

Modeling Air-Spring Suspension System of the Truck Driver Seat

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ABSTRACT

The suspension system of a heavy truck's driver seat plays an important role to reduce the vibrations transmitted to the seat occupant from the cab floor. Air-spring is widely used in the seat suspension system, for the reason that its spring rate is variable and it can make the seat suspension system keep constant 'tuned' frequency compared to the conventional coil spring. In this paper, vibration differential equation of air-spring system with auxiliary volume is derived, according to the theory of thermodynamic, hydrodynamics. The deformation-load static characteristic curves of air-spring is obtained, by using a numerical solution method. Then, the ADAMS model of the heavy truck's driver seat suspension system is built up, based on the structure of the seat and parameters of the air-spring and the shock-absorber. At last, the model is validated by comparing the simulation results and the test results, considering the seat acceleration PSD and RMS value.

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INTRODUCTION

Heavy trucks are specifically designed to transport heavy loads over long distances, drivers of commercial trucks are required to drive long and sometimes irregular hours. Considering the long hours of transportation, truck drivers deserve vehicles that will allow them to maintain a high level of comfort over the wide range of road conditions they encounter.

The ride comfort depends on the exposure duration, amplitude, and frequency of vibration to a human body [1]. While seated, the human body is most sensitive to vibrations at 4-10 Hz in vertical direction and 0.5-3 Hz in horizontal direction. For instance, vibration at 4 Hz is found to cause severe discomfort in humans due to the fact that the spine, shoulders, and the head resonate near this frequency. The natural frequency of an operator on a seat cushion system is below 4 Hz and even 2 Hz when equipped with a seat suspension system [2].

To attenuate vibrations transmitted to the occupant, suspension seats are generally used in the conventional coil spring and hydraulic damper combination. To further improve the ride performance of the heavy truck's driver seat, air-spring technology, initially used in vehicle seat suspensions, is

adopted. The reasons for the increased popularity of air-springs compared to the conventional coil spring and damper suspensions are presented by Quaglia, G. et al. [3] as follows:

- adjustable carrying capacity;
- reduced weight;
- variable spring rate with constant 'tuned' frequency;
- reduced structurally transmitted noise;
- variable ride height.

Researches on modeling seats mounting air-spring are going on for quite some time. Maciejewski, I. et al. [4] according to the nonlinear seat suspension dynamic behavior, proposed the Pareto-optimal approach to be used in the optimization of nonlinear seat suspension systems for the earth-moving machinery. Shurpali, M. et al. [5] introduced a black box modeling technique to estimate the relationship between air-spring's stiffness and the excitation's frequency and amplitudes. Liu, H. et al. [6] thoroughly analyzed the nonlinear characteristics of the rubber gasbag of the air-spring by using the nonlinear finite element analysis. Moshchuk, N. et al. [7] modeled the air-spring as a single pneumatic chamber, single rod jack with spring assistance to account for spring nonlinearities, in AMESim. Holtz, M. et al. [8] established the nonlinear air-spring for a suspension seat based on the

thermodynamic, heat transfer and fluid mechanic principles, but neglected the influence of change in air-spring area to air-spring's stiffness. Quaglia, G. et al. [9] derived the stiffness of their air-spring model based on the basic force-distance relationship.

In this paper, the mathematical model of air-spring is set up by considering the non-linear relation between air-spring's effective area and its height, which is obtained from static characteristic test, and the non-linear orifice model that represents the flow characteristics of the orifice which collects the air-spring and the auxiliary volume. Subsequently, through solving the differential equation in MATLAB, the deformation-load static characteristic curve of air-spring in various initial states has been obtained, and the result is used to express the stiffness performance of the air-spring in ADAMS.

MODELING OF AIR-SPRING

The typical on-highway truck seat of today incorporates a rolling lobe air-spring of a design similar to that shown in Figure 1. Air-spring suspension assemblies consist of a piston encased in a rubber air bladder. Inflation air enters the air-spring shown in Figure 1 through the opening labeled "combination stud/air fitting".

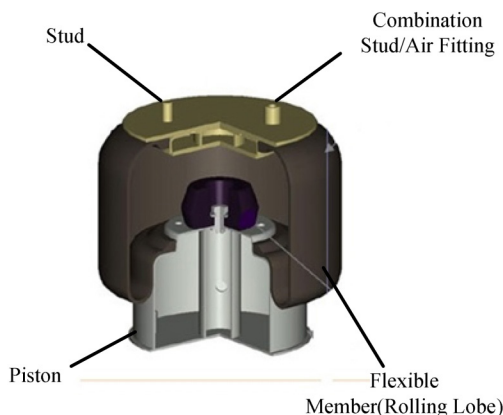


Figure 1. Rolling Lobe Air-spring

The simulation model of the air-spring with an auxiliary volume is developed by deriving the state equations based on the thermodynamic, heat transfer and fluid mechanic principles encountered when dealing with gasses.

The spring force is determined by means of the spring's internal pressure and incorporates the boundary work of the piston. The spring's pressure in turn is determined by a differential equation of the ideal gas. The assumption of ideal gas behavior is relevant since the relative pressure and temperature are in the regions where ideal gas behavior can be assumed. Thus, to obtain the change in pressure, one takes the ideal gas equation as an equation of state and differentiates it with respect to time.

To develop this model, the following assumptions are made:

- the air inside the spring is treated as an ideal gas;
- heat transfer doesn't take place between the spring and its surroundings in the dynamic state of the air-spring;
- the unknown damping in the rubber material can be neglected;
- conservation of mass inside the air-spring and auxiliary volume;
- only the vertical force acts on the sprung mass.

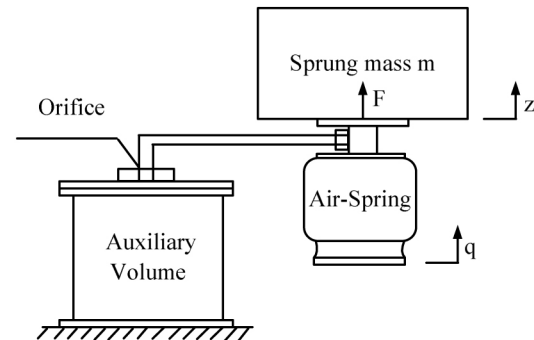


Figure 2. Physical model of air-spring with auxiliary volume vibration

The physical model of air-spring with auxiliary volume vibration, Figure 2, which is composed of sprung mass, air-spring, auxiliary volume and orifice. The system's excitation is vertical deviation q in the bottom of air-spring, and the response is sprung mass' displacement z generated under the action of air-spring' vertical forced F . The each component's mathematical model is established based on rigid body dynamics, thermodynamics and aerodynamics' theory.

In the process of air-spring vibrating, the air-spring's volume, absolute pressure, gaseous mass and effective area are all dynamic changes, which is caused by the deformation of air-spring, so the above state variables are functions of the air-spring's dynamic height. The air-spring's height changes with time.

$$\dot{A}_e = \frac{\partial A_e}{\partial h} \dot{h} \quad (1)$$

$$\dot{V}_s = \frac{\partial V_s}{\partial h} \dot{h} \quad (2)$$

$$\dot{m}_s = \frac{\partial m_s}{\partial h} \dot{h} \quad (3)$$

The effective area of the air-spring can be defined as the specific value of the vertical force generated by the air-spring force to the gasbag's relative pressure. The effective area is