Effect of the Change of Inertial, Elastic and Dissipative Parameters on the Ride Comfort of a Road Vehicle

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Abstract. The comfort on a vehicle is of great interest as it is related with the driver perception and hence with ride safety conditions. Road infrastructure in Colombia presents unique characteristics; for that reason, there is interest in how road vehicles can be adapted to perform properly when they are subjected to the road conditions of the country. This work is centred on the study of the effect that a change on a set composed by vehicle's inertial, elastic and dissipative parameters has on the ride comfort of a driver. The ride comfort of the driver is analysed in terms of exposition to vibrations induced by the road unevenness to the vehicle body. A computational approach is implemented, by means of a previously validated multibody model with seven degrees of freedom (DOF). Two road input configurations are considered, both of them generated by isolated bumps. The effect that a variation on several vehicle parameters has on the driver comfort was analysed using comfort indexes defined by the standard ISO 2631-1.

1. Introduction

After considering the effects on the mobility and safety, government of Colombia has defined that one of the areas of interest in the automotive sector is ride comfort. The main challenge in this case is the fact that the road infrastructure of the country has some weakness, and the vehicles that operate there are rarely designed and/or adapted to operate in the actual road conditions of the country. The conditions of the roads of the country can be modelled with the combination of two elements, in order to simplify the problem. The first element considers the intensification of the random excitation originated by the average road, which can be modelled through a power spectral density (PSD) input, considering the change on the parameters of the road model. The second element considers the excitation originated by critically damaged zones which can be managed as singularities that are analyzed separately.

Ride comfort is commonly associated to the quality of the driving experience and the driver perception, but it has many other implications, including its relation with vehicle safety [1, 2]. For vehicular analysis, ride comfort of a seated person has great relevance as is the normal driving position on a road vehicle. Vibrations corresponding to frequencies between 4Hz and 12Hz have a strong impact on the comfort of a seated person [3]. A road vehicle is mainly excited at the frequency band between 0Hz and 25Hz by road unevenness and between 25Hz and 200Hz by engine unbalanced forces and internal combustion pressure when operating under normal conditions [3, 4]. In order to perform comfort analysis, the frequency band between 4Hz and 12Hz must be excited; hence inputs with road profiles are commonly used. Due to the importance that comfort of driver and passenger has in vehicles, several studies have been made on the subject. Some of the studies have centered on analysing the effect that a variation of a vehicle characteristic has on the vehicle response [2] and ride comfort [5-7]. The use of both analytical and numerical models to perform comfort analysis on road vehicles has been widely implemented as a research tool. The three dimensional models that consider multibody dynamics systems have been widely implemented [6-10].

The present work is centred on the ride comfort analysis when the excitation is an isolated obstacle. The effect on the ride comfort of a set of parameters including inertial, rigidity and dissipative properties of a vehicle and its sub-systems is studied. Driver comfort is studied according to ISO 2631-1 standard. After implementing the recommended verifications given by the ISO 2631-1, the acceleration root mean square (rms) of the driver is used as a comfort index. The analysis is performed for the scenario of a vehicle passing over a speed bump configured in symmetrical and asymmetrical patterns. The modelled vehicle is a compact hatchback.

2. Vehicle model

A full vehicle three dimensional model with seven DOF is used to analyze the driver position's vertical vibration when the vehicle is excited by the road. As seen in figure 1 the model consists of a sprung mass (vehicle body) connected to an independent suspension carried by the axles and wheels unsprung masses which are in contact with the road.

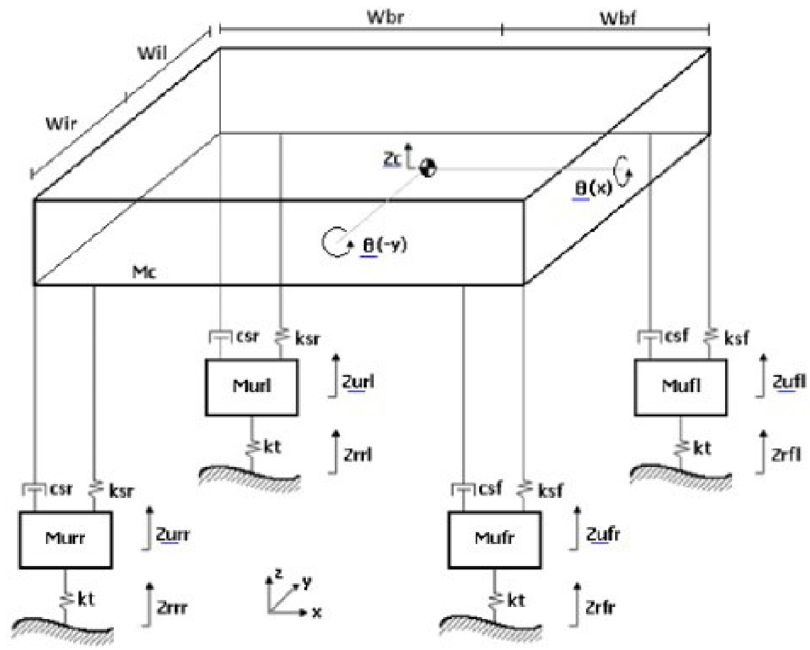

Figure 1. Full vehicle model diagram.

The sprung mass is represented by a set of ten parameters formed by mass, location of the centre of gravity and Inertia moments and products; its three DOF are vertical displacement (Zc), pitch (θy) and roll (θx). Each suspension corner is represented by a set of parameters composed by unsprung mass, suspension stiffness, tire stiffness and suspension damping; each unsprung mass has one DOF representing its vertical displacement (Zu).

This system is excited by the road irregularities defined by a couple of speed bumps aligned for the symmetric configuration and longitudinally separated 1m for the asymmetric configuration as shown in figure 2. These configurations are used to excite the system vertically, and in pitch and roll respectively. The outputs of the model are a set of kinematic variables measured on the driver location to compute the vibrations induced by the input. For this study, the weighted rms of vertical acceleration at driver's position is computed according to [3] as an index of human ride comfort. The model used was experimentally validated in [11].

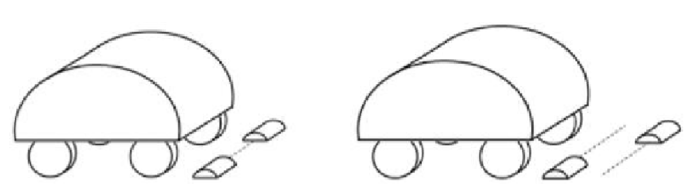

Figure 2. Symmetric and asymmetric inputs.

3. System response

3.1. Velocity response

From the analysis of the eigenvectors and eigenvalues of the system, the seven vibration modes of the system were found to be the ones described in table 1, where the vibration modes and their corresponding frequencies of damped vibrations (f_d) are shown.

Table 1. System vibration modes.

f_d [*Hz*]	Vibration mode description: predominant motion
11.51	Vertical motion of rear unsprung masses with a 180 degrees phase
11.44	Vertical motion of rear unsprung masses with a 0 degrees phase
9.40	Vertical motion of front unsprung masses with a 180 degrees phase
9.36	Vertical motion of front unsprung masses with a 0 degrees phase
0.90	Vertical motion of the centre of gravity and pitch with predominant vertical motion
0.69	Roll
0.61	Vertical motion of the centre of gravity and pitch with predominant rotation

It was found, that for the vehicle modelled with nominal parameters, the maximum discomfort at driver's position was given at a longitudinal velocity of 16 km/h. Analysing the frequency spectrum of the vertical excitation velocity (defined by longitudinal velocity and road bump geometry), it was found that the predominant vibration modes excited for maximum discomfort at driver's position were the vertical motion of front unsprung masses modes. This means that for this case, at a 16 km/h longitudinal velocity the excitation frequency induced by the road input is synchronized with the modes of vibration related to front unsprung masses motion.

3.2. Effect of a parameter variation on comfort for a range of velocities

The maximum discomfort on the driver position was computed for each parameter respect to a range of velocities. The inertial parameters analysed were the mass, location of the centre of gravity in the xy plane, the roll and pitch inertia moments and the horizontal plane inertia product of the sprung mass (M_c, X_{cg}, Y_{cg}, I_{xx}, I_{yy}, I_{xy}), the masses of the front and rear unsprung masses (M_{uf}, M_{ur}); the elastic parameters were the stiffness of the front and rear unsprung masses and the tires (K_{sf}, K_{sr}, K_t); the dissipative parameters were the front and rear unsprung masses dampers stiffness (C_{sf}, C_{sr}).

The effect of the change of each one of the described parameters was studied. For most of the parameters, the response to change of their nominal value between -50% and + 50% were considered. For X_{cg} and Y_{cg}, the variations of the parameters were considered as a fraction between -50% and + 50% of the wheel base and track, respectively. For I_{xy}, the variations of the parameter were considered as a fraction between -50% and + 50% of I_{xx}.

The parameters were classified according to three different behaviours. The first behaviour is a noticeable change on the magnitude of maximum acceleration rms (>5%) when the parameter is varied. The second behaviour is the change on the magnitude of the maximum acceleration rms and also a change on the velocity of maximum discomfort (>5%) when the parameter is varied. The third behaviour corresponds to no significant variation in magnitude of maximum acceleration rms neither in the velocity of maximum discomfort when the parameter is varied. Table 2 presents the classification of the parameters according to the dominant behaviour of discomfort curves.

Figures 3 and 4 show the acceleration rms obtained by passing over the bumps at different velocities between 1km/h and 100km/h. The effect of variation on M_c and K_t over the response of the system was studied. These parameters present the highest influence on the response, and they are presented as examples of behaviours 1 and 2, respectively.

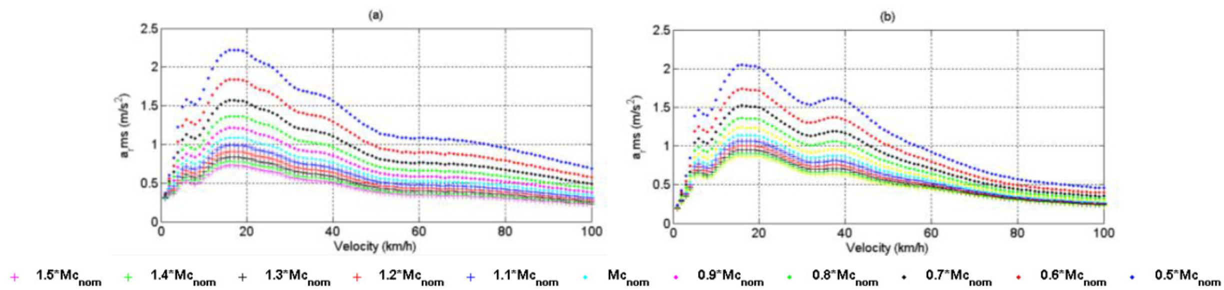

Figure 3. a_{rms} curves for different velocities varying Mc. (a) symmetric input, (b) asymmetric input. The maximum discomfort is found at the same velocity for different masses.

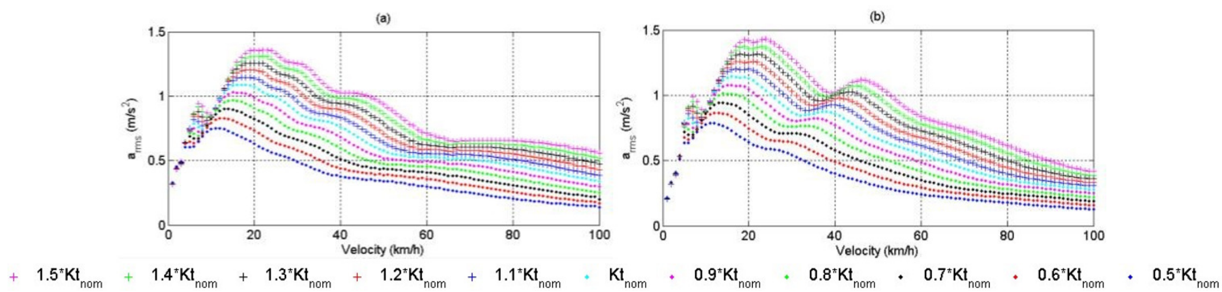

Figure 4. a_{rms} curves for different velocities varying Kt. (a) symmetric input, (b) asymmetric input. The maximum discomfort is found at different velocities for each Kt variation.

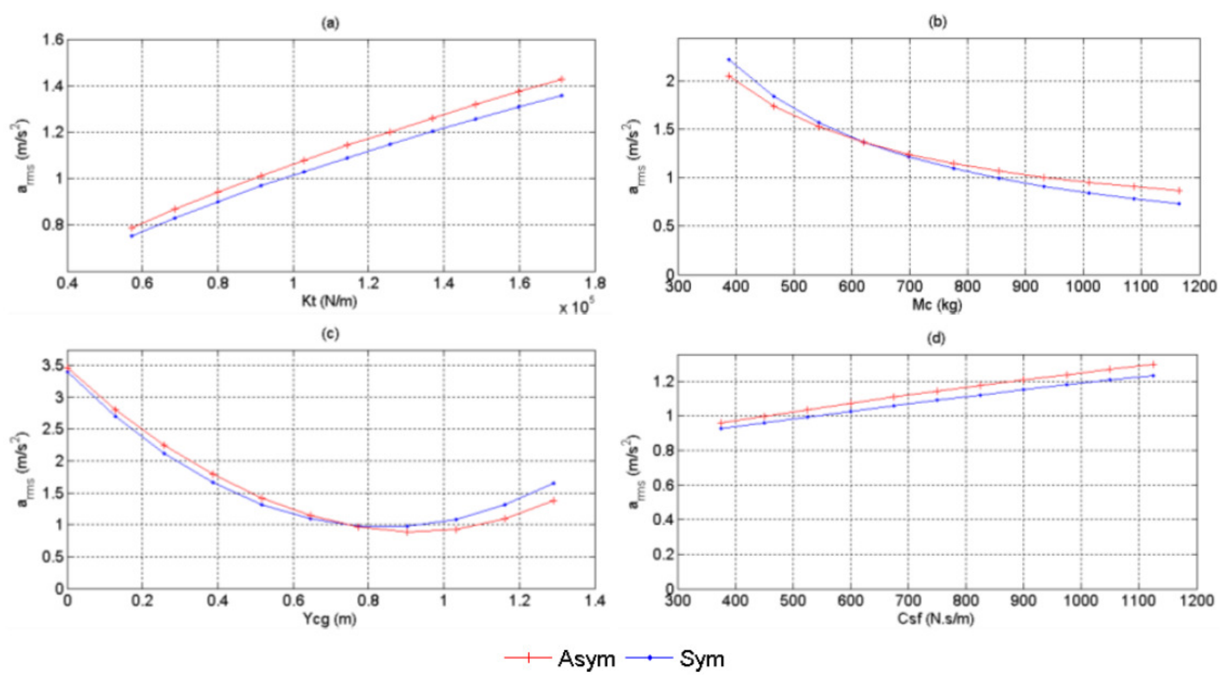

Figure 5. Comfort sensibility to parameter variation around the nominal value. (a) Tyre stiffness, (b) Vehicle mass, (c) Centre of gravity location on y-axis and (d) Front axle damping.

Table 2. Classification of the parameters according to their dominant behavior.

Behaviour	Symmetric input	Asymmetric input
1	C_{sf}, C_{sr}, M_c, X_{cg}, Y_{cg}	C_{sf}, C_{sr}, I_{xx}, M_c, M_{ur}, X_{cg}, Y_{cg}
2	K_t, M_{uf}	K_t, M_{uf}
3	I_{xx}, I_{xy}, I_{yy}, K_{sf}, K_{sr}, M_{ur}	I_{xy}, I_{yy}, K_{sf}, K_{sr}

3.3. General effect of a parameter variation on comfort

Data reduction was performed by considering a simple index, computed as the maximum discomfort on the driver position in the speed interval under 100km/h. The variation of this global index originated by the variation of each parameter was studied.

Figure 5 shows the change on the proposed index as a function of the change on K_t, M_c, Y_{cg} and C_{sf} independently and around their nominal values. The variations associated to these parameters are the four most significant inside the set of parameters included in the study.

4. Results and discussion

Based on the information obtained about the variation of the acceleration rms under changes of every single parameter, the final data processing took each parameter and evaluated the minimum value of acceleration rms that was reachable with changes of the given parameter. Parameters were ordered according to the difference between the nominal response of the system and the minimum value of acceleration rms reachable changing only a given parameter. This ordering generates a final ranking, in which the parameters with the highest opportunity for comfort improvement are quantitative compared.

The first eight places of the ranking are shown in figure 6. The first place in the ranking is for the tyre stiffness parameter, K_t, followed by the sprung mass, M_c, the lateral location of the centre of gravity, Y_{cg}, and the damping stiffness of the front suspension. The rest of the parameters bring lower opportunities for comfort improvement.

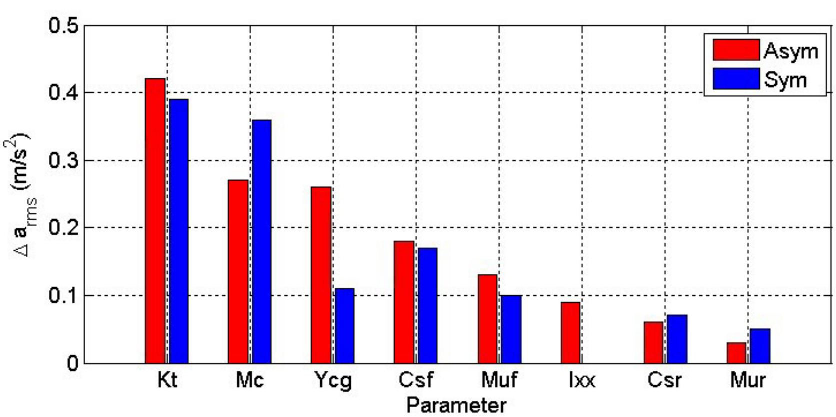

Figure 6. Comparison between the opportunities for comfort improvement associated to the different parameters.

The full investigation of the influence of the parameters on the response of the system was chosen in order to consider the non-linear dependence of the vibrations on the parameters, that is typically neglected when the influence is modelled by considering only local sensitivity (e.g., by considering only the partial derivatives of the index under study, instead of the complete response).

Appendix

The vehicle used for modelling is a hatchback lightweight model with a 3 cylinders and 0.8 litter engine, power steering, automatic transmission. The most relevant dimensions from the vehicle are listed next.

Table A1. Modelled vehicle relevant parameters.

Parameter	Units	Value
Wheel base	m	2.35
Track	m	1.29
Height	m	1.5
Curb weight	N	7612

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