Indirect Prediction of Rail-Wheel Contact Parameters and Novel Methods for Friction Control

Abstract

Railway safety and efficiency depend on a comprehensive understanding of wheel–rail contact behavior, yet key parameters such as wear number, derailment ratio, normal load, and contact location are challenging to measure directly during service. This thesis introduces a temperature-based, non-intrusive framework for estimating these parameters by exploiting the fundamental relationship between frictional heating and contact mechanics. At the system scale, a boundary element method (BEM) framework based on Green's function solutions is developed to predict wheel-tread and rail temperatures driven by frictional power dissipation obtained from a validated multibody dynamics model of a metro coach. Field trials conducted on an Indian metro line validate the model, demonstrating temperature rise patterns of 10–20 °C on curved tracks and indicating that approximately 40% of the generated frictional heat is absorbed by the wheel, with the remainder conducted into the rail. A deep neural network (DNN) surrogate model is subsequently trained to relate BEM-derived temperature features, operating conditions, and track geometry to essential contact parameters, achieving high predictive accuracy ($R^2 > 0.9$) for all outputs. Sensitivity analysis confirms temperature as the most influential input, reinforcing the physical link between frictional heating and contact behavior. At the material scale, three low-temperature deposition techniques—direct spray deposition, direct mist deposition, and air-assist mist deposition—are developed for water-based friction modifier coatings, with the latter two producing uniform coatings suitable for tribological testing. Ball-on-disc experiments elucidate the influence of friction modifier constituents, including oxides, minerals, binders, and solid lubricants, on coefficient of friction and wear mechanisms. An artificial neural network further demonstrates that coefficient of friction can be accurately predicted from contact temperature and load, establishing a temperature-based friction estimation approach applicable at nano- to micro-scales. Overall, the integration of multibody dynamics, boundary element modeling, laboratory tribology, and machine learning provides a unified, temperature-aware methodology for friction management and condition monitoring in modern railway systems.

Keywords: Wheel–rail contact; temperature-based monitoring; boundary element method; deep neural networks; friction modifiers; ball-on-disc tribology; multibody dynamics.