10th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2006, Barcelona-Lloret de Mar, Spain, 11-15 September, 2006

STATICAL STIFFNESS OF CNC MACHINE TOOLS

Sliwka J.
Department of Machine Technology, Silesian University of Technology
Poland
Gliwice

ABSTRACT
Both static and dynamic types of stiffness are the key features influencing the accuracy of a machine tool performance. Whereas the stiffness of a traditional machine tool depends solely on the mechanic system used, the CNC machine tool stiffness is determined not only by its mechanic system but by the control system as well. Using the traditional method for determining static stiffness factors, no significant differences were observed between traditional and modern CNC machine tools. However, having applied the method using dynamically variable force of low frequency (DDSS method), some essential discrepancies appeared in the static stiffness factors obtained.
Keywords: static properties, CNC machine-tool, DDSS method

1. INTRODUCTION
The experimental determination of the static stiffness factors is the most popular method for assessing the static stiffness of machine tools, which applies particularly to small and medium size machines. The process of factor determination involves simulating the machining force or machining force components while the machine tool is inaction and measuring the static dislocation of the machine’s units along specific directions.

The stiffness of traditional machine tools depends solely on their mechanic systems (a screw, a nut, bearings, guideways, transmission systems). However in case of CNC machine tools the stiffness is determined not only by the mechanic system used but by the electrical and control systems as well (the engine, the motor driver, route and velocity measurement devices, regulatory circuitry of the route, velocity and electrical current).

Using the traditional method for determining static stiffness factors, no significant differences were observed between traditional and modern CNC machine tools. However, having applied the method using dynamically variable force of low frequency (DDSS method), some essential discrepancies appeared in the static stiffness factors obtained. It has been observed, that the static stiffness of CNC machine tool depends on the frequency and amplitude of the force applied together with the servomotor reinforcement factor of a given machine. Thus it is possible to suggest that static stiffness factors determination due to DDSS is more preferable method than using traditional approach, especially in the context of CNC machine tools. Traditional methods rely on static exciting force for obtaining stiffness factors, whereas the operating machine tool is subjected to dynamically varying loads characteristic for DDSS method.

2. THE DDSS METHOD
The DDSS method of determining the static stiffness of machine tools is based on the equality of displacement brought about by a dynamic force with an amplitude of displacement caused by a variable dynamic force the amplitude of which equals the value of the static force. This is the case when the frequency of the excited force is much lower than the first frequency of the free vibrations of the object.

The DDSS method consists in the measurement of forced vibrations brought about by a harmonic force which is not as high as the frequency of the free vibrations of the investigated object. The

vibrations are measured by means of seismic sensors. The static stiffness is calculated as the quotient of the value of the amplitude of displacement (calculated basing on the amplitude of the acceleration of vibrations that is measured by means of seismic sensors) and the value of the amplitude of the loading force.
Due to the non-linearity of the stiffness characteristics of machine tools measurements must be taken for several values of the constant component of the exciting force. The time courses of the signals of the vibrations gauges and the sensor of the exciting force are recorded during the investigations, basing on which the values of the amplitudes of the acceleration of the vibrations can be determined. The next step is the conversion of the determined amplitudes of acceleration into amplitudes of displacement.

3. THE RESEARCH STAND ARRANGEMENTS

The necessary arrangements for examining the CNC axle static stiffness are depicted in the Figure 1. The research stand was arranged so as to enable swift change of the drive configuration i.e. nut driven or lead-screw driven. The control system applied enhanced easy change of the velocity reinforcement coefficient Kv. The stand included the following construction features:

- Travel range: - 1550 mm,
- Maximum motion velocity: - 60m/min,
- Movable (sliding) units weight: m_{st}= 78 kg,
- Mass moment of inertia of rotating elements (moving screw): θ_{zrs}= $40*10^{-4}$ kgm^2,
- Mass moment of inertia of rotating elements (moving nut): θ_{zrn}= $116,9*10^{-4}$ kgm^2,
- Motor's peak torque: M_{sz}=23,3 Nm,

In order to carry out the testing process the research stand has been additionally equipped with a generator applying the force onto a given unit while measuring its stiffness. We used a hydraulic force generator with the dual action motor type, with proportional steering.

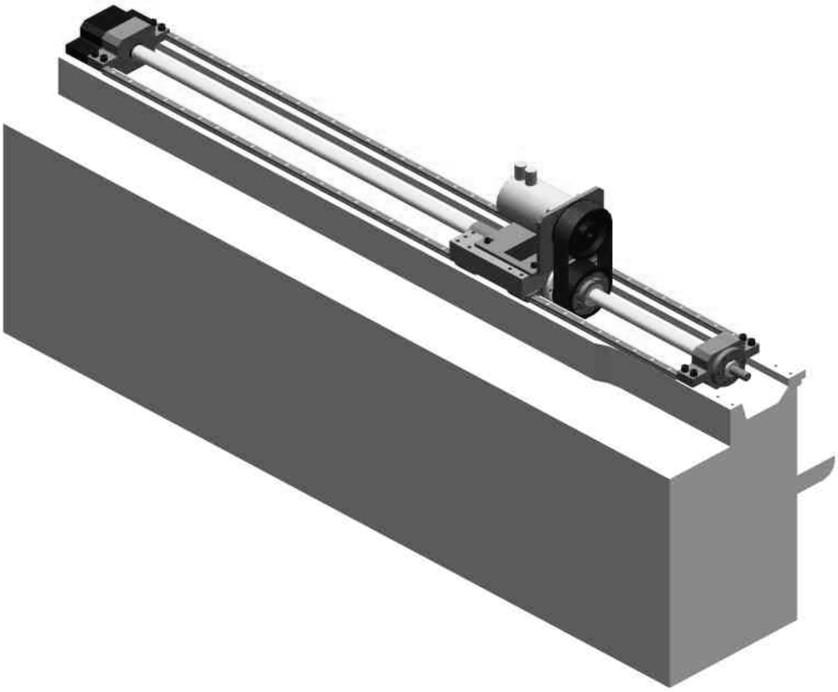

Figure 1. The model of research stand

The force generator has been constructed so as to apply the force onto various points of the machine bed stand (bed's length was approximately 2 m). Our aim was to determine stiffness at different points of the ball screw, which are responsible for transmitting the load from the slide to the servomotor shaft.

4. EXEMPLARY RESULTS

During every cycle of the research, the following readings were recorded: displacements measured by the induction displacement sensor together with the acceleration measured by the acceleration sensor. On the basis of the acquired readings, the displacement amplitudes were calculated. The measurements were carried out within the frequency range of the exciting force 1 – 10 Hz, every time for 3 values of the fixed component of force and for 3 values of the force amplitude. This served as the basis for further calculations of the stiffness indicators using the dynamic method for the displacements measured by the use of induction and acceleration sensors.

Track record of stiffness indicators, in frequency function, acceleration reinforcement factor K_v, force coercion amplitude, the component value of the fixed force coercion, the length of the screw responsible for the transmission of the force from the table to the motor spindle, has been created on the basis of the test results obtained through the use of the method relying on dynamic determination of the static stiffness. The exemplary results are displayed in the chart (see Figures 2).

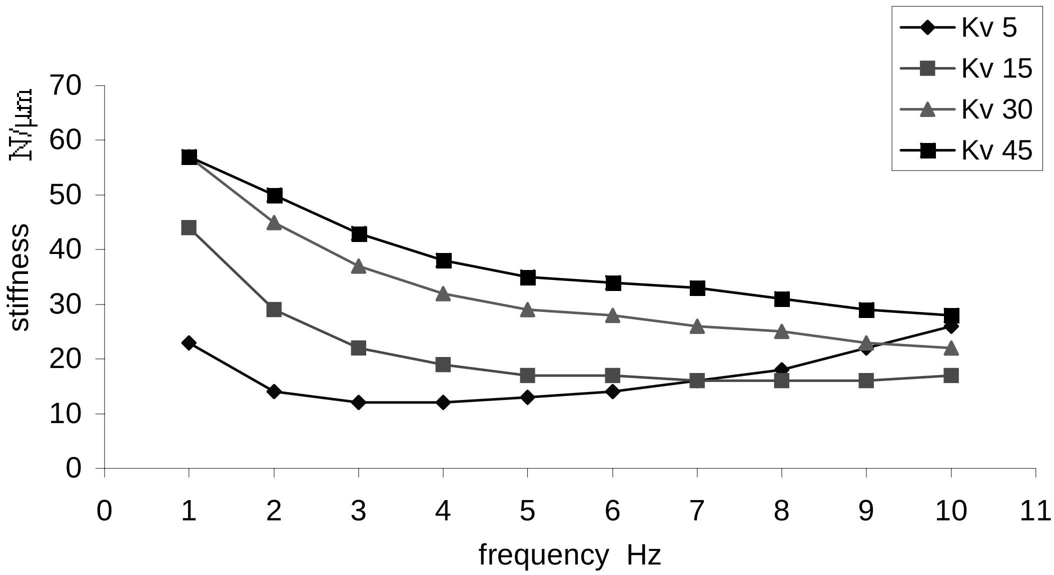

Figure 2. Acceleration reinforcement factor's K_v influence upon stiffness, with the drive placed by the ball screw side

5. CONCLUSIONS

1. The stiffness of the CNC axle considerably relies on the displacement measurement system applied, i.e. its allegiance with the so-called direct measuring systems (linear guides) or with indirect systems (encoders). CNC axle with the direct gauging system displays extremely high stiffness, which is difficult to determine. For practical purposes it can be assumed to be infinitely high. Whereas CNC axle with indirect gauging system is considerably lower and depends on variety of factors.
2. Stiffness of the OSN axle determined by the DDSS method depends on:
   - frequency of the exciting force, amplitude of the exciting force,
   - the component of the constant exciting force,
   - mechanical parameters (nut positioning in relation to the servo engine, which influences the length of the screw involved in the load transmission from the slide onto the engine) together with electrical and electronic parameters like the velocity reinforcement coefficient K_v),
   - the drive type, whether the ball screw or ball nut is propelled.

Further more detailed conclusions referring to the CNC axle with the indirect rotating measuring system (encoder) can be formulated as follows:

3. The carried out research proves the CNC axle stiffness with optimally suited regulatory parameters (settings), determined through conventional method hardly relies on electrical or electronic parameters, which means that alternation of the parameters has little influence upon stiffness indicator (for the range of changes in the velocity reinforcement coefficient $K_v = 5\text{-}45s^{-1}$ the stiffness varied approximately by 10% and while the increase of K_v entailed the stiffness increase as well). However, it changes considerably with a change of nut positioning in relation to servo engine (the change in the ball screw length involved in the force transmission process onto the motor shaft). The change for a tested device equaled approximately 35%/1mb.
4. The influence of the exciting force onto the OSN axle stiffness is considerable, although ambiguous. Generally, the stiffness level is much higher for exciting force of low frequencies than for those of higher frequencies. However in some cases the appearance of stiffness extremum (minimum) can be noticed (it refers only to ball screw drives and to distant positioning of a nut in relation to the engine). The closer the nut is to the servomotor, the influence of coercion frequency decreases.
5. The amplitude of exciting force has significant influence upon CNC axle stiffness. The following regularity concerning ball screw drive can be observed: provided the amplitude of exciting force is rather small, i.e. 20% of the constant component value, the stiffness increases rapidly. Provided the amplitude of the exciting force is relevantly high i.e. around 50% of the constant component-value, the CNC axle stiffness considerably decreases. The discrepancies may amount up to 100% (it refers to small values K_v). As the K_v increases, the amplitude's influence diminishes. In case of a nut drive no observations have been made referring to a significant impact of the exciting force amplitude upon OSN axle stiffness.
6. The CNC axle stiffness is also determined by the constant component-value of the exciting force. It can be explicitly observed in the case of ball screw drives. The research included cases for which the constant component of the exciting force differed by 100%. Thus some changes in the stiffness appeared (which referred generally to the increase by 10÷25%). The changes observed were more obvious for lower amplitudes of exciting force.
7. The type of drive applied (ball screw or nut drive) plays the key role in CNC axle stiffness determination by the use of DDSS method. The application of nut drive is responsible for drastic stiffness increase. As far as the ball screw driven CNC axle stiffness is concerned, the stiffness increase depends on the frequency of exciting force coefficient K_v or force's amplitude, and it can reach 250÷500%.

6. REFERENCES

[1] Sliwka J., Kosmol J.: A dynamic method of determining the static rigidity of heavy machine tool, Proceedining of the 10th International DAAAM Symposium, Vienna, Austria, 1999

[2] Grant no. 5 T07D 002 23 suported by the Polish Scientific Research Committee: Wyznaczanie sztywności statycznej obrabiarek sterowanych numerycznie metodą dynamiczną, Katedra Budowy Maszyn, Politechnika Śląska, Gliwice 2002-2005

[3] J. Sliwka, Determination of the static stiffness of machine tools means of dynamic excitement. Doctor's dissertation, Silesian Technical University, Gliwice, Poland 1999 (in Polish)