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DESIGN NOTE

Design of a non-magnetic translator for use in vacuum systems

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Abstract
A translator which is fully vacuum compatible is described. The translator uses completely non-magnetic components, and can therefore be used in experiments where a magnetic field cannot be tolerated, such as in high-resolution electron spectrometers. All construction components are UHV compatible, and can be baked at over 200 °C without failure.

Keywords: in-vacuum translator, electron spectrometer, xyz-translator, vacuum component

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1. Introduction

Many experiments carried out in vacuum chambers require fine adjustment of the position of components inside the chamber. This can sometimes be accomplished by using external feedthroughs or in-house stepper motors[1,2]; however, for many experiments these methods are not appropriate. In particular, for experiments that must minimize external or internal magnetic fields, the use of in-vacuum motors is impossible due to their large residual field.

Experiments with electron spectrometers are particularly susceptible to magnetic fields, and so cannot employ internal motorized translators. It is also often difficult to use external feedthroughs or manipulators, as many experiments require the component to be moved while under vacuum [1, 2]. Difficulties are often found when attempting to align elements of the experiment inside the vacuum chamber, many components being aligned iteratively before being secured to the chamber prior to pumping the system down. This can often be very difficult and time consuming, as components such as electron guns, electron analysers, photomultiplier tubes and atomic beam nozzles must be aligned with submillimetre accuracy [3–6]. It is therefore of benefit to employ an accurate alignment stage which can be deployed inside the chamber without compromising the integrity of the vacuum, which does not produce magnetic fields and which is easy to use.

The usual method adopted to adjust a component (such as a lens) external to a vacuum chamber is to use a high-resolution xyz-translator upon which the component is secured, thereby allowing accurate control of the position. These translators are routinely employed in optical and laser-based experiments, and most optical component distributors can supply extremely accurate adjusters for this purpose[3,4]. These adjusters usually employ ball or crossed roller bearings, and can provide interferometric accuracy and reproducibility.

Unfortunately, commercially available translators invariably use magnetic components in their manufacture, and also employ grease to lubricate the bearings. Neither of these construction methods is compatible with the experiments described above. It is therefore necessary to consider a method of providing accurate translation inside the vacuum chamber

1 Thermo Vacuum Generators, Maunsell Road, Hastings, UK (www.vacgen.com).
2 Caburn-MDC Ltd, The Old Dairy, The Street, Glynde, East Sussex, BN8 6SJ, UK (www.caburn-mdc.co.uk).
3 Newport Corp., 1791 Deere Avenue, Irvine, CA 92606, USA (www.newport.com).
4 Melles Griot Corp. 2051 Palomar Airport Road, Carlsbad, CA 92009, USA (www.mellesgriot.com).

without the use of lubrication and without the use of magnetic materials. Further, since many vacuum chambers are baked at temperatures in excess of 200 °C to improve the vacuum, it is desirable for the in-vacuum translator to be bakable at these temperatures over long periods without failing.

The translator described here allows these criteria to be met, by adopting materials which are non-magnetic, and by designing a bearing which does not require lubrication. The materials used include non-magnetic stainless steel, phosphor–bronze, ceramic and ruby. All components can be individually baked at temperatures in excess of 400 °C, but the translator uses non-magnetic phosphor–bronze springs which relax at temperatures above 230 °C, and this limits the bake-out temperature that can be employed.

2. Design of the translator

The requirement for a non-magnetic, vacuum-compatible translator that can be baked severely restricts the range of materials that can be used. A number of different non-magnetic materials can be employed, but it was decided to use 310-grade stainless steel for most components of the translator as this is used in many high-resolution electron spectrometers, is relatively easy to obtain and is hard wearing. Also, 310-grade stainless steel is far superior to 304-, 316- or 316LN-grade steels as it has a much lower magnetic susceptibility, and so can be used close to an electron beam without causing significant deviation. Further, unlike copper or aluminium, the surface remains clean, does not oxidize significantly after repeated expose to air, and remains conductive. Stray electric fields due to the charging up of patch surface contamination on the steel can be minimized by adopting clean conditions when the system is open to air, and by baking when under vacuum; 310-grade stainless steel is much easier to machine than either molybdenum or titanium, which could also be used, and is far cheaper than either of these materials.

Other materials that are used in the construction of the translator described here are phosphor–bronze, ceramic and ruby. Phosphor–bronze is a useful material in vacuum systems as it is non-magnetic and hard wearing. As such, this material is often used for in-vacuum gear assemblies inside electron spectrometers [3]. When treated correctly as described below, phosphor–bronze wire can also be used to manufacture non-magnetic springs, and it is this application that is employed here to provide the restoring force for the translator.

The final two materials used in the translator are ground ceramic rods and ruby balls. These materials are used to construct the bearings for the translator, and it is their hardness and finish that allow the bearing to perform smoothly without the need for lubrication. Ruby balls are relatively cheap, are manufactured to exacting tolerances and come in a range of diameters[5]. Ground ceramic rods are also easy to obtain, come in a range of lengths and diameters and are available from a number of manufacturers[6].

The design of the translator is shown in figure 1. The translator is based on proven designs incorporated in optical translators, with a number of changes being made principally to the bearing mechanism. The translator uses a base made of 310-grade stainless steel (A) which can be secured to the vacuum chamber via a number of M3 counter-bored clearance holes (B). A 10 mm diameter hole (C) is located centrally in the base so that light from a laser beam can pass through. Two 310-grade stainless steel side arms (D) are secured to the base using M2 screws (E). One of the side arms uses a clearance slot so as to allow the side arms to secure firmly the bearings in the assembly. These side arms locate two ground ceramic rods (F) which act as the stationary side of the bearing cage. Ground ceramic rods are used for the bearing cage as this reduces the necessity to grind the internal surfaces of the side arms accurately, which is difficult without specialized tools. Further, the hardness of the ceramic rods makes them extremely resilient to wear from the ruby balls (G) which are used in the bearings.

The sliding mechanism (H) of the translator is also constructed from 310-grade stainless steel, and is machined so as to have a 1 mm clearance from the base. The sides of the slide are constructed in a similar manner to the side arms, so that the ceramic rods (F) can act as the rolling side of the bearing cage. The slide comprises a number of M3 tapped holes (Q) arranged in an array so that components can be secured onto the top of the slide. A 10 mm diameter hole is also located centrally in the slide so that laser beams can pass through both the baseplate and slide.

The slide is machined so that the ceramic rods (F) are secured within the slide once the translator is assembled. This is achieved by machining the ends of the slide so as to act as a securing plate (I). It is necessary to secure the ceramic rods within the slide to prevent them moving when the slide assembly translates.

Centrally located blind holes (J) of diameter 3.5 mm are machined 14.5 mm into the top of the slide as shown in figure 1. These holes house two phosphor–bronze springs which are loosely constrained by two ground ceramic rods (K) 2 mm in diameter. The springs act to provide the restoring force to maintain the position of the slide as the adjustment screw (L) is rotated.

The restoring springs are made from 0.5 mm diameter phosphor–bronze wire which is tightly would onto a 2 mm diameter former. The phosphor–bronze springs are then stretched so that the distance between helixes of the spring is around 2 mm, and so that the springs slide smoothly on the 2 mm diameter ceramic guide rods. The springs are then fired in an oven at a temperature of 250 °C for 30 min, at which time they are slowly cooled back to room temperature over a period of 60 min. This annealing process improves the elasticity of the springs, and allows them to be stretched and compressed many times without causing a significant change in their natural length. A ceramic guide retainer plate (M) is attached to the baseplate via 2 mm A4 screws to prevent the springs and guide ceramics from pushing out of the translator when under tension.

Adjustment of the position of the translator slide is accomplished using the adjustment screw (L). The bush assembly (N) is constructed from phosphor–bronze, whereas the screw (L) is constructed from 310-grade stainless steel. Dissimilar metals are used to prevent vacuum welding at the

[5] Swiss Jewel Company, 325 Chestnut Street, Constitution Place, Philadelphia, PA 19106, USA (www.swissjewel.com).

[6] see e.g. Frialit-Degussit, Postfach 71 02 61, D-68222 Mannheim, Germany (www.degussit.co.uk).

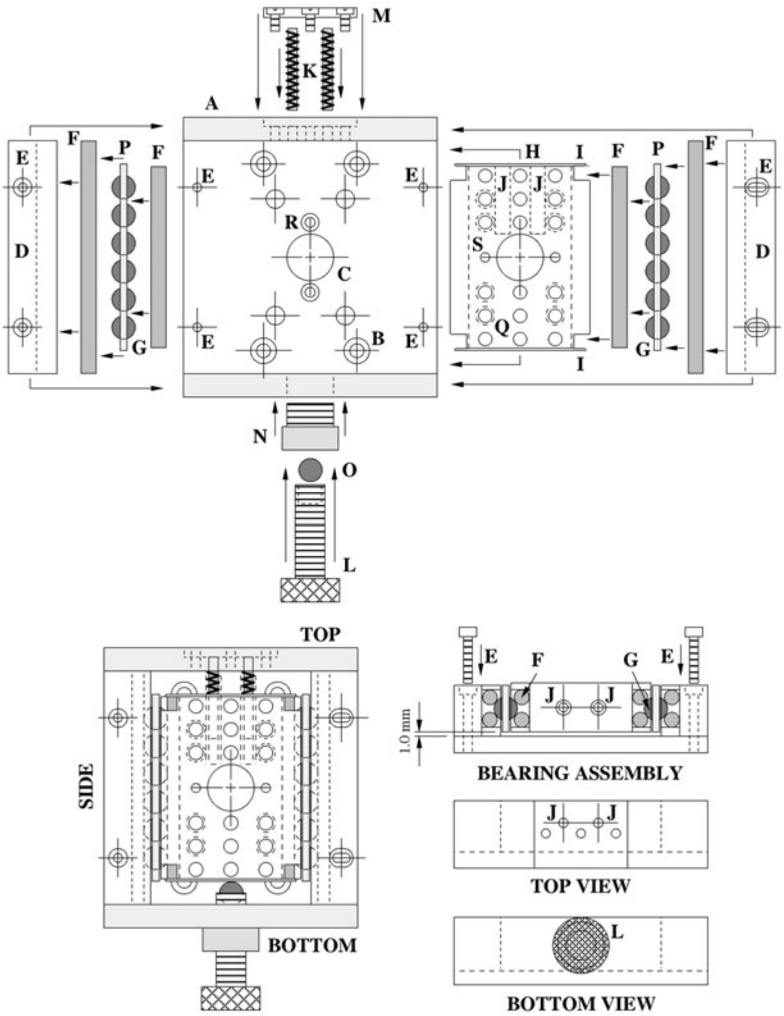

Figure 1. The translator detailing the individual components (A–S) as an exploded view, and showing the full assembly, bearing assembly and top and bottom view. For details, see text.

interface. The screw and bush use a fine pitch of 40 threads per inch to allow accurate movement of the slide when the screw is rotated. The screw thread is coated with colloidal graphite[7] prior to assembly, and the screw is then heated to $>100\,^{\circ}\mathrm{C}$ so as to secure the graphite onto the surface. The thread is then polished so as to unify the graphite on the surface of the stainless steel, and to allow a smooth motion of the adjustment screw. The end of the screw which pushes on the slide has a 5 mm diameter ruby ball (O) located in its end, so that there is only a single point of contact with the slide as the adjustment screw rotates.

The translator bearings comprise two sets of six ruby balls (G) 5 mm in diameter which are separated from each other by 1 mm using a phosphor–bronze ball race (P). The ruby balls locate on the four ceramic rods in each bearing housing. Since the balls rotate on all four ceramic rods located in both the side plate and slide, the ball-race assembly moves at half the speed of the slide. The total displacement of the slide is 10 mm, and so the ball race moves 5 mm during translation. By using six balls 5 mm in diameter equally spaced on either side of the assembly, the slide can travel its full displacement while maintaining continuous and uniform contact between the ruby balls and ceramic rods.

The apparatus is designed so that it can be easily assembled as an x-, xy- or xyz-translator as shown in figure 2. M2 clearance holes (R) in the baseplate are used to secure the y-translator onto the x-translator slide (S) as shown. A z-translator can then be attached by removing the M2 screws in the ceramic guide retainer plate (M) on the z-translator, and using M2 screws which pass up through the slide in the y-translator (Q) to locate into the tapped holes in the z-translator baseplate.

3. Assembly of the translator

Assembly of the translator is relatively straightforward. The components are thoroughly cleaned in an ultrasonic bath using soapy water to remove grease, and are then rinsed in water prior to being cleaned in methanol once more in the ultrasonic bath. The parts are dried using a hot-air gun, and are inspected to ensure that no residue is left on the ceramic rods and ruby balls. The adjustment screw is then coated in colloidal graphite as described above.

The fixed side arm is initially attached to the baseplate, and the translator is placed on this side. The ceramic rods,

[7] Acheson, 1600 Washington Avenue, Port Huron, MI 48060, USA (www.achesonindustries.com).

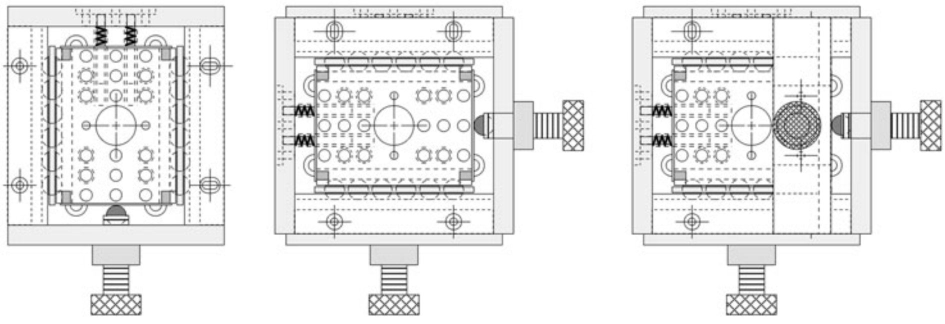

Figure 2. The translator configured as an x-, xy- and xyz-translator.

ruby balls and ball race are located into the fixed side plate and the slide is positioned so as to push against the ruby balls in the fixed side arm. The assembly is then placed horizontally and the second set of ruby balls, ball race and ceramic rods are positioned between the slide and the second adjustable side arm. The ceramic rods and ruby balls are moved so as to locate correctly within the slide and side arms, the adjustable side arm is moved to take up any sideways movement in the slide, and the side arm is secured to the baseplate. The mechanism can then be checked to ensure that the slide moves freely back and forth along the translator.

Once the slide is assembled correctly, the phosphor–bronze springs and ceramic guides are positioned into the slide and baseplate, and the guide retainer plate is installed. Finally, the phosphor–bronze bush and adjustment screw are attached to the baseplate, and the complete assembly is checked for accurate movement.

It should be noted that all tapped holes are through holes, and all screws used in the assembly of the translator are filed flat on one side. This ensures that no trapped volumes of gas are left in the assembly once the vacuum system is pumped down.

4. Experimental testing

A pair of in-vacuum translators assembled as an xy-translator have been installed in the Manchester (e, 2e) spectrometer for over four months [5, 6]. These translators have been subjected to baking of the system, and have shown no adverse effects due to this. No difference in the ultimate vacuum pressure has been seen with the translators installed, indicating the compatibility of the chosen materials for use under vacuum. More importantly, the translators have shown no sign of seizing after opening and closing the vacuum chamber many times over this period. The translators are found to operate as well after this period of time as they did when first installed.

5. Conclusion

A non-magnetic translator has been described which can be used inside vacuum chambers for accurate alignment of internal components prior to closing the chamber. The translator uses materials which are readily obtainable, does not require high-accuracy machining or grinding of components and so can be made on a milling machine in any standard mechanical workshop. The bearing assembly, which is critical for accurate movement, adopts the use of ground ceramic rods and ruby balls to ensure that the bearings operate smoothly without the need for lubrication. The translator uses UHV-compatible materials throughout, and has been tested at vacuum pressures down to 2×10^{-8} Torr. Although not tested under UHV conditions, the translator is expected to operate well under these conditions since it can be baked at temperatures up to 200 °C, all materials have low outgassing rates and there are no trapped gas volumes in the design. It is expected that this translator design will find many applications in experiments ranging from electron spectroscopy through to surface science experiments, where accurate and reproducible alignment of internal components in the vacuum chamber is essential.

A complete set of CAD drawings is available for this translator as a pdf file by linking to the electronic version of this document.

Acknowledgment

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