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IMPLEMENTATION SOLUTION FOR AN ACTIVE SUSPENSION SYSTEM FOR VEHICLES USING LINEAR ELECTROMAGNETIC ACTUATORS

C.G. JIPA[1] **C.A. STANCA**[1]

Abstract: *This paper presents a solution of the active suspension system for vehicles, using electromagnetic actuators. Compared to active hydraulic suspension systems, which have a greater reaction time and high energy consumption, the system presented has the advantage of better regulation dynamics as well as increasing energy efficiency with the possibility of energy recovery. In the paper is presented the concept but also its design and implementation on a demonstrator.*

Key words: *microcontroller, biaxial accelerometer, linear actuators, active suspension.*

1. Introduction

The suspension system is the most important part of the vehicle that influences the comfort of the passengers and the ability to keep the vehicle on the road. With increasing driving speeds, equipping vehicles with increasingly evolved suspension systems, capable of creating a vibration and noise ”barrier” between the running system and the body has become a necessity, especially since the speed on uneven roads is not limited by the performance of the propulsion system, but by the quality of the suspension [3].

The intelligence of a suspension system is characterized by the existence of a controller that takes data about the vehicle's dynamics and sends signals to the suspension system to improve the behavior (feedback control, which is missing in the case of passive suspensions) [3].

Suspension systems of vehicles can be classified into three categories:

a) passive suspension - includes all conventional suspension systems. The main feature is that once installed on the vehicle, the suspension parameters (hardness, ground clearance) can not be controlled from the outside [5];

b) semi-active suspension - this type of suspension includes a spring and an adjustable damper so that the energy storage and dissipation can be controlled [5].

c) active suspension - includes elastic and damping elements, along with drive systems (hydraulic engines, pneumatic engines etc.) [5].

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[1] Electronics and Computers Dept., *Transilvania* University of Braşov.

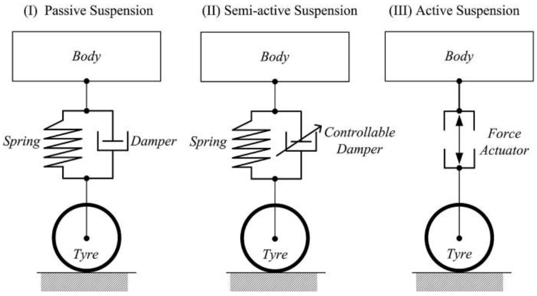

Fig. 1. *The main types of suspension* [1]

Automotive suspension was always a compromise. The manufacturers strive to set the suspension of vehicle for handling and comfort, incompatible features, otherwise.

The Table 1 shows some differences between the three types of suspension, implicitly their advantages and disadvantages [2].

Features of the main types of suspension Table 1

Parameter	***Passive Suspension***	***Semi-active Suspension***	***Active Suspension***
Structure	Very Simple	Complex	Simpler
Weight/ Volume	Very Low	Low	Very High
Cost	Very Low	Low	High
Ride Comfort	Bad	Medium	Very Good
Reliability	Highest	High	High

It follows from the above that passive suspension systems are less efficient, yet cheaper, so the choice of suspension will consider the compromise between quality and price.

2. Concept Presentation

Figure 2 shows the block diagram of the control system. The microcontroller is the core of the application. It receives information from the biaxial accelerometer about the direction of the acceleration (longitudinal or transverse) on the I^2C bus and generates corresponding commands to the actuator drivers.

3. Concept Implementation

3.1. Hardware System

a) The linear actuator shown in Figure 3 is in fact an electromagnet made of a cylindrical coil on a plastic insulating support having a ferromagnetic core on which is made the copper wire winding. In the extension of the coil core it is fixed a vertical plastic shaft on which a permanent ring magnet slides through which the chassis of the vehicle is pre-positioned and its linear displacement depending on the intensity of the magnetic field of the coil. When positioning the permanent magnet also contributes a spring of copper under the permanent magnet.

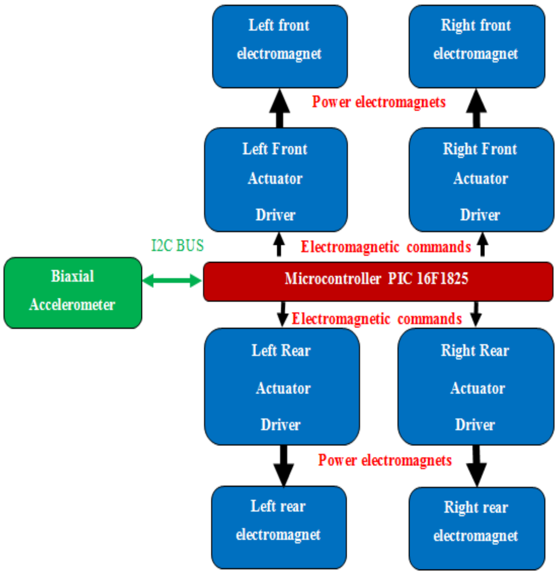

Fig. 2. *The structure of the control system*

b) The chosen microcontroller is PIC 16F1825, of its features, important for application are: power supply between 1.8-5.5 V; 14 digital pins; I^2C interface; PWM output.

Fig. 3. *Linear actuator*

c) Accelerometer MMA8452 (Figure 4), used to measure longitudinal and transverse accelerations, low-power, with 12-bit digital output, I^2C interface and power supply between 1.95-3.6 V.

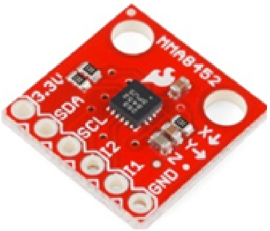

Fig. 4. *Accelerometer MMA8452* [4]

The system electronics, shown in Figure 5, were made on a test plate (Figure 6). The four transistors in the electronic circuit (Q1, Q2, Q3 respectively Q4 in Figure 5 - 1, 2, 3 respectively 4 in the assembly of Figure 6) are used to control the actuating coils (L1, L2, L3 respectively L4 in Figure 5), connected by the four connectors (J1, J2, J3 respectively J4 in Figure 5 - 6, 7, 8, 9 in Figure 6).

The connector 5 in Figure 6 is used to power the assembly with 12 V voltage. The system also contains the microcontroller U1 in Figure 5 - 10 in Figure 6, the integrated circuit XOR-NOT U2[A-D] in Figure 5 - 11 in Figure 6, the accelerometer 12 in Figure 6, the Schottky free-wheeling diodes D1, D2, D3 respectively D4 in Figure 5 - 13, 14, 15 respectively 16 in Figure 6, the voltage regulator LM7805 U4 in Figure 5 - 17 in Figure 6 and the parametric regulator for 3.3 V voltage consisting of R5 and D5 in Figure 5 - the group 18 in Figure 6.

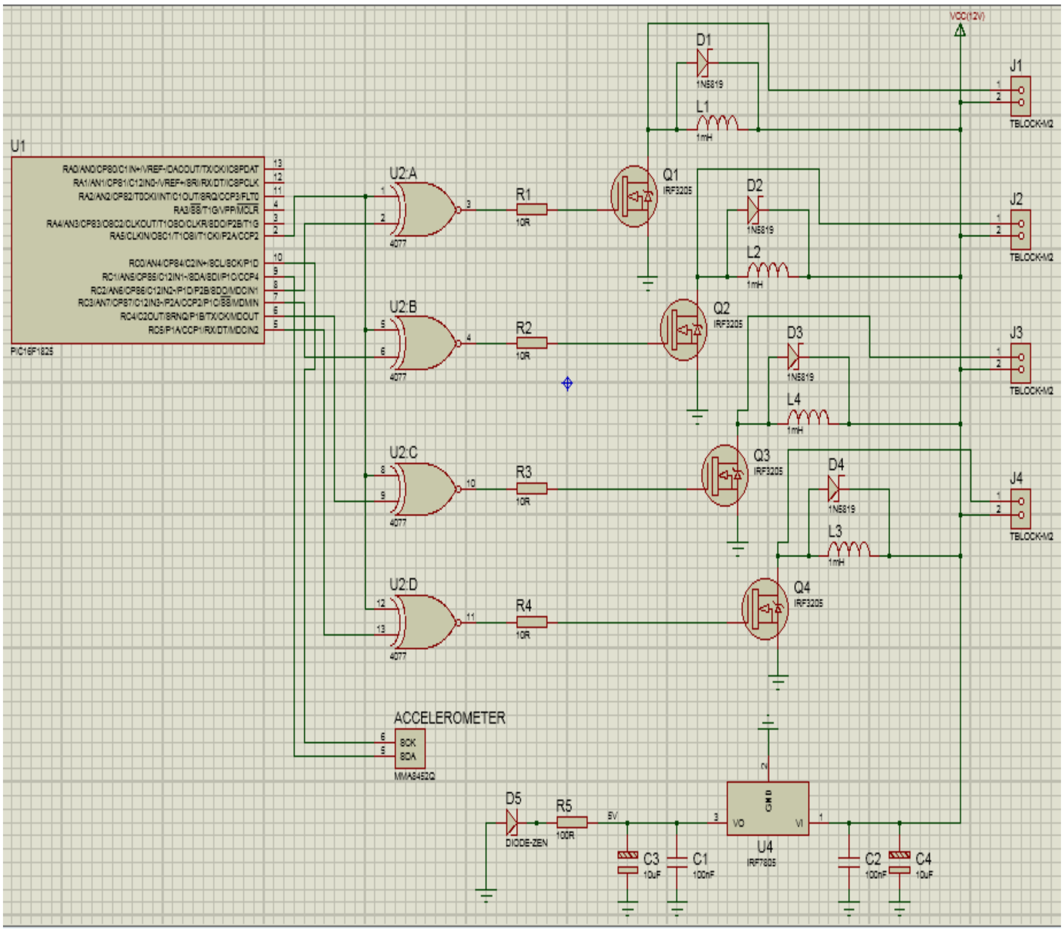

Fig. 5. *Electronic circuit diagram*

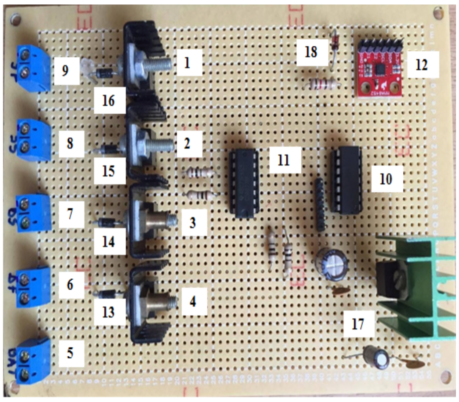

Fig. 6. *Test plate (front side)*

Figure 7 shows the whole system implemented on a demonstrator, in the program loading phase in the microcontroller's memory.

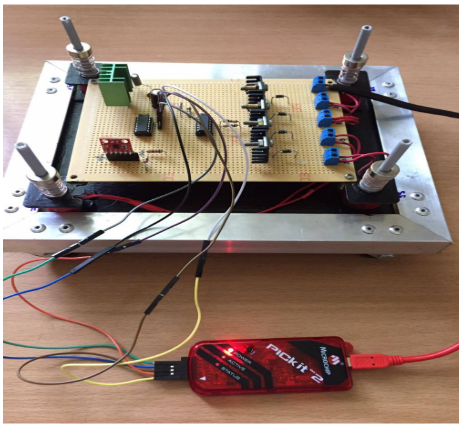

Fig. 7. The system's demonstrator

3.2. Software System

The control algorithm of the system is described in Figure 8.

The inclination of the vehicle on the Y and Z axes is determined successively, reading the value from the I2C bus to which the accelerometer is connected. Determination of non-zero values is marked by setting flags Fy respectively Fz in reading phase. Depending on the values of flags are properly control the actuators for the two axes. Actuators for each axis work complementarily; those from the acceleration arrow are commanded to rise, respectively the opposite ones to go down. This mechanism is simply implemented by the XOR-NOT gates (Figure 5). The equilibrium position is achieved with a 50% duty cycle (DC). Changing the position of the chassis respectively of the magnet in the actuator is achieved by increasing respectively decreasing this duty cycle proportional to the acceleration. In the case of combined accelerations, the change of the duty cycle is proportional to the average of the acceleration modules.

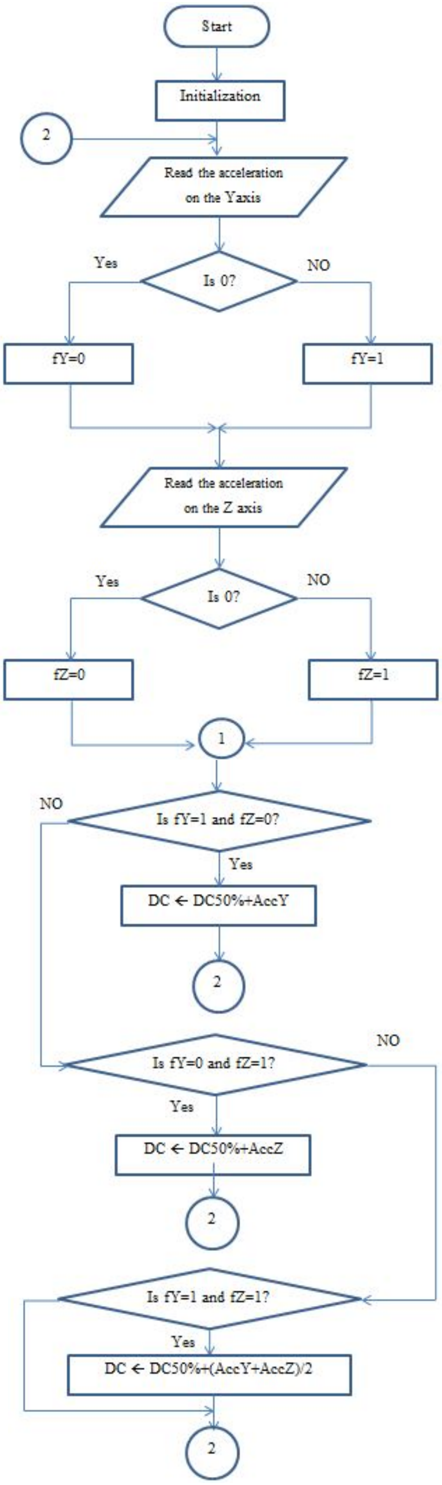

Fig. 8. *The control algorithm*
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4. Experimental Results

It was tested the system working for all possible situations: longitudinal accelerations/decelerations, lateral accelerations in both directions, combined longitudinal-lateral accelerations. The system worked correctly.

During the experiments, signals were sampled at different stages of development. For example Figure 9 shows the signals: SDA (Serial Data) signal on the I^2C communication bus data line (CH1 - yellow) and the PWM (Pulse Width Modulation) signal in the actuator equilibrium position (CH2 - blue).

Also, during the experiments, various permanent magnets were tested. Magnets initially used, of ferrite, had insufficient magnetic induction and therefore, were changed with some of the neodymium.

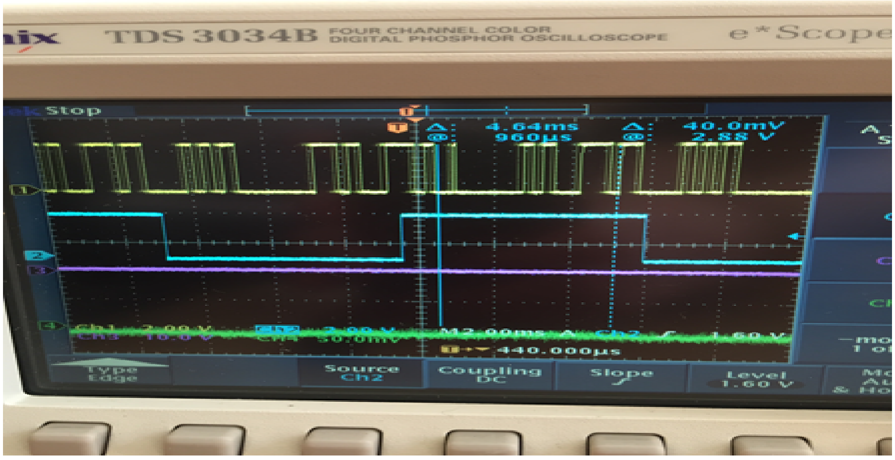

Fig. 9. *SDA and PWM signals for actuator in equilibrium position*

They have been tested several experimental damping systems:

1. Moving core electromagnet (nonlinear feature and small movement);
2. Air/Iron core electromagnet and permanent ring magnet that slides into a non-metallic tube (problems with permanent magnet position, which, because of the movements, it sat in the most convenient position - attracting) as in Figure 10;

Fig. 10. *Ring magnet in plastic tube*

3. Air/Iron core electromagnet and permanent ring magnet that slides on a non-metallic rod (final version), as in Figure 3. Initially, the supports on which the magnets slid were made of wood and were replaced later with plastic ones for better adhesion to the plastic material of the coil. To hold the magnets, in the case the coils are not powered, were used spiral springs of isolated copper.

5. Conclusions

The active suspension system is viable it works according to objectives. An improvement solution would be the use of countermagnets for prepositioning (establishing the equilibrium position) for active positioning using electricity, resulting saving energy.

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