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Developing of the Look Ahead Algorithm for Linear and Nonlinear Laws of Control of Feedrate in CNC

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Abstract—The problem of forming motion speed control and its solution in numerical control systems are investigated. A look ahead algorithm algorithm based of simple kinematic equations is offered, which is not sensitive to the instability of the cycle of data exchange with drivers. The results of algorithm's application in a real-world CNC system are included.

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1. INTRODUCTION

Toughening of requirements to tolerance of production of industrial workpieces results in need of increase in accuracy of operation of the machine equipment [1]. Within the CNC system this problem comes down to ensuring accuracy of try out of the movements set by the operating program. In the CNC systems the principle of conveyor processing of programs [2] according to which commands will consistently be transformed to the operating signals at the system output is implemented. At the same time two problems are solved:

a) formation of a command position (the coordinates corresponding to a programmable contour with a certain accuracy);

b) formation of command speed taking into account the extreme values of acceleration and jerk (acceleration derivative) corresponding to the set kinematic restrictions.

The CNC system carries out generation of the high-frequency sequence of command signals on the basis of the set program and machine parameters.

2. APPROACHES TO REALIZATION OF THE MECHANISM OF MOTION CONTROL

Classical approach to realization of the mechanism of motion control assumes the analysis of frames of the operating program in their initial form (Fig. 1, version A). The module of the forward frames scanning carries out calculation of the admissible speed in the current point of a contour on the basis of geometrical data of neighbour frames of the operating program [3]. Each type of a frame (linear, circular, different types of splines) requires its own analysis algorithm that complicates strict control of acceleration and jerk throughout a frame (and not just in joint points), especially at multicoordinate transformations.

Other approach provides crushing of frames of the operating program on linear segments (Fig. 1, version B) for the purpose of reduction of a contour to a mathematical form, simple for the analysis.

The interpolator when crushing will transform each frame to a linear segment which length is defined by the set accuracy and part presentation. As a result the module of the forward scanning

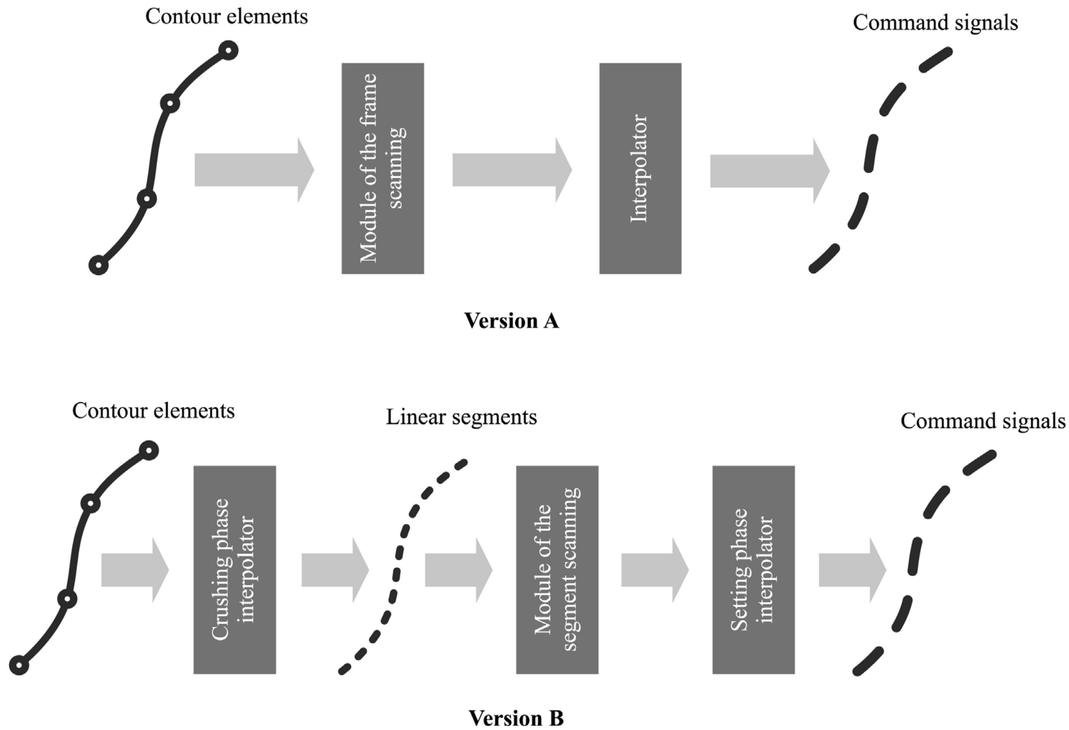

Fig. 1. Two approaches to motion control.

and the interpolator calculating command values when calculating speed and realizing kinematic transformations operate with uniform linear elements of a contour [4] that considerably simplifies a task and increases reliability of control of extreme sizes on all length of a contour.

3. ASSIGNMENT AND REALIZATION OF THE LOOK AHEAD ALGORITHM

The forward frame scanning is necessary for observance of restrictions for acceleration and jerk. Change of the direction of a vector of movement demands reduction of speed in separate points of a trajectory, and the distance from the current position to such points determines the most admissible current speed [5]. In Fig. 2 the example of the schedule of the movement speed for a dogleg contour is shown.

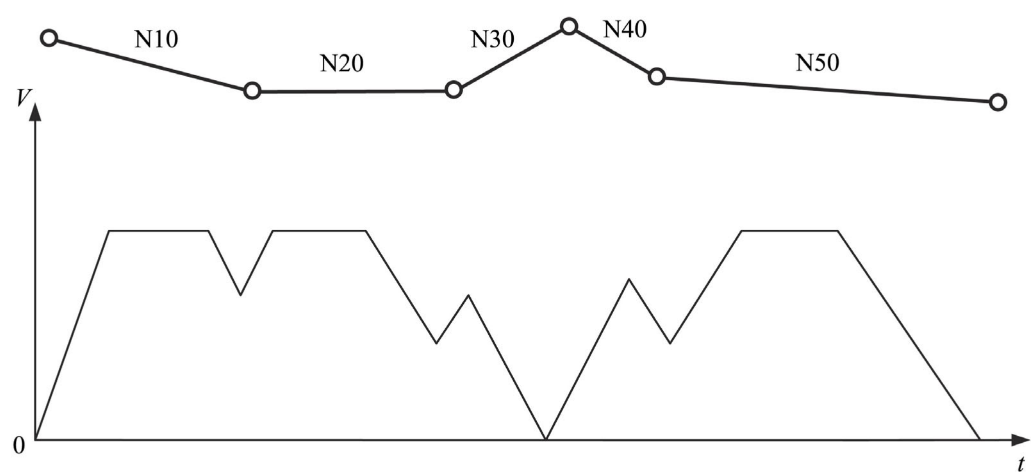

Fig. 2. The processed contour (from above) and the schedule of speed at acceleration restriction.

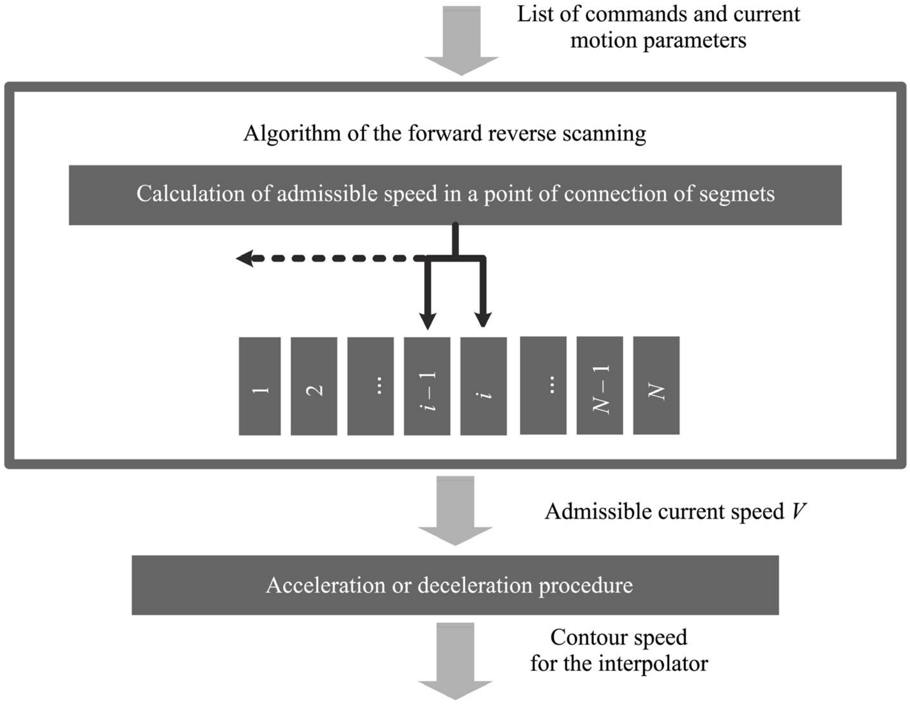

Fig. 3. Forward scanning and speed control algorithm.

For determination of admissible speed in a point of connection of the adjacent $(i-1)$th and ith segments it is enough to use two conditions: 1) restriction for acceleration in a connection point, and 2) restriction for the initial speed of ith segment, proceeding from its required final speed and length.

The rotation of a movement vector during the motion happens during an interpolation step, therefore, acceleration for axis jth equals to an axis speed increment for the period

$$A_j = \frac{V}{T}\left(\left|\frac{P_{j,i}}{S_i} - \frac{P_{j,i-1}}{S_{i-1}}\right|\right), \tag{1}$$

where $P_{j,i}$ and $P_{j,i-1}$—increments of positions of axes of motion segments from initial to final points, S_i and S_{i-1}—lengths of segments, V—planimetric speed of passing of a point of connection, T—interpolation cycle period. Let designate value in brackets from expression (1) for a separate axis as D_j. Then admissible speed in a point of connection is defined as follows

$$V_{\max}(i-1, i) = \min\left\{\frac{A_1T}{D_1}, \frac{A_2T}{D_2}, \ldots, \frac{A_nT}{D_n}\right\}; \quad M \leqslant F_{i-1}; \quad V \leqslant F_i, \tag{2}$$

where F_i and F_{i-1}—value of the part presentation giving for segments, $A_1, \ldots, A_n$—limiting accelerations of axes.

The second restriction is connected with a type of deceleration function and is generally written as follows:

$$V_s = V(S, V_e), \tag{3}$$

where $V(S, V_e)$—dependence of initial speed of the movement on length of braking path S (segment length) and final speed V_e.

Observance of the set kinematic restrictions on the big sequence of segments demands viewing of the next couples of segments since the end of a trajectory (Fig. 3). The number of the next segments which the CNC system thus analyzes is called preview buffer length. The longer the buffer, the greater the part presentation, the system can provide, following the specified limits

The end result of the look ahead algorithm is the admissible speed in this point of a contour. If the current speed of the movement is less admissible, the control is transferred to the procedure of speeding-up, otherwise the procedure of deceleration is performed. Then the received contour speed is transferred to the interpolator which calculates an assignment of positions for all axes.

4. ACCELERATION AND DECELERATION PROCEDURES

Speeding-up assumes cyclic increase in speed on the site of achievement of the preselected feed and comes down to calculation of the current acceleration. Speed on the current step of interpolation is defined from formulae

$$V_i = V_{i-1} + A\left(V_{i-1}, A_{\max}\left(\vec{P}\right)\right)\Delta t; \quad V \leqslant V_{\max}. \tag{4}$$

Here $A\left(V_{i-1}, A_{\max}\left(\vec{P}\right)\right)$—dependence of acceleration on speed and current restriction for acceleration, $V_{\max}$—value of admissible contour speed, V_i—speed on the current step of interpolation, Δt—time which has passed between the previous and current step. Limit contour acceleration $A_{\max}$ depends, in turn, on a vector which contains values of axial movements from initial to a final point of a segment:

$$A_{\max}\left(\vec{P}\right) = \min\left\{\frac{A_1 S}{|P_1|}, \frac{A_2 S}{|P_2|}, \ldots, \frac{A_n S}{|P_n|}\right\}, \tag{5}$$

where $A_1, P_1, \ldots, A_n, P_n$—limit accelerations of axes and an increment of positions of axes from initial to a final point of a segment of movement, S—segment length. The limit jerk is in the same way calculated:

$$J_{\max}\left(\vec{P}\right) = \min\left\{\frac{J_1 S}{|P_1|}, \frac{J_2 S}{|P_2|}, \ldots, \frac{J_n S}{|P_n|}\right\}. \tag{6}$$

Hindrance is implemented by equating of the current speed with the admissible current value found at the forward scanning.

5. LINEAR CONTROL OF PART PRESENTATION WITH ACCELERATION RESTRICTION

Linear control of part presentation is used in practice more often than other methods, especially for draft technological transitions as provides high efficiency of processing [6]. Acceleration size at linear speeding-up doesn't depend on the current speed:

$$V_i = V_{i-1} + A_{\max}\left(\vec{P}\right)\Delta t; \quad V \leqslant F. \tag{7}$$

Dependence of initial speed of a segment on a braking length is defined by the following expression

$$V_s = \sqrt{2AS + V_e^2}. \tag{8}$$

Here V_e—final speed on an interval, S—interval length, A—admissible contour acceleration.

6. CONTROL OF PART PRESENTATION WITH JERK LIMITATION

Linear control of part presentation easily is implemented, steadily and predictably works, isn't exacting to computing resources. However the raised standards for quality of a surface of a product and its accuracy demand accurate control of dynamic loads of machine knots that causes wide circulation of nonlinear control modes [7, 8].

The majority of realization of nonlinear functions of speed change represent parabolas (Fig. 4) providing a jerk value constant. Other laws (e.g., sinusoidal, logistic, exponential) allow to provide

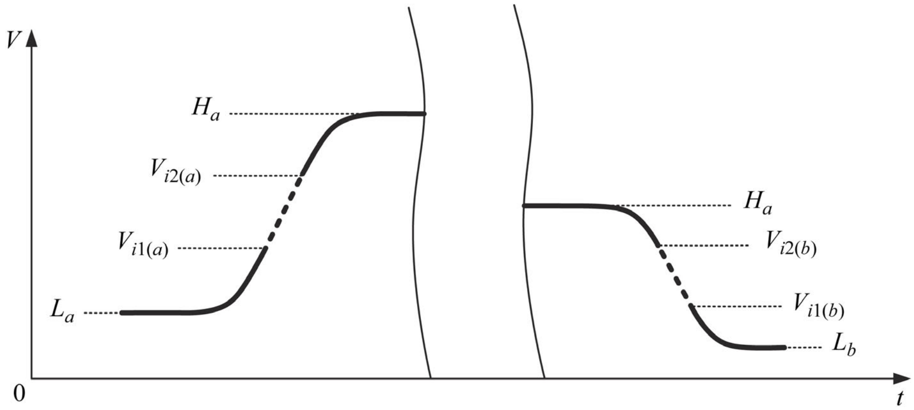

Fig. 4. Parameters of curves of acceleration and braking at jerk limitation.

a continuity of higher order derivatives, but their advantage rather theoretical as discretization of command speed leads to a strong noisiness of signals of the highest derivatives.

Curves are piecewise preset and are defined on three intervals: 1) exit to the maximum acceleration; 2) the movement with continuous acceleration; 3) exit to zero acceleration. The linear interval can be absent if length of a way is insufficient for an exit to the maximum acceleration.

In the mode of jerk limitation for calculation of the current speed at speeding-up and deceleration it is necessary to know initial and final speeds of the segment (L_a, L_b, H_a, H_b). For parabolic segments dependencies of acceleration on speed will have the form

$$A_1(V) = \sqrt{2J(V - L_a)}; \quad A_3(V) = \sqrt{2J(H_a - V)}. \tag{9}$$

The values of speed corresponding to the beginning and end of the line section of speeding-up are defined from ratios:

$$t = \frac{A_{\max}}{J}; \quad V_{J1} = \frac{A_{\max}^2}{2J} + L_a; \quad V_{J2} = H - \frac{A_{\max}^2}{2J}. \tag{10}$$

The given rules and relations are sufficient for the realization of the speeding-up procedure according to (4).

Let consider the lower segment of deceleration. The size of a braking length for initial and final speeds at given acceleration is set by a definite integral:

$$S = \int\limits_{te}^{se} V(t)dt = \left(\frac{Jt^3}{6} + L_b t \right) \Bigg|_{te}^{ts}. \tag{11}$$

Here ts and te—times of the beginning and end of the movement on a segment. This dependence leads to the equation of the third order relatively V_s which exact solution it is easy to receive by reduction to a quadratic equation. Though in practice more favorable is use of a method of Newton for the approximate numerical solution [9].

When processing of the operating programs the case of a zero lower threshold of a deceleration curve L_b most often meets. At the same time for determination of initial speed there is enough calculation of a cubic root:

$$V_s = \sqrt[3]{\frac{9J(S + I)^2}{2}}. \tag{12}$$

The symbol I has designated integral for te (see (11)) which value is expressed through the known quantities.

7. PRACTICAL EVALUATION OF RESULTS

The described algorithm is realized in the made in Russia CNC "AxiOMA Control" system [10]. Restriction of jerk allows to apply higher accelerations without risk of increase in an error of positioning. Linear and parabolic algorithms of acceleration/deceleration give the chance to reach high speeds of part presentation at reasonable load of a computing kernel of system, observing the given restrictions. In Fig. 5 the example of the graphic chart of speed for the case of cascade increase and reduction of part presentation is shown. Data are obtained through the oscillograph which is built in the CNC systems.

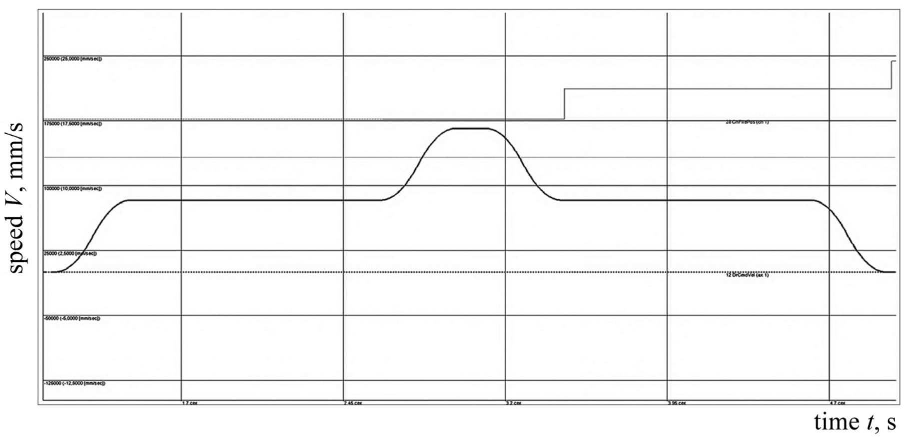

Fig. 5. The graphic chart of speed in the jerk limitation mode.

In the Table time of calculations is given in a motion control cycle for the regular machine of real time of the "AxiOMA Control" system.

Time of calculations of a preview. Core-i3 540 processor

Preview buffer length, number of commands, units	Linear law. Time of calculations, μs	Parabolic law. Time of calculations, μs
100	20 . . . 25	30 . . . 40
500	50 . . . 60	80 . . . 90
2000	140 . . . 160	210 . . . 230

Tests of an algorithm at start of a kernel of the CNC system on hardware base of a microcomputer Raspberri Pi (architecture of ARM, the ARM1176JZ-F 700 MHz processor) have been carried out. The estimation was made in this case indirectly, according to the actual time of the interpolation cycle, the measured value of which was $\leqslant 1$ ms at a buffer depth of 2000 commands. It is enough for the majority of technological tasks.

8. CONCLUSIONS

The approach to motion control allowing to realize the guaranteed control of restrictions for acceleration and jerk for any sequence of frames of the operating program is offered. The developed look ahead algorithm is realized on the basis of simple kinematic ratios and doesn't depend on constancy of the period of a cycle of interpolation that increases flexibility of a control system of the movement and expands the field of its application with environments of soft real time. Experimental data confirm operability of an algorithm and a possibility of its application for a wide class of the computers used as the CNC system kernel hardware.

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