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RESEARCH ARTICLE

The Examination of Dynamic Effects of Shape Optimized Vehicle Components

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Abstract

Nowadays the sustainability of surface transport requires continual innovation. This must be realized simultaneously in several areas such as traffic control, transport networks control, and the development of the vehicles. To former network design, computer control systems development, as well as statutory and economic regulatory systems are required. Exhaust gases emissions is a main air pollutant and has to be considered in vehicle development. On the efficiency of the internal combustion engines occurring combustion processes does not quite possible to improve significantly. For using electrical vehicle one needs to have appropriate infrastructures i.e. electric charger. However it is clear that with the reducing the mass of vehicles significantly the emissions is reduced. Further advantages of the mass reduction the vehicle dynamic parameters are improvements its examination we are dealing with. The motivation this study's to show how a suspension mass reduction affects on vehicle dynamic. For the optimization the initial mass of suspension was reduced approx. by 40%. Decreasing the suspension's mass shows the vehicle's vibration is improved.

Keywords

shape optimization, dynamic effect, suspension, unsprung mass, downsizing, spindle

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1 Introduction

During the development of vehicle we are always strive to make them more reliable, faster, convenient, cheaper and the more environment friendly in travel. The fulfilment of these criteria has not been easy for engineers especially so if we consider that increasingly shorter development time is available. In spite of this with the help of the engineering design and simulation software we can substantial results to be achieved. It is important to note that the software can only help in reducing the computation time. The hardest part of modelling is the definition of the load cases (the expected loads), the evaluation of results is the responsibility of engineers. In some areas the standards required for test conditions (Szyrocka, 2016).

It is well known that in the case of vehicles reducing the mass (the downsizing) is crucial importance since it the vehicles are such special machines that are moving. Logically, if everywhere may facilitated is worth. In this case we can reduce the material consumption (material price), the accelerated- and transported mass. Hence the reduction of masses of the moving components reduces the forces acting on them (II. Law of Newton). In general, the additional advantage of the mass reduction is it reduces the demand for energy (Zavada, Abramović, Čvek, 2014). This means that the fuels consumption and pollutant emissions will be reduced too (Török, 2015).

In aspect of vehicle dynamics and stability in the case that the unsprung mass is reduced, more improvements can be achieved.

For this reasons, one choose a part of the suspension system (the stub shaft Fig. 1). This component constitutes so-called unsprung (exactly lightly sprung) mass.

Previous study showed that with the help of the shape optimization significantly (with approx. by 40%) can be reduced the stub shafts mass (Ficzere and Török, 2013). It is important to note that the shape optimization causes in reducing the mass, the time of manufacturing, costs, fatigue properties, and dynamic behaviour as well (Ivanco et al., 2016). In this study we examine the reducing of the mass effect on the dynamic behaviour.

2 Methodology

The previously mentioned optimized stub shaft shown in Fig. 1.

Fig. 1 Shape optimized stub shaft

Due to the facilitation compared to the original shaft approx. 40% weight loss was achieved.

For the vehicle dynamics tests one should use a simplify model. The number corresponding to the stresses caused by load cases in reality are infinite, so only some extreme cases were examined. From the results can be inferred the further intermediate state as well. In our case a so-called quarter-vehicle model is used.

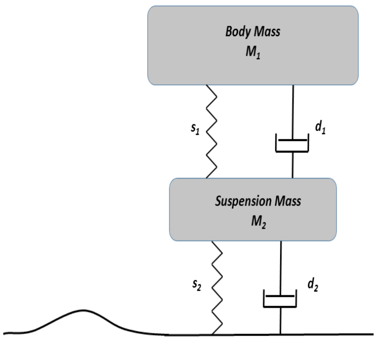

Fig. 2 Model of Car Suspension System (1/4 Car)
(Source: Based On Control Tutorials For Matlab & Simulink)

For the calculations were used a small category car data. The necessary initial data for the calculations (Ilosvai 2012):

- m_{all} = 800 kg (curb weight) ⇒ M_{11} = 200 kg
- m_{max} = 1160 kg (max. load) ⇒ M_{12} = 290 kg
- $m_{suspension}$ = 25 kg ⇒ M_{21} = 25 kg
- $m_{optimized\ suspension}$ = 15 kg ⇒ M_{22} = 15 kg
- suspension spring stiffness ⇒ s_1=160000 N/m
- suspension damping ratio ⇒ d_1=350 NS/m
- tire spring stiffness ⇒ s_2 = 375000 N/m
- tire damping ratio ⇒ d_2 = 15000 Ns/m

Although during the cited shape optimization only the spindle optimization was done. Based on the assumption we can get a similar order of magnitude results for elements of the suspension. This is evidenced by the fact that due to the reduction of mass forces smaller bearing, less powerful and smaller springs, dampers can be used. Based on this, we assumed that in the case of a full suspension is available a 40% mass reduction. The reduction must be done with correspondence to safety not to violate road safety rules (Bačkalić, Jovanović, Bačkalić, 2015).

As road excitation a h = 100 mm height road inequality sinusoidal character is assumed

- v = 10 m/s and
- v = 30 m/s

moving at a constant speed.

The examined features in the specified load cases:

- displacements of
  - chassis
  - wheel
- accelerations of
  - chassis
  - wheel

3 Results

After the simulations of different cases the following results were obtained.

Table 1 Amplitudes and accelerations in case of M_{11} = 200 kg and v = 10 m/s

M_{11} = 200 kg, v = 10 m/s			
		M_{21} =25 kg	M_{21} =15 kg
Amplitude [mm]	Chassis	33.22	33.07
	Wheel	32.19	31.65
Acceleration [m/s^2]	Chassis	23.9	23.61
	Wheel	230.6	258.3

The results are given in Table 1 for a practically empty car (M_{11} = 200 kg) with the speed of v = 10 m/s onto the bump driving adequate quarter vehicle model was used.

The results of the simulation are shown in the diagram below where the chassis and wheel's displacements are illustrated versus the time.In figure light blue is the chassis displacements, the yellow is the wheel displacements. For a better overview of the excitation (dark blue marked path) is not fully visible.

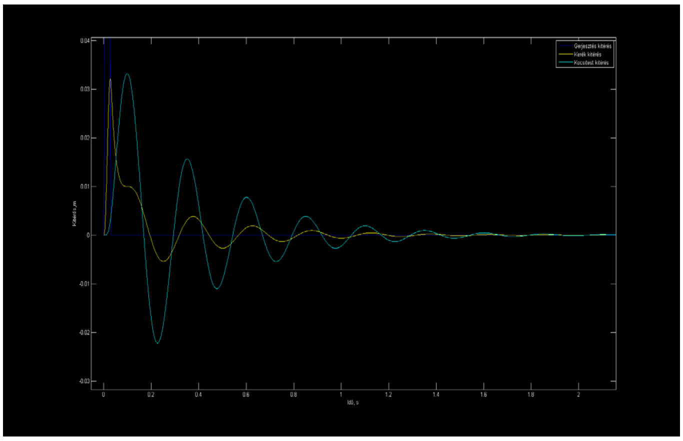

Fig. 3 Chassis and wheel oscillation (displacement [m] in time [s] as function)

For having better visibility of ratios show on the graph the total excitation as well as the chassis and wheel displacements.

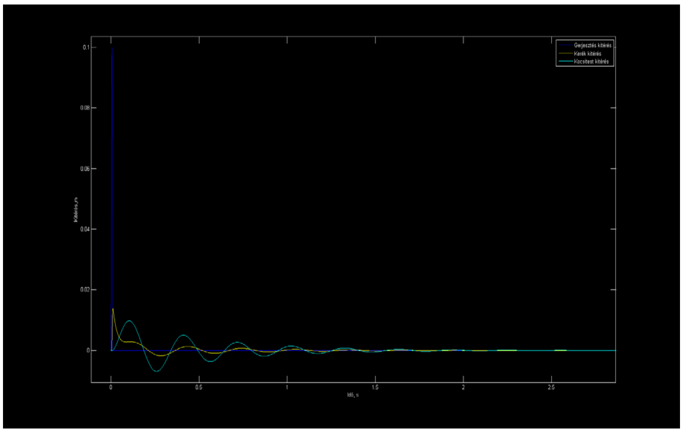

Fig. 4 The excitation, the chassis and wheel displacements [m] is the time [s] as a function

In Fig. 5 displacements and the degree of accelerations as a function of time for both the chassis as well as the wheel. The results are shown in the following diagram. (yellow for the wheel, purple is chassis acceleration).

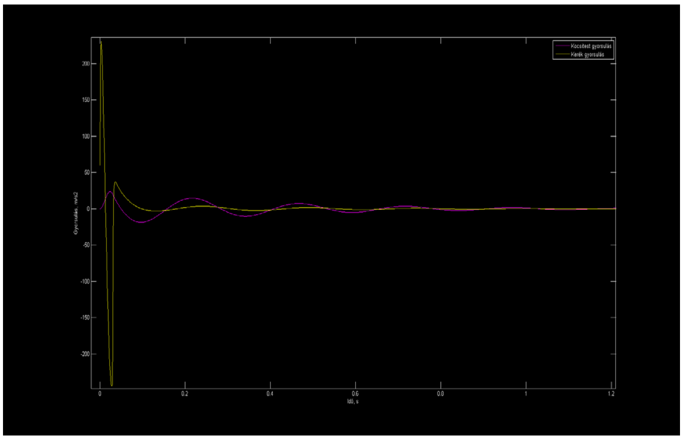

Fig. 5 The chassis and wheel accelerations [m/ s2] as a function of time [s]

Table 2 Displacements and accelerations in case of M_{11} = 200 kg and v = 30 m/s

M_{11} = 200 kg, v = 30 m/s			
		M_{21} =25 kg	M_{21} =15 kg
Amplitude [mm]	Chassis	11.16	11.11
	Wheel	13.7	13.88
Acceleration [m/s²]	Chassis	11.55	11.57
	Wheel	594.8	764.9

In Table 2 under the same conditions drove the car with three times higher speed (v = 30 m/s) over the road bump.

In next step the simulation was carried out with the loaded car (M_{12} = 290 kg) adequate quarter vehicle model. Table 3 shows the results of the tests with v = 10 m/s.

Table 3 Displacements and accelerations in case of M_{12} = 290 kg and v = 10 m/s

M_{11} = 290 kg, v = 10 m/s			
		M_{21} =25 kg	M_{21} =15 kg
Amplitude [mm]	Chassis	29.23	29.14
	Wheel	32.11	31.59
Acceleration [m/s²]	Chassis	16.84	16.65
	Wheel	230.5	258.3

Finally, the test was carried for a loaded car (M_{12} = 290 kg), with higher speed (v = 30 m/s). The results are shown in Table 4.

Table 4 Displacements and accelerations in case of M_{12} = 290 kg and v = 30 m/s

M_{11} = 290 kg, v = 30 m/s			
		M_{21} =25 kg	M_{21} =15 kg
Amplitude [mm]	Chassis	9.794	9.758
	Wheel	13.68	13.87
Acceleration [m/s²]	Chassis	7.992	8.01
	Wheel	594.8	764.9

4 Analysis

Investigate the results can establish that under the test boundary conditions with the given load effect:

- Displacements of the chassis due to the reduction of unsprung masses reduced with very small extent.
- In the case of the wheel's displacements by the weight reduction significant change cannot be detected.
- The acceleration of the car body both from the load cases and unsprung mass reduction shall be independent.
- The wheel accelerations in case of lower speeds (v=10 m/s) approx. with 10% increased due to the reduction of unsprung masses. This results is significant in terms of mass forces, leads to more than 30% decreasing.

- Carried out the simulations on the higher speed (v=30 m/s) the wheel accelerations increased in more extent. Therefore, the inertial forces from the wheel's accelerations around 23% decreased.
- The extent of the damping time the reduction of unsprung masses are not influenced significantly.

5 Discussion

The available mass reduction from the optimization of components add up the advantages and disadvantages as well (Stasiak-Betlejewska, 2015). Based on previous calculations the reduction in consumption and emissions caused by the mass reduction is not significant extent for the individual but at the social level has to be (Szendro, Csete, Török, 2014). Earlier it has been assumed that the reduction of unsprung masses can have a major influence on vehicle dynamics. However according to this study's results it is stated that for investigated cases with the given boundary conditions there are not significant differences in the point of view of the vehicle dynamics. It is important to note that the requisition deriving from mass forces of suspension decreased what is a further significant advantage at the design process.

It is also important to note that for the precise analysis results the authors consider it necessary to examine further cases (emergency braking, driving curve, compound stress) as well. The results are assumed to closer to the reality with a more accurate model for example in case of half or all vehicle models.

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