A Micro Tribotester for MEMS Elements

Choong Hyun Kim*, Hyo-Sok Ahn+

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Abstract

A computer-controlled micro tribotester has been developed to investigate the friction and wear characteristics of thin coatings, which can be applied to silicon-based materials. In the developed system, a step motor gives a reciprocating movement and an electromagnet applies a load between a ball and a plate specimen. Test results confirmed that the application of load in the range of 0.03 ~ 1.8N and with a sliding speed of 4.44 ~ 7.70mm/s was successfully accomplished. Advantages of the developed micro tribotester are: (1) realization of micro load and displacement applicable to microelectromechanical systems(MEMS) using DC motor and electromagnet (2) continuously variable load and reciprocating speed; and (3) high reliability, which allows for unattended use for long periods.

Key Words : Tribotester, Tribology, MEMS, Friction force

1. Introduction

MEMS become much more useful with the introduction of thin hard protective coatings on their silicon-based material surface. These thin coatings are an effective solution in protecting MEMS from undesirable tribological contacts between moving parts or between the moving and fixed parts.

The reasonable level of contact load involved in MEMS is reported to be in the range of 0.001~1N[1]. However, traditional tribotesters cannot meet this load condition[2,3].

Accordingly, numerous researches have been conducted to investigate the measuring technologies for micro-machines and to develop micro tribotesters that meet the need for the study of friction and wear characteristics of thin coatings[1,4].

In addition, although some micro tribotesters have been developed, they are expensive and/or not easy to build

* Tribology Research center, KIST (chkim@kist.re.kr)
Address: 39-1 Hawolgok-dong, Songbuk-gu, Seoul, 136-791
+ Department of Die and Mould Design, Seoul National Univ. of Technology

up[5~8].

This paper describes the development of a cheap micro tribotester using a step motor as the prime mover and with simple structures.

2. Description of the developed system

The specification of the developed tester is presented in Table 1.

As shown in Fig. 1, the developed micro tribotester consists of a loading system, a step motor driving system and a data acquisition(DAQ) system.

Table 1 Specification of the developed micro tribotester

Applied load	0.03 ~ 1.8 N
Sensitivity in measuring friction force	15μN
Max. stroke/sensitivity	8mm/1μm
Reciprocating speed	4.44 ~ 7.70mm/s
Diameter of a ball specimen	ϕ3mm

A ball specimen ***1*** and a plate specimen ***2*** are installed on a loading plate ***11*** and on a working table ***7*** using each specimen holder. The loading plate is attached to a support arm ***14*** and maintains its horizontal level using a movable balancing weight ***15***. The support arm is placed over the working table and established on a base ***5*** using an upright stand ***13***. The stand moves up and down using a ball-screw so as to provide some space between both specimens to install them.

An electromagnet ***12*** applies magnetic force on the loading plate, which is made of steel, by supplying a current to the electromagnet. Then, the loading plate will turn on a hinge ***16*** to apply a load between the specimens.

On the other hand, a ball-screw system ***4*** converts the rotation of the step motor ***3*** into linear motion to provide a horizontal reciprocating movement to the plate specimen through the working table.

In the step motor driving system, a pulse-signal-adjusting method to control the windings-excitation force and a current-value-adjusting method for the windings were employed to ensure the precise operation of the step motor and fine control of the stroke[9]. Moreover, the step motor driving system is suitable for a friction-and-wear

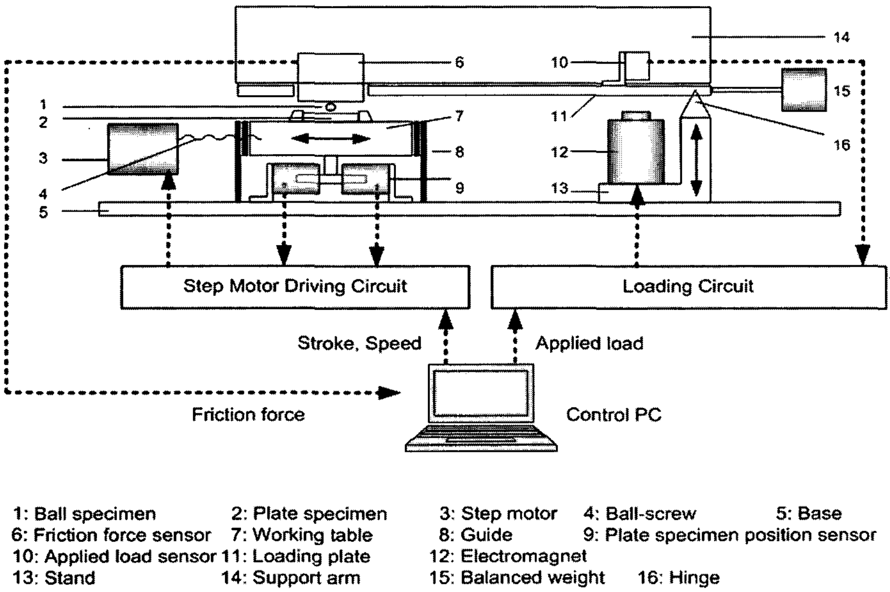

Fig. 1 Schematic view of the developed micro tribotester

tester that needs to be operated for a long time with the reduction of the amount of heat generated by the step motor.

The working table is supported by a guide ***8*** having horizontal elasticity so as to allow the working table to be horizontally reciprocated in a predetermined stroke and prevent the working table from being vertically moved.

As shown in Fig. 2, the guide is constructed by attaching an inner guide and an outer guide to each other, with the inner guide connected to the lower part of the working table and the outer guide fixed on the steel base of the tester, as explained in Fig. 1. The guide does not create an unnecessary displacement by the applied load in a direction perpendicular to the moving direction of the working table.

Three inductive sensors, ***6***, ***9*** and ***10***, measure the instantaneous horizontal displacement of the ball specimen, the horizontal location of the plate specimen, and the applied load, respectively, as shown in Fig. 1. The sensors transmit their output signals to linear variable differential transducer(LVDT) circuits, then these circuits generate and transmit operational signals to the step motor driving circuit and the loading circuit.

The DAQ system also maintains the stroke of the plate specimen and the applied load as predetermined values during a test, using those operational signals and closed-loop feedback circuits.

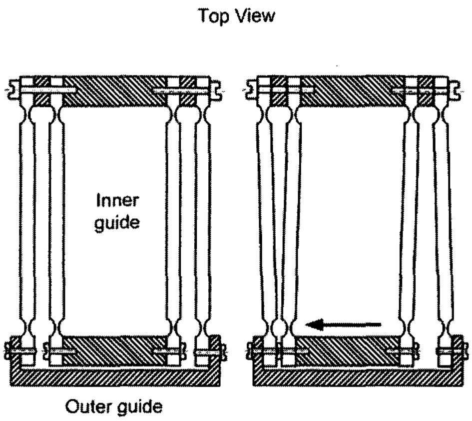

Fig. 2 Schematic view of the guide

3. Friction coefficient

The friction coefficient can be calculated by dividing the value of the friction force over the applied load. A schematic view of the friction force sensor is presented in Fig. 3.

Referring to Fig. 3, a stationary base ***17*** is fixed on the loading plate and a plate spring ***19*** connects the ball specimen holder to the stationery base. In addition, a thin metal plate ***18*** is attached to the ball specimen holder ***20***. During test, the ball specimen undergoes some friction force through the interaction with the plate specimen, and then the plate spring reveals an instantaneous movement. The movement of the plate spring will almost be same as that of the thin metal plate. Thus, the friction force is estimated by measuring the instantaneous horizontal displacement of the thin metal plate located inside the inductive sensor. When the spring constant and the instantaneous horizontal displacement of the plate spring are referred to as k and x, respectively, then the friction force F is kx.

4. Results and discussion

The developed micro tribotester was installed inside an

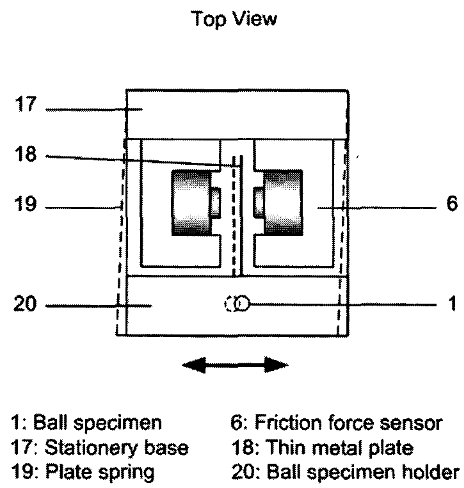

Fig. 3 Schematic view of the friction force sensor

environment chamber to control the temperature and humidity of the surrounding air.

Friction tests were performed using ϕ3mm diameter Si_3N_4 balls against diamond-like carbon (DLC)-coated plate specimens with 3nm coating thickness at normal loads of 0.18N and 1.8N. The tests were conducted at the relative humidity(RH) of 2.5%, 50% and 90%, with a reciprocating speed of 4.44 mm/s and a stroke of 3mm. The temperature was maintained between 28 ~ 31℃ during the tests.

Fig. 4 displays the frictional behavior of the DLC coating tested at 0.18 N. At 2.5% RH, the coefficient of friction was kept at a steady low value until 375 cycles. In the case of 50% RH, the test stopped at 550 cycles showed the initiation of coating damage. By contrast, the test at 90% RH revealed a complete failure of the coating after only 250 cycles.

The friction coefficient at various relative humidity with a load of 0.18 N is summarized in Fig. 5. The coefficient of friction was within 0.04 ~ 0.062 for the test at 2.5% RH and slightly increased to the range 0.07 ~ 0.085 at 90% RH, whereas it reached a much higher value between 0.105 ~ 0.125 at 50% RH. The results obviously demonstrated the influence of relative humidity on the tribological behavior of the coatings. The co-efficient of friction was higher at 50% RH compared to those at 2.5% RH and 90% RH. In the case of the test with a load of 1.8 N, we observed the same trend as that with 0.18 N.

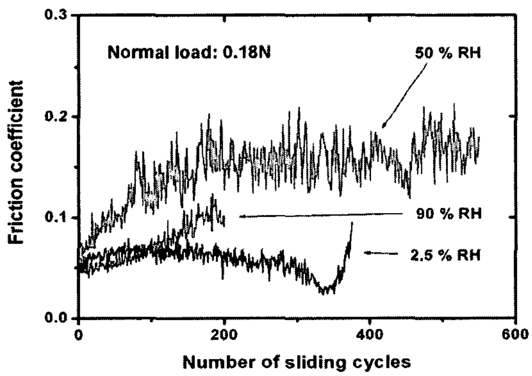

Fig. 4 Friction coefficient of the DLC coating versus sliding cycles tested at various relative humidity with a load of 0.18N

Fig. 6 shows the scanning electron- microscope (SEM) image of the original and worn surfaces tested at 50% RH for 1300 cycles. The dark region in the wear track indicated that the coating still remained, although the coating underwent considerable wear. Performance tests tell us that a stable operation could be achieved with an applied load range of 0.18~1.8N with the reciprocating speed of the tribotester at 4.44~7.70mm/s. With the exception of this range, the tribotester showed unstable performance with vibrations.

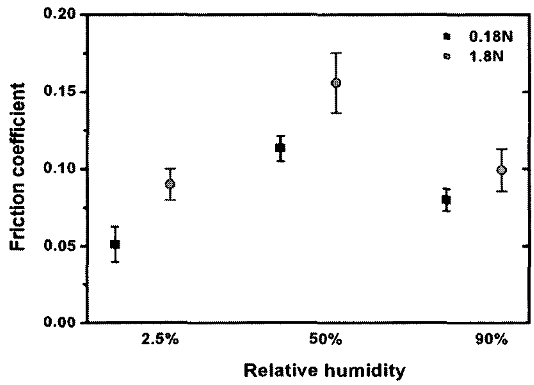

Fig. 5 Summary of the friction coefficient of the DLC coating

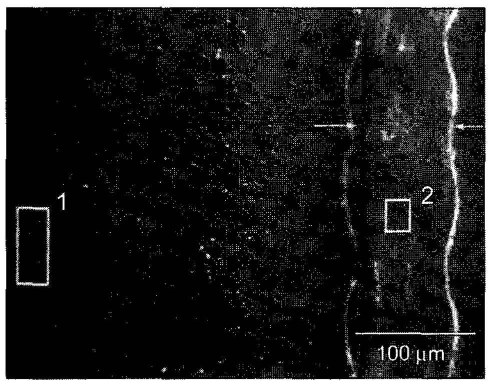

Fig. 6 SEM image of the DLC surface tested under the load of 0.18 N and relative humidity of 50%: Area #1 - original surface Area #2 - inside the wear track

These limited operational ranges likely come from the structure of the guide system consisting of several thin plates. A guide system using a ball-screw will be the solution to this problem in the future. On the other hand, the electromagnet generated no small amount of heat, but it was cooled enough by using a small fan.

5. Conclusion

Test results showed that the developed micro tribotester is good enough to serve as a friction-and-wear tester for the examination of various kinds of thin coatings for MEMS elements.

The applicable load and sliding speed ranges were 0.03 ~ 1.8N and 4.44 ~ 7.70mm/s, respectively, with high reliability.

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