New Online Auto Balance Device for High-speed Electric Spindle System

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***Abstract*—Mass imbalance is a common cause of vibration in rotating machinery, which can damage the rotary system or the whole system. To solve this problem, the best balanced measure is to perform real-time online dynamic balance compensation during operation. In this study, a new type of high-speed electric spindle system with online auto balance device and associated control circuit is developed by integration technology. It achieves that the device have short response time, high efficiency, energy saving features and other advantages. To verify its validity, co-simulation program of ADAMS/controls and Matlab/Simulink is developed to conduct virtual prototype balance simulation. The results show that vibration near the 10000 r/min reachs reduction of 95%, and high balance quality standards G0.4-G1 are also achieved through adjusting the angle of balance device and controlling vibration accurately.**

Keywords-High-speed electric spindle; Auto balance device; Energy conservation; Co-simulation.

I. INTRODUCTION

High speed rotors are very sensitive to vibration which has harmful effect on rotating machinery, such as machine tool's spindle or turbo-machine, etc [1-3]. The primary cause of vibration in rotating machinery is mass imbalance, which occurs when the principal axis of the moment of inertia is not coincident with the axis of rotation [4-6]. This imbalance can be minimized by balancing the rotor as far as possible. In recent years, several balance devices [7-9] have been rapidly developed to improve running accuracy of electric spindle and some of them have frequently been used for testing in the laboratory for years as well. However, there are still very few successful applications to direct electric spindle online balance devices now. In the present work, a new type of online auto balance device for high-speed electric spindle system is developed, which can better meet the demand of the accuracy and reliability. Compare to the traditional spindles produced by the machine tool manufacturers, there will be significant implications for enhancing industrialization, modularity and functionalization of the electric spindle systems, and meanwhile accelerating the development of new generation of the CNC machine tool.

II. DEVELOPMENT OF ON-LINE AUTO BALANCE DEVICE

Theoretical studies on dynamic balance showed that there were two main ideas from the reasons for the formation of imbalance [10-11]. The first was eliminating unbalance with an external force (equal and opposite in direction), such as indirect online balance device based on the principle of electromagnetic motor. But its disadvantage was energy consumption. The second was managing to move unbalanced centroid to balance one of rotor system, such as electromagnetic online mixing balance device controlled based on influence coefficient method [12-13], and yet its balanced process requires a certain response time.

Fig.1 shows the new balance device principle diagram. It can be seen that various physical signals are monitored on line, such as spindle speed, unbalance sizes and phases of not only main shaft but also balance block b and c. When excessive imbalance vibration appears, non-contact eddy current sensor receives the unbalance signals, meanwhile, photoelectric sensor b, c measure the spindle speed and vibration phase respectively. Then those three-way electrical signals enter single-chip microcomputer control system after signal conditioning and A/D converter, and can be displayed real-time through digital display device at the same time. The system calculates the exact size and phase of spindle unbalance after data processing. Finally, to balance the whole spindle, the balance block vector is calculated and the optimum phase angle is determined by influence coefficient method.

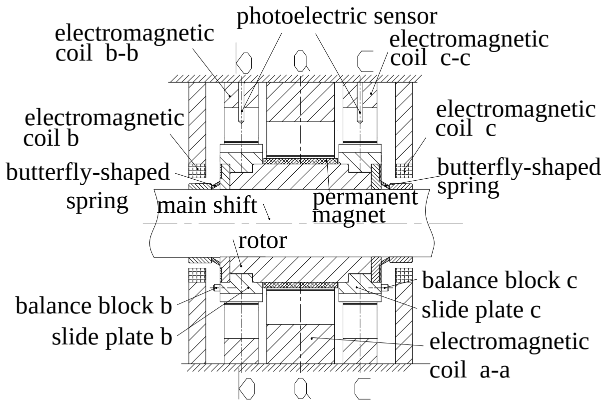

Fig. 1 Balance device principle diagram

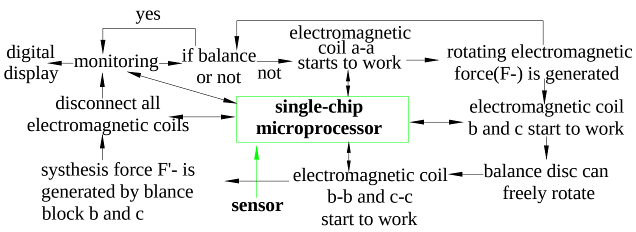

Fig. 2 Control process principle diagram

Fig.2 shows control process diagram for the new balance device. First, rotating electromagnetic force (F-) is generated by controlling exciting current and initial phase of electromagnetic coil a-a, and F- and spindle’s unbalanced force (F+) are eaual and opposite. As a result, F- can rapidly compensate for the unbalanced force. Then, electromagnetic coil located in the position of “b-b” and “c-c”(see fig.1) starts to work, and two steps are taken. The first step, the electromagnetic force is gradually increased by controlling procedures and regulating the current, and balance disc b and c are free to rotate when the electromagnetic force added equals to the elastic force of butterfly-shaped spring. The second step, the electromagnetic coil b and c conduct excitation current “i” driven by the data processor, which make balance disc b and c rotate to the desired direction to synthesis force F’- by controlling the move of balance block with the influence coefficient method. When the balance block moves to the desired location, balance disc reaches to the synchronous rotation speed of spindle by using control strategies of influence coefficient method. It is noted that F’- equal to F- and F- is imposed on the spindle at this time while F’- is not. Afterwards, new commands are given by microcomputer to disconnect all electromagnetic coils at once, and balance disc b, c are firmly pressed by butterfly-shaped spring b and c. At this moment, space rotating electromagnetic force F- disappears, and synthesis force F’- of balance block b and c make the mass of rotor system distributed again. At the end, required dynamic balance accuracy is reached and the balance work is finished.

III. HIGH-SPEED ELECTRIC SPINDLE SYSTEMS WITH ONLINE AUTO BALANCE DEVICE

A new type of high-speed electric spindle system with two online auto balance devices are developed. Specific parameters are as follows: grease lubrication, sleeve outside diameter 60mm, maximum speed 22000r/min, rated speed 15000/min, axial stiffness 80N/um, radial stiffness 165N/um and weight 30Kg.

Fig.3 shows the model of the overall system for the spindle assembly. The details of installation and connection are as follows: The high speed electric spindle with circle cooling water system are supported by double row ceramic ball bearings, which are installed back to back and inner rings are fixed on the main shift with locking nuts. Two balance device assemblies before and after are fixed with bearing supports respectively and those supports are again connected to the spindle sleeve with inner hexangular set screws so as to replace the unit of balance device easily. There are clearance fits between electromagnetic coils and outer shell in the balance device to install and disassemble. In order to avoid the wires wrapping, the electromagnet is fixed on outer shell through closed end cover. On auto balance device, an interference fit between balance disc support and the main shift can effectively avoid the generation of additional unbalance. Because axial space is small, butterfly-shaped springs are used to tightly compress the balance discs, which can not only withstand large loads with small deformation but also have the function of absorbing vibration. Balance disc and its support are in clearance fit so that it can rotate freely when driven. The balance device is axial constrained by round nut.

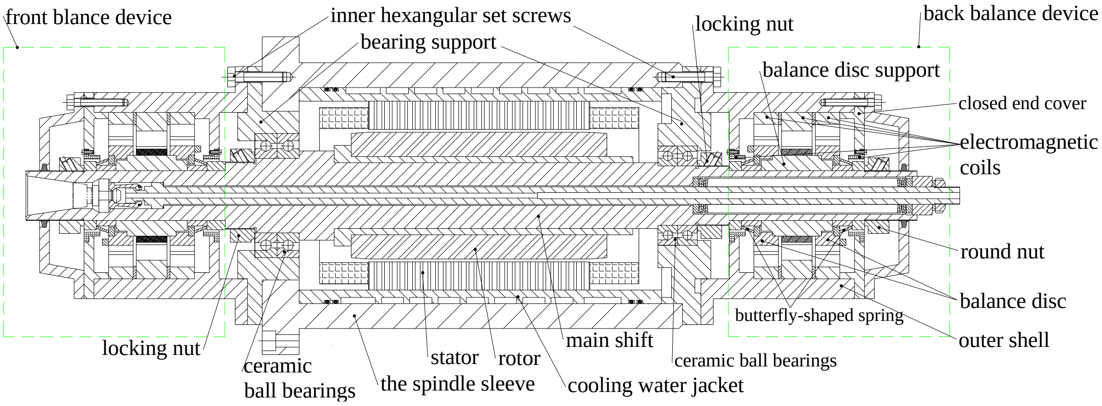

Fig. 3 Overall electric spindle system with auto balance device

IV. THE CO-SIMULATION OF DYNAMICAL SYSTEM MODEL BASED ON ADAMS AND MATLAB

Co-simulation program of ADAMS/controls and Matlab/Simulink is used to build virtual simulation model for the above prototype. The basic design process is shown in Fig 4.

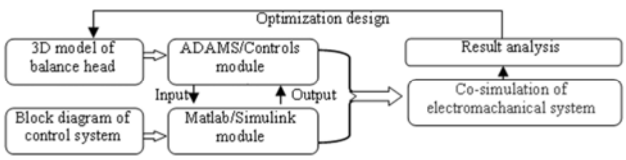

Fig. 4 The basic design process of co-simulation program

A. *ADAMS dynamic system model building.*

As shown in shown fig.5, balancing device model is built by the software Pro/E, and then is imported into the ADAMS environment, in which constraints, force, motion drive and load between components of the system are defined. At the meantime, in order to monitor the size and phase of mentioned physical signals, several corresponding sensors are also set through a number of marker points defined.

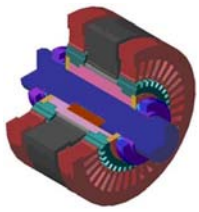

Fig.5 3D model of balance device

B. *Result analysis of co-simulation.*

For the high-speed spindle system whose speed is 10000r/min when rotating, simulation parameters are set, such as unbalance phase at 39° and unbalance value 10N. The simulation result is that the phase of two balance blocks is separately 108° and 324° finally, the adjustment time of balance block is 2.8s, vibration measurement is 21.4um before adjustment and 0.91um after adjustment, and the imbalance is reduced by about 95% before and after simulation. For high-speed spindle balance quality standards G0.4-G1, the maximum offset of high-speed spindle center of gravity is 2.865um(1mm/kg×3kg× 9.55/10000). As shown simulation curves in Fig.6, vibration value measured is reduced to 2um after simulation from 20um before that.

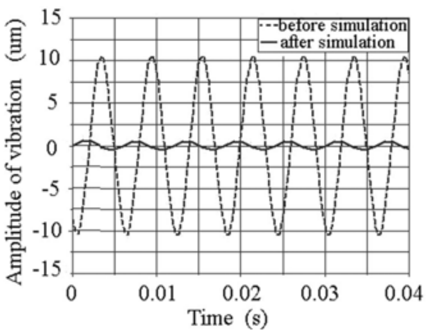

Fig. 6 The simulation curve of vibration measurement before and after the balance

V. CONCLUSIONS

- A new type of high-speed electric spindle system with online auto balance device and associated control circuit is designed through integration technology. It achieves the online auto balance compensation of high-speed electric spindle system. Also, it has short response time, high efficiency, energy saving features and other advantages.
- Co-simulation program of ADAMS/controls and Matlab/Simulink is developed to conduct virtual prototype balance simulation for the new high-speed electric spindle. It's proved that vibration near the 10000 r/min reaches reduction of 95%. The system achieves high balance quality standards G0.4-G1 through adjusting the angle of balance device and controlling vibration accurately.

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