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SIMULATION ANALYSIS OF A SEMI-ACTIVE VEHICLE SUSPENSION

TADEUSZ WESOŁOWSKI
KRZYSZTOF PÓŁTORAK

Warsaw Technical University

1. Introduction

In recent years the traditional passive car suspensions cannot meet the growing requirements concerning comfort and safety of driving cars. While searching the optimum characteristics of suspensions, it is often found that this problem can be solved by applying the system of changeable structure, adjusting its characteristic to conditions of motion i.e. by applying socalled active systems. The active suspensions are mostly hydropneumatic, because of the simplicity of controlling their action. Their action can be controlled mechanically. The suspension to which the energy is supplied during the controlling process e.g. the working medium is pumped in, react to slow-varying displacements of the car body, such as those occuring when the car is rolling on curves or is braking [1]. The systems like those are characterized, however, by a long delay of action, so they cannot react properly to road irregularities.

There are also suspensions which are controlled by changing the magnitude of damping in the system [3, 4, 5]. These are called semi-active suspensions. They react immediately to the road irregularities. The example model of such a suspension patented by the first author [6] is shown in Fig. 1. The spring k_1 and the hydraulic damper with a mutable characteristics controlled by an inertial transmitter having the mass m_0 is located betwen the car body m_1 and the wheel m_2. The transmitter consists of the spring k_0 and the damper c_0 which are connected to both the wheel and the mass m_0. This mass is connected with the valve c_{10} by means of a lever system and is used for a direct control of the valve. The position of the valve slide is changed when the acceleration acts upon the mass during the car motion and/or the distance between the car body and the wheel changes. Any change of the slide position results in the change of the damping factor. Thus, it is easy to get the desirable characteristics

$$c_{10} = f(x) \quad \text{where} \quad x = z_0 - z, \tag{1}$$

by appropriate selection of the slide in the throttling valve.

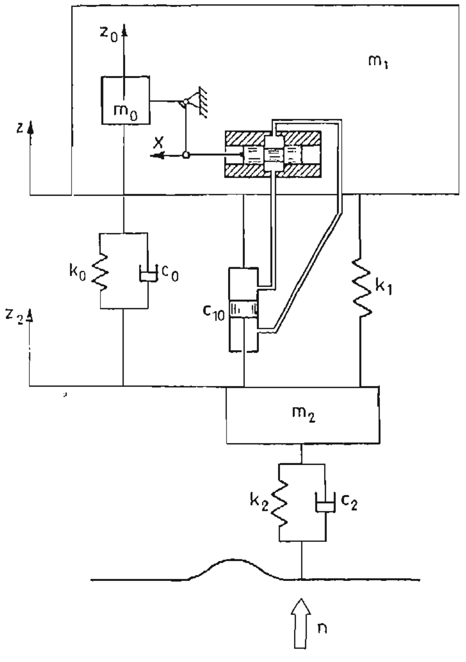

Fig. 1.

2. Analysis

The equation of motion of the inertial transmitter is derived basing on the scheme of the semi-active suspension shown in Fig. 1. The following assumptions are introduced:

— the valve is relieved and the mass of the slide is negligible as compared to m_0;
— the mass and the moment of inertia of connecting elements are neglected;
— the levers are long enough to assume the motion of the mass m_0 to be rectilinear;
— the mass m_0 can be neglected as compared to m_1 and m_2.

The equation of motion takes the form:

$$m_0 \ddot{z} c_0 + {}_0(\dot{z}_0 - \dot{z}_2) + k_0(z_0 - z_2) = 0 \qquad (2)$$

In the following the semi-active suspension shown in Fig. 1 is applied in — a plane model of a mobile crane (see Fig. 2) to absorb shocks acting on its leading axle. The application of the semi-active suspension in the vehicle like that seems to be especially justified because of several disadvantageous phenomena occuring in the currently applied passive system. For example so-called „galloping" is observed, which is a slow-decaying vibration of low frequency and big amplitude due to a huge moment of inertia of the car body. It occurs in the range of the working speed of the vehicle between 5 and 14 [m/s]. The application of the suspension with the mutable structure should lead to an observable diminishing of this vibration.

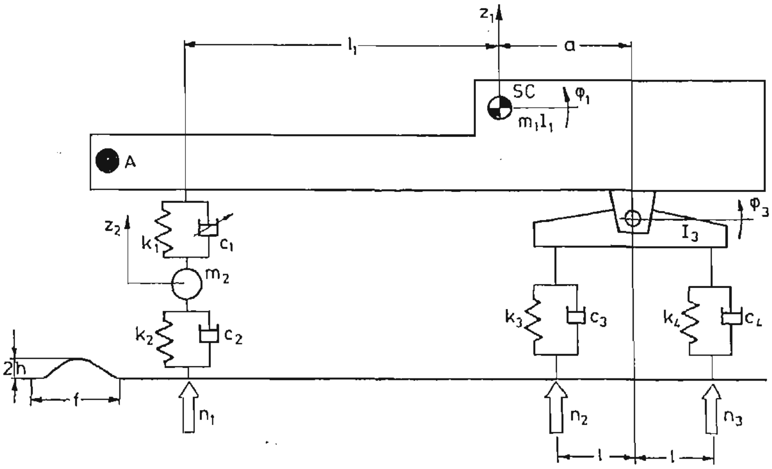

Fig. 2.

The currently presented in-plane model of the vehicle is a system of four-degree-of-freedom (without the inertial transmitter):

$$q_1 = z_1, \quad q_2 = \varrho_1, \quad q_3 = z_2, \quad q_4 = \varrho_3. \tag{3}$$

The Lagrange equation of the second kind is used to describe the model considered:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right)+\frac{\partial R}{\partial \dot{q}_i}+\frac{\partial V}{\partial q_i} = Q, \quad (i = 1, 2, 3, 4). \tag{4}$$

By taking

$$q_5 = z_0 \tag{5}$$

and placing

$$z = z_1 + l_1 \varrho_1 \tag{6}$$

into the equation of motion (2) of the inertial transmitter, the following equation of motion of the vehicle with the semi-active suspension can be obtained:

$$\mathbf{M}\ddot{q}+\mathbf{C}\dot{q}+\mathbf{K}q = \mathbf{Q}_c\dot{n}+\mathbf{Q}_k n, \quad q = q(z_1, \varrho_1, z_2, \varrho_3, z_0) \tag{7}$$

where

$$\mathbf{M} = \begin{vmatrix} m_1 & 0 & 0 & 0 & 0 \\ 0 & I_1 & 0 & 0 & 0 \\ 0 & 0 & m_2 & 0 & 0 \\ 0 & 0 & 0 & I_3 & 0 \\ 0 & 0 & 0 & 0 & m_0 \end{vmatrix} \tag{8}$$

$$\mathbf{C} = \begin{vmatrix} c_1+c_3+c_4 & c_1 l_1 - a(c_3+c_4) & -c_1 & l(c_3-c_4) & 0 \\ c_1 l_1 - a(c_3+c_4) & c_1 l_1^2 + a^2(c_3+c_4) & -c_1 l_1 & al(c_4-c_3) & 0 \\ -c_1 & -c_1 l_1 & c_1+c_2 & 0 & 0 \\ l(c_3-c_4) & al(c_4-c_3) & 0 & l^2(c_3+c_4) & 0 \\ 0 & 0 & -c_0 & 0 & c_0 \end{vmatrix} \tag{9}$$

$$\mathbf{K} = \left|\begin{matrix} k_1+k_3+k_4 & k_1 l_1 - a(k_3-k_4) & -k_1 & l(k_3-k_4) & 0 \\ k_1 l_1 - a(k_3+k_4) & k_1 l_1^2 + a^2(k_3+k_4) & -k_1 l_1 & al(k_4-k_3) & 0 \\ -k_1 & -k_1 l_1 & k_1+k_2 & 0 & 0 \\ l(k_3-k_4) & al(k_4-k_3) & 0 & l^2(k_3+k_4) & 0 \\ 0 & 0 & -k_0 & 0 & k_0 \end{matrix}\right| \tag{10}$$

$$\mathbf{Q}_c = \left|\begin{matrix} 0 & c_3 & c_4 \\ 0 & -ac_3 & -ac_4 \\ c_2 & 0 & 0 \\ 0 & lc_3 & l-c_4 \\ 0 & 0 & 0 \end{matrix}\right| \tag{11}$$

$$\mathbf{Q}_k = \left|\begin{matrix} 0 & k_3 & k_4 \\ 0 & -ak_3 & -ak_4 \\ k_2 & 0 & 0 \\ 0 & lk_3 & -lk_4 \\ 0 & 0 & 0 \end{matrix}\right| \tag{12}$$

The function n modelling irregularities of the road (single obstacle) is plotted in Fig. 2 The analytical form of this function is as follows

$$n = h\left(1 - \cos\frac{2\pi lv}{f}\right) \tag{13}$$

The excitation acts on the system successively at the time resulting from the speed of the vehicle and the distance of its axles.

3. Numerical calculations

The problem is solved by use of a digital simulation technique. The equations of motion are transformed into the Cauchy form, so the RKGS procedure included in the IBM library can be applied. The RKGS procedure is a ready-made Fortran subprogram for solving ordinary differential equations of the first order with known initial conditions. It is based on the Runge-Kutta method of the fourth order with the Gill's modification.

The size of the program and the time of its execution makes it possible to perform numerical calculations on the 16-bit microcomputer in Fortran language working under CP/M-86 disc operating system. The computer used is NEC PC-9801E equipped in 348 kB RAM, a double floppy disk drive and a printer. The program runs about 5 min. for typical data. The results, which include displacements, vertical speeds and accelerations of the driver's cabin for following points of time, may appear on the monitor screen or on the printer depending on the computer operator's wish.

The slection of the appropriate step of integration is extremly important in the simulation process. If the step is taken to big a part of the excitation acting on the system may be ignored. In order to avoid such a case and in order to obtain the most accurate mapping of the excitation function the program reduces automatically the step of integration when the obstacle is met (independently of the RKGS procedure).

The example calculations are carried out for the data as for the mobile crane HYDROST-253 ($m_1 = 26520$ [kg], $m_2 = 1160$ [kg], $I_1 = 160000$ [kgm^2], $I_3 = 160$ [kgm^2], $k_1 = 1147370$ [N/m], $k_2 = k_3 = k_4 = 1759680$ [N/m], $c_2 = c_3 = c_4 = 0$, $l_1 = 3.252$ [m], $l = 0.7$ [m], $a = 1.748$ [m]). The inertial transmitter data are as follows: $m_0 = 20$ [kg], $k_0 = 2692$ [N/m], $c_0 = 464$ [Ns/m].

The assumed dependence of the damping factor vs. the displacement of the mass m_0 taken for numerical simulation is shown in Fig. 3. This function is of parabolic type in the range $x < |0{,}07$ [m]$|$ and is constant for other values od x ($c_{1max} = 17000$ [Ns/m], $c_{1min} = 75000$ [Nm/s]).

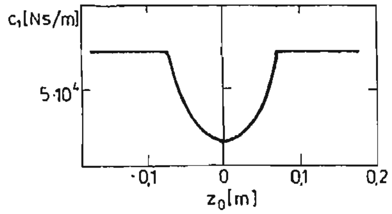

Fig. 3.

The simulative calculations are carried out for the speed of the vehicle equal to 5 [m/s]. The diagrams for the driver's cabin displacements with regard to time are shown in Fig. 4. Line *a* corresponds to the traditional suspension and line *b* to the semi-active suspension respectively.

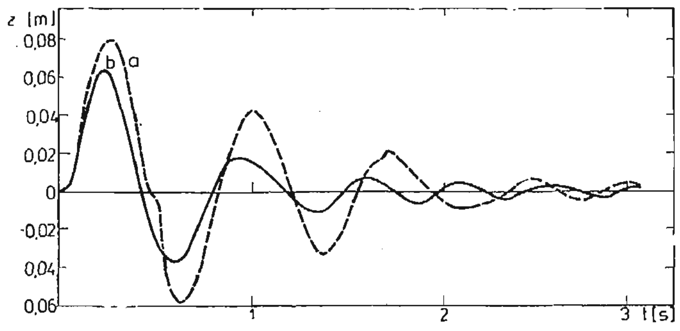

Fig. 4.

4. Concluding remarks

The comparison of the results obtained for both the traditional and the active suspension confirms that the application of the latter one results in a certain diminishing of the cabin displacements and the effective values of accelerations (a detailed analysis for a wide range of input data and several excitation functions will be the subject of a seperate paper).

The program discussed in a convenient tool for predicting the vehicle behaviour on the irregularities of the road.

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Резюме

СИМУЛИРОВАННЫЙ АНАЛИЗ ПОЛУАКТИВНОЙ ПОДВЕСКИ АВТОМОБИЛЯ

В докладе представлен метод симулированного исследования подвесок автомобиля при помощи ЗВМ. Сделано теоретический анализ полуактивной подвески, которая управляется инерционным датчиком. Представлены тоже, основанные на примерах, результаты вычислений.

Streszczenie

ANALIZA SYMULACYJNA PÓŁAKTYWNEGO ZAWIESZENIA POJAZDU

W pracy przedstawiono metodę analizy symulacyjnej zawieszeń pojazdów przy pomocy mikrokomputera. Analizie teoretycznej poddano model zawieszenia półaktywnego sterowanego nadajnikiem bezwładnościowym. Przedstawiono również przykładowe wyniki obliczeń numerycznych.

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