EXPERIMENTAL RESEARCH ON THE THERMAL BEHAVIOUR OF FEED AND POSITIONING KINEMATIC CHAIN

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Rezumat. *Cele mai importante direcții de dezvoltare ale maşinilor-unelte CNC sunt: precizie înaltă, fiabilitate, calitate, productivitate şi costuri de producție reduse. O contribuție remarcabilă în îndeplinirea acestor obiective o are lanțul cinematic de avans / poziționare* (*LCA / P*) *şi şurubul cu bile. Căldura generată de frecare produce erori ale mecanismelor din structura LCA/ P ce influențează precizia de poziționare pe axele comandate numeric. Ca urmare, se impune studiul comportării termice pentru reducerea şi compensarea deformațiilor termice ale cuplei şurub-piuliță cu bile, în scopul de a îmbunătăți precizia tehnologică a maşinii-unealtă*.

Abstract. *The most important directions in CNC development can be considered high precision, liability, quality improvement, the increase of productivity and reduction of the production cost. An outstanding contribution in fulfilling these conditions was brought by attaching at CNC structures a ball screw driving feed drive system. The friction heat generates errors on position accuracy on machine axis. The main purpose is to reduce the thermal deformation of ball screw for bringing accuracy in machine activity*.

Keywords: thermal behaviour, CNC machine, ball screw system, structural and thermal behaviour, advance and positioning kinematic chains

1. Introduction

In the whole industry the most important need is the high quality of finishing processing. Those CNC machine tools use high-speed ball screw. Also to have such a high performance we need to reduce the errors due to thermal moving elements, balls of bearings and support bearings, motors and ball screw nut has internal heat sources [1].

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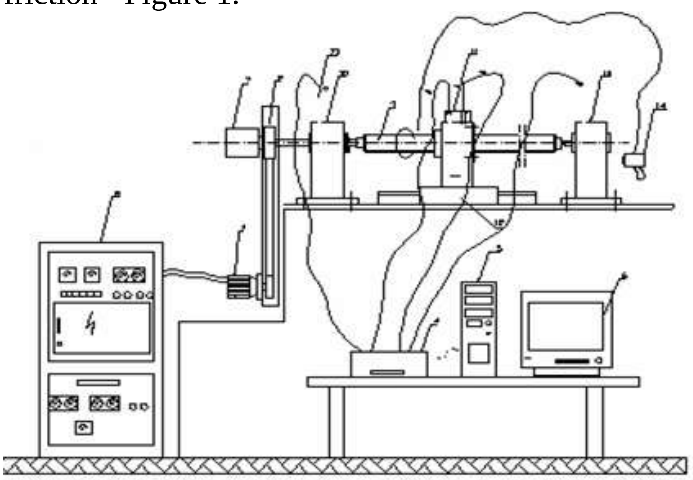
This affects the processing precision of the machines and at the same time positioning accuracy axis. In section 2 are described the mechanical characteristics of the ball screw and the importance for our researches. The thermal behaviour of the driveline advance / positioning system is explained in section 3.

In section 4, we shall explain the purposes of this study and the detailed methodology of the research.

2. Mechanical Components of a Ball Screw System

The ball screw is a precision mechanical linear actuator that uses steel balls between a screw shaft and a nut to transfer the motion which converts rotary into linear movement when the screw is rotated. Different from any conventional power transmission screw, which needs to overcome sliding friction between the screw and the nut threads, the ball screw operates similarly to bearing components could achieve high mechanical efficiency since it moves in relatively low rolling friction - Figure 1.



1. Electric motor
2. Belt drive
3. Ball screw
4. Acquisition board interface+Conditioner
5. Central unit+Aquisition board
6. Monitor
7. Encoders
8. Numerical command equipment
9. Central unit + Aquisition board
10. Bearings
11. Prestressed nut
12. Mass
13. Temperature sensors
14. Pyrometer

Fig. 1. Experimental module for ball screws thermal behaviour study.

As a tried and tested technology, ball screw drive systems are still used in a majority of machine tools which can meet the demands of higher productivity and tight part tolerances due to their low cost and high degree of stiffness. The high speed ball screw drive system generates more heat and it results in greater positioning error, adversely affecting the accuracy of high precision machined parts [3].

In our research on the study of the thermal behaviour of driveline advance / positioning, a defining role is the presence of the ball screw (see Figure 2).

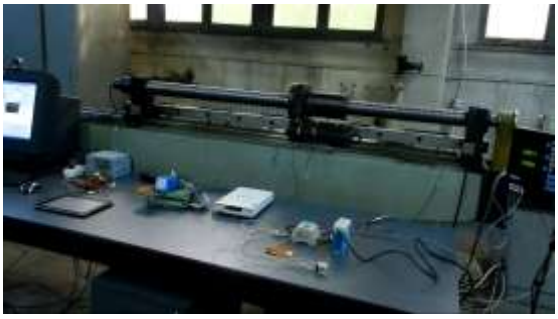


Fig. 2. Experimental stand.

An experimental stand was built for ball screw testing and it was configured for thermal behaviour experiments.

The experimental stand has the following components:

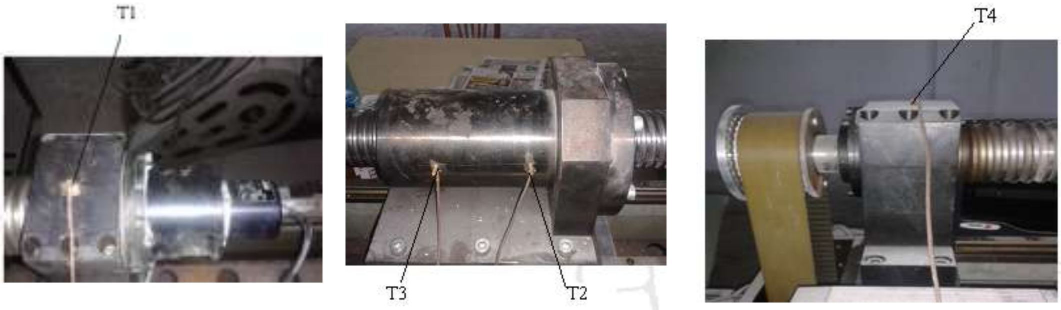
- electric motor with belt drive; incremental linear encoder LB 326;

ball screw; measuring and processing data system; PC; laser; interferometer laser; incremental rotary encoder S 500 Fagor; numerical command equipment.

Thermocouples were installed over the entire test stand for a more accurate recording of temperatures.

Mechanism suitable for contact temperature measurement (using thermocouples integrated in a system acquisition board National Instruments) or non-contact (infrared pyrometers two that will be attached by a thermal probe-type thermocouple), with a response time of 0.1 s.

The recording of the temperature with thermocouples T1 ... T6 is carried out continuously during the testing cycle while Pr1 and Pr2 of pyrometers thermocouple T7 initial temperature was recorded and the final temperature of the environment and to the side surfaces of the screw.



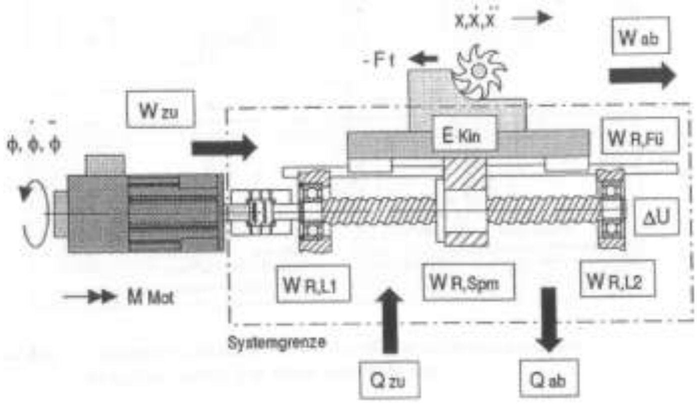
a b c

Fig.3 The positioning of encoders.

3. Thermal Behaviour of Driveline Advance / Positioning System

The errors caused by thermal factors represent 40-70% of the total errors in MUCN. Thermal influence sources that are identified, and are generated by: cutting process, tool machine, machine cooling system, ambient environment [4]. In figure 4 are presented the deformations caused by machine heating.

The heat transfer on the mechanical structure of advance and positioning kinematic chain plays an essential role in the process development.



$$W_{zu} - W_{ab} - E_{kin} = |W_{R,L1}| + |W_{R,L2}| + |W_{R,Spm}| + |W_{R,Fü}| \tag{1}$$

$$\Delta U = |W_{R,L1}| + |W_{R,L2}| + |W_{R,Fü}| + |W_{R,Spm}| + Q_{zu} + Q_{ab} \tag{2}$$

Fig. 4. Heat transfer on mechanical structure of LCA/P.

In the mechanical energy transfer system we find heat sources: nut shaft, bearings and cylinders (spindle). These sources of heat produce a heat flux density, by friction in the contact areas between the rotating elements and the thermal path. This represents a borderline Type 2 condition.

Due to the advance movement, the heat transfer site is variable in time.

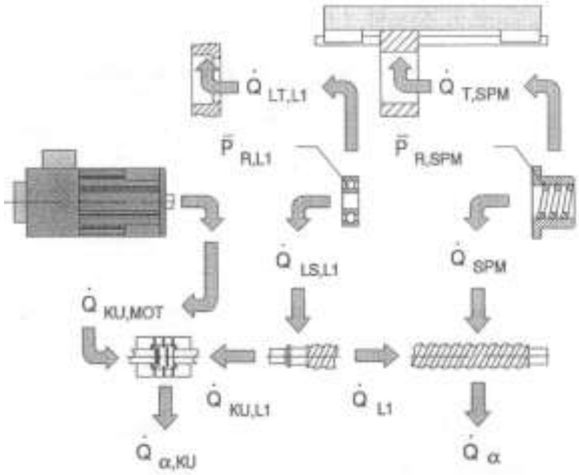


Fig. 5. Heat transfer scheme on mechanical structure of LCA/P.

All the rotary elements have been lubricated. Lubrication with grease in contrast to the lubricated by liquid circulation systems (oil), no heat transport occurs outside the system by cooling streams due to lubricating materials.

The thermal transfer between the screw axis and the environment is achieved by convection and radiation. Under these circumstances it can be assumed that the effects do not affect each other physically. Heat transfer from the threaded spindle to the environment in this case is proportional to the heat transfer coefficient α.

For LCA/P, the thermal behaviour is characterized by interdependence between the thermal parameters and technological precision parameters. The thermal stability is assessed frequently during its heating or cooling periods then the thermophysics structure reaches a state of thermal equilibrium (stabilization).
LCA/P with ball screw develops on amount of heat resulting from friction; that heat produces screw expansion influencing directly the positioning accuracy.
The result of a test, carried out by the company Heindenhain to determine the effect of heat on screw driver, as a result of friction in the bearings and position errors due nut, for LCA/P with semi-closed loop control is represented.

In these experiments, a mesh (discretization) of the structure was also made (see Figure 6) and also of the rolling bodies (see Figure 7).

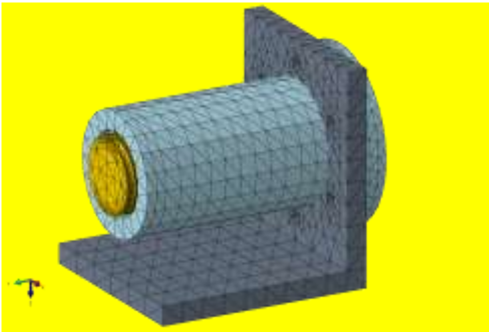


Fig. 6. Geometric discretization of the structure.

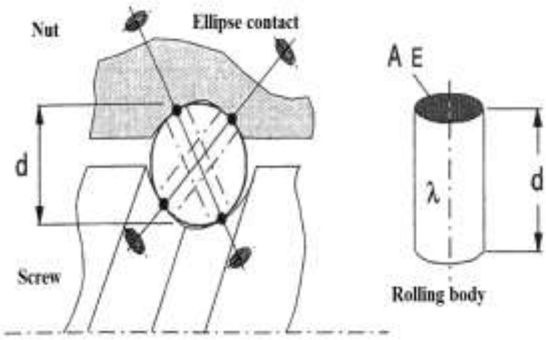


Fig. 7. Rolling bodies meshing

Motionless, the rolling body conducts heat. Determining its internal thermal resistance is derived mainly from the conceptual framework and it represents only a first approximation of the true facts.

4. Thermography and Heat Exchange Simulation

The main purposes of the research are improvement solutions of the thermal behaviour and heat exchange simulation [1]. To achieve the research goals of the feed and positioning kinematic chain a thermography and ANSYS simulation was made.

4.1. LabView simulation

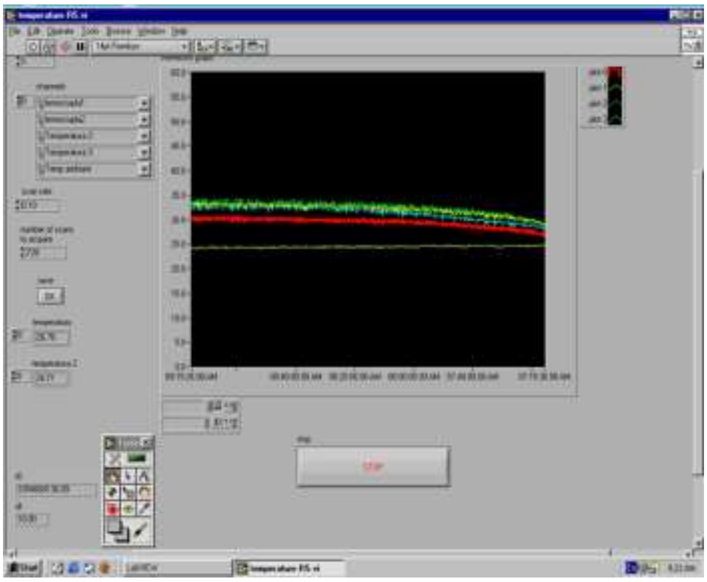
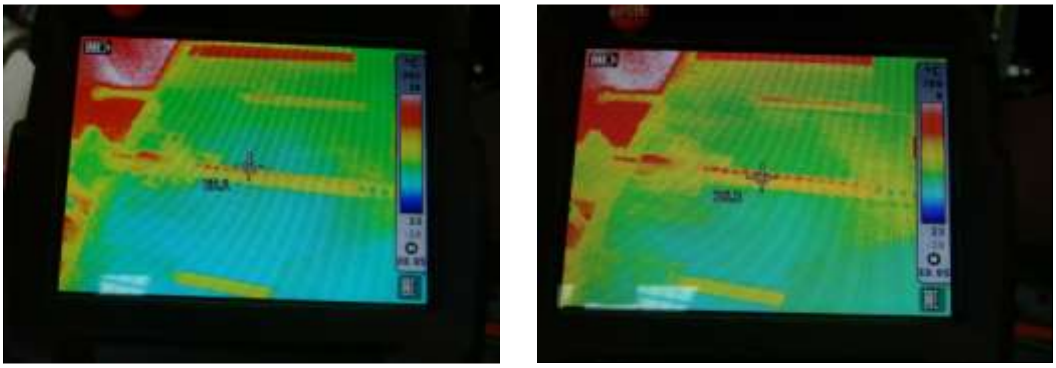


Fig.8 Results from LabView simulation.

4.2. Thermography

For thermography research was used a TESTO 870-2 camera [5] (Fig. 3 *a* - minimal temperature; *b* - maximal temperature).



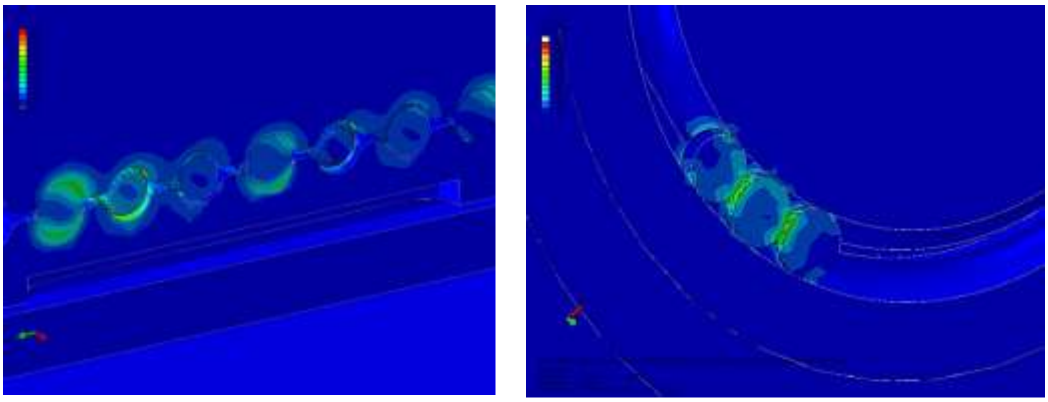
a. b.

Fig. 9. Thermography results:
a – ball screw temperature after one cycle; *b* – ball screw temperature after 1hour.

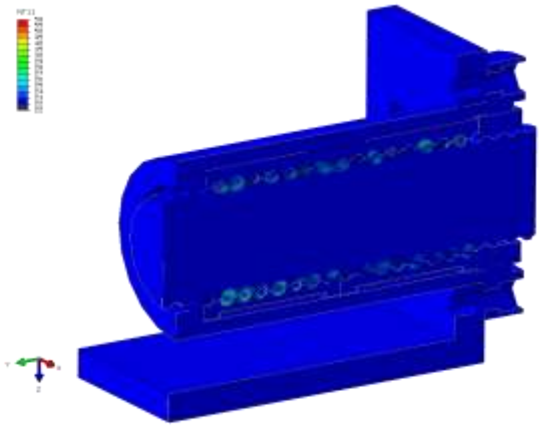
4.3. Heat Exchange Simulation

The model of ball screw feed drive system was developed in CAD software and running the optimization process using the Abaqus program.

Because the assembly includes almost 500 balls, a simplified simulation for 36 balls was made (see Figure 10). This analysis is used to determine temperature, heat transfer and tensions in balls. It is a very large analysis therefore the model is simplified and is considered that the balls behave in the same manner in the whole assembly.



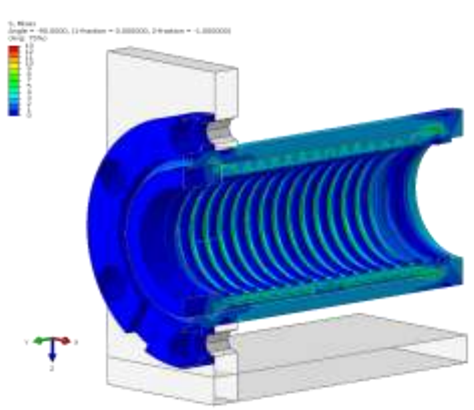
a. **b.**

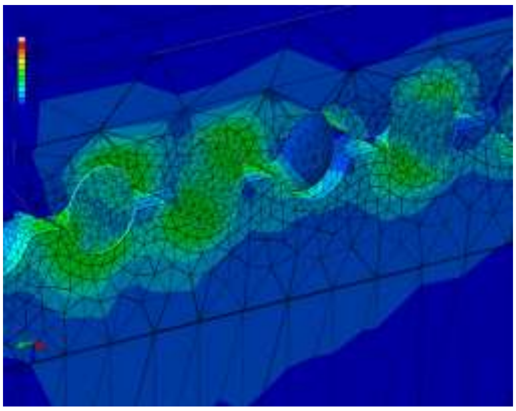


c.

Fig. 10**.** Ball screw thermal behaviour simulation.

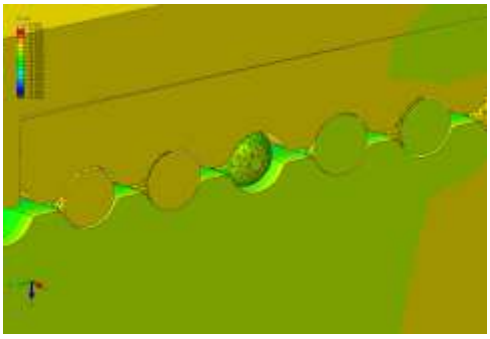
Other results for the simulation (velocity, stress, pretension) are presented in Figure 11.

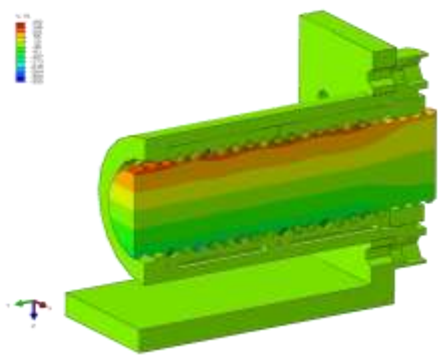


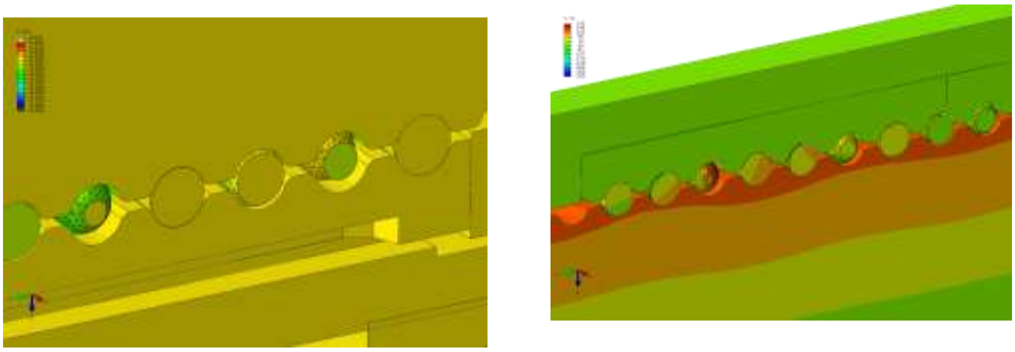


a

b







c d

Fig. 11**.** Results of simulation:
a – pretension; *b* –von mises stress; *c* – Minimum principal stress; *d* – velocity x.

As future research, an analysis will be done throughout the whole assembly; it will highlight only the external surface of the balls to see how the other components behave.

5. Conclusions

By comparing the experiment and the simulation, it results a strong dependence between temperature distribution and the ball screw displacement from 0 position to existing speeds in motion cycles. The short cycles are critical which occurs for example in small pieces milling and lead to strong local ball screw warming.

The local movement is not linear as happens with other manufacturing processes. Also we can discuss about numerous heat sources that influence the production process and the CNC machine, especially the cutting process.

Besides an increase in heat generation due to a stronger application of each component of the machine, CNC are influenced mainly by the cutting process itself. The heat generated at cutting is headed through the tool, through the piece and through splinters, which leads to the thermal influence on the other parts of the machine.

In the case of long processing times, the heat that is released on the cutting process can lead to a significant warming of the work piece. For the work piece that was taken as example it appeared at onshore processing a heat increase until 39° C. The table had an independent increasing heat compared to the work piece temperature, because of the direct contact with the piece.

Cutting experiments show that toward empty operating, the machine behaviour is modified because of hot splinters and high load on the main bearing (due to greater processing forces). In addition to heating the machine, the work piece heating had also a significant influence on the thermal deviations of the work piece dimensions.

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