NC 制御のための新しいパルス列生成の提案

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A New Method of Generating Pulse Series for Numerical Controller

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This paper proposes a new algorithm for V-F transformation and it is applied to a numerical controller. Unlike the existing models which operate with a fixed frequency, the frequency of pulse series produced by the numerical controller can be freely changed according to real-time velocity requirements by adopting the proposed method. Moreover, acceleration of the controller can also be controlled within the range of the motor system. Therefore, wind-up of the system caused by exceeding acceleration can be avoided. Structure and parameters of the numerical controller are thoroughly described in this paper, and method of adjusting the parameters of the controller to adapt to the servo system's torque - frequency characteristic is also introduced. At last, effectiveness of velocity and acceleration control using the proposed V-F transformation method is demonstrated by simulation results.

1. Introduction

Since developed in late 1960s, CNC technology has become a major contributor to the production capacity of industrial companies up to now. CNC systems primarily use both velocity and position control loops in monitoring and controlling the machine tool axes and this is done with the help of individual axis controllers. The function of an axis controller is to provide the appropriate drive signal to the actuator, usually in the form of an electric motor such as servomotor or step motor. Since these motors are driven by pulses, the total amount and frequency of pulses respectively decides motor's rotating angel and velocity, therefore, how to generate pulses is of great importance for the controller. Although the widely used controller PLC at present has many advantages, the fact that the frequency of pulse series produced by PLC is customarily fixed, or in other words the intervals of pulses cannot be freely changed brings limitations to it. Aiming at this problem, a numerical controller with a new algorithm for V-F transformation is proposed in this paper. The frequency of pulse series produced by the controller can be freely changed according to real-time velocity requirements by adopting the proposed method. In addition, acceleration of the controller can also be controlled within the range of the motor system according to its torque-frequency characteristic. Therefore, wind-up of the system caused by exceeding acceleration can be avoided.

2. V-F transformation algorithm

Functional diagram of the proposed numerical controller is shown in Fig. 1.The V-F transformer works as the velocity controller which is used to maintain the motor velocity. It receives the measured position commands and generates pulse series, the frequency of which corresponds to the required velocity in real time. To close the position loop, a pulse counter for counting the amounts of outputted pulses is also included. Thus, the counted number multiplied by pulse equivalent can be regarded as the actual position and the same time as feedback signals.

In Fig.1, e_i is used to represent the compared error between expected position and actual position of sampling period i, so the error accumulated from start to present *sum* can be described as

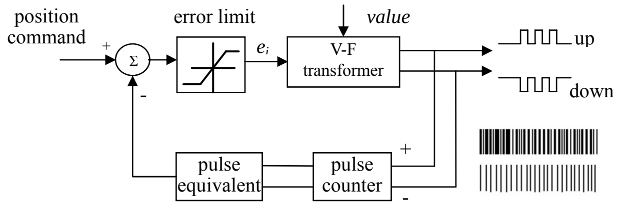

Fig. 1 Functional diagram of the proposed numerical controller.

$sum = \sum_{1}^{i} e_i$. The following algorithm is given for pulse generating:

If $sum = \sum_{1}^{i} e_i \geq value$,

one plus pulse is outputted;

sum=sum-value.

If $sum = \sum_{1}^{i} e_i \leq -value$,

one minus pulse is outputted;

sum=sum+value.

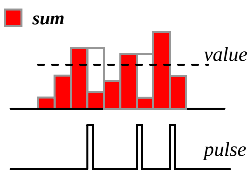

Fig.2 Diagram of V-F transformation

Here *value* is a constant positive number which is given to the V-F transformer beforehand and it is used to compare with the accumulated error *sum*. After one pulse is outputted, *sum* is supposed to be subtracted from *value* as shown in Fig.2. It is seen that the pulse frequency is decided by accumulation of position error between the target and the actual, thus pulse series responding to real-time requirements with arbitrary intervals can be produced.

Notice that there is an error limit before the V-F transformer in the controller. It is necessary because surplus error accumulation may cause overshoot and the error limit works in solving this problem. In order to make it work most efficiently, the valve of the error limit is supposed to be equal to the *value* given to the V-F transformer. That is because according to the algorithm above, the controller gets velocity saturation when one pulse is being sent out per sampling period. If the valve of the error limit is smaller than *value* in V-F transformer, it takes at least two or maybe more than two sampling periods to send out one pulse and this will lower the highest pulse frequency that can be provided by the controller, which also represents the maximum velocity the controller can actually provide. But if the valve of the error limit is larger than *value* of the V-F transformer, the error limit will not work efficiently in preventing overshoot. So the controller works most efficiently when the two parameters are equal. How to decide the value of the two parameters is also important. It is seen that the controller has higher responsiveness with smaller *value*, however, too small *value* may cause the whole system to become unstable. Therefore, the parameters should be adjusted according to actual requirements.

3. Acceleration control

It is known that usually each motor has a specific torque-frequency characteristic. The drive velocity and acceleration provided by the controller should be controlled within the motor's capacity to achieve the best performance. It is easier to do with the velocity part because the controller can mostly send out one pulse during a sampling period, so the velocity will not exceed by setting the motor's highest frequency as the sampling frequency of the controller. As for acceleration, the controller's performance without acceleration control should be investigated first. Suppose the maximum acceleration that can be provided by the controller without control is a_{max}, then we have

$$a_{\max} = \frac{v_{\max}}{T} = \frac{\delta \bullet f}{1/f} = \delta f^2 \quad (1)$$

where f represents the sampling frequency, T represents the sampling period, δ represents the pulse equivalent. Equation (1) means that maximum acceleration is obtained when velocity rises from 0 to max in a single sampling period. From the equation it is seen that the acceleration is extremely large and usually a motor cannot follow. In order to avoid wind-up of the system caused by exceeding acceleration, the following law is adopted before the V-F transformer for acceleration control:

$$|e_i - e_{i-1}| \le \frac{value}{k} \quad (2)$$

where e_i and e_{i-1} respectively represents the compared position error in sampling period i and i-1, and k represents the ratio of the maximum acceleration that can be provided by the controller and the actual maximum acceleration of motor. As seen in equation (1), the maximum acceleration is decided by the maximum velocity increase in a sampling period. According to that velocity increase is approximately in proportion to the increase of position error given to V-F transformer, since in a sampling period the velocity increases from 0 to v_{max} when position error increases from 0 to max—*value*(which is restricted by error limit), if it is required that the maximum acceleration of the controller be controlled under the motor's maximum acceleration a_{max}/k, means that maximum velocity increase in a sampling period be controlled under v_{max}/k, the increase of position error should be controlled under *value/k* as shown in Fig.3.

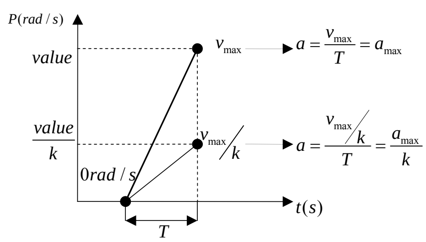

Fig.3. Comparison of position error and acceleration

4. Simulation results

In order to verify the effectiveness of the proposed method, firstly step signal *P=10* rads is forwarded into the controller. The controller parameters are set as follows: The sampling frequency is 140 kHz according to the highest frequency of servomotor SGME-02A, and the corresponding maximum speed is 430 rad/s. The maximum acceleration of the controller is set to 140 krad/s^2 according to the maximum acceleration of the motor. The valve of the error limit and *value* of the V-F transformer are both set to 1. From the simulation results shown in Fig.4 it is seen that the controller has fast responsiveness to the reference signal and high precision in positioning. The frequency of the produced pulse series is continuously changing according to requirements and intervals of pulses are unfixed. It is also seen that there is a transition period in the initial state during which the velocity gradually increases from 0 until max, and the acceleration is fairly controlled under the limit. In addition, sin response of the controller shown in Fig.5 also proved the effectiveness of the proposed method.

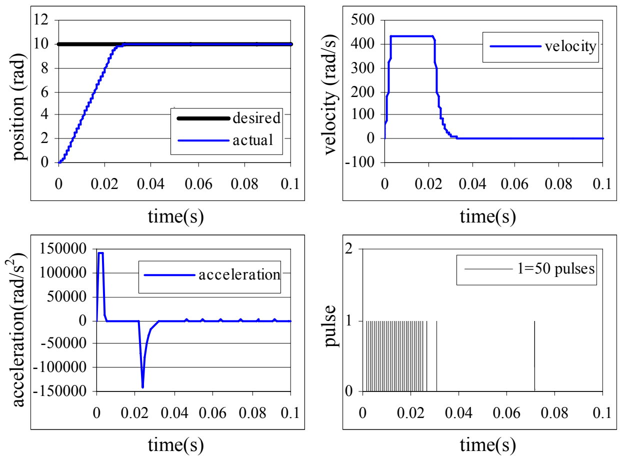

Fig.4 Step response of the controller

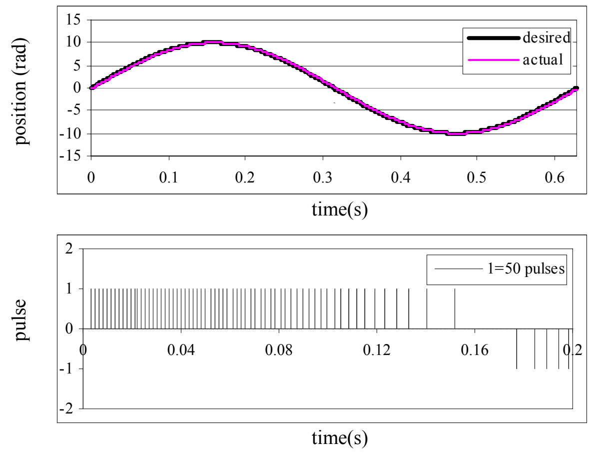

Fig.5 Sin response of the controller

5. Conclusion

The effectiveness of the proposed method of generating pulses for numerical controller is demonstrated by simulation in this paper. Step response and sin response of the controller show that the frequency of the produced pulse series is continuously changing according to real-time velocity requirements by adopting the proposed method. Moreover, acceleration is also controlled under the limit of motor.