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COMPENSATION OF IRREGULAR MOTION OF A MACHINE TOOL FEED DRIVE AXIS

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Abstract: *This contribution deals with the interaction of feed drive axes of NC machine tools, primarily focusing on the compensation of vibrations in the linear axis caused by a carried unbalanced rotating axis. These vibrations negatively influence both machining precision and surface quality. To suppress the effect of unbalanced mass, four compensators were designed as additive blocks supplementing the ordinary cascade control loop of the NC machine tool's feed drive axis. The paper also includes results of an experimental verification of these methods, carried out on a test bed which is a simplified model of a real NC machine tool.*

Keywords: ***Direct drive, mass unbalance, cascade control loop.***

1. Introduction

One of the significant features of a machine tool feed drive axis with a direct drive is that the motor force directly actuates the controlled mass (e.g. table with the workpiece) without any mechanical transmission element (indirect drive). Because there is less moving mass, a direct drive can be expected to achieve higher acceleration of the feed drive. On the other hand, direct drives are more sensitive to the impact of external forces as there is no protective effect of the mechanical elements – the impact of external forces on the motor is inversely proportional to the square of the gear ratio. Mass unbalance and impact forces directly affect the cascade control loops, negatively influencing both accuracy of the machining and surface quality. This issue is particularly significant in linear feed drive axes with direct drives which carry e.g. rotary or tilting tables. This paper introduces four methods for compensating the influence of a rotating unbalanced mass placed on the linear axis, fig. 1; these methods were verified on an experimental test bed in the Research Centre of Manufacturing Technology CTU in Prague. The results of the experiment are also presented here.

The linear axis, which carries a rotating unbalanced mass, is controlled by a cascade control loop with PI current control, PI velocity control and P position control. Dynamic stiffness of the linear axis (transfer function between the actual position and external force) substantially depends on the constant settings of velocity and position controllers. These settings, however, are limited by the stiffness of the machine structure (natural frequencies). For additional suppressing of the positional deviation caused by a rotating unbalanced mass, it is possible to supplement control loops with compensation functions.

Four compensation methods were proposed, three of them utilizing a similar principle (namely a compensation of current, velocity and position). These methods include an algorithm computing an excitation force, converting it to an appropriate physical dimension and introducing it into a respective control loop. A sufficient amplitude and phase shift of this correction signal ensures the generation of a counterforce to the external force caused by the rotating unbalanced mass. To adjust the compensators, however, several parameters are required which are difficult to determine during operation (i.e. the position and quantity of the unbalanced mass and its position relative to the linear axis). The fourth approach is based on an adaptive LMS algorithm which directly reacts to the deviations of the linear motor, introducing a correction signal with an appropriate amplitude and phase shift into the position control loop.

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2. Experimental verification of the compensation effect

Effects of the proposed compensators were verified during both constant and variable revolutions of the unbalanced mass (acceleration and deceleration using an s-function with defined jerk). The tests were performed with the linear motor in zero desired movement as well as in a constant velocity (acceleration and deceleration using an s-function with defined jerk) and harmonic movement. Linear as well as rotary motors were controlled in a position control loop.

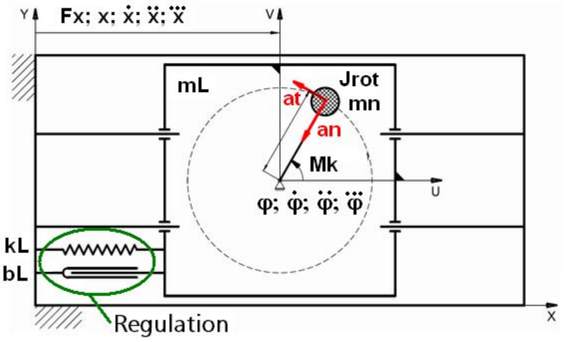

Fig. 1: Diagram of the experimental test bed

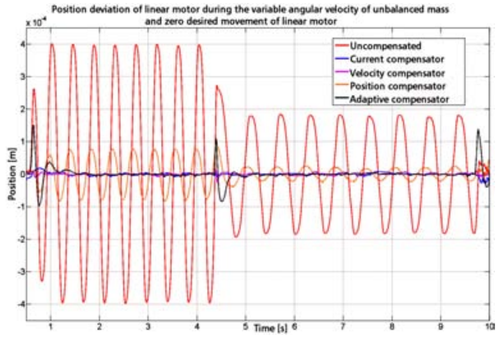

Fig. 2: Positional deviation of the linear motor in a zero velocity state and with a variable angular velocity of unbalanced mass

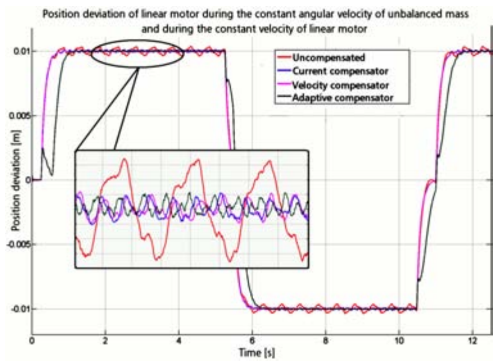

Fig. 3: Positional deviation of the linear motor with a constant velocity and with a constant angular velocity of unbalanced mass (residual vibrations are not caused by unbalance)

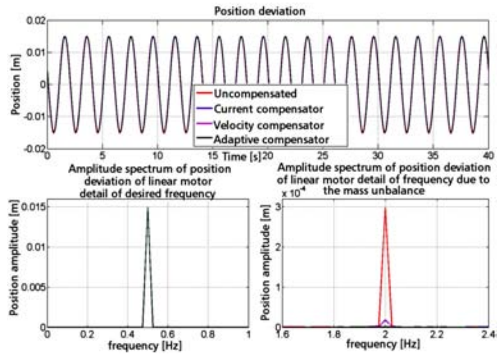

Fig. 4: Positional deviation of the linear motor in a harmonic movement and with a constant angular velocity of unbalanced mass

3. Conclusion

All proposed compensators significantly lower the excited vibrations of the linear axis caused by the rotating unbalanced mass in transitional and steady states. In a steady state, the current, velocity and adaptive compensators lower vibrations by a factor of more than 40, with residual vibrations corresponding to a few increments of the measuring system, fig. 2. The position compensator lowers vibrations by a factor of more than 5; this weaker effect is caused by the approximation of the compensator transfer function between the desired position and current. In transitional state, the current and velocity compensator provide the best results. The compensation effect is also significant during the movement of the linear motor; in case of a harmonic movement of the linear motor, the adaptive compensator performs best, and the harmonic component caused by the rotating mass unbalance practically disappears, fig. 4.

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