

Study on Wheel Stiffness Considering Balance between Driving Stability and Weight

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ABSTRACT

This paper studies various wheel stiffness configurations, with the aim of enhancing driving stability while minimizing the increase in weight associated with an increase in stiffness. Reinforcement was added to the wheel disk and the wheel rim of standard aluminum wheels for passenger vehicles in order to produce four wheels with different stiffness configurations. The effects of disk stiffness and rim stiffness on tire contact patch profiles and driving stability were quantitatively evaluated.

From the results of tests with the four wheels, it was observed that disk stiffness and rim stiffness have differing effects on tire contact patch profiles, and on driving stability. Disk stiffness influences especially tire contact patch length, and tire contact patch length influences especially maneuverability in driving stability. Rim stiffness influences especially tire contact patch area, and tire contact patch area influences especially stability in driving stability. The investigation also confirmed the effectiveness of using contact patch shape factors as intermediate indices in a method for analyzing the relationship between wheel stiffness and driving stability.

In addition, it was demonstrated that driving stability can be increased with a minimum increase in weight by optimizing the ratio between disk stiffness and rim stiffness. A method for optimizing wheel stiffness is presented in this paper.

CITATION: Hirano, A., "Study on Wheel Stiffness Considering Balance between Driving Stability and Weight," *SAE Int. J. Commer. Veh.* 8(1):2015, doi:10.4271/2015-01-1755.

1. INTRODUCTION

1.1. Background

Reducing the weight of automobile wheels - one of the vehicle's larger components - can be expected to increase fuel economy.

Wheel stiffness affects road holding ability and driving stability, so these influences should be considered when attempting to reduce the wheel weight.

When a vehicle cruises, its wheels are subjected to a variety of stresses from the road surface. In cornering maneuvers, lateral force acting on the tires deforms the wheels. Wheel deformation increases the wheels' camber angles against ground plane. The wheels' camber angles against ground plane affects road holding ability and driving stability [1], [2], [3], [4].

Figure 1 shows the results of a bench test comparing degrees of deformation in the camber direction between a wheel and suspension components. The lateral force equivalent to a cornering of the vehicle was applied to the tire. Deformation of the wheel by lateral force is not small as compared with other suspension parts.

The overall effect of wheel stiffness on driving stability is well known and empirically established. In particular, production model and racing model automobiles designed for enhanced driving stability require significantly stiffer and lighter wheels [1], [2]. However, many elements of the overall effect of wheel stiffness on driving stability have not been quantitatively clarified.

The relationship between wheel stiffness and driving stability has not been investigated as the primary subject of past technical papers, although a few remarks on the relationship are included in an academic journal of materials technology, and a public patent specification, and at least one book [5], [6], [7], [8], [9].

No test procedure has yet been established to measure driving stability in relation to wheel stiffness, nor is there an evaluation method for wheel stiffness itself. Thus, an issue arises concerning the difficulty balancing enhanced driving stability and minimized weight in actual vehicle development.

In conventional tire dynamics theories and vehicle dynamics theories, stiffer wheels have been regarded as desirable [10], [11]. However, increased stiffness generally involves a commensurate increase in weight, which creates an issue with fuel economy.

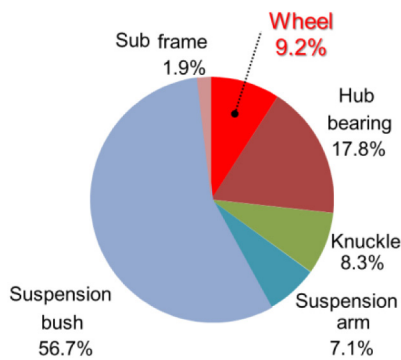


Figure 1. Distribution of deformation by percentage in wheel and suspension components

1.2. Purpose

This study presents a method for quantitatively determining the effect of wheel stiffness on driving stability, for optimizing the wheel stiffness, and, ultimately, balancing driving stability and wheel weight.

This paper proceeds as follows:

Section 2 describes methods for wheel stiffness tests, and tire contact patch profile tests, and driving stability tests using an actual vehicle.

Section 3 includes comparison results for wheels with different stiffness configurations, in terms of stiffness itself, tire contact patch profiles, and driving stability.

Section 4 provides a concept for optimizing wheel stiffness based on results obtained concerning the relationship between wheel stiffness, tire contact patch profiles, and driving stability. The optimization aims to enhance driving stability while minimizing the weight increase that results from additional reinforcement.

Conclusions are presented in Section 5.

2. TEST METHODS

2.1. Wheel Stiffness

Figure 2 shows the configuration of the aluminum wheel used in the tests. Table 1 lists specifications of the test wheel, while Figure 3 shows the additional reinforcement structure and positions of reinforcement in versions of the wheel with different stiffness configurations.

The four configurations used in the tests are:

1. Basic wheel
2. Wheel with increased disk stiffness
3. Wheel with increased rim stiffness
4. Wheel with both increased disk and rim stiffness

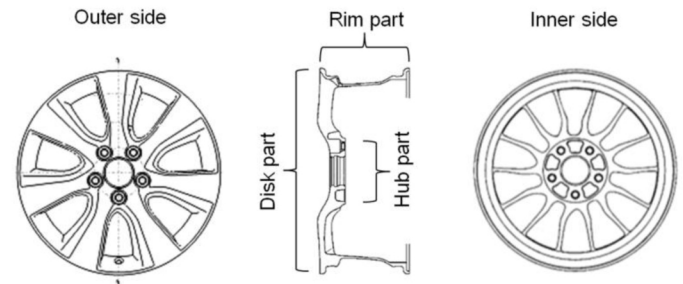


Figure 2. Test wheel configuration

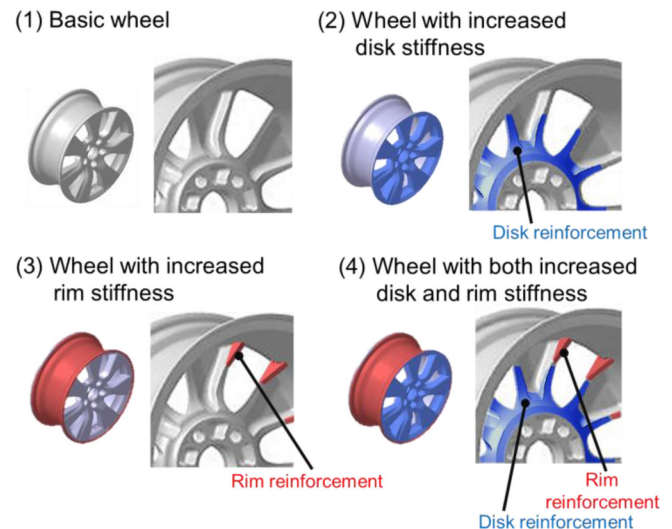


Figure 3. Configuration and positions of additional reinforcement

Table 1. Test wheel specifications

Type	-	Aluminum casting
Wheel diameter	inch	17
Rim width	inch	7
Shape of the tire bead profile	-	J
Bolt pattern	-	5
Bolt pitch circle (P.C.D)	mm	114.3
Inset	mm	45

The tests employed standard production wheels for passenger vehicles, chosen for their capability to yield test results applicable to other production wheels.

Wheel stiffness was tested by separating the disk and the rim, since a wheel is typically divided into these two portions. The effect of increased stiffness on driving stability in the presence of additional reinforcement to the disk and to the rim was studied.

It should be noted that for the rim, this reinforcement employed a resin composite with a density of 68% and a Young's modulus of 71%, respectively, of these physical properties of the base aluminum alloy (figures estimated based on a preliminary test result and the material composition). The mechanical properties of these two materials are similar: the ratio of Young's modulus to density is 25 (GPa/Mgm⁻³) for the base aluminum alloy and 24 (GPa/Mgm⁻³) for the resin composite material. Consequently, in considering the

amount of weight increase incurred relative to the change in stiffness obtained from the additional reinforcement, the use of the resin composite material for this purpose is not problematic [12].

A lateral force was applied in a triangle wave form from a tire contact table, with a limit of 80% of the vertical load on one front wheel in the inward direction (-) and outward direction (+) of the vehicle body.

The following schematic images for these bench tests show that deformation only occurred when the lateral force was applied in the inward direction.

The stiffness test methodology for wheels with different stiffness configurations is illustrated in Figure 4.

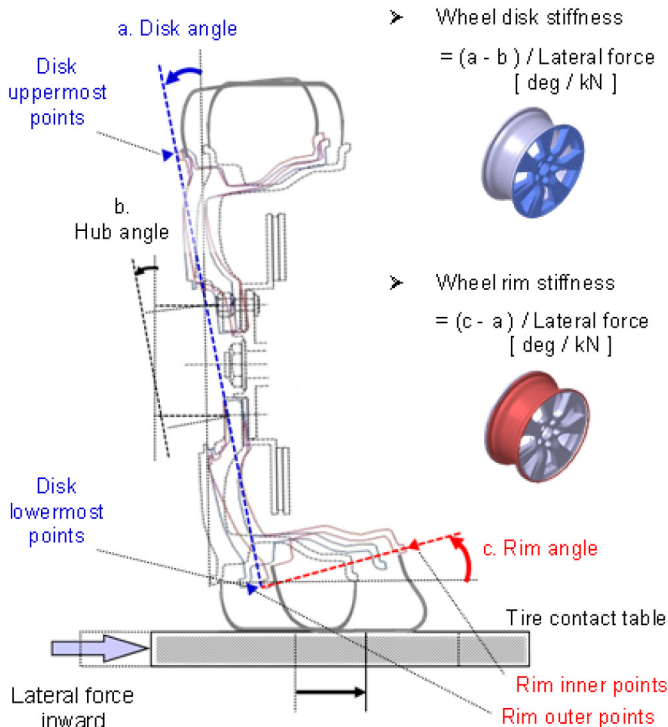


Figure 4. Method of wheel stiffness test

The disk angle was defined using a line connecting the uppermost and lowermost points of the disk. The variation in wheel disk angles was defined as the amount of disk angles minus the amount of hub angles.

The rim angle was defined using a line connecting the inner and outer points of the rim. The variation in rim angles was defined as the amount of rim angles minus the amount of disk angles.

This study used wheel disk compliance and wheel rim compliance as the indices for disk stiffness and rim stiffness, respectively.

2.2. Tire Contact Patch Profile Test

The effect of wheel stiffness on tire contact patch profiles was compared using the wheels with different stiffness configurations. The change in shape of each tire contact patch when a lateral force was applied from the tire contact bench was measured. Figure 5

presents a schematic diagram for the tire contact patch profiles test, while Figure 6 shows performance indices for tire contact patch profiles.

The test used a film-type measurement system for pressure distribution (pressure range of 0-300 PSI and plane resolution of 3.0×3.0 mm). Lateral force input conditions were identical to those described in 2.1.

Contact patch length, l , contact patch width, w , and contact patch area, S , were adopted as indices for tire contact patch profiles in the comparison of wheel stiffness.

Table 2 summarizes the general specifications of the test tire.

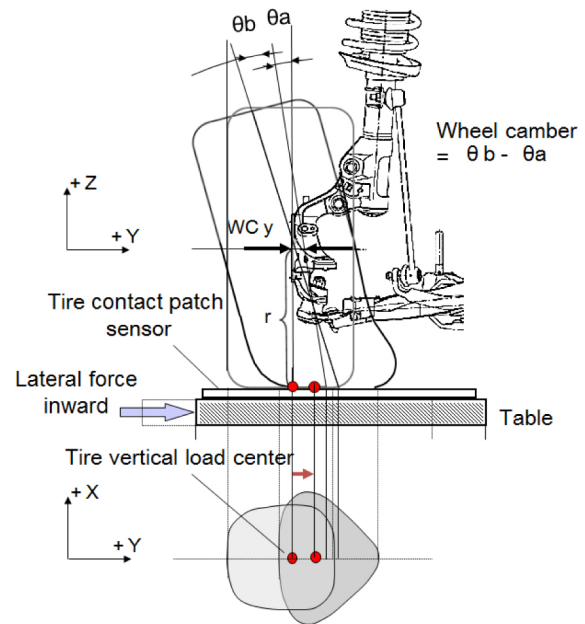


Figure 5. Tire contact patch evaluation test

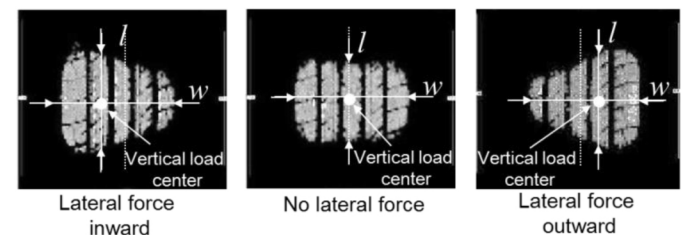


Figure 6. Performance indices for tire contact patch profiles

Table 2. Test tire specifications

Type	-	Summer
Nominal size	-	215/50R17 91V
Inflation pressure	kPa	220
Unloaded outer diameter	mm	650
Section width	mm	221
Vertical spring rate	(Under vertical load of 4.12 kN)	N/mm 232
Lateral spring rate		N/mm 145