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# HIGH-SPEED SPINDLE CONCEPT FOR SMART MANUFACTURING

An intellectualized machine tool is the foundation of the future manufacturing industry. As a core component of the machine tool, a spindle directly affects the machining quality, performance and it has a critical impact on the implementation of smart manufacturing [1]. Smart manufacturing is a process that employs computer controls, big data analysis, and machine tool automation to improve manufacturing efficiency [2].

It seems evident that the possibility of a further increase in the machining accuracy and productivity based on the CNC-controlled spindles is almost exhausted. It is necessary to search for new efficient spindle technical solutions aimed at superior precision, maximum productivity, and low consumption in the manufacturing process. The application of high-speed machining has long been one of the main ways to enhance manufacturing efficiency. It should be noted that the speeding up of machine tool spindles is at a standstill in recent years. One of the main reasons for this trend is shifting the market requirements towards multitasking, improving machining accuracy, environmental responsiveness, and saving energy. However, these requirements are difficult to achieve while simultaneously spindle speeding up.

Despite the progress made in smart manufacturing systems, only spindles with several intelligent functions such as active balancing and chatter control were implemented successfully for machining performance maximizing [3]. Accordingly, the multi-purpose spindle system for smart manufacturing that allows operating with maximum material removal rate in a wide range of cutting speeds has never been successfully developed.

The key scientific question of a presented concept is how to overcome the technical contradiction when high-speed machining between simultaneous maintenance of high indicators of productivity on the one hand and accuracy, energy efficiency, vibration and thermal stability on the other hand.

This new concept is based on applying an innovative cyber-physical spindle system with a set of intelligent functions (spindle efficiency optimization, thermal deformation compensation, chatter monitoring and control, forced vibration suppression) to achieve high machining performance and efficiency. The originality of the proposed concept is grounded on the idea of using a new hybrid design of the controllable fluid bearings (fig. 1) as a core element to solve the key scientific question.

The innovation of the spindle is based on the use of a fundamentally new design of bearings that allows us to control bearing stiffness and power losses at high-speed machining. The stiffness control is grounded on the regulation of fluid flow rate of bearing with proportional valves and clearance regulation between bearing surfaces utilizing elastic elements of the bearing casing. The power loss control is based on applying a hybrid bearing design to reduce pump and friction losses in the fluid supply system. This design allows changing hydrostatic lubrication mode when operating at low speeds to hydrodynamic lubrication mode with a partial fluid delivery when operating at high speeds.

Spindle efficiency optimization is suggested to perform on the basis of the minimization of power consumption at a wide range of speeds by reducing bearing friction and pumping losses. The idea of using water lubrication is suggested to solve the problem of reducing friction losses at high rotation speeds of a spindle. Besides, using water for both bearing lubrication and spindle cooling reduces energy consumption, significantly scales down environmental pollution, and provides eco-friendly operating maintenance. Applying the hybrid bearing design is proposed to reduce pumping losses in the fluid supply system by decreasing the flow rate at high speeds.

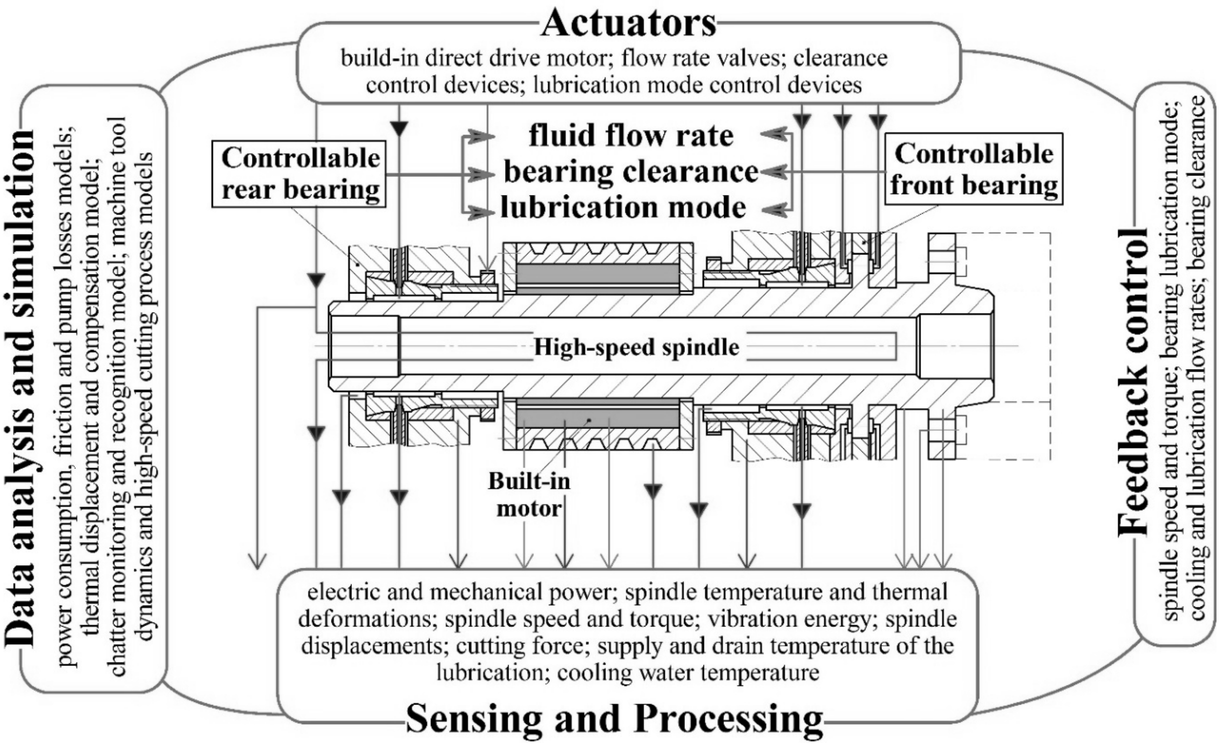

Fig. 1 – The functional scheme of a smart spindle with controllable hybrid fluid bearings

Thermal deformation compensation, which is a pivotal function to achieve high machining accuracy, will be implemented by thermal displacement detection by sensors (see fig. 1) and the controllable fluid bearings as an active actuator. Compensation of a spindle rotor thermal errors can be achieved by directionally shaping the bearing reaction in the opposite direction to the thermal displacements of the rotor.

Vibration energy, measured by a built-in accelerometer in the spindle casing, is suggested to use as a chatter monitoring parameter. The time-frequency analysis based on wavelet transformation can be used to recognize and define the frequency ranges of the chatter. Chatter suppression and control are planning to be implemented by the variation of spindle speed and active control of stiffness. The controllable fluid bearings will be used as actuators for changing spindle stiffness and, consequently, a spindle/chuck/workpiece subsystem's natural frequencies. This allows us to suppress effectively chatter at a wide range of cutting speeds.

Forced vibration suppression at high-speed processing is based on maintaining the stable size of a lubricant layer between bearing surfaces. Maintaining the stable lubricant layer allows us to operate with the maximum bearing stiffness determining the spindle's high vibration stability and accuracy. This is to be achieved by controlling the rotor position using bearing flow rate and clearance regulation. Feedback signals are realized by translational and angled displacements of the spindle rotor in 3D space.

System integration of spindle components is supposed to be implemented by a computing node locally embedded in a spindle. Communication, interoperable information models, and a hardware platform to ensure seamless integration with smart systems of a factory shall be further discussed.

## References

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