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SPINDLE – SYSTEM SZTYWNOŚCI WRZECIONA SBL 500 CNC

SPINDLE - HOUSING SYSTEM SBL 500 CNC

Obrotowy wrzeciennik (SH) obrabiarek odgrywa główną rolę w uzyskiwaniu wymaganej dokładności eksploatacyjnej i wydajności produkcji. Radialne łożyska kulkowe z kątowym kontaktem są obecnie coraz częściej stosowane w oprzyrządowaniu. Analiza systemu sztywności wrzeciennika - Spindle (SHS) jest bardzo złożona i skomplikowana. Kompleksowa analiza wymaga głębokiej wiedzy z matematyki, mechaniki, części maszyn, elastochydrodynamiki, techniki ruchu obrotowego i umiejętności programowania. Moduł programowy (SW) - Headstock Spindle - został zweryfikowany na Wydziale Inżynierii Produkcji przy projektowaniu precyzyjnego wrzeciona tokarki SBL 500 CNC.

***Słowa kluczowe**: Wrzeciennik, system sztywności wrzeciona, łożyska kulkowe z kątowym kontaktem, przyrządy maszyn, tokarka, analiza statyczna, analiza dynamiczna, modele matematyczne, dokładność, wydajność produkcji.*

Spindle Headstock (SH) of the machine tools play a major role in the fulfilling the required working accuracy and productivity. Radial ball bearings with angular contact are still more and more applied in an arrangement. The Spindle - housing system (SHS) complex analysis is very difficult and complicate. The analysis requires deep knowledge from mathematic, mechanics, machine parts, elastohydrodynamic theory, rolling housing technique and also programming skill. Software package (SW) - Spindle Headstock, Rel. 2.8 - carried out at the Department of Production Engineering has been applied for designing of the precise accuracy running spindle onto the lathe SBL 500 CNC (Fig. 6).

***Keywords:** Headstock, spindle-housing system, ball bearings with angular contact, machine tools, lathe, static analysis, dynamic analysis, mathematical models, accuracy, productivity.*

1. Introduction

The quality, quantity and effectiveness of production volume enhancing are considerably depending on technical and technological parameters of machine tools. The headstock plays the most important role in force flow of machine tool with principal rotating motion.

The headstock like tool or workpiece carrier has direct relationship to static and dynamic properties of cutting process, [1]. The *spindle-housing system (SHS)* stiffness has influence to surface quality, profile and dimension accuracy of production parts. It also has direct relationship to machine tool productivity, because ultimate cut width characterized by initialization of self-exciting vibration is directly proportional to machine tool stiffness and damping [4, 6].

The SHS complex analysis is very difficult and complicate. The analysis requires deep knowledge from mathematic, mechanics, machine parts, elastohydrodynamic theory, rolling housing technique and also programming skill [3].

2. Theoretical research

The main goal of theoretical research is to gain informations about headstock working conditions loaded by forces, which with their values and configuration are modeling real cutting forces. Creation of the mathematical models, which suitable define SHS static and dynamic characteristics was affected in past by computing technique level [5]. The most real judging of given housing already in construction design phase has increasing important in present time. It will reflect as in design quality as in economical cost of new machine developing. From given reasons, the requestion to carry out mathematical model arose, which as the most real as possible can describe SHS working properties. The parameters, which are not in known models or which are taking into consideration only partially, are implemented to calculation.

In the mathematical models creating, modular architecture Fig.1 is applicated [6]. It enables to independently create mathematical models relating to:

- single mounting elements - bearing nodes, spindle noses, clamping elements, supporting elements,
- complete spindle - housing system - stiffness, durability, running accuracy.

2.1. Static analysis

The static analysis describes the motionless spindle (n = 0 min^{-1}) and with constant loading forces. Many static mathematical models were created and factors which are usually taken into analysis contain equation (1). Resulting static deflection of the front-end spindle can be explicitly described [6] by multiparametrical equation in shape:

$$y_F = f\,[E, F_r, F_a, F_{Z1}\,(F_{Z2}), a, L, (b...), \rho, C_B, C_A, D1, V1, D2, V2] \qquad (1)$$

and depends especially on:

- spindle material and dimensions ($E, D1, D2, V1, V2$),
- loading forces position, orientation and magnitude (F_r, F_a, F_{Z1}, (F_{Z2}), r_F, b),
- bearing arrangement configuration and stiffness (C_A, C_B),
- spindle and bearing arrangement space configuration (L, a),
- spindle box construction.

Resulting static deflection of the front-end spindle:

$$y_r = y_{Mo} + y_L + y_t + y_{Fa} \quad [\mu m] \qquad (2)$$

is superposition of deflections from: bending moments (y_{Mo}), bearing stiffness (y_L), transversal forces (y_t), axial force (y_{Fa}).

Then radial stiffness and axial stiffness SHS equal to:

$$C_r = F_r / y_r \qquad C_a = F_a / y_a \qquad [N/\mu m] \qquad (3)$$

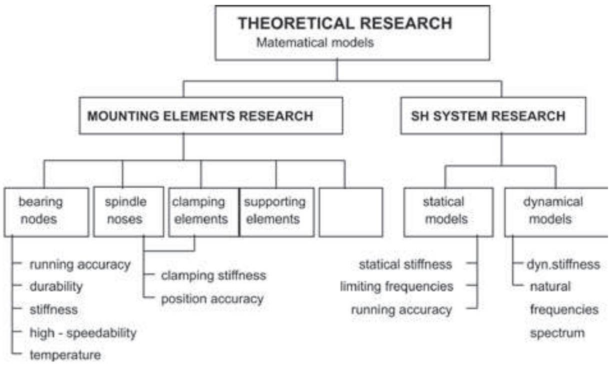

Fig.1. Modular structure of theoretical research [6]

The method of initial parameters in matrix shape - the method of transfer matrix was applicated in mathematical model [9] created for static parameters calculation. The main method advantage in computer form is possibility to repeat single calculating algorithms in matrix shape. Software package (SW) - Spindle Headstock, Rel. 2.8 - carried out at the Department of Production Engineering Faculty of Mechanical Engineering STU Bratislava [3].

The TRENS a. s. Trenčín as a Slovak manufacturer of machine tools preferably - lathes, offers a new generation of the lathes implementing a number of technological advances in designing, production and control systems [2]. Department of Production Engineering has been applied for designing of the precise accuracy running spindle on to the lathe SBL 500 CNC (Fig. 2a) [7,8]. All construction data and results of measurements were gained from producer.

frequencies are not in the resonant zone. In that case vibration amplitude of spindle could be considerably increased and spindle total stiffness will decrease to unsuitable values.

The most frequent determining dynamic characteristics of SHS are:

- spectrum of natural (resonant) frequencies (usually the first three frequencies),
- amplitudes of vibrations along spindle in dependence from revolving frequencies of spindle,
- resonant amplitudes of vibrations,
- dynamic stiffness of the spindle (at given revolving frequency of the spindle).

The SHS dynamic properties (dynamic deflection of spindle front-end, natural frequencies spectrum) [5], are effected with factors shown in Fig.4.

2.3. Mathematical models for determining of spindle dynamic properties

Nowadays, only one reliable manner how to find dynamic properties is experimental measurement and therefore is a very useful to create reliable mathematical models for determining of SHS dynamic properties.

In compliance with spindle mass reduction mathematical models are dividing into:

1) discrete with 1^{o} , 2^{o} and N^{o} degrees of freedom,
2) continuous.

The discrete mathematical model coming out from revolving vibration of spindles with N^{o} degrees of freedom is worked out in [1, 5] . This mathematical model for spindle dynamic

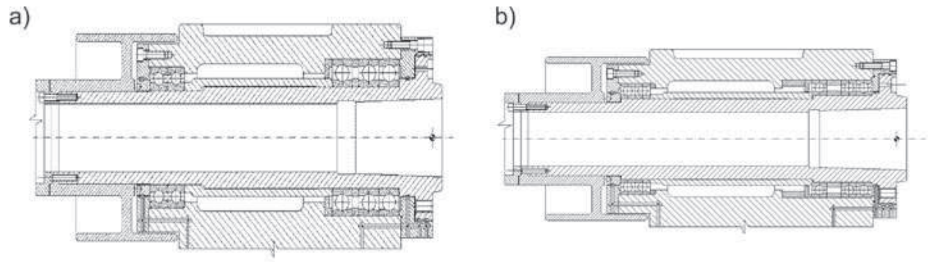

Fig. 2. Headstock of SBL 500, a) original design, b) optimalized design

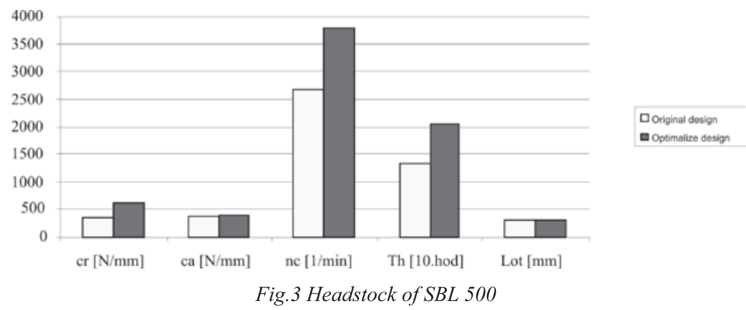

Fig.3 Headstock of SBL 500

2.2. Dynamic analysis

While static analysis of *spindle - housing system* describes spindle behavior in quiet, dynamic analysis describes spindle in real running and so real state is represented better. The dynamic characteristic is very important to know, especially at high-speed headstocks. It must be ensured that working revolving

properties calculating enables to take into calculation effects from rotating parts materials and dimensions, bearing arrangements stiffness and radial forces from cutting process and drive acting. The calculated results are spectrum of natural frequencies and dynamic deflection of spindle under discrete masses.

The deflection of spindle y_i loaded by concentrated forces in i-th point can be expressed in shape

Tab. 1. Results of static analysis Headstock SBL

	Unit	Value	Notice [%]
Total axial stiffness C_a	*[N/μmm]*	*372*	
Total radial stiffness C_r	*[N/μmm]*	*351*	
Total spindle displacement y_r	*[μmm]*	*18,45*	
forces composed of displacement resulted by			
- the bending moments y_{Mo}	*[μmm]*	*9,79*	*53,0*
- the bearing compliance y_L	*[μmm]*	*6,16*	*33,5*
- the cross-acting y_t	*[μmm]*	*2,49*	*13,5*
Limited frequency of rotation n_c	*[min^{-1}]*	*2695*	*unfit*
Life-time T_h	*[hour]*	*5175*	*unfit*
Distance between supports L	*[mm]*	*327*	

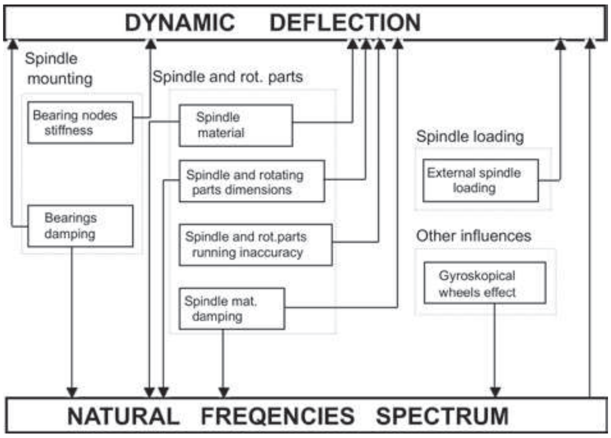

Fig. 4. Factors effected of SHS dynamic properties

$$y_i = a_{i1} F_{1o} + a_{i2} F_{2o} + \ldots + a_{ik} F_{ko} + \ldots + a_{in} F_{no} \quad [\mathrm{m}] \quad (4)$$

where a_{ik} (m/N) - Maxwell's effecting factor and every mass is acting on spindle by centrifugal force

$$F_{io} = m_i\, y_i\, \omega^2 \quad [\mathrm{N}] \quad (5)$$

where: m_i (kg) - mass of i-th discrete segment.

The application of given equations and their modifying for n masses, will create system of homogenical algebraic equations and solving of determinant D of this equations system are angular natural frequencies of transversal vibrations of the spindle ω_i (rads^{-1}).

The calculating procedure for determining of dynamic deflections y_i ,if spindle and rotating parts dimensions, bearing arrangements stiffness and radial external forces are taking to consideration, is very similar to previous. These calculating procedures are described in [5].

$$\Delta = \begin{vmatrix} 1 - a_{11}\, m_1\, \omega^2 & -a_{12}\, m_2\, \omega^2 & \ldots & -a_{1n}\, m_n\, \omega^2 \\ -a_{21}\, m_1\, \omega^2 & 1 - a_{22}\, m_2\, \omega^2 & \ldots & -a_{2n}\, m_n\, \omega^2 \\ \ldots & \ldots & \ldots & \ldots \\ -a_{n1}\, m_1\, \omega^2 & -a_{n2}\, m_2\, \omega^2 & \ldots & 1 - a_{nn}\, m_n\, \omega^2 \end{vmatrix} = 0 \quad (6)$$

It is quite easy to transform this mathematical model to computer comprehensive form and calculation of dynamic characteristics is quickly.

The most valuable is possibility to calculate dynamic stiffness at individual revolving frequencies of the spindle. Given mathematical model was verified on few spindles with programs which enable to calculate natural frequencies (COSMOS) and results were in good complianance [5].

The verified spindle in compliance with [7] was reduced to three-masses discrete system. The dynamic mathematical model described above was used for natural frequencies and dynamic deflections calculations. Tab.2 gives comparing of calculated and experimental values.

Tab.2 Experimental and calculated values of frequencies

Frequency	Calculated	Experimental	Difference
f_1 (Hz)	*1 201*	*940*	*+27,8 %*
f_2 (Hz)	*1 727*	*1610*	*+7,3 %*
f_3 (Hz)	*10 605*	*-*	*-*

The results can be considered as correct, in spite of relatively large difference of values (28 %) at the first frequency. It is caused by the fact, that dimensions of supplementary rotating parts was not in disposition. If these parts will take into calculation, values of theoretical natural frequencies will drop down.

The example of graphic output of calculated values is in fig. 5 [7]. The chart shows dynamic deflection of the spindle reduced to three - masses, in dependence on revolving frequency under separated masses. The first two resonant frequencies of solving spindle are marked in the chart.

3. Conclusion

One of main requestions at new spindle - housing system design is possibility of quick application in practice. The created methodologies of calculation must be verified and models must be digitalized to suitable user shape. These models must really illustrate characteristics of spindle - housing system.

The calculated results of mentioned application programme (Headstock Version 2.8) were verified with other real results of headstocks fy. TOS Lipník, TOS Kuřim and TOS Lipník.

At the designing procedures there had been changed the only one variable or parameter and the optimal mode has been

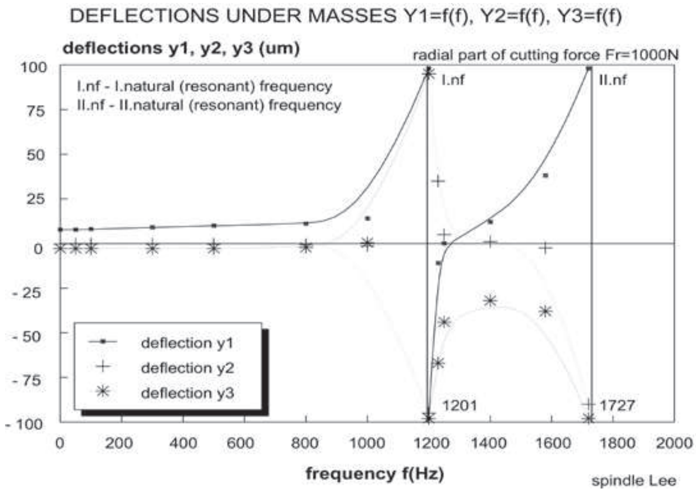

Fig.5. Dynamic deflections of the spindle in compliance with [5]

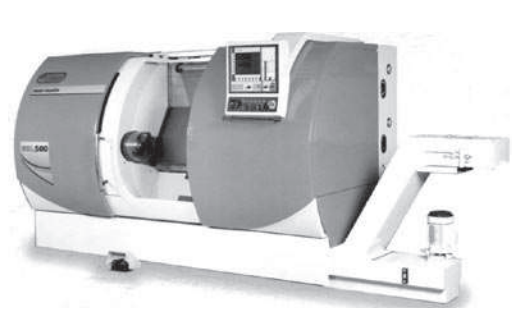

Fig. 6 CNC Lathe SBL 500

found out. The results calculated of static analysis Headstock SBL are presented in Tab. 1 and Fig 3. The results dynamic analysis is presented in Tab. 2 and Fig 5. The calculated results were verified with experimental measuring. The different between measured and calculated values is relatively small.

There is no doubt that the re-design has been successful story and proved high efficiency to find out the optimal mode. The more detailed information can be read in [7,8] and seen in the application in the machine tool made in the TRENS Inc., The Lathes SBL has been presented at the Exhibition in Nitra 2000 and at the Exhibition in Düseldorf.

The convergence of measured and calculated values gives good presumptions for wider application of created programme product in practise.

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