# Development of Noise-reducing Wheel

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## ABSTRACT

Tire cavity noise is a noise produced in the cabin by resonance in the hollow cavity inside the tire when it is excited by unevenness on the road surface, and this phenomenon is one factor of road noise.

A noise-reducing wheel was developed as a means of reducing tire cavity noise. In the proposed configuration, a thin, lightweight plastic Helmholtz resonator is fitted into grooves newly cut in the wheel well, balancing strength in relation to centrifugal force with fittability. The noise-reducing wheels have had the effect of reducing tire cavity noise to an inaudible level.

The newly developed noise-reducing wheels are used on the 2011 model HONDA LEGEND / ACURA-RL, mass-market vehicles.

## 1. Introduction

Tire cavity noise is a noise produced in the vehicle cabin when resonance in the circular cavity inside the tire excited by unevenness on the road surface causes the wheels to vibrate, and is transmitted to the body via the suspension as vibration. The resonance frequency is determined by the circumferential length of the circular cavity inside the tire, and is normally between 200 and 250 Hz in the case of standard passenger vehicle tires. Compared to other components of road noise, the sound pressure of tire cavity noise is high; in terms of hearing, it is close to a pure tone and it reverberates. These characteristics make it an abrasive sound for vehicle occupants, and it has long been one of the main road noise issues.

Because 1st-order resonance phenomena of the interior cavity of the tire, which are unavoidable in the case of air-filled tires, are the major factor in tire cavity noise, a fundamental solution to the issue represents a challenge unless resonance itself is dealt with. Taking a conventionally applied measure as an example, the structural vibration of the tires can be reduced, but when the balance between this measure and other tire functions is considered, the measure displays a low degree of freedom in implementation and a significant benefit cannot be expected. Looking at measures applied downstream from the tires, such as measures applied in the suspension transmission paths or body-soundproofing measures, in many cases the parts involved are distributed over a wide area of the vehicle, and the measures result in weight increases.

In the future, the achievement of automotive weight savings will be more significant as part of more intensive responses to environmental issues, and it is predicted that the application of downstream measures that result in weight increases will become increasingly challenging. In addition, given that the contribution of tire input noise will become increasingly important because powerplant noise is being reduced by switching from the internal combustion engine to the motor, it is predicted that there will be increasing need for a noise reduction technology that acts directly on the tire input and is able to offer a fundamental solution with good weight efficiency.

In the past 30 years, more than 100 ideas for devices to reduce tire cavity noise have been patented or presented in reports(1), but meeting market demands when realized as products has proven a challenge, and to date only a configuration in which sound-absorbent sponges are attached to the inner liners of the tires(2) has been developed as a commercially available product.

In developing a noise-reducing wheel, the project discussed here formulated a method in which a Helmholtz resonator, which would satisfy targets for

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functionality, cost, and the necessary productivity for mass production, was attached to wheels. This method was able to reduce tire cavity noise to an inaudible level regardless of type of tire.

## 2. Development Goals

The goals for the development of a tire cavity noise-reducing device were as follows.

(1) Realization of a 10 dB reduction in noise during operation of a complete vehicle, in order to reduce tire cavity noise to an inaudible level regardless of type of tire.

(2) Realization of an equivalent level of strength and durability to conventional tires and wheels in relation to centrifugal force at maximum speed and high levels of input when driving on poor road surfaces, crossing curbs, and similar situations.

(3) Realization of a device that is lightweight and that does not affect wheel balance, in order to reconcile noise reduction with passenger comfort (ride comfort and vibration).

(4) Realization of an equivalent level of operability to conventional tires and wheels when fitting and removing the tires or in other maintenance situations.

(5) Realization of a low-cost device configuration that takes the degree of challenge of production technologies and mass production into consideration and that does not affect the conventional tire and wheel manufacturing processes.

## 3. Basic Concept

The configuration was envisioned as a wheel assembly with a separate flat, lightweight plastic resonator fitted in the wheel well.

Figure 1 shows the basic configuration of the device. It displays the following characteristics:

(1) Thin, lightweight and rigid plastic helps enable resonator configuration with flat cross-section

(2) Fitted assembly configuration that helps prevent separation of the resonator due to catching on the grooves in the direction of the circumference of the wheel

(3) A structure that fixes the vents of the resonator by means of notched grooves in the wheel

The basic concept of the design of this configuration was to help ensure an increase in the holding force of the resonator when centrifugal force is acting on it (Fig. 2).

High-rigidity polypropylene was selected as the plastic resonator material in order to control increases in its unsprung weight and help ensure strength in relation to centrifugal force.

Low-cost and high-productivity blow molding, which offers a high degree of freedom in molding, was selected as the method of forming the device. The project aimed by this means to help enable the formation of a seamless resonator structure that was beneficial in terms of air-tightness.

In order to help ensure that the resonator would display

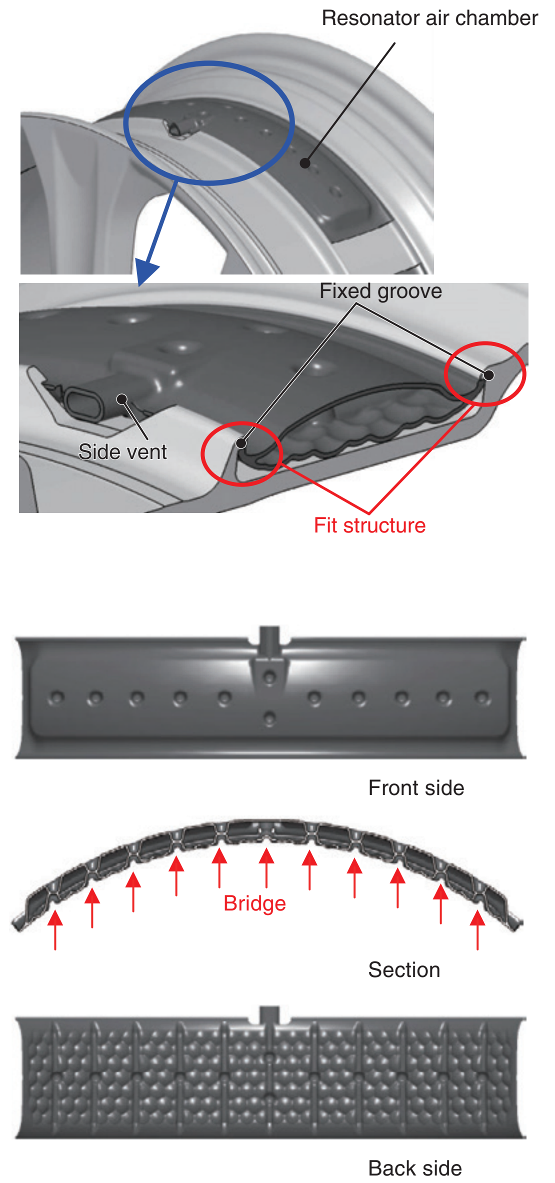


Fig. 1 Structure of noise-reducing wheel

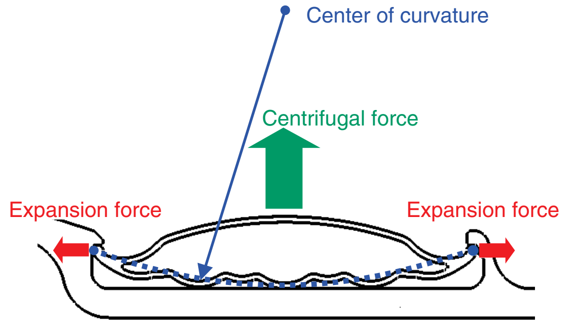


Fig. 2 Concept of structure under centrifugal force

an adequate level of noise attenuation, it was important to achieve air-tightness and realize sufficient resonator volume and vent area in a restricted space for the layout. Figure 3 shows the relationship between the volume of the resonator and noise attenuation, and between the cross-sectional area of the vent and noise attenuation.

The necessary basic specifications of the resonator were decided based on an understanding of the effect of the parameters discussed above.

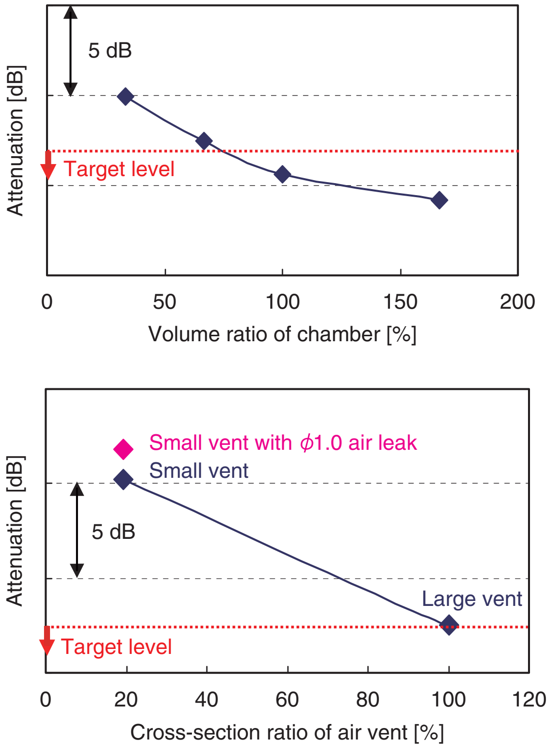


Fig. 3 Attenuation parameters of resonators

## 4. Main Development Details

This chapter will discuss the technological issues associated with realizing a lightweight, low-cost and high-productivity resonator structure displaying sufficient noise attenuation and strength and durability under all projected driving conditions, and the measures adopted in response to these issues.

### 4.1. Thin, Lightweight Structure and Noise Attenuation Performance

When a vehicle is driving at 300 km/h, the centrifugal force acting on the rim of the wheels reaches 1500 G. For a resonator to resist this maximum centrifugal force, its weight must be minimized. On the other hand, for a resonator to realize noise attenuation performance, it is necessary to attempt to ensure surface stiffness.

Taking the resonators used in automotive intake systems as an example, the thickness of polypropylene resonators is generally between 2.5 and 3.0 mm. However, the weight of a resonator of this thickness would become too high when fitted to a wheel acted on by centrifugal force, and therefore could not be used. It was therefore necessary to develop a plastic resonator structure with thinness and low weight as prerequisites.

In order to study the surface stiffness necessary to achieving the target sound attenuation performance, tests were conducted in which the thickness of a simple hollow base structure was varied. These tests provided insight into the relationship between the sound attenuation performance and the necessary thickness of the structure.

As Fig. 4 shows, when the minimum thickness for blow molding (considered as 100%) is used, the resonator displays almost no noise attenuation performance. While the level of noise attenuation displays a slight increase at 150% of the minimum thickness, at 200% there is a significant decline in the volume of the resonator, and the level of noise attenuation also declines.

Given this, it was judged that the achievement of the target noise attenuation performance would represent a challenge using measures focusing on the thickness of the housing alone if a simple hollow structure were employed as the basic cross-sectional structure of the resonator. It would therefore be necessary to consider a structure able to realize adequate noise attenuation performance with a thin housing.

CAE computations were therefore employed to introduce the necessary number of bridges to make the upper and lower surfaces within the hollow section (Fig. 1) continuous, and in addition brambles (spherical projections in a honeycomb alignment) were added to the external surface of the low-stiffness lower surface in order to increase surface stiffness. The results of calculations of the degree of attenuation of noise produced by excitation of the tires indicated that this configuration achieved the target noise reduction of 10 dB or more with no increase in weight against the hollow structure of minimum thickness discussed above (Fig. 5).

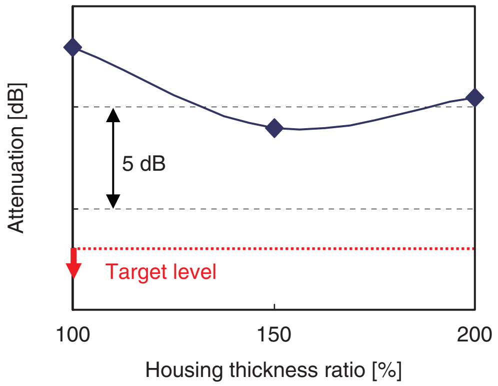


Fig. 4 Attenuation of resonator when thickness of housing is varied

### 4.2. Structure Reconciling Strength in Relation to Centrifugal Force with Fittability

In order to help ensure a sufficient level of strength in the resonator to resist maximum centrifugal force, it was necessary to optimize the structure based on an understanding of the load conditions, frequency of input, environmental conditions, and other factors affecting a resonator attached to a wheel, under all driving conditions. But in addition, from the perspective of fittability, a structure able to be fitted at low loads would be desirable. A design that balanced these two demands would therefore be necessary.

The bending stiffness of the resonator has the greatest effect on its strength and fittability, and when plastic materials are employed this parameter varies significantly with the environmental temperature in which the resonator is placed. The maximum temperature of the surface of a resonator was measured. As Fig. 6 shows, the elastic modulus of plastic materials declines to approximately 20% of the figure at normal temperatures when the material is placed in temperatures close to the highest temperature reached by a wheel rim under severe conditions.

Because it would be challenging to realize a significant reduction in these temperature-dependent changes in the elastic modulus by focusing on material characteristics alone, it was decided to increase the bending stiffness of the resonator by modifying its form, in order to help ensure the necessary bending stiffness for strength despite the low elastic modulus at the upper limit temperature. Fittability would be reconciled with this change by presupposing a shift from low-load fitting able to be performed by hand to high-load fitting by tool.

Using the CAE analysis of centrifugal force shown in Fig. 7, length adjustment of resonator arm section and lateral beads were added to the brambled lower surface of the hollow section to help ensure uniform bending of the resonator when acted upon by centrifugal force (Fig. 8), in an attempt to increase bending stiffness under centrifugal force while maintaining the surface stiffness important to noise attenuation performance.

The results of centrifugal force load tests using the structure described above showed that the structure displayed sufficient strength to resist the target maximum centrifugal force without any detachment or damage to the

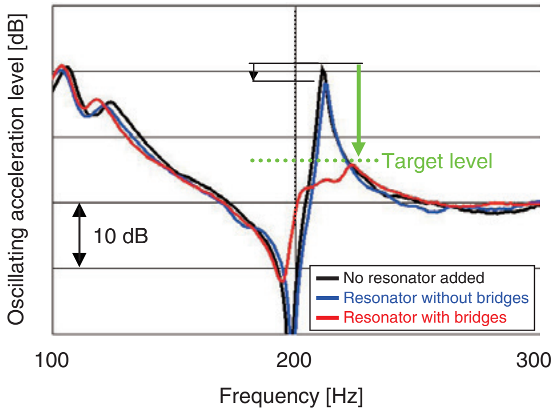


Fig. 5 Noise reduction results for tire tread hammering test on wheel rim

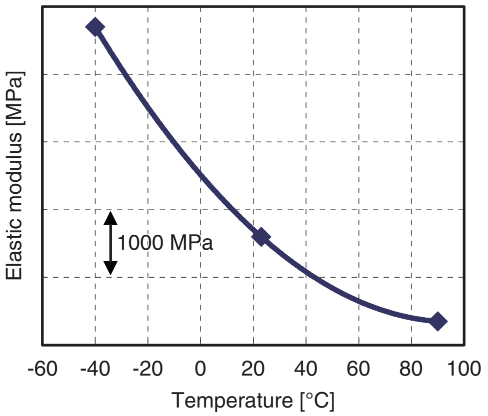


Fig. 6 Temperature-dependency of elastic modulus

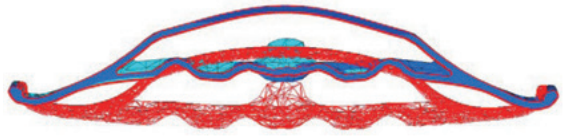
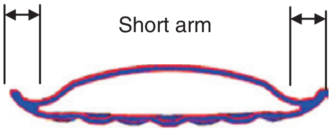
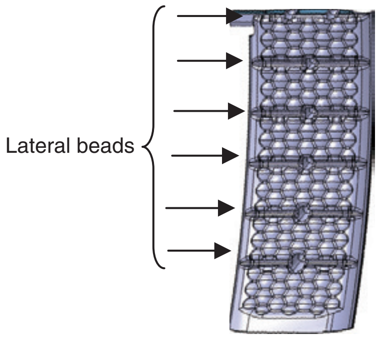


Fig. 7 CAE analysis result of centrifugal force

(a) Overview



(b) Section



(c) View of back side

Fig. 8 Structure for resistance to centrifugal force resonator with regard to the tire and the wheel assembly, and without aggravating the wheel balance. These studies helped to enable the realization of a resonator structure that balanced strength against centrifugal force with fittability.

### 4.3. Method of Fitting in Mass Production

In terms of production technologies, the greatest degree of challenge was represented by the process of fitting the resonator to the wheel. No examples existed of any parts other than TPMS sensors being fitted to wheels.

A consideration of the mass production of wheels with attached resonators indicated that the time available for the fitting of the resonator to the wheel would be restricted due to the line time necessary for the wheel manufacturing process and the fitting of the tire to the wheel. The issue was therefore the development of a method able to fit the resonator to the wheel within a restricted timeframe.

In addition, for fitting in the mass-production process, it was necessary to consider all combinations of the following product dimensional tolerances and environmental temperature (Fig. 9):

(1) Interference between resonator and wheel
(2) Stiffness of resonator (Thickness of blow molding)
(3) Environmental temperature during fitting

This necessitated parameter setting that would help to ensure fittability under all projected environmental temperature conditions. For example, because the stiffness of the plastic material would change significantly with variations in temperature, it would be essential to consider the necessity for increasing the fitting load at low temperatures (Condition E in Fig. 9) and the fact that the resonator could not be fitted at high temperatures because it would bend excessively and the fitting stroke would be insufficient (Condition C in Fig. 9).

Because the stiffness of the resonators had been increased in order to increase strength in relation to centrifugal force, as discussed above, it was necessary to press the prototype resonators a number of times with a specialized tool (Fig. 10) in order to fit them. However, this fitting method was inefficient and impractical from the perspective of the mass-production process, as discussed above.

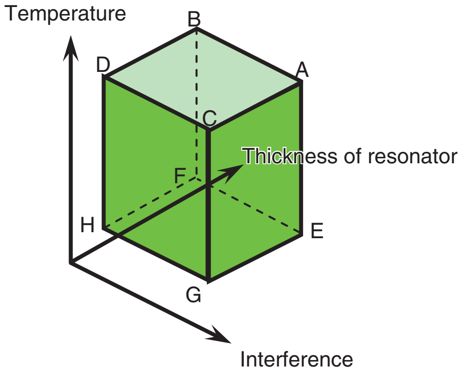


Fig. 9 Parameters for fitting

A method of fitting by means of an assembly device using an air cylinder was therefore studied. By making the shape of the "pusher" section of this machine (the section that presses the resonator) an arc that followed the shape of the arm section of the resonator, the project aimed to fit the resonators by pressing each one once.

The results of fitting tests on the resonators using a prototype machine demonstrated that it reduced fitting time by 80%, indicating the potential for use in mass production.

In addition, adjustment of the following items (Fig. 11) made fitting of the resonators possible in a wide range of temperatures projected for the mass-production process.

(a) Fitting area for resonator arm sections in wheel grooves
(b) Pusher position and stroke of assembly machine
(c) Pushing load of assembly machine pusher

The optimization of these three items ultimately made it possible to fit the resonators in the mass-production processes under temperature conditions ranging from -5 deg C to 40 deg C.

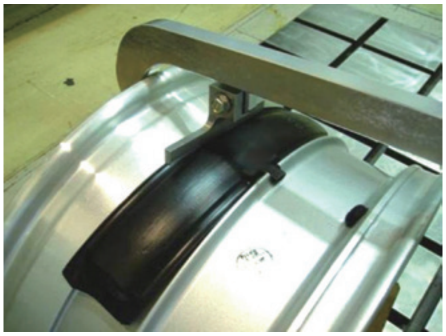


Fig. 10 Tool for fitting (prototype)

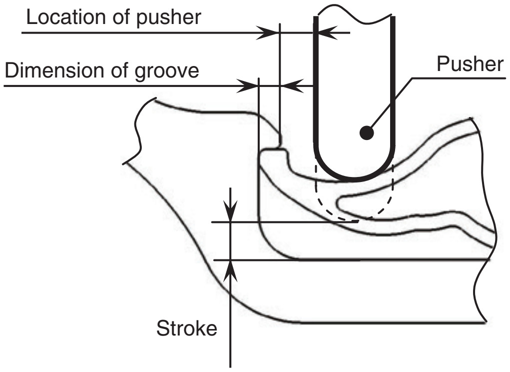


Fig. 11 Groove shape, pusher location and stroke optimization of resonator and wheel assembly machine

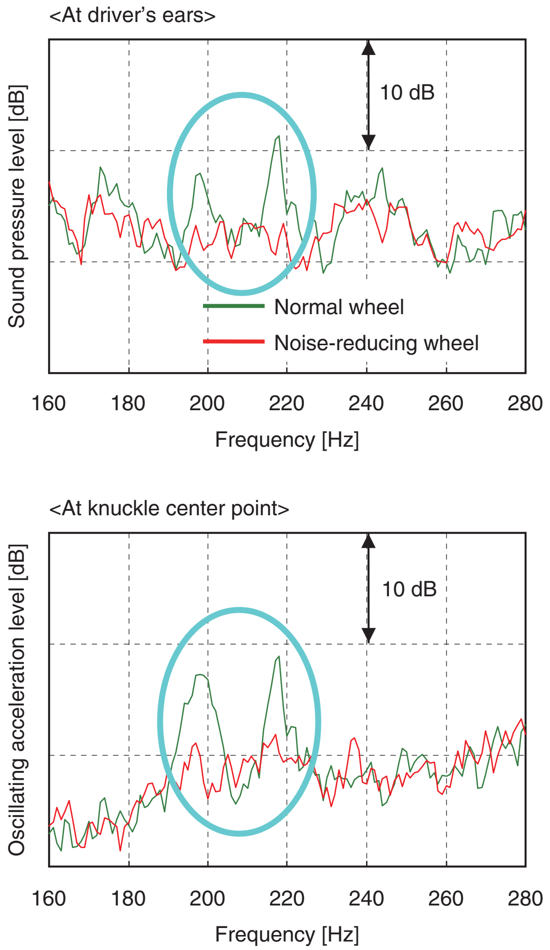


Fig. 12 Noise reduction effect when driving on rough road at 80 km/h

## 5. Effect of Use of Actual Resonators

Figure 12 shows results for in-cabin noise and knuckle vibration when driving on a rough road for a vehicle fitted with the noise-reducing wheels. There has been a 10 dB reduction in noise, and tire cavity noise has been reduced to an inaudible level.

The robustness of the effect of the noise-reducing wheels in relation to road surface roughness and vehicle speed conditions was tested next. Figure 13 shows the effect of the noise-reducing wheels on in-cabin noise when the vehicle was driven over road surfaces of varying roughness at different speeds. A reduction in noise of 10 dB was realized under all conditions (low input, high input, low vehicle speed, high vehicle speed), demonstrating that the noise-reducing wheels possess robustness in relation to road surface roughness and changes in vehicle speed.

## 6. Conclusion

A noise-reducing wheel structure fitted with a plastic resonator satisfying the conditions listed below was proposed, and realized in mass production for the first time in the world.

(1) A thin, lightweight plastic resonator structure able to reduce noise by 10 dB at the minimum thickness for blow molding

(2) A resonator structure and wheel fitting configuration able to resist the maximum centrifugal force of 1,500 G

(3) A resonator fitting setting and mass-production fitting method realizing a high level of fittability

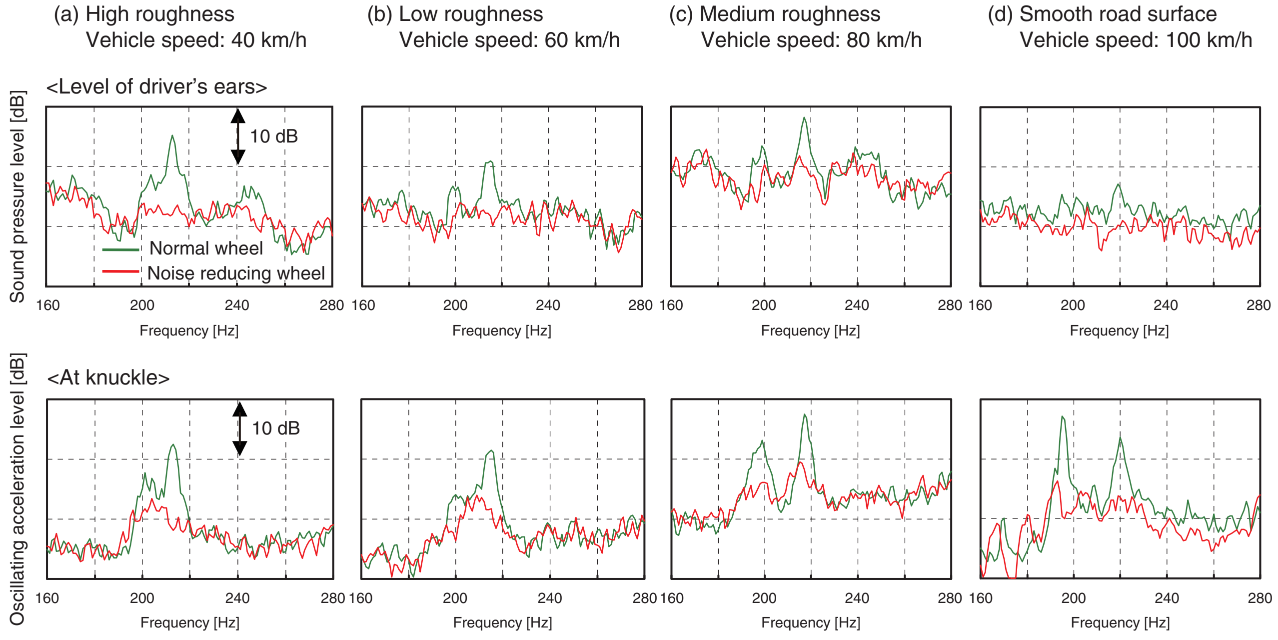


Fig. 13 Robustness of noise reduction in relation to road roughness and vehicle speed

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