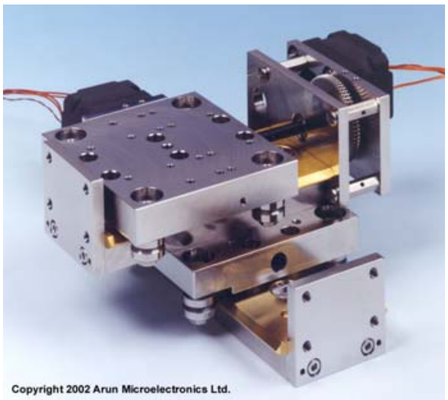
ARUN MICROELECTRONICS LTD

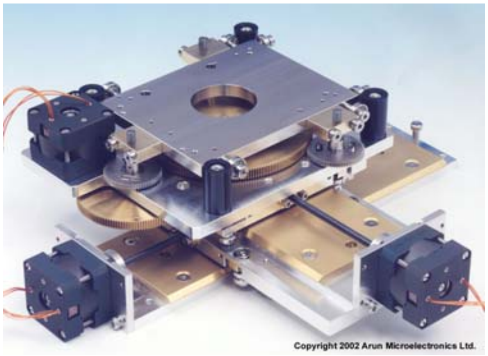
Vacuum Mechanisms from AML

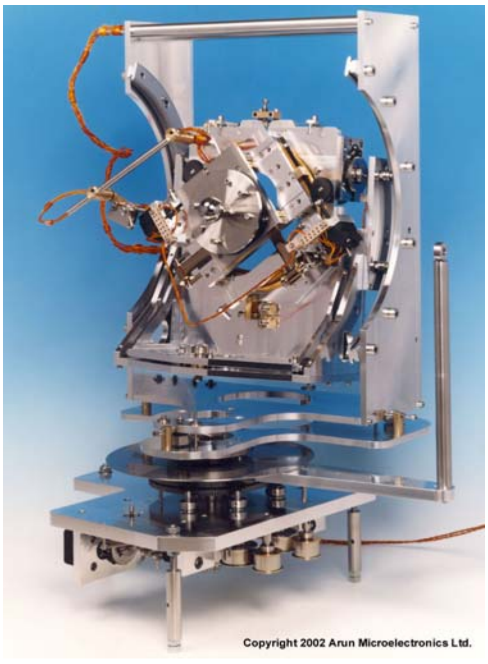
Arun Microelectronics Ltd. (AML) design and manufacture automated precision mechanisms for use in UHV, using well-proven vacuum-compatible stepper motors.

AML motors have been manufactured and applied since 1986 and are a mature and accepted UHV technology. Thousands of motors are in regular use. AML have unrivalled experience in the application of VCSMs to mechanisms, with several hundred succesful designs completed. There are standard ranges of linear mechanisms and rotation stages, although most mechanisms supplied are customised to some extent.



Application areas.





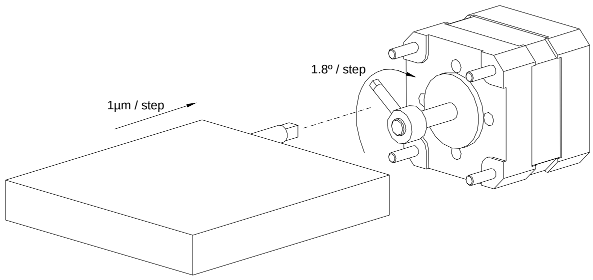
Stepper motor–based mechanisms should not be regarded merely as replacements for those based on other techniques, since they offer specific advantages and are suitable for applications not addressable by other means. The advantages of internally motorised mechanisms are that the number and range of motions, rigidity, accuracy, repeatability, speed, reliability and crosstalk between motions are much better than is possible with motion feedthroughs. Where there are several axes, or if the range of linear motion exceeds a few centimetres, or if the sample is large or heavy then stepper motors offer price as well as performance advantages. The main application areas are in clean vacuum systems, where the magnetic leakage fields of motors (a few microtesla) are not significant. These include sample transfer and sample scanning for surface analysis, mass analysis, ellipsometry, radioisotope dating, MBE, electron channelling, Rutherford Backscattering, deposition uniformity control, beam chopping, cluster-processing and VUV/X-ray monochromators.

AML vacuum mechanisms are not economic in non-vacuum applications.

Position control.
When driven correctly, stepper motors are inherently self-encoding digital devices. Provided the recommended speeds and accelerations are not exceeded then desired and actual positions remain exactly synchronised. There is no need for expensive encoders, other feedback devices or limit switches or the inconvenient wiring and feedthroughs that they need. A convenient reference location is provided for each axis so that any location on each axis can be achieved by execution of a single command by an SMD2 controller. Position information is maintained in the SMD2, even in the absence of power, and there is normally no need to re-establish the reference locations after an initial setup.

Speed Control.
The speed of rotation of a stepping motor is precisely controlled by the frequency of its drive: there is no slip or other uncertainty and no feedback devices are necessary. Above a few hundred Hz the stepping action of an unloaded motor is smoothed by the low-pass filtering of the kinetic energy stored in its rotor. The use of step division at lower speeds smooths the motion further and increases the damping factor.

Vernier stops.
Stepper motors may be stalled indefinitely without damage. AML mechanisms are designed so that they can be driven into their mechanical end-stops without affecting their performance in any way. The range of uncertainty in the position of an end-stop may be reduced by fitting a vernier stop. These are arranged so that a pin attached to the output plate of the mechanism moves into the plane of a radial arm attached to the motor shaft. The position at which this stalls the motor has a range of uncertainty of three steps, which can often be reduced to a single step. The repeatability of positions is usually more important than absolute position and this is typically less than a single step. Usually it will not be necessary to re-establish the end-stop position after installation and commissioning is complete. Vernier stops are inexpensive and effective.



Range of motion.
A practical maximum length of travel for linear mechanisms using leadscrews is 300mm. For longer travels, belt or wire drives are appropriate, but these have lower resolution. For rotation mechanisms with position-control, the maximum range may be restricted to slightly more than 360°. This limitation is necessary to ensure that the wiring from any sample-connection, heating device or other motorised stage mounted on the rotation stage can be brought out. Most rotation stages in stacked multi-axis mechanisms will require much less than 360° range: it is important not to over-specify range of rotation as this increases cost.

Resolution
Resolutions of 1 micron or 1 millidegree per step are easily achieved. For linear mechanisms, specifying 4 micron resolution minimises the cost. For rotation stages the optimum resolution is determined by the available space and load-matching considerations. Specifying the coarsest resolution acceptable will reduce the cost but better-than-specified resolution may be offered because of loading. Because a stepping motor is a digital device, the motion resulting from a single step has a defined tolerance, usually about 5% of a single step at the shaft of an unloaded motor. The motion resulting from any number of steps still has an overall tolerance of a fraction of a single step. Step division is not a satisfactory way of increasing resolution.

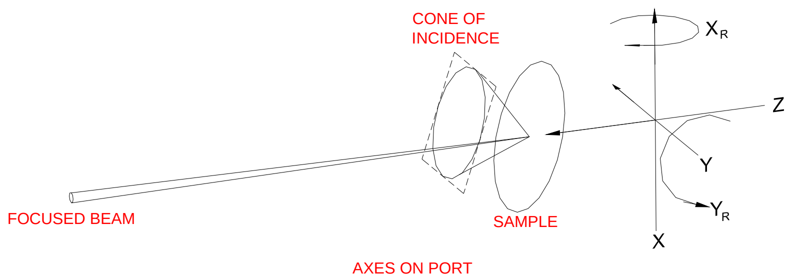
Repeatability
Repeatability of any position at constant temperature and approached in a consistent way is normally better than the resolution. Wherever possible, thermal expansion of the mechanism is equalised about the centre of travel. Thermal expansion of leadscrews of linear mechanisms due to self-heating may need to be considered where there is a very high duty-cycle motion. Thermally decoupling the motor from the leadscrew will reduce this effect by a large factor in low-resolution applications. AML will advise in specific cases.

Backlash.
Most motorised mechanisms are supplied with active backlash-control means fitted. Backlash is usually negligible, compared to resolution. The orientation of all axes with respect to gravity is significant in controlling backlash. In some cases gravity alone may be used to control backlash, reducing complexity and mechanical loading, although in other cases it may present challenges. For example, rotation of loads whose center of gravity is offset from the axis may result in a reversal of static torque: such cases can usually be avoided by careful analysis and design.

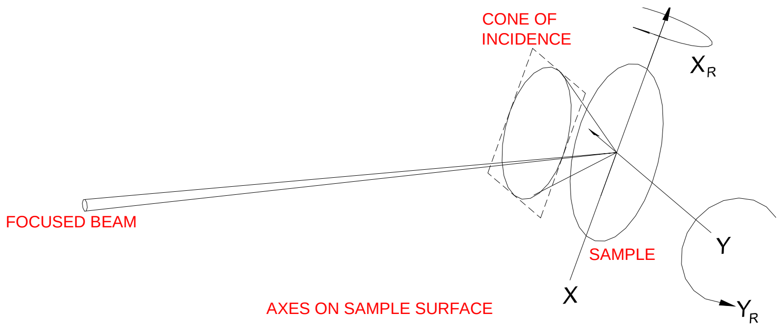
Crosstalk.
Multi-axis mechanisms based on multiple motion feedthroughs through the chamber wall incorporate universal and sliding joints to couple to compound mechanisms. This inevitably leads to crosstalk between motions and large backlash, both of which are negligible in mechanisms with internal motors.

Stability.
Hybrid stepper motors have a detent torque (without drive current) of about 10% of their rated torque. AML design mechanisms so that the combination of detent torque, static friction and gearing is sufficent to maintain the position of each axis with no movement when the phase current is removed. Position information is maintained in the SMD2 drive in the absence of power. Where the best stability is required all sources of vibration must be decoupled from the chamber: this is particularly important in the case of turbomolecular pumps.

Stacking order.
The stacking order of motions using vacuum motors is relatively unconstrained and this can lead to considerable advantages and operational convenience. Together with negligible backlash and crosstalk this makes accurate eucentric goniometers for large samples practical. Stacking order is an important concept, which is best illustrated by a typical example. Consider the requirement to illuminate any spot on a sample with a focused beam, which is fixed with respect to the vacuum chamber. The angle of incidence of the beam is to be varied over a cone or square pyramid, whose axis is normal to the sample surface, with its vertex on the incidence point.



Using an edge-welded bellows approach, the X and Y axes of linear motion usually have to be fixed with respect to the mounting port. This means that the location of the incidence point is convolved with the axes of rotation X_R and Y_R, which define the angle of incidence. The motion of the point of incidence across the sample is not the same as that of the X Y stage and it moves if the angle of incidence is changed. Because of the convolution of rotation and translation it will be necessary to have a Z motion along the axis of the port to restore the point of incidence to the focus of the beam. If the axis of the mounting port is not accurately aligned to the axis of the beam then it may be necessary to have a port-aligner.



Using vacuum motors the XY axes are fixed on the sample surface and the rotation axes are the same. Therefore, if the angle of incidence is changed the point of incidence does not change. The incidence point moves across the sample surface by exactly the same amount as the XY motion, regardless of the angle of incidence. Normal incidence and the centre point of the sample are defined by four numeric addresses (which may be zero) set into the SMD2 controllers. There is no need for a Z motion or port aligner.

Maximum Speed.
The speed of the output plate of the mechanism is the product of the stepping rate and the resolution. The maximum slewing speed of a mechanism is dependent on the load imposed, and the gearing between the motor and the output. The load is dominated in most cases by the weight of other mechanisms stacked on the output plate. Lightly loaded mechanisms can slew at >2kHz and the most heavily loaded will slew at 500Hz stepping rate. Because of the absence of the high loads due to atmospheric pressure, internally motorised mechanisms can be ten times faster than those based on edge-welded bellows and motorised externally. With high-resolution mechanisms translations of a few mm per second and rotations of a few degrees per second are practical.

Orthogonality and concentricity.
Orthogonality of linear axes will be set to ±0.5° and concentricity of rotations within 0.2mm. If finer settings are required then micrometer adjustment screws can be provided together with metrology attachments for adjustment after installation.

Loads and Forces.
Standard translation mechanisms can exert forces of about 10kg, which is limited by the leadscrew and nut combination. The rolling resistance of a translation mechanism is usually a few hundred grams. Mechanisms will usually support much larger masses than 10kg, depending on the guidance system. The effect of static torques exerted by offset loads must be considered. Standard rotation mechanisms are not designed to produce large output torques, so if the axis of rotation is not vertical it is important to keep the centre of gravity of the load close to the axis. Custom-designed large-force mechanisms and high-torque reduction gears can be provided.

Sample heating and cooling.
AML will supply and fit heaters, thermocouples and cooling braids for attachment to cryostats, as required.

Outgassing and bakeout.
AML motors and mechanisms are designed specifically for UHV, using appropriate materials, handling and construction techniques. For use in UHV, baking at 175° to 200°C is essential, after which outgassing rates of the order of 10^{-8} millibar litre per motor will be achieved. The actual gas load depends on the duty cycle of the motions and the phase current of the motors. Mechanisms are designed so that the motors can be switched off when the load is stationary and most motions can be swept over their entire range in less than a minute. As a 'rule of thumb', 100 litres sec^{-1} of additional pumping capacity per motor will be necessary to achieve ultimate UHV.

Sample holders and Sample changing.
De-mountable sample holders can be provided. They can be insulated and have pluggable electrical connections. Mechanised sample entry via a load-lock is performed either with a magnetically coupled linear feedthrough or with a passive mechanism activated by one of the motorised axes or an additional motorised mechanism. Typical situations are illustrated and discussed in AML Application Note 30.

Reliability
The only components in UHV stepper motors subject to wear are the bearings, which have a life of decades in normal service. Where there are moving parts in rolling contact dissimilar materials and surface treatments are selected to avoid galling or wear. Aluminium-bronze nuts (used in conjunction with leadscrews) have a life of several thousand hours of full-speed motion and are easy to replace. Worm drives are used only when necessary because of space constraints and are arranged to have low speeds and loadings and to be accessible for easy replacement. Linear guidance systems are designed to avoid sliding contacts.

Lubrication.
Sliding surfaces in leadscrews and worm drives are lubricated with NyeTorr ™ 5200 synthetic lubricating gel for mechanisms which are not intended to be baked. Lubrication increases the life of these components. Various dry-film lubricants and low-friction surface treatments can be used, according to the requirements of the application.

Space Requirements.
It is very important to consider the realistic space requirements of mechanisms before designing the chamber to accommodate them. Single axis mechanisms with light loads can usually be made with an output plate height of 30mm. They are designed for direct stacking, but where more than three mechanisms are stacked additional space for increasing the rigidity of the lower stages may be necessary.

Where space is very restricted, the design costs quickly escalate. For example, the additional cost of designing a six–axis goniometer to fit a minimal space can easily exceed the cost of a larger chamber.

Controls, cables and feedthroughs.
Mechanisms are designed for use with, and are normally supplied with SMD2 drives cables and feedthroughs. Usually one MLF18 feedthrough and cable per three motors and one SMD2 drive per two motors are required. All internal and external cables are are pluggable onto the electrical feedthroughs. Motors are wired to intermediate VTB6 terminal blocks fitted near the motors, where appropriate.

Specification of multi-axis mechanisms

Describe or define:-

1. the application
2. the axes with respect to either the mounting plane or the sample surface, as appropriate
3. the orientation of the axes and the sample surface at centre-travel with respect to gravity.
4. the stacking order of motions, if critical
5. the sample size, weight and position of centre of gravity, including any sample holder
6. the resolution and limits of motion for each axis
7. the maximum duty-cycle of motion for each axis
8. whether there is a requirement for a clear view through the sample or any cones or other volumes in front of the sample which must remain clear
9. heating, cooling, electric insulation or electric connection to the sample to be supplied or accommodated
10. the method of sample changing, if any
11. acceptable lubricants
12. the space available
13. the chamber wall temperature in normal operation and in bakeout.
14. any electromagnetic or ionising radiation, electric or magnetic fields or materials being deposited
15. the base pressure