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Numerical simulation of sliding wear between the rotor bushing and ground plane in micromotors

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Abstract

Since the advent of the first variable-capacitance electrostatic micromotor in 1987, there successively appeared many kinds of micromotors in micro-electro-mechanical systems (MEMS). However, wear behavior becomes a constrain factor of the development of micromotors and limits their service lifetime. In the paper, a linear sliding wear model with ratcheting effects is proposed to describe the wearing process and a simplified mathematical method is presented to simulate the wear of the rotor bushing sliding on the ground plane. The effects of geometry parameters, material properties and applied operating conditions on the evolution of dimensional and volumetric wear rates are explored for normally loaded rotating rotor bushing sliding on the ground plane. The hemispherical-bushing-on-ground-plane configuration finite element model (FEM) is established and the implementation of the contact problem based on ANSYS finite element software and contact element approach is introduced to investigate contact problems in micromotors. Numerical simulations and results of the contact stresses and contact pressure are studied and the effects of wear coefficient, material selections, surface roughness and geometry structures, etc., are discussed in detail. It is indicated that the non-linear effects cannot be ignored and these results must be evaluated on a relative scale to compare different design options.

Keywords: MEMS; Micromotor; Sliding wear; Rotor; Bushing

1. Introduction

Tribological behavior plays a key role in the reliability and robustness of micro-electro-mechanical systems (MEMS), and friction and wear are among the most serious problems in MEMS [1,2]. For micromotors to operate properly, friction and wear must be controlled because friction sometimes obstructs their operation, and wear limits their lifetime [3–9]. The power output from a micromotor and even whether or not it will rotate is critically dependent on the friction whereas wear will determine both the mechanical and the economic viability of the device [1]. However, wear has been widely investigated at such small dimensions, low surface roughness and light loads.

Sliding wear takes place when surfaces of components spinning contact each other. It has been suggested that the main parameters contributing to the sliding wear of a given system are the loads and the relative sliding of the contact [10]. Sliding wear between two bodies generally includes three steps [11], as displayed in Fig. 1. Firstly (see Fig. 1a), localized deformation develops beneath the coating surface due to the sliding contact loads. Such localized deformation can be the precursor of micro-cracks, which form as a result of the coalescence of micro-voids nucleated at inclusions in highly deformed regions at the coating subsurface, as shown in Fig. 1b. Continued sliding contact promotes crack growth and causes adjacent cracks to combine (Fig. 1c). Finally, cracks propagate towards the surface at weak points and wear debris is formed.

Some researches have been done to study the contact problems in micromotors in recent years [1,12–14]. Zhang and Meng [12] presented a mathematical model of the contact between the rotor and bearing hub in a micromotor. The contact stress and strain distributions were calculated and simulated with FEA under the scaling effects of micro-scale. The results showed that the contact effect cannot be ignored at micro-scale in micromotors. Suzuki et al. [13] used simple macroscopic riders sliding on a disc and studied qualitatively a range of MEMS materials under lubricated and dry sliding conditions. Their riders were designed to obtain the same contact pressure as in a side-drive

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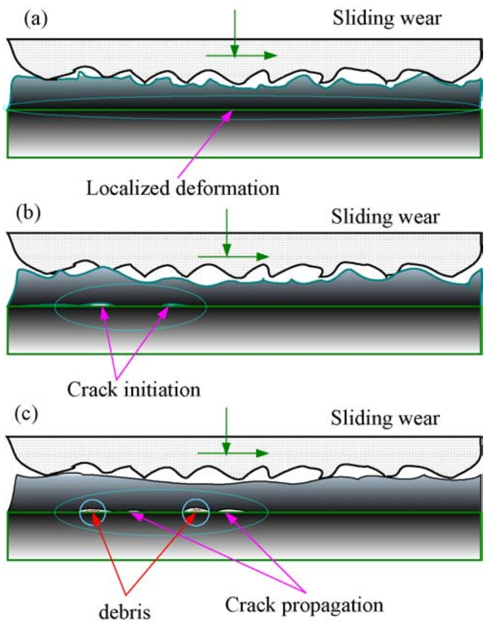

Fig. 1. Schematic illustration of the wear process: (a) accumulated localized deformation; (b) crack initiation in the subsurface; (c) crack propagation and wear debris formation (darker regions denote the higher levels).

micromotor but using loading which are orders of magnitude higher than in MEMS. Their results indicated that the wear rate in MEMS is expected to be far less than the bulk case and that the wear rate depends on the load even under the same contact pressure. Beerschwinger et al. [1] investigated the wear of MEMS-compatible materials in micromotors for a range of contact areas and contact forces typical of MEMS. Two possible types of wear mechanism were identified, one being dominated by asperity fracture and the other by asperity deformation. DLC, SiO_2, Si_3N_4 and SCS fell into the first category and polysilicon into the second. In addition, any micromotor design should not only consider the wear rates at appropriate sizes and contact pressures but also the implications of wear on the electrostatic and mechanical behavior of the motor [14].

One task of practical importance is how to predict the wear of normally non-ideal contact surfaces [15]. Their shapes vary due to sliding velocity, load, material parameters, surface topographies and will be changed as a result of wear and tangential traction. The process of wear has been widely modeled using the finite elements method, although these approaches have studies only one wear mechanism [16]. The contact analysis in FEM is a non-linear problem. The importance in modeling, accurately, wear mechanism for any pair of materials using the FEM is the ability to obtain precisely the amount of material worn out for any sliding situation and for any geometry of a mechanical system.

The paper is organized as follows. In Section 2, we describe the background of contact problems in variable-capacitance micromotors. In Section 3, we present a wear model of a hemispherical bushing sliding on ground plane in the wearing process. In Section 4, we investigate the dimensional and volumetric wear of the hemispherical rotor bushing mentioned above. In Section 5, we set up the finite element model (FEM) of the

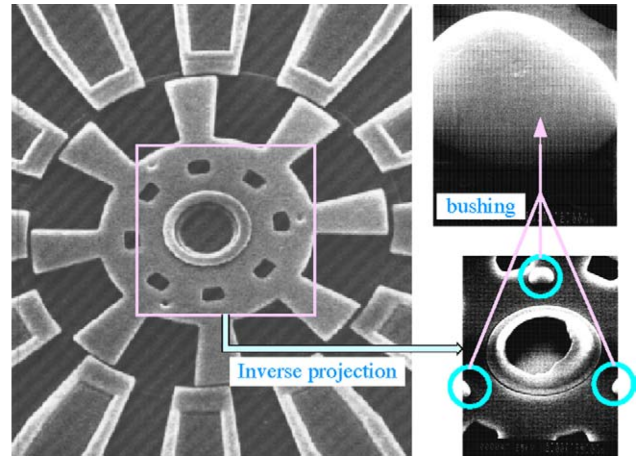

Fig. 2. SEM photo of a micromotor with 12/8 (stator/rotor) poles and 3 hemispherical bushings.

configuration and analyze the characters of the contact pairs. Numerical simulations results of the dimensional wear, volumetric wear, contact stresses and contact pressure are studied and the effects of wear coefficient, material selections, surface roughness and geometry structures, etc., are discussed in Section 6. Finally, we end the paper in Section 7 with conclusions.

2. Problem background

Surface micro-machining, bulk micro-machining and the LIGA (a German acronym for X-ray Lithography, Electrodeposition, and Molding) process of silicon and its compounds have been applied to the fabrication of many types of micro-actuators, including variable-capacitance micromotors [6–9].

The paper considers a typical variable-capacitance micromotor from the literatures [6,8,9] as the investigation object, as shown in Fig. 2. Fig. 3 displays a schematic diagram of a cross-sectional view. A part of geometry parameters and material properties of the micromotor shown in Fig. 3 are listed in Tables 1 and 2, respectively.

As illustrated in Figs. 2 and 3, the rotor is supported on bushings and is free to rotate about a center-pin bearing. Bearing backsides of the micromotor are made with three hemispherical bushings. During the operation of the motor, the rotor is intended to be in electrical contact with the ground plane or the shield beneath it by bushing or bearing. The bushing friction and wear would result from the gravity of the rotor and an attractive force of the rotor and the ground plane depending on the capacitive

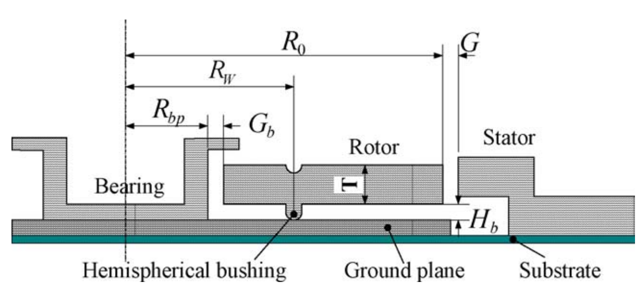

Fig. 3. Cross-section view of a variable-capacitance micromotor shown in Fig. 2.