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A STUDY OF ACTIVE VIBRATIONS DAMPING WITH THE APPLICATION OF ACTIVE TOOL

The article represents a short overview of solutions available on the market, which allow for vibrations damping during the machining process. The description also provides information on the essence of chatter vibrations. The next part of the following paper includes the model of active machine tool based on piezoelectric actuator with work piece and the model of machining process. Next, the results of simulation research are presented for two control systems. All simulations were carried out in Matlab Simulink Software.

Key words: vibrations damping, active tool, LMS, piezo actuator, external modulation.

1. INTRODUCTION

Contemporary technology, research and its application place a growing emphasis on the quality, roughness and precision of produced details. This concerns nearly every area of life and science from aircraft industry through automotive and electronic or optical industry. The question of vibration is closely related to the precision of cutting details, where the control of vibrations is of a great importance. In order to achieve active vibration damping, piezoelectric actuators are often used because of their advantages such as: low weight, little dimensions and the fact they may work with wide bandwidth of frequency. Multilayer piezo-stacks actuators are used in active tools. Thanks to emplacing piezo actuator in tool which is designed especially for this purpose, it

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is possible to assemble the tool in the lathe relatively easily as it is not necessary to interfere with the control system and kinematic structure of the machine.

2. WHAT ARE CHATTER VIBRATIONS?

Researchers have been showing interest in the chatter effect for more than a hundred years now. In 1940s first hypotheses regarding this effect were formulated and researchers provided the first evidence of chatter. While carrying out the research on the chatter vibrations, investigators started to think on how to effectively damp them. One of the pioneer in this branch was R. N. Arnold, who described the effect of chatter and made up one of the first mathematical descriptions with the help of mathematical equations [2]. Chatter vibrations may be attributed to the effect of dynamic chip thickness. Vibrations occur due to lapping frequency from cutting force and natural frequency tool and piece. This causes a deterioration in the quality of the cut surface, faster consumption of the tool, decreasing efficiency of machining process and escalation of noise, leading in some cases even to the destruction of the tool [3], [4]. External modulation has a highly adverse impact on the machining process; this phenomenon arises when the tool, after the first crossing, comes across some micro roughness during the second crossing [5].

3. MATHEMATICAL MODEL OF ACTVIE TOOL

In order to carry out an analysis of tools' behavior, it is necessary to make a simulation model based on mathematical model, which is comprised of differential equations. The mathematical model comprises the following sets: the tool, cutting force and work piece.

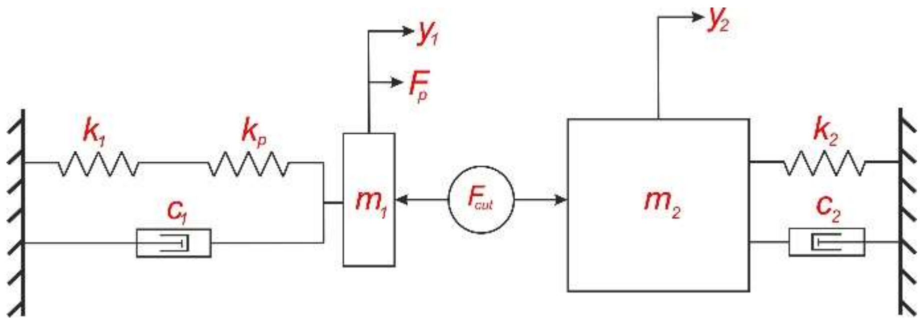

Fig. 1. Model of system: tool – cutting force - piece

The simplified model presented above includes the previously mentioned model of tool, cutting force and the model of work piece. The model provided above presents stiffness k_1, which is stiffness coefficient of the tool material and coefficient k_p, which is the stiffness of piezoelectric actuator. Figure 1 presents also dumping coefficient c_1 and the mass of tool m_1. Cutting force F_{cut} affects the tool and work piece in opposite directions, appended piezoelectric actuators generate additional force F_p. Work piece represents: mass m_2, stiffness coefficient of work piece material and dumping c_2. y_1 and y_2 variables set out temporary displacement of tool and work piece. To simplify the picture, the drawing presents only one x – direction. On the basis of the assumptions presented above, mathematical equations were derived:

$$\begin{cases} \frac{dx_1}{dt} = \dot{y}_{x_1} \\ \frac{dx_4}{dt} = -(\frac{k_1 k_p}{(k_1 + k_p)m_1}) y_{x_1} - \frac{c_1}{m_1}\dot{y}_{x_1} + \frac{F_p - F_{cut_x}}{m_1} \\ \frac{dx_2}{dt} = \dot{y}_{y_1} \\ \frac{dx_5}{dt} = -(\frac{k_1 k_p}{(k_1 + k_p)m_1}) y_{y_1} - \frac{c_1}{m_1}\dot{y}_{y_1} + \frac{F_p - F_{cut_y}}{m_1} \\ \frac{dx_3}{dt} = \dot{y}_{z_1} \\ \frac{dx_6}{dt} = -(\frac{k_1 k_p}{(k_1 + k_p)m_1}) y_{z_1} - \frac{c_1}{m_1}\dot{y}_{z_1} + \frac{F_p - F_{cut_z}}{m_1} \\ \frac{dx_7}{dt} = \dot{y}_{x_2} \\ \frac{dx_{10}}{dt} = -\frac{k_2}{m_2} y_{x_2} - \frac{c_2}{m_2}\dot{y}_{x_2} + \frac{F_{cut_x}}{m_2} \\ \frac{dx_8}{dt} = \dot{y}_{y_2} \\ \frac{dx_{11}}{dt} = -\frac{k_2}{m_2} y_{y_2} - \frac{c_2}{m_2}\dot{y}_{y_2} + \frac{F_{cut_y}}{m_2} \\ \frac{dx_9}{dt} = \dot{y}_{z_2} \\ \frac{dx_{12}}{dt} = -\frac{k_2}{m_2} y_{z_2} - \frac{c_2}{m_2}\dot{y}_{z_2} + \frac{F_{cut_z}}{m_2} \end{cases} \quad (1)$$

In order to synthetize control system comfortably, a model of the system with the application of state space is introduced:

$$\dot{x} = Ax + Bu \tag{2}$$

$$y = Cx + Du \tag{3}$$

where state vector and vector of inputs are:

$$x = \begin{bmatrix} y_{x_1} \\ y_{y_1} \\ y_{z_1} \\ \dot{y}_{x_1} \\ \dot{y}_{y_1} \\ \dot{y}_{z_1} \\ y_{x_2} \\ y_{y_2} \\ y_{z_2} \\ \dot{y}_{x_2} \\ \dot{y}_{y_2} \\ \dot{y}_{z_2} \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \\ x_9 \\ x_{10} \\ x_{11} \\ x_{12} \end{bmatrix} \qquad u = \begin{bmatrix} F_{cut_x} \\ F_{cut_y} \\ F_{cut_z} \\ V \\ 0 \\ 0 \end{bmatrix} \tag{4}$$

Symbols F_{cut_x}, F_{cut_y}, F_{cut_z} are cutting forces on x, y and z directions. Cutting force depends on: the width of cutting layer, the value of feed, coefficient of proper resistance of machining and temporary vector of displacement. As it was mentioned above, piezoelectric actuator generates force F_p which is made up of: $n-$ quantity of stocks, $d_{33}-$ piezoelectric constant, k_p- stiffness of piezoelement and voltage $V-$ which is one of the inputs included in vector u.

4. x-LMS CONTROL

X-LMS control algorithm is one of the optimization and adaptive control systems. Contrary to e.g. LQG control algorithm, least mean square algorithm is not based on a model of the controlled object. Therefore adaptive properties of the control system enable a more effective adaptation to the shifting conditions of the machining process. LMS (least mean square) adaptive algorithm utilizes a finite response impulse filter as an input with signal of error and reacts to the feed forward loop. Coefficients h of FIR filter are not constant in time and they tune themselves in a way that output signal $y(n)$ approaches a state where it would be equivalent to the noise in signal $d(n)$. Coefficients h are shifted in FIR filter with every registered sample. To actual values of h vector corrected values are appended and they are calculated with the application of LMS algorithm, which is demonstrated in equation 5 [9].

$$H(n+1) = H(n) + \Delta H \tag{5}$$

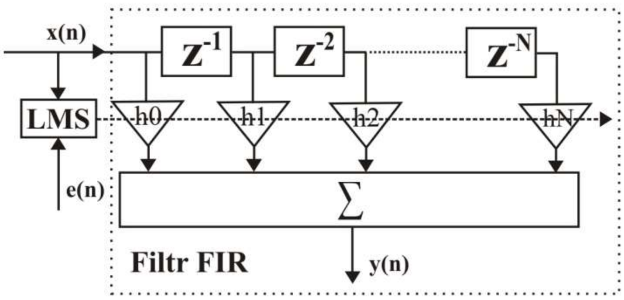

Fig. 2. Diagram of LMS control

The algorithm is based on the gradient decent approach to correlated noise cancellation. As a gradient decent algorithm, the intent of the algorithm is to extract or de-correlate a reference signal from an input signal containing correlated reference signal components [9].

$$e(n) = -C(q)W(n,q)q^{-1}e(n) + d(n) \tag{6}$$

$$\nabla e^2(n) = -c(n) * \begin{bmatrix} e(n-1) \\ e(n-2) \\ \vdots \\ e(n-M \end{bmatrix} e(n) \tag{6}$$

The LMS algorithm operates on the quadratic error performance surface defined in (6). There are two classical processes in which the algorithm chases the minimum of the quadratic performance surface: the Newton and the steepest decent process [9].

3. SIMULATIONS

Based on the arguments presented above, simulations were carried out with the aid of Matlab and Simulink software. Simulink's model contains: two control systems - LQG and previously described x-LMS working in close loop of control system, model of tool, cutting force and working piece defined by state space and effect of dynamic chip thickness model. Presented findings were achieved for the following parameters:

rotational speed of spindle – 250 rpm
feed – 0,6 [mm per turn]
width of cutting layer – 1,2 [mm]
machining material – steel S420N

Additionally, it was assumed that stiffness of the work piece is lower than the stiffness of tool. The signal in control loop is derived from one direction.

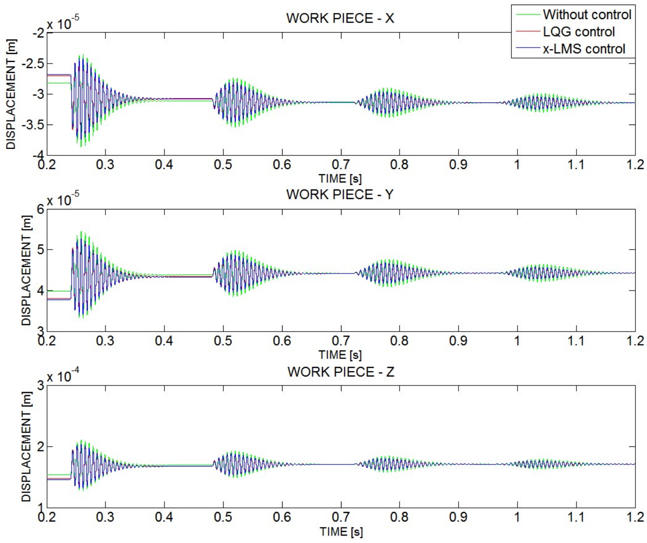

Fig. 3. Displacement of work piece in time domain for X-Y-Z axis

As it is presented on figure 3, the amplitude of the displacement of the work piece without control on X axis is higher than for x-LMS control system by about 0.029 mm. Thereby the disparity of displacement between simulation with active control and without control on Y axis amounts to 0.048 mm while on the Z axis it amounts to a mere 0.0053 mm. Displacements of the work piece on all axes for both control systems (LQG and x-LMS) are approximately the same.

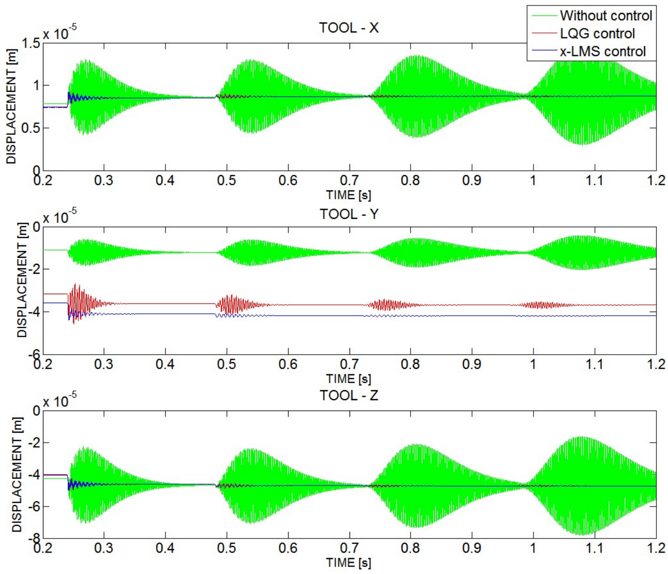

Fig. 4. Displacement of tool in time domain for X-Y-Z axis

In turn, figure 4 presents the results put forward for tool displacement. It can be immediately noticed that the effectiveness of control system is significant. Thanks to using LQG and x-LMS system, the improvement achieved on axis X amounted to about 0.009 mm. The improvement achieved on axis Y amounted to about 0.0012 mm for LQG control and to 0.035 mm for x-LMS control. In turn, the improvement achieved on Z axis for both control systems equaled 0.022 mm. It is also worth noting that the amplitude of vibrations without control has risen.

The efficiency of adaptive and optimal control systems is confirmed also by Fig. 5. presented below which represents the cutting force on all three axes. On every axis the cutting force decreases by nearly 15 N, which is important for the machining process and the durability of the tool.

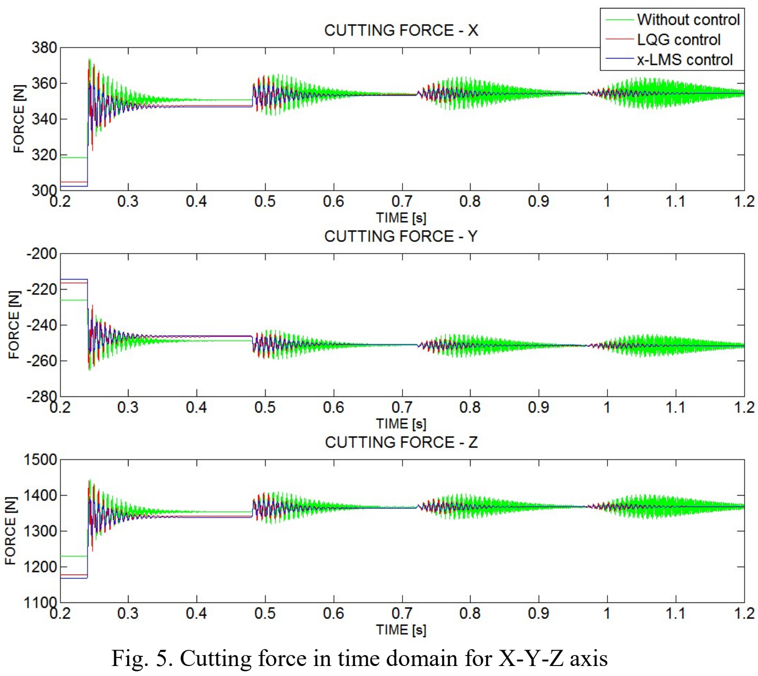

Fig. 5. Cutting force in time domain for X-Y-Z axis

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ANALIZA AKTYWNEJ KONTROLI TŁUMIENIA DRGAŃ Z ZASTOSOWANIEM AKTYWNEGO NARZĘDZIA

Artykuł stanowi krótki przegląd rozwiązań dostępnych na rynku, pozwalających tłumić drgania w trakcie obróbki skrawaniem. W opisie można również znaleźć informacje dotyczące istoty drgań samowzbudnych. Kolejną cześć artykułu stanowi model aktywnego narzędzia na bazie piezoelektrycznego siłownika wraz z przedmiotem obrabianym oraz modelem procesu skrawania. Następnie zaprezentowane zostały wyniki badań symulacyjnych dla dwóch układów sterowania (LQG, LMS). Całość symulacji przeprowadzona została w środowisku Matlab Simulink..

Słowa kluczowe: tłumienie drgań, aktywne narzędzie, LMS, piezo siłownik, regeneracja śladu