ON THE DYNAMICS OF FRICTIONAL CONTACT LAYERS

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Summary: Boundary layers in frictional contact show a rich dynamic behaviour. This dynamic behaviour is correlated with wear patterns on the surface. These patterns are to be found in many frictional systems. A famous example for these structured surfaces are pad surfaces in commercial brake systems. Measurements and simulations indicate the influence of the surface topography dynamics on low up to high frequency effects in time varying friction forces, temperature behaviour and even noise and vibration phenomena of brakes.

INTRODUCTION

Looking on nonlinear structures with contact interfaces usually the effect of nonlinearities outside the contact interface is in the focus. The friction in contact zones usually is reduced to rather simple friction rules derived from Coulomb's laws. But there are very famous systems like clutches or brake systems, where characteristic wear patterns are to be found [1]. The friction interfaces play a key role for the dynamics of the total system [2]. In the last years a lot of investigations have been done for these systems, detecting a rich dynamic inside the friction layer correlated with time and load dependent wear pattern [3]. These wear patterns are to be found in many other frictional contacts, for instance in gears, in bearings, in the rail wheel contact, on blackboards (during chalk moving on it) or even on contact interfaces in hip joint endoprothesis there are to be found biological films, which may be interpreted as friction resulting patterns.

SURFACE PATTERNS IN FRICTION LAYERS

In the contact areas the topographic inhomogeneities like asperities or material inhomogeneities lead to inhomogeneous normal stresses. When there is an additional tangential motion between the contacting surfaces these inhomogeneous stress fields result in inhomogeneous tangential friction loads. Areas of different friction powers cause areas of different temperature loads. This again modulates the normal stresses in the contact region by thermo-elastic effects. Another essential effect is the modulation of the wear particle flow in the contact zone. The inhomogeneous temperature load modulates the material conglomeration at the higher load areas usually consisting on compacted wear particles. So these effects cause special surface patterns and consequently they at least also have an impact to the wear of the system.

The so called running-in process moves for instance a rather smooth surface by frictional effects into a structured surface with wear patterns on a mesoscopic scale. This surface transition is characteristic for the tribological system. The patterns may occur on only one surface and the other surface has patterns or films on a much smaller length scales. The resulting surface structures seem to be rather independent from the initial surface topographies. The pattern structure of the surfaces is often stable for a rather long time. The patterned surface seems to be the result of a very general self-organization effect to be found in nearly every frictional contact.

Brake systems are very famous examples of such a tribosystem generating patterned surfaces. In this system a phenolic bounded aggregation of different materials, the pad, is pressed against a grey cast iron disk. Usually the disk shows patterns in form of very thin films and on the pad surface smooth patches are to be found, see figure 1. Often these patches are caused by hard particles inside the pad, disturbing the flow of debris [1]. In the following we are dealing with brake systems.

LONG TIME DYNAMICS OF WEAR PATTERNS

Essentially, the frictional boundary layer between brake pad and disc in brake systems are characterized by specific hard surface structures [1] in the pad, with a diameter ranging from 50 microns to some hundred microns. These so-called 'patches' (see Figure 1) are extremely hard and transmit the main part of the friction power. Moreover, the patches vary in size, depending on the external loading of the tribological interface. They are permanently generated and formed in the boundary layer but leave the system after a certain period of time. This life cycle is generated by the interdependency of friction, heat and wear, see figure 1, resulting in a closed loop interaction of energy and material dissipation.

The process of birth and destruction of patches leads to an equilibrium of flow of contact patches in the brake pad interface. High loads produce after some time a surface with less but large patches, lower loads creates a larger number of smaller patches. The total size of patches in the surface is too changing when the friction power of the system is changing. This can be related with the computation of the dynamics of macroscopic friction coefficients [2], whose 'inertia' can be well described by differential equations in the form of balance equations.

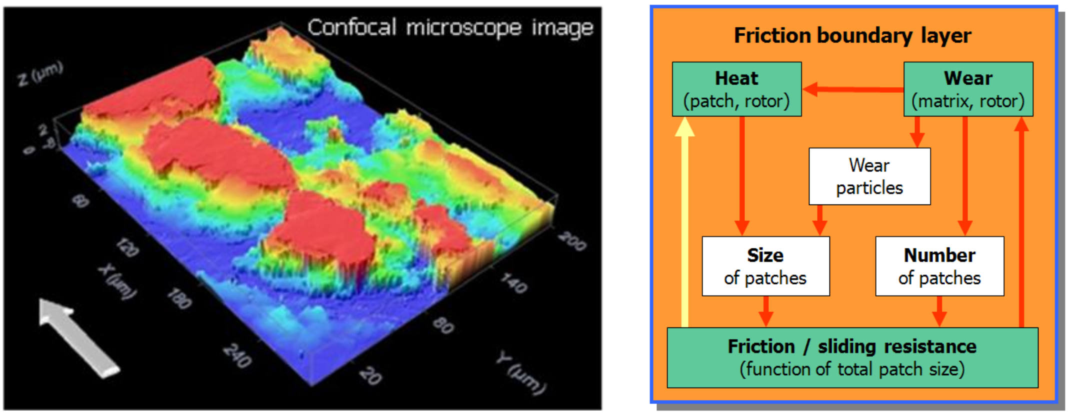

Figure 1: Confocal microscope picture of contact patches, closed loop interaction of friction, heat and wear.

Looking in detail to the surface there are to be found different forms of patches, some of them are very hard, others are rather soft. So the topography is much more complex. But the main mechanism of the surface changes and the friction behavior can be approved by measurements and complex simulations with cellular automata [3]. The time constants for these effects are rather large, time scale of seconds and more. These effects are explaining the results of classical test procedures as the AK Master Test showing highly varying friction forces for a brake with different loads and different load histories.

SHORT TIME DYNAMICS OF WEAR PATTERNS

There is to be found a dynamics in the contact zone not only in a rather low frequency range driven by the surface topography change but also in a high frequency range. In some cases the wear patterns in the contact zone consisting of the compacted debris can be idealized as self sustained oscillators vibrating in some velocity intervals with usually stochastically distributed frequencies. Because these wear patterns are lying on the same body, they are coupled by the stiffness of the material. This is a classical Cerruti problem. The quantity of elastic coupling of the oscillators depends on size and distance of the wear patterns. In some cases this weak coupling causes a phase synchronization of these oscillators at least in some parts of the contact zone. This effect of self synchronization transforms these local friction induced vibrations into some macroscopic tangential vibrations of the pad with only very few frequencies.

Summarizing the friction loads on all local contact zones within the total contact interface in the unsynchronized case a stable mean value with a broad frequency band stochastic vibrations is the macroscopic output of this frictional interface modulated by slow surface topography changes showing typical “inertia effects” of the global friction coefficient. But when there is a phase-synchronization even in some parts of the contact interface, the global friction coefficient shows - usually embedded in the noisy spectrum of force variations by the non synchronised patches – some strong rather periodic signals with only few frequencies. They depend on the relative velocity of the contacting partners. This effect of synchronization depends strongly on the load history, which determines the sizes and distances of the patches and with this the elastic coupling of them. One special effect of this could be a macroscopic stick slip behavior within the contact interface [3]. This can be the initiation of macroscopic vibrations of the brake system. With this boundary layer effects the dependency of load and load history of noise and vibration in brakes can be explained in accordance with experimental results.

CONCLUSIONS

The research on dynamics of frictional interfaces is at the beginning. This effect seems to be a general self organising effect of nature protecting the softer partner in contact with respect to wear.

References

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