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Systems and Methods for Modelling Radial Contact of a Micro-Shaft

Field of the invention

The present invention relates to systems and methods for obtaining and analysing experimental data relating to a micro-motor, particularly the contact
5 of a rotating micro-shaft with stationary components.

Background of Invention

Machine stability is critical for most portable devices, and it is a particularly great concern for a high-speed mechanism in a micro-scaled system, such as
10 a MEMS device. In the design of a micro-rotating mechanism, such as a motor, the rotation speed and accuracy of revolution are of utmost importance. These revolving characteristics may change if there is no effective bearing system to maintain a uniform contact during operation. In many powered systems vibration of the dynamic components causes
15 deterioration of the mechanical mechanism after prolonged surface collisions, as well as abrasive wear during its operation. Furthermore, frequently misalignment failures cause breakdowns due to inadequate handling and maintenance, resulting in degradation or deformation of contact surfaces, and this affects the functional life of the micro-system. Many undesirable defects
20 come from repeated abrasion and resonance of the sliding surfaces, especially when the clearance is very small.

Despite much research progress in minimizing the wear and friction resistance of contact surfaces, such as by using a thin lubrication film, it would
25 be advantageous to be able to employ active surface monitoring of a micro-mechanism when assessing the level of abrasion or collision shock for engineering evaluations, and in particular it would be advantageous to provide a surface-sensing assembly to detect spinning characteristics. However, the

availability of micro-scaled contact sensors is limited by their thickness and sensitivity, and most are difficult or impossible to implement if the contact surfaces are not flat.

5 Summary of the Invention

The present invention aims to provide an architecture and method of surface geometry monitoring on a cylindrical shaft subjected to abrasion.

In general terms, the invention proposes that a curved surface of a micro-scaled rotational device is provided with an array of piezoelectric cells and electronic circuitry for obtaining electronic signals generated by the cells in
10 response to forces exerted on the cells during rotation of the device.

One possible definition of a micro-scaled rotational device is one having a shaft diameter of less than or equal to about 2mm. However, slightly larger devices are envisaged also.

15 The micro-scaled device is typically, though not necessarily, a micro-motor, such as a Micro-Electrical-Mechanical-System (MEMS) motor assembly.

The present invention further proposes a method of evaluating the contact pressure on the curved surface of the micro-scaled device, by sensing the
20 electronic signals generated by the cells. Thus, contact pressure on the cells may be quantified and recorded, for example over a long duration.

The method makes it possible to evaluate the rotational stability of a rotating sleeve about a fixed shaft, through easy monitoring of the position of surface collisions.

25 Alternatively, or additionally, the method makes it possible to calculate the level of abrasion and wear on the contact surface due to random impacts.

Note that these properties are not easily measured by existing techniques, especially when the rotation speed is high and variable.

Furthermore, the method makes it possible to obtain the vibrational force along the curved surface substantially instantly. Generally, the surface
5 properties of the curved surface will change with excessive abrasion due to high loading force, and from a mechanical point of view, the contact interface influences the resistance behaviour as the curved surface slides across another surface. In this manner, real time assessment on the geometric
10 distribution of contact forces and the corresponding change in the surface profile helps to identify wear on the relatively moving surfaces.

In a preferred embodiment of the invention the cells provide an array of highly sensitive force transducers in a form of thin layer which is wrapped round the cylindrical surface of the spindle shaft. For a miniature motor having very
15 minute components, such a thin layer is preferably made by appropriate deposition and etching processes, to create many individual cells that are active for micro-force detection. Every cell is electrical connected and systematically arranged to output an electrical signal which is generally constant but responds when the cells are compressed due to vibration impact
20 during revolution.

The design is suitable for a stationary spindle shaft, to measure surface contact of the shaft with another component. To be precise, it is suitable to measure contact abrasion between the respective cylindrical surfaces of a
25 rotor and shaft during rotation. As described above, random collisions of the stationary and rotating surfaces often happen due to unbalanced revolving force, especially when the gap clearance between the surfaces is very small. This phenomenon is generally known as the Non-Repeatable-Run-Out

(NRRO), and subsequently wear and tear occur on the colliding surfaces, after prolonged operation.

The present architecture enables direct measurement of the force on the
5 cylindrical surfaces, whereby the abrasion interaction between two surfaces
can be evaluated in terms of pressure and profile. In this regard, the normal
loading on the contact surface is determined during the process, and thus its
friction resistance at the contact is predicted for the purpose of assessing the
wear condition of the surface with increasing length of abrasion. This process
10 may take into account both the magnitude and interval of the surface
collisions.

Furthermore, the present architecture enables the revolving behaviour and
resonance mode shape of a rotating mechanism to be examined and
15 modelled, based on the information about impact positions and their
uniformity. Likewise, the surface property of the cylindrical surface can be
evaluated in term of magnitude of contact.

The present invention may be use to provide a dynamic modelling system, to
provide understanding of the motion of a moving body, so as to detect the
20 vibration mechanism of the structure. Often, such vibration leads to wear or
surface deterioration at the contact interface between static and rotating
components despite the use of lubrication film. These abrasions cause loss of
energy and also provoke misalignment of the components, which possibly
affect the performance of a system, especially in a micro-mechanical system.
25 In this regard, a geometric model of the structure is preferred for evaluating
the magnitude and positioning of abrasion resulted from surface collisions, in
order to minimize the above-mentioned disadvantages.

The layer of cells may be fabricated by conventional semi-conductor
fabrication processes.

The invention can be used both for testing during an engineering process, and also in real applications. The methods of the invention may be conducted in-situ, without user operation and handling, in any testing environment.

Brief Description of The Figures

5 Preferred features of the invention will now be described, for the sake of illustration only, with reference to the following figures in which:

FIG. 1, which is composed of Figs. 1(a) and 1(b), shows an embodiment of the invention which permits contact modelling of a revolving micro-mechanism;

10 FIG. 2 shows schematically the structure of a piezoelectric sensor cell which can be employed in the embodiment of Fig. 1;

FIG. 3 is composed of Figs. 3(a) and 3(b) which respectively show in perspective view and in an enlarged view an array of piezoelectric sensor cells provided on a spindle of the embodiment of Fig. 1;

15 FIG. 4 shows schematically an automatic recording process using the embodiment of Fig. 1;

FIG. 5 shows the output of modelling the contact stress distributions of spindle shaft structure using the process of Fig. 4 when the motor is at rest; and

20 FIG. 6 shows the output of modelling the contact stress distributions of spindle shaft structure using the process of Fig. 4 when the motor is spinning.

Detailed Description of the embodiments

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Referring firstly to Fig. 1(a), a micro-motor assembly 100 is illustrated in perspective view which is a first embodiment of the present invention. The assembly 100 comprises a spindle shaft 101 that is firmly secured onto a stator base 103. Threaded on the spindle shaft 101 is a rotor 102.

Fig. 1(b) shows the same assembly 100 but the stator base 103 and rotor 102 are shown in cross-section. A permanent magnet 104 is embedded within the rotor 102, while the stator base 103 contains a series of multiple copper coil windings 105. The windings 105 are powered by electrical connections 106 and when an electrical current flows through them an electromagnetic force is induced by interaction with the magnetic field of the magnet 104. This causes the rotor 102 to spin in its plane about the spindle shaft 101.

10 Designs essentially as shown in Fig. 1 are of much interest in the field of MEMS devices for their size and applicability in portable devices. Note that usually it is not intended to provide a roller bearing is between the static and revolving bodies owing to size limitations in the micro-mechanical device, so adequate spacing is required between the contact surfaces to minimize
15 frictional resistance between them. Nevertheless, it appears that imbalances in the rotation motion are inevitable during the motor's operation, causing irregular and random collisions of the inner sleeve of rotor 102 against the surface of the shaft 101. The embodiment makes it possible to evaluate the contact and abrasion conditions of the revolving rotor 102 against the curved
20 surface of a spindle shaft 101 during the rotation.

As illustrated in Fig. 3, the spindle shaft 101 is provided with an array of multiple sensing cells 300 which is wrapped around the exterior cylindrical surface of the spindle shaft 101. Each sensing cell 300 is neatly arranged on
25 an intersection point of a regular matrix formation. The cells 300 are made thin and flat above the curved surface of the shaft, without affecting the tangential sliding motion of a rotor 102 that moves across it. The array of cells extends around the whole axis of the shaft 101. Signal voltages generated by the cells 300 are electrically connected out of the device by electrical
30 connections passing through the conductor lead 106.

One possibility is for the sensing cells 300 to be formed from piezo-electric material. One specific possibility such construction is illustrated in Fig. 2 which shows a single piezo-electric structured sensing cell 200. As, shown in FIG.2, such a cell structure includes a body 202 of piezo-electric material sandwiched between two thin electrode layers 201, 203 to conduct electrical output to a voltage measuring device. In consideration of sensitivity of the force detection, the physical dimensions of this structure 200 are appropriately designed to maximize the stress-voltage ratio. A small change in the volume of the piezo-material 202 may trigger a significant level of electrical signal to be registered quantitatively when external stress is applied. The layout of the sensor cell 200 is optimized to the required resolution of detection, as well as the physical dimensions of the mechanism.

Referring again to Fig. 3, the fabrication process of the force-sensing layer of cells 300 on the curved surface of the spindle 101 aims to provide uniform thickness, and is carried out taking into account any constraints or possibilities offered by available adhesion processes. For example, it is possible to lay multiple thin layered films on a substrate, such as steel, using sequential vacuum deposition processes. With appropriate optimization of deposition process parameters such as temperature or pressure, it is possible to create desirable low-friction characteristics that alleviate contact resistance between two contact surfaces, and also eliminate film delamination due to excessive abrasion.

In one preferred possibility, shadow mask deposition using a target is employed to provide the array of thin uniform sensor cells 300 on the cylindrical shaft 101. At each of a series of times a respective portion of the shaft is directed at a target, and by rotating the shaft 101 all portions of the shaft are brought to face the target sequentially.

Alternatively, the array 300 of cells may be provided by firstly by depositing a layered structure onto the spindle 101, and then dividing or slicing the layers to singulate the layers into multiple sensor cells 300. The slicing may be
5 performed by laser cutting, which has the advantage of permitting removal of material without material contact.

The electrode layers 301, 303 each extend over multiple cells 300 (as shown) such that each cell 300 lies on the intersection of one strip-like outer electrode
10 layer 301 and one strip-like inner electrode 303. The electrode layers 301, 303 are deposited as thin conductor layers that form an electrical network to output changes in voltage potential when the piezo-material 302 is in use. Each of the layers 301, 303 is individually electrically connected to an electrical contact path extending through the body 106.

15 Each cell 300 is identified by a row and column of the matrix formed by the electrodes 301, 303. Analogous to a keyboard, every cell 300 has its own row-column configuration, which is independent of the adjacent cells. When a mechanical load is applied to any cell 300, the piezoelectric material in it
20 generates an electrical signal. Depending on the contact area and position, the loaded cells 300 will produce respective voltage magnitudes based on the load distribution.

Optionally, an additional thin electrically-insulating film layer (not shown), such
25 as Diamond-Like-Carbon, may be coated over the entire cylindrical surface, covering the matrix of sensor cells 300. The film layer protects the surface from wear and scratches from abrasion with dust or debris during the operation. The thickness of this protective layer is uniform over all sensing surfaces, and selected to avoid impairing the sensitivity of the sensing

mechanism. The film is particularly useful in applications involving prolonged testing.

- Referring to Fig. 4, a process for using the assembly of Fig. 1 is shown. The
5 respective electrical conduction paths for the electrode layers 301, 303 are
connected to a data-logger 402 which records the fluctuating value of
electrical voltage generated by each individual sensor cell 300 independently.
A computer 401 is used constantly to calculate from this data changes in the
contact surface stress for every individual sensing cell 300, and this data is
10 recorded on the computer 401 (e.g. for showing at each of a number of
moments the stress across all of the cells). Preferably this process is
performed continuously (e.g. at short intervals) during the revolving operation
of the rotor 102 about the shaft 101.
- 15 Each sensor cell 300 is activated when stress is applied to it. If all cells 300
are uniform and have identical sensitivity, a stress distribution profile can be
generated when load is applied to the spindle extending over multiple cells of
sensor array.
- 20 The preferred form of stress-distribution plot employed in the embodiment is
one in which a generally cylindrical geometrical form is illustrated, as in the
upper left part of Fig. 4. The generally cylindrical form has, however, a varying
radial dimension corresponding to increasing stress. Such a plot is shown in
Figs. 5 and 6, in each of which there is a cylindrical-shape model having a
25 similar geometry to the shaft 101, and made up of multiple nodal points 501
that indicate the stress magnitude of a corresponding sensor cell 300 (or of a
group of such cells).

- When the motor 100 is not in motion, as illustrated in FIG.5, the respective
30 contact stress distribution is motionless, since the area of the spindle 101 in

contact with the rotor 102 does not fluctuate. In this state, the surface model 500 of the shaft 101 is static, and no deformation of the nodal points 501 is observed.

- 5 As soon as the rotor 101 starts rotating, as illustrated in Fig. 6, there are inevitable dynamic surface contacts between shaft 101 and rotor 102, and correspondingly the nodal points 501 on the surface model 600, as indicated in Fig. 6, are deformed according to the magnitude of the force on the sensor cells 300. These changes of the model 600 are instantaneous, and are
10 reproduced on the scale and position of contacts at the vibration of the moving rotor 102 in a high-speed revolution.

Repeated vibration and abrasion degrades the surface gradually over time, and this transition is reflected by changes in the stress model. Calibration for
15 changes in voltage with standard surface deformation of the sensor cell 300 is preferably carried out to correlate the voltages with the measured contact forces repeatedly. This comparison is particularly useful in determining the levels of vibration which lead to surface wear, or to break down of the micro-system. Thus, the embodiment provides effective monitoring advantages for
20 understanding collision behaviour, as well as contact motion between the moving surfaces.

Although only a single embodiment of the invention has been described in detail, many variations are possible within the scope of the invention as
25 defined by the claims. For example, the spacing of the cells of the array may be selected according to the desired sensitivity of the method.

Claims

1. A micro-scaled rotational device having a curved surface, the curved surface being provided with:
 - (a) an array of piezoelectric cells for generating electrical signals in response to a compressive stress; and
 - (b) circuitry to convey said electrical signals from the cells out of the device.
2. A device according to claim 1 which is a micro-motor.
3. A device according to claim 1 or claim 2 which is a MEMS device.
4. A device according to claim 1, claim 2 or claim 3 in which the cells comprise PVDF.
5. A device according to claim 1, claim 2 or claim 3 in which the cells comprise a ferroelectric material.
6. A micro-motor according to any preceding claim further comprising a wear-resistant film covering the piezoelectric cells.
7. A device according to any preceding claim in which the curved surface is on a stationary component of the device.
8. A device according to claim 7 in which the curved surface is on a shaft of the device carrying a rotor.
9. A device according to any preceding claim in which the curved surface is cylindrical, and the cells are provided are placed at positions equally spaced around the axis of the cylindrical surface.

10. A method of measuring contact pressure on a device according to any preceding claim, the method including obtaining said electrical signals and converting them into force data indicative of contact pressure on the cells.
11. A method according to claim 10 including using the force data to obtain
5 a geometrical display of the position and location of the pressure force on the curved surface.
12. A method according to claim 11 in which the geometrical display comprises a generally cylindrical body having radial variations at respective positions and of respective magnitudes corresponding to the force data.
- 10 13. A method according to claim 10, claim 11 or 12 further comprising using the force data to obtain vibration data indicative of vibration of a rotating body of the device.
14. A method according to any of claims 10 to 13 further comprising recording the force data.
- 15 15. A method according to claim 14 further comprising using the recorded force data to obtain data indicative of wear and abrasion.
16. A method for fabricating a micro-scaled device according to any of claims according to any of claims 1 to 9, the method including performing a semi-conductor fabrication process to fabricate said cells on said curved
20 surface.