Research and Development on Railway Simulators

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The Railway Technical Research Institute (RTRI) has been developing “railway simulators” as a common platform for developing advanced railway simulation technology and has successively implemented research projects every five years since 2010. In the last five years (2015-2019), RTRI has developed a “virtual railway test line” and a “coupling environment for individual simulators”. The virtual railway test line, which reproduces the dynamic behavior of the railway system during train operation under various conditions, is used to perform virtual running tests. The railway simulator coupling environment, which uses coupled calculations by linking multiple simulators, is used to carry out comprehensive analyses. This report outlines these achievements and introduces future research prospects.

Keywords: railway simulator, virtual railway test line, coupled analysis, vehicle dynamics, overhead contact line, pantograph

1. Introduction

There has been a tremendous improvement in computing power over recent years, providing a basis for the ongoing development of large-scale parallel computing programs and proposals for new computational mechanic techniques. On a similar note, numerical simulation has been raising expectations in the field of railways as a solution for studying phenomena difficult to reproduce or investigate by experiments or active duty car tests. Following the trend, RTRI has been engaging in the development of railway simulators as a tool to improve the quality and efficiency of research and development efforts and thereby help optimize railway systems and understand complex phenomena.

The main purpose of developing this railway simulator is to precisely reproduce the physical phenomena that occur in railway infrastructure.

Figure 1 shows the overall concept of railway simulators. RTRI has developed and been using in its R&D programs various simulation techniques, ranging from those related to dynamics for train run, aerodynamics and environment and accident and disaster to those for energy, electromagnetic environment, transport and more. The railway simulators are linked to each other for research and development purposes, offering enhanced capability especially in large-scale parallel and other sophisticated computation and coupled computation of multiple simulators.

This paper presents an overview of the railway simulators, centering on the virtual railway test line, a constellation of train run simulators.

2. System configuration for railway simulators

Studies on an optimal environment for the execution of various simulations by railway simulators have led to the system configuration in Fig. 2 that meets execution, development, and other related requirements.

The common platform built in the management server is the simulation execution environment. Simulations are executed by super computers and Windows Servers that are automatically selected for the execution. These servers are connected to each other on the network for transmission of input and output data, program execution control and other actions. In addition, a visualization server is provided to display simulation results. By combining the essential functions, the configuration is capable of handling the complete process from the execution of simulation to the visualization of results.

3. Virtual railway test line

The virtual railway test line is a railway test line created in a virtual space on a computer by coupling dynamics-related train run simulation techniques (for vehicles, tracks, current collection, etc.) (Fig. 3). The virtual test line was developed in the following process: first the train run
simulation techniques were improved while techniques for coupling those simulations were studied; then techniques were developed for the simulation of vehicles and tracks capable of handling elastic tracks and car bodies, the simulation of overhead contact lines and pantographs capable of handling detailed three-dimensional structures, the simulation of wheel/rail rolling contact capable of handling a single bogie model and the simulation of ballasted tracks capable of large-scale and long-term deterioration analyses; and finally the technique for coupling those simulations was developed. In the following sections of this paper, the individual simulation techniques are outlined and a running simulation that was conducted on the RTRI’s test track as part of a running test on the virtual railway test line is presented.

3.1 Simulation of vehicles and tracks

To study the complex mechanical behavior of vehicles and tracks in detail, analysis models for vehicle dynamics, elastic car bodies, elastic tracks, drive control, etc. were developed and, using these models, coupled simulations were conducted (Fig. 4).

The vehicle and train models largely consist of car bodies, bogies and wheels and the elements that connect those components such as springs and dampers, all of which are compatible with SIMPACK [1], a general multibody dynamics simulation software. The software accommodates not only rigid vehicle models but also three-dimensional elastic car body models consisting of hexahedron members, expanding the scope of simulation beyond rigid models to include, for example, high-frequency car body vibration.

The simulation technique for drive control [2] uses models of inverters and motors, which are components of the traction circuit of electric motor cars, and of air brakes, capable of simulating powering and braking.

The track is represented by a FEM track model in which the rails, sleepers and the ground are mass points, directly under the moving wheelsets and connected by springs and dampers: together, these form a moving support spring model. The rails, sleepers and sleeper support springs are solid elements; and the rail fastening system and track pads are spring elements.

Coupled computation using these models enables simulation of the dynamics of vehicles running on an elastically supported track.

3.2 Simulation of overhead contact lines and pantographs

A simulation technique for overhead contact lines (OCL) and pantographs was developed as a tool to support the designing/development of pantographs and OCLs, and to help identify the causes of accidents involving OCLs and pantographs. While this type of research used to involve theoretical and dynamic behavior analyses, with the latter using two-dimensional models, the virtual railway test line environment enables simulation of three-dimensional OCLs and pantographs [3].

Figure 5 (a) shows a three-dimensional pantograph model. The model consists of three-dimensional FEM models of the pantograph head, contact strips, horns, articulated frame and other pantograph components. The simulation technique enables the modeling of complex structures such as the multi-segment contact strips which can follow the OCL. The simulation is also capable of creating three-dimensional models of OCLs, making it possible to handle any alignment of tracks, multiple contact lines and change in static geometry in changing temperature. Figure 5 (b) shows an example of simulation for when the train passes the crossing section from the sidetrack to the main track. The distance between the pantograph and contact wires, and the contact force during the transition can be simulated in each of the side track phase, the two-point contact phase with the contact strip on the side track and the horn on the main track and the main track phase. Furthermore, when coupled with vehicle dynamics simulation, the technique can also simulate the behavior of OCLs and pantographs that consider the tilt and acceleration and deceleration of vehicles.

3.3 Simulation of wheel/rail rolling contact

As a vehicle runs on rails, a load of several tons was applied via each rolling wheel on a small area of a rail, called a contact patch, measuring about several dozen to 100 mm². As this happens, complex forces work on the contact areas, leading to wear, cracking and other damage and deterioration of the wheels and rails. Given the circumstances, a wheel/rail rolling contact simulation technique [4] was developed as a tool to understand what is actually occurring and thereby prevent associated damage and deterioration of wheels and rails so that ride comfort and vehicle running safety can be maintained and maintenance workload prevented from increasing.

The technique is designed to run a structural analysis program which, by means of elastic and elasto-plastic analyses based on the three-dimensional FEM, calculates in real time non-steady impact behavior (force, stress, acceleration, etc.) generated between the wheel and rail and its subse-
quent transmission. Using the technique, the stress distribution and slip ratio at the wheel-rail contact point can be simulated when a four-wheel bogie passes a curved section.

In addition, to study the nonlinear characteristics of materials resulting from the wheels becoming hotter from braking, an algorithm was developed that combines a thermal conduction analysis feature, which takes into account thermal conduction, heat transmission, and heat generation from radiation and friction, with a structural analysis feature, enabling structural analysis that can factor in thermal expansion, heat-induced reduction in yield stress and other factors.

3.4 Simulation of ballasted tracks

Ballasted tracks require continuous attention and maintenance as ballast is constantly deteriorating from wear, rotation, movement, etc. under the load of passing trains. To help resolve the issue, a ballasted track simulation method was developed that is based on a discrete element method for elastic granules and capable of modeling individual ballast granules to analyze the behavior of ballasted track while factoring in the elastic deformation and generated stress of individual granules [5].

As shown in Fig. 6, the method is capable of not just modeling the shape of individual ballast granules but also of slightly rounding the pointed tips of ballast granules when those contact points are subjected to a load exceeding the threshold and thereby reproducing ballast wear. This has made it possible to monitor the ballast for any tendency to settle and amount of settlement as trains come and go, which thus far has been difficult to follow [5].

3.5 Running simulation using the virtual railway test line

Figure 7 shows the flows of a running simulation. Two-way coupled simulation is performed by combining vehicle dynamics and drive control, while one-way coupled simulation can be carried out to determine pantograph position, by inputting above-roof displacement as part of vehicle dynamics simulation.

Results of simulation on the virtual railway test line environment can be represented by various graphs. They can also be visualized from various viewpoints using three-dimensional animation. Figure 8 shows examples of a representation of results from a simulation performed on the virtual railway test line environment using models of the RTRI’s test track and test cars. They are visualized images of (a) car body / bogie / track, (b) overhead contact line / pantograph and (c) overall setting including track alignment from relevant viewpoints, and graphic representations of (a) car body roll angle, (b) longitudinal level irregularity of pantograph and (c) train speed. The simulation technique makes it possible to observe what needs to be observed in detail from whatever angle desirable and view videos that show how vehicles, overhead contact lines, tracks and other components behave and change their behavior over a period, as if they are all real.

4. Non-train run simulations

Simulation techniques have also been developed or improved in areas other than for running trains, such as those related to air flow, train operation, passenger flow, railway communication environment and earthquake damage. Those are outlined below.

4.1 Simulation of air flows

Vehicles, each an elongated object, moving along close to the ground is unique to railways. It is therefore essential to understand associated aspects of hydromechanics. Analysis of train sets essentially needs to be conducted on a large scale. Therefore, minimizing the hours spent creating analysis models is a must, as is parallelizing the programs. Given the circumstances, RTRI has been developing an air flow simulation technique based on a Cartesian grid method for practical analysis [6].

The past five years have been spent verifying and improving the accuracy of the air flow simulation method while conducting large-scale fluid simulation. Circular cylinder flows with high Reynolds numbers were reproduced using a Cartesian grid method. A simulation technique for flows around the bogie that factors in the rotation of wheelsets was developed. Those were then applied to understand the meandering flows under the floors of a train set and other phenomena [6].
4.2 Simulation of train operation and passenger flows

To carry out comprehensive evaluations, including from the viewpoint of passenger flows, of high-level train control methods being studied by RTRI, a train operation simulation technique was developed that could handle a moving block system, predictive control under a fixed block system and predictive control under a moving block system.

In addition, based on the results of questionnaires on the positions on vehicles preferred by passengers, an onboard passenger flow simulation was developed. Onboard passenger behavior models were developed that are capable of reproducing passenger behaviors while maintaining the current estimation accuracy of boarding/alighting time by applying behavior models in which walking speed changes depending on preferred positions of specific passengers relative to the positions of other nearby passengers.

Furthermore, a simulator for train operation and passenger behavior incorporating the onboard passenger behavior models was developed, making it possible to estimate train delays and passenger comfort.

4.3 Simulation of railway communication environment

To build a railway communication environment simulation method for integrated analysis including of transmission quality, radio noise and electromagnetic induction associated with communication between the railway systems, research was conducted on coupling train control and operation-related simulators with other simulators including of radio data transmission lines, radio noise radiation, electromagnetic induction and surge analysis, which successfully led to an intended coupled simulation method.

4.4 Simulation of earthquake damage

Railway lines stretch over long distances, along which various structures are built, which makes it important to identify potential risks of injury and damage associated with major earthquakes before they hit and take appropriate action. With that in mind, an earthquake disaster simulator [7] was developed that is capable of automatically modeling tremor-generating faults and structures and running seismic response analyses. As for automatic modeling, archives of faults, the ground and structures are built and the simulator uses data from the archives to automatically create analysis models. In seismic response analyses, the simulator runs parallel computing using supercomputers. To support decision making on what appropriate action to take, the simulator offers functions to display the results of the analyses, such as GIS data and turning data on damage into images.

5. Conclusion

This paper outlined some of the railway simulators developed by RTRI. RTRI started developing railway simulators ten years ago. The first five years (2010-2014) were spent designing and developing the core systems and the last five years (2015-2019) have been spent on improvement and introducing additional functions.

The next five years (2020-2024) will be devoted to the verification of the simulators’ applicability to real-world phenomena, study on methods for the modeling of real sections and the development of further analysis methods, all for the realization of the virtual railway test line as a practical function.

When verifying applicability of the virtual railway test line, a range of real-world phenomena will be considered to identify and achieve any improvements needed. The study on methods for the modeling of real sections will look at ways to efficiently obtain a range of vehicle and field-related parameters using the existing database and sensing technologies.

As an extended analysis function of the virtual railway test line, a snowplowing run simulation technique will be developed for the evaluation of vehicle running safety on snow-covered tracks. RTRI’s further targets include more precise modeling of subjects being analyzed and, using those models, running more accurate simulation, which should take longer to complete, and using those models and simulations to substitute for experiments. Precisely in such environment, which can be called a “numerical laboratory,” RTRI will strive to develop simulation techniques for contact loss, arc and microscopic structures, and create a numerical wind tunnel.

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