Wear 314 (2014) 189–197

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Actual states of wheel/rail contact forces and friction on sharp curves – Continuous monitoring from in-service trains and numerical simulations

Akira Matsumoto [a,*], Yasuhiro Sato [a], Hiroyuki Ohno [a], Makoto Shimizu [b], Jun Kurihara [b], Takuya Saitou [b], Yohei Michitsuji [c], Ryo Matsui [c], Masuhisa Tanimoto [d], Masa-aki Mizuno [e]

[a] *National Traffic Safety & Environment Laboratory, Japan*
[b] *Tokyo Metro Co., Ltd., Japan*
[c] *Ibaraki University, Japan*
[d] *Nippon Steel & Sumikin Technology, Inc., Japan*
[e] *Nippon Steel & Sumitomo Metal Corp., Japan*

ARTICLE INFO

Article history:
Received 11 November 2013
Accepted 24 November 2013
Available online 1 December 2013

Keywords:
Rail–wheel tribology
Contact mechanics
Rolling friction
Condition monitoring
Lubrication

ABSTRACT

The authors researched and developed a new measurement method that can continuously measure the contact forces and derailment coefficients at all curves of commercial lines. This new method can determine the derailment coefficients, which change according to the friction coefficients and other factors, using the measuring system on in-service trains. In this paper, the analysis results for actual curve data collected on commercial subway lines are introduced. Additionally, parameters that are influential on the changes of the derailment coefficients, such as "friction" and "track irregularity," are discussed using the regression analysis on the accumulated data with the newly developed system.

1. Introduction

The "derailment coefficient" is the ratio of the lateral (L) and vertical (V) contact forces between the wheel and rail, particularly in the outside rail (high rail), and is determined by the geometry of the wheel/rail contact and the friction conditions at any given moment. Since this geometry and the friction conditions are subject to constant changes, the derailment coefficient, which is indicated as $(L/V)_{\mathrm{out}}$ in this paper, also fluctuates continuously. For example, the friction of the wheel/rail contact may increase as the number of passing trains rises during peak hours [1].

Measuring the derailment coefficient has traditionally required the use of special wheelsets equipped with many strain gages and other equipment, such as slip rings or telemeters, to transmit the data to on-board processors [2]. Tread braking of wheelsets equipped in this way is generally impossible because the strain gages and other equipment would be damaged by the generated heat, so this type of wheelset is not suited for commercial use.

2. Continuous monitoring systems for contact forces of in-service trains

In the newly developed measuring system, no measurement apparatuses (such as strain gages and slip rings) are equipped on the rotating parts of the bogie, i.e., the "wheelset." The vertical contact forces are measured by the displacement of the axle springs using magnetostrictive sensors, and the lateral forces are measured by the bending deflection of the wheel using non-contact eddy-current gap sensors attached to the side of the bogie frame. Figs. 1 and 2 show the difference between the conventional and new methods.

The layout of the measuring system for the lateral force is shown in Fig. 3 [3]. The lateral distortion of the wheel is very small (0.008 mm/1 kN), so additional sensors (Nos. 5 and 6 in Fig. 3) are attached to compensate for the axial and inclination movements of the wheelset in addition to the main sensor (No. 2).

In order to verify its accuracy, comparisons with the conventional methods were first performed on the bogie test rig at the National Traffic Safety and Environment Laboratory (NTSEL), which has a unique curve test capability. After the laboratory tests, the following improvements were made:

(1) Improvements of the bogie structure, e.g., use of small thrust clearance bearings.

---

* Corresponding author. Tel.: +81 422413216; fax: +81 422768602.
E-mail address: matsumoa@nifty.com (A. Matsumoto).

0043-1648/$ - see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.wear.2013.11.046

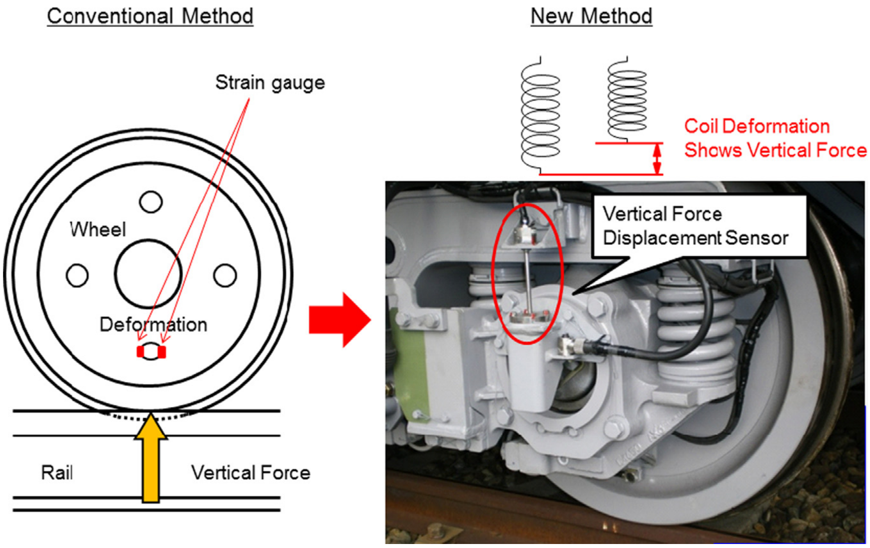

Fig. 1. Difference between conventional and new methods for vertical contact force measurement. The conventional method needs many strain gages on the wheels and slip rings or telemeters for data collection from the rotating parts (wheelsets). The new method measures the vertical displacement directly from the bogie frame and is free from wheel rotation.

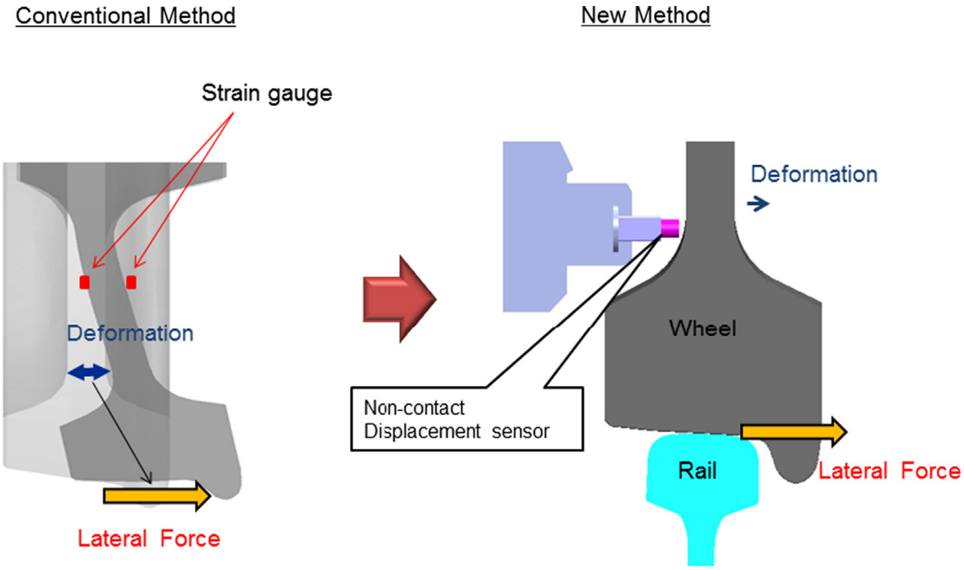

Fig. 2. Difference between conventional and new methods for lateral contact force measurement. The new method measures the wheel bending deformation directly from the non-rotating parts using non-contact gap sensors.

(2) Fine machining to prevent lateral irregularities in the web of the wheel.
(3) Reduction of unwanted fluctuations in the signal for the lateral irregularities of the wheel web by data processing considering the wheel rotation.
(4) Compensation for the shift in the force acting points due to braking.

After these improvements, a number of running trials were made on a commercial line [4]. These confirmed that the newly developed method was sufficiently accurate for further development. As shown in Fig. 4, the differences in the lateral forces between the two methods did not exceed 2 kN, and the difference in the derailment coefficient $(L/V)_{out}$ determined by the two methods was no more than ± 0.1.

With regard to the sampling rate, the measured data for the lateral forces are averaged per rotation of each wheel. It is enough for our purpose, but more frequent data acquisition should be required for faster phenomena. If a higher frequency (i.e., more than 2–3 Hz) is required, more frequent calculations will be possible using compensations for the distribution of each wheel side shape. Vertical force measurement is affected by the inertia of a wheelset, but there are no serious problems for monitoring the derailment coefficients.

In 2009, a newly designed disc-braked trailer bogie with this measuring system was developed and mounted under one car of a six-car train. This “measuring train set” started commercial operation on the Marunouchi line. Now, three “measuring train sets” have run on the Marunouchi ($G = 1435$ mm), Chiyoda (1067 mm), and Tozai (1067 mm) lines. Fig. 5 shows the outlook of the bogie and the sensors on the “measuring train set,” and Table 1 shows an outline of the three subway lines where the “measuring train sets” have been running. The total length of these three lines is about 82 km, which is 42% of the total Tokyo metro line length.