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KINEMATICS AND DYNAMICS STUDY ON THE BEADS OF THE MAIN AXLE BEARING FOR TECHNOLOGICAL SYSTEMS WITH HIGH ROTATION SPEED

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ABSTRACT

The paper presents a mathematical model for the analysis of kinematics and dynamics of the beads of the main axle bearing inside a high speed cutting machine tool. The use of this model creates the premises of determining the bearings rigidities in order to analyze the stability of the vibration.

KEYWORDS: kinematics, dynamics, bearing bead, high cutting speed, rigidity, stability.

INTRODUCTION

The main characteristics which reflect the level of improvement and exploiting at machine tools are: productive capacity, high stiffness, easy manipulation, etc. Simultaneously, a perfecting in the technological processes was needed, by means of mechanization, automation and intensified operating modes, leading to a rigorous design of the cutting tools.

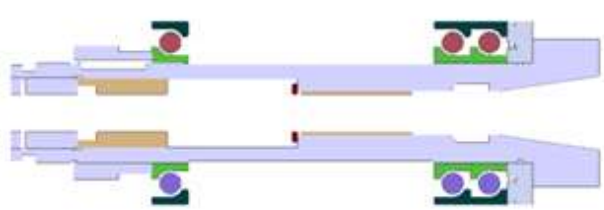
The increased performances of the machine tools, of the CNC machining centers, the continuous development of new products, or products manufactured using CAD/CAM techniques, contribute to the increased precision of the manufactured parts.

Also, the CNC machining centers are evolving by means of:

- Having an increased productivity and flexibility by reducing the non-productive times;
- Developing a surveillance and security system;
- Increasing the dynamic performances (high rigidity, higher cutting speeds, enhanced positioning accuracy);
- Multi-spindle machines for highly complex parts.

In this context, the rigidity of the main spindle of the machine tool has a particular importance for the increase in dimensional precision and the quality of the obtained surfaces (Figure 1).

Figure 1:



Longitudinal section through the main axis;

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MATERIALS AND METHODS

The article proposes a method to analyse the kinematics and dymanics of the bearing beads of a high speed rotating shaft, by using the derivative axiom of momentum and the derivative axiom of angular momentum. It creates the premises for the analysis of the axle bearing stiffness.

RESULTS AND DISCUSSION

It was experimentally found that the bearing`s rigidities are not constant, these being influenced by the final loading and the axle speed rotation.

For this purpose, it is necessary to make an evaluation of the kinematics and dynamics of the beads from the rolling bearings. Figure 2 presents a bearing bead during the dynamic loading of the spindle.

We consider a reference system Txyz, which is attached to the bead and is chosen as following:

Tx- parallel with the longitudinal axis of the spindle;

Ty- radial axis;

Tz- tangent axis;

We record:

αi = the contact angle of the bead with the interior ring;

αe = the contact angle of the bead with the exterior ring.

We consider B the contact point of the bead with the exterior ring. Because the bead performs a rolling movement towards the exterior ring, we accept:

Formulae 1:

$$\overrightarrow{v_B} = \overrightarrow{v_T} + \vec{\omega} x \overrightarrow{T_B} == (v_{Y_x} - \omega_z r \cdot cos\alpha_e)\vec{i} + \left(v_{T_y} - \omega_z r \cdot sin\alpha_e\right)\vec{j} + (v_{T_z} + \omega_x r \cdot cos\alpha_e - \omega_y r \cdot sin\alpha_e)\vec{k} (1)$$

Thus:

Formulae 2:

$$\begin{cases} v_{T_x} - \omega_z r \cdot cos\alpha_e = 0 \\ v_{T_y} + \omega_z r \cdot sin\alpha_e = 0 \\ v_{T_z} + \omega_x r \cdot cos\alpha_e - \omega_y r \cdot sin\alpha_e = 0 \end{cases} \quad (2)$$

In case of C, which is the contact point of the bead with the interior ring:

Formulae 3:

$$\overrightarrow{v_B} = \overrightarrow{v_T} + \vec{\omega} x \overrightarrow{OC} = (v_{Y_x} + \omega_z r \cdot cos\alpha_i)\vec{i} + \left(v_{T_y} - \omega_z r \cdot sin\alpha_i\right)\vec{j} + (v_{T_z} - \omega_x r \cdot cos\alpha_i - \omega_y r \cdot sin\alpha_i)\vec{k} \ (3)$$

Supposing that between the interior of the ring and the bead is no gliding, the velocity of the point C must be tangent (parallel with Tz) and equal in size with the velocity of the point C, belonging to the interior ring.

Formulae 4,5:

$$\overrightarrow{v_c} = \Omega \cdot R_c \vec{k} (4)$$

R_C= contact radius;

$$\begin{cases} v_{T_x} + \omega_z r \cdot cos\alpha_i = 0 \\ v_{T_y} - \omega_z r \cdot sin\alpha_i = 0 \\ v_{T_z} - \omega_x r \cdot cos\alpha_i + \omega_y r \cdot sin\alpha_i = \Omega R_C \end{cases} \quad (5)$$

The condition for the first two equations in (2) and (5) to be fulfilled is:

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Formulae 6:

$$\begin{cases} v_{T_Z} = v_{T_Y} = 0; \\ \omega_Z = 0; \end{cases} \quad (6)$$

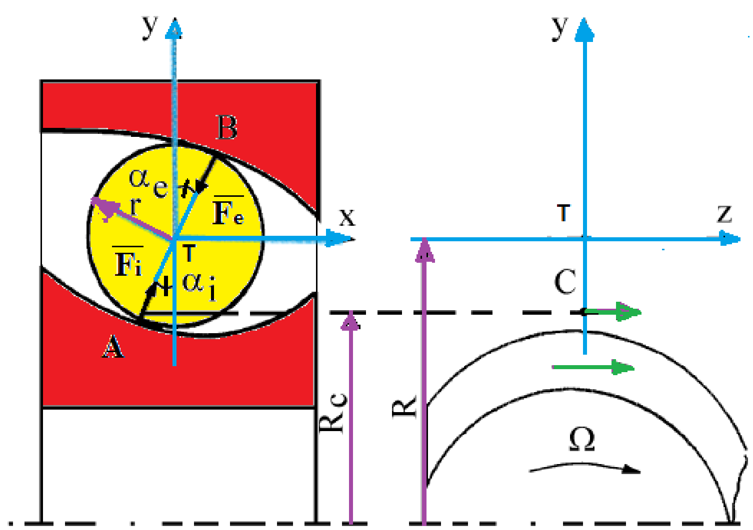
We consider W*b*, the angular rotation velocity of the bead center around the axis of the shaft. We can write:

Formulae 7:

$$v_{T_Z} = \Omega b \cdot R \quad (7)$$

Where R= the radius of the circle opened by the center of the bead;

Figure 2:



The loading of the bearing bead during the dynamic stress applied to the spindle;

Corresponding to figure 2, we have:

Formulae 8:

$$\begin{gathered} R = R_C + r\cos\alpha_i \\ R = R_e - r\cos\alpha_e - d \\ R_C = R_e - r(\cos\alpha_e + \cos\alpha_i) - d \end{gathered} \quad (8)$$

It is accepted that $\omega_y = 0$. The last relations from (2) and (5) become:

Formulae 9:

$$\begin{gathered} \Omega_b(R_e - r\cos\alpha_e - d) + \omega_x r\cos\alpha_e = 0 \\ \Omega_b(R_e - r\cos\alpha_e - d) - \omega_x r\cos\alpha_i = \Omega[R_e - r(\cos\alpha_e + \cos\alpha_i) - d] \end{gathered} \quad (9)$$

Because the variation of α_i and α_e around α is very small, we have:

Formulae 10:

$$\begin{gathered} \omega_x = \frac{-\Omega[R_e - 2r\cos\alpha - d]}{2r\cos\alpha} = -K_1\Omega \\ \Omega_b = \frac{\Omega[R_e - 2r\cos\alpha - d]}{2(R_e - r\cos\alpha - d)} = K_2\Omega \end{gathered} \quad (10)$$

Having K_1 and K_2 dependent on the construction of the bearing:

Formulae 11:

$$K_1=\frac{R_e-2r\cos\alpha-d}{2r\cos\alpha}$$
$$K_2=\frac{R_e-2r\cos\alpha-d}{2(R_e-r\cos\alpha-d)} \quad (11)$$

The dynamic analysis of the bead is made by using the impulse derivative axioms and the kinetic momentum axiom. These are given by the following relations:

Formulae 12-16:

$$m_b\overrightarrow{a_T}=\overrightarrow{F_\imath}+\overrightarrow{F_e} \quad (12)$$

$$\overrightarrow{a_T}=-\Omega_b^2R\vec{\jmath} \quad (13)$$

$$\overrightarrow{F_\imath}=F_j sin\alpha_e\vec{\imath}+F_i cos\alpha_i\vec{\jmath} \quad (14)$$

$$\overrightarrow{F_e}=-F_e sin\alpha_e\vec{\imath}-F_e cos\alpha_e\vec{\jmath} \quad (15)$$

$$\begin{cases} F_i sin\alpha_i-F_e sin\alpha_e=0 \\ F_i cos\alpha_i-F_e cos\alpha_e=-m_b\Omega_b^2R \end{cases} (16)$$

Where:

$\overrightarrow{a_T}$ = the bead weight center acceleration, where the bead makes a rotation movement around the bearing;

$\overrightarrow{F_\imath}$ = the interaction force between the bead and the interior ring;

$\overrightarrow{F_e}$= the interaction force between the bead and the exterior ring;

The kinetic moment axiom:

Formulae 17:

$$m_b\cdot\overrightarrow{r_T}x\vec{a}+\underset{J_T}{\Rightarrow}\cdot\vec{\varepsilon}+\vec{\omega}x\left(\underset{J_T}{\Rightarrow}\cdot\vec{\omega}\right)=\overrightarrow{M_T} \quad (17)$$

Thus, we have:

Formulae 18-20:

$$\begin{cases} \vec{r}=\vec{0} \\ (\vec{\varepsilon}=0) \end{cases} \quad (18)$$

$$\cdot\vec{\omega}x\left(\underset{J_T}{\Rightarrow}\cdot\vec{\omega}\right)=\overrightarrow{M_T} \quad (19)$$

$$\underset{J_T}{\Rightarrow}=\begin{pmatrix} J & 0 & 0 \\ 0 & J & 0 \\ 0 & 0 & J \end{pmatrix} \quad (20)$$

Where:

$\underset{J}{\Rightarrow}$ = inertia tensor of the bead relative to its own landmark, with attached matrix;

J = inertia moment of the bead, relative to any diametric axis;

Formulae 21:

$$\cdot\,\vec{\omega} x \left(\underset{J_T}{\Rightarrow} \cdot \vec{\omega}\right) = 0 \qquad (21)$$

$\overrightarrow{M_T}$ = the resulting moment of $\overrightarrow{F_e}$ and $\overrightarrow{F_i}$ forces relative to point T;

We have:

Formulae 22:

$$\overrightarrow{M_T} = 0 \qquad (22)$$

The equation (21) is completely satisfied.

CONCLUSION

- The kinematic and dynamic analysis of the beads of the main axle bearing creates the premises to the analysis of their rigidity;
- In order to assure the equilibrium condition, the constant K_1 and K_2 are highlightened; these depend on the constructive characteristics of the spindles;
- The dynamic analysis of the bead is made by using the impulse derivative axioms and the kinetic moment derivative axiom;
- For the present application, these are completely satisfied.

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