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DYNAMIC CORRECTIONS OF THE TOOLING ERRORS POSSIBILITIES WITHIN THE MECHATRONIC ACTUATOR FOR MOTORS WITH PERMANENT MAGNETS

The results of research work on the open control system for CNC machines were presented. The first part of the paper shows the experimental results of circular tests that were done according to ISO 230-4 in horizontal plane of three-axis milling machine. Basic errors and their characteristics were shown. Certain errors could not be corrected by the control system adjustments and they became the major obstacle to improve milling accuracy. Multiple approaches of designing open control system for servodrive with error-oriented corrections were proposed and investigated in the second part of the paper.

Key words: CNC, servodrive, open control system

1. CNC MOTION CONTROL FOUNDATION

CNC (Computerized Numerical Control) machine control system is responsible for controlling motion of the machine driven by electrical motors. Typical industrial motion control system (Fig. 1), which control CNC tooling machine, consist of central unit, HMI, distributed I/O and servodrives with motors.

Human-machine-interface and distributed input/outputs are important part of the machine control system but their role is not discussed in this paper.

The main unit of CNC control system is PLC (Programmable Logic Controller) or PAC (Programmable Automation Controller) deterministic controller. One of its important function is to communicate with servodrives to obtain motors movement and movement of machine axes in consequence. Sequence of movements is generated upon user G-Code program: program is read, following positions are

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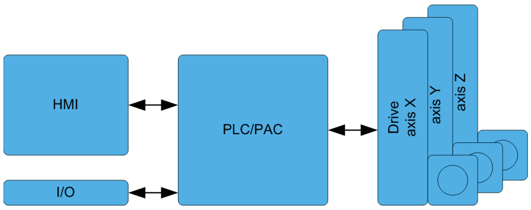

Fig. 1. CNC system diagram
Rys. 1. Diagram systemu CNC

decoded and interpolated [4, 14]. Obtained set position values or current set values – depending on the manufacturer – are then transferred to servodrive.

Functionality and important parameters of CNC systems are determined during installation of the machine. Although many manufacturers calls their motion systems "open" [10, 14] there is only little possibility to change functionality of those systems after "first run". Motion control system is opened when user can modify main parts of the system, change functionality and add new features.

Servodrive – energoelectronic converter – works usually as a position comparator. Actual position from motor encoder (or linear encoder) is compared with set position evaluated by the main unit [6]. The difference in positions becomes input (error) value of the internal regulator within servodrive (Fig. 2).

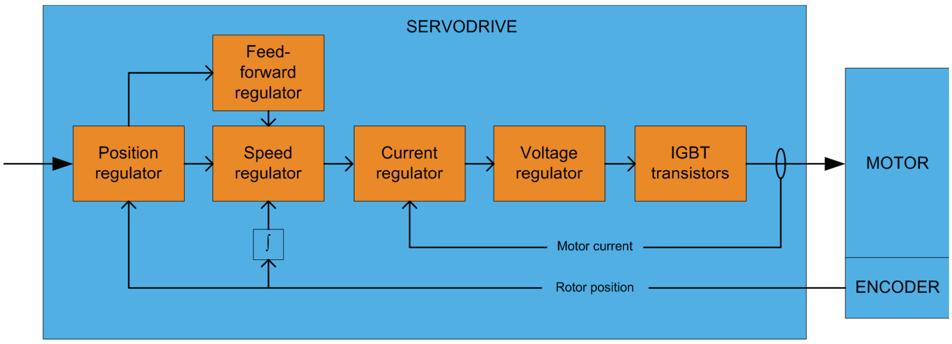

Fig. 2. B&R servodrive internal regulator
Rys. 2. Wewnętrzna struktura układu regulacji serwonapędu B&R

Internal regulator consists typically of three-five cascade stages of simple regulators: position, speed and current (torque). Different structures of regulators may be found depending on the design: from simple PI (Position-Integral) loops to regulators with internal models [18].

In presented (Fig. 2) cascade structure of B&R servodrive following loops works with sampling time (in order): 400 μs, 200 μs and 100 μs. In this topology every new set position for servodrive must be delivered from main unit every 400μs. On the one hand it requires fast CPU (Central Processing Unit) in the main unit but on the other enables fast reaction of servodrive to set position changes.

1.1. Positioning errors in CNC machines

Many errors of positioning in CNC machines may be reported [5, 7, 9, 13, 17, 19] but this paper presents and shortly describe ones of those that was found during practical circular tests according to ISO 230 of the industrial milling machine [2, 3].

Servo mismatch

One of the most recognized error of CNC system is servo mismatch [11] (Fig. 3). This type of error is no longer a problem in modern CNC systems because axes synchronization is done electronically. However improper configuration may lead to unexpected errors shown in Figure.

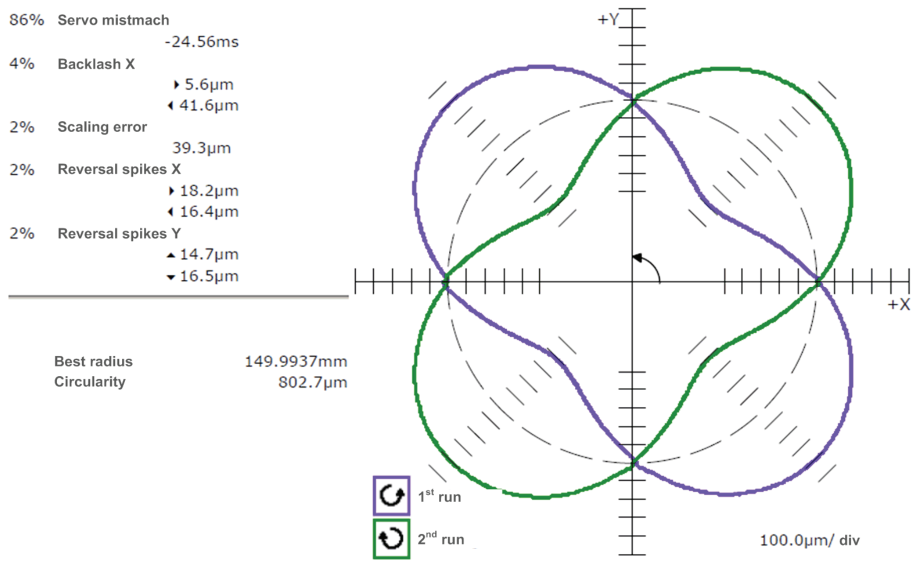

Fig. 3. Servo mismatch
Rys. 3. Błąd nadążania serwonapędu

Backlash

Backlash [12, 16] is an error connected with mechanical construction of machine axis. It is the consequence of dimension tolerances of the main axes components which transfer rotating move into linear: shaft and nut (Fig. 4). Backlash is observed when axis is changing direction of the movement. CNC machines are usually equipped with backlash-free (pre-tensioned) double nuts. All of the regular CNC systems have backlash correction functions.

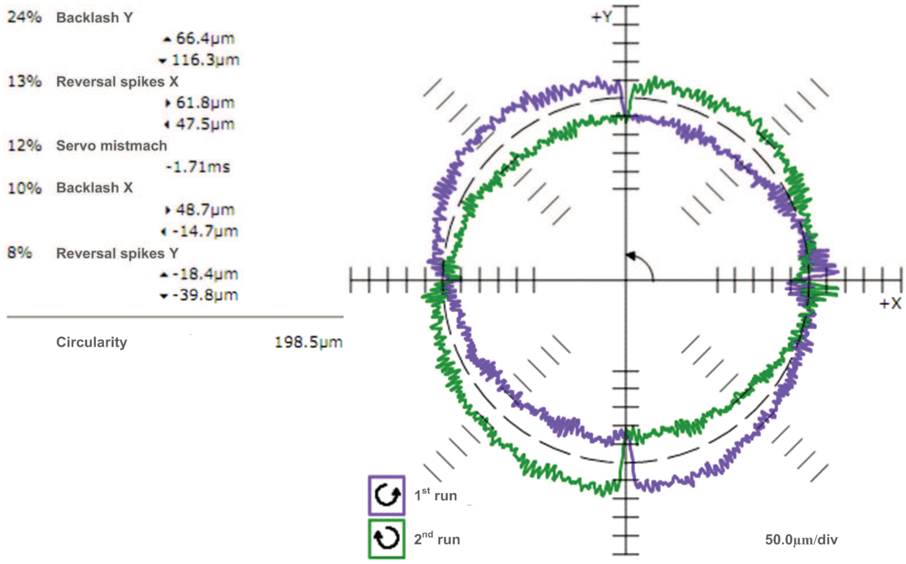

Fig. 4. Backlash
Rys. 4. Luz

1.2. Dynamic errors

Although there are many variants of internal regulator structures in servodrives one feature is common: parameters of control loops needs to be tuned. Servodrives are featured with auto-tuning options but they are not reliable since there is usually no information on how the parameters of regulators are obtained. Incorrect parameters of internal control loop [15] may lead to oscillations and dangerous vibrations (Fig. 5).

Servodrives internal control loop parameters tuning result in assumed quality of control (Fig. 6) but another problem were found during set-up procedure: reversal spike error [8].

Reversal spike error may be observed when machine is supposed to “draw” a circle and one of the machine axes crosses Cartesian axis while second moves to the maximum position, stops and starts moving in opposite direction. Every dissynchronization in this process leads to reversal spikes (Fig. 6). This error may be caused by both mechanical (i.e. static vs. dynamic friction) and electrical (i.e. lag error, insufficient torque) issues.

Correction function for this type of error was not implemented in CNC system by the manufacturer. A good way to avoid this and similar problems in the future needed to be implemented in order to improve quality of control: an open control system.

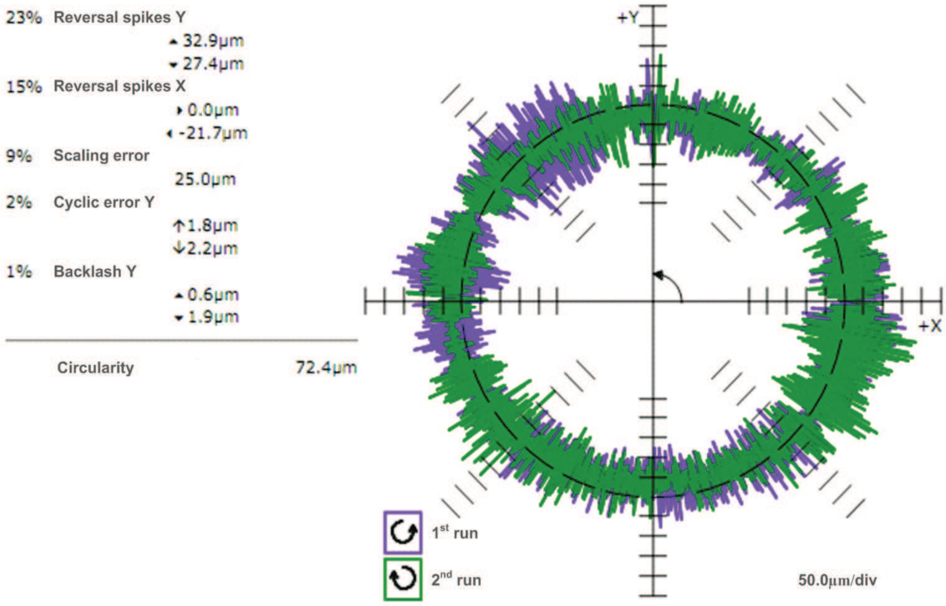

Fig. 5. Dynamic errors
Rys. 5. Błędy dynamiczne

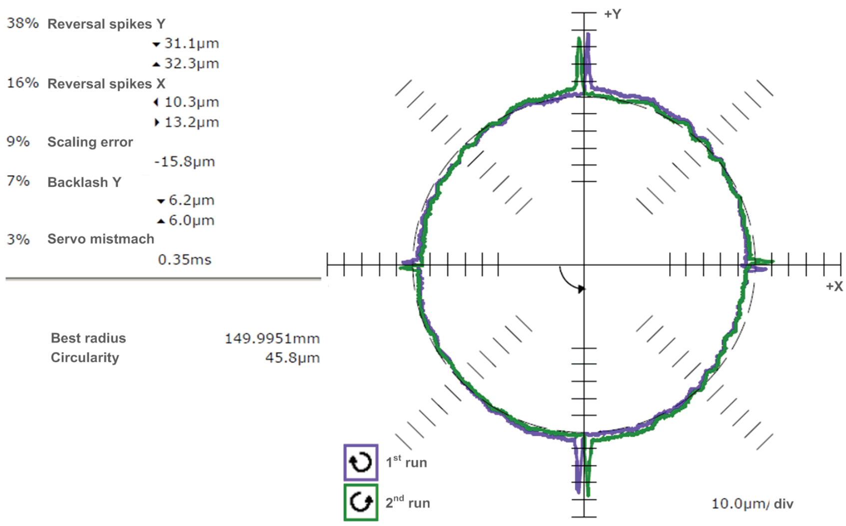

Fig. 6. Dynamic errors
Rys. 6. Błędy dynamiczne

2. OPENNESS OF CNC

In this section methods and topologies to convert typical industrial CNC system to open motion control system are presented. They can be divided into three subgroups: on-line corrections of servodrive internal control algorithm and PLC-motion topology where control loop is done in PLC evaluating set current/torque for servodrive.

2.1. On-line correction: additive position

It is possible to add corrective position to set position for the servodrive every 400µs (depends on communication protocol being used between main unit and servodrive) to quickly implement geometric corrections of the machine [13], formerly measured with appropriate tools. This may be perceived as a substitute for so-called *off-line* corrections where G-code machine program is modified according to the geometry measurements of the machine.

Additive position correction (Fig. 7) was done in software on the basis of master-slaves axes concept. This idea involves master axis which is a virtual axis simulated in software. The role of the slave axis – real axis of the machine is driven by motor – is to follow the master axis. This kind of coupling is done programmatically and is independent to user program. User can generate his own trajectory (set of points) which will be added to the G-code trajectory in certain time points.

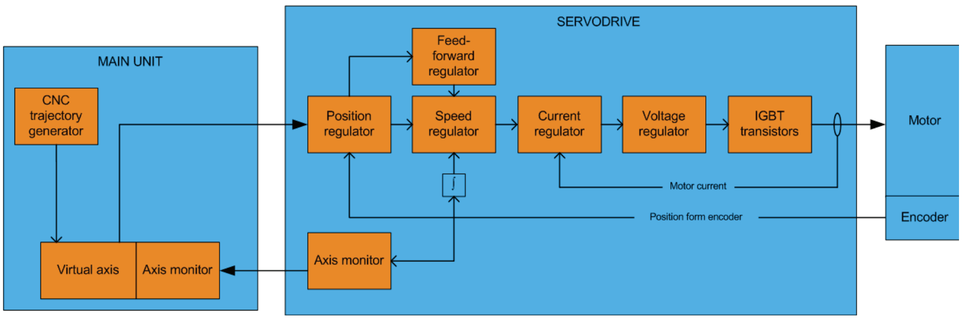

Fig. 7. Additive position with virtual axis
Rys. 7. Dodatkowa wartość położenia z wykorzystaniem osi wirtualnej

2.2. On-line correction: additive current/torque

Additive current/torque correction topology (Fig. 8) was created to give access to the user directly to the current controller. One may found it useful to momentary rise/reduce set current of the motor in order to overcome short-period disturbances. Current regulator loop is the fastest control loop in servodrive since it is usually the last configurable stage of controller. Current loop cycle time average out at 50–100 μs, but additive value can be refreshed every 400 μs however.

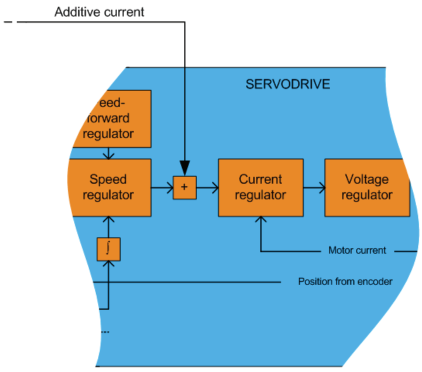

Fig. 8. Additive current value
Rys. 8. Dodatkowa wartość prądu

2.3. On-line corrections: control loop parameters

Parameters of control loops regulators such as proportional gain, integral gain, etc are usually evaluated in the "set-up" procedure of the machine and remains constant as long as the machine runs. From the control theory point of view it is hard to control the object (or obtain assumed quality of control) if its parameters become out of tolerance [1]. Machine parameters as a controlled object changes obviously over time due to for example wear. Multiple approaches to control non-stationary objects may be found in literature, one of the simples is to adjust control parameters to achieve maximum possible quality of control. Maximizing possible control quality is a matter in new machines as well, where different control loops parameters may be needed in different positions of the machine due to additional friction in the end of the motion guides or increased impact of an ball screw inertia.

Control loop parameters correction was design to change writable parameters of the servodrive control loop regulators on-line: without necessity to restart the machine or even stopping the movement. It is possible to transfer five parameters to the servodrive and receive five values from the servodrive every one cycle of the network. All parameters of the regulators that may be changed during set-up procedure of the machine may be adjusted by the user.

2.4. PLC-motion topology: set current/torque

The most advanced topology presented in this paper is topology (Fig. 9) where position and speed controller in servodrive were disabled. Control loop algorithm is now calculated by the main unit (PLC/PAC). Control loop – designed by the user – evaluate set current for the servodrive upon difference between actual position of the motor and set position from CNC trajectory generator. Current/torque set value is transferred to the servodrive every cycle of the network.

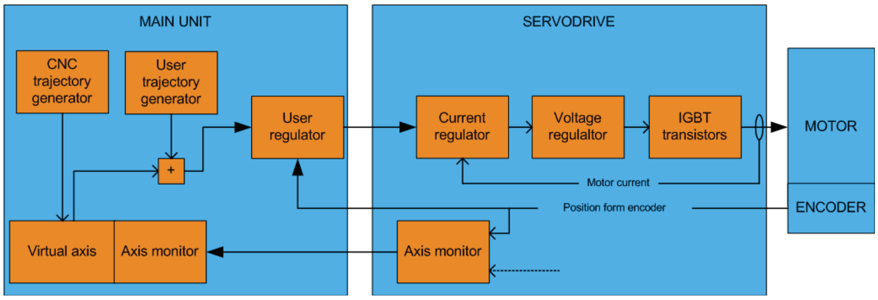

Fig. 9. Servodrive set current evaluated by the PLC
Rys. 9. Zadana wartość prądu wypracowywana przez PLC

Functionality of the servodrive vastly improves enabling user to implement his own control algorithms suitable for specific application or algorithms with additional inputs from sensors connected to the I/O of the main unit to prevent for example excessive vibrations or react on signal from force sensor.

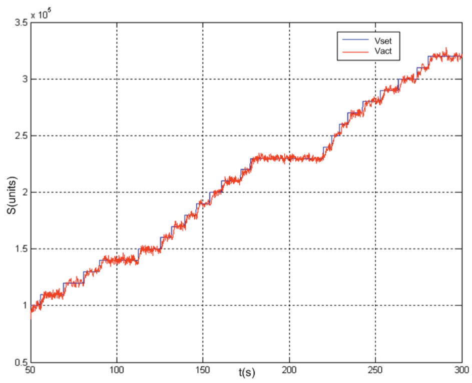

Fig. 10. PID control in PLC
Rys. 10. Regulator PID w sterowniku PLC

Experimental results (Fig. 10) were done to show functionality of presented topology. Wiener-Hammerstein model of the motor was identified with the use of Matlab System Identification Toolbox. Simple PID loop was tuned in Simulink® simulation. The program code was generated directly from Simulink and transferred to PAC. PID control loop run in 400 μs cycle – new current set value for servodrive was evaluated 400 μs after actual position signal from motor encoder. Experimental results verified simulated behavior of PID control of the motor in PLC.

3. SUMMARY

Selected methods to change typical industrial CNC motion control system to open control system that are being developed were presented. Openness in control systems gives user a possibility to implement required or desirable correction functions and follow increasing demands on quality of control in CNC machines.

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REFERENCES

[1] **Domek S**., **Dworak P**., **Pietrusewicz K**., Hybrid Model-Following Control algorithm within the motion control system, New York, Piscataway 2009, p. 1476–1481.
[2] **Domek S**., **Pajor M**., **Pietrusewicz K**., **Urbański Ł**., Otwarty modułowy system sterowania obrabiarki CNC, Modelowanie Inżynierskie, 2009, vol. 6, nr 37, p. 77–82.
[3] **Domek S**., **Pietrusewicz K**., Mechatronika w doskonaleniu konwencjonalnych urządzeń technicznych na przykładzie obrabiarki wielofunkcyjnej, Przegląd Elektrotechniczny, 2009, nr 9, p. 81–87.
[4] **Habrat W**., Obsługa i programowanie obrabiarek CNC. Podręcznik operatora, Krosno, Wydawnictwo i Handel Książkami KaBe 2007.
[5] **Junyong X**., **Bo W**., **Youmin H**., **Tielin S**., Experimental research on factors influencing thermal dynamics characteristics of feed system, Precision Engineering, 2010, vol. 34, no. 2, p. 357–368.
[6] **Krishnan R**., Electric motor drives: modeling, analysis, and control, London, Prentice-Hall 2001.
[7] **Li X**., **Venuvinod P. K**., **Djorjevich A**., **Liu Z**., Predicting machining errors in turning using hybrid learning, The International Journal of Advanced Manufacturing Technology, 2001, vol. 18, no. 12, p. 863–872.
[8] **Mei X**., **Tsutsumi M**., **Tao T**., **Sun N**., Study on the compensation of error by stick-slip for high-precision table, International Journal of Machine Tools & Manufacture, 2004, vol. 44, no. 5, p. 503–510.
[9] **Pahk H.-J**., **Lee S.W**., Thermal error measurement and real time compensation system for the CNC machine tools incorporating the spindle thermal error and the feed axis thermal error, The International Journal of Advanced Manufacturing Technology, 2002, vol. 20, no. 7, p. 487–494.
[10] **Pietrusewicz K**., CNC open architectures, Control Egineering, 2008, vol. 55, no. 1, p. 17–18.
[11] **Ramesh R**., **Mannan M.A**., **Poo A.N**., Tracking and contour error control in CNC servo systems, International Journal of Machine Tools & Manufacture, 2005, no. 45, p. 301–326.
[12] **Rostalski P**., **Besselmann T**., **Barić M**., **Van Belzen F**., **Morari M**., A hybrid approach to modelling, control and state estimation of mechanical systems with backlash, International Journal of Control, 2007, vol. 80, no. 11, p. 1729–1740.
[13] **Schwenke H**., **Knapp W**., **Haitjema H**., **Weckenmann A**., **Schmitt R**., **Delbressine F**., Geometric error measurement and compensation of machines – An update, CIRP Annals – Manufacturing Technology, 2008, vol. 57, no. 2.

[14] **Suh S.-H**., **Kang S.-K**., **Chung D.-H**., **Stroud I**., Theory and design of CNC systems, Berlin, Springer 2008.
[15] **Urbański Ł**., **Pietrusewicz K**., **Majda P**., Badania doświadczalne właściwości dynamicznych napędu posuwu obrabiarki CNC, Mechanik, 2010, nr 3, p. 162–168.
[16] **Vörös J**., Modeling and identification of systems with backlash, Automatica, 2010, vol. 46, p. 369–374.
[17] **Yang S.-H**., **Kim K.-H**., **Park Y.K**., **Lee S.-G**., Error analysis and compensation for the volumetric errors of a vertical machining centre using a hemispherical helix ball bar test, The International Journal of Advanced Manufacturing Technology, 2004, vol. 23, no. 7–8, p. 495–500.
[18] **Younkin G.W**., Industrial servo control systems: fundamentals and applications, Marcel Dekker 2003.
[19] **Ziegert J. C**., **Kalle P**., Error compensation in machine tools: a neural network approach, Journal of Intelligent Manufacturing, 1994, vol. 5, no. 3, p. 143–151.

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KOREKTY BŁĘDÓW DYNAMICZNYCH I POZYCJONOWANIA W UKŁADACH MECHATRONICZNYCH Z SILNIKAMI Z MAGNESAMI TRWAŁYMI

S t r e s z c z e n i e

W artykule przedstawiono wyniki prac nad otwartym systemem sterowania maszyn CNC. W pierwszej części zawarto wyniki testów kołowości zgodnych z normą IS0 230-4, wykonanych w płaszczyźnie poziomej trzyosiowej frezarki. Wskazano błędy dynamiczne i pozycjonowania. Tradycyjny system sterowania CNC nie ma możliwości kompensacji wszystkich potencjalnych błędów, dlatego w drugiej części zaproponowano koncepcję i badania otwartej architektury serwonapędu umożliwiającej korektę błędów.

Słowa kluczowe: CNC, serwonapęd, otwarty system sterowania