Recent Research and Development in Railway Dynamics

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This paper introduces the latest research and development through numerical analyses and experimental tests conducted by the Railway Dynamics Division on overhead contact lines, railway vehicles, tracks and structures. This includes analyses, tests on the interaction of the overhead lines and pantographs, wheel/rail rolling contact, developments relating to the wheel load reduction control bogie and the low cost ladder sleeper based on wheel load measurements. This paper also introduces the development status of the "Railway Simulator" using advanced HPC (High performance Computing), designed to clarify dynamic phenomenon to optimize the railway system.

Keywords: railway dynamics, dynamics, simulation, interaction, contact phenomenon

1. Introduction

After reorganization in July 2000, the Railway Dynamics Division comprised 4 research laboratory offices, namely: Vehicle mechanics, Current collection dynamics, Track dynamics, and Structural mechanics, involving researchers in railway vehicles, current collection and tracks from the Basic Research Division, and engineers in structure and disaster prevention from the Engineering Development Division. Based on activities in the Basic Research Division, the aim was also the application and development of research taking into account possible end uses, such as contribution to development of technical standards, etc., while focusing on elucidation of phenomena specific to railways, boundary domain problems, and interaction problems. Since April 2012, research and development has been carried out through a 5-research laboratory office system, following the addition of a Computational Resources in the Railway Dynamics Division are more easily assigned to basic and essential research, compared with Research Divisions dealing with specific fields relating to railway vehicles, electric power, tracks, and structures, etc. As it has a cross-sectoral nature, it can also examine complicated problems spanning several fields.

Given its particular organization, the Railway Dynamics Division has been placing emphasis on: 1) Formulating bespoke analysis and measurement technologies geared to solve problems faced by railway operators, 2) Proposing of specific performance improvement measures, and 3) Developing the railway simulator using HPC to support research and development activities across all RTRI (Railway Technical Research Institute).

This paper introduces the latest research and development relating to the abovementioned areas.

2. Development of railway-specific analysis technologies

2.1 Development of overhead contact line - pantograph simulator

The development of thane overhead contact line - pantograph simulator is aimed at making new pantographs and overhead contact line structure development more efficient, with a view to reducing contact loss and variation in contact force, as well as contributing to investigating the cause underlying overhead crossing de-wiring accidents, etc. To do this, an arbitrary overhead contact line and pantograph shape modeling method was applied, using three-dimensional finite elements, and through three-dimensional contact calculations (Fig. 1).

The overhead contact line model was developed for the following reasons:
- To enable detailed evaluation of the components, which is needed to a number of things, namely: the vibration of the overhead contact line, including metal fittings such as hangers, etc.;
- To take into account geometric non-linearity and influence of tensile force applied to the overhead contact line and of wave propagation;
- To consider the influence of temperature variation;
- To add a function that enables automatic generation of the very complicated shapes found on actual overhead contact lines, including curves, based on principal specifications, etc.

The pantograph and overhead contact line model was designed to express three-dimensional contact, including contact loss at high-speed running and sliding friction.

The aim of the pantograph model was:

![Fig. 1 Overhead contact line and pantograph simulator](image)
- To enable reproduction of elastic deformation at component level by using three-dimensional Euler beam elements;
- To enable reproduction of geometric non-linearity during large deformation;
- To take into account the behavior of railway vehicles on which pantographs are mounted, etc., in addition to mechanism analysis by component.

After completion of the overhead contact line and pantograph models, work is now turned toward analyses which can be made by combining both models. Details regarding the latest state of progress in this regard can be found by referring to the specific research paper on this topic [1].

### 2.2 Development of wheel/rail rolling contact simulator

Normal forces as well as tangential forces are generated at wheel/rail contact surface. Such forces increase in curves, and become impulsive on rail joints, etc. These contact forces are deemed to generate microscopic damage and cause wheel/rail wear, while accumulation of the two contributes to wheel irregularity (uneven wear, wheel flats), rail shelling, and crack generation and propagation.

In conventional wheel/rail contact assessment methods using MBD and FEM, the contact surface is evaluated as a theoretical value, and the degree of pseudo jamming is assumed. In the new simulator however the wheel/rail contact area (contact patch) is represented with a 1mm mesh size, in order to clarify the target phenomena in close to microscopic detail. A dynamic elasto-plastic analysis is performed while considering wheel rotation, to evaluate local plasticity and wear in the microscopic area that becomes a trigger for deterioration and damage, and which cannot be evaluated through the conventional method.

The simulator was developed based on FrontISTR which is a structural analysis software using a large-scale parallel finite element method, through collaborative research with Professor Okuda of Tokyo University [2, 3].

The vehicle model on the other hand, was extended step-by-step i.e. one wheel/one axle, two wheels/two axles (one side) at a time, and a precise FEM model of one bogie (four wheels/two axles) required for elucidating the main factors of deterioration and damage was completed, by FY2017 (Fig. 2). Furthermore, the carbody and the pairing bogie, necessary to the behavior of one entire railway vehicle are evaluated with MBD, making coupled calculation possible.

Building a track model is complicated and time consuming, because of the small mesh size, transition curves and cant. A method was therefore designed to automatically create complicated curve models, by inputting the necessary specifications (curve length, curve radius, cant, transition method: cubic parabola or half sine wave shape transition curve).

A conventional direct method, which is very stable, was used for the numerical calculation method. An iterative method was introduced, which has an algorithm to eliminate degrees of freedom suitable for large-scale parallel calculation by HPC, which made it possible to double calculation levels, compared to actual models.

A basic functioning version of this simulator was completed in FY2017, and was applied to actual research, from FY2018, namely:

- Application of iterative method, incorporating algorithm to eliminate degrees of freedom.
- Automatic creation of complicated curve models
- Evaluation of transition curves (cubic parabola/ half sine wave transition curves) and cant.
- Single-bogie model capable of detailed evaluation of stress variation inside the contact patch
- Behavioral evaluation of body and bogie by coupling with MBD

![Fig. 2 Wheel/rail rolling contact simulator](image)

### 3. Proposal of specific performance improvement measures

#### 3.1 Development of the wheel load decrement control bogie

In location where there are large twists in the track, such as the exit of transition curves following a sharp curve, wheel support under the bogie changes from the usual four-point support to a near three-point support. This is when the risk of derailment increases, if lateral force is applied to the wheel with a diminished wheel load. RTRI has developed a wheel load decrement control bogie, which has rotation mechanism installed on the joint between the side beam and cross beam of the bogie frame, in order to improve the three-point support by improving the bogie’s capacity to follow twisting in the track (Fig. 3).

Up until now, performance assessments of this bogie were conducted on the RTRI test line [4]. In FY 2016, running tests covering a cumulative total of 5,300 km were conducted on a test line outside RTIR, confirming that the bogie was able to control the maximum reduction ratio in wheel load to 30 to 40% less that with an ordinary bogie. These tests were conducted on the RTRI test line [4]. In FY 2016, running tests covering a cumulative total of 5,300 km were conducted on a test line outside RTIR, confirming that the bogie was able to control the maximum reduction ratio in wheel load to 30 to 40% less that with an ordinary bogie. Details on this can be found in [5].

The most important component of the wheel load decrement control bogie exists in its rotation mechanism. Abrasion tests will therefore be carried out on the rotation mechanism alone, as well as when mounted on the bogie to verify durability with a view to introduction into service.
3.2 Development of low-cost longitudinal sleeper

A longitudinal sleeper was developed save on maintenance work and raise environmental performance. The sleeper comprises 2 beams made of prestressed concrete arranged in parallel to the rails, with connectors to link them together. The sleepers are being used in service by 3 JR companies and 28 private railways (total track length 55.6 km). However, an improved longitudinal sleeper needs to be developed, in view of lighter vehicles, adoption of long rails, and improved track maintenance and vehicle maintenance technologies developed over recent years.

Parametric sensitivity was therefore measured using numerical analysis, along with long-term wheel load measurement using a multipoint measurement system, exploiting the significant improvements achieved over recent years, in the field of measurement systems [6]. A lower cost longitudinal sleeper with a smaller cross section than a conventional sleeper was proposed. Strength tests were carried out on specimens and performance tests conducted on the test line inside RTRI (Fig. 4). Details of this can be found in the paper [7] in this issue. Long-term durability tests however are planned for the low-cost ladder sleepers, by installing them on a commercial line.

4. Development of a Railway simulator

4.1 Development of an individual simulator

RTRI has been developing a Railway simulator which can reproduce the various types of event occurring during train operations, on computer. The purpose of this development is to raise the quality and efficiency of railway research and development [8]. The railway simulator is designed to deal with problems that are specific to the railways, and which are ordinarily difficult to examine with theoretical analysis, experiments, measurements, and observations. The simulator which uses HPC technology, is geared to make clarification of railway related phenomena more efficient.

The simulator is designed for 17 areas of development, including the aforementioned – Pantograph/catenary simulator and Wheel/rail rolling contact simulator; in addition to the vehicle dynamics simulator, elastic track simulator, traction control simulator, ballast track simulator, airflow simulator, seismic disaster simulator, and train operation/ passenger behavior simulator, etc.

4.2 Development of coupled simulation

Coupled simulation is the combination of simulation technologies from different fields, and multi-disciplinary problems can be elucidated. Coupled simulation offers a practical analysis that can be performed at high speed, by using the efficient analytical methods that have proved to be effective in each field, in order to examine the influence of various interactions.

Ten different combinations are being investigated, including, pantograph/catenary and vehicle dynamics simulator; wheel/rail rolling contact and vehicle dynamics simulator; wheel/rail rolling contact and ballast track simulator; and seismic disaster and vehicle dynamics simulator, etc.

4.3 Construction of common platform

Research output aimed specifically at the railways have often remained limited in use, with outcomes only being used within the limited scope of the specialist field in question. The Railway simulator however, is designed to be used across different fields and have a more holistic application, covering operational aspects as well as user interfaces, thereby playing the role of a multi-disciplinary simulator that can be used in other areas of research other than the specialist domain of the developer. To achieve this, a common platform, which will form the core of the simulator, is being developed which will serve as an interface for different research laboratories, giving them access to the high-performance computer and network, etc.

The common platform will be used to display analytical results through an integrated display, and launch each simulator according to predetermined procedures, while making it possible to monitor analytical progress.

The common platform is already able to launch 7 kinds of simulator, including, the elastic track simulator, the pantograph/catenary simulator, the electromagnetic induction simulator, etc. A coupled simulation manager on the common platform controls the combined use of simulators, and has already been programmed to operate the wheel/ rail rolling contact and vehicle dynamics simulator; and the airflow and Aeroacoustics sound simulator, with confirmation that resulting analyses are normal (Fig. 5).

The integrated display makes it possible to see different analytical results graphically, and allows visualization of behaviors using virtual reality, in total, 6 kinds of results can be displayed synchronously.
4.4 Construction of virtual test line at RTRI

The RTRI test line is indispensable for empirical research in various fields. Analytical verification of running tests when possible however can contribute to higher quality research and development. In addition, high demand to use the RTRI test line can cause congestion, therefore, replacing some trials with digital tests would increase research and development efficiency. A such, a virtual test line is being developed at RTRI, as a model case to apply the Railway simulator.

The RTRI virtual test line has defined file sets of calculation conditions each simulator, to facilitate operation, and maintain consistency among the simulators. The file sets are created in a unified manner, based on required input data specifications of each simulator, i.e. 1) Railway track conditions are input as one file set, including for example, track center lines, turnouts, catenary, wayside buildings, etc., 2) Vehicle conditions form another file set, including specifications and running conditions of the R291 test train, etc., 3) While 3D models and virtual space information files etc. are created to display the abovementioned items, such as VR movies, etc. Digital running tests are scheduled to commence before the end of FY2018 (Fig. 6).

5. Conclusion

This paper introduces the latest in research and development work in railway dynamics and describes the development of a Railway simulator. The research and development underway aims to develop analyses and measurement technologies that can be used to find solutions to problems faced by railway operators, which can form the basis for specific countermeasures.

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