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Procedia Engineering 206 (2017) 157–162

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2017

Influence of Kinematic Perturbations on Shape-generating Movement Trajectory Stability

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Abstract

The article considers the influence of kinematic perturbations on stability of the tool shape-generating movement trajectory on the part of the turning machine executive element. The case of a lengthwise turning is considered. The trajectories of shape-generating movement consist of machine actuators motion trajectories and tool tip and detail elastic deformations displacements relative to the machine carrier system. The perturbations of machine actuators motion trajectories are determined by kinematic disturbance which depends on the accuracy and the state of the cutting-machine tool. They are determined by radial and axial spindle beating and speed variations of the support drive longitudinal movement in relation to the ideal axis of rotation parts and its displacement coordinates. Mathematical models of the cutting process perturbed dynamics are shown. By means of numerical simulation, it was shown that kinematic perturbations fundamentally alter the stability properties of the stationary shape-generating movement trajectories by parametric self-excitation.

Keywords: *dynamic quality of turning proces; kinematic perturbations; stability of shape-generating trajectories.*

1. The problem statement

The accuracy of metal-cutting machine depending on its condition influence on the possibility of the manufacture of the parts of given quality is considered [1-4]. The geometric deflection of control displacements of executive elements is focused on in the definition of accuracy. They are perturbing executive elements movement, distort trajectories specified by controls and influence on dynamic quality of cutting process. The stability of trajectories

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10.1016/j.proeng.2017.10.453

movement of tool relative to part are analyzed based on the definition of dynamic quality, and attracting set generated in their vicinity is also considered [5-15]. As determined as stochastic models are considered [16,17]. It is shown that the kinematic perturbations modify tool trajectory with respect to detail through their transformation by the elastic system of machine according to dynamic feed formed of cutting process [18-20]. However, the kinematic perturbations modify not only trajectories but influence on their stability. In this article the authors investigate the influence of kinematic perturbations on stability of motion.

2. The justification of mathematical models

To analyze the stability it is necessary to consider the equation of dynamic cutting process took into account strain creep of tool in movable coordinate system of support movement and spindle rotate without kinematic perturbations. Let's limit to the case of a lengthwise turning with fixed programming technical regimes such as frequency of spindle $\Omega_0 = 1/T = const$ therefore, programmed speed of cutting $\mathrm{V}_{0,2} = \mathrm{const}$, speed of lengthwise $\mathrm{V}_{0,3} = \mathrm{const}$, speed of transverse motion equals zero, value allowance $t_P^{(0)} = const$.

Treatment is being carried out by tool with main angle in plane $\phi = \pi/2$ (fig. 1). Origin of coordinates is considered in point of the tool contact trip with detail on the assumption that there are no elastic deformations. Let's limit to the case of a perfect rigid body treatment. The properties of this system have already been studied previously [8] – [11]. There is necessity to add additional perturbations to the executive element movement trajectories unrelated with control and being periodic function of time. They are defined by radial and axial spindle beats and also variations of lengthwise speed and errors of support position relative to the axis of tool rotation. The elastic deformations $\mathrm{X} = \{\mathrm{X}_1, \mathrm{X}_2, \mathrm{X}_3\}^{\mathrm{T}} \in \Re^3$ are considered in space. In this case the dynamic cutting system equations [21] is

$$m\frac{d^2X}{dt^2} + h\frac{dX}{dt} + cX = F(X, \frac{dX}{dt}, t_{p,\Sigma}, V_{2,\Sigma}, V_{3,\Sigma}) \qquad (1)$$

where $m = [m_{s,k}]$, $m_{s,k} = m,$ with $s = k, m_{s,k} = 0,$ if $s \neq k$ then $s,k = 1,2,3$, $h = [h_{s,k}], s,k = 1, 2, 3,$ $c = [c_{s,k}], s, k = 1, 2, 3$ - symmetric and positive-definite matrix of inertial, speed and elastic coefficient; $F(X, \frac{dX}{dt}) = \{F_1(X, \frac{dX}{dt}, t_{P,\Sigma}, V_{2,\Sigma}, V_{3,\Sigma}), F_2(X, \frac{dX}{dt}, t_{P,\Sigma}, V_{2,\Sigma}, V_{3,\Sigma}), F_3(X, \frac{dX}{dt}, t_{P,\Sigma}, V_{2,\Sigma}, V_{3,\Sigma})\}^T$. Here are $t_{P,\Sigma}(t) = t_P^{(0)} + \Delta t_P(t)$, $V_{2,\Sigma}(t) = V_{2,0} + \Delta V_2(t)$, $V_{3,\Sigma}(t) = V_{3,0} + \Delta V_3(t)$ - functions of variations allowance trajectory $t_P^{(0)}(t)$, cutting speeds $V_{2,\Sigma}(t)$ and lengthwise feed $V_{3,\Sigma}(t)$, consist of constants $t_P^{(0)}$, $V_{2,0}$, $V_{3,0}$ and variations $\Delta t_P(t) = X_1^{(0)}(t) + Z_1(t)$, $\Delta V_2(t) = dZ_2(t)/dt$, $\Delta V_3(t)$ (kinematic perturbations (fig.1)).

The forces in the state coordinates should be provided hereafter [22], [23]. The forces generating in the area of the tool front face $F^{(1)} = F_0^{(1)}\{\chi_1, \chi_2, \chi_3\}^T$, and forces $F^{(2)} = F_0^{(2)}\{0,0,1\}^T$ and $F^{(3)} = F_0^{(3)}\{1,0,0\}^T$ are acting on the tool back face are described (fig.1). Here $\{\chi_1, \chi_2, \chi_3\}^T$ are slope coefficient of force orientation $F^{(1)}$. The forces $F^{(2)}$ and $F^{(3)}$ are orientated in a directions X_3 and X_1. Let's pretend $F_0^{(1)}$, $F_0^{(2)}$ and $F_0^{(3)}$ in the state coordinates [21-23]

$$\begin{cases} F_0^{(1)} = \rho_0\{1 + \mu \exp[-\alpha_1(V_{0,2} + \Delta V_2(t) - v_2(t))]\}\{t_P^{(0)} + \Delta t_P(t) - X_1\}\{\int\limits_{t-T}^{t}[V_{0,3} + \Delta V_3(\xi) - v_3(\xi)]d\xi\}; \\ F_0^{(2)} = F_{0,3}\exp\alpha_2[V_{0,3} + \Delta V_3(t) - v_3(t)]; \\ F_0^{(3)} = F_{0,1}\exp\alpha_3[\Delta V_1(t) - v_1(t)], \end{cases} \qquad (2)$$