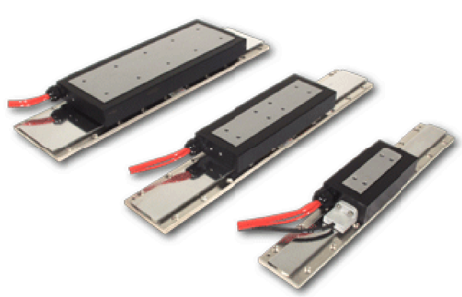
Alternative Linear Motion Systems

ME EN 7960 – Precision Machine Design
Topic 5

Iron Core Linear Motors

- Provide actuation forces from 30 N (7 lbf) continuous to over 11,000 N (2,500 lbf) peak
- Two-part construction features a 3-phase laminated coil and a single sided magnet track consisting of rare-earth magnets mounted on a rigid steel base plate
- These linear motors deliver excellent performance in rapid point-to-point positioning applications while virtually eliminating the efficiency-robbing effects of friction, inertia, backlash and wear associated with rotary-to-linear drive mechanisms



Source: Anorad

Iron Less Linear Motors

- Provide actuation forces from 8 N (2 lbf) continuous to nearly 2,000 N (450 lbf) peak
- Their two-piece assembly features a 3-phase ironless coil and a balanced dual-sided "U" shaped magnet channel
- Their ironless coil design eliminates cogging (magnetic détente) and makes them the optimal choice for extremely consistent velocity control in scanning-type applications and allows them to achieve the highest levels of positioning accuracy, repeatability and resolution

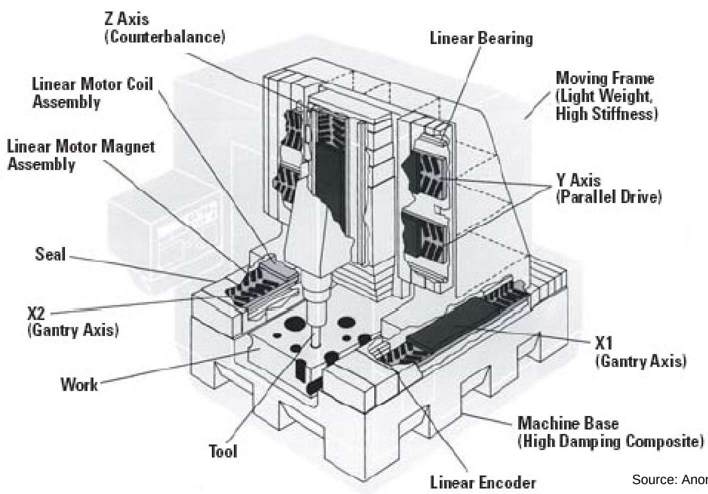
Source: Anorad

Linear Motors

- Pros
  - Direct drive minimizes the number of parts
  - Velocity and acceleration not limited by the actuator
    - Ranging from less than 1μm/s to more than 10m/s
  - Unlimited travel
  - Smoothness of motion
  - Accuracy and resolution is not limited by the actuator
  - Zero wear
  - Very simple installation
  - Very clean operation
- Cons
  - Optimal transmission ratio is not achieved
  - High currents, large thermal loads
  - Some motors create high attractive forces (10x the thrust force)
  - Vertical axes require safety breaks and/or counter balances
  - Much more expensive components ($10/lbf thrust vs. $2/lbf for a ball screw system).
  - Not self-locking, therefore needs constant servo control

Typical Application

A typical concept of a linear motor machine.



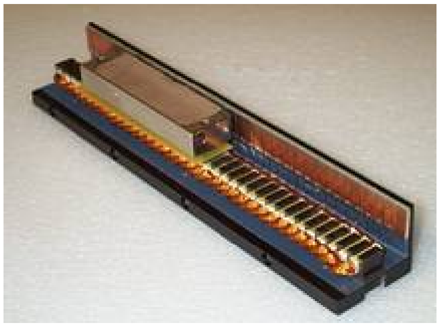
Source: Anorad

Brushless DC Linear Motor

- Never a problem with an unused portion's brush surfaces corroding
- Good power density
- Non-contact generation of force
- Closed loop control provides resolution limited only by sensor and electronics
- Ironless-core design has flux crossing gap that is intersected by windings
  - No attractive force to load bearings
  - Requires a sandwiched design

Brushless DC Linear Motor (contd.)

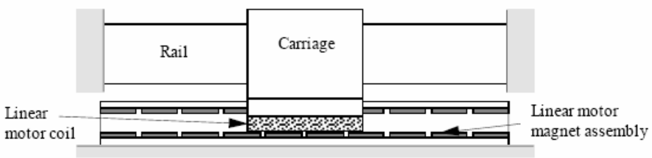
- The DC brush linear motor is ideal for long stroke, open or closed loop servo, linear motion applications with speeds from 1 in/s [25 mm/s] to 100 in/s [2.5 m/s]
- The motor is commutated using brushes on the moving permanent magnet secondary in conjunction with a stationary commutator bar on the coil assembly. This results in only the coils directly beneath the secondary with current flowing in them.
- The short moving brush assembly is magnetically attracted to the long stationary laminated coil assembly. A customer supplied bearing system is required to guide the moving secondary and to maintain a .025" [0.63mm] gap between the secondary and the coil assembly.



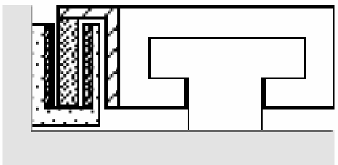
Source: H2W Technologies

Mountings

- Linear motor moving coil mounted to the underside of an air bearing carriage that rides on a simply supported rail:



- Linear motor moving coil mounted to the side of an air bearing carriage that rides on a T-shaped rail that is fully supported along its length

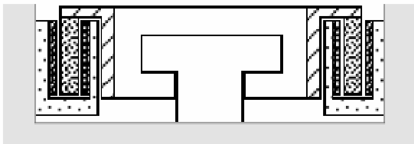


Source: Alexander Slocum, *Precision Machine Design*

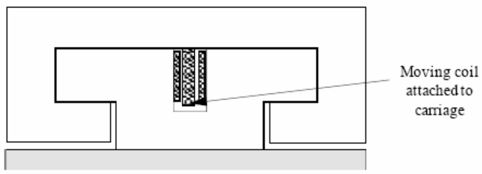
Warning: Motor force is not aligned with center of friction and center of mass. Moments will occur as a result, resulting in rotation of the slide.

Mountings (contd.)

- Linear motor moving coil mounted to the sides of an air bearing carriage that rides on a T-shaped rail that is fully supported along its length



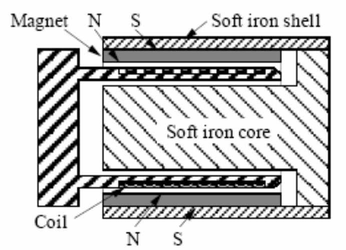
- Linear motor moving coil mounted to the inside of an air bearing carriage that rides on a T-shaped rail that is fully supported along its length



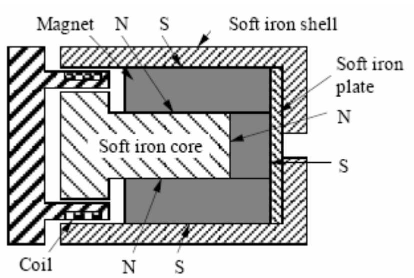
Source: Alexander Slocum, *Precision Machine Design*

Voice Coils

- Ideal for short strokes
- No phase switching circuitry required
- Can be used to drive fast tool servos (e.g., for piston turning machines)



Conventional moving coil actuator



Flux-focussing actuator

Source: Alexander Slocum, *Precision Machine Design*

Voice Coils (contd.)

- Typical configurations:

Source: H2W Technologies

Types of Linear Motors

Types	**Axial force F_a**		**Attractive force**
	Rare earth	**AlNiCo**	
Voice coils	2	1	0
Stepping motors	1		5-10 x F_a
Brushless DC motors			
- Ironless core	2	1	0
- Iron core	2	1	5–10 x F_a

Source: Alexander Slocum, *Precision Machine Design*

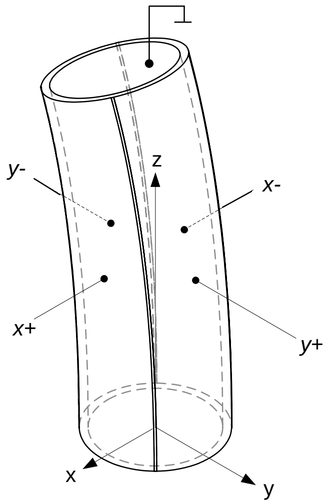
Piezoelectric Actuators

- Sub-nanometer resolution
- Large force generation (> 10,000 N)
- Sub-millisecond response
- No backlash, stiction or friction
- No magnetic fields
- Extremely low steady-state power consumption
- No wear and tear
- Vacuum and clean room compatibility
- Operation at cryogenic temperatures
- Variety of stacked PZT translators with typical displacement ranges of 5 to 200 µm

Source: Physikinstrumente

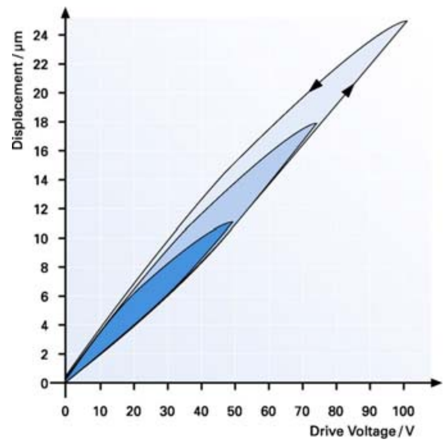
PZT Principle

- PZT are made from a ceramic material (crystal) that changes dimensions when a voltage is applied



But

- Hysteresis
- High actuation voltage >100 V
- Aging
  - Aging refers to reduced piezo gain, among other things as a result of the de-poling process
  - Aging can be an issue for sensor or charge-generation applications (direct piezo effect), but with actuator applications it is negligible because re-poling occurs every time a higher electric field is applied to the actuator material in the poling direction

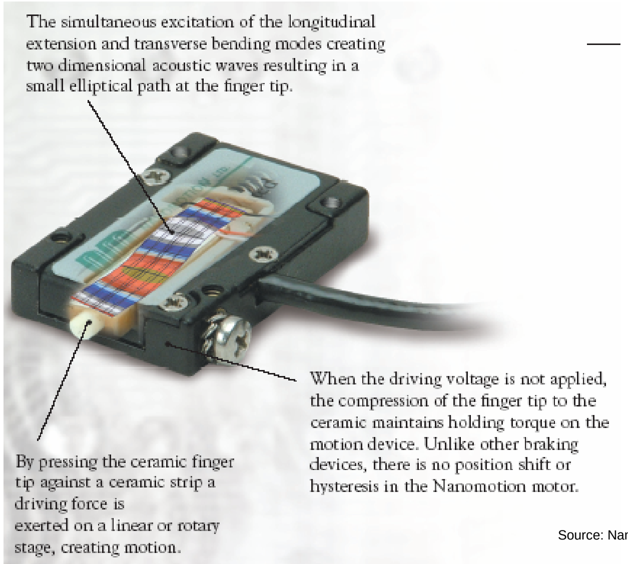


Piezo Linear Motor (Nanomotion)

- The Piezoelectric effect in piezo ceramics converts electrical field to mechanical strain
- Under special electrical excitation drive and ceramic geometry of Nanomotion motors, longitudinal extension and transverse bending oscillation modes are excited at close frequency proximity
- The simultaneous excitation of the longitudinal extension mode and the transverse bending mode creates a small elliptical trajectory of the ceramic edge, thus achieving the dual mode standing wave motor

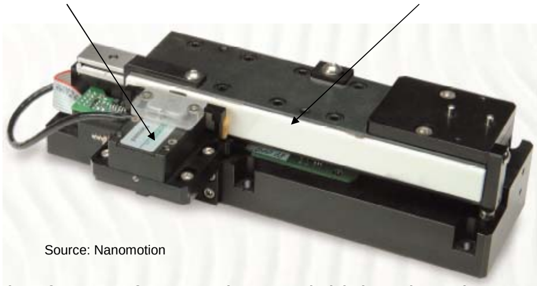
Source: Nanomotion

Piezo Linear Motor (Nanomotion)



Source: Nanomotion

Piezo Linear Motor (Nanomotion)

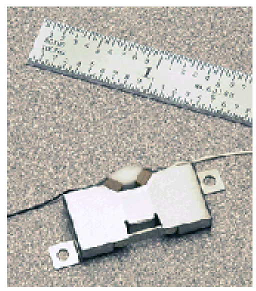


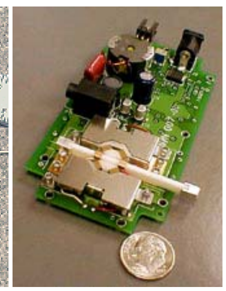
Source: Nanomotion

- By coupling the ceramic edge to a precision stage, a resultant driving force is exerted on the stage, causing stage movement
- Travel can be linear or rotary, depending on the coupling mechanism
- The periodic nature of the driving force at frequencies much higher than the mechanical resonance of the stage and allows continuous smooth motion for unlimited travel, while maintaining high resolution and positioning accuracy typical of piezoelectric devices
- While the driving voltage is not applied, the ceramic plate is stationary and generates holding torque on the stage
  - Holding torque of the Nanomotion motor does not cause any position shift

Piezo Linear Motor (EDO Ceramics)

- The piezoelectric motor operates using solid state piezoelectric ceramic crystals
- The piezoelectric effect exhibited by the ceramic crystals causes the ceramic to expand and contract as an electric field is applied across the polarized electrodes of the crystal
- The expansion and contraction under an alternating electric field causes a controlled, sinusoidal vibration
- This vibration drives the friction shoe that is coupled to flat friction strips, through friction, providing well controlled linear motion for the motor
- Each vibration cycle produces a small step, as small as a few nanometers
- The accumulation of these steps at a rate of 130,000 steps per second allows the motor to travel at speeds of up to 12 inches per second with a blocked force of up to 0.4 pounds

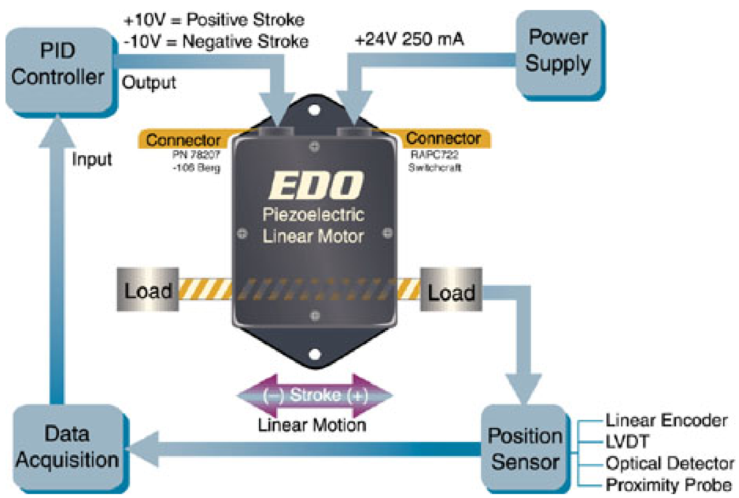




Source: EDO Ceramics

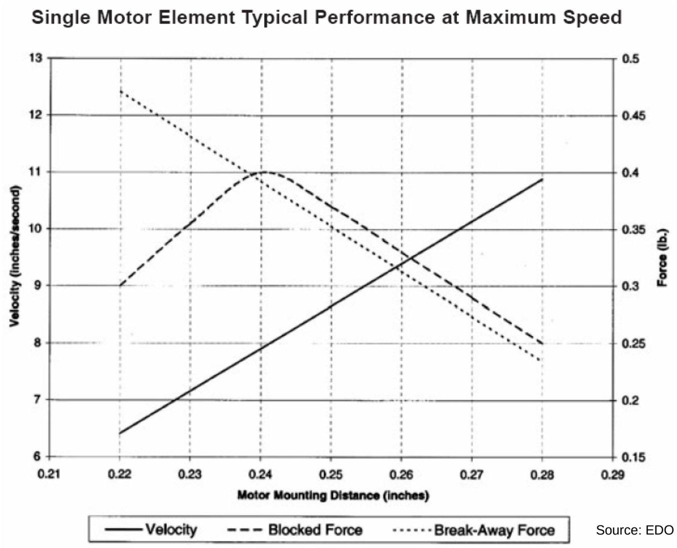
Flexure Head Video

Schematic of Servo Loop



Source: EDO Ceramics

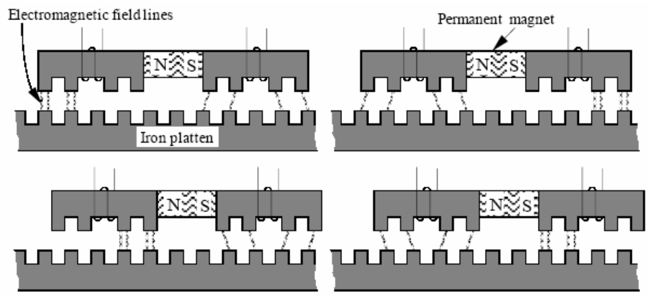
Piezo Linear Motor (EDO Ceramics)



Source: EDO Ceramics

Stepping Motors

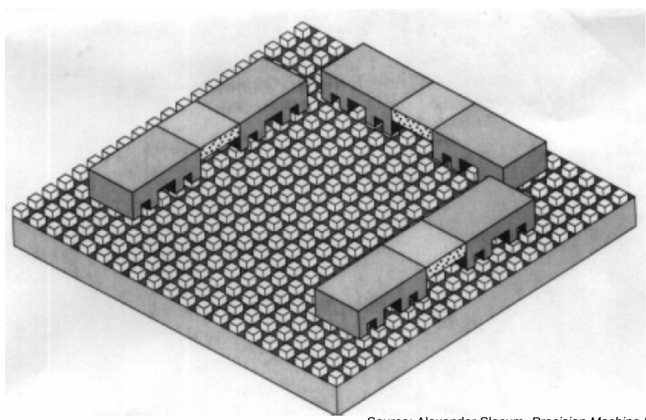
- Simple design
- Modest efficiency
- High attractive force requires robust bearings
- Microstepping can be used
- Closed loop servo mode, good to sensor resolution
- Current sequence in a Sawyer motor to produce linear motion:



Source: Alexander Slocum, *Precision Machine Design*

Sawyer Motor

- A two axis Sawyer motor (platen and air bearing to support the motor not shown).
  – Multiple forcers are used to control yaw.



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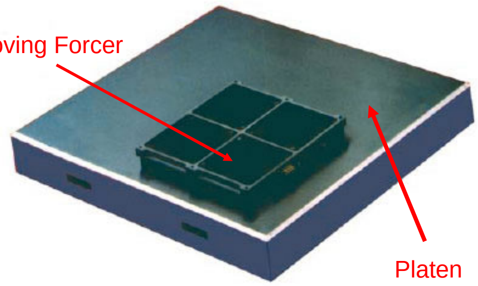
Sawyer Motor



Moving Forcer Assembly:

- The forcer is made up of an aluminum housing that contains the motor windings, lamination stacks, and permanent magnets
- The active surface of the lamination is slotted to form teeth with a pitch of .040" [1 mm]
- The forcer comes in different widths and lengths, depending on the required force
- Multiple forcers can be supplied with a single platen to allow for independent moving heads

Platen:

- The platen is a precision ground steel plate that is slotted to form 0.02” x 0.02” [0.50x 0.50 mm] square teeth on the surface
- The spaces between the platen teeth are filled with epoxy to provide a flat air-bearing surface for the forcer
- The stroke of the forcer is a function of the length and width of the platen

Source: H2W Technologies

Sawyer Motor (contd.)

- Dual Axis Linear Stepper Motors are ideal for open loop positioning applications with light payloads
- Speeds up to 80 in/s [2 m/s] and strokes up to 40” x 60” [1 m x 1.5 m]
- Linear stepper motors are capable of very precise position, velocity and acceleration control when coupled with a microstepping drive and indexer
- The moving assembly called the “forcer” is supported by magnetically preloaded air-bearings imbedded in the active surface of the forcer between the forcer and platen
- The bearings support the payload and maintain the required .001” [0.025 mm] gap between the platen and the forcer
- The motion achieved with a full step is .010” [250 microns] and with a microstep it’s .00004” [1 micron]
- Integrating a linear encoder with the stepper motor provides a closed loop system

Source: H2W Technologies

Sawyer Motor - Advantages

- Low profile and small cross section
- High speed
- Low cost positioning stage solution
- No servo tuning required
- Multiple forcers on a single platen

Source: H2W Technologies