



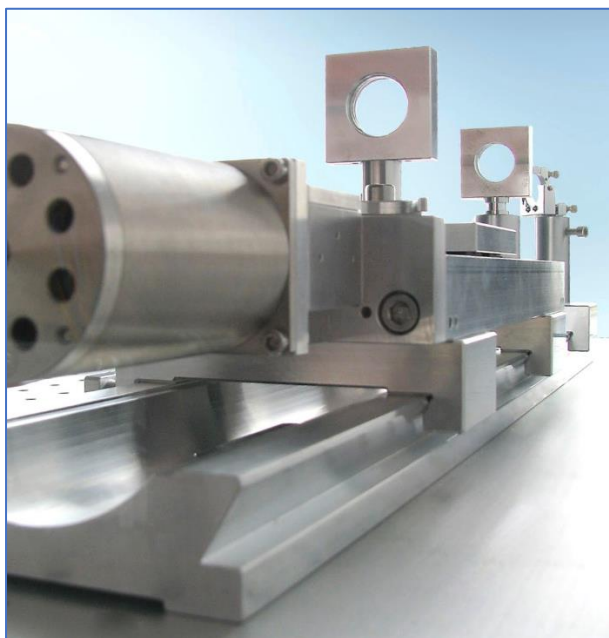
Considerations for Motion Control in Vacuum Environments

A Technical Briefing by Dr Mike Soulby,
Photonics Application Specialist,
Pro-Lite Technology Ltd

August 2020

Introduction

Motion control within a vacuum environment is becoming increasingly relevant to wide range of scientific research and industrial applications. A large number of manufacturing processes are now carried out in a vacuum to ensure the highest cleanliness and purity standards of the manufactured products.



The semiconductor industry is one major example of the prolific use of vacuum technology. Ultra-high vacuum conditions and precision motion control technologies are required for the growth and fabrication of devices from detectors and laser

sources, to the production of processor chips that are used in today's modern technology.

It is not only the semiconductor industry; fundamental physics research, such as the work carried out at the Large Hadron Collider (LHC) and other high-energy beamline facilities required ultra-high vacuum conditions to operate successfully.

As new technologies and applications are developed, the need for capable motion control solutions that can operate within a vacuum environment will continue to increase.

Pro-Lite is able to supply vacuum rated motion control products suitable for standard high-vacuum pressures all the way down to extreme ultra-high vacuum pressures of 10^{-11} mbar. Here we consider some of the issues you should be aware of when selecting equipment that will be used within a vacuum environment.

What is a vacuum?

If the pressure inside a vessel or container is reduced below the standard atmospheric pressure, then the inside of that container would be classed as a vacuum. The level of that vacuum depends on how quickly the air can be removed from the vessel and also how easy it is for the container to fill back



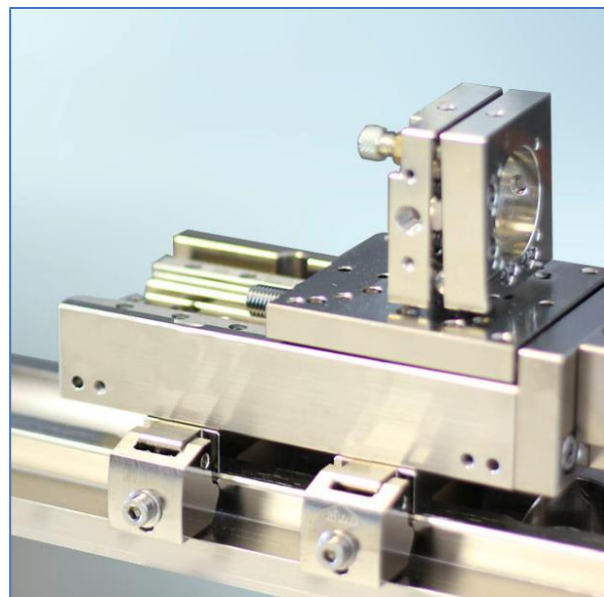
up with air, i.e. are there any leaks or are the materials suitable for use in a vacuum.

Eventually an equilibrium condition will be reached, the final pressure that can be achieved and maintained will define the class of vacuum. There are four main vacuum classes that you will encounter: low vacuum (also known as a rough vacuum), high vacuum (HV), ultra-high vacuum (UHV) and extreme ultra-high vacuum (XHV).

Vacuum class	Pressure (mbar)
Atmospheric pressure	1013.25
Low / rough Vacuum	10^{-3}
High Vacuum (HV)	10^{-6}
Ultra-High Vacuum (UHV)	10^{-9}
Extreme Ultra-High Vacuum (XHV)	10^{-11}

Outgassing

One of the most important considerations when working in a vacuum is outgassing. Outgassing is the release of gas trapped within, or the evaporation of, material from a solid when it is subjected to heat or vacuum pressures.



Outgassing is undesirable within photonics vacuum applications as the released material can condense onto optical elements, in some cases causing permanent damage to precision optical surfaces.

The release of gas and other particulates can also limit the ultimate pressure that a vacuum chamber can reach. This can have negative consequences, particularly if a long mean free path is required for an application, such as optical coating or semiconductor growth and fabrication. A high outgassing rate will decrease the mean free path and increase the likelihood of collisions with unwanted gas molecules, leading to contamination and impurities in the optical coating or final sample material.

Outgassing from equipment when used in a vacuum can often be attributed to one of the following reasons:

- Moisture
- Release of gas molecules from the surface or from within the material.
- Trapped gas pockets, e.g. behind blind screw holes.
- Greases and lubricants
- Paint and adhesives



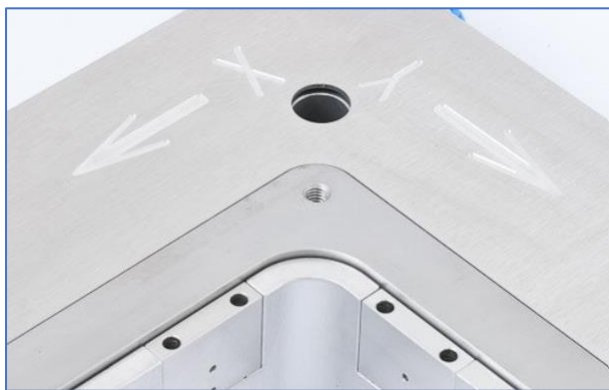
Reduction of outgassing from materials is vitally important for improving the overall vacuum environment and final pressure that can be achieved. There are several key approaches to reduce the outgassing rate:

- Use of vacuum compatible materials, adhesives, and lubricants.
- Thorough bake-out process
- Design considerations to reduce trapped air pockets
- Cleanliness and packaging

All these aspects need to be carefully considered if you are selecting motion control equipment that is to be used in a high-vacuum environment.

Material Selection

To ensure that you can safely and confidently use motion control equipment within a vacuum environment, the materials, components and accessories need to be suitable for vacuum use.



Many vacuum motion control stages are made from bare, unanodised, 6061 aluminium. It is often the most cost-effective material and can be used down to pressures of 10^{-6} . For HV and UHV vacuum classes, series 300 or 400 stainless steel is the commonly used. It also has a lower coefficient of thermal expansion than aluminium, so will more closely match any thermal expansion of bearings and guides. This allows the bearings to run smoothly with the correct pre-load and minimal

backlash during any temperature variations due to motor heating or application processes.

Other materials such as copper, nickel, titanium, and ceramics can also be employed effectively within a vacuum environment. However, the following materials should be avoided due to their high outgassing rates: plastics and PVC cable sheaths, elastomers, paints and adhesives. Anodised aluminium and alloys of aluminium with a high zinc content should also be avoided.

Look for information on the lubrication used. You should make sure that the stage uses a low vapour pressure grease, to minimise the outgassing of damaging hydrocarbons, which can have a serious impact on any optical surfaces in your system. Solid greases with extremely low vapour pressures are available for the most demanding vacuum applications.

All cables should be sheathed in non-PVC materials, such as Teflon. It is also important to only include the absolute minimum number of cables and connectors required to operate the motion system in order to help keep costs down.

Vacuum Bake-out

Vacuum bake-out is the process of using elevated temperatures inside a vacuum to remove any volatile material from the motion control stage materials before it is commissioned into its final application.

The bake-out process helps to drive out any trapped gas or moisture from the materials, it effectively accelerates the outgassing process for the period that it is at an elevated temperature.

Depending on the materials used the bake out process can last anything from a few hours to over a day; it is often carried out at temperatures ranging from about 80°C up to 200°C.



New vacuum compatible motion control equipment will have undergone a bake-out process during manufacture; however, it is often necessary to carry out your own further bake-out cycle prior to final use. Details of this further bake-out cycle should be given in any user literature that accompanies the product.

Design considerations

The most common cause of trapped air pockets is due to blind tapped screw holes. The screw hole design should be changed to a through-hole design where possible. This will allow the gas trapped behind a screw to escape during vacuum pumping. If it is not possible to accommodate a through-hole in the design, then the alternative is to use a vented fastener or screw. A vented fastener typically has a hole drilled axially and centrally through it to allow any trapped gas to escape from the space behind it.

You should check with the manufacturer that the motion control stage uses through holes and vented fasteners to help minimise the number of trapped gas pockets that could potentially outgas when under vacuum conditions.

Cleanliness and packaging

Another way to reduce the possibility of outgassing and contamination in a vacuum environment is to ensure that the strictest cleaning standards are maintained from assembly to final packaging.



Prior to assembly all metallic components should be thoroughly cleaned in an ultra-sonic bath and wiped clean with solvents, such as acetate and isopropyl alcohol, and allowed to air dry. All of this should be carried out in a clean room or clean chamber to minimise the risk of contamination.

Cleaning is designed to remove debris, soiling and surface coatings. It is also used to dissolve oil and grease from mechanical components such as lead screws, prior to the application of a more suitable vacuum compatible lubricant.

Care is also needed when handling vacuum compatible equipment to avoid fingerprints, hair and human skin cells being left on the equipment. Every precaution should be taken to minimise the risk of contamination.

The assembled vacuum motion control stage should be sealed in an airtight vacuum package,



securely sealed to ensure no moisture or air can reach the stage during transportation or storage. Typically, equipment will be sealed within two vacuum packages, further minimising the risk of contamination during transportation.

Heat management withing a vacuum

There is an increasing need to mount vacuum compatible motion control stages within the vacuum environment, rather than use the long-established method of using sealed drive couplers with the motor mounted externally to the vacuum chamber. Having the motor within the vacuum chamber has several advantages including, improved accuracy, backlash and resolution due to elimination of long drive linkages and being able mount directly onto the stage or motor.

However, one major disadvantage of internally mounted vacuum motors is the potential for the motor to dangerously overheat. Conventional non-vacuum rated motors are primarily cooled through convection into the air and through conduction into any surface the motor or stage is in contact with. In a vacuum environment convection is not possible and if there is insufficient heat extraction through conduction the motor it can overheat causing damage to the motor or even the application.

It is desirable to use motors that minimises any generated heat whilst having efficient heat sinking features. One method to prevent heat build-up is to run the motor on a reduced drive or duty cycle, by reducing the amount of time that a motor is running continuously giving the system time for the heat to be extracted. For example, running at a 50% duty cycle would mean the motor is only running half the time significantly reducing the heat generated. There are some drawback to this approach, such as reduced velocity, driving force and continuous running time.

In most case a ultra-high vacuum environment motor will require a combination of careful motor placement and mounting to ensure efficient heat extraction, carefully designed motors and intelligent drive regimes to minimise and remove any excess heat allowing it to run smoothly and safely.

Vacuum compatible products from Pro-Lite

Pro-Lite represents several suppliers that offer motion control stages and positioners for use in vacuum environments. With a wide selection of high-quality options, we are confident that we can support you in finding the right solution for your application.

OWiS – Vacuum Rated Optical Beam Handling and Positioning Systems

The vacuum product from OWiS vacuum line includes manual and motorised linear stages as well as optical components, rails and slides. Customised solutions are also possible, please contact us for more information.



OWiS can offer motion control solutions that cover the entire range of vacuum pressures from



low/rough vacuum down to extreme ultra-high vacuum pressures (10^{-11} mbar).

Manufactured in OWiS' own clean rooms all the materials are carefully selected, and only vacuum compatible materials including special aluminium alloys, special guides, couplings, ceramics and greases are used. For the most demanding applications special nickel-plated aluminium components are used.

The vacuum products are baked out at approximately 80°C and tested after a heating cycle of a of 12 hours. A mass spectrum of 0 to 100 a at a pressure of $<10^{-7}$ mbar confirms that any residual gas peaks are minimised.

For more information please visit

https://www.pro-lite.co.uk/File/opto-mechanics_overview.php

Piezosystem Jena – Piezo Nano Positioning

Piezosystem Jena offer piezo micro positioning, piezo nano positioning and metrology solutions. Many of their product options are available in vacuum compatible versions.

Piezoelectric actuators and stages for vacuum applications are produced from materials with low outgassing characteristics. Multilayer stacks with new insulation materials produce very low outgassing behaviour and a well suited to ultra-high vacuum applications.



Cables and connectors are made with Teflon, Polyimide or Kapton insulation which naturally do not outgas and will work well under different vacuum conditions, even down to ultra-high vacuum pressures.

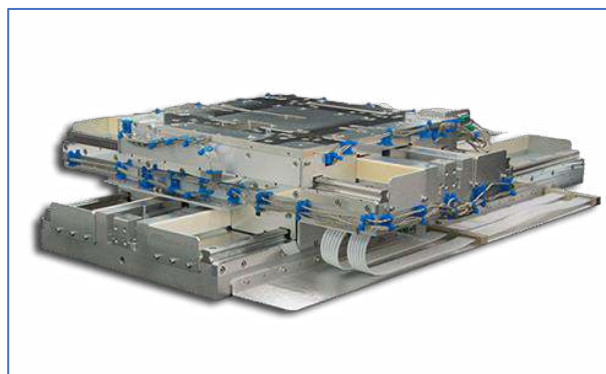
For more information please visit

https://www.pro-lite.co.uk/File/psj_piezoelectric_nanopositioning.php

Nanomotion – Ultrasonic piezo motors and stages

Nanomotion's line of ultrasonic piezo motors are available in a wide variety of sizes and options suitable for environments from standard atmospheric pressures down to ultra-high vacuum pressures and beyond.

Nanomotion motors can facilitate high duty cycle and heavy-duty operation even in ultra-high vacuum environments due to efficient heat dissipation through the ceramic fingers and intelligent duty cycle management permitting longer continuous running cycles.



The motors have been proven in several demanding vacuum applications for the semiconductor industry, including micro-stages to a large 300 mm wafer inspection stage. They have also been employed in space rated application in low Earth orbit (LEO) for use in super-resolution ground imaging and communication.



For more details please visit

[https://www.pro-
lite.co.uk/File/nanomotion_piezo_motors.php](https://www.pro-lite.co.uk/File/nanomotion_piezo_motors.php)