Evaluating Wheel Slide Protection Performance Responding to Train Braking

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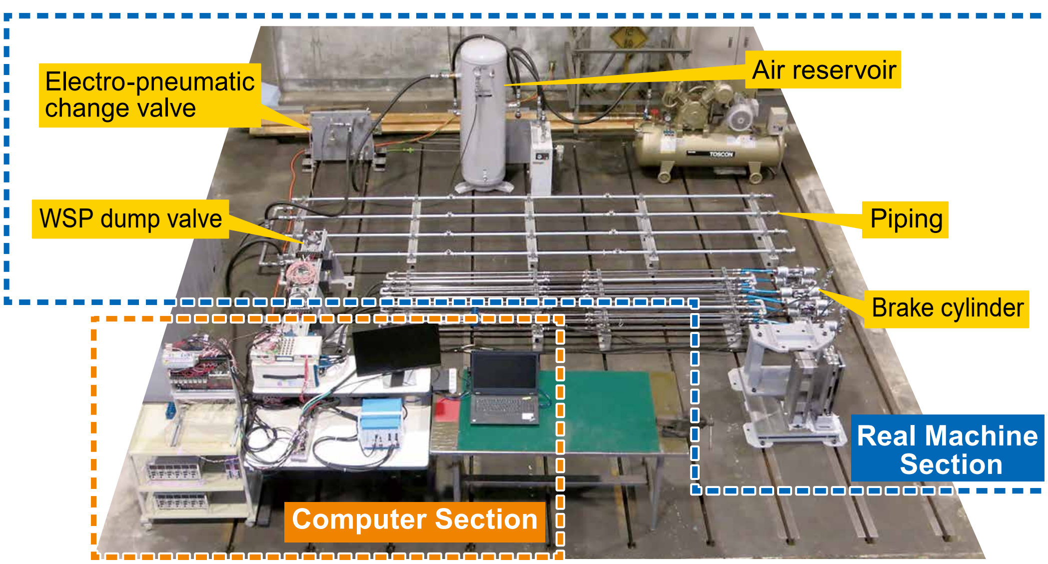
The wheels of railway vehicles are slippery, and if a slide occurring during braking it may result in risks of extending the stopping distance and damaging the wheels; wheel slide protection (WSP) is provided to countermeasures against these. WSP is a mechanism that adjusts the braking force according to the wheel slide state. WSP is an important safety-related technology and undergoes performance evaluation by a running test. However, since the slipperiness cannot be known until the train actually runs, it can slip too much or loosen the brakes too much. Thus, we considered a test method that simulates the slipperiness on a computer. This paper outlines the WSP performance evaluation method we have developed.



Overall view of the WSP Simulator

Overview of the WSP Simulator

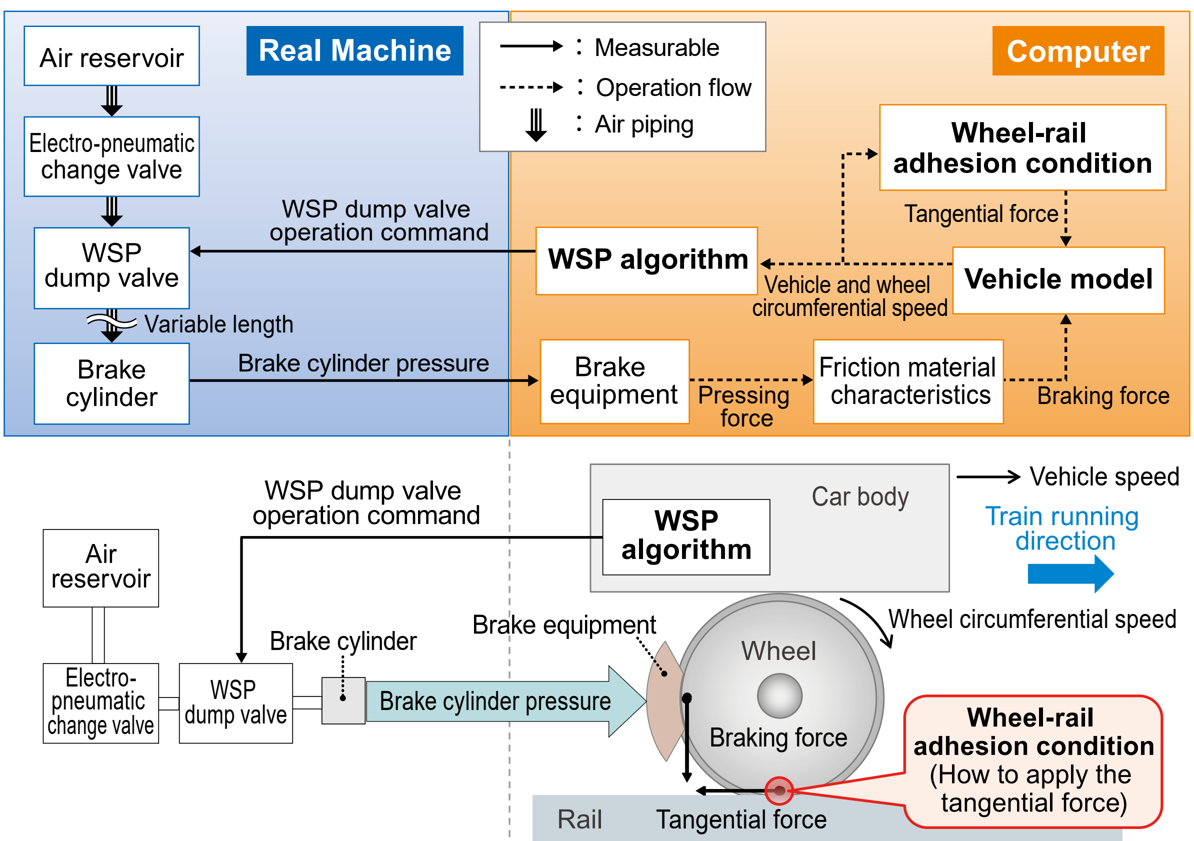
Overall view of the WSP Simulator shows the overall view of the WSP Simulator we have developed. It is test equipment for air brakes and is a hybrid simulator that uses a real machine to reproduce the brake cylinder (BC) pressure, which is difficult to model on a computer because the behavior differs greatly depending on the pipe length and volume, and uses a computer to simulate the other elements.

As shown in Block diagram and schematic, the simulator consists of the Real Machine Section and the Computer Section, the former of which uses piping and control valves for one actual vehicle from the air reservior to the BC, and the latter of which mainly specifies the vehicle model, WSP algorithm, and adhesion condition.

The vehicle model, which consists of mathematical formulas that express the movement of the vehicle inside the simulator, represent the movement in the traveling direction of the vehicle and the rotational movement of the wheels. The WSP algorithm automatically adjusts the BC pressure during a slide. It commands one of the three operations of exhaust, hold, and air supply to the WSP dump valve according to predetermined conditions. The adhesion condition refers to the frictional state between the wheel and rail, and herein it means how the tangential force between the wheel and rail is applied.

WSP Simulator Output Example

WSP Simulator output example shows the result of reproducing the deceleration of the vehicle by using the WSP Simulator. After starting the braking at time 0 s on the horizontal axis there is a rise in BC pressure. Only this BC pressure is the measured value, and based on this data,



Block diagram and schematic

the Computer Section computes the speed information, including the vehicle speed and wheel circumferential speed, and conveys it to the WSP algorithm. The WSP algorithm outputs the exhaust, hold, or air supply operation (determined from the slide detection conditions) to the WSP dump valve of the Real Machine Section as a command. The simulator has a loop in which the Computer Section computes the speed information again after reading the BC pressure changed by the operation of the WSP dump valve of the real machine. It continues looping until the vehicle stops (i.e. vehicle speed = 0 km/h), and computes the stopping distance, which is the distance along which the vehicle travelled during the period from the start of braking to its stop.

Comparison between Test Methods and Adhesion Condition

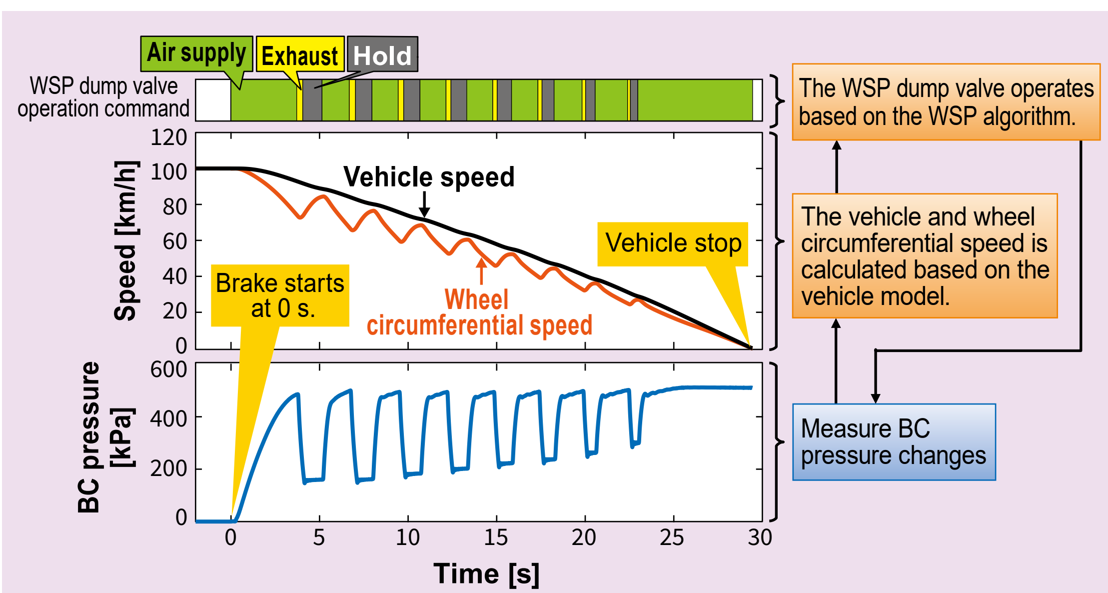
The performance of WSP is obtained as a result of the mutual influence of the WSP algorithm, adhesion condition, and BC pressure behavior. A simulation can evaluate these influences accurately and efficiently.

While the on-track test is the most realistic and convincing test method, it has limits to how much WSP performance can be evaluated with a limited number of tests.

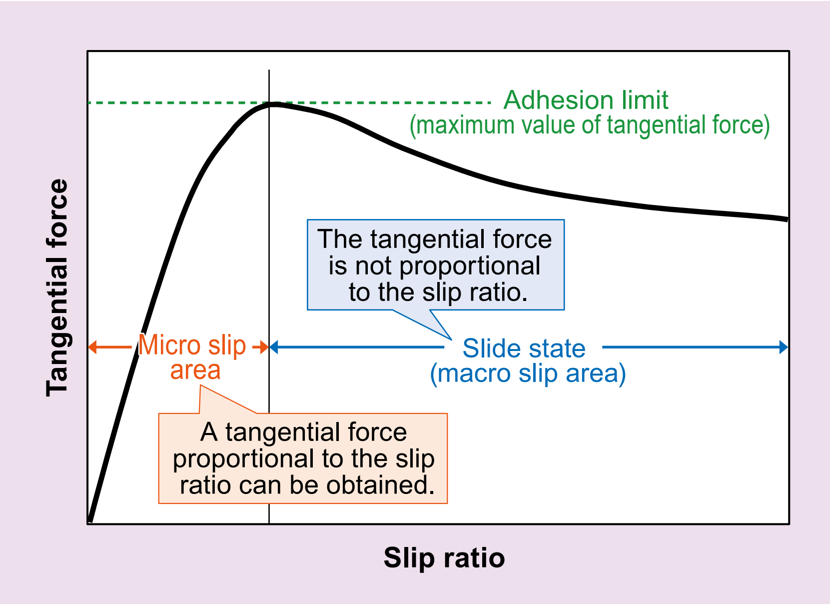
By contrast, the WSP Simulator allows the tester to set the BC pressure behavior and the adhesion condition among the three factors that affect the performance. The tester can specify, as a known amount, the adhesion condition that is liable to fluctuate and difficult to reproduce in the on-track test. Thus, this simulator is useful, for example, for comparing the performance when different WSP algorithms are applied to the same adhesion condition.

As seen from the comparison between the two methods, it is important to give the WSP Simulator an adhesion condition that is as close as possible to the on-track test. From the results of various research that analyzes the mechanism of adhesion between the wheel and rail (e.g. [1] and [2]), we refer to the findings such as detailed theoretical models and approximate values of experimental results and set the adhesion condition suitable for the test purpose.

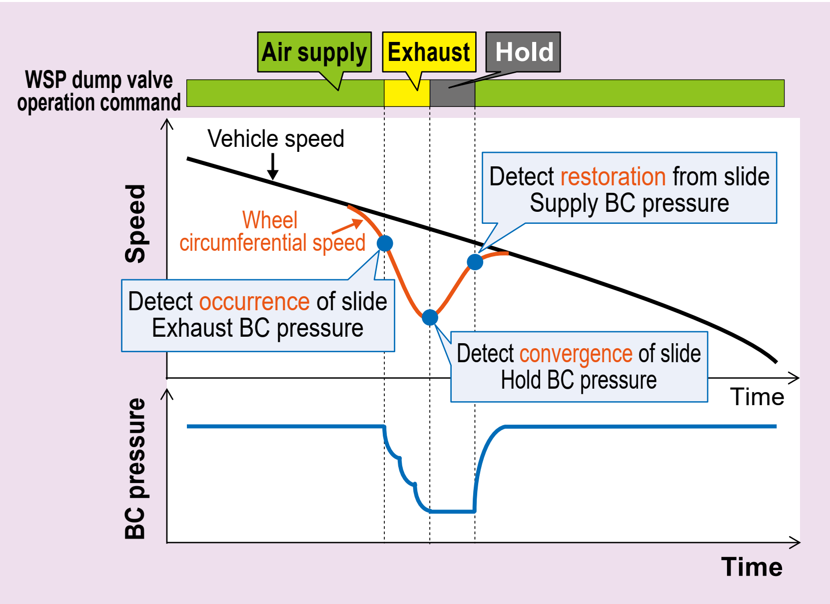
For the adhesion condition, this paper applies the relationship between the slip ratio and tangential force in Relationship between the slip ratio and tangential force, which is known as a general characteristic. The slip ratio, obtained by dividing the



WSP Simulator output example



Relationship between the slip ratio and tangential force



Overview of slip ratio WSP

difference between the vehicle speed and wheel circumfer-ential speed by the vehicle speed, is one of the indices showing the magnitude of the slide at that time.

In the WSP Simulator, the adhesion condition is given by quantifying the relationship between the slip ratio and tangential force intended by the tester (e.g. the adhesion limit value, the slip ratio that reaches the adhesion limit, and the tangential force behavior in slide state).

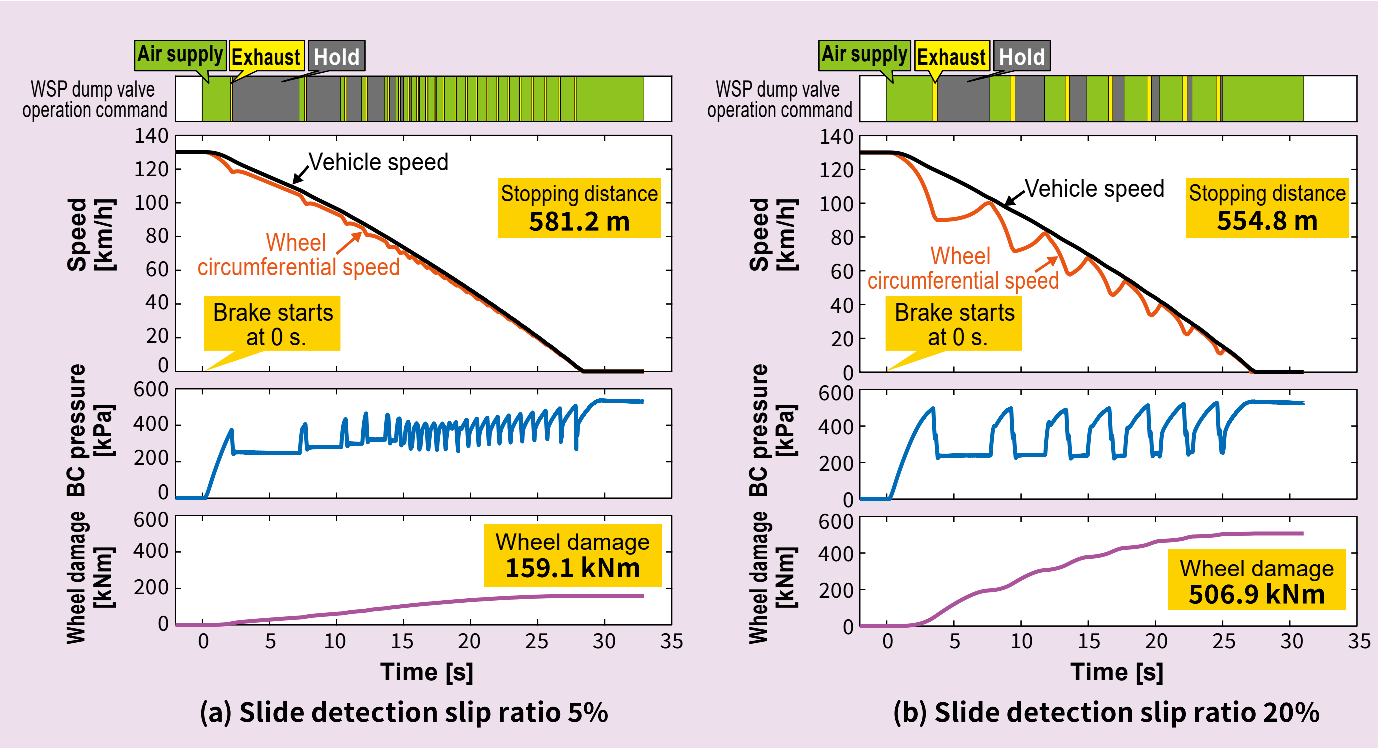
Performance Evaluation Indices

What is good performance WSP? As for evaluation indices to judge good or bad, since an increase in the stopping distance has a particular effect on safety, we choose it herein as the most important evaluation index.

Next, the physical quantity defined as the amount of wheel damage [3] is used as the evaluation index for wheel flat prevention. It corresponds to work due to friction between the wheel and rail during a slide. It is 0 if no slide occurs; the value increases as the slide continues. It is calculated from speed information and braking force.

Test Results and Evaluation Examples

This section shows an example of an evaluation performed with the WSP Simulator. Overview of slip ratio WSP overviews the WSP algorithm (slip ratio WSP) to be evaluated. Once the slip ratio reaches the specified threshold, it detects the occurrence of a slide and exhausts the BC pressure, detects that the slide has turned to convergence, and maintains the BC pressure. Then, after detecting the restoration from the slide and supplying the BC pressure, it repeats the previous steps. As for the threshold value of the



Test results from changing the slide detection slip ratio

slip ratio at which to detect a slide, the following two were evaluated: (a) 5% (reducing the allowable slip ratio, with priority given to wheel flat prevention) and (b) 20% (not loosening the brake as far as possible, with priority given to the not increasing the stopping distance).

Test results from changing the slide detection slip ratio shows the results of operating the brake from a speed of 130 km/h with the BC pressure behavior and adhesion condition in common. As a result, the stopping distance was 581.2 m in condition (a) and 554.8 m in condition (b); the wheel damage was 159.1 kNm in condition (a) and 506.9 kNm in condition (b). In this example, we conclude that condition (a) is superior in terms of load on the wheel, but (b) is superior if safety is considered to be the highest priority (e.g. for emergency braking).

Conclusion

We expect to utilize the WSP Simulator as a new development tool for the WSP algorithm and as a method to reduce the number of trials during the on-track test by checking the performance of this algorithm before performing that test. In the future, we will improve its modeling accuracy and expand its functions to make it a more user-friendly simulator.

References

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3) Nonaka, T., Ohyama, T., Endo, Y., Yoshikawa, H., "Anti-lock Braking System for Train Sets on Railways (1st Report, Formation of Dynamic Model and Methods of Evaluation for Controls)," Transactions of the JSME Series C, Vol.71, No.705, pp.1604-1610, 2005 (in Japanese)