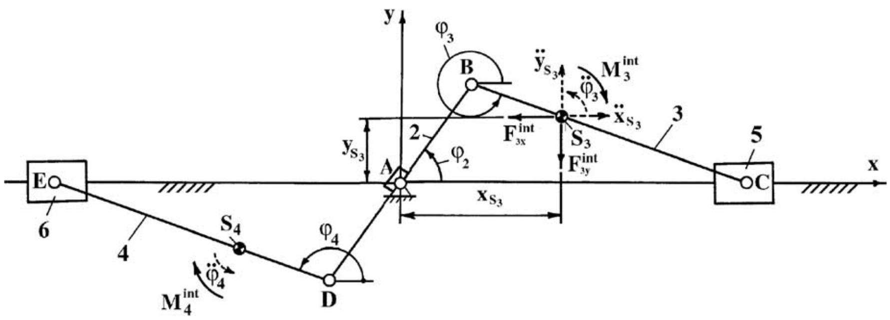

Fig. 1. Self-balanced slider–crank system.

In this mechanical system the symmetry relative to the input crank achieves the complete shaking force balancing. However, the shaking moment of such a system is not balanced and it can be presented for the mechanism with constant input angular velocity ($\dot{\varphi}_2 = \text{const}$) by the following expression:

$$M^{\text{int}} = -\sum_{i=3}^{4} I_{S_i}\ddot{\varphi}_i - \sum_{i=3}^{4} m_i \ddot{y}_{S_i} x_{S_i} + \sum_{i=3}^{4} m_i \ddot{x}_{S_i} y_{S_i} \tag{1}$$

where I_{S_i} is the moment of inertia relative to the center of mass S_i of the connecting coupler ($i = 3, 4$); $\ddot{\varphi}_i$ is the angular acceleration of the connecting coupler; m_i is the mass of the connecting coupler; $\ddot{x}_{S_i}$ and $\ddot{y}_{S_i}$ are the linear accelerations of the center of mass S_i along the x and y axes; x_{S_i} and y_{S_i} are the coordinates of the center of mass S_i along the x and y axes.

It should be noted that the shaking moment (1) is independent of the reference point because the shaking force is fully balanced.

2. Shaking moment cancellation using the copying properties of the pantograph

Fig. 2 shows a self-balanced slider–crank system with an imagined articulation dyad $B'D'E$, which forms a pantograph with the initial system. The similarity factor of the formed pantograph is $k = l_{AD}/l_{AB} = 1$ and $l_{BB'} = l_{DD'}$, $l_{B'D'} = l_{AD} + l_{AB}$.

By substituting dynamically the mass m_3 of the connecting coupler 3 by point masses at the centers B, B' and C and using following condition

$$\begin{bmatrix} 1 & 1 & 1 \\ l_{BS_3} & -l_{CS_3} & l_{B'S_3} \\ l_{BS_3}^2 & l_{CS_3}^2 & l_{B'S_3}^2 \end{bmatrix} \begin{bmatrix} m_B \\ m_C \\ m_{B'} \end{bmatrix} = \begin{bmatrix} m_3 \\ 0 \\ I_{S_3} \end{bmatrix} \tag{2}$$

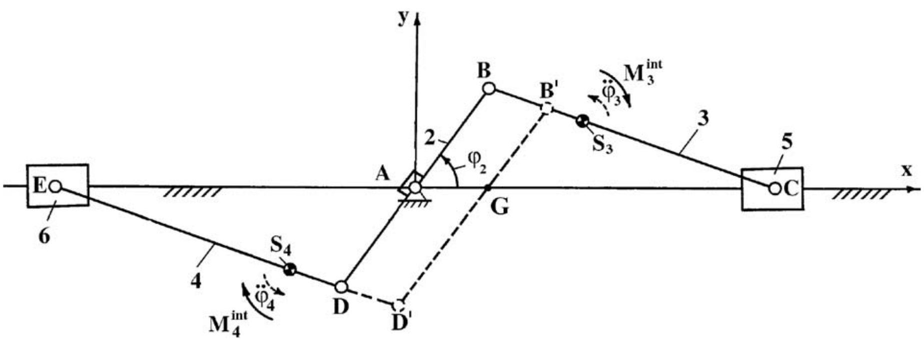

Fig. 2. Self-balanced slider–crank system with an imagined articulation dyad B′D′E.