INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 4 : G02B 7/00, G01J 3/06 G03F 9/00, B23Q 1/16 H01L 21/68

(11) International Publication Number: WO 88/09945
(43) International Publication Date: 15 December 1988 (15.12.88)

(21) International Application Number: PCT/GB88/00433
(22) International Filing Date: 3 June 1988 (03.06.88)
(31) Priority Application Number: 8713050
(32) Priority Date: 4 June 1987 (04.06.87)
(33) Priority Country: GB

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(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent), US.

Published
With international search report.

(54) Title: POSITIONING APPARATUS PARTICULARLY FOR USE IN A VACUUM ENVIRONMENT

(57) Abstract

The invention provides a positioning apparatus for accurately positioning one part of a device relative to another and is designed to be vacuum compatible for use in vacuum chambers at ultra-high vacuum. To achieve this, no lubrication is allowable on relatively movable parts so that all sliding contact at relatively movable surfaces must be avoided. The preferred embodiment is for use in rotating a diffraction grating inside a Cerny-Turner monochromator at ultra-high vacuum. A linear piezo electric INCHWORM translator (60) is used inside the vacuum chamber to drive an output member (64) in very small incremental steps with very high accuracy. A tape (61) is used to transmit the linear motion of the output member into rotary motion of the diffraction grating support (53). This is achieved by wrapping the tape around a cylindrical support (58) of the diffraction grating and attaching both ends of the tape via a tensioning device (65) to the output member (64) giving slip-free transmission of motion. A flexural pivot (48, 49) is used for supporting the cylindrical support from fixed structure to allow the rotation of the support without sliding of backlash. A detector e.g. an opto-electronic scale reader (74) reads the position of the rotary support directly from a tape scale (73) wrapped around it to provide an indication of the movement of the grating.
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POSITIONING APPARATUS
PARTICULARLY FOR USE IN A VACUUM ENVIRONMENT

The present invention relates to positioning apparatus for positioning a movable part of a device relative to a fixed part thereof.

Many actuators are available for accurate positioning of a movable part relative to a fixed part. Many suffer to greater or lesser degrees from inaccuracies related to friction between relatively movable contacting surfaces which give rise to stick-slip phenomena and a requirement for lubrication. Other inaccuracies stem from manufacturing tolerances which give rise to backlash and a lack of precision in the positioning of the movable part.

Very few actuators or measuring devices can operate in conditions of high vacuum. There is a problem in providing apparatus for precisely positioning a worktable or like component in conditions of high vacuum because hitherto the actuation devices have been operated externally of the vacuum chamber, and have involved considerable force to transmit the actuation loads into the vacuum. Known mechanisms have limited accuracy and suffer from hysteresis due to backlash in the linkages required to transmit the motion from the outside to the inside of the chamber.

The problem is aggravated in positioning apparatus for operation in ultra-high vacuum (i.e. pressures in the region of $10^{-9}$ millibar) because of the need to lubricate relatively sliding surfaces of the known devices which
produces contamination of the remaining atmosphere in the 
vacuum from the lubricant.

In accordance with the present invention there is provided 
a positioning apparatus for positioning a movable part of 
a device relative to a fixed part thereof comprising:

drive means for producing an output in the form of 
movement of a driven output member,

transmission means for connecting the driven output 
member to the movable part and for transmitting said 
movement of the driven output member to the movable 
part,

support means for supporting the movable part from 
said fixed part while allowing said movements to be 
transmitted to the movable part,

and wherein all relative movements between relatively 
movable components of the drive means, the transmission 
means and the support means take place without relative 
sliding motion between any contacting surfaces thereof.

The positioning apparatus of the invention is of general 
application. However, because relative sliding motion 
between any contacting surfaces of relatively movable 
components of the apparatus is eliminated, the apparatus 
is vacuum compatible, and has particular application to 
devices which require positioning of a movable member 
accurately in a high vacuum environment. Thus 
applications for the positioning apparatus can be found in 
vacuum chambers of devices used, for example, in 
semi-conductor manufacturing processes in which masks must 
be positioned accurately on silicon chips in a high vacuum 
environment, or in monochromators for use in devices 
utilising electromagnetic radiation or charged particles,
for example, spectrometers or synchrotons.

The drive means may be disposed externally of the vacuum environment and the support means may include a magnetic or electro-magnetic coupling to levitate the movable part of the device. In this case the transmission means may also be electro-magnetic whereby there is no contact at all between the drive means and the movable part.

In the preferred form of the invention however, the drive means is disposed within the chamber.

The drive means may provide a rotary or linear movement which may be continuous or stepped.

Also in accordance with the present invention there is provided vacuum compatible positioning apparatus for use with a device including a vacuum chamber and for accurate angular positioning of a rotatable part of the device relative to a fixed part thereof within the chamber said apparatus comprising:

support means for supporting the rotatable part of the device from the fixed part for rotation about an axis,

drive means for producing an output in the form of linear movement of a driven output member,

transmission means for positively connecting the driven output member to the rotatable part and for producing an amount of rotational movement of the rotatable part which is directly equivalent to the linear movement of the driven output member,

and wherein all of the support means, the drive means and the transmission means are contained within the vacuum chamber and all relative movements of components thereof
take place without relative sliding motion between any contacting surfaces of said components.

For operation in ultra-high vacuum all of the movable components of the apparatus may thus be lubricant free.

A preferred form of vacuum compatible drive means for vacuum operation is an electrically operated stepped linear piezo-electric drive of the type known as an INCHWORM and manufactured by Burleigh Instruments Inc. of U.S.A. which fulfils the requirement of having no relatively sliding movement between any of its relatively movable contacting surfaces and hence requires no lubricant.

Where the movement required in the relatively movable part is rotary, the use of a linear drive means requires that the transmission means must be capable of converting linear movement of the output of the drive means into rotary movement of the movable part.

A preferred form of vacuum compatible transmission means for mounting in a vacuum chamber which converts linear to rotary motion with great accuracy and no lost motion comprises a tensioned tape wound around a cylindrical surface on the movable part, both ends of the tape being connected to the output of the drive means so that the tape rotates the movable part with no sliding between the tape and the movable part. In fact the tape may be fastened to the movable part to ensure that there is no slippage between the tape and surface of the movable part on which it bears.

A preferred form of vacuum compatible support means which allows a limited amount of sliding-free rotation of the rotatable part comprises a flexural pivot having axially separate portions which are fixedly connected respectively
to each of the fixed and rotatable parts of the device and having their axes aligned with the rotational axis of the movable part, said portions being interconnected by a flexible intermediate portion which is capable of twisting about the axis of the pivot member.

The apparatus also preferably includes a detector for determining the movement of the movable part and for providing a signal indicative thereof.

The detector is preferably arranged to determine the actual movement of the movable part rather than the movement of the drive means. Hence in the embodiment which uses a tape transmission to drive a rotatable part of a device a second tape in the form of a graduated scale may be attached to the cylindrical surface and an opto-electronic scale reader may be provided inside the chamber to register the movement of the scale.

Alternatively a laser interferometer may be used to provide accurate measurements of the movement of the output of the drive means and the angle through which the cylindrical surface has moved can then be obtained by calculation.

The invention will now be more particularly described by way of example only, and with reference to the accompanying drawings in which:

Fig. 1 is a schematic plan view of an infra-red spectrometer device including a monochromator which utilises positioning apparatus of the present invention,

Fig. 2 is an exploded view of the positioning apparatus of the invention used for rotating one of the optical components of the monochromator of Fig.1,
Fig. 3 is a plan view on arrow III-III of the apparatus of Fig. 2 with all of the components assembled.

Fig. 4 is a sectional end elevation on the line IV-IV of Fig. 3,

Fig. 5 illustrates the transmission means of the positioning apparatus of Fig 2 which connects the drive means to the movable part, and

Fig. 6 is an enlarged view of the movable part together with the tapes for the transmission means and the encoder of the detector.

Referring now to the drawings, in Fig. 1 the device is of modular construction and comprises a source chamber 1, a main (or sample) chamber 2, and a detector chamber 3. All three chambers are equipped with means (not shown) whereby they can be evacuated to pressure levels in the ultra-high vacuum range (defined above), and optical communication is established between them by means of vacuum-compatible infra-red transmissive windows 4 and 5.

The main chamber 2 simply contains a manipulator 6 on which the sample is to be placed. Infra-red radiation is directed at the sample from the source chamber 1 through the window 4 and the reflected radiation passes through window 5 to the detector chamber 3.

The detector chamber 3 houses a Cerny-Turner monochromator, which is known per se, together with the associated focussing optics and is not therefore described in detail. Briefly however, the arrangement consists of a first optical system including a concave mirror 30 onto which reflected infra-red radiation from the sample is directed, plane mirror 31, a slit 32, plane mirror 33, and concave mirror 34 which co-operate to provide a collimated
beam of light which is directed onto a diffraction grating 35. The radiation from the diffraction grating is focussed through a second concave mirror 36 and a plane mirror 37 and leaves the chamber through a second slit 38 to be focussed onto a detector 39.

The diffraction grating 35 has to be mounted for rotation within the chamber, and the rotation has to be very accurately controlled and measured in order to obtain useful results from the monochromator. Hitherto vacuum levels in monochromators have been limited to relatively low levels of around $10^{-4}$ Torr because of the lack of a vacuum compatible drive system for rotating the table which has the required level of accuracy. The invention in one of its aspects provides such a drive system and thus enables the monochromator to operate at the same ultra-high vacuum conditions as the sample chamber and to achieve the associated benefits as described below.

Referring now to Figs. 2, 3 and 4 the assembly of the support and drive mechanism for the diffraction grating is shown in more detail. The monochromator includes an optical table 40 forming part of the fixed structure and the diffraction grating support assembly, which constitutes a movable part of the device, is attached to the underside of the table 40 by means of screws 41 which screw into a housing 42 of the assembly.

Within a recess 43 of the housing 42 is arranged a swivel block 44 to which the diffraction grating mount 53 is attached by means of screws 45 and a locating spigot 46. The swivel block 44 is supported for rotation on top and bottom flexural pivots 48 and 49 respectively, of the type known as FREE-FLEX (RTM) and supplied by the Electric and Power Division of the Bendix Corporation. Each of the pivots 48, 49 has two axially separate portions 48a, 48b, and 49a, 49b respectively, which are interconnected by a
flexible portion 48c, 49c respectively which allows twisting of the pivot about its longitudinal axis. The top pivot 48 is fitted by press fitting the portions 48a and 48b into suitable aligned holes 50 and 51 in the housing and swivel block respectively. The bottom pivot 49 is fitted by press fitting the portions 49a and 49b into aligned holes 51 and 52 respectively in the swivel block and a closure member 54 which extends across the open end of the recess 43 and is attached to the housing 42 by means of screws 56. The longitudinal axes of the flexural pivots 48 and 49 are thus aligned with the rotational axis of the swivel block. It can be seen that there is no relative sliding between contacting surfaces of the pivots 48, 49 and the surfaces of the holes in the housing, swivel block and closure member. Relative rotation of each pivot to the extent required by the swivel block is allowed by twisting of the flexible portions 48c respectively.

The swivel block itself consists of a circular base 58 and a crescent shaped flange 59 which in the assembled position protrudes from the housing 42 through a crescent shaped slot therein. The diffraction grating 35 which is itself a flat glass square is attached to the mount 53 by clips 55 so that its axis of rotation lies accurately on the rotation axis 58a of the swivel block.

The swivel block is rotated by means of a transmission system which is positively connected to the output member of a drive means so as to ensure that there is no lost motion between the two. Thus the amount of rotation of the swivel block is directly equivalent to the movement of the output member of the drive means. Movement of the base is measured by an encoder 70 which is described in more detail with reference to Fig. 6.

Referring now to Fig. 5 the transmission system consists
of a stainless steel tape 61 of a fixed length connected between a pair of brackets 62 and 63. The two brackets are carried by a plunger 64 which constitutes the output member of the drive means 60, which is a piezo-electric linear translator of the type sold under the trade name INCHWORM by Burleigh Instruments Inc. The precise length of the tape and the tension to be applied thereto is controlled by a spring 65 which separates two parts 67 and 68 of an extension 66 attached to the plunger and carrying the bracket 63. The tape is wrapped around the circular base 58 of the swivel block, and it can be seen from the Figure that any translational movement of the INCHWORM will move both brackets 62 and 63 together thus rotating the swivel block about the axis 58a.

One form of encoding device suitable for low vacuum application is that sold under the trade designation EN-830 by Burleigh Instruments Inc. and as can be seen in Fig. 6 it is connected to a second stainless steel tape wrapped around the circular base 58. The second tape 71 is connected to the encoder by a tensioning system exactly like the tensioning system of the INCHWORM including a plunger attached to a two part extension which includes a spring tensioner. Thus rotation of the swivel block by the INCHWORM will cause longitudinal movement of the plunger of the encoder which is measured by the encoder to provide a signal indicating the amount of rotation of the diffraction grating.

As shown in Fig. 6 each of the tapes 61,71 are provided with a narrow portion 61a,71a and a slotted portion 61b,71b through which the narrow portion extends so that they can overlap on the base 58 to completely surround it, and the tapes are attached to the base 58 by screws 61c,71c.

Since the INCHWORM can move forwards or backwards in very
small and extremely accurately determined steps of about 10 nanometers with virtually insignificant backlash, and since there are no bearings requiring lubrication in the above described drive, transmission and support mechanism for the diffraction grating, the complete positioning apparatus is vacuum compatible and can operate within the ultra-high vacuum environment of the monochromator and convert the precise linear motion of the INCHWORM to equally precise angular motion of the diffraction grating.

The advantages gained by use of a tape under constant tension in the transmission system are that there is a balanced moment about the pivot axis, and the motion is backlash free. Thus the swivel block rotates about its axis 58a with substantially zero transverse centre shift and there is no lost motion between the Inchworm output and the rotation of the diffraction grating. Thus the grating can be positioned with extremely high accuracy.

For operation in high and ultra-high vacuum however, the detector required to determine the movement of the grating has to be of a type having no lubricated parts. A suitable detector includes a metallic tape scale for example as described in our international application published under number WO88/00331 in association with an opto-electronic scale reader made from ultra-high vacuum compatible materials. Such a detector is shown diagrammatically in Fig. 3 wherein the tape 71 and encoder 70 are replaced by a tape scale 73 and a scale reader 74.

Alternatively a laser interferometer may be used to detect the motion of the INCHWORM output.

Electrical connections to the INCHWORM and encoder, and fibre-optic cables required for use with an opto-electronic scale reader or interferometer can be made through a conventional vacuum seal so that once evacuated the apparatus can work for long durations without
attention.

By being able to operate the whole system in the ultra-high vacuum environment the following benefits are achieved.

1. Thermal interference to the light source is minimised; and the life of the heated element is significantly increased.

2. Interference from the residual gas surrounding the light source, the sample and the detectors is minimised.

3. All three chambers may be evacuated to the same level of vacuum so that the windows between the chambers may be eliminated, thus further reducing signal degradation and enhancing sensitivity.

4. If the windows are retained, the additional option is available for pressurising the sample chamber while still operating the light source and detection system at ultra-high vacuum thus increasing the flexibility of the system. Since the chambers are isolated the pressure in the sample chamber can be changed without affecting the pressures in the other two chambers.
CLAIMS:

1. Positioning apparatus for positioning a movable part of a device relative to a fixed part thereof, said apparatus comprising:
   drive means for producing an output in the form of movement of a driven output member,
   transmission means for connecting the driven output member to the movable part and for transmitting said movement of the driven output member to the movable part,
   support means for supporting the movable part from said fixed part while allowing said movements to be transmitted to the movable part,
   and wherein all relative movements between the relatively movable components of the drive means, the transmission means and the support means take place without relative sliding motion between any contacting surfaces thereof.

2. Positioning apparatus as claimed in claim 1 and wherein the positioning apparatus is arranged to rotate a rotatable part of the device relative to a fixed part, the drive means provides an output in the form of linear movement of the driven output member, and the transmission means converts the linear movement of the driven output member to rotary movement of the rotatable part of the device.

3. Positioning apparatus as claimed in claim 1 and wherein the drive means comprises a piezo-electric translation device.

4. Positioning apparatus as claimed in claim 2 and wherein the transmission means comprises a tape and tensioning means therefor, both ends of the tape being connected to the driven output member of the drive means and the remainder of the tape being wound around the
movable part.

5. Positioning apparatus as claimed in claim 2 and wherein the support means comprises at least one flexural pivot having an axis extending in the direction of the axis of rotation of the movable part of the device and including axially separate portions which are fixedly connected respectively to the fixed part and the movable part of the device and which are interconnected by a flexible intermediate portion which is capable of twisting about the axis of the pivot member.

6. Positioning apparatus as claimed in claim 5 and wherein a pair of pivot members are used spaced along the axis of rotation of the movable member, each of which has a portion fixedly connected to the movable part of the device, and a portion fixedly connected to a portion of the fixed part of the device.

7. Positioning apparatus as claimed in claim 1 and wherein a detector is provided for determining the amount of movement of the movable part of the device and for providing a signal indicative thereof.

8. Positioning apparatus as claimed in claim 7 and wherein the detector comprises a scale in the form of a scale provided on the movable part of the device and a scale reader for reading the movement of the scale.

9. Positioning apparatus as claimed in claim 8 and wherein the movable part of the device is rotatable and is provided with a cylindrical surface, the scale being in the form of a tape wound around the cylindrical surface.

10. Vacuum compatible positioning apparatus for use with a device including a vacuum chamber, and for accurate angular positioning of a rotatable part of the device
relative to a fixed part thereof within the vacuum chamber, said apparatus comprising:

- support means for supporting the rotatable part of the device from the fixed part for rotation about an axis,
- drive means for producing an output in the form of linear movement of a driven output member,
- transmission means for positively connecting the driven output member to the rotatable part for causing an amount of rotational movement of the rotatable part which is directly equivalent to the movement of the driven output member,

and wherein all of the support means, drive means, and transmission means are contained within the vacuum chamber, and all relative movements of components thereof take place without relative sliding motion between any contacting surfaces of said components.

11. Positioning apparatus for angularly positioning a rotatable part of a device relative to a fixed part thereof, said apparatus comprising:

- drive means including an output member, for producing sliding-free linear motion of the output member,
- transmission means positively connecting the output member to the rotatable part in sliding-free manner for causing an amount of rotation of said part which directly corresponds to the amount of linear motion of the output member,

- and support means having portions fixedly connected respectively to each of the rotatable and fixed parts of the device, and having a flexible portion which allows said rotation of the rotatable part.
# INTERNATIONAL SEARCH REPORT

**International Application No** PCT/GB 88/00433

## I. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both National Classification and IPC

**IPC**: G 02 B 7/00; G 01 J 3/06; G 03 F 9/00; B 23 Q 1/16;

**H 01 L 21/00**

## II. FIELDS SEARCHED

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## III. DOCUMENTS CONSIDERED TO BE RELEVANT

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* "Z" document member of the same patent family

## IV. CERTIFICATION

**Date of the Actual Completion of the International Search**
8th September 1988

**Date of Mailing of this International Search Report**
30 SEP 1988

International Searching Authority
EUROPEAN PATENT OFFICE

[Signature of Authorized Officer] P.C.G. VAN DER PUTTEN

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