



Methodology to design a vibration absorption footplate for motorcycle application: From phenomena investigation to prototype performance evaluation

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ABSTRACT

The aim of this research is to reduce driver vibration exposure by acting on the modal response of key contact structures.

The footplate is one of the components with which the driver comes into contact while riding. For this reason, footplate geometry and structural properties were investigated with a view to re-designing this component in order to reduce driver exposure.

Due to the massive chassis area on which the footplate is constrained, vibrations induced by engine unbalances easily propagate in quasi-steady conditions on all surrounding components, inducing a wide frequency band of load excitation. Even though the footplate geometry allows for fairly high natural frequencies, these could occur in the excitation range. Therefore, the first step of the methodology proposed entails the use of a numerical and experimental (modal analysis) procedure to identify the local vibration modes of the original components to detect if/when/how the resonances of the above mentioned components are excited.

Due to an awareness of the weakness of the original solution, structural modifications, using numerical models, were studied. The footplate geometry was modified to minimize nodal displacement of the footrest beam binding. All structural modifications were designed, developed and installed on the vehicle.

Finally, in order to predict modification efficiency, both the new footplate and the original one were experimentally compared. The comparison was made by means of modal investigations and by positioning the reference vehicle on a suitable roller test bench in order to simulate real working conditions.

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1. Introduction

The research in question focuses on ride comfort; nowadays, this issue is considered one of the most important dynamic characteristics of vehicles.

Although mechanical vibrations may originate from poor road quality, tires and a good suspension system are able to reduce their negative effects. Another cause of reduced comfort can be found in the propagation of vibrations due to inertia engine unbalances.

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Mechanical vibrations are propagated right through the vehicle structure until reaching the driver. In terms of vibrations, the footplate, together with the handlebar, is one of the most significant contact components.

In view of the above, current research provides a methodology to design highlighted component taking into properly account vibration propagation reduction.

Specialized literature and international standards support investigations on human exposure to mechanical vibrations.

In particular, ISO 2631-1 [1] is the international standard used to define the methods of quantifying whole-body vibration in relation to human health and comfort, the probability of vibration perception and the incidence of motion sickness. The frequency range considered for health, comfort and perception is 0.5 Hz to 80 Hz while that considered for motion sickness is 0.1 Hz to 0.5 Hz.

Acceleration spectra are properly weighted because the manner in which vibrations affects health, comfort, perception and motion sickness depends on the vibration frequency content. Therefore different frequency weightings are required considering the different axes of vibration.

Finally ISO 2631-1 suggests boundaries to standardize subjective levels of exposure at which certain vibration conditions may be tolerated. The above mentioned boundary values are not real limits but are simply used to give approximate indications of likely reactions to various overall vibration magnitudes. In fact, reactions to various magnitudes depend on passengers' expectations both vis-a-vis trip duration and the type of activity that passengers expect to perform (e.g., reading, eating, writing).

Therefore, while in one situation a particular vibration condition might be considered the cause of unacceptable discomfort, in another it could be classified in a totally different way.

In regard to vibration isolation, in "Two approaches for optimum design of motorcycle engine mount systems" [2], Kaul, Dhingra and Hunter define two optimization procedures to minimize the total force transmitted to the frame. The methodology proposed is targeted at isolating system frequencies from operating frequencies using a two rigid-body model. Both optimization procedures contemplate engine mount stiffness, orientation, and position as design variables.

In "Frame flexibility effects on engine mount optimization for vibration isolation in motorcycles" [3], the same authors include the influence of frame flexibility in the engine mount optimization problem.

Flexible chassis effects on the dynamic response of engine-mount systems are discussed by Kim, Jho and Yim in "Influence of chassis flexibility on the dynamic behavior of engine mount systems" [4]. According to the results of their analysis, it transpires that the coupling effects between the chassis structure and the engine mount system are significant, not only when the natural frequencies of any two modes (i.e., of the chassis and engine mount system, respectively) are similar, but also when the mode shapes resemble one another.

Finally in "Motorcycle vibration and its control using computer-aided engineering" [5], Tomita, Inoue and Ochi suggest a strategy to improve motorcycle ride comfort, mainly by minimizing the vibrations induced by engine inertia. Their article deals with the engine crankshaft layout (i.e., the source of the vibration), the engine mounts, the frame design developed using the finite element method (hereunder referred to as F.E.M.) and the design of the front wheel suspension system. The authors conclude by suggesting isolation of those contact parts responsible for directly transmitting vibrations to the rider (handlebar, footrest and saddle).

With reference to our research, the methodology proposed to reduce vibrations on the footplate can be divided into the following stages:

- A detailed modal analysis of the original footplate to identify the Frequency Response Function (hereunder F.R.F.), damped natural frequencies, vibration modes and damping ratio (Section 2.1). Numerical models have been developed able to fit experimental responses of original state of vehicle.
- The results were presented and discussed to underscore the strengths and weaknesses of the original component (Section 2.2.).
- Functional designs highlighting target functions for the component (Section 2.3.) were proposed. Suitable numerical models were implemented to estimate new system efficiency. Optimization algorithms were adopted to best perform target function suggesting optimal value ranges of structural parameters. Prototypes were designed to comply with the numerical results achieved by means of numerical optimization.
- Performance indexes were defined. Results, based on modal experimental analysis, were used to compare the response of new component with the one of the original footplate (Section 2.4.).
- To simulate on-road conditions, the last step entails measuring the vibrations originating from the components with which the driver physically comes into contact while the engine is running (Section 3). A synthesis index was defined in order to compare the vibrations generated by the original design versus those generated by the optimized one (described in detail in Section 2).

2. Footplate analysis and modal identification

The footplate is involved in vibration transmission to the driver. The original components found on the reference vehicle were analyzed. Several critical observations are likely to lead to new solutions capable of improving component performance. Furthermore, a new prototype will also be described.

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