Electrodynamic Feed Units for Small Machine Tools

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Abstract

Uni- and multiaxial feed units for small machine tools with travel ranges up to appr. 20 mm can advantageously be realised with simple single-phase electrodynamic direct drives. Design and performance of a first demonstrator of a compact uniaxial feed module with embedded position control are presented in this paper.

1 Introduction

Concepts and components for small machine tools that fulfil the increasing demands of micro manufacturing with respect to flexibility, modularity, cost-effectiveness and miniaturization are currently being developed within a German research programme [1]. Working spaces of small machine tools of a few cm^3 enable unique technical solutions that are not just derived from downsizing of conventional large machine tools [2].

Three-phase linear motors have been used for long as highly dynamic direct feed drives for large strokes. In contrast, small maximum travel ranges of appr. 20 mm are sufficient for many feed units of miniature machine tools, allowing simple and cost-efficient motor designs with only one magnetic and electrical phase per axis. All subsystems of those feed units can be combined to compact modules due to their simplicity. Those modular feed units are currently being developed within the above-mentioned programme at Technische Universiät Dresden. A first demonstrator of a uniaxial feed module was built and is currently tested (Fig. 1).

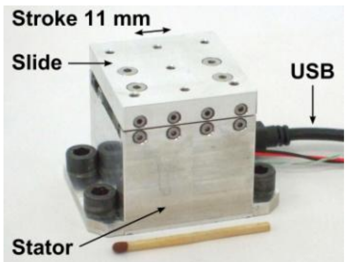

Figure 1: First demonstrator of a small electrodynamic feed module with embedded position control

2 Design of the Demonstrator

Figures 2 and 3 illustrate the design of the single-phase electrodynamic feed unit shown in Fig. 1. The stator contains an U-shaped laminated sheet package with winding and the control electronics on a printed circuit board. A magnetic low-cost position sensor with a resolution of 0.488 µm is placed on that board. The slide, which acts as the tool or workpiece holder, contains permanent magnets on a back iron and a magnetic scale for the position sensor. In this first demonstrator, the slide is guided by ball guides. Unlike in most linear stages with preloaded closed ball guides, the guide system is arranged as an open ball guide (Fig. 3) and is preloaded with lateral magnetic forces. This results in a particularly compact design and in easy assembling. Alternative guide concepts as well as different module geometries (e. g. cylindric, planar) will be considered for future designs too.

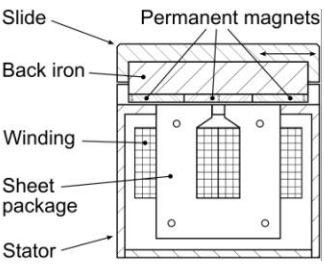

Figure 2: Schematic cross-sectional view of the electrodynamic feed unit

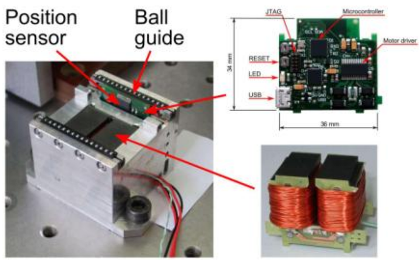

Figure 3: Stator components of the demonstrator

The single-phase electrodynamic motor is of moving-magnet type. Compared to motor designs based on moving coils, they possess higher force densities mostly due to smaller air gaps and larger cross-section areas of windings. Structure, properties and dimensioning of those actuators are thoroughly described in [3] and [4]. Due to the simple single-phase design, the travel range of the slide roughly is limited to the breadth of the stator poles.

The measured stationary force-current-position characteristic $F(I, x)$ of the first demonstrator is shown in Fig. 4. Within a large range of winding currents I and mover positions x the motor force F is nearly proportional to the current, as is typical for electrodynamic motors. The force drop at large negative positions and currents as well as at large positive positions and currents is mostly due to saturation of the ferromagnetic stator core. It is expected that this force drop can be reduced with an optimized magnetic design. The chosen arrangement of the permanent magnets results in a centering force acting on the mover without current as of a conventional spring (stiffness appr. 1 N/mm, see Fig. 4 at $I = 0$). This relatively small force can be avoided with different magnetic designs, if needed [4]. The force values for ±1 A in Fig. 4 depict the continuous force capability of this first demonstrator. Peak forces up to 39 N are on hand for a fast and stiff control of the slide position.

3 Embedded Position Control

The integrated control electronics realises digital state space control of the mover position in conjunction with a reduced state observer. The sampling rate of the position control loop is 5 kHz, and the measured bandwidth (-3 dB) of the closed-loop position control is 38 Hz (Fig. 5). Set positions are easily transferred with any terminal program from a computer to the feed module via USB. Control through common fieldbusses as well as compensation of actuator non-linearities with the embedded control software can be realized with future work. Force control can be realized too.

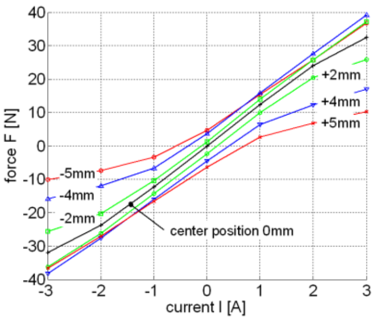

Figure 4: Measured force-current-position characteristic $F(I, x)$ of the first demonstrator

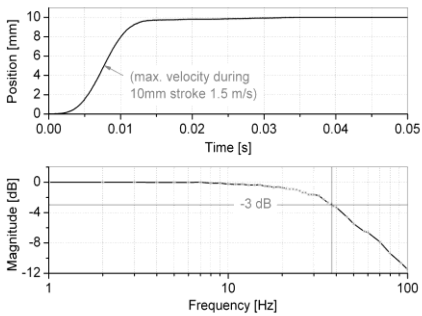

Figure 5: Measured controlled response to a 10 mm step (top) and measured closed-loop frequency response (bottom)

4 Preliminary Technical Data

Features of this first demonstrator of a low-cost, uniaxial single-phase electrodynamic feed module are:

- travel range 11 mm,

- continuous force according to values for ±1 A in Fig. 4 (reduction of force drop towards end positions expected with future optimized magnetic design),
- position sensor resolution 0.488 µm, measured two-sided repeatability 3.0 µm (DIN ISO 230, confidence interval 4 σ), measured position accuracy 5 µm,
- response time to 10mm step 0.03 s, position control bandwidth 38 Hz (Fig. 5),
- Set positions via USB e. g. with any terminal program from a computer.

5 Conclusions and Outlook

Technical data achieved so far with this first demonstrator of a simple uniaxial single-phase electrodynamic feed module for small machine tools and its good dynamics are promising. Those modules could become a cost-efficient complement to other feed drives, e. g. piezo stages or leadscrew motor systems. Future work will focus on the design and test not only of additional and improved uniaxial, but also on the design of multiaxial electrodynamic feed units with only one phase per axis.

6 Acknowledgements

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