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SINUSOIDAL SWEEP CONTROL OF AN IMPROVED PNEUMATIC SUSPENSION

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ABSTRACT

This paper presents the analytical and experimental validation of an improved pneumatic suspension. This improvement is based on the right selection of the suspension elements, that is, the right selection of the air spring and reservoir size. As a result of this kind of selection, the suspension stiffness ratio is increased. This conclusion is taken from a previous work of these authors and allows showing both analytically and experimentally how the suspension presents better performance. The system is evaluated by means of a controlled sinusoidal sweep.

Keywords: stiffness ratio, transition frequency, controlled sinusoidal sweep.

1. BACKGROUND

Today's industry car not only depends on the price or the performance. It is also important to improve the passenger's safety and comfort. For this purpose, some works have developed in [1], a hydraulic innovative suspension solution, combining a hydraulic actuator and nitrogen bulbs, are presented to carry out a semi-active suspension. Other authors like [2], incorporate a pneumatic piston with a diaphragm along with two chambers communicated by means of an orifice. In works like [3] a pneumatic actuator is used to supply an additional damping force to a conventional spring-damper suspension. In this work, we present an improved suspension based on these authors' previous work conclusions [4]. As a result, the improved suspension is simulated both analytically and experimentally obtaining good performance for the pneumatic suspension.

2. EXPERIMENTAL WORKBENCH

The experimental workbench used in this work has the elements presented in fig. 1: An air spring (models 31062 or 31042 of Norgren), an auxiliary reservoir (2 l. or 24 l.) and two pipes from the air spring to the reservoir. This reservoir is connected to controlled pressure valve which is able to fill the pneumatic suspension up to a desired initial pressure. These two pipes have different size both in width and length so that, their C_R coefficient defined in [4], goes from 10^{-5} to 10^{-8} N^5/ms. The air spring bottom side is assembled to a hydraulic actuator load unit (model MTS 810) whereas its upper side is carrying the sprung mass (120 kg). Both the excitation and response are monitored by means of two LVDT (model DC-EC 2000 of Schaevitz). Moreover, two electro valves 2/2 way are placed between each pipe and the air spring as can be seen in fig. 1. These two valves are used to close or open the air flow through one or other pipe depending on the strategy control.

This work presents an analytical and experimental validation of the improvement suggested in the previous work [4]. The conclusions of that work recommend increasing the stiffness ratio (R_K). This stiffness ratio was defined as the ratio between the two suspension stiffness limit values reached when said suspension was excited at high and low frequencies respectively. Increasing this ratio involves finally the reduction of the air spring volume and the increase of the reservoir one as far as possible.

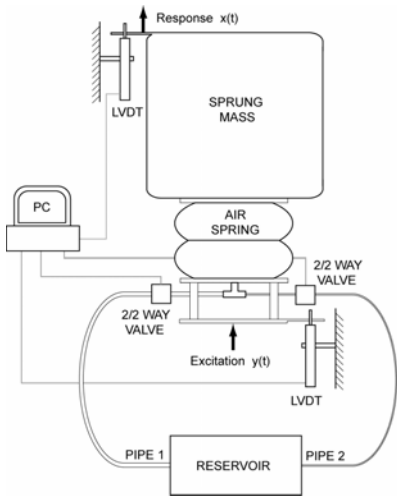

Figure 1. Experimental workbench for the pneumatic suspension.

3. STIFFNESS RATIO IMPROVEMENT

As it has been previously introduced, the main goal of this work is the stiffness ratio increase. The selection of those suspension elements (air spring and reservoir) presented above, allows us to reach a higher stiffness ratio (reached with an air spring 31042 and the larger reservoir). This is first evaluated at the workbench and then simulated by these authors' model [4]. The improvement can be seen both at the dynamic stiffness and dynamic response tests. The first test, evaluates the suspension dynamic stiffness at different frequencies, comparing previous and present suspension elements, that is, when R_K changes from 1.58 to 2.06. For the stiffness test, the excitation input was a 5 mm amplitude sinusoidal wave exerted by the load unit at the bottom side of the air spring while the upper side is locked (and therefore the sprung mass is not used). The initial pressure inside the pneumatic suspension was fixed to 3 bar in any suspension case. The input signal frequency was growing from 0.1 to 25 Hz. The output force signal was measured by the load cell of the hydraulic unit. This is repeated for each system (corresponding to each R_K ratio) and for each pipe (corresponding to each C_R coefficient).

3.1. Stiffness results

The stiffness results can be seen in fig. 2. In this figure is shown both the analytical and experimental results for any suspension case described above.

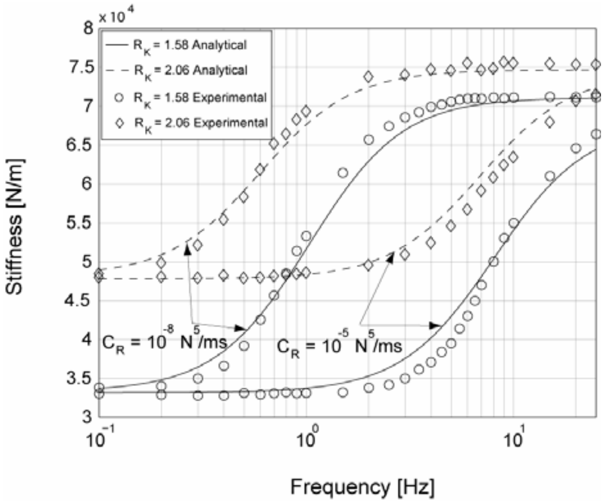

Figure 2. Comparison between stiffness results for different R_K values.

It is easy to notice how the distance between the stiffness values at high and low frequencies grows in the case of $R_K = 2.06$. The experimental results are well reproduced by the model both for $R_K = 1.58$ and $R_K = 2.06$.

3.2. Transmissibility results

The transmissibility tests were carried out at the same hydraulic load unit. In this case, the excitation signal was a 1 mm amplitude sinusoidal wave. The output signal was the displacement dynamic response of the sprung mass. These two signals are monitored by two LVDT. The initial pressure of the pneumatic suspension was set to 1 bar or 2 bar depending on if the system used means that $R_K = 1.58$ or $R_K = 2.06$ respectively. The sprung mass (120 kg in any case) now can move up and down by means of a linear bearing that the hydraulic upper gag grasps.

The results of these tests can be seen in fig. 3. This figure also shows the transmissibility results for the model simulation, and they are very close to the experimental ones. The figure points out the improvement effect on the suspension behavior when the R_K coefficient has been increased. This increment involves that now, the two curves (for $C_R = 10^{-5}$ N^5/ms and for $C_R = 10^{-8}$ N^5/ms) present its eigenfrequencies at a large distance. This means that the value of the crossing point of those two curves at the transmissibility diagram drops down from a value of 4 to a value of 2.5 approximately. This fact will be used next when the pneumatic suspension is excited with a sinusoidal sweep.

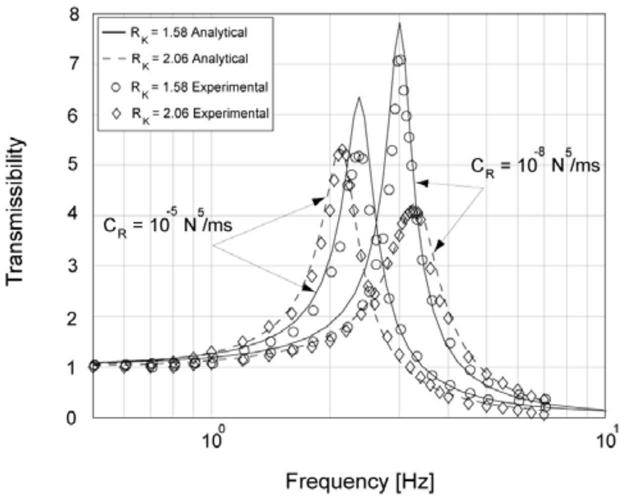

Figure 3. Comparison between transmissibility results for different R_K values.

4. CONTROLLED SINUSOIDAL SWEEP

A sinusoidal sweep is now applied to the pneumatic suspension with the purpose of incorporate a control strategy. The input signal of the sweep is a constant 1 mm amplitude wave, whereas the frequency changes from 0.5 to 10 Hz. The experimental set up and initial conditions of the test are the same as the transmissibility ones. The control strategy is related with this authors' previous work [4]. This result suggests to change the C_R coefficient from one value to the other (for a given R_K system) when a specific frequency has been reached (in the sweep in this case). This transition frequency is written as follows:

$$\omega_{tr} = \omega_s \sqrt{\frac{2}{\theta^2 + 1}} \tag{1}$$

where ω_s and θ are related to analytical stiffness variables defined in that work. Figure 4 shows both experimentally and analytically the sweep test for the system defined with the ratio $R_K = 2.06$. The sweep begins at low frequencies with the C_R coefficient equal to 10^{-8} N^5/ms. This means that one 2/2 way valve is open and the other remains closed for that purpose. When the frequency ω_{tr} is reached, the valves change its state, that is, open to closed and vice versa. Therefore, the system works with the coefficient C_R equal to 10^{-5} N^5/ms. The transition time was measured experimentally and analytically and result 1.14 s. and 1.07 s. respectively.

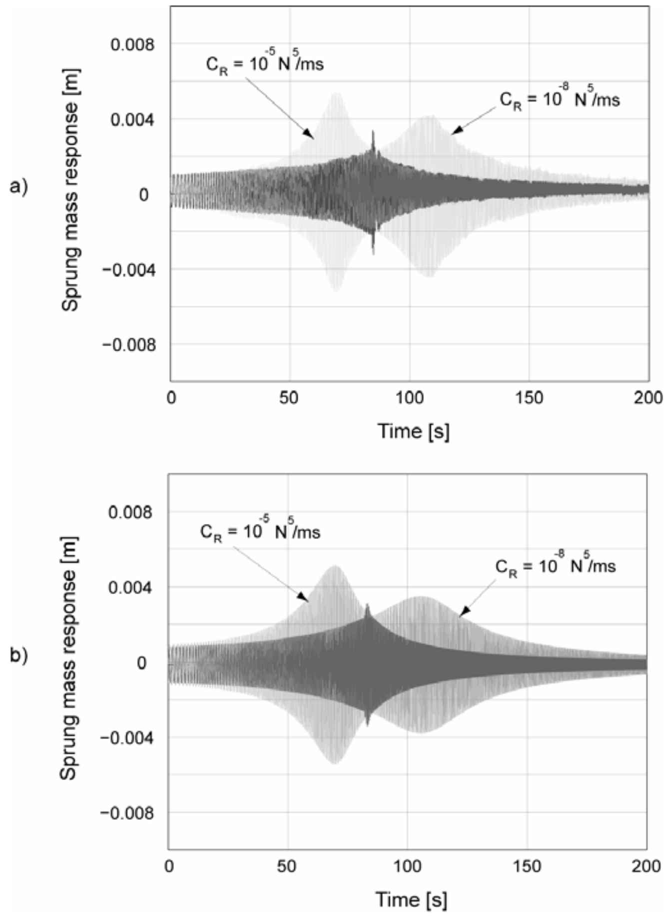

Figure 4. Sinusoidal sweep with switching control. a) Experimental results, b) Analytical results.

5. CONCLUSIONS

An improved pneumatic suspension has been presented in this paper. The conclusions reached in previous works have been validated here. The frequency difference between the two eigenfrequencies corresponding to the two C_R coefficients is now larger. As an advantage, a reduction in the dynamic response has been reached. This has been possible by means of the right selection of the pneumatic suspension elements.

6. REFERENCES

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