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Measuring Braking Stiffness Using a Novel Intelligent Tire

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A method for measuring tire-road contact loads using wheel strain has been developed as part of intelligent tire technology. This approach enables direct estimation of forces acting on the contact patch during vehicle operation without relying on conventional external sensing systems, thereby simplifying instrumentation and improving robustness. In this study, the proposed method was applied to evaluate braking characteristics during straight-line driving under various road surface conditions.

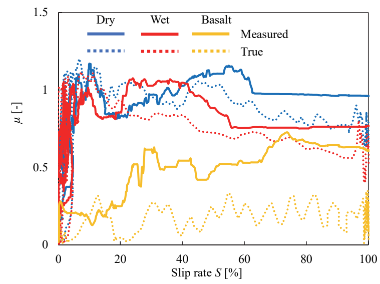
The intelligent tire measures strain generated on the inner surface of the wheel rim using strain gauges. Through calibration experiments conducted with a dedicated driving simulation device, the relationship between measured strain and triaxial contact loads (longitudinal, lateral, and vertical forces) was identified with sufficient accuracy. Based on this relationship, the contact loads during vehicle operation can be estimated by solving a set of simultaneous equations derived from multiple strain measurements distributed along the wheel.

Experiments were carried out using a traction test vehicle equipped with the intelligent tire. Measurements were performed under controlled conditions with a vertical load of approximately 3 kN and a vehicle speed of around 65 km/h. Road surfaces corresponding to dry, wet, and icy conditions were tested to cover a wide range of friction levels. The estimated contact loads were compared with reference values obtained from a force measurement system installed on the test vehicle. The results demonstrated good agreement between the proposed method and the reference measurements, although slight deviations were observed when the tire rotation approached a near-stop condition.

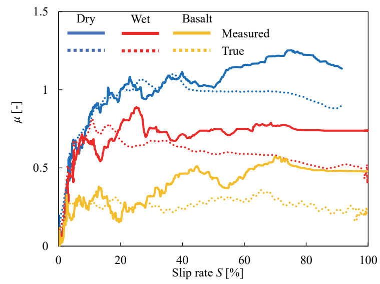
Using the measured contact loads, the relationship between slip ratio and road-tire friction coefficient (μ-S relationship) was analyzed. Figures 1 (a) and 1 (b) show the results for normal and studless tires, respectively. The results showed that the intelligent tire successfully captured characteristic differences depending on road surface conditions and tire types, including normal and studless tires. In particular, lower friction levels on icy surfaces and higher friction at low slip ratios for studless tires were clearly observed, indicating that the method can distinguish subtle differences in tire performance.

Furthermore, braking stiffness was derived from the μ-S relationship using a least-squares method within a low slip ratio range (4-6%) as shown in Fig. 2. Figures 2 (a) and 2 (b) show the results for normal and studless tires, respectively. The obtained braking stiffness exhibited clear distinctions between different tires and road conditions, indicating that it effectively reflects braking performance characteristics and can be used as a quantitative index for comparison.

These findings demonstrate that the proposed intelligent tire system is capable of accurately measuring tire-road interaction and evaluating braking performance. The method has strong potential for applications in vehicle dynamics analysis, road condition estimation, and advanced braking control systems such as ABS and traction control.

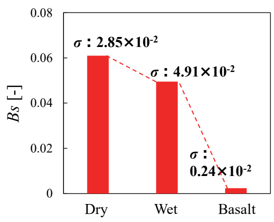


(a) Normal tire

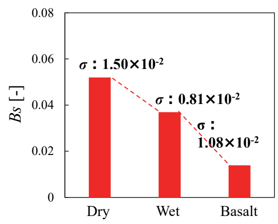


(b) Studless tire

Fig. 1 Measurement results of μ-S characteristics



(a) Normal tire



(b) Studless tire

Fig. 2 Calculation results of braking stiffness