Surface topography and friction dynamics in brake systems described by a Cellular Automaton

M. Mueller (Institute of Dynamics and Vibrations, TU Braunschweig),
G.P. Ostermeyer (Institute of Dynamics and Vibrations, TU Braunschweig)

PROBLEM DEFINITION

For the description of a friction event it is necessary to understand the friction coefficient $\mu$ as a process-parameter dependent not only on the surface-structure but also for instance on the relative velocity, normal load, temperature and the event itself. In brake systems, for example, growing and destroying processes of hard thin patches determine the friction power and the transfer of kinetic energy into heat and plastic deformations, such as wear. So the interaction of friction and wear is given by an equilibrium of flow of different processes resulting in growing effects or lowering effects on the friction coefficient itself [2] - [4]. The aim of this paper is to show the detailed interaction of this topographical dynamics and the friction behavior with the Method of Cellular Automata.

APPROACH

To get an idea about the dynamics in the boundary layer between brake disc and brake pad we discretised this area with the help of a Cellular Automaton (see Fig 1).

The discrete elements of a Cellular Automaton, the cells, contain a certain set of properties, which are updated by simple rules every step. The rules are alike for each cell and only dependent on the properties of neighbor-declared cells. Thus, concerning the computing time, the element size can be chosen very small, because no equation system or differential equation has to be solved.

The boundary layer is the area, where wear particles flow, where wear particles are detached and where the hard thin patches determine the friction power. For the discretisation (Figure 2) it is of decisive importance to be able to reproduce the typical measured patch structure [1].

Because of the fact, that the measured patch size amounts about 100-500 $\mu$m, we chose a cell size of roughly 10-50 $\mu$m. For the description of a friction process we regard the following dynamical aspects:

- the wear particle stream
- the detachment of wear particles
- the heat conduction / heat radiation
- growing processes of patches
- destroying processes of patches
- the friction power.

All these issues cause each other and are responsible for the dynamic changing of the surface topography. The above standing aspects were characterized by the cell properties [5]:

- status (cell is “patch” or “not patch”)
- temperature
- density of wear particles
- normal load on the cell
- neighborhood.

The tribological processes in brake systems are multiscale problems. Here we introduce two timescales. The timescale of microseconds represents the heat flux and the wear particle motion. The patch structure will nearly not change within this timescale.

On the other hand the timescale of seconds is determined by patch- growing and -destroying processes. The temperature- and wear particle density fields are assumed to be stationary.
RESULTS

Figure 3 shows the computed results for the surface structure and its appropriate fields of the wear particle density (flow from left to right) and the temperature.

The typical surface structure of a brake pad has been reproduced. The patch’s disturbance according to the wear particle flow is clearly visible. Their heat production and the resulting temperature field can be seen as well.

In Figure 4 the total number of “patch”-cells, nonlinearly coupled with the friction coefficient $\mu$, and the average temperature with respect to time are plotted for the seconds-timescale. The run-in phase is characterized by a fast rising of the friction coefficient $\mu$ and the temperature and their reaching of an equilibrium. By increasing the normal load $N$, the temperature level rises and the friction coefficient decreases. This (as well measured) “fading”-behavior has also already been described with a set of differential equations in [4]. Within that simulation with a Cellular Automaton this effect is not an original new result, because its root is to be found in the rules. However, it shows the consistency of the rules we introduced. But there are some further results which are not put a priori into the rules: for example, there is a periodicity of roughly 1000 timesteps, which corresponds with the lifetime of a patch. The maximum size of one single patch amounts about 100 cells, so the fluctuations in the upper diagram are caused by the simultaneous destruction of up to twenty patches. These remarkable oscillations should be an explanation for the measured periodical behavior of $\mu$ within hours. This kind of input-output-considerations are the basic idea of Cellular Automata simulations.

CONCLUSIONS

Our Cellular Automaton is able to describe the detailed dynamical changing of a brake pad’s topography. Local effects can be considered. The developed orthogonalized rules give us the possibility to find explanations for measured phenomena, such as the fading effect and the $\mu$-periodicity. The simulation of friction events with the help of Cellular Automata is a promising way to reproduce and predict measured values of friction processes and to find conclusions concerning their causation.

In future works we will - in connection with measurements - apply this method to the microseconds-timescale to understand the interaction of wear, the surface topography and further friction phenomena, e.g. “squealing”, “brake judder” and “hot banding”.

REFERENCES

[1] Eriksson, M “Friction and contact phenomena of disc brakes related to squeal”, Comprehensive summaries of Uppsala dissertations from the faculty of science and technology, Uppsala 2000