Abstract: A highly position-stabilized indexable table or “dial” in which the dial is supported relative to a steel surface on a frame by one or more air bearings. A flexure mechanically connects the indexing motor to the dial in such a way as to be torsionally non-compliant, but axially compliant to decouple the dial from the motor shaft along the Z-axis. In one embodiment, the air bearings are mounted to the frame at uniformly angularly displaced positions under the dial. In another embodiment, the bearings are partially integrated into the dial. Negative (suction) preload can be used in either embodiment to increase air bearing stiffness and/or to allow inverted processing; i.e., mounting part fixtures on an undersurface of the dial.
ROTARY FLEXURE AND AIR BEARING
SUPPORT FOR ROTARY INDEXING SYSTEM

FIELD OF THE INVENTION
[0001] This invention relates to supports, commonly called "dials", for precisely indexing fixtures for workpieces in and out of processing stations, such as laser drilling stations, and more particularly to a dial support system that protects a dial against out-of-plane excursions while at the same time relaxing the performance specifications of the bearings associated with the dial indexing motor.

BACKGROUND OF THE INVENTION
[0002] It is known to use rotatable dials to index workpieces in and out of processing stations, such as laser drilling stations, where precise control over the location of the workpiece is required. The dial is typically circular and has a central, vertical axis of rotation, referred to as the "Z-axis". A motor is mounted to index a table supporting the workpieces on command. The frame typically includes a dimensionally stable surface underlying the table.

BRIEF SUMMARY
[0003] In conventional rotary indexers, the mass of a dial is supported by bearings of the indexer motor. Large, expensive and highly precise indexer motor bearings are required to protect the dial against out-of-plane excursions. That is, the dial is mounted to minimize play in the thrust direction, i.e., along the axis of rotation, and to minimize tipping or tilting as a result of radial play. In the case of large diameter dials, such as those of one meter or more in diameter, expensive measures have been taken to prevent tipping or tilting when vertical forces are applied near the outer edge of the dial. The measures include increasing the size of the indexer thrust bearings and adding outrigger structures that engage the dial when in an indexing location. Larger thrust bearings and outriggers add cost, and outriggers consume processing time and can cause positional errors.
[0004] In contrast, embodiments of the present invention provide for a high degree of stability and protection against out-of-plane excursions for indexable dials without the expense of larger indexer thrust bearings and without the problems created by selectively
engageable outriggers. In brief, the invention removes the task of supporting the dial mass from the indexer comprising the motor and thrust bearings.

[0005] In general, this is accomplished first through the use of a flexure element mechanically interconnecting the indexer and the dial, and second by an air bearing system supporting the dial. The flexure element is non-compliant in torsion while at the same time essentially decoupling the table from the indexer along the Z-axis. The air bearing system supports the dial mass and allows smaller, less expensive indexers to be used.

[0006] As hereinafter described, the air-bearing arrangement can take several forms and may incorporate vacuum preloading as well as partial integration into the dial structure. For a complete understanding of the invention, reference should be taken to the following description of illustrative embodiments thereof.

**BRIEF SUMMARY OF THE DRAWINGS**

[0007] The description herein makes reference to the accompanying drawings wherein like reference numerals refer to like parts throughout the several views and wherein:

[0008] FIG. 1 is a perspective drawing of a laser drilling system incorporating embodiments of the invention;

[0009] FIG. 2 is a perspective drawing of a first dial support system for the drilling system of FIG. 1;

[0010] FIG. 3 is a perspective drawing of the first dial support system of FIG. 2 from another angle;

[0011] FIG. 4 is a schematic cross-section of an alternative support system for the dial of FIG. 1;

[0012] FIG. 5 is a schematic cross-section of a second alternative support system;

[0013] FIG. 6 is a partial schematic side view of an exemplary air bearing installation; and

[0014] FIG. 7 is a partial schematic side view of an inverted dial embodiment.

**DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS**

[0015] Referring to FIG. 1, there is shown a laser drilling system 10 comprising a frame 12 supporting a steel plate 14, the top surface of which is leveled. Supported above plate 14 is an indexable dial 16 supported by a system of air bearings 28 hereinafter
described. Dial 16 is designed to receive workpieces on fixtures 17 that allow the workpieces to be precisely positioned for processing steps such as laser drilling performed by a laser system 18 under the control of a real time computer 20. As soon as dial 16 is on position, a command to verify alignment and laser a workpiece is given. A programming station 19 is provided. The balance of system 10 comprises housings 22 for subsystems for providing power, temperature control, air processing and other needs for laser system 18. Details of such system components may be found in my co-pending application serial no. 12/394,966, filed February 27, 2009 and assigned to Electro Scientific Industries, Inc. [0016] Referring now to FIGS. 2, 3 and 6, a first support system for dial 16 will be described. Dial 16 is shown as circular and is mounted for rotation about a vertical Z-axis by an indexing motor 24 secured to frame 12. FIGS. 2 and 3 show dial 16 supported by four equally circumferentially- and radially-spaced air bearings 28 that may be of a type available from New Way Air Bearings of Philadelphia, PA. According to that company's product literature, their bearings produce a fluid film achieved by supplying a flow of air under positive pressure through a porous carbon diffuser in the bearing. New Way Air Bearings are susceptible to use in a combination positive air flow/vacuum mode using both positive air pressure and vacuum ports to provide vacuum preloading, a feature that can be used to advantage in the present invention as it adds stiffness to bearings 28. FIG. 6 shows how bearings 28 are mounted to plate 14 by means of a standoff 30 and a spherical joint 31 with a fine pitch thread. Standoff 30 is attached to plate 14, and joint 31 is attached to bearing 28.

[0017] FIGS. 2 and 3 show how dial 16, which may be up to or in excess of one meter in diameter, is mechanically interconnected to the output shaft S of motor 24 through a flexure member 26, which is a plate-like structure made of low carbon steel. Flexure member 26 has a substantially circular center section 42 directly attached to an output member, such as output shaft S, of motor 24 by two screws, and four flexure arms 44 that are attached by screws to the bottom of dial 16 in the relationship shown in FIG. 2 (see also FIG. 4). The configuration of flexure member 26 is such as to be stiff in torsion; i.e., it transmits torque from motor 24 to dial 16 in a highly non-compliant way. However, flexure arms 44 allow substantial compliance along the Z-axis so as to prevent excursions of motor output shaft S along the Z-axis from being transmitted to dial 16. In short, flexure member 26 selectively decouples dial 16 from motor 24 along the Z-axis.

[0018] Air bearings 28 lie approximately 12 to 15 inches radially outwardly from the center of the rotating structure shown in FIGS. 2 and 3 and thus provide substantial
support for dial 16 when supplied by positive pressure from an air source. As also
discussed above, air bearings 28 may be operated in a dual mode by connecting to a
vacuum source thereby to provide vacuum preloading, which increases the stiffness of air
bearings 28 and also permits rapid switching to a mode in which the vacuum preload
dominate and effectively sucks the bottom surface of the dial 16 onto the upper surface of
bearings 28 for positional stability during, for example, a laser drilling process. While
four bearings are shown, it will be understood that a greater or lesser number may be used,
three being the minimum in the case of discreet bearings.

[0019] Referring now to FIG. 4, a first alternative embodiment of the invention is
shown. In FIG. 4, motor 24' is mechanically connected to flexure 26 through a spacer 27,
which is an output member of motor 24'. Flexure arms 44 of flexure member 26 are in
turn fastened to the underside of dial 16'. Dial 16' is shown sitting closely adjacent to the
top surface of plate 14. Plate 14, as shown in FIG. 1, is supported by frame 12. A vacuum
and compressed air slip ring manifold structure 46 provides compressed air to bearing
inlets 36 that exit as orifices from the underside of dial 16' to provide the lifting aspects of
air bearings 28. Circular recesses or concavities 40 are milled into the underside of dial
16' and are connected by vacuum lines 38 to a vacuum source through slip ring manifold
structure 46 to provide the vacuum preloading aspect described above. The positive air
pressure to bearing inlets 36 can be shut off, thus creating a vacuum that draws the
underside of dial 16' to the top surface of plate 14 as previously described.

[0020] Flexure member 26 prevents Z-axis excursions from passing from motor
24' to dial 16', whereas air bearings 28 provided by bearing inlets 36 and vacuum lines 38
with recesses 40 maintain the stability of dial 16' during and between indexing operations.
Flexure member 26 also allows dial 16' to drop down against the plate surface as described
above.

[0021] FIG. 5 shows a still further embodiment of the invention in which positive
and negative (i.e., vacuum) air pressure conduits 36' and 38', respectively, run through or
under plate 14' rather than through dial 16" such as in the embodiment of FIG. 4. This
embodiment thus eliminates the need for a rotary coupling, such as slip ring manifold
structure 46, to supply air to dial 16". In FIG. 5, compressed air from external of plate 14'
flows via conduits 36' to orifices in plate 14' under dial 16", while conduits 38' are
attached to an external vacuum source to draw a vacuum in milled concavities 41 in plate
14'. Controls can be provided for regulating the positive and negative pressure flows
independently of one another.
While the invention has been described with reference to several embodiments in which the dial overlies the bearings, it is within the scope of the invention to locate and size the vacuum system such that it holds dial 16 against gravity, thus allowing parts to be processed in an inverted manner as desired. Such an embodiment is shown in FIG. 7, where dial 16" is below plate 14". Air pressure conduits 36" and 38" are similar to those of FIG. 5, but suction via conduits 38" holds dial 16" against gravity. Indexing motor 24, represented by separator 27 and output shaft S, is under dial 16". However, the indexing motor 24 may also be above dial 16".

While the invention has been described in connection with certain embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures as is permitted under the law.
What is claimed is:

1. An indexable dial system for translating workpieces in and out of a processing station comprising:
   a dial having an axis of rotation;
   a motor for selectively indexing the dial about the axis of rotation;
   at least one air bearing attached to a surface of the dial; and
   a flexure mechanically connecting the motor to the dial, the flexure being essentially torsionally non-compliant about the axis of rotation but compliant along the axis of rotation.

2. The system according to claim 1 wherein the at least one air bearing comprises a plurality of air bearings at equidistantly-spaced locations around the axis of rotation.

3. The system according to claim 2, further comprising:
   a frame supporting the motor wherein each of the plurality of air bearings is attached to a plate mounted on the frame and facing the dial.

4. The system according to claim 3 wherein the plate comprises a plurality of concavities in a surface thereof facing the dial, the system further including:
   at least one negative air pressure conduit coupled to each of the plurality of concavities and extending through the plate and externally from the plate; and
   a plurality of positive air pressure conduits extending to the surface through the plate and having at least one path extending externally from the plate.

5. The system according to claim 1 or claim 2 wherein the dial comprises a plurality of concavities in a surface thereof and a plurality of bearing inlets extending from the surface to an opposing surface, the system further including:
   at least one vacuum line coupled to each of the plurality of concavities.

6. The system according to claim 5, further comprising:
   a slip ring manifold structure extending through an opening in a central portion of the flexure to the opposing surface of the dial.
7. The system according to claim 1 or claim 2 wherein the flexure comprises a plate-like structure including a substantially circular center section attached to an output member of the motor and a plurality of flexure arms arranged about the center section, each of the plurality of flexure arms attached to the dial.

8. The system according to claim 1 or claim 2, further comprising:
   a plate having a surface facing the dial and a central aperture about a circumference of the flexure, each air bearing coupled between the dial and the surface of the plate.

9. The system according to claim 8 wherein the motor extends through the central aperture.
INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/034360

A. CLASSIFICATION OF SUBJECT MATTER
B23Q 16/00(2006.01)i, B23Q 16/02(2006.01)i, F16C 32/06(2006.01)i, B23K 37/04(2006.01)i, B23Q 16/06(2006.01)i, B23Q 16/08(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
B23Q 16/00, B23K 26/10, B23Q 1/66, B23Q 16/02, B23Q 16/06, B60K 41/24

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords rotary, index, dial

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>See Column 2, Line 30 - Column 4, Line 22; Claim 1; Figures 3-4.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>See Column 2, Line 10 - Column 2, Line 26; Claim 1; Figure 1.</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>JP 2001-212726 A (SUMITOMO HEAVY IND LTD) 07 August 2001</td>
<td>1-9</td>
</tr>
<tr>
<td></td>
<td>See Paragraph [0011] - Paragraph [0014], Claim 1; Figures 1-3.</td>
<td></td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of Box C

See patent family annex

"A" special categories of cited documents
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

Date of the actual completion of the international search: 30 JULY 2010 (30 07 2010)

Date of mailing of the international search report: 02 AUGUST 2010 (02.08.2010)

Name and mailing address of the ISA/KR
Korean Intellectual Property Office
Government Complex-Daejeon, 139 Seonsa-ro, Seogu, Daejeon 302-701, Republic of Korea

Facsimile No 82-42-472-7140

Authorized officer
KIM, Jeong Rak

Telephone No 82-42-48 1-5410

Form PCT/ISA/210 (second sheet) (My 2009)
<table>
<thead>
<tr>
<th>Patent document cited in search report</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 5784932 A1</td>
<td>28.07.1998</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>US 5540120 A1</td>
<td>30.07.1996</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>JP 2001-212726 A</td>
<td>07.08.2001</td>
<td>JP 3632746 B2</td>
<td>23.03.2005</td>
</tr>
</tbody>
</table>

Form PCT/ISA/210 (patent family annex) (My 2009)