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System Synthesis of Machine Tool Manufacturing Process Control Based on Synergetic Conception

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Abstract

The paper presents a new concept of synergetic control synthesis (NC programs) in machine tools machining. It discusses the issues using the synergetic management concept in the unity of the state space expansion and compression. Constructing a hierarchy system of differential equations for the controlled system is discussed as well. The paper presents synthesis of control law as the selecting the optimal trajectory on the manifold of technologically admissible trajectories. An example of such selection for longitudinal turning is presented. The approach seems particularly effective when it comes to machining low-rigid and geometrically complex parts.

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Keywords: Synergetics; dynamics; stability; evolution; self-organization; control; machine tool; quality.

1. Introduction

To illustrate system approach let us confine to the case of lathe turning. In most modern CNC machines feed based on servo DC drives are used. We assume that we are given three adjustable drives for moving three elements: a support of longitudinal and transverse movements and a rotating spindle (fig. 1).

The equations of motion of DC motors in linearized statement can be written as:

$$T_{EM} T_E \Omega'' = (c_e)^{-1} (U - U_C) - T_{EM} \Omega' - E\Omega \qquad (1)$$

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where $\Omega = \{\Omega_1, \Omega_2, \Omega_3\}^T$ - vector of rotation frequencies;. $U = \{U_1, U_2, U_3\}^T$ - vector of servomotors armatures tensions; $U_C = \{U_{C,1}, U_{C,2}, U_{C,3}\}^T$ - resisting moments $M_C = \{M_{C,1}, M_{C,2}, M_{C,3}\}^T$ vector, reduced to servomotors electrical parts; $T_{EM} = [T_{EM,i}]$, $T_E = [T_{E,i}]$ - diagonal matrixes; $T_{EM,i} = (J_i R_i)/(c_{m,i} c_{e,i})$ - electromechanical time constant of i-th motor; $T_{E,i} = L_i / R_i$ - electric time constant; J_i, L_i, R_i, $c_{m,i}$, $c_{e,i}$ - servomotors characteristics;

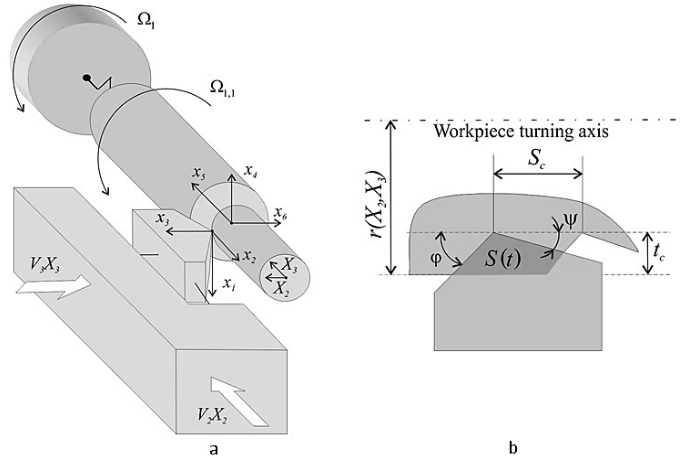

Fig. 1. (a) Simplified dynamic model of turning process; (b) scheme of a shear area forming.

$U_{C,i} = R_i / c_m \left[M_{C,i} + T_{E,i} \left(M_{C,i} \right)' \right]$, $M_c^{(i)}$ - shaft resisting moment of i-th motor. Operation $\{\cdots\}^T$ - is a transposition operation, $i = \overline{1,3}$, E - unit diagonal matrix.

Traditional approach regards functional elements drives as autonomous. U_C is considered as disturbance which is not interconnected with system state coordinates. As opposed to traditional approach, synergetic conception of system analysis is based on state space expansion-compression principle [1].

2. State space expansion principle

Procedure of the state space expansion [2, 3] corresponds to representation of U_C in coordinates of system state space. Therefore all elements that connect machine function elements with cutting process must be included into control object. Resisting moment U_C is formed as the result of the interaction between the supplemented coordinates of the expanded system and different constraints. The main ones are constraints formed in friction units [3, 4], and the constraints formed in the cutting area [5, 6].

We illustrate the procedure of the state space expansion on the example of the main connection characterizing a metal cutting machine. This is the interconnection of the machine subsystems through the cutting process [7].

Suppose that the trajectories of motion of the machine executive elements as the phase trajectories $V_2(X_2)$, $V_3(X_3)$, and the trajectory of the spindle speed in the function of the executive elements coordinates X_2, X_3 are given. In addition, we assume that the frequencies $\Omega = \{\Omega_2, \Omega_3\}^T$ are proportional to the executive elements speed: $V_2 = k_2 \Omega_2$, $V_3 = k_3 \Omega_3$. The rotor of the main drive is elastically connected with the workpiece. Therefore,

$$M_{C,1} = c_\alpha (\alpha_1 - \alpha_{1,1}) = c_\alpha \Delta\alpha \quad (2)$$