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Design and implementation of a linear jerk filter for a computerized numerical controller

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Abstract

The proposed filter is placed in front a buffered digital differential analyzer, and is formed by combining three modified moving average filters. It can export the position commands to ensure smooth and accurate motion of a tool with a linear jerk change. These output commands can guarantee contour accuracy despite the error in the chord height. The acceleration and jerk can be designed simply by specifying the number of registers. The filter can be implemented using three circular buffers to simplify the arithmetic and reduce the computation time. The high precision motion commands are confirmed by installing the filtering algorithm in a digital signal processor of a computerized numerical controller. The radius of the command trajectory does not become distorted at high speed 30 m/min. The commands filtered by the linear jerk filter stabilize the beginning and end of the actual motion of the machine table.

Keywords: CNC; Command control; Digital differential analyzers; Filter design; Moving average filter; Buffer storage; Shift registers; Computer architecture

1. Introduction

Several highly performing servos (Srinivasan & Tsao, 1997; Tung & Tomizuka, 1993) and controllers (Koren, 1980; Kulkarni & Srinivasan, 1989; Chiu & Tomizuka, 1995) for machine tools have been developed to reduce greatly the tracking error and contour error. The linear motor replaces the intermediate mechanical components and conventional rotary servos to improve dynamic bandwidth (Pritschow & Philipp, 1990; Alter & Tsao, 1994). Although the performance of the feed-drive system suffices, the improvements in command smoothness and accuracy need further contribute to the high-speed motion. Strongly impacting the mechanical parts causes the structure to resonate. The smoothness of the commands stabilizes the beginning and end of the motion. Notably, reducing the shock to the machine's structure reduces the uncertainty in the disturbance from outside of the control loop.

Conventional moving average filters (Van de Vegte, 2002) are installed following the resulting feed of the interpolator, as shown in Fig. 1 (Nozawa, Kawamura, & Sasaki, 1985; Hara, 1991; Chen & Lee, 1998). The filtered position reference should be fed to the position controller to yield the frequent control signals that control the servo drives. These algorithms from the interpolator to the position controller are normally implemented using software, which should be executed during a fixed sampling period. The filters and the position control algorithm can also be implemented using an integrated circuit (Jeon & Kim, 2002). However, although a moving average filtering algorithm (Van de Vegte, 2002) should be placed after a reference-word interpolator (Bergren, 1971; Masory & Koren, 1982; Koren, 1979) to accelerate the speed, according to filter theory, the resulting circle along the position command is distorted as described by Nozawa et al. (1985)

$$\Delta R \approx T_a^2 V^2/(24R_0), \quad (1)$$

where T_a represents the duration of acceleration; V (μm/μs) is the prescribed feed rate of the part program, and R_0 (μm) represents the desired radius of the circular motion.

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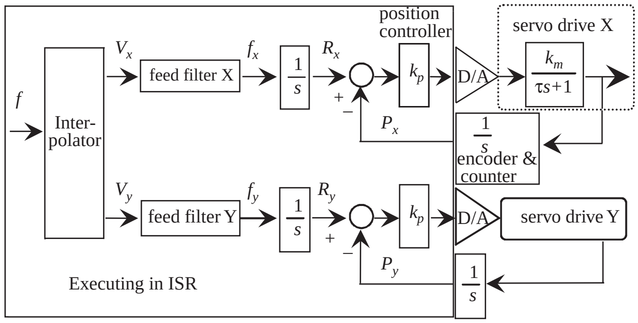

Fig. 1. Block diagram of traditional motion control in a CNC.

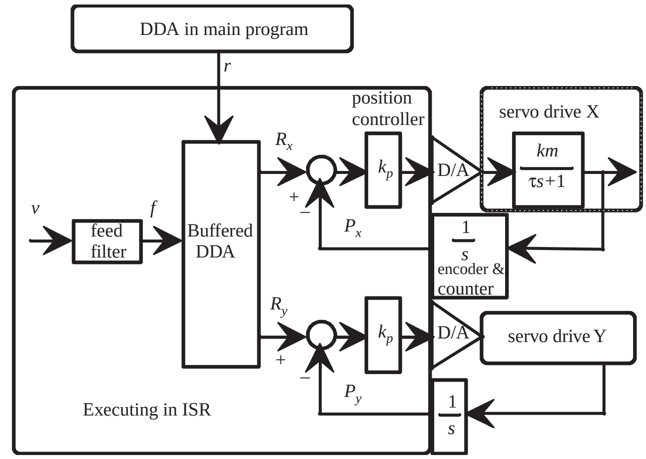

Fig. 2. Block diagram of proposed motion control in a CNC.

Meanwhile, in a high-speed machining process, the linear jerk feed filter (Hara, 1991) is crucial in improving the acceleration and jerk variation. The distortion of a circle is given by

$$\Delta R \approx R_0 - R_0\left[1 - \frac{(T_a V)^2}{24R_0^2}\right]^3. \tag{2}$$

This value of ΔR increases dramatically when the system is operated at a very high speed. Although Chen and Lee developed a finite impulse response filter to reduce the radial error (Chen & Lee, 1998), an error still occurs in practical commands representing a circle. The moving average filter can simply filter the speed. However, the algorithm takes a long time to shift the data and add the data when it is implemented by a software program. The radial error in the position reference during the circular motion is also a problem.

If feed filters are not included in the motion control system, then the radial error of the trajectory can be ignored because of the accuracy of the interpolation. However, the impact on the transition mechanism is increased when the traveling speed is high. The new acceleration and deceleration algorithms adaptively operate the feed input f, such as shown in the references (Erkorkmaz & Altintas, 2001; Guo, Wang, Li, & Liu, 2002). The smooth velocity with a jerk constrained along a parametric curve can be obtained by varying the interpolation period (Erkorkmaz & Altintas, 2001). Hence, the jerk, acceleration, feed rate and displacement should be determined before motion start. The time-consuming calculation of the difference between the interpolation periods must be made when the maximum feed is changed. The linear acceleration and deceleration algorithm has been implemented accurately with linear motion (Guo et al., 2002). Fast and accurate measurement of the time of the end of the deceleration supports fast positioning. However, fast motion along a curve with a designed acceleration and jerk is required.

This study applies a proposed filtering algorithm, combining three modified moving average filters (Van de Vegte, 2002), to filter a step-wise changed feed $v(t)$ into a smooth feed $f(t)$. A few instructions implement this filtering algorithm. The filtered feed $f(t)$ is directly fed into the input of the interpolator, as shown in Fig. 2, after which the feed filters are neglected. The distances associated with the filtered and unfiltered feed rates are proven to be equal. That is, the displacement during filtered feeding motion consists with the one during step-wise feeding motion. The problem is that the sum of the feed should be identical to the resulting displacement of the interpolation. When the feed rate is $1\text{BLU}/T$, where basic length unit (BLU) and T represent the basic length unit and the sampling interval, respectively, the count of the iterations of the digital differential analyzer (DDA) (Koren, 1976; Koren & Masory, 1981) is identical to the value of displacement of the motion. However, the speed is changed by changing the interpolation period, which is constrained by the execution performance of the hardware. The buffered DDA software architecture (Chang, 2003) was originally developed to improve the command speed, such as the reference word interpolation. The position commands are pre-stored by the DDA in the main program and pulled by the interrupt service routine (ISR) as a position reference, according to the required feed. In this work, an improved filtering algorithm is included in the software architecture to select some position references that guarantee both acceleration and deceleration, and minimize the radial error. Experimental results concerning a motion control board with a digital signal processor (DSP) confirm that position references, feeding in speed 30 m/min, are performed on a circular trajectory with linear jerk acceleration and without a radial error.

2. Linear jerk filtering algorithm

When the feed rate is programmed in a part program or is changed using a rotary switch on the control panel,