Friction controlled precision positioning

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Abstract

A new principle for precision positioning using friction contacts is introduced. Shear forces smaller than the sticktion limit are applied to a contact, generating a remanent displacement that originates from the pre-sliding friction regime. This paper shows experimentally that this method allows continuous low velocity positioning in the sub millimetre range with nanometre resolution.

1 Introduction

Friction is an important issue in high precision positioning systems. In many systems friction is a problem that has to be controlled and preferably avoided, for instance by positioning contactlessly using magnetic or air bearings. On the other hand using friction is often required, as it is one of the few ways to fixate an object stably without active control. When motion capabilities have to be combined with passive stability, for instance for the alignment of optical components, friction based systems such as the commercially available piezo-inertia and -walking actuators, or the novel Thermal Slider [1] are used. This paper adds a new friction positioning method that is able to generate a continuous nm resolution motion.

2 The pre-sliding effect

Traditionally friction is seen as a 2 phase process, stick and slip, characterised by an irregular, discontinuous motion profile. The analysis of metallic point contacts showed that at micrometre scale motion there is no full slip, but only a creep-like motion [2]. This is better known as the pre-sliding phase, the phase between stick and sliding. In this pre-sliding phase a remanent displacement, one that remains after removing the contact shear force, occurs by applying a shear force below the sticktion limit. The sticktion limit is the load at which full sliding occurs; this is dependent on contact properties and history. Pre-sliding generally determines the motion in low velocity friction contacts and is observed with various material combinations.

3 Positioning using pre-sliding

To achieve a well-controllable displacement, a preferably linear, or at least smooth relationship between force and motion velocity is required. In the presence of friction this implies avoiding the relatively discontinuous and unstable transition to the full sliding phase, and using purely the pre-sliding phase for positioning. In the most crude sense this means that the applied force must remain below the contact sticktion limit. This in turn implies that the motion velocity is limited, typically to the level of several μm/s, in order to remain within the pre-sliding phase. In practice, the relationship between force and pre-sliding velocity is non-linear and dependent on variables such as motion history and normal load. Precise positioning can be achieved by applying feedback to control and limit the pre-sliding speed. The current focus is however on showing the positioning potential of actuation in the pre-sliding regime.

4 Experimental setup

Preliminary research showed that the material combination PTFE-steel has a relatively large pre-sliding range. Therefore it was used to investigate the actuation capabilities. The used experimental setup is schematically shown in figure 1.

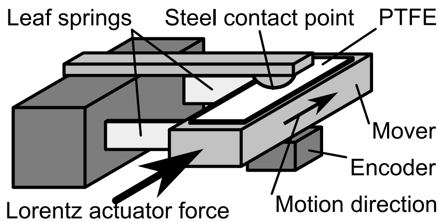

Figure 1: Schematic drawing of the experimental friction contact set-up.

It comprises a leaf spring suspended mover with a PTFE pad on top, and a suspended contact point applying a normal force of 15 N. The mover suspension is only compliant in the motion direction, effectively smaller than 0.1 N/mm due to a positive control stiffness using the encoder and the Lorentz actuator. The actuator also exerts the net shear force to the contact. The displacement details were recorded by a capacitive sensor (not shown in the figure) with 0.3 nm resolution at 1 kHz.

5 Experiments

First, it will be demonstrated that a remanent displacement can be generated in both positive and negative motion direction. For that purpose different shear force levels between 0.1 N and 1.0 N are applied. At regular intervals of one second the force is gradually reduced to zero to verify that the displacement is indeed remanent. Figure 2 shows the forces on, and the displacements of the contact point in positive motion direction. As the behaviour in negative direction is comparable, remanent displacement in both directions was clearly achieved. When the force is brought back to zero a reverse creep-like motion is visible, although significantly smaller than the intended motion.

Next, the average motion velocity is (non-linearly) dependent on the applied force. At low force magnitude the remanent displacement velocity is negligible and merely the displacement due to the finite stiffness of the measurement setup (0.2 N/μm) is observed. The velocity then increases with the applied force reaching velocities larger than 10 μm/s before finally approaching full, unstable sliding.

Finally, this measurement shows a time dependency of the remanent motion velocity. The pre-sliding velocity decreases over time at forces below 1 N, indicating that the motion range using pre-sliding may be limited. However, a pre-sliding motion of 0.5 mm was generated using step-wise pre-sliding actuation.

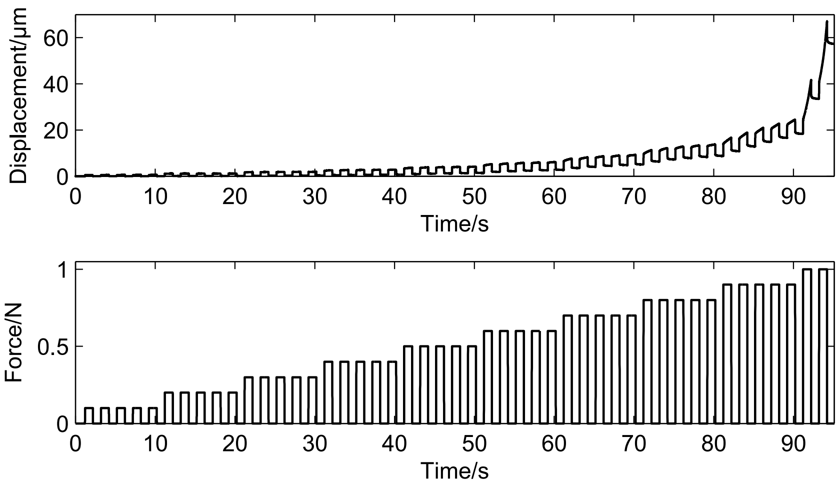

Figure 2: Step-wise pre-sliding motion in positive motion direction due to forces between 0.1 N and 1 N. The behaviour in the negative direction is comparable.

In figure 3, applying constant shear forces is demonstrated. This actuation type also creates remanent displacements with the features described before. At 0.9 N the average pre-sliding speed is 2.5 μm/s. 10 seconds after the load ended, the creep velocity was reduced to 15 nm/s and after travelling a total distance of 65 μm.

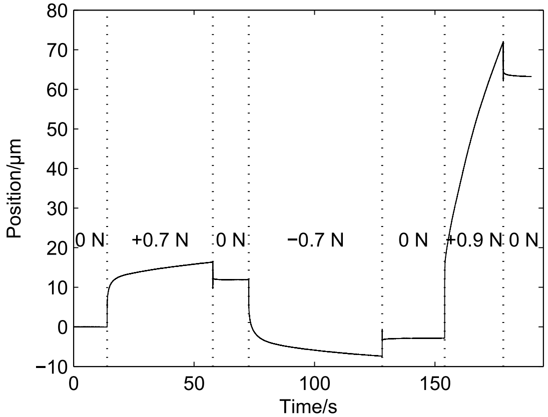

Figure 3: Continuous pre-sliding motion due to different constant shear forces, indicated in the graph. Also position stability after motion is demonstrated.

6 Discussion and conclusion

It was shown that by enforcing a friction contact with forces below the static friction limit, remanent displacement can be generated in the micro- to millimetre range at velocities of several μm/s. Therefore, this principle of applying forces such that the contact remains in the pre-sliding regime, can be used for precision positioning tasks when the motion speed may be limited. The friction regime still exhibits several non-linearities, but an open-loop stable motion was shown for the PTFE-steel contact. Also the motion velocity can be controlled relatively easily by varying the force.

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References:

[1] van Schieveen J P et al. 2009 *Euspen conf. proc.* Vol. II pp 110-3

[2] van de Ven O S et al. 2012 *Euspen conf. proc.* Vol. I, pp 478-81