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Model for the study of active suspensions

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Abstract. In the beginning of the paper are briefly presented various types of semi-active and active suspensions. The advantages and disadvantages of the solutions analyzed are highlighted. There is a mathematical model for the study of an active suspension. In the next chapter we present a calculation model of active suspension controls based on elements of linear dynamic systems theory. The optimal synthesis of the dynamic system is based on a set performance criterion. At the end of the paper are presented the numerical results obtained for a two-degree system model used in several configurations.

1. introduction

Since 1970, the idea of suspension control has emerged. In the automotive industry, various concepts have emerged with regard to suspension control, so in the early 1980s, starting with the development of electronics, the concept of controlling road adaptability for the semi-active and active suspension of vehicles began to develop.

In this regard, following thorough studies, this topic becomes of great interest. Semi-active and active suspensions have been a subject of research for a long time because of their potential to improve vehicle performance. Many analytical and experimental studies have concluded that semi-active and active suspensions can provide substantial improvements over passive ones [10],[1].

Suspension passive -conventional suspension systems are passive suspensions consisting of a spring and shock absorber, making the link between the wheel and the body. The primary function of the arc is to store the energy of the vibrations, and that of the shock absorber is to dissipate the energy stored in the arc. The suspension system passively does not have flexibility [15].

Suspension semi-active - suspension systems have the ability to make changes in the damping coefficient and spring characteristics so that dampers can change the level of energy dissipation but do not provide energy to the system [7]. The damping coefficient can be controlled by a switch to increase comfort [15].

Suspension active – suspension systems are driven by an electric motor or a hydraulic cylinder, generating independent forces [7] having the ability to change the damping coefficient continuously.

2. Solutions used by car manufacturers in various models

2.1. Hydraulic or pneumatic suspension

The active or pneumatic suspension is made of a spring and a device that acts hydraulically or pneumatically by making damping forces between the suspended and the unsupported mass BMW has developed an active suspension with the hydraulic stabilizer bar. The system is made of: hydraulic pump, lateral acceleration sensors, command emitter, hydraulic suspension block and two active stabilizing bars with rotary hinged devices.

The advantages of this solution are:

Mercedes has developed the hydraulic active suspension system, consisting of a hydraulic arc, hydraulic structure, high pressure accumulator, hydraulic pump, shock absorbers and control unit. The control unit analyzes the signals received from the sensors, acting on the hydraulic system, while the vehicle is running. The hydraulic system independently controls the oil flow for each hydraulic spring [14].

AUDI has developed an active pneumatic suspension system, consisting of a pneumatic spring, reservoir, control unit, sensors, compressor, pressure sensor electromagnetic valve block. The active pneumatic suspension uses compressed air from a compressor or electric motor to perform damping [14]. The sensors measure certain parameters and the control unit determines the control mode in which the amount of air required for each shock absorber.

Ground clearance is done automatically, depending on the vehicle's driving conditions. The sensors constantly monitor the height of the car, so the amount of air in each shock absorber is adjusted to maintain the vehicle's height from the ground [4].

2.2. Active electromagnetic suspension

The electromagnetic active suspension system consists of an electromagnetic device and a mechanical spring. The device can function to recover energy from the suspension, thus reducing the energy consumption of the vehicle.

The following figure shows a BOSE suspension that uses a linear electromagnetic motor. A power amplifier provides power to the engine for vibration control. It also stores the energy generated at each compression of the suspension.

An electromagnetic damper compresses or relaxes much more, eliminating the discomfort of the passengers.

2.3. Advantages and disadvantages

Table 2. Advantages and disadvantages

Parameters	Passive suspension	Semi-active suspension	Active suspension
Construction	simple	complex	very complex
Cost	low	medium	high
Comfort	bad	good	very good
Dynamically perfected	passive	passive	good

3. Calculation methods used in the study of active suspensions

In the paper [3] there is a calculation model for the active suspensions.

This quarter car model allows research to increase or decrease the displacement of the suspended and unscrewed mass depending on the irregularities of the running track (fig. 1).

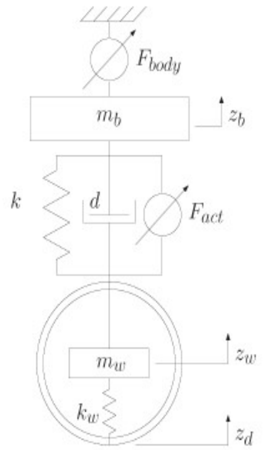

Figure 1. Suspension active.

In the paper [14] there are two calculation models for active suspensions. One refers to an active suspension in parallel and the second to a suspension (fig. 2).

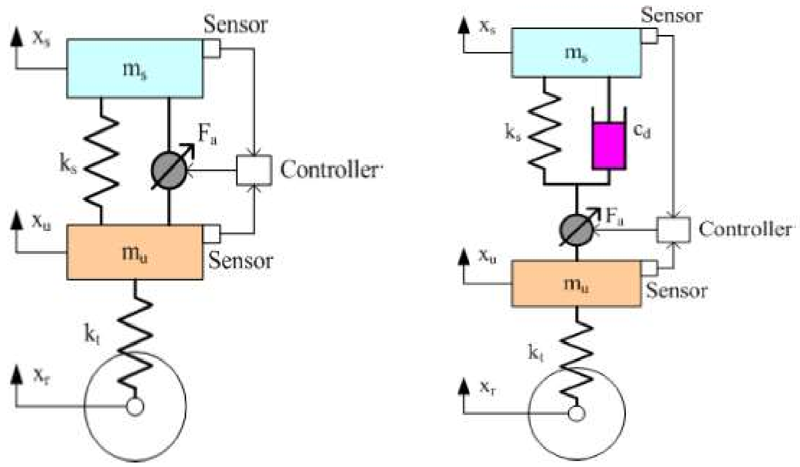

Figure 2. Suspension active.

4. Dynamic systems

It is called a dynamic system a mechanic system that evolves in time. The time evolution is described by a system of first order reductive differential equations,

$$\begin{cases} \dot{x}_i = f_i(x_1, x_2, ..., x_n, u_1, u_2, ..., u_m, \mathrm{t}) \\ i = 1, 2, ..., \mathrm{n} \end{cases} \tag{1}$$

where $(x_1, x_2, ..., x_n)$ they are called state vectors and $(u_1, u_2, ..., u_m)$ are called command vector.

If the functions f_i, depend directly on time, the system is unsparing and if it does not depend directly on time, the system is called autonomous.

A linear autonomous system with constant coefficients is written in the form,

$$\begin{aligned} \{\dot{x}\} &= [A]\{x\} + [B]\{u\} + [D]\{w\} \\ \{y\} &= [C]\{x\} \end{aligned} \tag{2}$$

where:

$\{x\} = (x_1 \ x_2 \ .... \ x_n)^T$ represents the state vector;

$\{u\} = (u_1 \ u_2 \ .... \ u_m)$ is the command vector;

$\{y\} = (y_1 \ y_2 \ .... \ y_p)$ is the observable vector;

$\{w\} = (w_1 \ w_2 \ .... \ w_k)$ is the excitation vector;

$[A] = (a_{ij})_{\substack{1 \le i \le n \\ 1 \le j \le n}}$ is the matrix of coefficients; (3)

$[B] = (b_{ij})_{\substack{1 \le i \le n \\ 1 \le j \le m}}$ is the command matrix;

$[C] = (c_{ij})_{\substack{1 \le i \le p \\ 1 \le j \le n}}$ is the observables matrix;

$[D] = (d_{ij})_{\substack{1 \le i \le n \\ 1 \le j \le k}}$ is the excitation matrix.

The system

$$\begin{aligned} \{\dot{x}\} &= [A]\{x\} + [B]\{u\} \\ \{y\} &= [C]\{x\} \end{aligned} \quad (4)$$

is called stabilizable if there is a $\{u\}$ so as to achieve equality:

$$\lim_{t \to \infty} \{x\} = \{0\} . \quad (5)$$

Obviously, a system in which the matrix $[A]$ has its own negative real values or its own complex values with the negative real is stabilizable, because such a system can be taken $\{u\} = \{0\}$.

Either the system

$$\{\dot{x}\} = [A]\{x\} + [B]\{u\} \quad (6)$$

with the initial state $\{x_0\}$.

It is required to determine {u} the optimal control that drives the system $\{x_0\}$ from $\{0\}$ the state towards the time interval *T* minimizing the functional performance:

$$J = \int_0^T L(\{x\}, \{u\}, t)dt . \quad (7)$$

The most common performance criterion is:

$$J = \frac{1}{2}\int_0^T \left(\{x\}^T[Q]\{x\} + \{u\}^T[R]\{u\}\right)dt \quad (8)$$

where $[Q]$, $[R]$ represents weight matrix, $[Q]$ being positively semi defined, $\left(\{u\}^T[R]\{u\} \geq 0,\ \forall\{x\} \in R^n\right)$ and $[R]$ positively definite $\left(\{u\}^T[R]\{u\} > 0,\ \forall\{u\} \in R^p\right)$.

It is shown by varied calculation that the solution is

$$\{u\} = [K]\{x\} \tag{9}$$

the reaction matrix being

$$[K] = -[R]^{-1}[B]^T[P] \tag{10}$$

where the matrix $[P]$ is the solution of the Riccati algebra equation:

$$[P][A] + [A]^T[P] - [P][B][R]^{-1}[B]^T[P] + [Q] = [0]. \tag{11}$$

5. Numerical results

In the figure (figure 3) the following is an active suspension system with the following notations:

- m_1 - 1/4 car body mass,
- m_2 - suspension mass,
- k_1 - spring constant of suspension system,
- k_2 - spring constant of wheel and tire,
- c_1 - damping constant of suspension system,
- c_V - control force,
- z_1, z_2 - the displacements of the two masses,

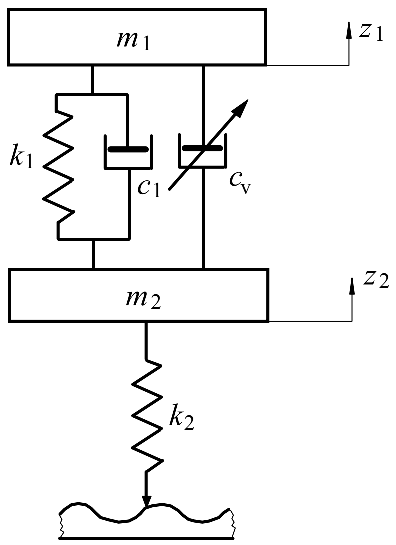

Figure 3. Suspension active.

In the initial step, the passive suspension response time will be analyzed by comparing the results of the analysis with the response time of an active suspension.

The following numerical data were used:

- $m_1 = 400$ kg,
- $m_2 = 200$ kg,

- $k_1 = 8000$ Nm,
- $k_2 = 80000$ Nm,
- $c_1 = 600$ Ns/m.

The active suspension response time is shown in Figure 5.

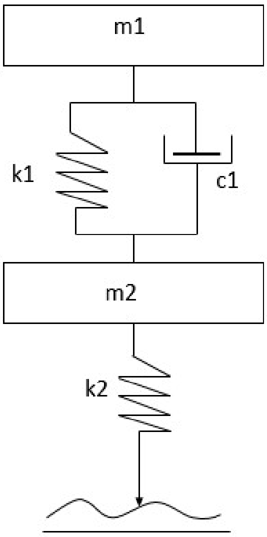

Figure 4. Suspension passive.

The passive suspension response time is shown in figure 5.

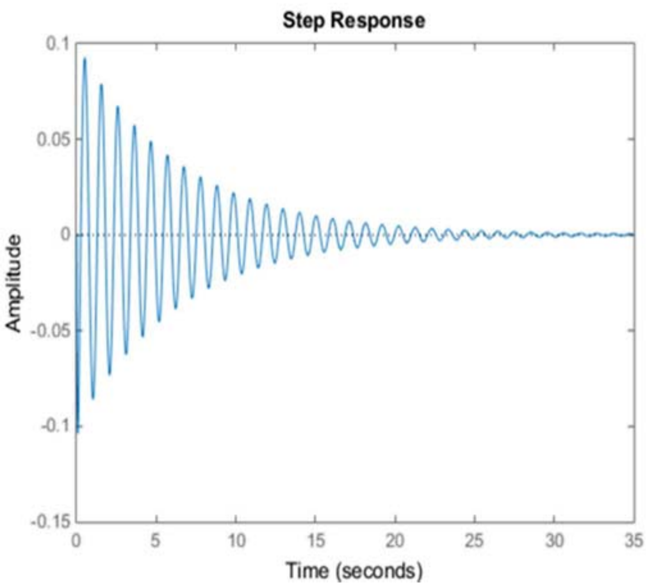

Figure 5. Response for suspension passive

In order to obtain numerical data for the active suspension, a calculation program was developed in Matlab where on the basis of the relations 1 ... 10 the graphs of Figures 6 - 8 were obtained.

The following numerical data were used:

- $m_1 = 200[\text{kg}]$
- $m_2 = 200[\text{kg}]$,
- $k_1 = 8000[\text{N/m}]$,
- $k_2 = 80000[\text{N/m}]$.

For constants c_1 were used 3 values:

- $c_1 = 400$ [N*s/m], $c_1 = 600$ [N*s/m] and $c_1 = 1200$ [N*s/m].

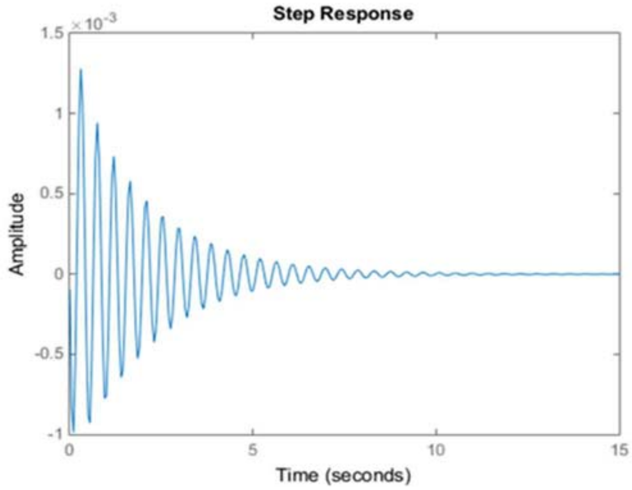

Figure 6. Closed-Loop Response with PID Controller for $c_1 = 400$ [N*s/m]

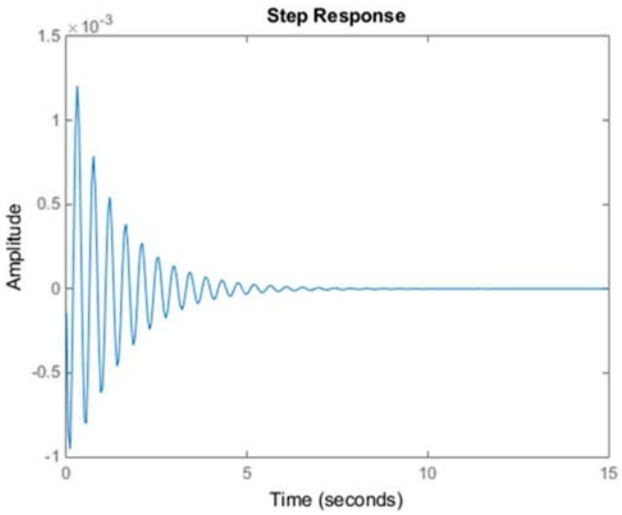

Figure 7. Closed-Loop Response with PID Controller for $c_1 = 600$ [N*s/m]

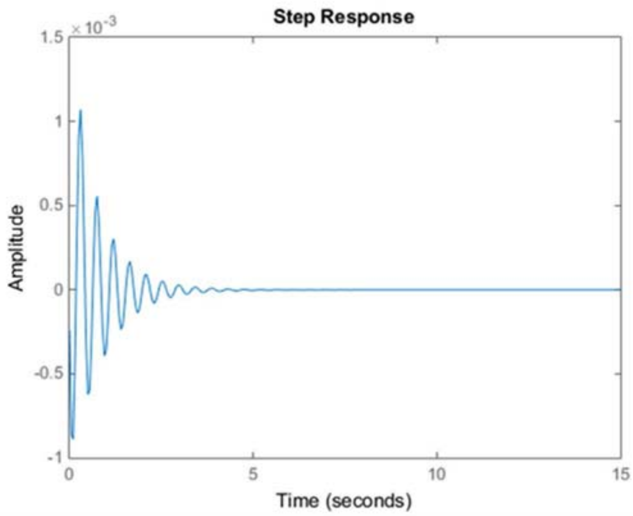

Figure 8. Closed-Loop Response with PID Controller for $c_1 = 1000$ [N*s/m]

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6. Conclusions

Active suspension systems can maintain the necessary stability and comfort due to the adaptability of the suspension according to the driving conditions.

In the present paper we presented the main types of active suspensions, and the model shown showed the efficiency of the active suspension using the Matlab computing program.

The analysis of the three diagrams resulted in the following conclusions:

- the damping time was reduced by about 30%
- the mass distribution m1 has considerably decreased

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