DEVELOPMENT OF CONDITION-BASED TAMPING PROCESS IN RAILWAY ENGINEERING

Maintenance of ballasted tracks becomes an increasingly demanding task with the continuous increase of railway traffic of both passengers and freight. Nowadays, most of track maintenance work is conducted using modern tamping machines. The process of lifting, leveling and non-synchronous, directional constant pressure tamping has been proven to provide optimal results in regard to continuous ballast compaction and restoration of initial track geometry.

Most desirable method of track maintenance, from an economic point of view, is condition - based predictive maintenance. This method dictates that decisive parameters should be adjusted to the encountered track condition. State-of-the-art tamping machines, however, operate with previously defined tamping parameter combination, whereby only a minority of parameters are adapted to the ballast bed condition.

Research conducted in the scope of this thesis investigates fundamentals of the tamping process and the soil mechanical component of ballast compaction. For this purpose, comprehensive investigation of the track tamping process during regular track maintenance in different ballast conditions is conducted, primarily focusing on the interaction between the tamping tine and the ballast matrix during ballast compaction. For the very first time, these two components are observed on a vibration cycle scale, and a new method of measuring and interpretation of their force-deformation relationship in form of a load-displacement diagram is developed. This presentation made it possible to determine tamping characteristics, such as reaction force and compaction energy, that result from a given set of tamping parameters. Comparison of tamping characteristics between tamping machine employment at different locations made it possible to clearly identify the ballast bed condition based on its interaction with the tamping tine. This observation represents the base for future development of condition-based tamping process in which the tamping parameters would be adapted to the ballast condition measured by the machine during tamping.

Irrefutable evidence of a periodic loss of contact between tamping tine and ballast matrix is presented based on contact points obtained from load-displacement diagrams. Existence of this contactless phase in each vibration cycle reduces ballast wear and has a positive influence on the compaction process. Soil dynamic behavior of track ballast during compaction was investigated and in-situ tests were conducted in order to enable a qualitative description of track ballast dynamic fluidization, a phenomenon that plays a decisive role in clean ballast compaction by both tamping unit and dynamic track stabilizer.

A numerical simulation of the tamping tine - ballast matrix interaction during compaction was developed, providing the possibility to model continuous fouling of the track ballast by adjusting one single parameter - elastic stiffness of the ballast model. Model calibration was conducted using in-situ measurement results and it was utilized to carry out a comprehensive study of tamping parameters and their effect on the load-displacement curve and tamping characteristics.

Measurement system and analysis algorithm presented in this thesis provide the possibility to transform and upgrade the tamping unit from track maintenance into a Smart tamping tool, resulting in optimization of the tamping process and a prolongation of ballast life-cycle, while increasing the quality of the whole track system.