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EXPERIMENTAL INVESTIGATION ON DYNAMIC PROPERTIES OF TURNING MACHINE

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S u m m a r y

Paper present results of experimental investigations on dynamic properties of rope threading lathe TAE 45N. Prototype of this uniquely designed machine tool was delivered for the tests focused on finding dominant mode shape. Influence of the dominant mode on the cutting process is determined. Significant velocity and acceleration of headstock, during machining, can result in high vibration amplitudes, and its influence was estimated.

Keywords: modal analysis, dynamics of machine tool, rope threading lathe

Badanie właściwości dynamicznych tokarki do gwintów falistych

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

W artykule przedstawiono wyniki badań doświadczalnych unikatowej tokarki do gwintów falistych TAE 45N. Badania prototypu tej obrabiarki zostały przeprowadzone w celu wyznaczenia dominującej postaci drgań, oddziałujących na realizację procesu skrawania. Przyjęty cel wynika głównie z zastosowanej kinematyki obróbki charakteryzującej się dużą prędkością i przyspieszeniem głowicy narzędziowej, w trakcie jej realizacji.

Słowa kluczowe: analiza modalna, dynamika obrabiarek, tokarka do gwintów falistych

1. Introduction

Rapid development of machine tool industry encourages manufacturers to in-depth analysis of dynamic processes taking place during operation. In turning process, vibrations are substantial problem resulting in tool wear, productivity decrease, reducing dimensional accuracy and poor surface quality [1, 2]. A phenomenon known as self-excited vibrations may occur during cutting. Self-excited vibrations are caused by a feedback mechanism that results in increasing relative vibration amplitude between workpiece and cutting tool. This type of vibration emerges due to alterations in chip thickness and cutting force, and lack of dynamic stiffness of machine tool in certain directions. Defining machine tool

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compliance, which effectively means defining dynamic properties, becomes pivotal at a design stage. This can be solved using mathematical model established e.g. by finite element model or conducting an experiment. The solution comes with experimental modal analysis, widely used method for machine tools dynamic investigations. Modal analysis results in estimation of dynamic modal parameters i.e. a set of modal shapes with corresponding natural frequencies and damping coefficients.

A number of papers treats about machine tools investigations, focusing on different dynamic aspects [3-5]. Pawełko and Dolata [6] present analysis of finite element model of portable machine tool construction containing modular components. They performed dynamic analysis, which includes computing eigenfrequencies and corresponding modal shapes. Author paid particular attention to parts of the structure directly responsible for cutting force transfer. They concluded that only a few mode shapes significantly affect stability of examined structure.

Kono et al. [7] developed a methodology for tuning machine tool supports stiffness, to suppress rocking vibrations. Presented approach was based on contact stiffness model proposed in [8] and developed placement procedure. The method was experimentally verified for a small machine tool prototype, which dynamic characteristics was determined for several placement schemes, and had a positive effect on enhancing the stiffness of machine tool support.

Hosseinabadi and Altintas [9] present methodology of modelling and active damping of structural vibrations in machine tools. Authors developed a mathematical model, which has been experimentally verified and next implemented in sliding mode controller [10]. Proving that inertial vibrations of the machine tools can be actively damped. However, it is emphasized that implementation of the active damping requires the identification of modes affecting the control loop.

Siddhpura and Paurobally [11] analyzed emergence of regenerative chatter in facing and turning process. Successfully detecting self-excited vibrations close to the dominant mode of machine tools using force, acoustic or acceleration signals. Authors drawn a conclusion that regenerative chatter can be predicted by online monitoring these signals.

Sitarz et al.[12] modelled feed drive servomechanism of rope threading lathe, and tested influence of the spindle rotational speed value on the inertia forces. Authors additionally defined required torque of electric motor, due to a predetermined thread geometry, and the tool position error, which is directly connected with machining accuracy. Summarizing that, to achieve optimal dynamic properties, mass, damping and dynamic susceptibility of feed drive system has to be minimalized. Increase of drive control accuracy, which directly translates to increasing productivity of machining process can be achieved by slight reduction of spindle rotational speed. In [13] authors modified previously developed model, considering turret and support as flexible and on this basis gained information about error values and vibrations occurring. Confirming previously drawn conclusions.

In presented paper, an experimental investigation on dynamic properties of rope threading lathe TAE 45N prototype was conducted. Process of modal parameters estimation was carried out and as a result modal model was built. Significant mode shapes from the viewpoint of rocking and self-excited vibrations was identified and briefly described. According to fact that specimen was a prototype, structural elements characterized by excessive levels of vibration were indicated.

2. Experimental modal analysis

TAE 45N rope threading lathe (Fig. 1). due to its unique design and the type of realized operation, required conducting experimental tests and on this basis, assessment of its dynamic properties. Expression “unique design” refers mainly to the feed drive system construction, which consists of two carriages (X-axis and Xs-axis) responsible for the movement in the X-axis. Sophisticated solution of two carriages responsible for the realization of movement in the X-axis is directly connected with the need to performing fast motion in the X-axis, enabling performing complex geometry of rope thread. The feed drive system is presented in detail in Fig. 2.

The examined prototype was completely assembled. It affects the accessibility of certain locations on the structural elements, mainly due to the presence of the housings.

Fig. 1. Examined turning machine TEA 45N

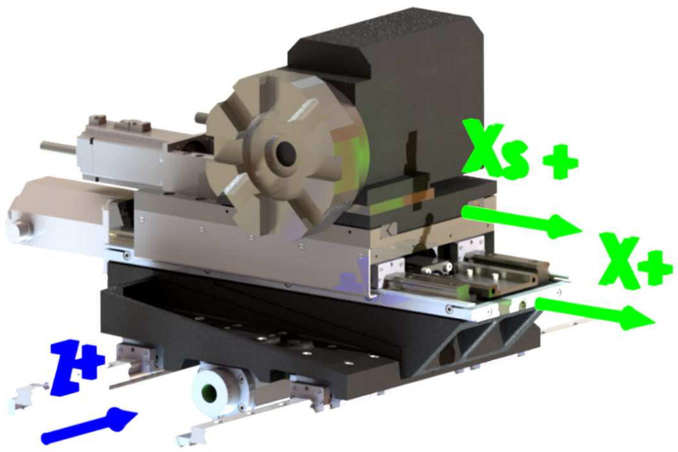

Fig. 2. Feed drive system details

The research plan included measuring dynamic response of rope theading lathe at points depicted in Fig. 3. According to fact that machine tool is configurable structure it is nescessary to unambiguously define relative position of kinematic pairs, for which experiment was conducted. The configuration of machine tool bodies was determined according to the most common operational variant of machining. Additionaly, examined specimen had applied brakes at all linear axes. Proper excitation method was used according to significant masses of the bodies and their relative positions. Parameters of excitation was monitored during experiment on the basis of preliminary tests, and coherence functions analysis. Examined lathe was excited at two points at the workpiece and the tool.

Experimental setup was presented schematically in Fig. 4. The structure was subsequently excited at selected points, using modal hammer. In both excitations points, impact was realized in the three orthogonal directions. Dynamic response of the examined structure was measured using triaxial IPC accelerometers, characterized by sensivity of 10 mV/(m/s^2) and frequency range up to 2000 Hz.

The experiment was performed using LMS-Siemens TestLab software and Scadas III hardware and included data processing, monitoring power spectral density function and coherence function, building and validating modal model. Modal parameters estimation process was realized using Polymax algorithm and validated using MAC criterion.

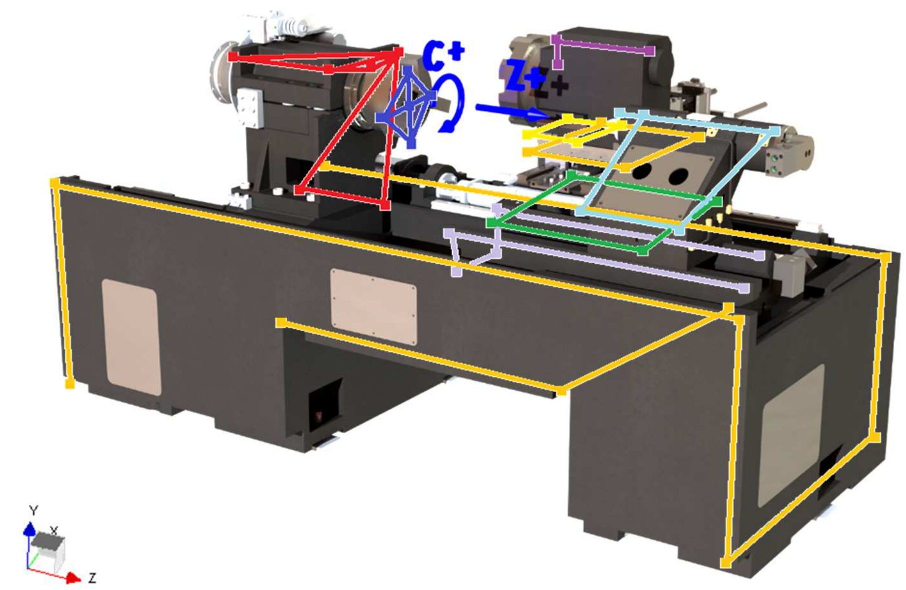

Fig. 3. Measure points arrangement

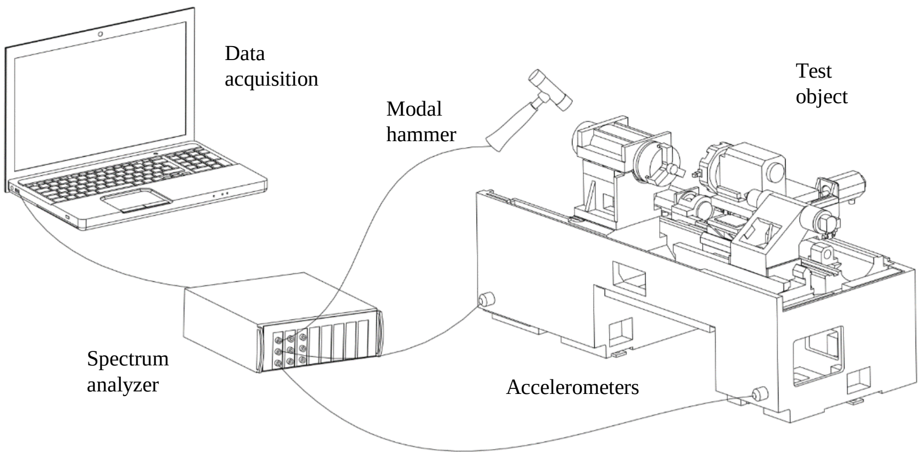

Fig. 4. Experimental setup

2. Findings

As a result of experiment, 990 frequency response functions were determined using H1 type of FRF estimator. On their basis, modal model was build using Polymax method for estimating a set of natural frequencies (in range 10÷400 Hz), modal shapes and damping coefficients, with default values of tolerance on frequency – 1%, damping – 2% and mode shapes vector – 5%. On the basis of stabilization diagram modal model poles were selected and mode shapes were estimated. Modal Assurance Criterion (MAC), was used to indicate physical mode shapes with low orthogonality level. The final form of rope threading lathe model is presented in Table 1.

Table 1. Modal model of rope threading lathe TAE 45N

Mode	**Frequency, Hz**	**Modal damping, %**
1	29,955	4,57
2	45,196	2,77
3	50,205	1,22
4	83,213	1,69
5	**93,397**	**1,59**
6	**102,221**	**0,68**
7	**143,528**	**3,42**
8	150,019	2,25
9	168,718	2,95
10	235,842	2,33
11	263,219	4,46
12	275,707	1,56
13	377,410	2,90
14	399,161	1,46
15	452,158	2,71
16	749,180	0,75
17	760,452	0,84

Further, analysis of mode shapes was carried out, to indicate machine tool components having a tendency to vibrate with excessive amplitude. Estimation of relative movement of carriages in X direction was crucial according to need of performing fast motion enabling performing complex geometry of rope thread.

First three mode shapes can be interpreted as rocking vibrations and understood as interaction between entire machine tool and their support. None of components tend to vibrate in different directions or with noticeable phase lead. These are mode shapes that can be observed for most of machine tools with typical construction. The rotational nature of them, may be result of low support torsional stiffness. Exemplary rocking vibration mode shape was depicted in Fig. 5.

The mode 5 (Fig. 5.) is characterized by a relative movement of feed drive components (X-axis carriages and turret) in Z direction, along linear guides located on the bed. The significance of the amplitude of the dynamic susceptibility function and a unequivocal movement at a relatively low frequency, have a direct impact on the geometric parameters of machined surface. Slight movement of the spindle with the work holder in counter phase relative to the aforementioned drive feed components can be also observed.

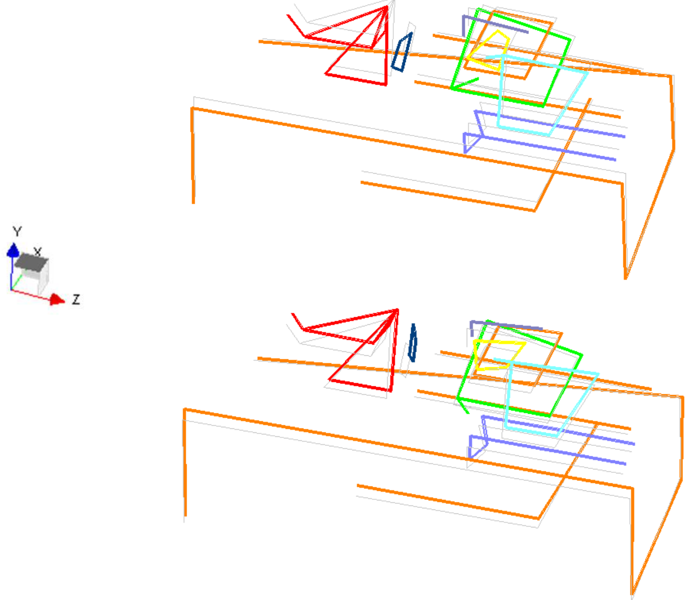

Fig. 5. Mode 5: 29.955 Hz, 4.57 %

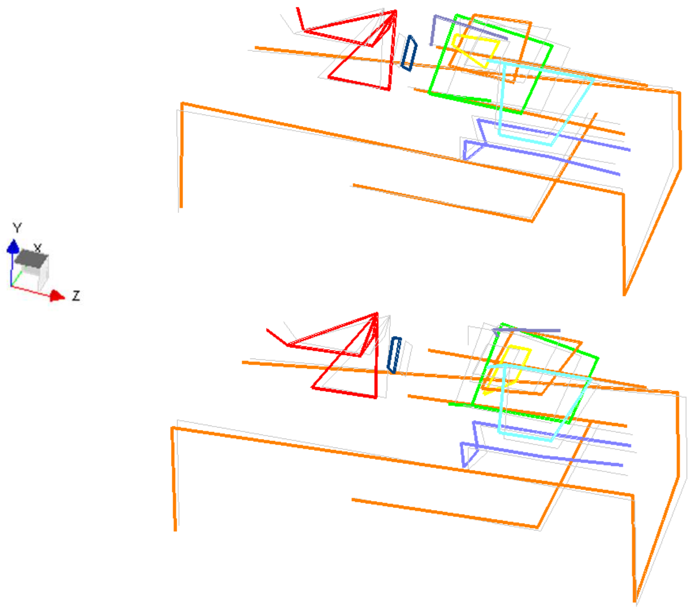

Fig. 6. Mode 6: 93.397 Hz, 1.59 %

Mode 6 and model 7 depicted in Fig. 6 and Fig. 7 is very important from viewpoint of a regenerative chatter formation process and can be described as an excessive motion of feed drive system in X direction. Massive turret is connected to X-axis carriage through additional Xs-axis carriage, which can result in stiffness decrease.

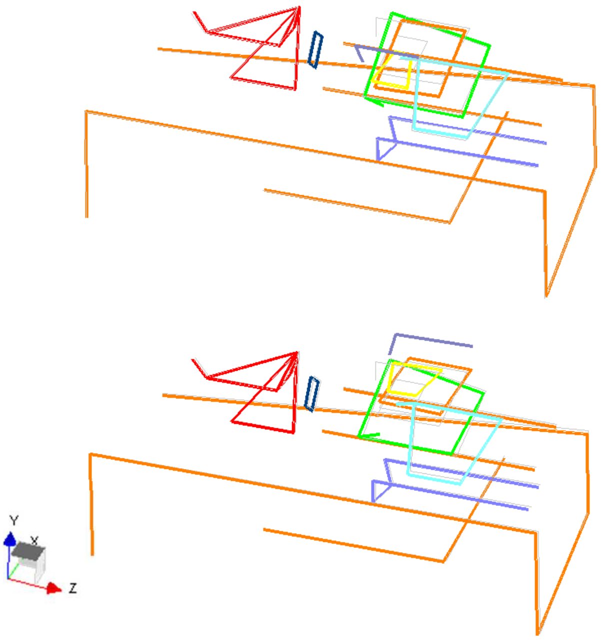

Fig. 7. Mode 7: 102.221 Hz, 0.68 %

3. Conclusions

Summarizing, results of some dynamic investigations of a rope threading lathe prototype were presented. Modal model was built, significant mode shapes form viewpoint of rocking and self-excited vibrations were animated and pithily described, components characterized by an excessive vibrations level were indicated.

However, there are some important issues worth noticing. Rocking vibrations occur, in low frequency range, characterized by rotation in three orthogonal axes. The reason may lie in the insufficiently rigid support.

Limited number of measure points, due to the presence of housings, significantly impedes mode shape interpretation. However, the most important are modes number 5 and 6 at a frequency around 100 Hz. They depict the movement of Xs-axis carriage to which a massive turret is mounted. A strong interaction between Xs-carriage dynamic properties and turret inertia can significantly influence of cutting process conditions. Turret mass reduction can be an efficient method of increasing operational capabilities of machine tool.

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