Adaptive Control of the Spindle Position by Means of Mechatronic Systems

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Abstract - **In this paper, the approaches to improve the accuracy of spindle rotation are given. They are based on use of adaptive microprocessor, system with automatic regulator adjusting parameters depending on technological factors, and variable structure control actuators drives. The automatic control system with laser triangulation sensors and adjustable hydrostatic bearings was proposed. The schematic technical solutions concerning adaptive control of the spindle position based on regulation of flow characteristics and geometrical parameters of hydrostatic bearing arrangements are given.**

Keywords - **adaptive control, spindle rotation, laser triangulation sensor, adjustable hydrostatic bearing.**

I. Introduction

The most promising in terms of increasing the accuracy and productivity of machining process is the use of adaptive control of machining processes. An integral part of such systems are mechatronic units, which represent a set of power, information and controls. The combination of interconnected industries such as hydraulics, electronics and mechanics makes it possible to establish efficient control systems of machine tools [1, 2]. Modern control systems cannot be imagined without information meters, secondary equipment and computers for the implementation of adaptive algorithms. One of the important benefits of implementing adaptive control based on mechatronic modules is the ability to use digital interface, which allows the use of such systems in modern CNC machines.

II. Results of research

The following approaches to improve the accuracy of spindle rotation with hydrostatic bearings (HB) are proposed which based on use adaptive microprocessors in the feedback channel of automatic control systems (ACS), application of ACS with parameters automatic adjusting depending on technological factors and use variable (flexible) structure of drives control (Fig. 1).

The spindle unit with HB of machine tool in the operation exposed the permanent, periodic, random power loading, factors of surrounding environment. Significant impact on the precision spindle do its parameters of bearings, including the radial gap δ_0, the fluid flow rate q_{ki} through the pockets of HB, the working fluid temperature T, the pressure p_{ki} in the pockets of HB, the viscosity μ of the working fluid supply system.

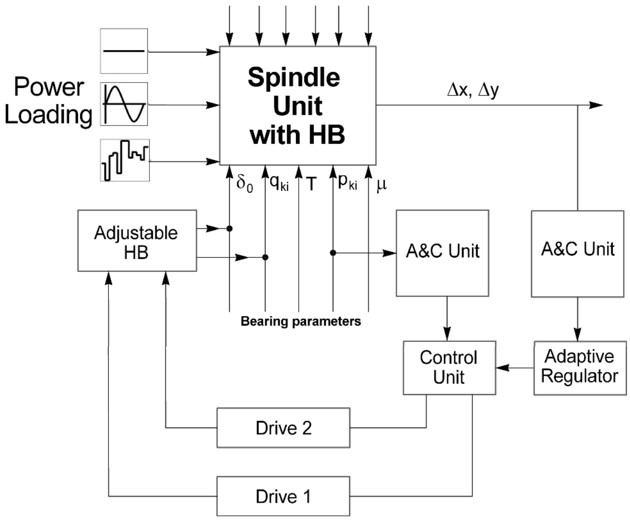


Fig. 1 Scheme of adaptive control implementation of spindle position accuracy with HB

On the Fig. 1 control circuit is proposed which provides of application of two ACS working modes depending on the nature of changes in processing conditions. In the mode number 1 is fulfilling regulation of flow rate characteristics q_{ki}; in the mode number 2 is fulfilling both regulation of flow rate characteristics q_{ki} and geometric characteristic (the value of the gap size δ_0) simultaneously. Mentioned modes correspond the particular structure of ASC with connection drive number 1 when system work in the first mode, or both drives simultaneously when system work in the second mode. Moreover, the decision to change of the operation mode and the ACS structure is assigned to the adaptive controller. The ability to change self structure depending on the processing conditions on machine tools is a fundamental difference of the proposed adaptive ACS

Schematic structure of the adaptive ACS based on adjustable adjustable journal HB with four pockets is shown on Fig. 2.

The spindle offset Δx, Δy measure by means of contactless laser triangulation sensors 7 that are installed in the appropriate directions. Digital signals from the sensors are delivered to the adaptive controller 5 which in real time calculates the current value of the radius vector ρ_i of the spindle 1 trajectory and compares it with the maximum permissible value ρ_{max} in which the output spindle accuracy is satisfactory. If $\rho_i \leq \rho_{max}$, then ACS operates on the mode number 1, otherwise, the adaptive controller switches the system for working in mode 2. The principles of ACS operating in the mentioned modes are considered in detail in the works [3].

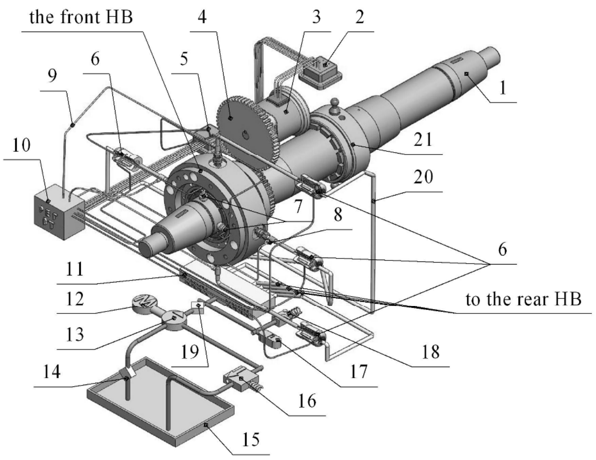


Fig. 2 Schematic solution of adaptive ACS (for front adjustable spindle HB): 1 - spindle; 2 - stepping motor controller; 3 - stepping motor; 4 - wheel gear; 5 - adaptive controller; 6 - proportional flow valves; 7 - contactless laser sensors; 8 - dynamic pressure fluid sensors; 9 - connecting cables; 10 - flow valves regulator; 11 - hub flows; 12 - electric motor; 13 - hydraulic pump; 14 - roughing cleaning filter; 15 - tank; 16 - safety valve; 17 - accumulator; 18 - pressure switch; 19 - finishing cleaner filter; 20 - hydraulic line; 21 - thrust hydrodynamic bearing

The current value of the radius vector ρ_i is determined by the relationship:

$$\rho_i = \sqrt{\Delta x_i^2 + \Delta y_i^2} \quad (1)$$

Functional scheme of adaptive ACS is shown on Fig. 3.

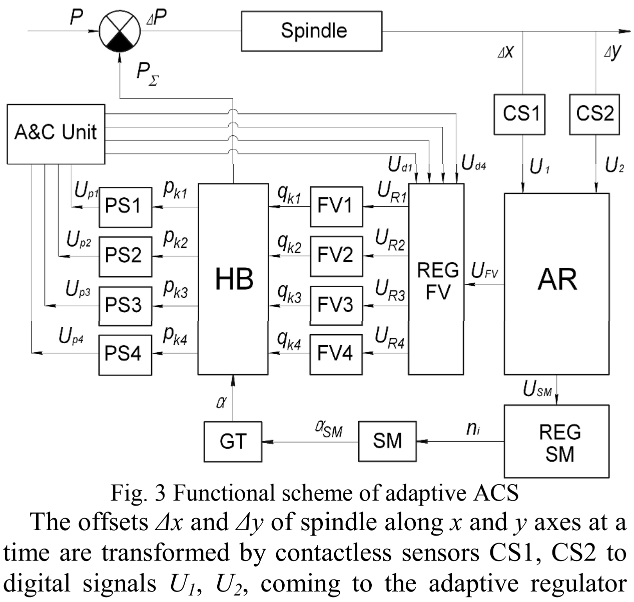


Fig. 3 Functional scheme of adaptive ACS

The offsets Δx and Δy of spindle along x and y axes at a time are transformed by contactless sensors CS1, CS2 to digital signals U_1, U_2, coming to the adaptive regulator AR, where signal U_{FV} goes to the regulator REG FV of the control system supplies of adjustable HB. The microprocessor regulator generates on the output the signals U_{ri} are directed to the proportional flow valves FV1...FV4, which, in turn, change their throughput capability q_{ki} in accordance with regulation algorithm. The result is the corresponding values of bearing capacity P_Σ in adjustable HB to compensate for the external load P on the spindle. Fluid pressure in the pockets p_{ki} is measured by the dynamic pressure fluid sensors PS1...PS4 [4], analog signals from which U_{pi} after amplification and conversion in A&C unit to digital form U_{di} in the block CB are coming in to the regulator. Performance of the system is limited by the response speed of adjustable journal spindle HB that not exceeds 25 Hz. During this the adaptive ACS works in the mode number 1.

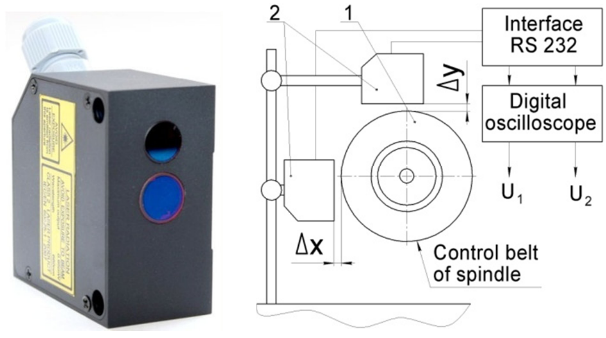
If $\rho_i > \rho_{max}$, then the digital signal U_{SM} from AR is supplied to the regulator REG SM of control system of HB geometric parameters which has the response speed of about 1 Hz. The rotation angle of the stepping motor SM α_{SM} (see Fig. 3) is proportional to the number n_i of electric pulses that come to it from the REG SM by the program. On the output shaft of stepping motor is rigidly fixed gear (GT), which transmits the rotation (α) of a toothed wheel (see Fig. 2), by means of a threaded connection is placed at the tail of the hydrostatic sleeve. The hydrostatic sleeve becomes axially movement while the rotation of the specified gear thereby changing the gap δ_0 in the HB. The signal U_{FV} from AR simultaneously enters to the regulator REG FV. During this the adaptive ACS operates in the second mode until the condition $\rho_i \leq \rho_{max}$ is performed. Thus, the system of flow rates regulation works continuously but system of geometrical parameters regulation works while condition $\rho_i > \rho_{max}$ is.

One of the main elements of the proposed adaptive ACS are the contactless sensors CS1, CS2. The correct choice of sensors is provided ACS sensitivity to small displacements of the spindle within parts of a micrometer and overall system performance and reliability [3]. Taking into account the working processes occurring in the machine technological system and measuring parameters an application of the laser triangulation measuring type RF603.5-10/2-232-I-IN-12-CG-3 [3] (Fig. 4) is proposed which are not require amplification devices and have the ability to display the output signal both analog and digital form. The operating range of sensors measurement is 2 mm, linearity is ± 2 μm, resolution is 0.2 μm, maximum sampling frequency is 9.4 kHz.

To control the gap while ACS works in the second mode a new design of journal segmental hydrostatic bearing is proposed [6] (Fig. 5).

The main part of the adjustable hydrostatic bearing is housing 3, which has a bore with a conical surface and five holes are machined perpendicularly relative to the axis of the mentioned holes; the angle between them is 72 degrees.

In the housing bore 3 sets the five segments 6 which on the inner surface are bearing pockets ellipsoid shape with located in the center the threaded hole. At the segments ends paralleled of the bearing axis grooves for the set of the springs special form are machined parallel connected segments and determine their relative position in the radial direction.



a) b)

Fig. 4 Laser triangulation sensor a) and measuring schema of spindle displacements b): 1 - spindle; 2 - laser sensors

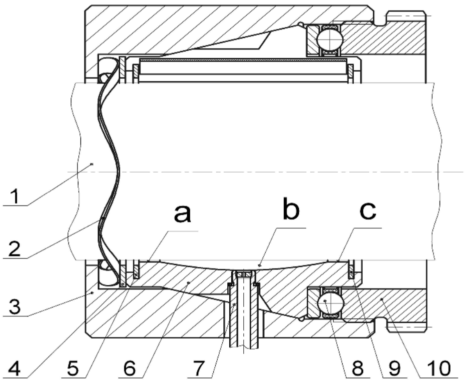


Fig. 5 Adjustable journal segmental hydrostatic bearing: 1 – spindle; 2 - wave spring; 3 - housing; 4 - washer; 5, 9 - rings; 6 - segment; 7 - fitting; 8 - thrust ball bearings, 10 - tensioning nut

The threaded holes of segments are combined with five holes and screw into them the fittings 7, which serve to supply the working fluid to the bearing surface.

The accuracy of the segments relative position in the axial direction is provided by split elastic rings 5 and 9, which are set in radial grooves machined along with the other two ends of the segments.

Between washer 4 and end of housing stepped hole 3 is set wave spring 2, which is designed to create a preload in the axial direction until the gap adjust. To reduce the friction force moment when adjusting the gap between the ends of the segments 6 and a tensioning nut 10 thrust ball bearings 8 is installed. It reduces the effort that is applied to the tensioning nut when adjusting the radial gap in bearing arrangement.

The adjustable journal segmental hydrostatic bearing operates next way. The working fluid through the proportional flow valves FV (see Fig. 3) is supplied through the fittings 7 to the pockets *b* of segments 6 where a carrier layer of fluid is created which supports the spindle 1 in a certain position. Drain the fluid to the tank from pockets is through the lands a, c and f which use as throttling element and when the radial gap change they allow to adjust the stiffness of the bearing and fluid flow rate.

Adjust the size of the radial gap is performed by rotating a tensioning nut 10 that is screwed into the housing hole 3 and due to the thrust bearings 8 provides axial displacement of the segments 6. Mentioned segments 6 moving by tapered belts on the inner conical surface of the housing 3 also move in the radial direction, providing regulation the gap size between the bearing surface of the shaft 1 and segments 6. The tensioning nut 10 is designed as a gear, which transmits rotation gear is installed on the output shaft of precision stepping motor (see Fig. 2). It enables high accuracy of value regulation of radial gap.

Implementation of the embracing surface of the hydrostatic bearing with five separate segments connected by springs special shape allows to simplify machining technology and expand the range of technological methods for forming pockets in segments.

REFERENCES

[1] Heisel U., Strutinskiy S., Sidorko V., Filatov Yu, Storchak M. Development of Controllable Spherical Fluid Friction Hinges for Exact Spatial Mechanisms. Production Engineering, vol. 5, 2011, pp. 241-250.

[2] Kuznetsov Yu., AL-Refo I., Dmitriev D. Construction and Research of Pyramidal Arrangement Milling Machine-Tool of "Triglide" Type. International Journals of Engineering & Sciences - International Journal of Mechanical & Mechatronics Engineering (IJMME-IJENS), vol. 13, Issue 04, pp. 24-28, Aug. 2013.

[3] Strutynskyi V., Fedorynenko D. Statistical Dynamics of Spindle Units with Hydrostatic Bearings: monograph (2011) Publishing house "Aspect-polygraph", 464 p. (in Ukrainian)

[4] Fedorynenko D., Boyko S., Sapon S. Search of Spatial Pressure Functions in Adjustable Hydrostatic Radial Bearing. Acta Mechanica et Automatica, vol. 9, No. 1(31), 2015, pp. 23-26.

[5] Fedorynenko D., Sapon S., Kosmach A., Boyko S. Information-measuring Complex for Research Spindle Trajectories with Hydrostatical Bearings. Scientific Bulletin of national mining University, vol. 6 (150), 2015, pp. 42-48. (in Ukrainian)

[6] Fedorynenko D., Sapon S., Tsekov B., Boyko S. Adjustable Segmented Hybrid Fluid Bearing. Patent of Ukraine No 100782, 2015. (in Ukrainian)

III. CONCLUSION

The automatic control system of spindle position is proposed based on laser triangulation sensor and regulation flow rate characteristics and geometrical parameters of spindle hydrostatic bearings. The application of laser triangulation sensor allows ensuring high reliability and precision in a wide range of external loads.

The new design of hydrostatic journal bearing technical is proposed that provides increase of maintainability and reliability of spindle unit in general.