A Non-Contact Linear Motion System and Its Application
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The Axtrusion is a new linear motion concept developed by Professor Alexander Slocum and Roger Cortesi of the Massachusetts Institute of Technology’s Mechanical Engineering Department. The name Axtrusion comes from the shape of the axis’ cross section, which in principle is simple enough to be extruded. The Axtrusion is intended for use in applications where the emphasis is on high speed, no wear, and low error motions, such as in high-speed motion of workpieces in semiconductor manufacturing equipment. It is designed to enable air bearing systems to be competitive in price with high performance ball bearings systems while providing all the advantages of a non-contact motion system.

The functional requirements of the Axtrusion concept, shown in Figure 1, are:

- No contact between the way and the carriage, allowing for very high-speed operation and zero wear. The elimination of lubrication reduces maintenance requirement and machine downtime. Non-contact is also the primary means of reducing error motion.
- Moderate stiffness by using magnetically preloaded air bearings.
- The system should be insensitive to temperature changes, thereby reducing thermal growth.
- The geometry should remain simple, and minimal precision parts and features should be used to keep manufacturing inexpensive and easy.

![Figure 1: Principal components of the system that uses linear motor magnet attractive force at an inclined angle to preload all the bearing pads](image)

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The attractive force between the motor coil and the magnet track preloads the bearings, which support the vertical and horizontal loads. By carefully choosing the groove angle and motor location, the designer can specify the amount of preload on each bearing pair. The pairs are the top outboard pair, the top inboard pair and the side pair. There have been many designs in the past that have used magnets to preload air bearings, but the Axtrusion appears to be the only design where a single magnet track can be placed to evenly preload all the carriage’s bearings.

Porous graphite air bearings are quite easy to work with and can easily be replicated in place, which greatly simplifies the manufacturing process. The bearings and motor coil of the prototype were potted in-place in to the carriage, allowing the axis to be assembled in just under 2 hours. Granite was used for the ways because of a special characteristic: if cracked or chipped, the granite will fracture completely downward without creating the slightest crater rim. This allows the air bearings to continue to slide over the fracture unimpeded.

Figure 2: The replicating fixturing (left) allowed the assembly of the Axtrusion prototype in 2 hours. The jacks on the removal fixturing (right) are used to draw the motor coil away from the magnets enough to be able to remove the carriage from the way.

The static stiffness was measured by adding weights and recording the deflection with an interferometer. The vertical stiffness was found to be 422 N/micron with 100 psi air supply. The dynamic performance was determined by modal analysis. The animated modes are shown at [http://pergatory.mit.edu/research/Cortesi/modal/modal.htm](http://pergatory.mit.edu/research/Cortesi/modal/modal.htm). The results are summarized in Table 1.
Table 1: Modal analysis summary for the Axtrusion with 100 psi air supply to the bearings

The accuracy of the Axtrusion is affected by the change of the magnetic attraction force as the open faced motor carriage passes over the permanent magnets. This primarily causes sinusoidal pitch errors. The maximum measured pitch error is 2.44 arc seconds; the maximum yaw error is 1.59 arc seconds. For a high-speed material handling system or a modest accuracy machine tool, this is insignificant. For higher precision systems, the magnets would need to be attached to the carriage and they would be attracted to a uniform steel plate rather than utilizing the linear motor.

![Graph showing pitch data for the Axtrusion prototype over 320 mm of travel.](image)

Figure 3: The pitch data for the Axtrusion prototype over 320 mm of travel.
The Axtrusion is the basic building block for the Minimill, a desktop 3-axis milling machine. It uses two identical L’s to make the machine structure for the X and Y axis.

**Figure 4:** The two “L” structural concept for building the X and Y axis of the Minimill.

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