

Development of a Linear Motor Drive Testbed and Initial Thermal Behavior Results¹

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Introduction

The machine tool industry is moving toward using linear motors for both conventional and high speed machine tools due to many advantages: low maintenance, faster assembly times (compared with the more conventional ball screw drives), and improvements in both dynamics and accuracy. Linear motors are also used in ultra precise machine tools and coordinate measuring machines. On the other hand, lack of adequate information about the performance characteristics of such systems limits their widespread use. Therefore, as linear motors become more widely accepted, there is a need to develop methods to characterize their performance. A linear motor testbed has been established within the Manufacturing Engineering Laboratory of the National Institute of Standards and Technology (NIST) in support of this need. The testbed is used to investigate both measurement methods and key performance characteristics. For example, while the thermal characteristics of a linear motor are investigated, the influences of those thermal characteristics on the drive structure itself and thermal contributions to failure modes are also explored. Attention is given to determination of the most effective measurement methodologies for the overall performance of the drive.

Background

Over the last three decades, linear motors have been developed for a variety of different applications, most notably in transportation [1,2, for example] and for semiconductor fabrication [3,4, for example]. Applications in the entertainment [5,6], health [7] and nuclear industries [8] have also been documented.

Within the machine tool industry, acceptance of linear motors for machine drives has been gradually increasing. Widest acceptance has been seen in high speed, lower thrust applications such as the machining of large, monolithic aluminum aerospace parts [9]. This is, in fact, the type of application that Pritschow [10] concludes was most appropriate for linear drives in his comparison of linear and conventional (ballscrew) drives. Several recent areas of research strive to support the introduction of linear motor drives into machine tools by addressing particular aspects of these devices. Van Brussel and Van den Braembussche [11] and McNab and Tsao [12] each investigate the control of linear motion drives in light of the direct coupling of changes in load to the motor. Abdou and Tereshkovich [13] use finite element modeling of linear motor geometry and electric and magnetic field distribution to perform a static analysis of a linear motor drive, concluding that the cutting force affects factors such as flux and current densities and dissipated power more than the electric and magnetic field characteristics. Liebman and Trumper [14] address the issue of heat removal from the linear motor coil with an oil-cooled end-turn coil design.

¹ Note: minor differences between this electronic version and the paper version in the proceedings may occur due to the NIST final review process.

Testbed Development

The linear motor drive testbed was developed to study the characteristics of such systems on machine tools that influence the machine tool accuracy as well as operational/maintenance requirements. It is therefore important to create realistic structural, loading and other functional features that simulate the actual machining conditions. Since the metrology and condition monitoring are important aspects of the study, one of the design criteria was to accommodate various sensors and measurement instruments without obstructing the motion. The detailed description of the testbed design is given below.

The testbed is comprised of a synchronous (permanent magnet) type linear motor, ball bearing linear motion guides, a precision scale for position feedback and a precision motion axis controller, all selected to be typical of an industrial machine tool application. The components are assembled in a standard slideway configuration, mounted to a precision ground surface plate. While the testbed utilizes components typical of small-scale machine tools, the lessons learned can be scaled up to match the very high speed and high force applications found within, for example, the aerospace industry.

The linear motor is, of course, the heart of the testbed. A synchronous, ironcore motor was selected over the asynchronous type due to the higher force per unit area available in synchronous motors and the resulting broader applicability of this type of motor. The testbed motor has a peak force rating of 500 N, a coil mass of just 3 kg, a magnetic attractive force of about 2.5 kN, and a magnet track length of 1 m. Under the testbed design, velocity of up to 3 m/s is allowable with acceleration of up to 2 g.

In designing the testbed, several factors were kept in mind. Symmetry about the axis of motion was maintained whenever possible, to minimize the effect of thermal growth on the system and to ease wear on the linear motion guides through even loading. The scale used for position feedback was placed as close to the axis of motion as was practical in order to minimize Abbe error. Height of the drive above the linear motion guides was minimized for better dynamic stability. To achieve the current compact height, the scale was mounted flat along the baseplate, rather than vertically against a mounting block. While this necessitated that the scanning head be shimmed down from the underside of the carriage, it resulted in a lowered center of mass of the moving mass. These features can be seen in the end view schematic given in Figure 1.

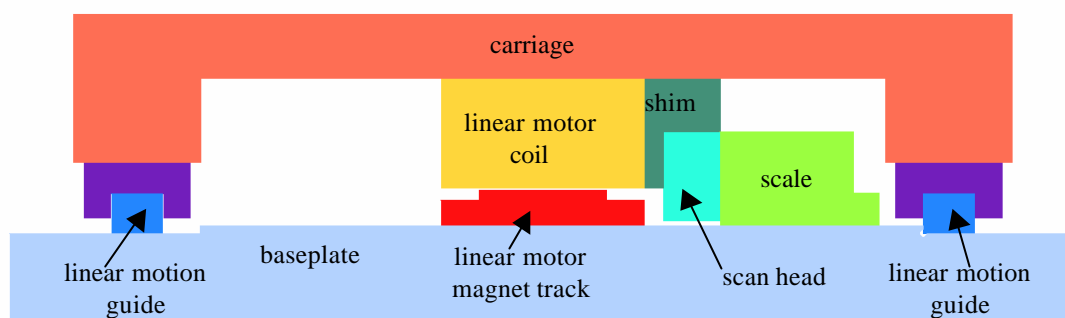


Figure 1: End view of linear motor drive testbed.

A solid model of the system was developed after component selection. A view of this model is shown in Figure 2. The solid model was used in the design finalization process to optimize testbed features. An

example of such optimization is minimization of the moving mass. This is done through selection of an appropriate platen thickness and fillet radii combination to minimize the volume of the carriage while maintaining an acceptably low level of deflection under the magnetic attraction forces from the motor and

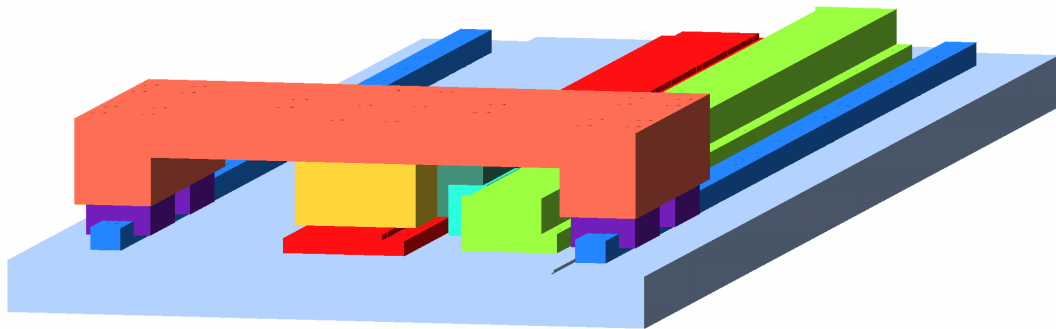


Figure 2: Solid model of the linear motor drive testbed design.

gravity. Figure 3 shows a mapping onto the carriage solid model of the finite element analysis-generated deflections. Maximum deflection was predicted by the model to be less than 4 μm with this carriage geometry. Planned future use of this model includes use for running “what if” scenarios for further study of thermal effects and use in the development of an accelerated life testing plan.

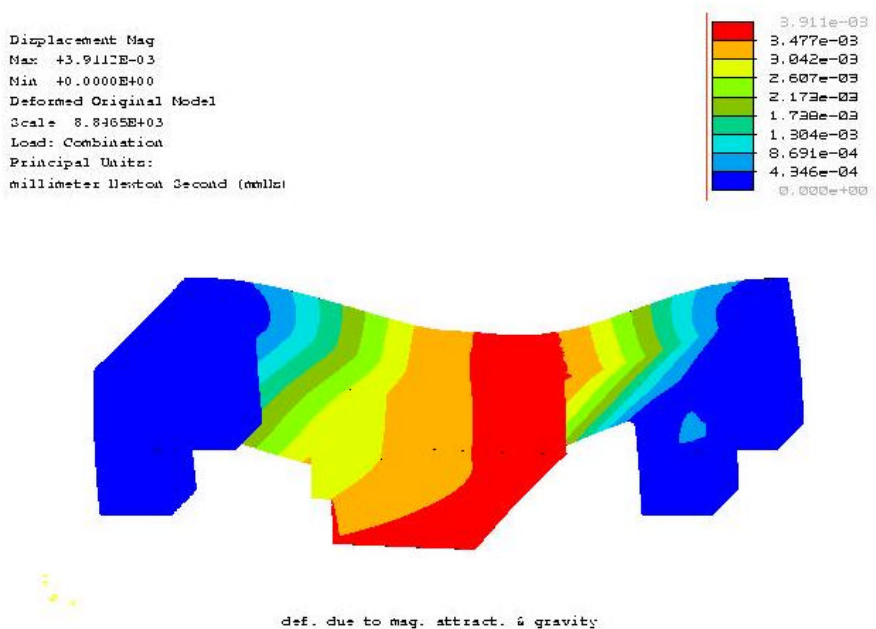


Figure 3: Exaggerated view of carriage deflection due to both the magnetic attraction forces of the motor and the effect of gravity.

The testbed has been instrumented with thermocouples, accelerometers and capacitance probes. An infrared imaging system has also been used to monitor, more qualitatively but on a more system-wide scope, the thermal behavior of the linear motor drive. Details of the metrology system, the experimental methodology, and initial thermal study results are given in the poster presentation.

Future Studies

In addition to more detailed thermal studies in those areas indicated by the initial work, the testbed will be used to investigate other performance issues related to the use of linear motors in machine tools and coordinate measuring machines. Dynamic stiffness and thrust ripple have been identified for early investigation.

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