8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineeering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

INFLUENCE OF SAM DEGRADATION ON MEMS-GEAR DYNAMICS

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Key Words: *MEMS, SAM, micro-gear dynamics, nanoscopic contact mechanics.*

ABSTRACT

All machines and mechanisms have contacting parts that transmit motion and forces. Thus, irrespective of physics of scale, accurate predictions for load bearing conjunctions are critical. Recently, the technology of manufacturing micro-electromechanical systems (MEMS) has improved significantly. However, improving their reliability is owed to the fundamental understanding of the kinetics of small gaps. The complexity arises from the significant role of surface energy effects. Rough surfaces promote asperity adhesion. If wetted, nano-menisci bridges form. To reduce both effects, the mechanisms are encapsulated in inert atmospheres and coated by hydrophobic self-assembled mono-layers (SAM). However, progressive wear of the protective SAM exposes the silicon substrate [1].

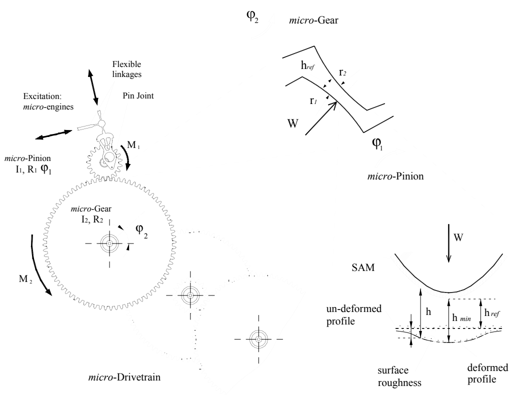

Figure 1: MEMS gears: General view

There has been little fundamental analysis of such vanishingly small conjunctions under transient impact conditions. This paper attempts to contribute towards a growing understanding of the problem. Figure 1 shows a set of MEMS gears, the contact of meshing teeth and surface topography. The operation speed is usually very high (KHz). To understand SAM wear, it is a common practice to subject MEMS gears to step changes in contact kinematic conditions, where lower operational speeds ($\sim$1Hz), increase the chance of adhesion. It has been observed that MEMS gears operate smoothly at high speeds irrespective or surface conditions, but progressively erratical at low speeds (and eventually stop).

If ingression of water is inhibited, the forces acting between meshing pairs of teeth are due to asperity deformation, adhesion (described by the JKR model) and impact forces. SAM wear and impact behaviour of the contact are closely intertwined. Both affect the inertial dynamics of the mechanism, which itself determines the prevailing impact conditions. A certain repetitive impacting condition is required, below which a diminished impact force would not overcome the adhesion [2]. However, a large impact force would damage the SAM. Thus, there are bounds of operation speeds for micro-gears where the lower limit is far more restrictive.

Inertial dynamics of a micro-gear pair is given by:

$$\begin{cases} I_1\ddot{\phi}_1 + R_1 W = M_1(t, \phi_1, \dot{\phi}_1) \\ I_2\ddot{\phi}_2 - R_2 W = M_2(t, \phi_2, \dot{\phi}_2) \end{cases} \tag{1}$$

where M_1 is the excitation moment on the pinion and M_2 the resisting moment. The JKR model for the contact of a pair of asperities (with the equivalent tip radius β and contact footprint a) states [3]: $P^\beta = P_0^\beta - P_a^\beta = [4E'a^3/3\beta] - \sqrt{8\pi a^3 \Delta\gamma E'}$. If a negative exponential distribution is assumed for N such asperity pairs, then [2]: $p_{asp} = N[P_c^B/\sqrt{2\pi}] \int_{-L}^{\infty} f(\Delta/\Delta_c) \exp\{-(h+\Delta)^2/2\} d\Delta$. Where $P_c^{\mathbf{B}} = 1.5\pi\mathbf{B}\Delta\gamma$; $\mathbf{B} = \sqrt{2/\pi} \int_0^\infty \exp(-\rho^2/2\beta^2) d\rho$; $\Delta = \delta/\sigma$; $\Delta_c = \delta_c^\beta/\sigma$; $h = l/\sigma$.

Noting that the inertial impact force must equate the integrated contact pressure distribution [4], then:

$$W = \iint p_{asp} dx dy \tag{2}$$

Now, simultaneous solution of (1) and (2) provides the results.

A decelerative step is imposed, from a rotational speed of 3.5KHz to approximately 1Hz, with SAM percentage coverage levels of 100%, 70% and 50%. Figure 2(a) shows that at high speeds operational integrity is assured, whilst at low speeds the behaviour becomes erratical with wear of the SAM layer (lower percentage coverage). Note that a wear model is not included in the analysis. This constitutes the next natural extension to the current work. Figure 2(b) shows a more detailed system behaviour at lower speeds on a logarithmic scale. For the simulated conditions, 50% coverage of the contacting surfaces constitutes the limit of adhesion for low speed operations.

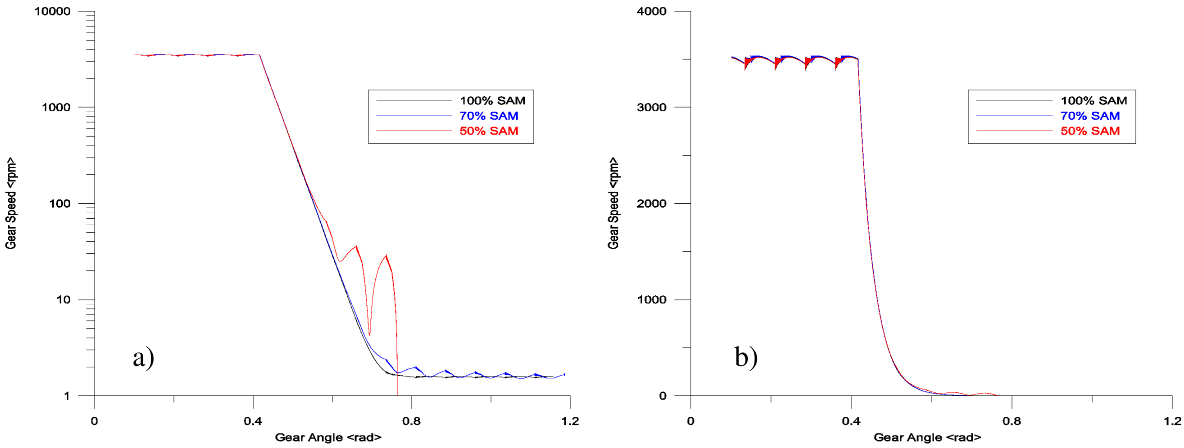

Figure 2: Transient behaviour with SAM percentage coverage of meshing surfaces

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