Development of numerical and experimental tools for the simulation of train braking operations

Abstract

Despite being a mature and reliable technology, the traditional railway braking system is not exempt from critical issues and limits, that require further investigations and analyses. Since on-track tests feature high costs, low repeatability, and often lead to traffic interruptions, the simulation of braking operations with numerical codes, enabled by the high power of modern computers, and with laboratory devices is often the best compromise solution. Therefore, this thesis deals with the development of numerical and experimental tools for the investigation, simulation and optimization of railway braking operations.

Because of the large in-train forces that can arise on long trains, which increase the derailment risk, one of the goals of the present thesis was the implementation of an efficient and accurate longitudinal train dynamics (LTD) code. In previous activities, the research group had developed an LTD model implemented within the Simpack multibody (MB) code, but the model produced numerical instabilities and divergences in the simulation of freight trains with many vehicles. The new code, named LTDPoliTo, was written in MATLAB, making use of vectorization programming strategies and built-in functions for the management of large arrays, storing the main input data of the simulations. The code was validated in the simulation scenarios suggested in an international benchmarking activity. The final version of LTDPoliTo can estimate the air brake forces generated on common European freight vehicles, using a simplified

approach which only requires the knowledge of the wagon braked weight. Moreover, because typical LTD codes cannot calculate the wheel-rail contact forces, that are needed for the estimation of the safety indexes, including the derailment coefficient, this thesis shows a possible approach to compute these indexes from the outputs of LTD simulators. The proposed method relies on training closed-form surrogate models, working as digital twins of computationally expensive and long-lasting MB simulations.

The air brake system adopted on trains is based on the friction forces that are generated at the wheel-rail contact patch, which are strongly dependent on the possible presence of contaminants at the contact interface. Contaminants are known to reduce the friction coefficient and to modify the adhesion curve shape, thus affecting safety and performances of braking operations. Therefore, a second goal of the thesis was the setup of an innovative multi-axle roller-rig, previously designed by the research group. The configuration of the test bench allows to simulate the adhesion recovery phenomena activated by the friction forces, which partially remove the contaminant layer sticking to wheel and rails. The bench setup required the calibration of the sensors installed on the rig and the implementation of a bench control software. In a subsequent activity, the original bench configuration was modified, and a new motor control strategy was designed, to simulate the vehicle inertia on the bench.

Finally, the thesis shows the development of a numerical tool for the computation of the worn profile of railway wheels and of a numerical tool allowing to estimate the wheel temperature during tread braking operations. These tools are essential to estimate the damage of the railway wheel running surface, and their outputs can be used to tune innovative monitoring systems. The wear tool is based on dynamic simulations run in Simpack, while the wheel thermal model relies on finite element (FE) modules for the solution of the wheel-shoe conformal contact problem and for the subsequent estimation of the temperature field in the wheel during drag and stop braking operations.