Controlled Pre-sliding for Precision Positioning

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Introduction

Delicate tasks, such as alignment of optical elements or high precision sensors, often require motions in the millimetre range with sub-micrometre precision. The alignment function must, however, be combined with a good position stability after alignment. As disturbances should be minimized in these applications, it is preferred to achieve this stability passively, or in other words, without active control, and with a high stiffness. These demands make friction clamping a preferred way to achieve stability, but stick-slip effects might lead to problems with precision positioning.

To solve the problems during precision position tracking in the presence of friction, typically complex friction models are used to reduce the tracking error. For an alignment task, however, only the final position accuracy and stability are relevant and not the motion in time. Due to this boundary condition, the motion profile remains flexible and a simple control structure can be used. In earlier work [1] the pre-sliding regime was identified as a good option for positioning friction contacts. This paper shows experimentally how a simple control structure can be used for precise positioning in the pre-sliding regime.

The pre-sliding effect

Traditionally, friction is seen as a process with two discrete phases, stick and slip. On micrometre scale, however the transition between stick and slip is not discrete but smooth. This creep-like transition is better known as pre-sliding. Pre-sliding velocities are typically small, in the order of nanometres to micrometres per second. The pre-sliding forces are below the sticktion limit (static friction). PTFE was used in preliminary experiments because of its clear pre-sliding behaviour. Fig. 1 shows an example of a pre-sliding motion in a single PTFE-steel contact. When applying a positive or negative force below the sticktion limit the motion is, typically for pre-sliding, steady and smooth and depends (nonlinearly) on the applied force and on time.

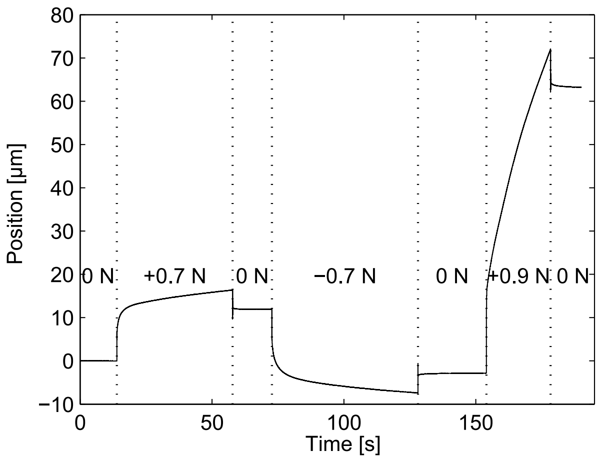

Fig. 1: Pre-sliding displacement due to shear forces on a single PTFE-steel contact with contact shear forces between -0.7 N to 0.9 N. The normal force is constant and approximately 15 N.

Controlled pre-sliding

Smooth positioning on (sub-)micrometre scale is possible by remaining in the stick-slip transition zone. As the motion trajectory is not relevant for the alignment task, the following three positioning strategies can be proposed to perform the full alignment task.

1. Apply forces larger than the static friction limit. Stick-slip will occur, this is therefore suitable for fast coarse positioning.
2. Control the *motion velocity* to values of the same order of magnitude as the pre-sliding velocity, typically (sub)micrometre per second. The motion is smooth and therefore used for fine positioning.
3. Control the *forces* such that they remain below the static friction limit, for instance using a limited integral control action. Velocities are typically lower than with strategy 2, making it suitable for fine positioning.

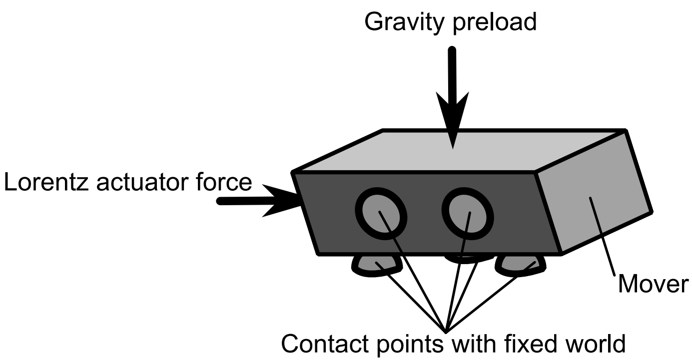

Fig. 2: Schematic drawing of the experimental setup. The gravity preload is approximately 2 N. The five contact points are placed such that they are all preloaded, allowing motion in one direction only.

Positioning experiments

Fig. 2 shows an experimental setup that consists of a mover placed on five contact points. A shear force is applied using a Lorentz actuator. Using this setup two experiments were conducted.

First, using PTFE-aluminium contact points, the three positioning strategies mentioned before were subsequently executed to approach position 0. The transitions between the different strategies were made with a fuzzy controller based on the positioning error. The measurement results are shown in Fig. 3. Using strategy 1 (0-0.8 s) the relatively large forces cause a fast approach of the target, but also significant overshoot. Strategy 2 (0.8-2.3 s) uses velocity control to reduce the position error from 100 µm to 1 µm with a speed of 70 µm/s. PI position control in the pre-sliding region, strategy 3, was used to obtain the final positioning accuracy (2.3-10 s). The target position was reached within the sensor resolution of 10 nm.

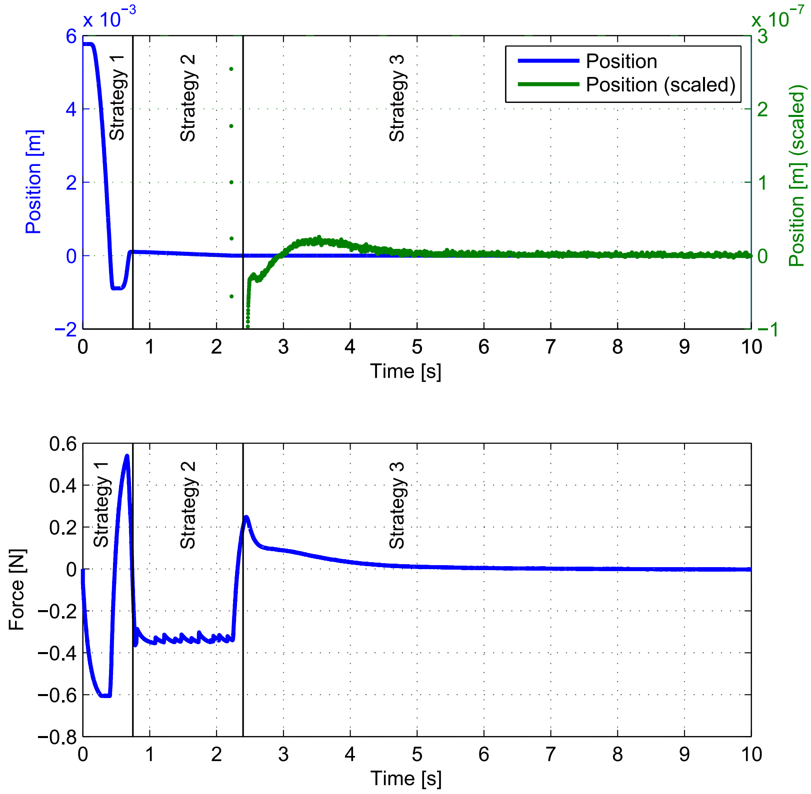

Fig. 3: Measured position and applied force when approaching position zero using the three motion strategies. The contact points were PTFE-aluminium.

The friction properties of PTFE contacts are beneficial for sliding but also cause a limited passive stability. Therefore a second experiment was performed with the same setup, now using aluminium-steel contacts. These contacts also exhibit the pre-sliding effect but have better stability properties. The measurement in Fig. 4 shows velocity control (strategy 2) in positive (1-4 s) and negative (7-10 s) direction and the position stability zero force (4-7 s). The velocity set-point was 10 μm/s. Proportional control only maintains a steady pre-sliding velocity, causing a steady-state velocity error of 3 μm/s. The slow start of the velocity control is caused by a low-pass filter on the control force, which is required for achieving a steady sliding speed. When switching off the actuator force (after 4 s) an elastic jump of 200 nm is observed. After that no position drift is observed within the 10 nm sensor resolution.

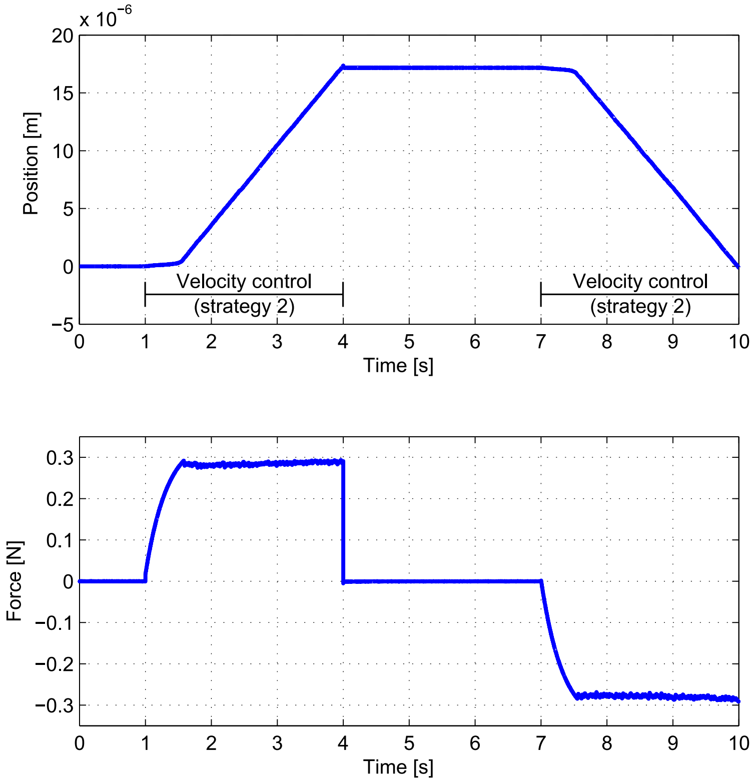

Fig. 4: Measured position and applied force for standstill and bidirectional velocity control of steel-aluminium contacts. The velocity is proportionaly controlled and the force is low-pass filtered.

Conclusions

It was shown that precise nanometre scale positioning of a mover suspended by PTFE-aluminium friction contacts is possible using several different displacement strategies. It was also shown that pre-sliding actuation of a more stable aluminium-steel point contact is possible using low speed velocity control. Like with the PTFE-aluminium contact, this was achieved by deliberately remaining in the pre-sliding friction regime during positioning. These results indicate that positioning in the pre-sliding regime is a good option for performing accurate alignment tasks.

Acknowledgement

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References

[1] van de Ven O S et al. 2014 Euspen conf. proc. Vol. II, pp 396-9