The ServoRam™

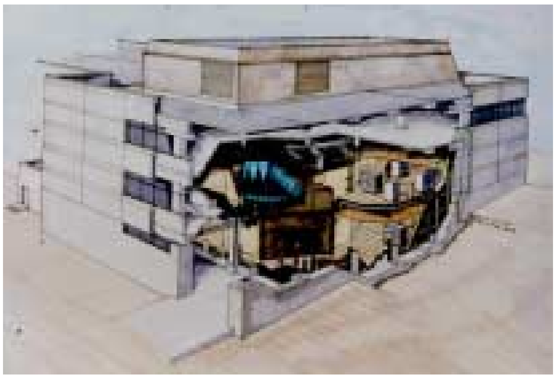
This is an electric motor that looks like a hydraulic ram. The only moving part is a cylinder, as it is in a rotary motor, but it moves freely along the axis of the motor instead of rotating. And the armature is fitted with a sliding seal to the outer tube, so that it also acts as a conventional piston.

This unique and patented design allows powerful and rapidly changing electromagnetic forces to be directly superimposed upon quasi-static or gas spring forces, saving energy and simplifying many mechanisms. The innovative, award-winning, British machine is a dual-action, free-piston, linear, 3-phase, brushless servomotor. **It is a force-generator** that is scaleable from less than 1Kg to more than 100 Tonnes thrust, with piston travel distances from 10 mm to more than 100 metres and at velocities of more than 100 metres/second.

The ServoRam™ is powerful, robust, reliable, versatile, silent, efficient, sensitive, clean, fast and extraordinarily precise. Its performance in motion control cannot be surpassed by any other technology – at any price.

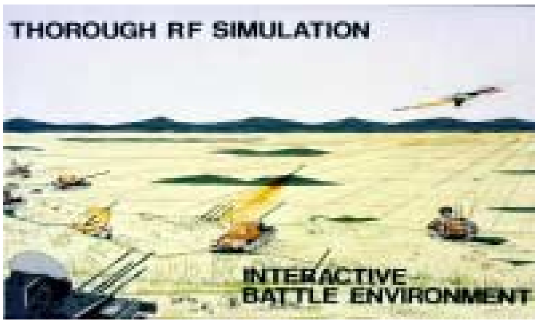
The evolution of the ServoRam™

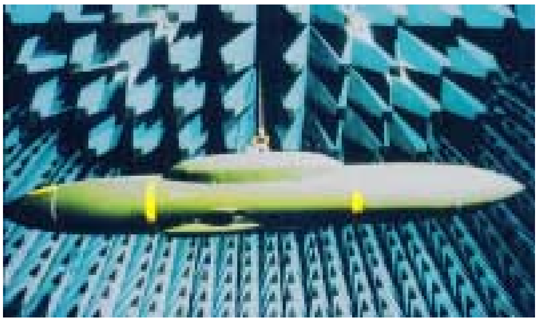
The EW Simulator at Stanmore



Almost twenty years ago, Phillip Denne designed and built Europe's largest and most complex EW simulator for Marconi at Stanmore, to test various types of electronic warfare equipment. The £8 million TEMPEST classified facility was opened by Princess Anne in 1983.

Electronic Warfare is a game of Hide and Seek, a sort of lightning-fast blindfold mobile three-dimensional chess game played between computers and microwave equipment at extremely high speed and without the real-time intervention of any human being. For example, radar systems and jamming equipment will try to outwit each other as an aircraft comes streaking in across enemy territory whilst the enemy tries to get a fix on the aircraft and fire off guns or missiles to knock it out of the sky. The jammer must win the EW battle if the aircraft is to survive. The electronic warfare simulator is designed to test to the limits in a real-time scenario the efficiency of several kinds of EW equipment hardware - and the skills of the programmers, who try to incorporate within the high-speed control software of the radar, the jammer or the missile-guidance system all the secret information and all the counter strategies from which the device must choose from instant to instant as the EW battle proceeds.





The problem is that everything happens very quickly, is very complex and quite invisible. It is incredibly difficult to follow the test sequence in real time, to understand what is happening, who is winning, who is losing, and to know where to look afterwards in the recorded data to find out why. The whole thing is, in any case, imaginary. It is a simulation, and it is designed to convince the software in the equipment under test that it is not sitting quietly in an anechoic chamber in a TEMPEST-rated building at Stanmore but it is, perhaps, fixed to an aircraft thousands of miles away, streaking in fifty feet above the ground at Mach 1 against a densely-defended target.

Denne therefore decided that he would transform the microwave signal parameters into visible images that could be shown on a TV screen - a view of the microwave world as it would be "seen", for example, by the microwave sensors in an attacking aircraft. He was astonished to discover how exciting this visual simulation was, for the visiting VIPs and for the senior military personnel from many countries who watched the displays on the TV screens. Clearly, those normally dour and serious individuals were fascinated and found themselves caught up in what they saw. Denne resolved that he would find some way to allow the general public to experience that sort of excitement; so he left Marconi and set up a company that built its first simulator in 1985.

Super X Ltd

Super X "Venturer" machine. **Super X assembly hanger in Bournemouth**

Margaret Thatcher and Richard Branson ride the Super X Venturer

An entertainment simulator consists of a small cinema in which a group of between twelve and forty people watch a projected television display and listen to a soundtrack, whilst the whole cinema moves on a "motion base". The idea of the entertainment simulator was a great success and the UK Government specially featured the new machine in the British Pavilion of EXPO 88 in Australia, where Margaret Thatcher and many other VIPs rode it. The " Venturer" quickly became the world's most popular simulator and Super X Ltd was rated No. 12 in the "Top 1000 Companies" competition in 1990.

The importance of motion cues.

Ask anyone what a simulator is and the answer will be about teaching pilots to fly aircraft. Mention entertainment simulators and you will learn that the most important thing about them is that they move - to the general public a simulator is not a simulator unless it moves. But entertainment simulators do not actually simulate anything. They are fantasy machines in which the laws of nature are modified so that the experience that the public pays to receive does not closely resemble any physical reality. Instead, the machine portrays reality as the common man would prefer it to be - at least for three exciting minutes.

If you have watched a simulator working from the outside you will see that it weaves and dodges about through small angles of pitch and roll and it also bobs up and down a few inches, apparently in a random way. But when you get <u>inside</u> the capsule the effect is quite extraordinary. This is because no one drives - or flies - in accordance with visual cues as the primary response. Careful studies show that a person engaged in vehicle guidance control responds first to tactile disturbance and only later to visual field disturbance. This is thought to be due to the experiences of early life, which teach balancing skills as fast reactions to external forces on the body. These reactions are entirely subconscious and they act on the human brain to update the model of body motion and to predict its future position - there is no delay in an interposed, consciously-accessible reasoning process

Learning to react to motion cues

Driving "by the seat of the pants"

When we take control of a vehicle - for land, sea or air - we bring with us our fast reactions to body forces and we use them to measure our mastery of the vehicle. We deliberately learn how to blend with the vehicle - to feel that it is a natural extension of our body - and to get an instinctive understanding of where the edges of the vehicle are and what is happening to them. By using the controls to move the vehicle, we also gain an ability to predict the future position of the craft and when it is moving we learn how to interpret its interactions with the surrounding medium. We say that a vehicle is under control when it "feels right" - when the driver is able to make the vehicle feel as he/she wishes, whether in response to input commands or against disturbances from the outside environment.

Vehicle control is an example of how important sensations of force - of acceleration - are to us in our daily lives and how we use the instinctive responses of the human body to control machines. The most important aspect of this brain function is that motion sensations go directly to the subconscious. There is no conscious thought between sensory input and trained or instinctive response. All the appropriate body chemical responses are triggered.

The essence of simulation - of Virtual Reality - is that it should be a compelling fantasy. That is, during the progress of the simulation it must appear to be "real", even if you understand that it wasn't real when you think about it afterwards. If you have never ridden a good simulator then you will be very surprised just how compelling the experience can be. Thorough simulation is capable of disconnecting you thoroughly from the real world and immersing your mind within a Virtual World, in which the laws of physics can be different and in which you need not be limited to being the self that you are in your life outside the simulator.

Stress, especially stress from motion cues, increases the psychological "grip" of a simulation on the participant. Entertainment simulators are very profitable machines, because motion is always involved in the most exciting entertainment experiences, and because precise and accurate motion cues have such a powerful and irresistible effect

The problems of hydraulic motion systems

Until recently, the only way to produce such precise and powerful motion cues for simulation has been by using hydraulics. Electric motors driving screw jacks can be "beefed-up" to produce a large thrust but they cannot be designed to have also the extreme sensitivity and the fast response that is vital to the simulation illusion. A good motion system must be equally capable of producing (say) the strong sensations of "cornering" in a vehicle as in providing the differences in road feel from gravel or tarmac or grass. Hitherto, only hydraulic rams have been able to do this, at great expense and complication and with the inevitable oil leaks and fine oil spray onto the surroundings. When the simulator is used indoors, the damage to nearby fabrics, the fire hazard and the possible toxic effects of the oil mist create major problems. But there is a very large market for small simulators indoors, in arcades and family entertainment centres and in portable trainers for military and civilian personnel**.**

Typical small entertainment simulator **Its hydraulic motion base**

The power consumption difficulty was solved first. The hydraulic rams were replaced by pneumatic rams and the space beneath the pistons was pressurised to support the dead weight of the capsule. Then the pressurised part of the pneumatic ram was connected to a small reservoir (a few litres) so that it formed a low-rate gas spring. The gas springs removed from the actuators the requirement to support the deadload and they acted as reservoirs in which energy could be stored and extracted later. The actuator rams now only needed to provide impulsive forces - there was no requirement for a steady upthrust. Power would only be consumed when the simulator was in motion and the only power required would be that necessary to change the kinetic energy of motion and to overcome any frictional losses – a small fraction of the power used in a conventional motion base.

Electromagnetic rams

Since the forces must be coupled to a floating mass the actuators have to be electromagnetic. There is no other way to take a firm grip on a freely-suspended inertial object. Because no suitable electromagnetic rams were available, it was necessary to develop a new type of actuator, which was later found to have many other industrial applications. The UK Government considered that the project was of far-reaching importance and provided substantial support throughout its development.

In concept, the new actuator is a multi-pole permanent-magnet rotary electric motor split down to the middle, rolled out flat and then rolled back up again by taking the long edges of the strip and bringing them round to form a cylinder. The armature is treated in the same way and then the armature shaft is inserted along the axis of the cylinder to make a piston shaft.

Finally – and most importantly – the outer surface of the armature is sealed to the inner surface of the cylindrical stator, so that acts simultaneously as a fluid piston and an electromagnetic force generator. Because all the electromagnetic fields close back upon themselves within the steel housing, the machine is very efficient and environmentally benign.

Prototype ram under test

Later design on a three-axis motion base

For a motion base designer, one of the most interesting features of the product is that there is a direct electrical connection between the computer and the piston. The electric current itself provides the force and the acceleration of the ram is a direct function of that current. Acceleration is what the occupant of the simulator actually feels. Because there are no transport lags or fluid inertia, the system is inherently of wide bandwidth, able to respond as rapidly as it is possible to change the current in the coil inductance. The rate of change of force is very great, so that it is possible to produce motion cues that are exactly timed and precisely controlled.

Electromagnetic motion bases consume only a few hundred watts in place of the several kilowatts required for even a small hydraulic motion system. They can be used for cinema-seat simulator mechanisms, for low-cost personal training simulators, and for small entertainment machines.

The electromagnetic ram as a force-measuring device

If body movement interaction were to be generally available, Virtual Reality would become powerfully convincing and much more than just a visual experience. Some of the most exciting and enjoyable sports have a strong element of body movement control in them - and they are some of the most difficult and dangerous to learn. They are large markets for training simulation that involves body motion. For example: -

Skiing, ski-boarding, ski jumping, skidoo racing.
Ice skating, roller skating, skateboarding.
Surfing, wind surfing, sailboarding, jet ski racing, water skiing.
Sailing, yachting, white-water canoeing.
Tobogganing, Bobsleigh racing, Motorcycle racing, Horse riding, Hang gliding

The air-sprung electromagnetic motion base is a force-balance system. The force generated by each ram is continually controlled to be exactly that which is needed to hold the desired position of the simulator - no more and no less. The current in an electromagnetic ram is therefore a direct measure of the load on it, having taken the gas spring pressure into account.

So when a human occupant of a simulator on an electromagnetic motion base moves or leans to left or right, fore or aft, the currents flowing in the rams will immediately adjust themselves to the degree necessary to compensate for the shift in the centre of mass, holding the position of the motion base constant. Thus by monitoring the relative values of the currents flowing in the rams, it is possible to know the position of the c.o.g. of the moving platform - that is, to sense any movements of the human occupant(s). The movements can then be fed back into the control computer to modify the progress of the simulation.

To illustrate the concept of body motion control a local champion surfer posed with a VR helmet on a motion base. Later, the principle was demonstrated on “Tomorrow’s World” and the company won several prizes for this imaginative use of Virtual Reality.

The “Virtual Surfer” photograph became the logo of the electromagnetic ram in the VR industry.

Recent advances in electromagnetic ram technology

The first prototype ram used ferrite magnets in the stator to produce radial fields and the piston (armature) carried an array of coils that was driven by an off-the-shelf power amplifier. The original patent applications were based on this arrangement. The efficiency of the system was then improved by the use of axial disc magnets and polepieces on the piston, placing the coils in the stator and adding a commutator board for their selection according to the piston position. Thrust amplitude was controlled by specially-designed power modulators, which were the small square boxes that can be seen on the base of the 3-axis motion base in the photograph below.

Axial magnet piston

3-axis base showing power drivers

Early Stewart Platform motion base

AEA Technology base for Pilkington

The power switches in the commutator were later re-designed so that they also performed the modulating function for each individual coil current, making the commutation rather less jerky and distributing the power handling function across the circuit board.

But the modulating commutator design became obsolete because its hardware and software were complex, it was intolerant of coil faults and it was very inflexible. The modulating commutator was physically attached to the ram and it shared the operating environment, making the product unsuitable for many industrial markets. Each ram coil was separately controlled, so that no change could be made to the physical parameters of the magnetic circuit or to the operating stroke of the ram without a thorough redesign of the hardware and software of the commutator. Every type of ram had to have its own special modulating commutator.

Modulating commutator ram **Commutated ram 6 DOF motion base**

Denne therefore developed a much simpler, more precise and reliable technology in which the magnetic configuration of the ram itself was modified so that it became the exact equivalent of a three-phase rotary servomotor. The new ram is mechanically robust, tolerant of high operating temperatures and may be made completely waterproof. The improved machine has only three wire connections, there are no electronic circuit boards on the ram and, whatever its size or thrust rating, it may be connected to a standard type of three-phase servomotor drive unit. A patented technique of gas spring control, using the drive electronics and based on the force-sensing properties of the ram, greatly reduces power consumption in motion bases, in stabilised platforms and in many industrial applications.

Assembly Industries 5 KN thrust, 1.5m stroke ServoRam on bench test

Large Digitron 3-phase ServoRam **McGeoch 3.5 KN ServoRam**

Performance

The small industrial ServoRam on the right will hold a "virtual cam" profile accurate to within 50 microns when moving a mass of 200 Kg at more than 1 metre/second with accelerations in excess of 1g. As another example, the Assembly Industries ServoRam will control a reciprocating mass of 100 Kg at 2 metres/second with a positioning accuracy of 50 microns. The integral double-acting and self-tuning gas springs lower the mean power consumption of the machine to about one Kilowatt, eliminating the need for any special cooling.

Advanced Motion Technologies 6 DOF Motion Base

The base uses McGeoch RTL industrial rams producing 3500 Newtons peak thrust.
It is conservatively rated for 600 Kg payload.

Some advantages of the ServoRam™

No stray fields. The "piston-in-cylinder" topology means that all the magnetic fields are contained within the ram, so that there are no spurious effects on its surroundings, no electromagnetic interference and no problems with swarf or steel grit.

Cleanliness. Modern versions of the ram are fully sealed. They will operate under water, in a vacuum, in a hostile or in a sterile environment.

Silence. Most other types of electric linear actuator are noisy and their noise level increases with thrust rating and with wear. This can be a problem in machinery that operates continuously and in close proximity to a human being. The silence of the ServoRam™ is compatible with a clean, high tech environment.

Simplicity and reliability. Nothing moves except the output element. Nothing wears except two bearings and one air seal.

Wide operating tolerances. There is no requirement for micron filtration or white-glove maintenance. The piston ring bearings allow the armature to follow changes in stator axis alignment.

High peak-to-mean thrust ratio. There is no hard limit to the transient peak thrust capability of the ram over a short time interval. 10:1 ratings are typical.

Speed of response. This is an order of magnitude better than the very best hydraulic device. The ram has an exceptional rate of change of applied force.

Power regeneration. Using the ram in reverse mode, the machine operates as a generator - a controllable damper with an electrical power output that may be returned to the supply system.

Ease of control. Thrust is an **exactly linear** function of drive current, which may be made the controlled parameter and independent of the position of the piston. There is **zero hysteresis**. There is **zero time delay** between current flow and output thrust.

Precision. Zero backlash, zero transport lag, hard coupling and a wide control bandwidth result in extreme precision, which is limited only by that of the position transducer. An accuracy better than one micron can be achieved.

Dual Action. The pneumatic properties of the ram are intended to be used for the static, quasi-static or energy-storage functions. The electromagnetic forces are directly superimposed on the same output element for precise positioning.

Auto-tuned spring function. By a patented technique the pneumatic or gas spring forces can be continuously tuned for maximum speed and minimum power demand. This greatly enhances performance.

Scaling. The ram topology is scaleable over a wide range of thrusts and piston travel lengths, using off-the-shelf magnetic components.

Industrial applications of the ServoRam™

Passenger Lifts. Many passenger lifts in buildings up to five storeys high are raised by hydraulic rams. Electromagnetic rams can be used to replace them with an efficient, silent, clean and much more reliable product. Changing demographics have created a market for a lift module that may be added to existing homes and it is expected that a lift module using a ServoRam™ can be made for a price sufficiently low to allow it to be fitted as standard in general private housing. It should be noted that the rodless version of the ServoRam™ removes any limit to travel height.

Automobile Suspensions. Several makers of cars and off-road vehicles are considering the use of active electromagnetic suspension systems – a revolutionary improvement in suspension. In fall-back mode, acting as a damper, the ServoRam™ can vary its characteristics under computer control in milliseconds if required, so that an electromagnetic suspension system can instantly adapt to every road condition. The energy absorbed by the damper (sometimes 300 Watts a wheel) is not thrown away as heat but can be fed back into the battery supply, saving fuel. Simultaneously, the fluid piston element may be arranged to act as a self-levelling, height-adjusting fluid spring.

Rail Coach Suspensions. Theoretical studies carried out by Loughborough University as part of an EEC programme have shown that the ideal suspension for a rail vehicle is a combined gas and electromagnetic system. Recent work shows that the ServoRam™ can now achieve the necessary forces, displacements and power levels for this market.

Industrial Automation. The advantages of extreme precision, cleanliness, silence, high peak thrust, unlimited speed, intrinsic force sensing, reliability and wide control bandwidth mean that the ServoRam™ has many factory applications. For example, the rams can replace hydraulics in food and drug manufacture, where contamination is very expensive. The gas spring technology and the unique ability of the electromagnetic actuator to "freewheel" when handling inertial loads also save power in high-speed reciprocating machinery such as that for sorting, transferring and packing goods.

Machining Hexapods. New forms of precision mechanisms are now being developed to manoeuvre a power tool around a metal part for shaping and machining operations. The tool is carried at the apex of a six-axis arrangement of linear actuators that is called a hexapod. The ServoRam™ actuator in a hexapod has the advantages of silence, speed and extreme precision, coupled with a unique ability to sense at every instant the reaction force on the working tool.

Doors and Vents. Although vent actuators only operate at infrequent intervals and their first cost must be low, they are often almost inaccessible, so that maintenance is very expensive and reliability is vital. The ServoRam™ has created interest because it has only one moving part - the piston itself.

Security. The power needed to operate a ServoRam™ can be stored in a small space - for a year or so in a battery or for several minutes in a charged capacitor. This means that the device can be self-contained, so that it may be used to carry out a security action in a no-power emergency. It would be possible for the device to drive a bullet-proof security screen into position faster than a robber could pull the trigger.

Stabilised Platforms. When optical devices like cameras or measuring equipment have to be mobile on a land or sea surface they need to be isolated from disturbances when they are in use. This is also true for guns, radar antennae and missile launchers. Previously, most stabilising arrangements have used "hard" mechanisms with powerful motors, gears and cranks to generate the movements that are necessary. There is considerable interest in using the ServoRam™ gas-spring suspension to decouple the stabilised platform from external disturbances. The very fast electromagnetic forces are superimposed to hold a precise position.

Cross-country vehicle seating. Human beings need stabilisation to avoid fatigue and injury when driving vehicles such as earth-moving equipment across rough terrain for long periods. Although soft spring suspensions have already been tried, it is clear that a significant improvement will result from the use of electromagnetic actuators that combine an air spring and an active position-stabilising function.

Pile Driving. As a result of earlier studies by a British architectural consultant, it seems to be feasible to use both the fast rise-time and the force-sensing feedback properties of the ServoRam™ in a novel form of high-speed pile driver. This works by applying a powerful impulsive waveform to the pile at a frequency that adapts automatically to the characteristics of the soil and makes it more fluid.

The technology is protected by the following Patents and Patents in Application: -

GB9719735.4	**GB9704889.6**	**PCT/GB98/02823**
GB9719738.8	**GB9719739.6**	**PCT/GB98/03088**
GB9721747.5	**GB9709737.0**	**PCT/GB98/03092**
GB9721748.3	**GB9719736.2**	**PCT/GB98/00495**
GB9727443.5	**GB9727446.8**	**PCT/GB99/03745**
GB9824499.9	**GB9927461.5**	**GB9915709.1**
US5440183	**GB9801237.0**	**GB9915708.3**
GB9724078.2	**EU92915909.3**	**GEO 003664**
JP5-502123	**CA2113344**	**EU92915111.6**
US5605462	**CA2113340**	**EU95902873.9**
US08656307	**CA2182372**	**JP51605195**
AU61070/98	**CA2280973**	**CN98802810.7**
IL131467	**JP10536371**	**KR997007680**
SG99038622	**and many others**	

The distinguishing features of the ServoRam™ and its performance advantages

Linear Motors

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

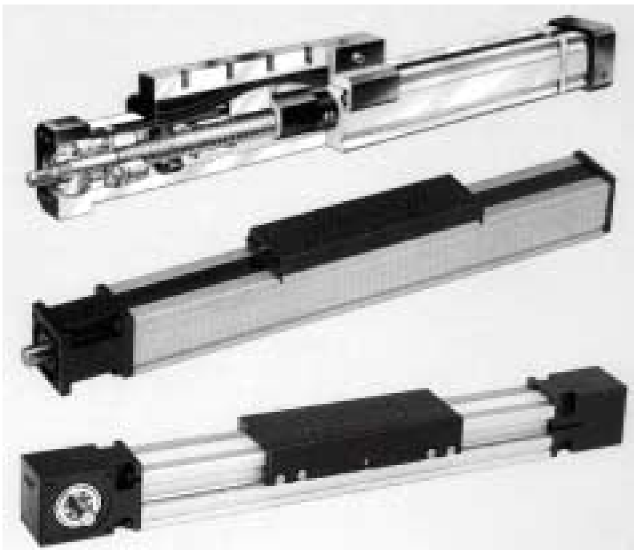
(Showing 12 linear actuators and 1 linear motor)

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. This limits the speed of response of the actuator, so that it cannot be used to oscillate something backwards and forwards very rapidly or precisely.

The stressing also causes wear and eventually produces a significant noise. Ballscrew mechanisms are infamous for this, because the balls contact the screw over very small areas and therefore operate at very high contact pressures. This gradually pushes metal away from the contact points to make roughly-shaped ruts in the screw material, destroying the smooth action of a new machine.

Section of a ballnut element, showing balls and screw channels

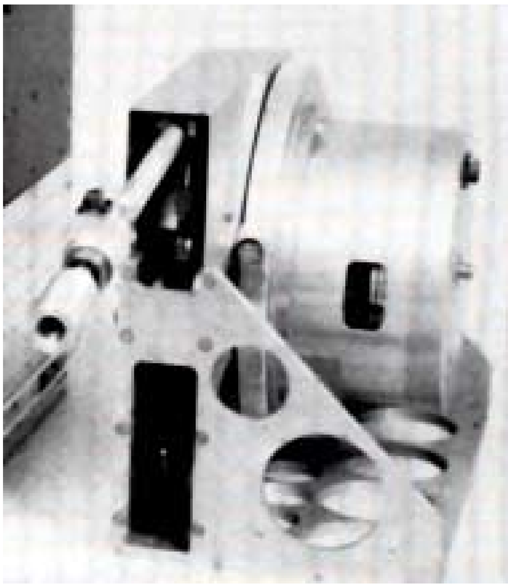
Belt-drive actuators have the wind-up problem but they also have problems caused by belt flexing and vibration. Increasing the belt tension makes the bearings wear more rapidly. Steel belts are often used for the larger forces – but in the end these stretch and begin to slip on the worn drive pulleys.



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.

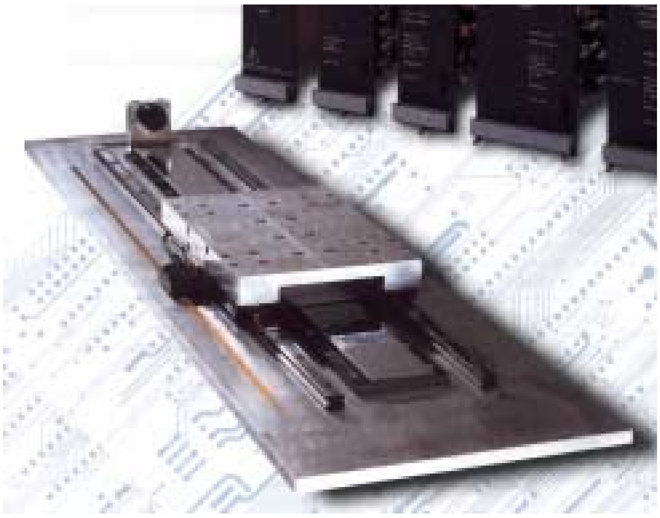


Cranked push-rod actuator

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

"Unrolled motors"

True linear motors have been around for a long time – in fact the earliest electric motor designs were linear ones. 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 electric motors are still made that way.



Typical flat bed linear motor

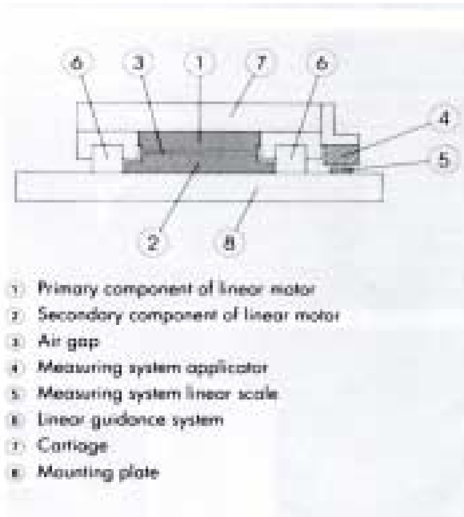
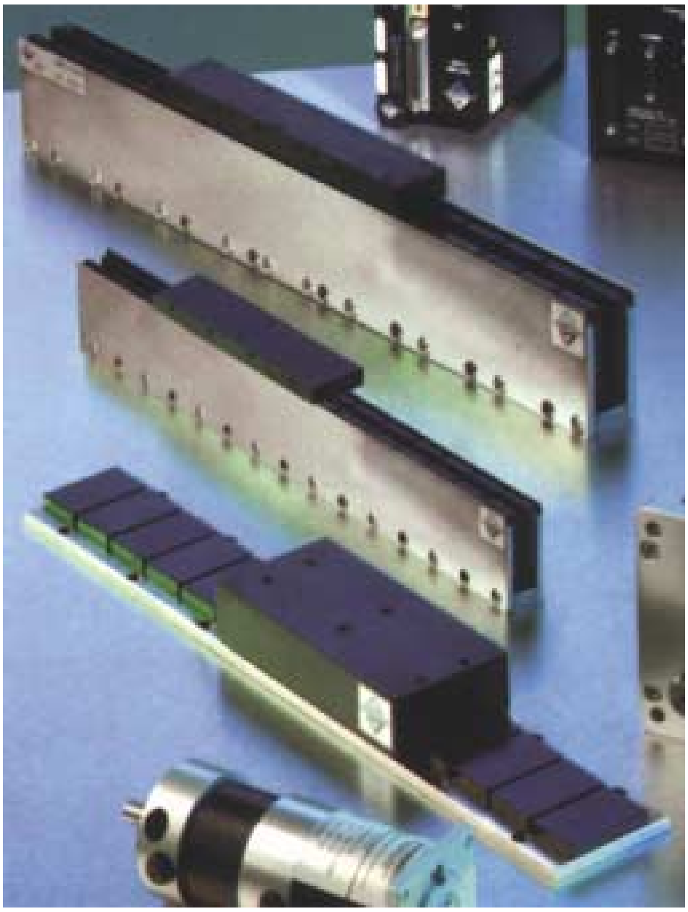


Diagram of Section

The first problem with the "flat motor" design is that it is very inefficient. The magnetic fields produced by the machine spray out in all directions and the working flux densities are low.



The second problem is that 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.

The third problem is that steel dust or magnetic grit is attracted into the body of the machine by the high magnetic fields and damages the bearings.

The fourth problem is that large machines have large stray magnetic fields and they cannot be used unguarded in close proximity to the general public.

The fifth disadvantage of the "rolled-flat" motor design is that those 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.

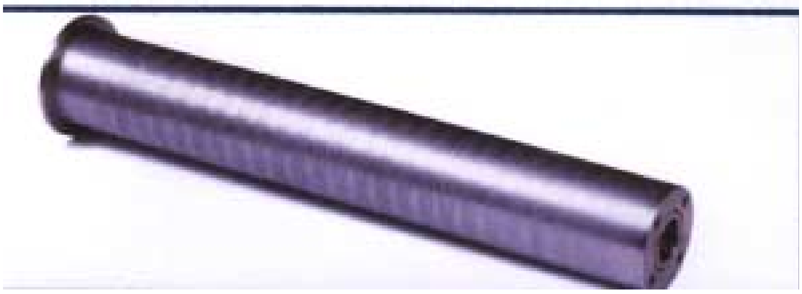
Catalogue picture from Aerotech, showing "U" and flat design permanent magnet motors. (Note exposed magnetic fields)

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.

Cylindrical motors

Many of the disadvantages of the flat machines can be overcome by making them cylindrical. A typical example is shown. Only a small number of manufacturers use this technique, which is heavily protected by patents

Avcon cylindrical motor



Magnetic armature of an Avcon 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 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 Avcon armature)

Linear Drives, a UK company, sells a range of motors in which the outer rolled-up "stator" is actually shorter than the inner central "armature" 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 or other sensitive equipment. It is also necessary to supply power to a moving coil assembly using a flexible lead. This disadvantage is common to most types of linear motor design.

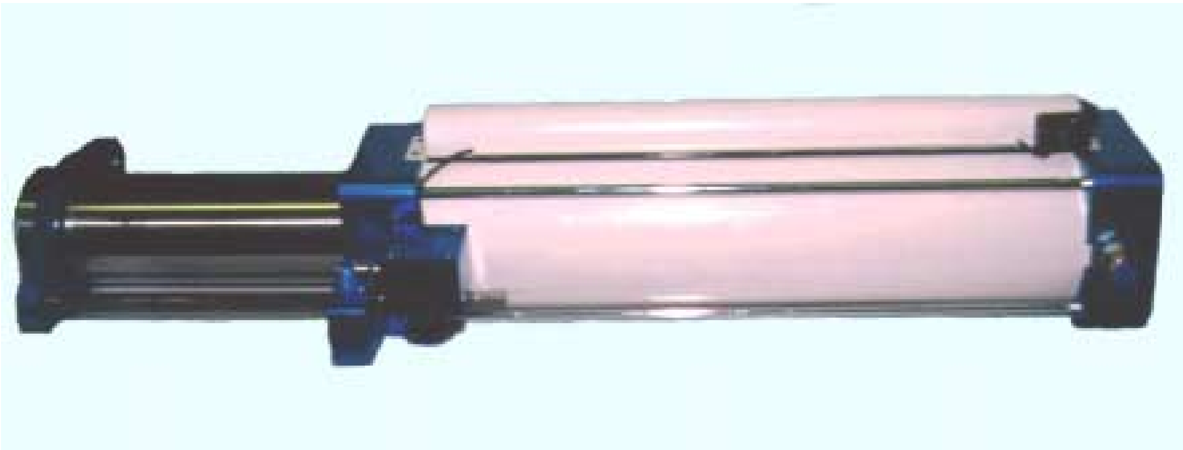
Precision Bearings

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, all the manufacturers of cylindrical linear motors do the same thing. Aura, Avcon, Indramat, Normag and others make a range of actuators in which the armature rides on a shaft along the 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.

With very few exceptions, all previous linear motors have been designed to be used in a fixed vertical or horizontal position – with a strong bias towards the horizontal. No previous machine has been designed to act as a freely-pivoting inclined actuator or "ram".

Electromagnetic rams

Only one company in the world – Advanced Motion Technologies – now licences a range of patented electromagnetic actuators that have the appearance and general utility of hydraulic rams and are designed to operate in any position or orientation.

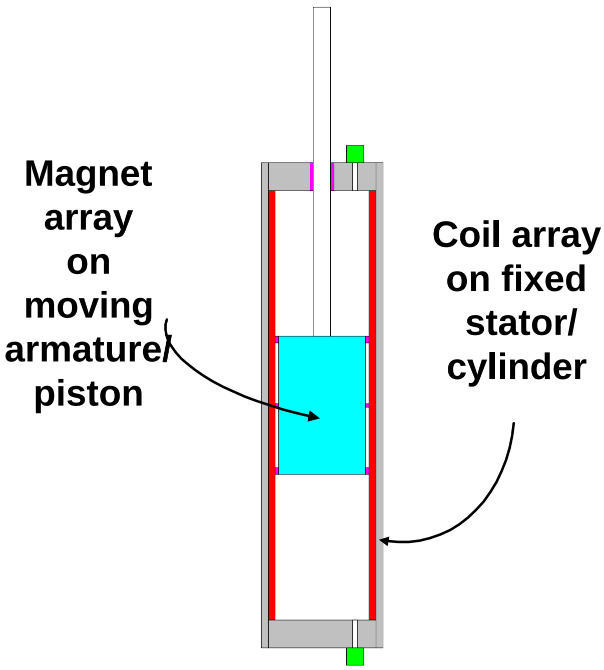


AMT ServoRam made by McGeoch RTL

The reason for this is that the design was approached from a different direction to that of the other manufacturers of linear motors. Denne 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 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 machines use 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.

Thus the basic form of linear motor looks like a hydraulic ram. Because the "piston" armature can be sealed to the stationary structure, it may also act as a fluid power element, especially as a part of a gas spring system. This is a valuable and patented feature of the machine.



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

ServoRams™ are significantly different from any other form of linear motor and they have the following unique advantages: -

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

Motion base for a professional training simulator, using industrial ServoRams™