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A modified method of vibration surveillance by using the optimal control at energy performance index

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ABSTRACT

A method of vibration surveillance by using the optimal control at energy performance index has been creatively modified. The suggested original modification depends on consideration of direct relationship between the measured acceleration signal and the optimal control command. The paper presents the results of experiments and Hardware-in-the-loop simulations of a new active vibration reduction algorithm based on the energy performance index idea modified in such a way, that it directly utilises the acceleration feedback signal. Promising prospects towards real application of the modified method in case of the high speed milling are predicted as well.

1. Introduction

The performed former experiments evidenced that the active vibration control of flexible plates produces promising results in scope of reducing vibration level [1]. The energy performance index [2] was utilised with success earlier, in case of the spindle speed optimal control during high speed milling [3]. However, in case of accelerometer-based vibration measurement, the algorithm of signal processing meets a lot of difficulties due to necessity of integrating instantaneous acceleration values. Thus the main goal of this paper is to develop a method of on-line vibration surveillance, which is thought to be competitive with respect to previous attempts towards control of non-stationary discrete systems. The latter depends on usage of direct acceleration feedback in the algorithm.

The used control algorithms for computing control signal in the active vibration reduction purposes often utilise integration of velocity or acceleration signal [4]. The results of other research on a cantilever beam vibration control disclosed that active damping is efficient only in case of generating acting force with a use of the derivative controller during the displacement measurement [5]. In publication [1], for vibration damping the Authors proposed the energy performance index method [6], which was earlier applied with success i.e. for the optimal spindle speed generation during the High Speed Machining surveillance [3], as well as—for the motion control of wheeled mobile platforms along the planned trajectories [6,7]. The performed experiments proved that active vibration damping of flexible plates is possible and provides positive results [1]. However, further development showed that the practical use of the algorithm meets some problems related to acceleration signal filtration and integration. Due to this, an approach in which direct acceleration feedback is used within control algorithm is proposed [8].

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A set of intentional activities, aimed at securing the desired performance of a vibration process, is called vibration surveillance [2,3,6]. The surveillance of vibration depends upon monitoring of physical quantities, which affect the process quality (e.g. vibration level, amplitude of displacements), and generation of instantaneous values of control command, in accordance with the applied proper rule.

The group of active damping methods has a great potential for possible applications in scope of linear non-stationary systems. That is why the main goals of this paper are:

– to develop a modified method of the optimal control at energy performance index, on a basis of the direct acceleration feedback [8],
– to evidence that the proposed method of active optimal control is really efficient, in the scope of the real structures vibration surveillance.

Three measures of the vibration reduction are applied and it is expected that comparing to a system without active damping [9]:

– dimensionless damping coefficient should be increased,
– peak values in the vibration amplitude spectrum should be reduced,
– vibration time should be shortened as well.

However, an incremental formulation of the energy performance index depends upon the state feedback interaction [6]. In case of acceleration measurement the latter requires time-domain integration. There are a lot of approaches concerning the acceleration feedback, but performed in the frequency domain [10], or even—referred to the delayed closed loop systems [11]. Thus, determination of the optimal control command based upon energy performance index has been modified in such a way that it utilises only time-domain acceleration feedback, without necessity of integration of the above [8].

2. Optimal control of non-stationary system at energy performance index

2.1. Matrix description

Non-stationary controlled dynamic system with n degrees of freedom is a system, whose properties are described by inertia matrix $\mathbf{M}^*_{(n\times n)}$, damping matrix $\mathbf{L}^*_{(n\times n)}$, stiffness matrix $\mathbf{K}^*_{(n\times n)}$, vector of generalised displacements $\mathbf{q}^*_{(n\times 1)}$, vector of generalised forces $\mathbf{f}^*_{(n\times 1)}$, matrix of control commands $\mathbf{B}^*_{u(n\times p)}$, and vector of control commands $\mathbf{u}_{(p\times 1)}$, where p is a number of control commands [6]. Thus we obtain the following matrix equation describing behaviour of the system, i.e.:

$$\mathbf{M}^*(t)\ddot{\mathbf{q}}^* + \mathbf{L}^*(t)\dot{\mathbf{q}}^* + \mathbf{K}^*(t)\mathbf{q}^* = \mathbf{f}^*(t) + \mathbf{B}^*_u(t)\mathbf{u} \tag{1}$$

For convenience, we omit in further notations of matrices $\mathbf{M}^*$, $\mathbf{L}^*$, $\mathbf{K}^*$, $\mathbf{f}^*$ and $\mathbf{B}_u$ their dependence of time.

Subsequently we can describe behaviour of such controlled non-stationary system in state coordinates [6]:

$$\begin{cases} \dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{D}\mathbf{z} + \mathbf{B}\mathbf{u} \\ \mathbf{y} = \mathbf{C}\mathbf{x} + \mathbf{w} \end{cases}, \tag{2}$$

where

$\mathbf{x} = \left[\dot{\mathbf{q}}^{*T}\ \mathbf{q}^{*T}\right]^T_{2n\times 1}$ —vector of state coordinates,

$\mathbf{A} = \begin{bmatrix} -\mathbf{M}^{*-1}\mathbf{L}^* & -\mathbf{M}^{*-1}\mathbf{K}^* \\ \mathbf{I} & \mathbf{0} \end{bmatrix}_{2n\times 2n}$ —state matrix,

$\mathbf{D} = \begin{bmatrix} \mathbf{M}^{*-1} \\ \mathbf{0} \end{bmatrix}_{2n\times n}$ —matrix of disturbances,

$\mathbf{B} = \begin{bmatrix} \mathbf{M}^{*-1}\mathbf{B}^*_u \\ \mathbf{0} \end{bmatrix}_{2n\times p}$ —input matrix,

$\mathbf{C}_{q\times n}$ —output matrix,
$\mathbf{z} \equiv \mathbf{f}^*$ —vector of disturbances,
$\mathbf{y}_{q\times 1}$ —vector of outputs, i.e. measured responses of a system,
$\mathbf{w}_{q\times 1}$ —vector of the measurement noise.

In particular case, when all components of the generalised displacement' vector $\mathbf{q}$ are registered, then $\mathbf{y} \equiv \mathbf{q}$.