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Parameter identification aspects of tribological systems containing hard particles

Raphael Bilz[1,*], **Praveen Sridhar**[1], and **Kristin M. de Payrebrune**[1]

[1] Institute for Computational Physics in Engineering, Technische Universität Kaiserslautern, Erwin-Schrödinger-Str. 56, 67663 Kaiserslautern, Germany

Tribological systems are often characterized based on time-averaged quantities such as wear rates, friction coefficients and material properties. It is well known that some tribological metrics show variations depending on the laboratory conducting the study and the reproduction method selected. Perhaps the key to overcome this problem is to avoid a strong compression of the information generated. In this context, the arising forces and the coefficient of friction in three-body wear systems are investigated in more detail. The mean value of a time series of these physical quantities is only a single property and by no means an exhaustive description. A more detailed consideration of the variances could be a necessary condition to allow an appropriate comparison of tribological parameters and a correct interpretation of the properties of tribological systems. For this purpose, we examine two very simple tribological systems exemplarily and take a closer look at the properties of some characteristic process quantities.

1 Introduction

Tribological systems are present in almost all technical systems and are therefore of particular interest to industry, economy and science. Usually, the interaction of many factors determines whether a tribological system is suitable for a specific application and whether it has beneficial properties in terms of wear and friction. Therefore, experimental investigations are indispensable. Tribological systems affected by wear, in which hard particles are present, belong to the category of three-body wear systems. Examples of such systems can be found in vehicles in sandy or dirty environments, as well as, for example, manufacturing processes such as lapping and polishing, in which such tribological systems are intentionally applied. However, there are still difficulties regarding the comparability and transferability of experimental investigations. The objective of this study is to identify differences in apparently similar experiments and to better understand the local phenomena occurring in three-body wear systems. Histograms are used for the evaluation.

2 Materials and Methods

In Fig. 1 two tribological systems A and B, which are used for the investigation of the occurring forces, are shown schematically. For proper spatial and temporal resolution of the measured data and to be able to directly control the influencing parameters, five particles ($5\,\mathrm{mm}$-cubes) are used in the experiments, which roll between two metal plates (upper and lower body) coated with silicone (type ADDV-42 from R&G Faserverbundwerkstoffe GmbH), depicted in light blue in Fig. 1. Below the lower body, the forces are measured using a dynamometer (type 9119AA1 from Kistler) with a sampling rate $f_s \approx 10000\,\mathrm{Hz}$. The lower body moves horizontally with velocity v, while the degrees of freedom of the upper body are constrained by a linear guide so that it can only move vertically. The normal force is applied to the upper body. Two different methods are used to achieve the same average normal force. In system A, additional weight is used for this purpose, whereas in system B a preloaded spring is used.

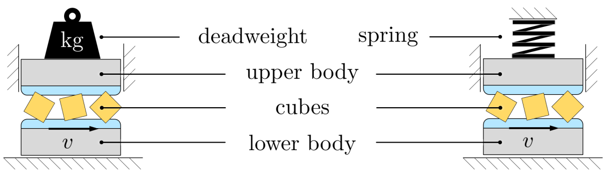

Fig. 1: Sketch of the test stands: system A (left) and system B (right)

3 Results and Discussion

This section presents results showing the influence of the velocity v and the method of normal force application on the occurring forces F_T and F_N and on the coefficient of friction $\mu = \bar{F}_T/\bar{F}_N$, which is calculated as the ratio of the time-averaged mean value of the tangential forces $\bar{F}_T$ and time-averaged mean value of the normal forces $\bar{F}_N$. In this evaluation, the occurring time-dependent tangential force $F_T(t)$, normal force $F_N(t)$ and the coefficient of friction μ of experimental data are examined.

In Fig. 2 (top left), the relative frequency of occurrence of the F_T-F_N-value pairs of an experiment with system A at a relative tangential velocity $v = 100\,\mathrm{mm/s}$ is shown in a bivariate histogram. Histograms of the individual variables are also

* Corresponding author: e-mail raphael.bilz@mv.uni-kl.de, phone +49 (0) 631 205 5101

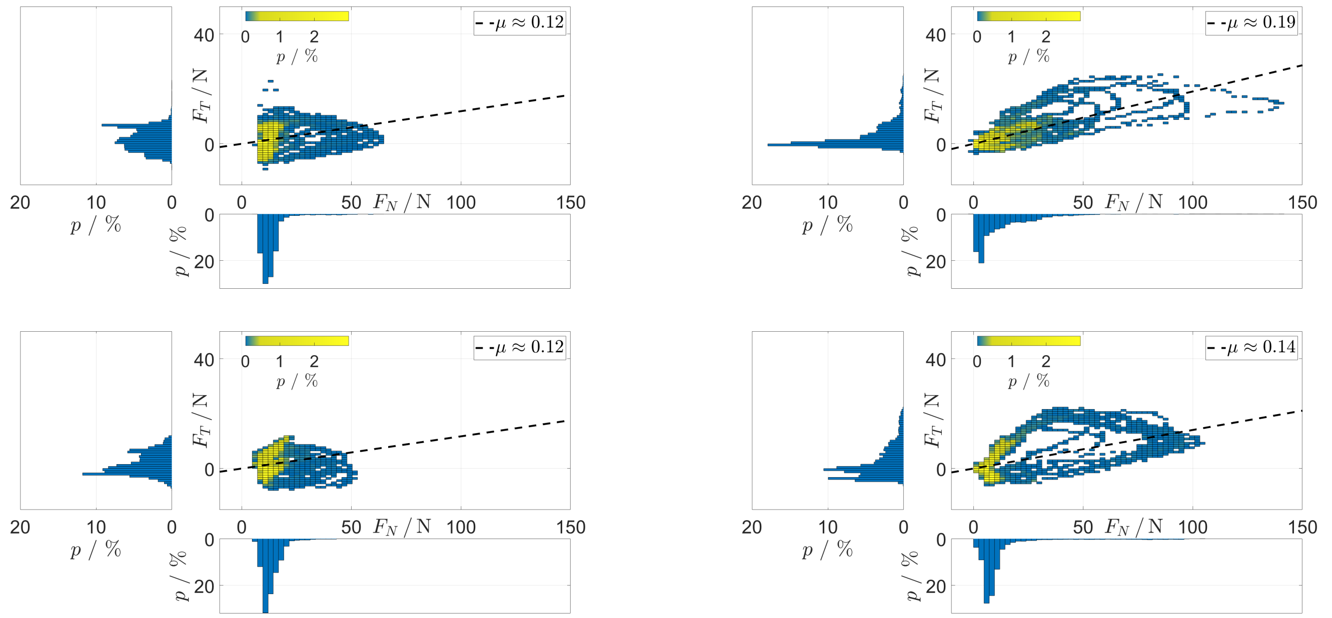

Fig. 2: Histograms of measured forces $F_N(t)$ and $F_T(t)$: system A (top) vs. system B (bottom), velocity $v = 100\,\mathrm{mm/s}$ (left) vs. $v = 200\,\mathrm{mm/s}$ (right).

attached to the axes. Even a single measurement by itself shows the considerable scattering of the measured data in the F_T-F_N plot. Accordingly, these measurement data are inaccurately represented by the proportional function $F_T(t) = \mu \cdot F_N(t)$ with $\mu = \bar{F}_T/\bar{F}_N$, represented by the dashed line. Nevertheless, this relationship is commonly assumed in the analysis of tribological systems.

Fig. 2 (top right) shows the measured data of system A at $v = 200\,\mathrm{mm/s}$. The velocity has a significant influence on μ. If v exceeds a certain velocity limit v_{lim}, which depends (among other things) on the particles' size and orientation, then the contact of the upper body with the particles is temporarily interrupted and F_N drops to zero. The investigated velocity ranges in relation to the velocity limit ($v_{\mathrm{lim}} \approx (142 \pm 14)\,\frac{\mathrm{mm}}{\mathrm{s}}$ for system A and $v_{\mathrm{lim}} \approx (179 \pm 18)\,\frac{\mathrm{mm}}{\mathrm{s}}$ for system B), calculation according to [1], are very low compared to the velocities investigated in other studies, e.g. [2]. However, the intention here is merely to show *that* v affects μ and not to show what this relationship looks like in general.

Moreover, the method of applying the normal force F_N influences μ and that even if the average normal force $\bar{F}_N$ is the same for both systems A and B, compare Fig. 2 (top) with Fig. 2 (bottom). Interestingly, at low velocities, the difference is less prominentl between system A and B, comparing the forces and μ of Fig. 2 (top left) with Fig. 2 (bottom left). These observations can be attributed to the different inertias of systems A and B. Thus, the systems A and B behave less differently at lower velocities. However, at higher velocities v the inertia has a correspondingly stronger effect.

4 Conclusion

Simple three-body wear systems were used to show that the force ratio of tribological systems $\mu = \bar{F}_T/\bar{F}_N$ is not constant and can be affected by both, the velocity v and the method of normal force application.

Potentially, the average forces $\bar{F}_T$ and $\bar{F}_N$ as well as the force ratio $\mu = \bar{F}_T/\bar{F}_N$ have insufficient explanatory power to exhaustively characterize the behavior of the three-body wear systems investigated here, because μ may significantly depend on, for example, the velocity and even the method of normal force application. Comparing μ of different measurements provides little information about the causes of differences and whether they are insignificant or have a systematic nature. Therefore, further benchmarks should be consulted as quantification methods that enable the identification of differences in experimental procedures, e.g. histograms may capture crucial information and enable differentiated comparisons of experiments.

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