Experimental Investigation in the Friction Characteristics of High Precision Planar Ball Guides

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Abstract

Detailed knowledge about the rolling friction behaviour is a precondition for the mechanical design and the development of control systems for precision drives based on ball guides. Until now research was focused on the rolling friction behaviour of linear guideways and cannot be adapted for planar ball guides. The following contribution presents an experimental study of planar guides with regard to ball-plane contact friction behaviour.

1 Motivation

A growing number of high precision applications (e.g. wafer positioning) require a technical vacuum environment. The preferable deployment of aerostatic guides is than hindered by the need of elaborate suction systems. Common alternative solutions based on cumbersome stacked linear guideways struggle with low stiffness, unwanted moving masses and an unfavourable position of the gravity centre.

The planar ball guide avoids these disadvantages and promises high rigidity, compact design and enables the runner to be moved in three DOF related to the fixed guide surface [1]. It consists of two functional guide surfaces and balls arranged in a flat cage in between.

An essential precondition for the mechanical design and the design of the control system of high precision positioning systems based on ball guides is a detailed knowledge about the rolling friction behaviour [2]. Since there is a lack of scientific studies on the rolling friction behaviour of ball-plane contacts - in particular the elastic motion hysteresis - this work will address on that. The relevant displacements and associated forces are very small thus defining a challenging measurement task. All parasitic effects causing noise need to be minimised to achieve reliable results.

2 Friction-force behaviour and breakaway-path

Based on previous studies of linear guideways the friction-force curve can be divided into three stages (Fig. 1) [3]. The changeover from stage II to III defines the breakaway-path.

The results of pre-existing investigations of all three stages with ball-V-groove contacts cannot be transferred to a planar ball guide, because of differences in the mechanical contacts (Tab. 1).

Table 1: Measurement setups and their rolling measurement results

Measurement setup	Type of rolling contact	Normal load	Breakaway-path (changeover from II to III)
[3] – 1990	not documented	580 N	100 µm
[5] – 2008	point contact: ball in V-groove	46.5 N – 123.2 N	40 µm – 60 µm

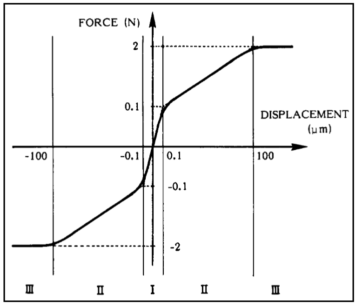

Figure 1: Classification of friction force-displacement curve [3]

3 Measurement setup

The planar ball guide has been reduced to its simplest form to create clearly predetermined conditions (Fig. 2). To avoid any sliding friction the cage has been eliminated. In order to force the runner to move strictly downhill the measurement setup has been inclined in relation to the field of gravity (Fig. 3). So, additional guides that would cause parasitic effects are not required. The motion path of the runner is measured interferometrically and the friction force is taken by a force sensor based on strain gauges adapted from a precision weighing cell. The coupling between the runner and the force sensor is realised by a fibre, which minimises influences on the runner by parasitic force.

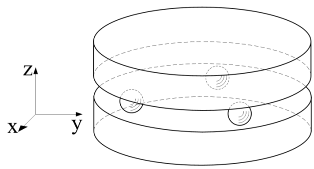

Figure 2: Elementary planar ball guide

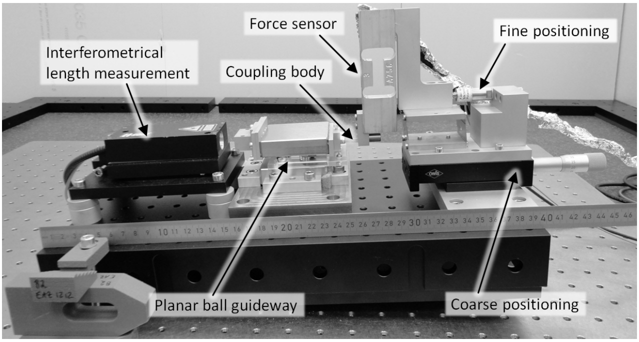

Figure 3: Measurement setup

4 Results

Preliminary experiments with the presented measurement setup were conducted with planar steel plates with an overall geometrical deviations of 4 µm (flatness, waviness, roughness) and steel balls of class G28 (DIN 5401) with a diameter of 10 mm. The normal force per ball of 1.5 N is defined by the weight of the upper plate. During the initial experiments the rolling friction and the motion course of the runner were measured. The friction-force is determined by the force difference between the forward (traversing from 0 µm to 225 µm) and the backward (traversing from 225 µm to 0 µm) trace (Fig. 4).

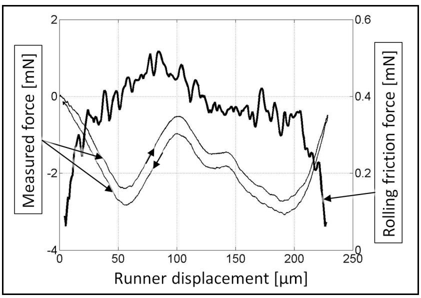

Figure 4: Measured friction-force behaviour up to 225 µm runner displacement

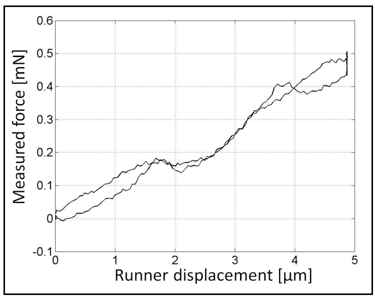

Figure 5: Measured force up to 5 µm runner displacement

The measured force (Fig. 4) shows the rolling friction force superposed by influences mainly caused by the geometrical deviations.

However, a breakaway-path of about 25 µm can be derived from the measurement results (Fig. 4). This breakaway-path of the planar ball guide is smaller than the breakaway-path of linear guideways (Tab. 1). Motion steps smaller than 5 µm are not evaluable at the current state because the friction force is below the measuring uncertainty of the used force measurement system (Fig. 5).

5 Conclusions and Outline

This paper focuses on the measurement setup to determine the friction-force behaviour of ball-plane contacts. In order to allow investigations in rolling friction the overall design of the setup has been systematically optimised to the indispensable elements thus reducing parasitic effects to a minimum.

A breakaway-path of about 25 µm has been confirmed by initial measurements taken with the presented measurement setup. To improve the resolution of the force measurement a force sensor is currently under development.

Acknowledgements

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