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TRACKING ERRORS DECREASING IN CNC SYSTEM OF MACHINE TOOLS

ABSTRACT *In the paper the procedures and practical methods of tracking errors compensation in servo-drives are considered. The PID controllers of servo-drives do not decrease tracking errors enough in the case of fast changes of the motion velocity. The good method of decreasing of the tracking errors in cascade servo-drives is to use the feedforward command and feedforward friction compensation. The exemplary results of the test of CNC system based on servo-drives with PMSM motors with proposed control method including the on-line calculation of feedforward loops parameters are presented.*

Keywords: *CNC system, tracking error compensation, on-line calculation*

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1. INTRODUCTION

High precision machining is one of the most important targets in machine construction. It is particularly difficult to get this in case of high speed and high acceleration machining. Generally the machining errors depend on machine construction and CNC (Computer Numerical Control) system.

The most of CNC systems are based on servo-drives with DC (Direct Current brush motors) and PMSM (Permanent Magnet Synchronous Motors) motors. The servo-drive controllers are generally cascade PID controllers. The PID controllers of servo-drives do not decrease tracking errors enough by fast changes of the motion velocity. The good method of decreasing of the tracking errors in cascade servo-drives is to use the feedforward command and feedforward friction compensation [1, 2]. The feedforward loops are the open loops. The correctly designated parameters of feedforward loops give very good results in tracking errors compensation. Most solutions for feedforward loops parameters settings are based on theoretical models of: servo-drive, axle of power transmission and machining. The parameters of feed forward loops are stable and off-line designated. Friction and elasticity may change during machine motion and change due to machine exploitation. Therefore the designated models lose their accuracy. Inaccurate models of servo-drive, axle or machining can generate tracking errors. These problems appear particularly in light, inexpensive and not high precision machines. The good method to improve the machine precision and decrease the tracking errors is the model verification during the motion and machining process and adequately on-line designation of the feed-forward parameters.

2. CNC CONTROL SYSTEM WITH FEEDFORWARD CONTROL

There are two kinds of feedforward controls applied in CNC control system to improve the tracking performance. The one is the command feedforward control. The other is the friction feedforward control. These are open loop controls. The block diagram of servo system with the command feedforward is shown in Fig. 1. The velocity reference value is the sum of position loop output

and velocity feedforward value. The torque reference value is the sum of the velocity loop output and torque feedforward value.

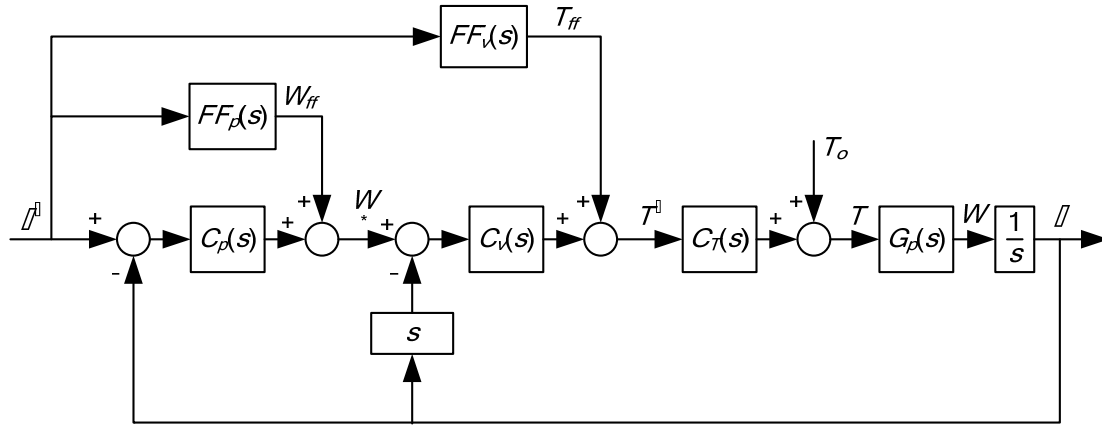


Fig. 1. Block diagram of servo system structure with command feedforward control

We can assume $C_T(s) = 1$ for perfect current control. For motion unit given by first order equation: $G_p(s) = \frac{1}{Js + D}$, the transfer function from the torque input T^* and servo-drive position is expressed as:

$$G(s) = \frac{\theta(s)}{T^*(s)} = \frac{1}{Js^2 + Ds}. \quad (1)$$

The perfect position tracking can be achieved if:

$$FF_v(s) = Js^2 + Ds. \quad (2)$$

Thus the output from velocity $FF_v(s)$ feedforward controller is:

$$T_{FF}(s) = (Js^2 + Ds)\theta^*(s),$$

$$T_{FF}(t) = J \frac{d^2\theta^*(t)}{dt^2} + D \frac{d\theta^*(t)}{dt}. \quad (3)$$

Assuming that the bandwidth of velocity loop is much larger than the bandwidth of position loop and

$$\frac{\Omega^*(s)}{\Omega(s)} \approx 1 \quad (4)$$

the perfect tracking of position can be achieved if:

$$FF_p(s) = s,$$

$$\Omega_{FF}(s) = s\theta^*(s),$$

$$\Omega_{FF}(t) = \frac{d\theta^*(t)}{dt}.$$
(5)

The friction feedforward control compensates the motion unit resistance. To reduce the machining errors caused by friction, the torque T_{fr} is added to the input of current controller (Fig. 2). Friction is modelled as a static map between velocity and friction torque.

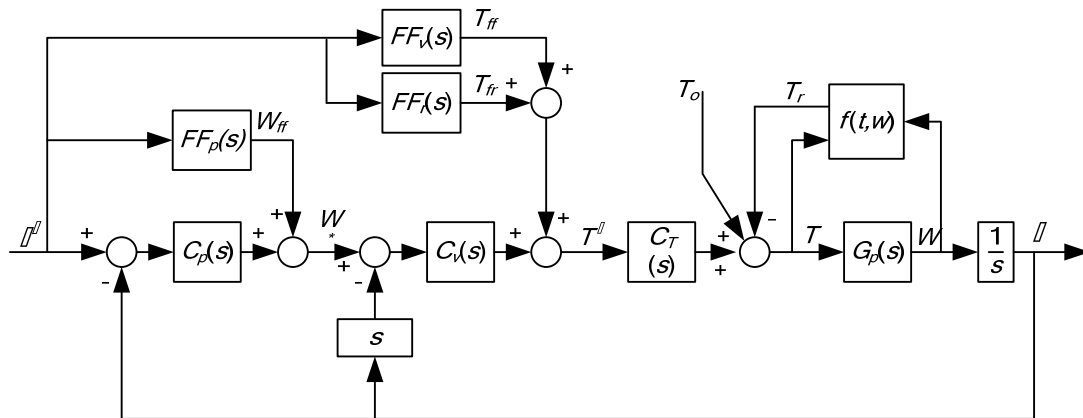


Fig. 2. Block diagram of servo system structure with friction feedforward control

The CNC control system with both feedforward controls is shown in Fig. 3. This is PC based CNC system based on servo-drives with PMSM motors [3]. It includes serial communication between PC computer and several axis servo-drives.

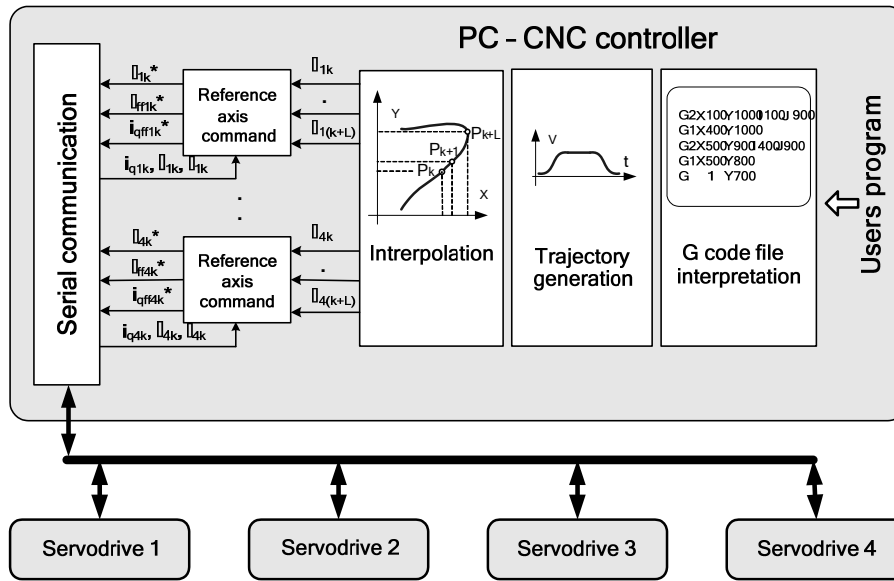


Fig. 3. The architecture of CNC control system with feedforward control

The motion unit resistance expressed through $i_{q1k} \div i_{q4k}$ current values, real speed values $\omega_{1k} \div \omega_{4k}$ and tracking errors $\varepsilon_{1k} \div \varepsilon_{4k}$ are sent every communication period cycle during machine running from servo-drives to CNC controller. The CNC controller calculates position displacement $\theta_{1k}^* \div \theta_{4k}^*$ from interpolator unit, designates velocity feedforward $\omega_{ff1k}^* \div \omega_{ff4k}^*$ and torque $i_{qff1k}^* \div i_{qff4k}^*$ feedforward parameters and sends them back to 1÷4 servo-drives.

The block diagram of the servo-drive with PMSM motor is shown in Fig. 4 [3, 4].

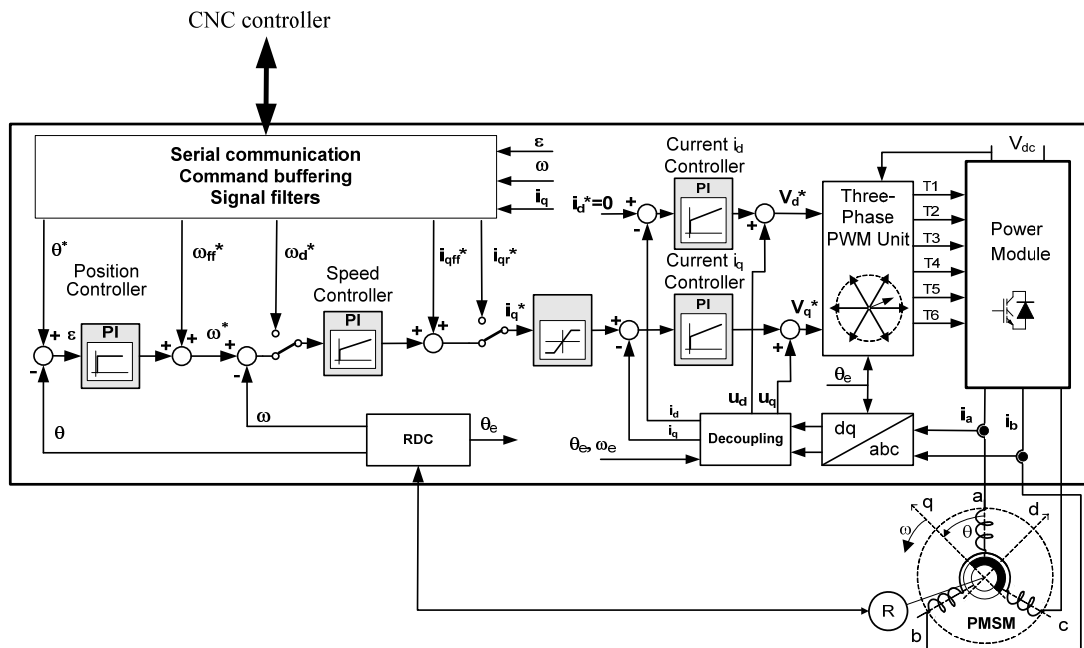


Fig. 4. Servo-drive with PMSM motor with on-line feedforward control

The velocity feedforward ω_{ff} is designated by (5). The i_{qff}^* include the sum of torque feedforward $T_{ff}(t)$ (3) and friction $T_{fr}(t)$ feedforward parameters. The $T_{fr}(t)$ is measured as the i_q current during low speed movement of the motion unit. The tracking error ε is used to test the tracking error decreasing obtained by feedforward control. Too large tracking errors require verification of the machine models.

The ω_d^* is the speed reference value in velocity control mode of servo-drive runs and i_{qr}^* is the current reference value in torque control mode of servo-drive runs.

3. EXPERIMENTAL RESULTS

The exemplary test results of tracking errors decreasing in the CNC system with implemented method of on-line calculation of feedforward loops parameters applied in milling machine are below presented. Fig. 5 shows the tested milling machine.

Fig. 6. presents different waveforms of tracking errors in Y axis of the test station. The servo-drive SDMT-5 [4] was configured as follows: position controller of type P, velocity and current controller of type PI, resolution of servo-drive $2\pi/16384$, ball screw pitch 20 mm/rev.



Fig. 5. Experimental test station with milling machine

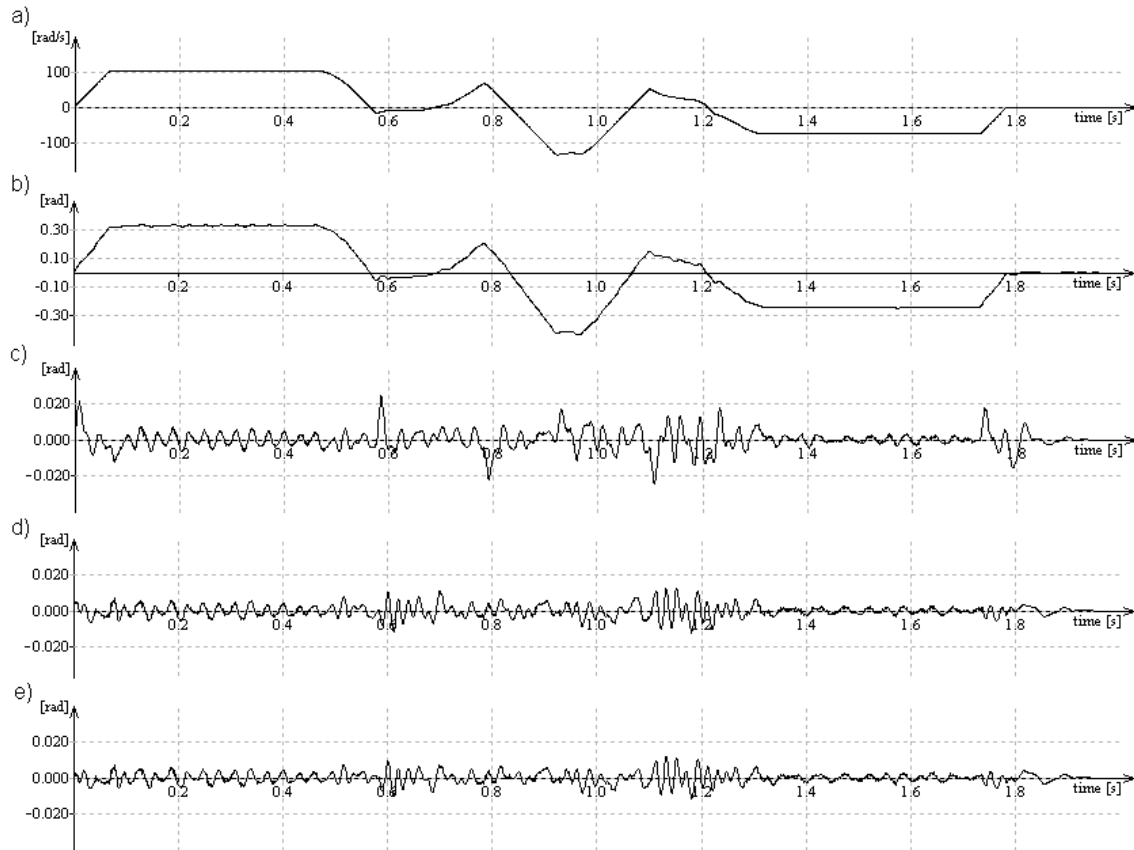


Fig. 6. Waveforms of velocity and position tracking errors in Y axis of milling machine: (a) motion velocity; position tracking errors for: (b) CNC system without feedforward compensation, (c) feedforward loop $FF_p(s) = 1$ (Fig. 1, 2), (d) feedforward loop $FF_s(s) = Js^2$ and $FF_p(s) = 1$ (Fig. 1, 2), (e) feedforward loop $FF_p(s) = 1$, $FF_v(s) = Js^2 + Ds$ and motion unit resistance T_{fr} (Fig. 2); 0.01 rad = 26 increments, 1 increment = $2\pi/16384$ rad

There are very large tracking errors in case of CNC system without feedforward compensation (Fig. 6b). The Ω_{ff} feedforward loop ($FF_p(s) = 1$) considerably decreases the tracking errors. The FF_v and FF_r feedforward loops (T_{ff} and T_{fr}) decrease tracking errors less. There wasn't realised the machining process during measurement. Since the motion unit resistance was very small, so the influence of FF_r for decreasing tracking errors was also small.

Figure 7 shows different waveforms of the tracking errors in Y axis for servo-drive configured as follows: position controller of type PI, velocity controller of type P and current controller of type PI. The PI position controller decreases tracking errors for steady state speed (Fig. 7b). The efficiency of tracking errors decreasing is less effective (Fig. 7c,d) because speed controller is of P type and its reaction is smaller on Ω_{ff} .

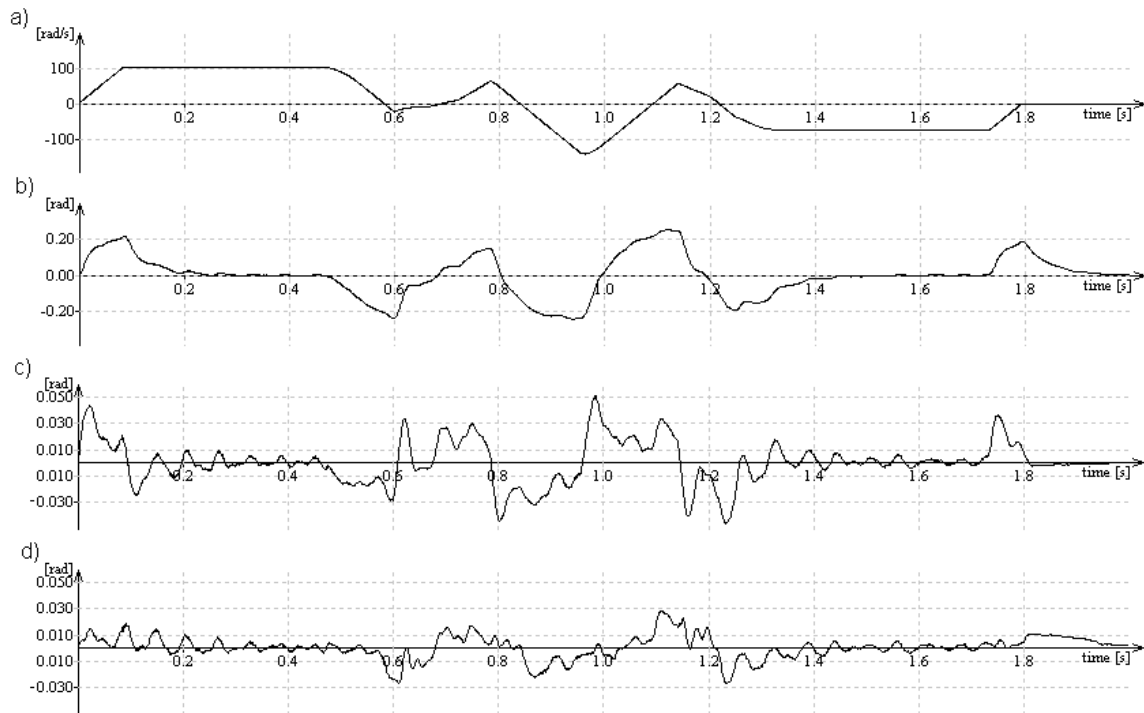


Fig. 7. Waveforms of velocity and position tracking errors in Y axis of milling machine: (a) motion velocity; position tracking errors for: (b) CNC system without feedforward compensation, (c) feedforward loop $FF_p(s) = 1$ (Fig. 1, 2), (d) feedforward loop $FF_s(s) = Js^2$ and $FF_p(s) = 1$ (Fig. 1, 2); 0.01 rad = 26 increments

6. REMARKS AND CONCLUSION

The practical tests proved that presented CNC system with feedforward command and feedforward friction compensation considerably decreases tracking errors. There is possibility to measure the motion resistance during machining process, compensate the machining resistance and improve the precision of machining. Decreasing of the tracking errors and machining errors leads to lower gain value of integral part of PI controller and limits position overshoot. That overshoot appears by speed change and by change of motion and machining resistance. The on-line continuous measurement of motion resistance and tracking errors ensures the system resistance against the changes of friction and inertia.

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ZMNIEJSZANIE BŁĘDÓW ŚLEDZENIA
W SYSTEMACH OBRABIAREK
STEROWANYCH NUMERYCZNIE

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STRESZCZENIE *W pracy przedstawiono procedury i praktyczne metody kompensacji błędów śledzenia w serwonapędach. Regulatory PID serwonapędów nie redukują błędów śledzenia wystarczająco w przypadku szybkich zmian prędkości ruchu. Wskazano, że dobrym sposobem na zmniejszenie błędów śledzenia kaskady serwonapędów jest wykorzystanie pętli sprzężenia wyprzedzającego, także do kompensacji tarcia. Przedstawiono przykładowe wyniki badań układu sterowania numerycznego bazującego na serwonapędach z silnikami synchronicznymi o magnesach trwałych PMSM pracujących według proponowanej metody kompensacji za pomocą pętli sprzężenia wyprzedzającego.*