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50. Internationales Wissenschaftliches Kolloquium
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Tribology of Nanopositioning

ABSTRACT

The performance of nanopositioning is to a large extent limited by friction-caused errors, in particular when direct-drive mechanisms are employed. The absence of a transmission mechanism combined with the existence of nonlinear friction, notably the stick-slip, often creates problems such as tracking errors in the positioning control. The tribology (friction, wear and lubrication) is thus crucial for the further development of the nanopositioning technology. It aims to provide friction models for the system control, to search for bearing materials and tribological coatings for both vacuum and environmental applications, and to investigate the lubrication of the nanopositioning system. This contribution describes the study of tribology of nanopositioning performed in the special cooperative research centre SFB622 in Ilmenau. Topics such as bearings, thin film lubrication and tribological coatings will be introduced.

BEARINGS AND MATERIALS

Two kinds of bearings, the rolling-element linear-motion bearings and the sliding bearings were tested by a microtribometer[1-2]. In measuring the pre-rolling motion of linear bearings, we observed a linear relationship between the friction force and the driving displacement at driving strokes less than ~1µm. In this range, the relative displacement of the two guideways was fully reversible. Increasing the driving strokes resulted in, at first friction hysteresis, typical nonlinear spring behaviour of linear spring, then jumps of friction forces. Compared with the ~1µm in dry running, the maximum stroke below which the displacement of the guideways was reversible was ~0.5 µm in lubricated running. These results demonstrate that nanopositioning is possible in the range of less than ~1 µm when it is transmitted by linear bearings.

The sliding friction measured from various bearing materials shows that the surface conditions play a crucial role in determining the tribological performance of the slide bearings. For chromium steels in a ball-on-plane setup, large fluctuations of friction were observed in high-cycle sliding. Such a rough sliding is closely related with the continuous change of the microstructure of surfaces, specifically, the build-up and peeling of the oxide films [2]. The hardness of the substrate affects the friction fluctuation too. As a contrast to the smooth sliding from copper, significant fluctuations of friction were observed from thin chromium coatings on silicon substrates [3]. For polymer materials, the transfer films are important in determining the sliding behaviour. The sliding of polytetrafluorethylen (PTFE) based composites produces thick transfer films with a consequence for rough friction [4]. Some hard filler intentionally introduced to increase the strength of polymers can result in an enhanced wear and thick transfer films. The characteristics of the filler material such as its shape, concentration, and the interface between the filler and the matrix are important for the tribological performance.

LUBRICATION AND COATINGS

Due to the low operating speed, the lubrication of the nanopositioing system is dominated by boundary lubrication, at most thin film lubrication with only a few layers of molecules coming into contact. If the thin films are optimized both in structure and properties, for example a self-organized monolayer of opctadecyltrichlorosilane or perfluorodecyltrichlorosilane on Si, the coefficient of friction as well as stick-slip can be significantly reduced [5]. Another important issue is how to increase the bonding strength of the lubricant molecules to substrates. Our results demonstrated that by tuning the end group of molecules, for example from perylene to perylene-tetracarboxylic-dianhydride, which are with the same backbones but different ending groups, the bonding strength at interface can be increased several orders [6]. Another possible lubrication is by solid lubricant coatings, which is also the most possible solution of lubrication in vacuum. We developed a nanoscale WC/C coating with crystalline WC as hard phase, amorphous carbon (sp^2 rich DLC) as low friction phase (lubricant film) and in a multilayered structure to ensure a proper supplier of lubricant [7-8]. This coating shows a wear rate of ~nm/hour after a proper running-in. Further optimization of the processing of this coating and the evaluation of its tribological performance in vacuum are in progress.

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