Adhesion modelling in railway vehicle multibody dynamics considering the effect of environmental temperature

Zhiyong Shi[1], Leandro Nencioni[1], Andrea Rindi[1], Enrico Meli[1]

[1] Department of Industrial Engineering
University of Florence
Via S. Marta n. 3, 50139 Firenze, Italy
enrico.meli@unifi.it

EXTENDED ABSTRACT

1 Introduction

The field of railway engineer has been one important part of multibody dynamical simulation since early years. The significant advantage of multibody approach on satisfying calculating effort enable the numerous engineering application. It has been nowadays recognized as a reliable and mature computer aided engineering tool. In railway dynamics simulations, creep forces determination is an crucial issue. An adhesion model to increase the accuracy of determining creep forces is the pursuit of many numerical studies in this field. It is challenging to obtain an accurate adhesion model because the adhesion phenomenon occurs in the interface of wheel-rail contact, and the wheel-rail contact is an open system, which is affected by rather complex factors [1]. This paper is going to present an extension of the adhesion modelling for multibody system dynamical simulation, which is able to consider the influence of the environmental temperature.

2 State of the art

Experimental investigations have revealed that the adhesion coefficient is directly related to several factors such as the train speed, the axle load, the temperature, the surface roughness, the surface contaminated layer parameters, the third body particle and others [2]. Weather conditions including humidity and environmental temperature affect the state of wheel and rail surfaces. This further influences some parameters or process, such as the friction coefficient and the oxidation process of the materials. For example, a friction map focused on the relationship between the friction coefficient and ambient temperature is drawn in [3]. Tests under 3, 10, and 20 $^{\circ}C$ conditions were performed. Moreover, a series of experimental investigations have been performed to study the adhesion characteristics affected by altered temperature conditions [4, 5]. However, most studies are generally in a small range of values of temperature or limited conditions for a single value of slip ratio. Quantifying the influence of environmental temperature on the adhesion coefficient calculation has not received sufficient attention from the view of adhesion modelling. Therefore, an adhesion model that consider the influence of environmental temperature can extend the application and improve the accuracy of multibody system dynamical simulations in railway. We firstly perform laboratory tests to obtain the data concerning the wheel-rail adhesion coefficient, under various conditions with different temperatures. Based on the Polach model [6] and the results obtained from the laboratory tests, we propose our new adhesion model.

3 Methods

A rolling-sliding twin-disc wear apparatus was used in this study for tests. Figure 1 illustrates a schematic diagram. The apparatus allows the discs to run against each other with controlled normal and tangential forces to reproduce the rolling-sliding contact of wheel and rail. The results of adhesion coefficient and slip ratio under different temperature are plotted in Figure 2. Based on the results from the above experiments, we collect the data about the environmental temperature, the slip ratio, and the adhesion coefficient. We propose the new laws to consider the influence of temperature, based on the Polach theory [6]. It's seen from Figure 2 that low temperature (-40, -20, and 0$^{\circ}C$) generally brings higher adhesion coefficient compared to at room temperature (20 $^{\circ}C$) with the same slip ratio. With the temperature decreases from room temperature to -20 $^{\circ}C$, the adhesion coefficient increases. While the temperature drops from -20 $^{\circ}C$ to -40 $^{\circ}C$, the adhesion coefficient exhibits a slightly downward trend. The method proposed by [6] can be expressed in the following:

$$f = \frac{F}{Q} = \frac{2\mu}{\pi}\left(\frac{k_A\varepsilon}{1+(k_A\varepsilon)^2} + \arctan(k_S\varepsilon)\right) \tag{1}$$

with

$$\varepsilon = \frac{2}{3}\frac{\pi a^2 bC}{\mu Q}s \tag{2}$$

where a and b are half-axes of the contact ellipse, Q is the wheel load, μ is the coefficient of friction, ε is the gradient of the tangential stress in the area of adhesion, and s is the creepage. C is the contact shear stiffness coefficient, which can be derived from Kalker's linear theory. According to the Polach algorithm, we firstly calculate the friction coefficient. Assume friction coefficient is independent of slip velocity. Assign a group of values for the friction coefficient, we preform curve fitting for tested

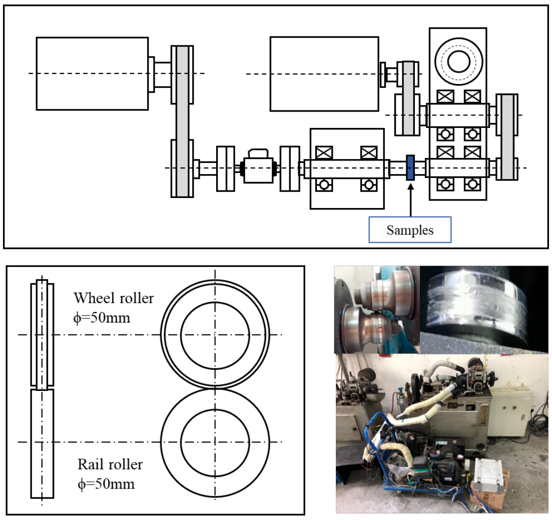

Figure 1: Schematic diagram of the twin-disc test apparatus: MJP-30A

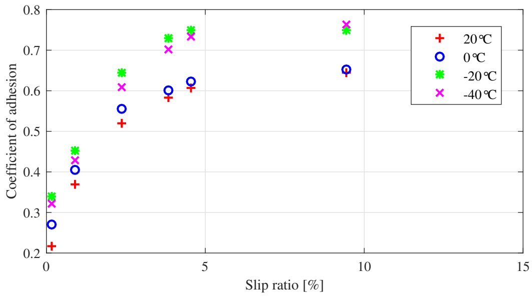

Figure 2: Coefficient of adhesion vs. slip ratio at different temperature

coefficients of adhesion. Subsequently, we further calculate the coefficients in the Polach formula. Through curve fitting with obtained friction coefficient, we obtain the k_A and k_S. The new model establishes the relation between k_A and k_S and T, expressing the Eq. 1 as:

$$f = \frac{F}{Q} = \frac{2\mu}{\pi}\left[\frac{k_A(T)\varepsilon}{1+(k_A(T)\varepsilon)^2} + \arctan(k_S(T)\varepsilon)\right] \tag{3}$$

Applying the new model for adhesion, we perform simulation based on a UIC-Z1 multibody vehicle model. The 50-degree-of-freedoms multibody vehicle model is generated including one carbody, two bogie frames, eight axle boxes, and four wheelsets, and all the kinematic constraints that link the bodies to each other. The Wheel Slide Protection (WSP) system of the railway vehicle UIC-Z1 has been modelled to better investigate the vehicle behaviour during the braking phase under degraded adhesion conditions.The multibody model consists of two different parts that mutually interact during the dynamical simulation: the 3D model of the railway vehicle and the 3D wheel-rail contact model.

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