The distinguishing features of the ServoRam™ and its performance advantages

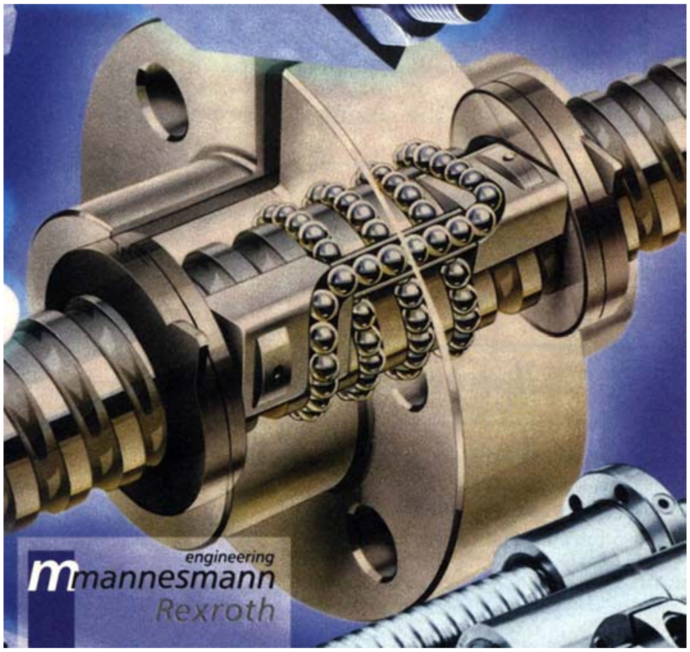
What is a Linear Motor?

There are many suppliers of electrical machines that produce a linear motion – and in general they are referred-to as "linear motors". But large numbers of these machines are not linear motors at all. It is true to say that they are **linear actuators**, because power supplied to the machine makes an output element travel in a straight line. But inside the mechanism there is usually a rotary motor – whose power output is then used to drive a ballscrew or a belt, or a geared crank to which the final output element is connected. Some companies sell both kinds - some are true linear motors and some are rotary-driven linear actuators.

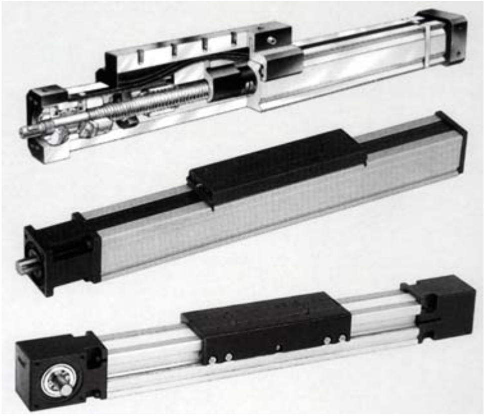
Catalogue picture from Industrial Devices
(Showing 12 linear actuators and 1 linear motor)

Rotary-driven linear actuators have many moving parts. The rotary motor in the core of the machine has to stress (or "wind-up") the gears and their bearings before a significant output thrust is produced. The time it takes to do this limits the speed of response of the actuator, so that the machine cannot be used to move an object backwards and forwards very rapidly whilst maintaining a high degree of precision.

The stressing also causes wear and eventually produces a significant noise. Ballscrew mechanisms are especially prone to this, because the balls contact the screw over very small areas and therefore operate at very high contact pressures. The pressure gradually pushes metal away from the contact points, causing roughness in the screw material and preventing the smooth action of the mechanism.



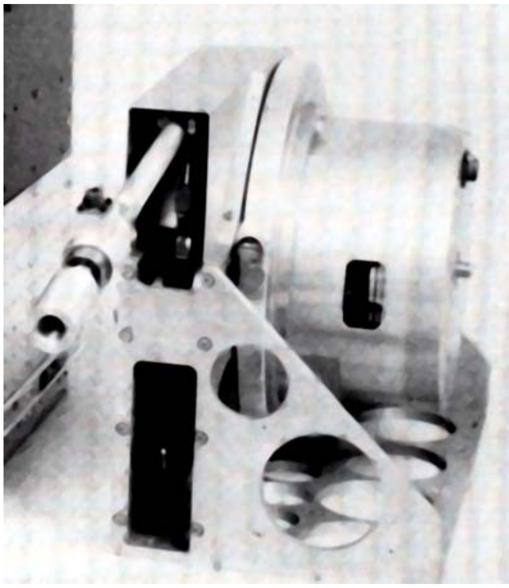
Section of a ballnut element, showing balls and their screw channels



Belt-drive actuators have the wind-up problem but they also have problems caused by belt flexing and vibration. Increasing the belt tension to improve the precision only makes the bearings wear more rapidly. Steel belts are often used for the larger forces – but in the end these stretch and begin to slip on the worn drive pulleys.

Ballscrew and Belt-Driven linear actuators made by Modular Robotic Systems

Gear and crank units work by moving an offset arm to which a push rod is attached. They are common in flight simulators and “fly-by-wire” aircraft, where they are used to apply forces to joysticks and rudders to represent aerodynamic forces. But they cause strong off-axis forces on the bearings and the mountings of the mechanism, which can produce high wear rates and fatigue fracture of the mountings.

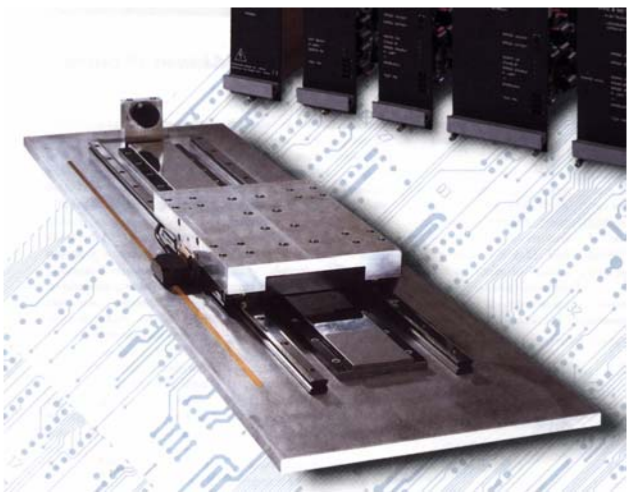


Cranked push-rod actuator

A true linear actuator has no rotating parts. No gears. No cranks. No off-axis forces. The machine has only one moving part, which is itself the output element.

"Linear motors are unrolled rotary motors"

True linear motors have been around for a long time – in fact the linear electric machine existed before Faraday made the first rotary electric motor in the laboratories of the Royal Institution, London. But there was a strong resurgence of interest about twenty years ago, when Professor Laithwaite in the UK did a good job in popularising the concept. He said that a linear electric motor was like a rotary electric motor that has been cut down to the middle and stretched out flat. Most of today's linear electric motors are still made with flat surfaces.



Typical flat bed linear motor

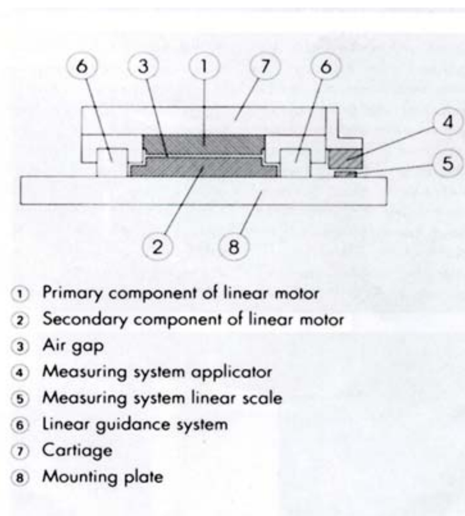
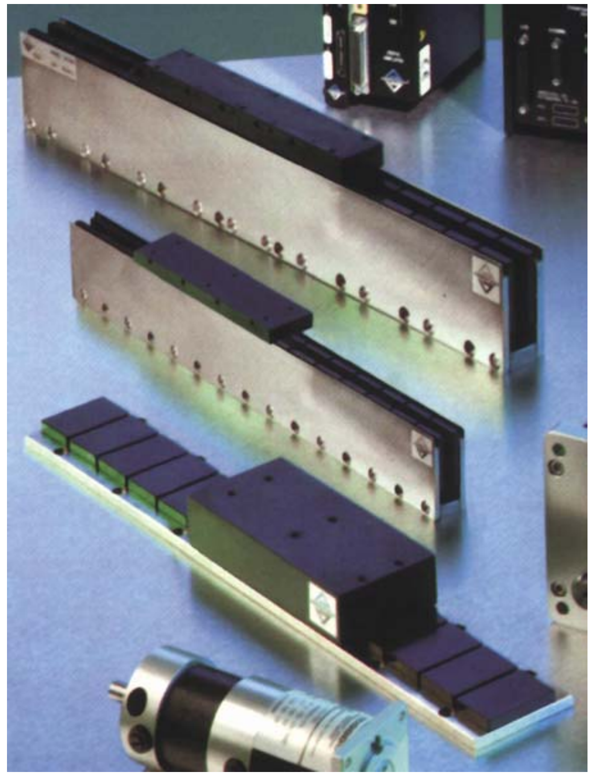


Diagram of Section

- But the "flat motor" design is not very efficient. The magnetic fields produced by the machine spray out in all directions and the working flux densities are low.
- The moving part – the flat armature – experiences strong attractive or repulsive forces relative to the flat stator. The moving armature has to have a stiff guide rail and it must travel on precision bearings so that it can move along the stator close to - but not actually touching – the fixed structure. The spurious attraction or repulsion forces are many times greater than the output forces, so that the bearings wear quickly.
- Large machines have large stray magnetic fields and they cannot be used unguarded in close proximity to the general public.
- Steel dust or magnetic grit is attracted into the body of the machine by the high magnetic fields and damages the bearings.
- The "rolled-flat" motor machines that must generate a large force are compelled to be big and heavy – the flat moving part has to be physically large, which is often inconvenient.
- Most linear motors that are available today use an array of permanent magnets on the stator and have a moving coil armature. It is therefore necessary to connect to the armature with a power cable that flexes constantly - and the power rating of the machine is limited by the problem of removing from the armature the heat that is generated in the electrical coils.

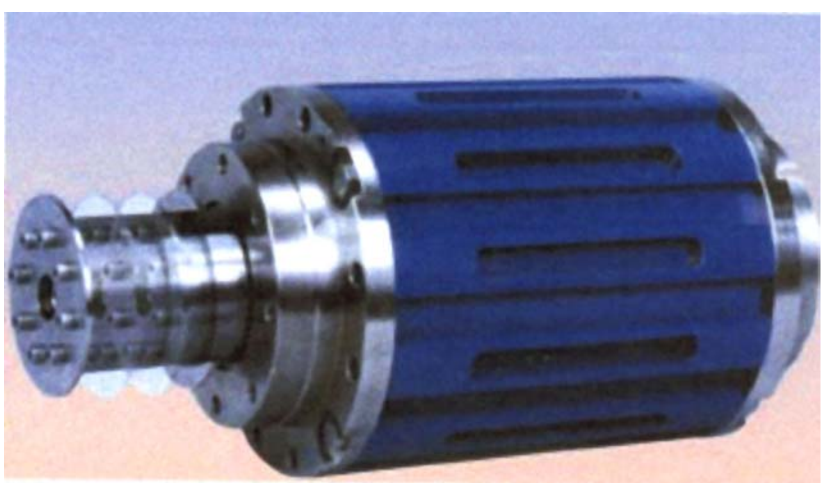


Many large-thrust flat motors now use a “U stator” construction, in which two stator plates are used, one on either side of the flat armature, which moves in a slot between them. This modification moves the spurious forces in the machine closer to balance and it reduces the stray fields, but the inefficiency and poor environmental tolerances remain.

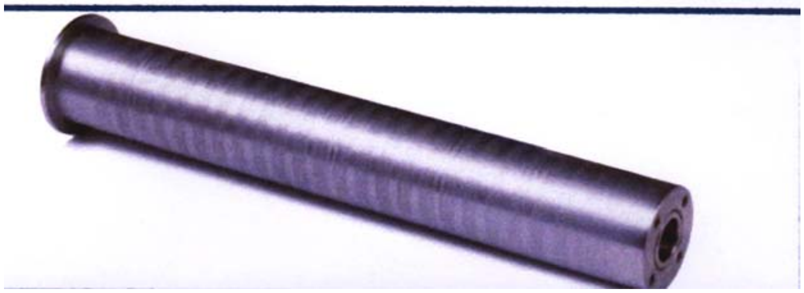
Catalogue picture from Aerotech, showing flat “U” design permanent magnet motors. (Note exposed magnetic fields)

Cylindrical motors

Many of the disadvantages of the flat machines can be overcome by making them cylindrical instead – rolling the “flattened motor” up again in another way. Only a small number of manufacturers use this technique, which is heavily protected by patents



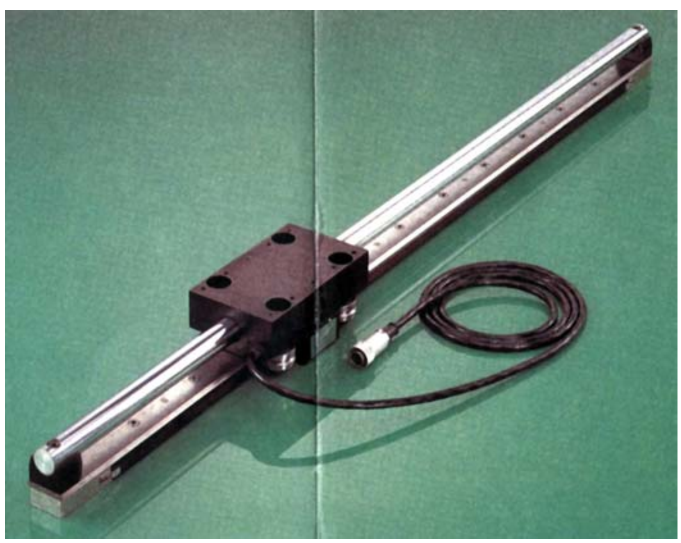
Calinear cylindrical motor



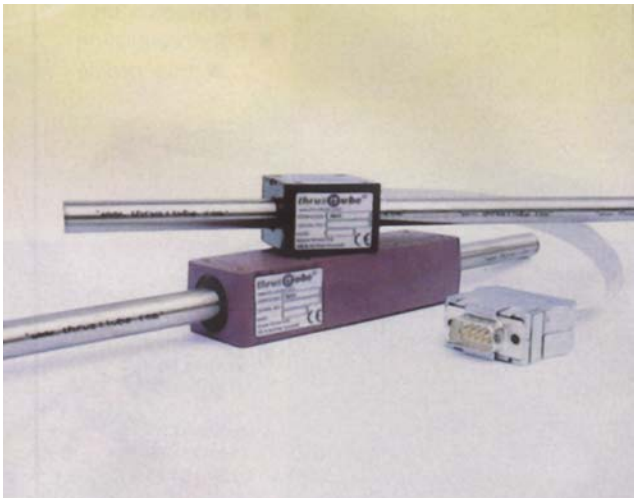
Magnetic armature of a Calinear cylindrical motor. (Rides on a central shaft)

One advantage of cylindrical symmetry is that all the spurious forces between the stator and the armature are balanced, so that the wear on any bearings is greatly reduced. The second advantage is that the machine is smaller for any given output thrust, since the force-producing element is "curled up" into a smaller space.

Some flat bed linear motors - and some cylindrical linear motors – are induction machines. These do not use permanent magnets and are therefore cheaper to make, but they use more power and get hot. Cooling is more difficult for a linear machine than for a rotary machine, since there is no rotating shaft for a cooling fan. It is better to use permanent magnets to produce the magnetic fields that interact with the electrical currents of the machine, thus reducing the cooling requirement. Permanent magnet armatures are now common in flat linear motors, and are becoming so in cylindrical linear motors.



Actuator made by Linear Drives Ltd.
(The rod is a permanent magnet stator, made like the Calinear armature)



Linear Drives, a UK company, sells a range of motors in which the outer moving coil armature is shorter than the central stator rod and fits over it like a short sleeve. The long central rod (which is packed with magnets) must be kept clean and at a distance from any loose steel objects and from equipment that is sensitive to magnetic fields. It is also necessary to supply power to a moving coil assembly using a flexible lead, which is a disadvantage that is common to most types of linear motor.

Actuator by BEI Kimco Magnetics Inc.
(The magnetic stator rod and moving coil are similar to that of Linear Drives, but the stray fields are reduced by a slotted outer steel case)

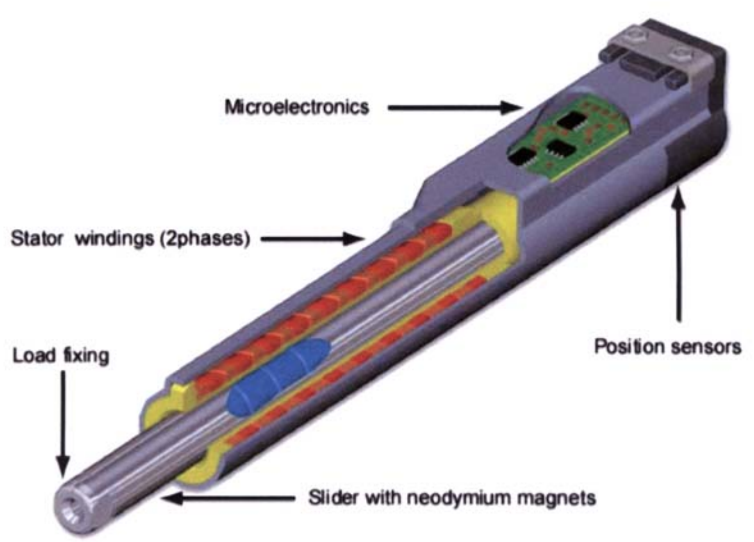
Precision Bearings

As previously explained, all the conventional flat types of linear motors have to use high-quality bearings to resist the powerful magnetic forces. To keep the moving part from touching the stationary part, most of the manufacturers of cylindrical linear motors do the same thing. Aura, Calinear, BEI and several manufacturers of linear induction motors make a range of actuators in which the armature rides on a shaft along the central axis of the machine. For larger motors the shaft is fixed to the armature and sticks out of the machine through bearings at both ends. For smaller machines the armature guide rod is fixed at one end and the armature slides along it as a sleeve.

"Linmot" actuator with moving coil armature sleeve running on a long magnetic stator rod.

The Linmot actuator in its usual, short-stroke configuration is a notable exception to this, as shown opposite.

The armature is in the form of a rod filled with magnets, to a similar design to that of Calinear, Linear Drives and BEI Kimko, as described above. But the rod moves within a continuous tube of bearing material that also supports the stator coil assembly



Exposed magnetic fields

It should be noted that none of the cylindrical actuators described above is hermetically sealed and that all except the BEI Kimko machine have magnetised parts that emerge from the stator or which are themselves an extended and exposed stator assembly. This makes the actuators difficult to use in a dirty environment or in an atmosphere where there are iron dust particles.

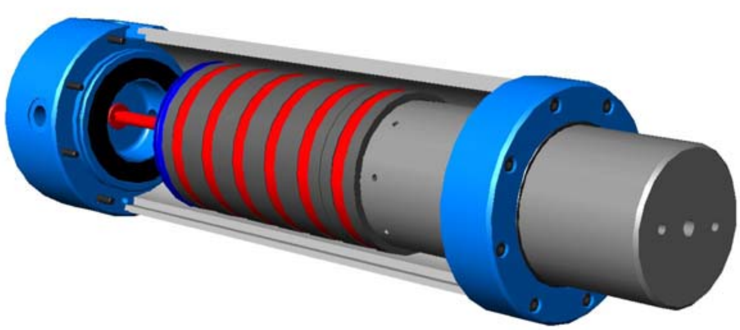
Dual-action electromagnetic rams

Only one company in the world – Advanced Motion Technologies Inc –offers a range of patented dual-action electromagnetic/pneumatic actuators. These have the appearance and general utility of hydraulic rams and are designed to operate in any position or orientation in a hostile (or sterile) environment.

The reason for this is that the design of the ServoRam was approached from a different direction to that of the other manufacturers of linear motors. The inventor was in the simulator business and was required to solve a problem relating to simulator motion bases, which have traditionally used hydraulic rams as actuators. He had to produce large forces from the beginning and he was not constrained by his experience to think in terms of conventional rotary or linear motor design.

Other designers of linear motors thought in terms of rotary motors, which are always arranged to have a small clearance between the fixed and moving parts – for obvious reasons!

In contrast, the ServoRam has an armature that is in the form of a piston. The piston moves on simple piston rings that bear against the inside of a cylinder – a polished tube lining the stator (or fixed part) of the machine. The piston is fitted with an output shaft, rod or thrust tube that protrudes through one end only of the cylindrical machine. The other end of the machine can therefore be mounted on a universal joint so that it can pivot and swing in any direction.



The unique dual–action ServoRam mechanism

The ServoRam linear motor looks like a hydraulic ram. Because the "piston" armature can be sealed to the stator cylinder, it may also act as a fluid power element, especially as a part of a gas spring system. This unique ability is a very useful and patented feature of the machine, which can work at any angle.

The gas spring takes over the work of supporting a deadload without using any electrical power (acting like the springs on a vehicle hood or trunk). What is more, when the ram moves an inertial load very quickly backwards and forwards, the spring acts as an energy storage reservoir. Both these features greatly reduce the electrical power that has to be supplied to the actuator, making it extremely efficient.

ServoRams™ are very different from other forms of linear motor and they have the following unique advantages: -

- They use a piston type of armature, with simple bearing rings.
- The motors have a fluid seal that allows the armature to act simultaneously as a pneumatic element. That saves a great deal of energy and makes the machines more efficient than their competitors
- Their sealed construction allows them to be used, if necessary, under water or in a poor environment like a steelworks or chemical factory.
- The rams are available in five different topologies, to suit almost any application
- They may be scaled across a huge range of thrusts, velocities and piston travel distances
- The gas spring pressures are tuned automatically – peaking efficiency.
- The gas spring reservoir can be part of the motor – reducing complexity
- The rams are simple to make and to service
- The motor has a constant linear reluctance and provides an extremely smooth output force – increasing precision.
- The rams are part of a range of patented motion bases and stabilised platforms
- They are compatible with new and patented forms of automobile suspension system

The picture shows ServoRams™ driving a high-performance motion base for a professional training simulator.

