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# Experimental Investigations on Stick-Slip Phenomenon and Friction Characteristics of Linear Guides

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**Abstract**

In the present study, we investigate the stick-slip phenomenon and friction behaviour of industrial ball bearing linear guides to get some precise and comprehensive data on this matter. As friction influences some important characteristics of machine tools and the provided data from the manufacturer's catalogue do not cover all the details of various working conditions, it is essential to investigate it thoroughly. Translational guides with various preloads and under different external loads and running velocities are experimentally investigated. Afterwards, to provide a more practical condition, a slide is mounted on four carriages, and the same experiments are conducted. Finally, the friction force-time diagrams and also the friction coefficients are compared and evaluated for different working conditions.

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*Keywords:* Linear guideways; Machine tools; Friction; stick-slip phenomenon; Ball bearings

## 1. Introduction

Due to the increasing demands from the industry, precision manufacturing is one of the vital necessities for today's machine tools [1]. Therefore, the behaviour of the machine components in different working situations should be investigated. Friction is unavoidably present in many mechanical systems, whose performance is considerably influenced by contact stiffness parameters [2].

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To maximize their performance, all the components included in the structural loop of machine tools should be thoroughly investigated. With a deep understanding, one can judge about their possible error sources [3]. The structural loop consists of the spindle shaft, the bearings, the housing, guideways and frame, drives, tool and work-holding fixtures [4]. Friction influences some significant characteristics of machine tools, such as their accuracy, energy efficiency, reliability and length of service, especially for high speed machines [5, 6]. Wear resistance and low friction to avoid gripping, stick-slip phenomena and aging of the surfaces are one of the functional requirements for longitudinal guides [6, 7]. Furthermore, consuming little electricity and reducing coolant use are some of the important requirements for today's industry [9].

The contact joints are one of the most complicated elements of machine tools and the evaluations of their properties at the design stage are not very accurate [10]. The role of friction minimization on accuracy enhancement of hydrostatic guideways has been studied [11]. Some researchers have investigated the static stiffness and friction behaviour of translational guides [12]. Some researchers have studied about the influence of friction in machine tools' performance. The effect of thermal deformations on the motion of machine tool slide guide has been studied [13, 14]. Some researchers have pointed out in their works that the static and dynamic characteristics of supporting assemblies of machine tools are mainly affected by guideways [15].

Stick-slip motion of plain machine tool slide-ways has been simulated numerically [16]. Frictional vibrations are phenomena, which take place between contacting surfaces with relative motion and their wear occurs by friction [8]. Friction models for precise positioning system in machine tools and their numerical validations are investigated [17]. Various factors influencing the cutting tool life are studied to increase it [18].

In this work, we have investigated the stick-slip effect and friction behaviour of ball bearing linear guides through experiments. Guides with different preload levels, namely light and medium preloads and normal guides (without preload) are investigated. Friction behaviour is studied for guides without external loads and under loads of 25 kg and 160 kg. Then we have carried out experiments with different travelling velocities of 19 mm/s, 52 mm/s and 325 mm/s, to study the influence of it on backlash and friction behaviour. Finally, the same tests are conducted for a slide mounted on four carriages.

## 2. Test stand

To study the stick-slip phenomenon and friction behaviour, a test bench has been devised, which consists of a carriage, guide rail, pneumatic cylinder, force transducer and a chain (Fig. 1**Pogreška! Izvor reference nije pronađen.**).

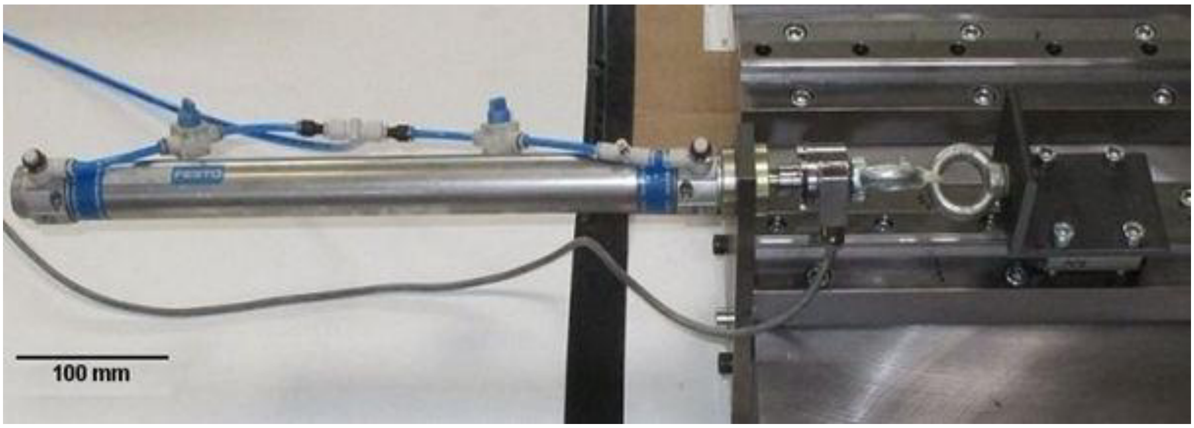


Fig. 1. The experimental set-up of the stick-slip effect and friction tests.

The experiments have been carried out in three states of carriages, namely not loaded, under loads of 25 kg (**Pogreška! Izvor reference nije pronađen.**) and 140 kg (Fig. 3). It was aimed to study the effect of external loading on the stick-slip effect and friction behaviour. The tests have been done in the same route length of about 0.39 m. Furthermore, the experiments for each state have been repeated five times, and the average values of the forces needed for their movement have been plotted.

Fig. 2. The experimental set-up under a load of 25 kg.

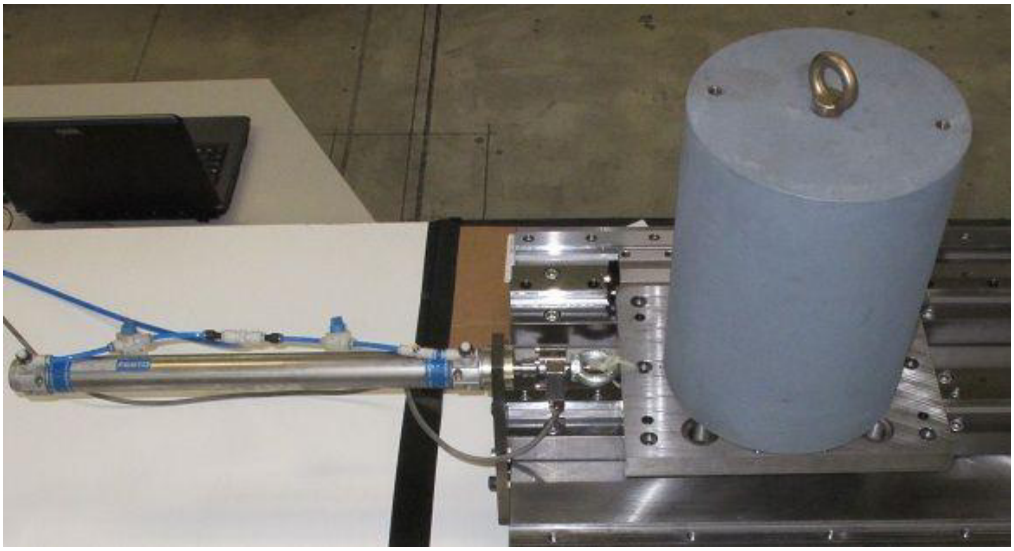

Fig. 3. The experimental set-up under the external load of 160 kg.

While the force needed to move the not loaded carriage is measured about 5.26 N, those needed for carriages under 25 kg and 160 kg loads are 13.46 and 57 N, respectively (Fig. 4). By dividing the value of the pulling force into the applied weight, the static friction coefficient is found as 0.4 for the not loaded carriage and 0.052 and 0.036 for those under 25 and 160 kg, correspondingly.  It is clear that the friction for the not loaded state is higher than the loaded ones. That is because of the sticking friction due to the lubrication grease, which decreases when external loads are applied.

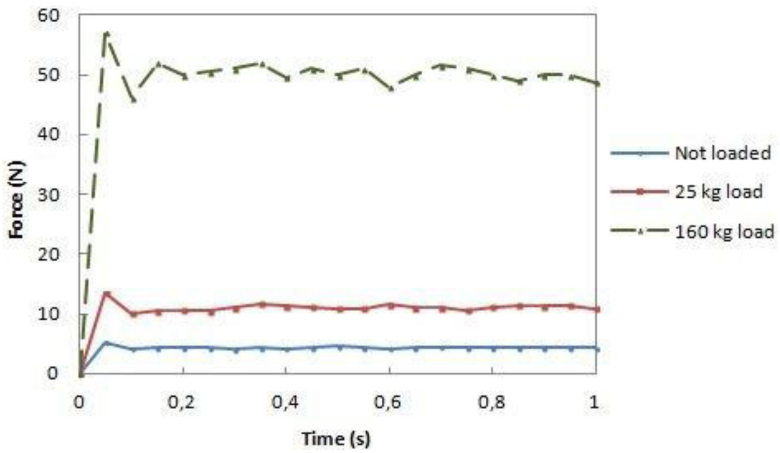


Fig. 4. The force-time curve of the friction tests for the carriage without preload.

The second preload class investigated with friction tests was the carriages with light preload (C1). As it is shown in Fig. 5, the friction forces for these loads are between 6 and 60 N. The average force needed to move the not loaded carriage was about 6.7 N, and for the carriages under loads of 25 kg and 160 kg were 14.7 N and 60 N, respectively. Therefore, the average static friction coefficient for the not loaded carriage was about 0.55 and for the two loaded states (25 and 160 kg) were about 0.057 and 0.038.

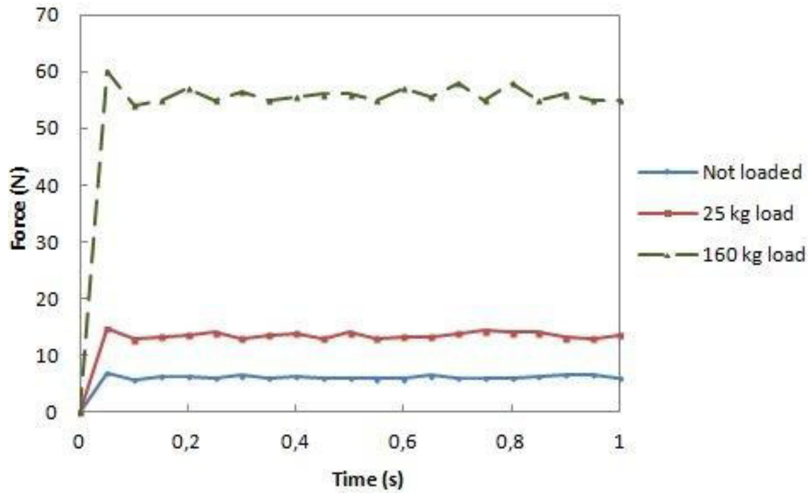


Fig. 5. The force-time curve of the tests for the carriage with light preload (C1).

Finally, the experiments were undertaken for the medium preloaded guide (preload C0). Like the previous tests and as it can be seen in Fig. 6, the friction coefficient of the guide decreases with the increase of the applied loads. The average values of the measured forces for three states were 9.2, 18 and 64 N and the static friction coefficients were nearly 0.7, 0.071 and 0.041.

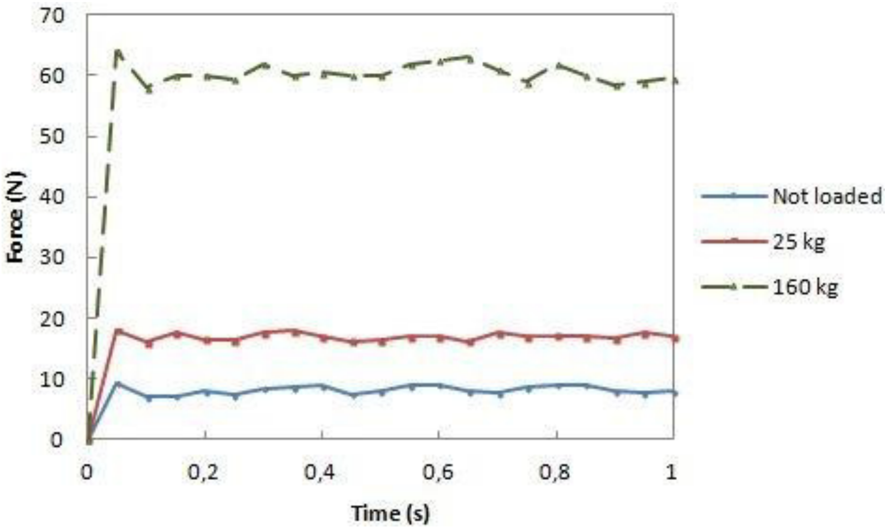


Fig. 6. The force-time curve of the tests for the carriage with medium preload.

To obtain a quantitative feeling about it, the effect of the preload factor on friction behaviour of the linear guides is shown in Fig. 7. It is obvious that the friction and preload have a direct relationship to each other. Employing carriages with light and medium preloads has made an increase of 7 and 16 percent in the friction.

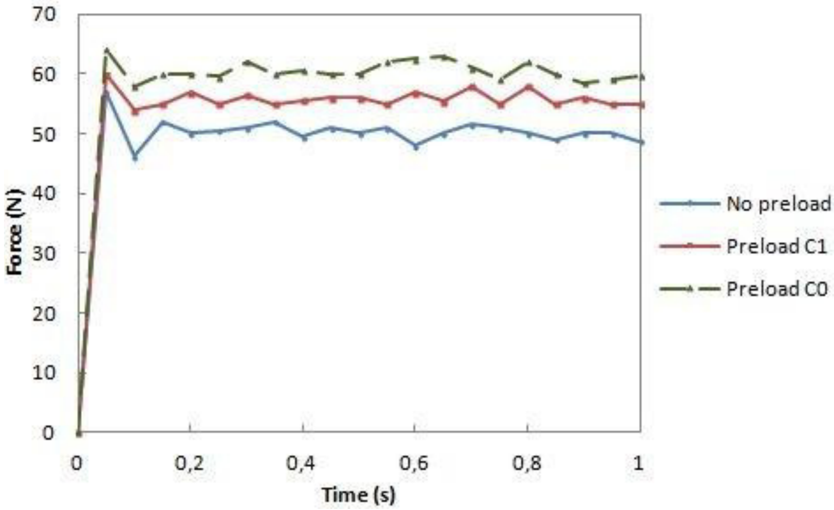


Fig. 7. A comparison between friction behaviour curves of the three preload classes under a load of 160 kg.

## 3. The effect of velocity

The influence of running velocity on the friction behaviour of linear guides has been investigated with three different velocities of 19, 52 and 325 mm/s. As it can be seen in Fig. 8, velocity is one of the causes of friction increases and especially stick-slip effect in the guides. By increasing the travelling velocity from 19 mm/s to 325 mm/s, the static friction force has increased from 18 N to 87 N. In other words, with this velocity change the friction force has an increase of about 380 percent. Comparing dynamic friction curves in the figure; one can observe that the differences are less than that of static friction and the curves are quite smooth.

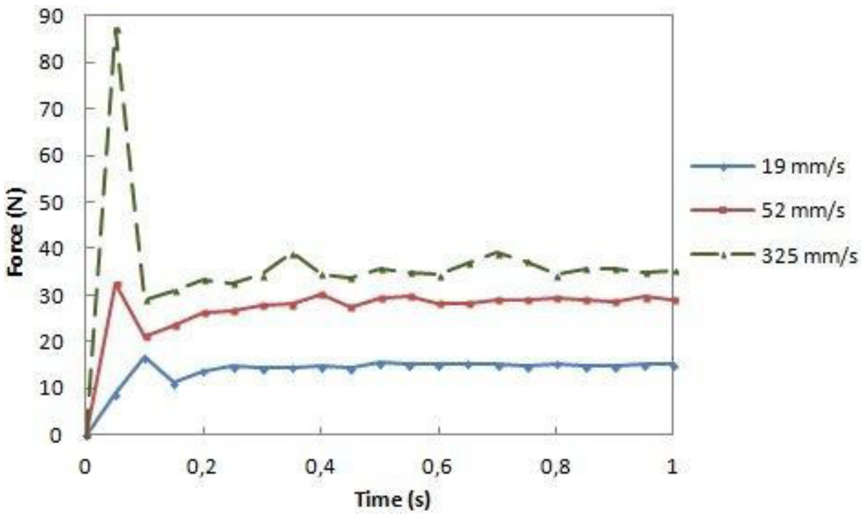


Fig. 8. The friction curve of the guide with light preload and different velocities.

## 4. Friction experiments with the slide

The same experiments have been carried out to study the friction behaviour when a slide is mounted on four carriages. As before, three different preload classes (without preload, light and medium preloads), and four external loads (not loaded, and under loads of 36 kg, 140 kg and 180 kg) have been studied (Fig. 9).

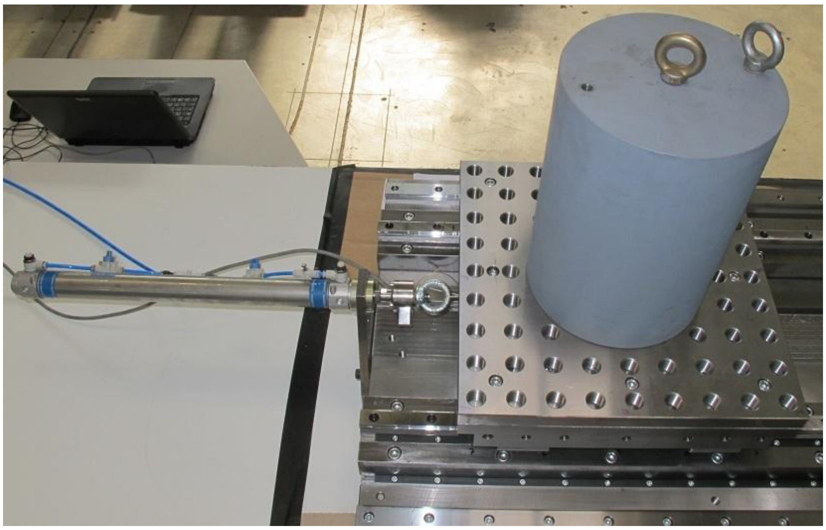

Fig. 9. Friction experimental set-up of the slide under a load of 140 kg.

The measurement results for the slide mounted on not preloaded carriages can be observed in Fig. 10. Clearly, by the increase of the loads, the friction forces increase too, but it doesn't have a linear trend, and some irregularities are observed, which are due to the sticking friction of the lubricators and are not unexpected for such experiments.

The minimum and maximum static friction forces are measured about 49 N and 85 N for the not loaded carriage and that under the external load of 85 kg, respectively.

Comparing these curves with those of single carriages, it may be noticed that the differences between various external loads in these experiments are less than those results. The reason is the weight of different body components of the slide, which are used to form a rigid body and play as external loads on the carriages.

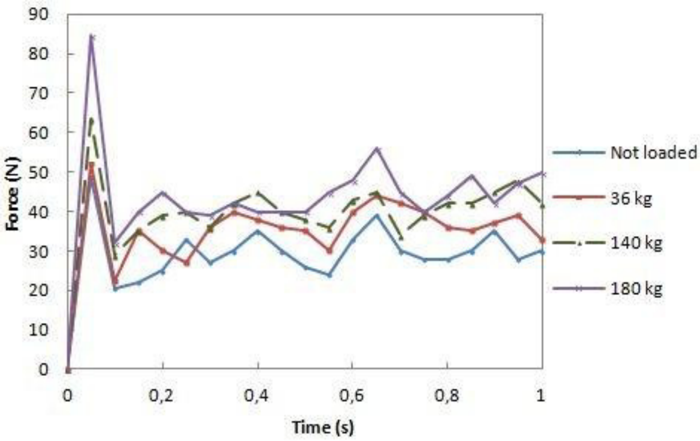


Fig. 10. Friction behaviour of the slide on four carriages with no preloads.

While the maximum static friction force for the slide mounted on the carriages with light preload is slightly over 100 N and the minimum is about 63 N (Fig. 11).

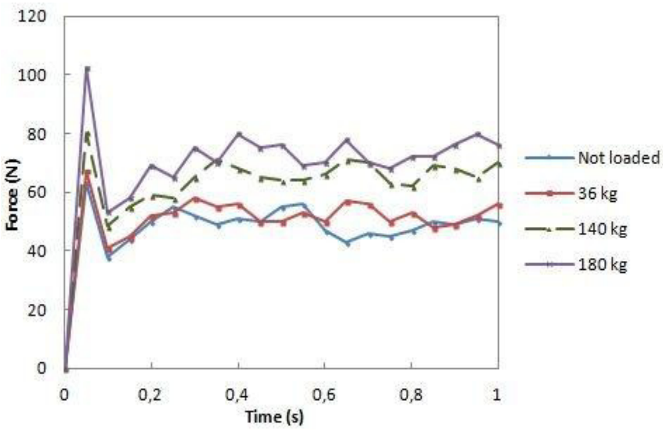


Fig. 11. Friction behaviour of the slide on four carriages with light preload.

The time-friction force curves for measurements of the slide mounted on medium preloaded carriages are shown in Fig. 12. The maximum static friction force was measured for the 180 kg load and was about 140 N and the minimum force for not loaded slide was measured nearly 80N.

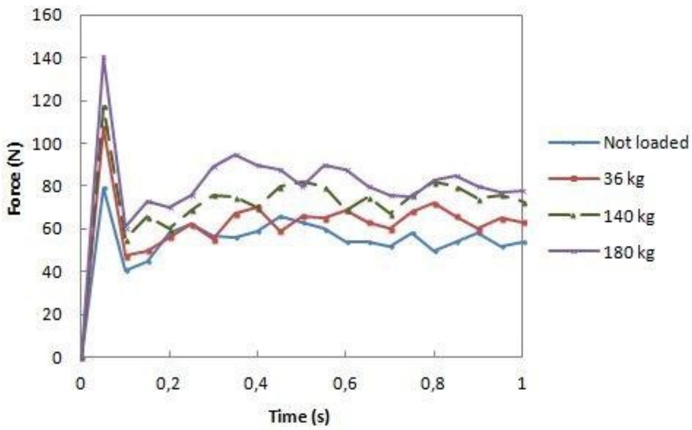


Fig. 12. Friction curves of the slide on carriages with medium preload.

## Conclusions

It was aimed to investigate about the smoothness of movements, and influence of preloads and travelling velocity on the friction characteristics of linear guides. All of these factors are studied experimentally. Based on the results obtained from the experiments carried out in this research work, some conclusions can be obtained as follows:

1) Stick-slip effect and friction behaviour of machine tool linear guides are some important issues, which should be thoroughly investigated.
2) Much larger friction coefficients have been measured for not loaded carriages.
3) Because of the sticking friction which is due to lubrication grease, the changing range of the dynamic friction curves (during travelling) is high.
4) By increasing the preload of the carriage, the friction factor increases considerably.
5) The friction force-time curves are relatively smooth during the travelling.
6) By increasing the travelling speed, a relative increase happens in the dynamic friction but the static friction and backlash rise considerably.
7) The stick-slip phenomenon observed when a slide mounted on four carriages is larger than that of single carriage.

As the next steps, investigating the friction behaviour of other types of machine tools linear guides such as ball bearing or non-contact guides can be of interests. Also, modelling the friction via mathematical or FEA methods can be conducted.

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