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## Method and Apparatus for Measuring a Surface Property

### Field of the Invention

This invention relates to a method and apparatus for measuring a surface property, more particularly but not exclusively for surface wear detection.

### Background of the Invention

A common problem of component surface deterioration happens 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 a sleeve during operation. This problem is particularly prevalent when the shaft is loaded heavily during the rotation, or when the operation environment is unclean. Frequently, friction causes the contact surfaces to degrade leading to failure and breakdown due to inadequate maintenance and care, thus affecting the functionality of the motor.

Thin lubrication films are used in many applications to reduce friction and wear and a research goal in this field is minimizing the amount of wear and also reducing the friction resistance of sliding contact where such films are used. Dry lubrication films are most

preferred for micro-mechanisms, such as watches, micro-motors or Micro-Electrical-Mechanical Systems (MEMS) where space is limited.

In the design of MEMS motors, the total assembly is compacted at a micro-scaled dimension. Frictional resistance needs to be overcome when there is surface contact between the static and rotating components, hence such a dry lubricating film is essential for the surface of the spindle shaft as well as the sleeve of rotor.

The formation of a thin film on a curved surface is conducted with consideration of the adhesion as well as its thickness uniformity. 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 probable mechanism break down if film delaminates due to excessive abrasion.

Testing equipment is important to evaluate the durability of a coated thin film as a check of film behaviour before applying the film to a product assembly. A common lubricating film test rig uses a mass loaded ball arranged to slide on a rotating planar-coated work piece. Sliding resistance at the contact between ball and work piece can be detected using a linear force transducer that measures the deflection 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. Conventionally, for evaluation of a thin

coated film specimen, the specimen is set to spin at a constant rate to produce repeated abrasion cycles with a loaded contact ball touching the test surface in order for film evaluation.

Such a prior art test equipment is illustrated in FIG. 1, in which a planar surface is used in the evaluation of the wear life. A thin lubricating film is deposited on a flat substrate 101 with good surface smoothness and flatness. The substrate is connected to a platen 102 which is rotated by a motor 103. A force sensor 106 is attached to a ball 104 which is in contact with the substrate 101. The sensor can uniformly determine the friction force on the film surface as the substrate 101 rotates. A cantilever arm 105 is designed to hold the contact ball onto the test surface, and to provide the detection of frictional force parallel to the surface. A loaded weight 107 is commonly added onto the contact ball 104 to reduce the number of testing cycles.

For an accurate test for a non- flat surface, such as a motor spindle mechanism, a close resemblance of the mechanism is desirable so that the film adhesion on such a non-flat surface may be understood. Thus, a set-up configuration for such a mechanism, of a loaded stationary cylinder contacting against another rotated cylindrical shaft, is used.

However, testing this in practice becomes a challenge when the test specimen is very small since it is difficult for the forces on the contact area to be measured. Micro-scaled contact sensors are available, but the material and dimension of such sensors cannot be varied, leading to inflexibility.

It is an object of the invention to provide a method and apparatus for measuring a surface property which addresses this problem.

### Summary of the Invention

According to the invention in a first aspect, there is provided a method of measuring a surface property of a circular member comprising the steps of placing the circular member within a circular opening of a test member, rotating one of the circular member and test member relative to the other and measuring the rotational force on the other of the circular member and test member.

According to the invention in a second aspect, there is provided apparatus for measuring a surface property of a circular member, the apparatus comprising a test member having a circular opening in which a said circular member is receivable; rotation means arranged to be coupled to one of the said circular member and the test member and a force sensor arranged to measure the rotational force on the other of the test member and the said circular member.

The testing method and apparatus are particularly suitable for monitoring of contact behaviour at the interface between two cylindrical contacts of a micro-scaled mechanism such as between a thin lubricating film-coated cylindrical motor shaft and mounting.

The described embodiment proposes a method and apparatus for wear detection based on the changes in surface texture of a coated film on a cylindrical spindle shaft, as contact surface in a Micro-motor, or Micro-Electrical-Mechanical-System (MEMS) motor assembly, to investigate the reliability of the small components within such small mechanism that are not easily modeled and simulated, especially when the rotational torque is small and variable.

The described embodiment enables a replication of loading in a real operation of such a miniature motor, which is not possible with conventional tribology testing equipment that normally only allows for planar specimens. Generally, surface property changes with excessive abrasion of high loading force, and from the mechanical point of view, the contact interface influences the resistance behaviour during sliding across a thin-coated surface. In the described embodiment, a direct detection is described based on the distribution of loaded abrasion and surface profile to measure the gradual wear of coated film.

In the described embodiment, a coated spindle shaft specimen is tested out of the MEMS motor assembly, by being placed on a test stand attached to a driving mechanism, preferably a high stability motor, such as those used in a Hard-Disk-Drive (HDD). In this

regard, the rotation of the shaft is independent of MEMS motor's rotation deficiencies; other than friction related factors.

A rotation mechanism is set up to hold a thin-coated shaft to be studied comprising a commercially available motor and a force sensor placed perpendicular to the axis of motor. The coated shaft is preferably held horizontally in order to reduce contact between parts of the mechanism.

Preferably both sides of the shaft are held by the shaft holders are connected to the motor and the other shaft holder supported by a bearing system, for stable rotation of the coated shaft.

A high rotational speed of this motor is preferred, above the operating speed of the MEMS motor, for the purpose of accelerating wear detection. The structure allows experimental tests to be conducted at a higher load setting, which in turn accelerates the wear, for shortening the evaluation period.

Such a structure allows a direct contact on a coated film, whereby the surface property of the interface can be evaluated. A slight change in surface contour triggers deviation on resistance force due to friction. Here, the frictional resistance of the coating is directly related to the contact pressure changes with increasing length of sliding. In this regard, the change

in tribological resistance of the contact is detected in terms of mechanical force that is recorded digitally on a spreadsheet by means of data recorder.

#### Brief Description of the Drawings

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 shows a prior art tribological measuring apparatus for a planar-coated sample;

FIG. 2 shows an embodiment of a measuring apparatus of the invention;

FIG. 3 shows the planar force vectors at the contact interface between rotating components of the embodiment of Fig. 2.

FIG. 4 shows the planar surface contact of the ring disk against the shaft holder of the embodiment of Fig. 2.;

FIG. 5 shows unstable rotation of a coated shaft; and

FIG. 6 is a schematic diagram of automated recording of measured data of the embodiment of Fig. 2.

Detailed description of the preferred embodiment of the invention

An embodiment of the invention will now be described with reference to Fig. 2 in which a test rig 200 is shown for evaluating the wear resistance of thin-coated film provided on a circular member, in this case a cylindrical shaft 201 that is used in a micro-motor assembly, with a constant normal load being applied onto the film layer.

The load is applied by a test member in the form of a ring disk 202 having a central circular opening, the side of which is pulled against a surface of a coated shaft 201 by attaching a hanging weight 209 with a cord 208 to the disk 202. The circular opening of the ring disk 202 resembles the corresponding surface of the rotor sleeve of a micro-motor in which the shaft 201 is received, such that the area of contact can be replicated. The disk is preferably made from the same material as the rotor sleeve and has the same surface characteristics. A small area contact 300 is thus attained at the interface.

The shaft 201 is rotated by a high speed electric motor 203. Ideally durability over  $10^9$  test cycles should be measured, so with a motor rotation speed of 6000 rpm, this implies a testing time of 10,000 hours. In order to minimise testing time a higher rotational speed is

preferred and depending upon the choice and rating of the motor, testing rotational speeds of about 50,000 rpm are available.

Measurement is performed by a force sensor 206 attached to the ring disk 202. The force sensor 206 is connected to the disk 202 via a connecting cord 207 to hold the disk 202 in place and measure the displacement rotational force on the ring disk 202 in response to rotation of the shaft which gives an indication of the resistance at the contact area 300 of the ring disk 202 and the rotating shaft 201. This resistance is due to the friction force at the contact surfaces.

FIG. 3 is a schematic force diagram of the test rig 200 which works on the standard tribological concept that friction force is generated with a normal loading ( $P$ ) perpendicular to the direction of sliding movement. In this regard, when the surface of the circular opening of the ring disk 202 is pulled to contact radially against the coated shaft 201 rotated in a clockwise direction, the latter 201 will experience a resistance ( $F_R$ ) in motion due to friction. Such contact friction on the shaft 201 surface brings the ring disk to rotate in the same direction that induced 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 the 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 the detected tension force obtained quantitatively on the force sensor 206 has equal magnitude as the

friction force experienced on the coated shaft 201 surface. This film surface property can be evaluated in the normalized form known as the Coefficient of Friction ( $\mu$ ):

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

Repeated abrasion on the coated film degrades the surface gradually over time, and this transition is reflected by the change in measured  $\mu$  value. Calibration for the change in film roughness with standard sample surface of known  $\mu$  value is preferably carried out to correlate with the measured data repeatedly. This comparison is particularly useful in determining the failure level when the measured  $\mu$  value increases dramatically due to wear occurrence of the film. 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 300; increasing load induces larger frictional resistance on the surface.

One of the preferred features of the embodiment illustrated in FIG. 2 is to place the coated shaft horizontally. In order to measure the friction force exactly, the ring disk 202 should contact only against the coated shaft 201. If the coated shaft 201 and the ring disk 202 are set up vertically in the manner shown in FIG. 4, the planar surface contact 400 of the ring disk 202 against the shaft holder 204 is inevitable during the test measurement due to gravity (G), and this contact area 400 causes friction force. An intended isolation between these surfaces is preferred during the testing in order to eliminate additional friction force other than

that from the coated curved surface of the shaft 201. Hence, the horizontal configuration of the coated shaft 201 and the ring disk 202 shown in FIG. 2 is preferred.

If only one side of the coated shaft 201 is held by the shaft holder 204, the rotation of the coated shaft 201 during the test measurement may become unstable. FIG. 5 shows the unstable rotation of the coated shaft 201. In this condition the contact force between the contact surfaces 300 is also unstable and it is difficult to measure the accurate friction force. Therefore in FIG. 2 it is preferred that both sides of the coated shaft 201 are held by the shaft holders 204 and while one holder is connected to motor 203, the other is supported by the bearing system 205, which guarantees stable rotation of the coated shaft 201.

In the abrasion study, the small converging contact 300 at the interface between the ring disk 202 and coated shaft 201 is desirable in the measurement for the change in surface property of the coated surface over a extensive test duration. The coated film should possess smooth surface after deposition, and does not cause bad interaction against the contacting ring disk 202 during testing. Other important specifications for ensuring reliable testing include good shaft 201 roundness and good alignment of force sensor with respect to the contact surfaces.

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  $\mu$  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 of the coated film under abrasive loading.

Although an embodiment of the invention has been described, this is not to be construed as limitative.

For example, the test member has been shown as a disc. The member can be of any form having a circular opening such as a hollow cylinder and can have any external shape, such as a square block having a circular bore therethrough.

Although the circular member is shown rotated and the force sensor attached to the test member, this may be reversed. The force sensor may also measure the force indirectly, for example if using an electric motor as the rotation means, the back emf of the motor may be measured to determine the resistance to rotation.

Any suitable rotation means may be used, such as an electric motor or other fluid driven motor. In a particular variation applicable to testing rotor shafts of micro motors, the test member may be configured as a motor stator, so that the test member and rotation means may be combined.

Although weighting of the test member is desirable to accelerate the wear process, this is not essential and in some circumstances the weight of the test member itself will be sufficient.

Although for most applications, a horizontal mounting of the circular member is preferred, for some applications, for example where the circular member will be mounted in an orientation other than horizontal in use or the difference in resistance to rotation when mounted in another orientation is constant and thus can be ignored, other mounting orientations may be used. Although, where the circular member is a shaft, mounting at both ends is desirable, mounting at a single end is also envisaged, particularly where the circular member is short, for example a stub shaft.

Claims

1. A method of measuring a surface property of a circular member comprising the steps of placing the circular member within a circular opening of a test member, rotating one of the circular member and test member relative to the other and measuring the rotational force on the other of the circular member and test member.
2. A method as claimed in claim 1 wherein the circular member is rotated.
3. A method as claimed in claim 1 or claim 2 wherein the force is measured by a force sensor coupled to the test member.
4. A method as claimed in claim 3 wherein the force sensor restrains movement of the test member.
5. A method as claimed in claim 1 or claim 2 wherein the rotating step is performed by an electric motor and the force is measured by measurement of the back emf of the motor.
6. A method as claimed in any one of the preceding claims wherein the test member is weighted.
7. A method as claimed in any one of the preceding claims wherein the circular member is disposed in a horizontal orientation.
8. A method as claimed in any one of the preceding claims wherein the circular member has first and second ends and is supported at both.

9. A method as claimed in any one of the preceding claims wherein the circular member is a cylindrical shaft of a micro motor.
10. A method as claimed in any one of the preceding claims wherein the surface of the cylindrical opening of the test member has the same surface property as a member which the circular member would engage is use.
11. Apparatus for measuring a surface property of a circular member, the apparatus comprising a test member having a circular opening in which a said circular member is receivable; rotation means arranged to be coupled to one of the said circular member and the test member and a force sensor arranged to measure the rotational force on the other of the test member and the said circular member.
12. Apparatus as claimed in claim 13 wherein the rotation means is coupled to the circular member.
13. Apparatus as claimed in claim 12 wherein the force sensor is coupled to the test member.
14. Apparatus as claimed in claim 13 wherein the force sensor restrains movement of the test member.
15. Apparatus as claimed in claim 11 or claim 12 wherein the rotation means is an electric motor and the force sensor comprises means for measuring the back emf of the motor.
16. Apparatus as claimed in any one of claims 11 to 15 wherein the test member is in the form of a disc.

17. Apparatus as claimed in any one of claims 11 to 16 further comprising a weight attached to the test member.
18. Apparatus as claimed in any one of claims 11 to 17 further comprising a support means for the circular member.
19. Apparatus as claimed in claim 18 wherein the support means comprises first and second spaced supports.
20. Apparatus as claimed in claim 18 or claim 19 wherein the support means is arranged to support the circular member in a horizontal orientation.
21. Apparatus as claimed in any one of claims 11 to 20 wherein the circular member is a cylindrical shaft of a micro motor.