

Indoor/Outdoor Testing of a Passenger Car Suspension for Vibration and Harshness Analysis

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ABSTRACT

This paper presents a validation method for indoor testing of a passenger car suspension. A study was done to design a supporting modular structure with comparable inertances with respect to a vehicle's actual suspension and body connection points. For the indoor test, the rear axle is positioned on a rotating drum. The suspension system is excited as the wheel passes over cleats fixed on the drum and transient wheel motions are recorded. The indoor test rig outputs (i.e., wheel and chassis accelerations) were compared with experimental data measured on an actual vehicle running at different speeds on the same set of cleats along a flat road. The comparison results validate the indoor testing method. The forces and moments acting at each suspension and chassis connection point were measured with a set of patented six-axis load cells. The forces, moments, wheel and subframe accelerations were measured up to 120 Hz. This study yielded a set of performance indexes by analyzing the forces and acceleration measured on the suspension system (the force measure is possible only on the indoor test rig). The influence of the running conditions and suspension settings on the indexes for vibration behaviour of the tire and suspension system was assessed and a global sensitivity analysis has been completed.

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INTRODUCTION

Vehicle dynamic and NVH behavior is strictly related to the forces transmitted to the vehicle chassis by the tire properties and by the suspension elasto-kinematic characteristic [1]. Due to the large number of factors influencing the chassis vibrations, it is rather difficult to accurately model the suspension vibration behavior [2]. Direct measurement of the forces and moments acting at the suspension-chassis joints can be the only effective way for analyzing the vibration suspension behavior. Very few applications are presented in the literature referring to full suspension indoor testing [8, 9, 10, 11]. This paper presents the validation of a method for the indoor testing of a road vehicle suspension. The objective was to measure and analyze the forces and moments at the suspension-chassis joints in the frequency range 0-120 Hz. The research was conducted at the Laboratory for the Safety of Transport at Politecnico di Milano and involved positioning a rear axle on a rotating drum. A special study was undertaken to design a modular supporting structure with comparable inertances (adjustable stiffness elements) with respect to the actual

suspension/body connection points. Commercially-available six-axis load cells could not be applied [12, 13, 14, 15], so patented six-axis load cells were used for measuring the forces/moments acting at each suspension/body connection point. During the test, the suspension system is excited as the wheel passes over different cleats fixed to the drum and transient wheel motions are recorded. The wheel and chassis accelerations measurements from the indoor test rig were compared with experimental measurements from a reference vehicle that was run at different speeds on a flat road and using the same set of cleats. The results of this comparison allowed for full validation of the indoor testing method. By analyzing the forces and the acceleration measured on the suspension system (the force measure is possible only on the indoor test rig), a set of performance indexes has been derived from the analysis of the data both in time and frequency domain [17, 24]. The influence of the running conditions and of the different suspension settings on the relevant performance indexes related to the vibration behaviour of the tire/suspension system has been assessed and a global sensitivity analysis has been completed. The

analysis method employed and the test facility allows performing a quick and efficient suspension tuning, by varying the suspension parameters.

EXPERIMENTAL TEST RIG

RUOTAVIA TEST RIG

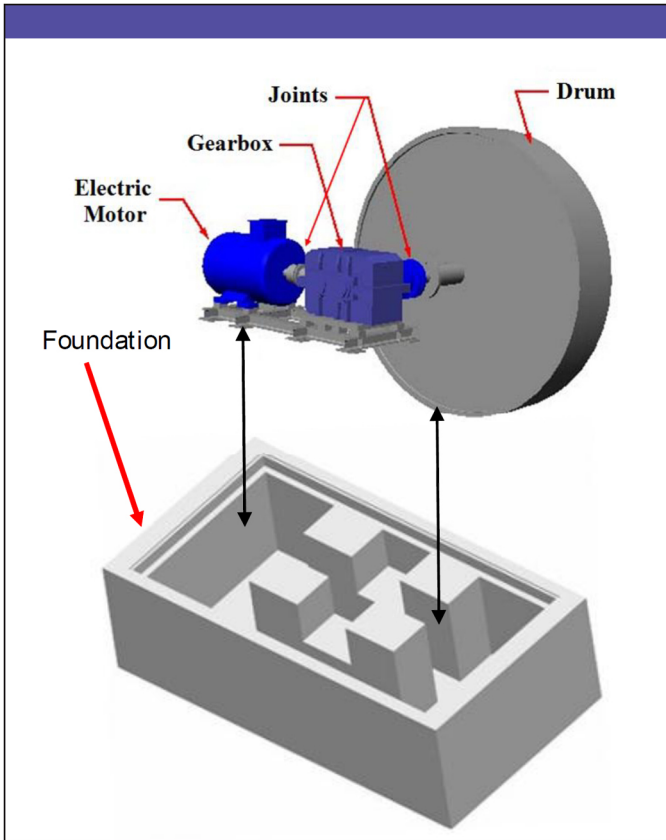


Figure 1. RuotaVia Rig.

The experimental activities have been performed by means of the RuotaVia Rig [16]. The RuotaVia test facility (Fig. 1) is located at the Laboratory for the Safety of Transport of the Politecnico di Milano. Both steady state and transient measurements on either full vehicles or vehicle sub-systems (single suspension system or vehicle axle) can be performed. The main technical specifications of the RuotaVia facility are summarized in Table 1. The test facility is composed of a steel drum (2.6 m diameter) providing a running contact surface for vehicle wheels. The drum components have been studied through optimization techniques in order to obtain high stiffness properties along the radial and lateral direction with a limited mass and to avoid the undulation of the ring (working surface) during high speed testing. The maximum radial tolerance of the drum has been measured at the centre of the running surface. This value is smaller than 0.04 mm. A reduced surface unevenness level is fundamental for the characterization of the tire/suspension vibration and harshness behavior. The

driveline is composed by a controlled electric asynchronous four poles motor (160 kVA), and by a two ratio gearbox. The rotational speed of the drum is measured by means of a 4096 points encoder. The first natural frequency of the drum (relevant for dynamic measurements) is 96 Hz and the maximum tangential speed is about 450 km/h. A stiff concrete foundation supports the rig and isolates it from the laboratory.

Table 1. RuotaVia rig data sheet.

Foundation	
Structure	Concrete 3.85 x 6.90 x 4.30 [m]
Insulation	Stiffenite
Mass	140 [ton]
Drum	
Diameter	2600 [mm]
Width	550 [mm]
Mass	5500 [kg]
Polar moment of inertia	5660 [kg m ²]
First natural frequency	95 [Hz]
Working surface	Steel or different μ tapes
Driveline	
Transmission	Two speed gear box
Lower gear ratio	1:15
Higher gear ratio	1:3
Motor	Electric asynchronous, 4 poles
Power	160 kW cos ϕ 0.85
Control	Neuro-vectorial inverter
Braking system	
Main brake	Pneumatic disc brake
Emergency brake	Pneumatic disc brake
Caliper	Knorr Bremse, type SB7112 radial 24"
Disc	Self venting disc, 430 mm diameter, type Brembo 09.7380.20
Brake peak power	1.1 [MW]
Max working loads	
Fx - longitudinal	100 [kN]
Fy - transversal	100 [kN]
Fz - vertical	100 [kN]
Max speed	440 [km/h]

SUSPENSION SUPPORTING STRUCTURE

A special upper structure has been designed to support the suspension subframe under test. The structure is composed of 2 steel parts: an upper part called *hat* (Fig. 2) and a bottom part called *table* (Fig. 3).

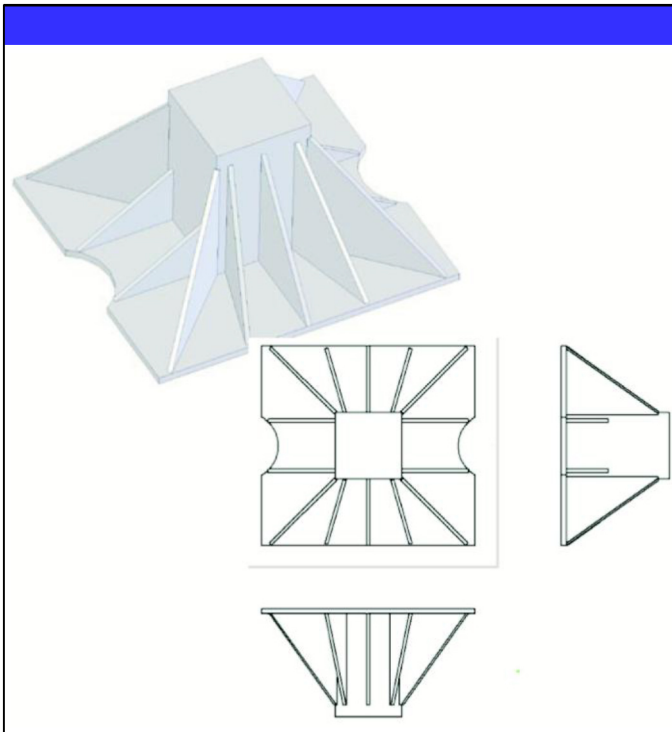


Figure 2. Hat.

The suspension subframe is fitted under the hat and the hat will be fixed on the table by means of 4 M30 bolts. The whole structure lies on the RuotaVia rig steel frame.

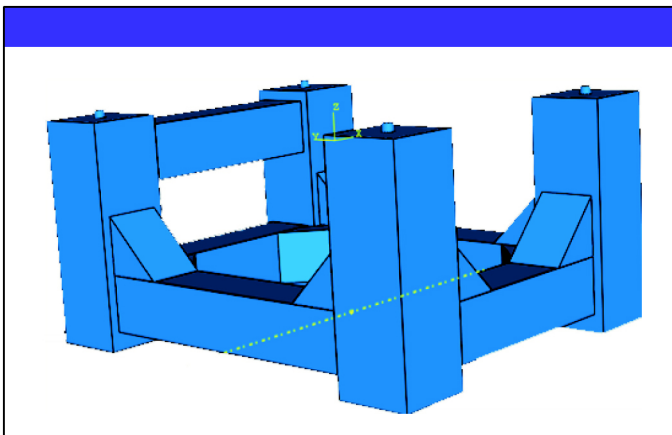
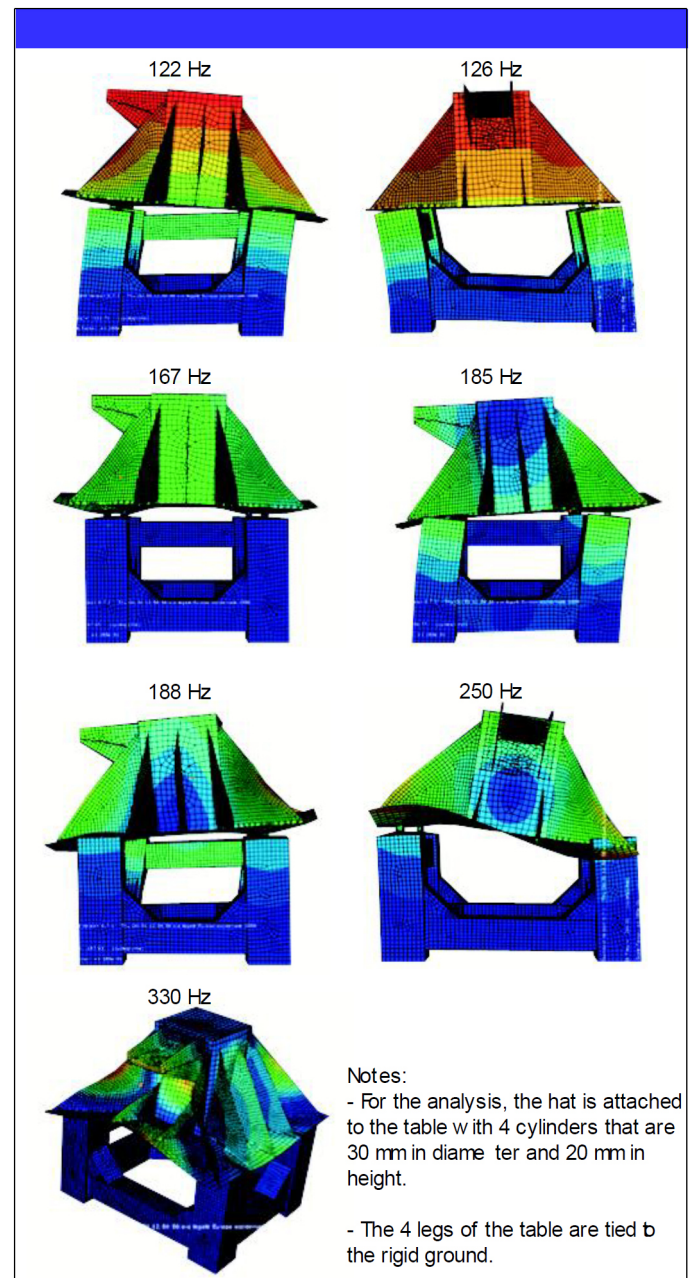


Figure 3. Table.

The structure has been designed to avoid parasitic vibrations due to the structure natural frequencies that can affect the measurement. The FEM modal analysis shows that the first eigenfrequency of the supporting structure is above 120 Hz. The whole structure natural modes are shown in Table 2.

Table 2. Upper structure natural frequencies.



The dynamics of the whole supporting frame (that is, the structure and 6-axis load sensors) must be similar to the chassis dynamics to obtain accurate data from the test rig [7, 8]. If the frame interacts with the suspension system, the measured loads can be a poor estimation of the actual ones. A finite element (FE) model was used to predict the dynamic performance of the connection structure (Table 2). The acceleration is defined as the ratio between the acceleration $a(\omega)$ and the applied force $F(\omega)$ at a defined point in the frequency domain [12, 23].

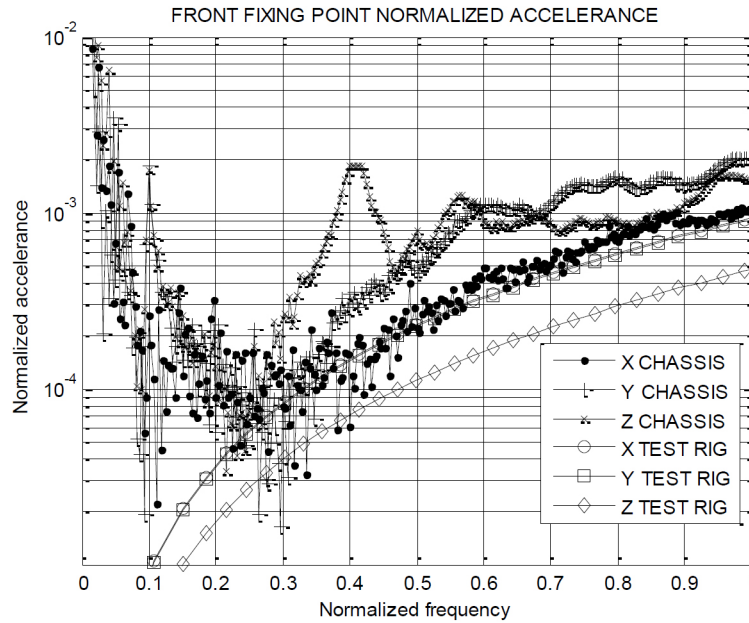


Figure 4. Front fixing point acceleration.

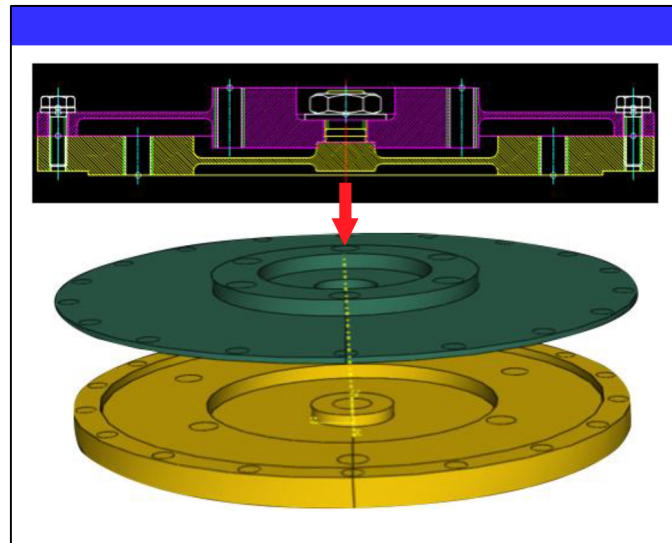


Figure 5. Calibrated stiffness element.

$$A(\omega) = \frac{a(\omega)}{F(\omega)} = -\omega^2 \alpha(\omega) = 4\pi^2 \frac{f^2}{k} \quad (1.1)$$

with

$$x(t) = Xe^{i\omega t} \Rightarrow a(t) = -\omega^2 Xe^{i\omega t} \quad (1.2)$$

where $x(t)$ is the sinusoidal input (displacement) of the system (with amplitude equal to X), ω is its natural frequency, and $a(t)$ is the ratio X/F . The theoretical combined load cell and structure (hat + table) acceleration have been

calculated and compared with the measured acceleration of the car chassis (Fig. 4). The equivalent stiffness of the designed test structure is always higher (or equal) with respect to the car chassis.

To match the actual equivalent stiffness of the body frame, the interposition of calibrated stiffness elements that reduce the structure stiffness is needed. As shown in Fig. 5, such an element has been designed and manufactured and is composed of two precision belleville springs coupled in parallel.

The axial stiffness of the studied elements can be tuned by changing the thickness of the two belleville springs. The interposition of the calibrated stiffness element allows the test