



APPARATUS AND METHOD OF TESTING ABRASION RESISTANCE

Field of the Invention

The invention relates to tribological testing of materials for abrasion resistance, and in particular for materials used in microelectrode mechanical systems (MEMS). Whilst the method and apparatus may be applicable to materials having a planar application, the invention is particularly advantageous for use with materials used on curved surfaces.

Background

A common problem of component surface deterioration occurs when two sliding surfaces come in contact for an extended duration, such as in the case of a motor assembly where the shaft spins against the sleeve during operation. It is especially critical when the shaft is loaded heavily during rotation, or when the operating environment is unclean. Frequently, friction related failures cause break down due to inadequate maintenance and care, causing the contact surfaces to degrade, and thus affect the functionality of the motor. Much research into thin lubricating film is directed to minimizing wear, and also reduces frictional resistance at the sliding contact. Dry lubricating film is most preferred for micro-mechanism, such as watches, or MEMS where dimensional spaces are limited.

In this regard, testing equipment is important to evaluate the durability of coated thin film as a prompt check of film behaviour before entering into production. Mechanical fixtures are



setup to maintain a uniform contact during the test, to determine change in surface properties due to repeated abrasion of a high-speed mechanism.

A common film test setup uses a loaded mass in the shape of a ball to slide on a rotating planar work piece. Sliding resistance at the contact can be detected using a linear force transducer that measures force resistive in the cantilever arm of the ball holder. Frictional force is then predicted from the collected values of the resistance intensity over a period of time. The durability of the film can be estimated by observing the incremental change in frictional force, as an indication of surface damage.

To more closely resemble the loading condition for a motor spindle mechanism, a set-up configuration of a loaded stationary cylinder sleeve contacting a rotating cylindrical shaft is most preferred to understand the film adhesion on a non-flat surface. However, this becomes a challenge when the test specimen is very small, and the contact area hard to reach with a force sensor. Despite the availability of micro-scaled contact sensors, there are limited options to vary the material and dimensions of such sensors.

Summary of Invention

It is therefore an object of the present invention to measure abrasion resistance as a function of change in frictional force, over time, for a material applied to a curved surface.

In a first aspect, the invention provides a device for measuring the abrasion resistance of a material comprising:

a shaft having a surface of said material;

an element having an aperture, through which said shaft is inserted, said aperture

5 being greater than the diameter of the shaft;

biasing means for biasing the element so as to form a contact area between the shaft and an inside face of the aperture;

rotation means adapted to rotate the shaft for a predetermined length of time whilst the biased contact between the shaft and inside face is maintained;

10 restraining means adapted to apply a restraining force to the element to prevent rotation caused by friction at the contact area, and;

a measuring device for measuring the restraining force over the predetermined length of time.

15 In a second aspect, the invention provides a method of measuring the abrasion resistance of a material comprising the steps of:

forming a shaft having a surface of said material;

inserting said shaft through an aperture of an element said aperture being greater than the diameter of the shaft;

20 biasing the element so as to form a contact area between the shaft and an inside face of the aperture;

rotating the shaft for a predetermined link of time whilst contact between the shaft and inside face is maintained;

applying a restraining force to the element to prevent rotation caused by friction at the contact area and;

5 measuring the restraining force over the predetermined length of time.

In a preferred embodiment, the shaft may be homogeneously formed from the material.

Alternatively, the material may be a layer applied to the surface of the shaft and in a most preferred embodiment, may be a film. In this last case, the film may be a friction reducing
10 film used for MEMS or other micro scale device whereby low friction surfaces are important, but difficult to quantify because of the application to a curved surface.

In a preferred embodiment, the element may be a plate having a substantially uniform thickness. In a more preferred embodiment, the plate may be a disc and thus have a plan
15 shape which is substantially curved or circular.

The element may be substantially free from other external loads other than the frictional force and the biasing means. To this end, the invention may include a device or assembly upon which the plate may be located, which permits little or no resistance to the rotation of
20 the plate. In a most preferred embodiment, the element may be located on a device providing an air lubrication layer upon which the element sits and, therefore, providing a low frictional resistance to rotation.

In this most preferred embodiment, the air lubrication layer may be provided by a planar surface having a series of spiral grooves imparted to the surface. The spiral grooves may be arranged so as to provide an air lubrication layer on rotation of said surface. In this most preferred embodiment, the element may therefore be placed upon the air lubrication layer and benefit from the low frictional resistance.

In a preferred embodiment, the biasing means may include an application of an external normal force applied to the element so as to restrain the element from rotating due to the application of the frictional force.

In a more preferred embodiment, the external force may be applied by a cable attached between the element and a weight, said weight directed downwards due to the cable being engaged with a pulley. Thus, in this embodiment, the external force will be equal to the gravity load imparted by the weight, subject to any frictional resistance of the pulley.

Alternatively, the external load may be a tension or a compression spring mounted between the element and a fixed point and thus either applying the load in tension or compression with the external force being equivalent to a force corresponding to the spring constant of said spring.

The rotation of the shaft can be achieved by a number of different means with the invention not being limited to any particular arrangement. Therefore, as an example, the shaft may be

rotated by a motor capable of maintaining a uniform rotational speed for the length of time designated for the test.

5 In determining the length of time for the test, said predetermined length of time may depend upon external conditions such as temperature and pressure. It may also depend upon the application for which the material is to be used, and the magnitude of the external force. As the external force is proportional to the applied frictional force, the magnitude of the external force may be a function of the degree to which the researchers may wish to accelerate the test so as to shorten the test period. The length of time of the test, that is said predetermined
10 length of time may be in the range of one second up to several days. In theory, the test may not have a limit, and so may be determined based on the application of the film. In practice, an upper limit of 600 hours, and more may be appropriate. The actual period may be a function of the material, such as a polymer film or a ceramic coating.

15 In a preferred embodiment, the measuring device may include a load sensor in communication with the element such that the restraining force may be measured directly. Further, the measuring device may include a data logging means such as a computer having an analogue to digital converter to convert the analogue signal from the load sensor to a digital record to be recorded by the computer. In any event, the measuring device and
20 possibly its ability to record data over a significant length of time may be required in order to determine significant or progressive change in a frictional force from a review of a graph generated from said measuring device.

Brief Description of Drawings

Figure 1 is an isometric drawing of test apparatus of the prior art;

Figure 2 is an isometric drawing of test apparatus according to one embodiment of the
5 present invention;

Figure 3 is an exploded isometric view of a shaft assembly according to one embodiment of
the present invention;

Figure 4 is a plan view of a facing plate according to one embodiment of the present
invention;

10 Figure 5 is a schematic drawing of a ring disc according to one embodiment of the present
invention;

Figure 6 is a schematic view of the measuring system according to another embodiment of
the present invention;

Figure 7 is a graphical representation of results measured following a test according to one
15 embodiment of the present invention;

Description of Preferred Embodiment

It will be convenient to further describe the present invention with respect to the
accompanying drawings, which illustrate possible arrangements of the invention. Other
20 arrangements of the invention are possible and consequently the particularity of the
accompanying drawings is not to be understood as superceding the generality of the
preceding description of the invention.

The design of MEMS motors involve assemblies measured in micrometres. Consequently, to maintain the very small size of the assemblies, clearance between components is limited and therefore high speed rotational members are undesirable. Inevitably, however, contact
5 between moving parts will occur, leading to friction. To minimize the friction and consequential wear of the parts, dry lubricating films are used both on flat planar surfaces and curved surfaces, for instance, the sleeve of a rotor.

The successful formation of a lubricating film on a curved surface is dependant upon, *inter*
10 *alia*, adhesion of the film to the part and uniformity of film thickness. By controlling deposition process parameters, such as temperature and pressure, it is possible to create the desired low-friction characteristics and reduce the risk of mechanical breakdown if the film delaminates due to excessive abrasion.

Conventionally, to evaluate a thin coated film specimen, the specimen is set spinning at a
15 constant rate with a loaded contact ball contacting the specimen surface, and the resulting damage to the specimen measured over time. This can be repeated for several materials, under various loading conditions. Thus, for the simple commercial testing apparatus shown in Figure 1, making a relative comparison between specimens using a planar surface is
20 sufficient to evaluate the wear life of a specimen relative to other specimens.

A thin film is deposited on a flat substrate **101** with good surface smoothness and flatness, so that a force sensor **106** attached to a contact ball **104** can reliably determine the friction on the film surface. A cantilever arm **105** is designed to hold the contact ball onto the test surface, and to provide the detection of friction parallel to the surface. A loaded weight **107** is
5 commonly added to increase the absolute frictional force and accelerate abrasion/wear during the testing cycles.

The method according to one embodiment of the present invention aims to evaluate the wear resistance of thin-coated film with a constant normal load applied to the film layer and,
10 specifically, for a cylindrical shaft **201** that may be used in a MEMS motor assembly. Measurement is performed by a force sensor **206** attached to a ring disk **202**, which is placed in contact with a specimen of coated film on a shaft **201**. The ring disk **202** is analogous to the rotor sleeve in the design of micro-motor, replicating the type and area of contact. As shown in FIG. 2, the force sensor **206** measures the restraining force of ring disk **202** which
15 is generated by contact of the ring disk **202** and the rotating shaft **201**.

The test module **200** is set up by securing the coated shaft **201** onto a shaft holder **204** through the sleeve holes of the ring disk **202**, illustrated in FIG. 3. A rubber stopper ring **211** is placed above the ring disk **202** as a means to avoid axial wobbling and shuddering of the
20 ring disk **202** when the shaft **201** spins at high speed during the test. The ring disk **202** sits freely on a facing plate surface **205** of the shaft holder **204**, and contact of the ring disk **202** against the facing plate surface **205** of shaft holder **204** is inevitable during the test

measurement due to gravity. It is therefore preferable to isolate these elements during testing to eliminate friction other than that from the coated curved surface of the shaft **201**.

A feature of this proposed structure is to introduce a spiral groove thrust bearing on the planar surface of shaft holder **204**. An air lubrication layer can be generated by air pressure due to the wedge action between varying gaps of two surfaces during relative motion. To produce the wedge action some pattern of varying gap must be engraved in either surface. For the proposed structure, an additional step in the etching process is added for creating a spiral ridge and groove profiles of several micrometers depth on a thin flat silicon plate **205**. This plate **205** is then mounted so as to be facing the flat surface of the ring disk **202** on the shaft holder **204**, illustrated in FIG. 4. In this manner, a thrust bearing created on the structure surface relies on hydrodynamic pressure to support the load. The spiral-grooved thrust bearing profile **400** consists of a series of uniformly spaced shallow grooves. The depth of each groove is up to several times the bearing clearance. Due to the inclination of the grooves, a uniform airflow induces a component normal to the sliding direction during the rotating operation. In this manner, the shallow inclined grooves function as a viscous pump, and capillary blockage of the induced flow causes the pressure in the gap to rise and enabling the bearing to lift the ring disk **202** correspondingly. When the ring disk **202** is elevated above the plate surface **205** of shaft holder **204**, frictional resistance on the planar contact surface can be reduced to a negligible level during the measurement.

A small contact area **500**, as displayed in FIG. 2, is attained at the interface when the ring disk **202** is biased against the coated shaft **201** surface by attaching a suspended weight **209** with a cord **208** that runs over a simple pulley **210**. Having such a pulley **210** arrangement for the suspended weight **209** helps in minimizing the shift of the cord **208** that may lead to misalignment of the force vectors during the test.

In testing a specimen, the small contact area **500** at the interface between the ring disk **202** and the coated shaft **201** is used for the measurement of the change in surface property of the coated surface over a extensive test duration. Depending on the amount of load **209** applied radially on the ring disk **202**, the friction force varies owing to the corresponding shear force at the contact interface **500**; increasing load induces larger frictional resistance on the surface. Yet again, the coated film should possess a smooth surface after deposition, and not cause a poor contact with the contacting ring disk **202** during the test. Other important factors for ensuring reliable testing include good shaft roundness, and good alignment of the force sensor with respect to the contact surfaces.

FIG. 5 reveals the basic schematic of the test module **200** which works on the standard tribological concept where friction force is generated with a normal loading (P) perpendicular to the direction of sliding movement. In this regard, the sleeve surface of the ring disk **202** is pulled to contact radially against the coated shaft **201** rotating in a clockwise direction. The shaft **201** will experience a resistance (F_R) in motion due to friction. Such contact friction on the shaft **201** surface urges the ring disk to try and rotate in the same direction and so induces

an increase in tension in the connecting cord **207** between ring disk **202** and force sensor **206**. In other words, this resistance can be expressed as the opposing force against the direction of shaft's rotation that generates a tension in the attaching cord **207** adhered to the surface of ring disk **202**. In this manner, the magnitude of detected tension force is obtained quantitatively on the force sensor **206** as equal in magnitude to the friction force experienced on the coated shaft **201** surface. Using mathematical relationships, this change in film's surface property can be evaluated in the normalized form known as the Coefficient of Friction (μ), administered in the following ratio:

$$\text{Coefficient of Friction } (\mu) = \frac{F_R}{P}$$

Continuous abrasion on the coated film degrades the surface over time, and this transition is reflected by the change in measured μ value. Calibration for the change in film roughness with standard sample surface of known μ value is preferably carried out to correlate with the measured data. This comparison is particularly useful in determining the failure level when the measured μ value increases dramatically due to wear occurrence of the film.

Active monitoring of the dynamic force output on the force sensor **206** helps in providing continuous detection during the abrasion process, whereby the increase in μ value can be constantly evaluated and recorded on a linked computer **600**, as illustrated in FIG. 6. A series of digital detected values can be presented via a user-friendly computer system to help

identifying the film property or wear trend 700 of the coated film, shown in FIG. 7, under abrasive loading.

CLAIMS

1. A device for measuring the abrasion resistance of a material comprising:
 - a shaft having a surface of said material;
 - 5 an element having an aperture, through which said shaft is inserted, said aperture being greater than the diameter of the shaft;
 - biasing means for biasing the element so as to form a contact area between the shaft and an inside face of the aperture;
 - rotation means adapted to rotate the shaft for a predetermined length of time
 - 10 whilst the biased contact between the shaft and inside face is maintained;
 - restraining means adapted to apply a restraining force to the element to prevent rotation caused by friction at the contact area, and;
 - a measuring device for measuring the restraining force over the predetermined length of time.
- 15 2. The device according to claim 1, wherein the material is a layer applied to the surface of the shaft.
3. The device according to claim 2, wherein the layer is a film is adhered to the shaft.
4. The device according to claim 3, wherein said film is a friction reducing film for use with MEMS.
- 20 5. The device according to any one of the preceding claims, wherein the element is a plate or a disc

6. The device according any one of the preceding claims, wherein the biasing means comprises an external force applied in a direction normal to a longitudinal axis of the shaft.
- 5 7. The device according to claim 6, wherein the biasing means includes a cable attached at one end to the element and at an opposed end to a weight, said cable engaged with a pulley intermediate the ends.
8. The device according to any one of the preceding claims, wherein the predetermined length of time is in the range of 1 second to 600 hours.
- 10 9. The device according to any one of the preceding claims wherein the measuring device includes a data logging device for recording the measurement of the restraining device.
10. The device according to claim 9, wherein the data logging device comprises a computer capable of converting an analogue signal from the load sensor into a digital record of the restraining force.
- 15 11. A method of measuring abrasion resistance of a material comprising the steps of:
 - forming a shaft having a surface of said material;
 - inserting said shaft through an aperture of an element, said aperture being greater than the diameter of the shaft;
 - 20 biasing the element so as to form a contact area between the shaft and an inside face of the aperture;

rotating the shaft for a predetermined length of time whilst contact between the shaft and inside face is maintained;

5 applying a restraining force to the element to prevent rotation caused by friction at the contact area and;

 measuring the restraining force over the predetermined length of time.

12. The method according to claim 11, wherein the foaming step further includes applying foam to the surface of the shaft.

13. The method according to claims 11 or 12, wherein the predetermined length of time
10 is in the range of 1 second to 600 hours.

14. The method according to any one of claims 11 to 13, further including the step of logging the restraining force as a function of time following the measuring step.