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ADAPTIVE-PASSIVE CONTROL SYSTEM FOR HAND-ARM PROTECTION TO VIBRATIONS

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Abstract: *One of the major causes of professional diseases is related to the vibrations transmitted to the hand-arm system. Several studies have been carried out in order to get thorough knowledge of the phenomenon and to identify ways for reducing the vibrations level. Since 2002 the 44 EC Directive came into force, which imposes to the hand-tool manufacturers additional requirements for their products so that the vibrations induced to the human body to be within the accepted limits. This paper proposes a new system for protection to vibrations, based on piezoelectric sensors for signal acquisition, a fuzzy controller for signal processing and a magneto-rheological fluid absorber. It uses the adaptive-passive control strategy, combining the feasibility features of the passive control with the adaptability of the active control, using relatively small energy sources outside the system. At the same time, the solution may be implemented at a significantly smaller cost as the active control system.*
Keywords: *hand-arm vibrations, adaptive-passive control, fuzzy controller.*

1. INTRODUCTION

The presence of noise and vibrations within the common activities of humans has always represented a major problem. Starting from buildings and toward the electronic microscopes, continuing with aircrafts, sport equipment, satellites, vehicles, electrical transformers, bridges, manufacturing machine tools, etc., everything can be influenced by noise and vibrations in their normal operation and can influence, at their turn, the surrounding environment, generating professional diseases for humans working in this type of environment.

Hand-Arm Vibrations – known in the literature by the acronym HAVs – represent an important cause for professional diseases in the case of the persons working in vibration environment. Several studies related to the effects of vibrations upon the hand-arm system have been carried out, aiming to identify the ways of reducing the amplitudes or the vibration transmission to the human body [1]. One solution widely adopted is the use of anti-vibration gloves, which absorb the vibration energy. ISO Standard 10819 specifies the amplitude of vibration transmissibility to be achieved by the glove - measured for mid (16-400Hz) and high (100-1600Hz) frequencies. However, the anti-vibe gloves can get some impairment of dexterity, which makes them unusable for certain target groups, as dental technicians, for example. Another way for reducing the vibration level consists in redesigning the tool according to this requirement, which is also considered by the tools manufacturers, mainly since 2002 when the EC/ 44 Directive entered into force - concerning the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibrations) [2]. Still, the problem is not entirely solved, representing a challenge both for the tools manufacturers and for the employers that have to ensure a healthy working environment for their employees.

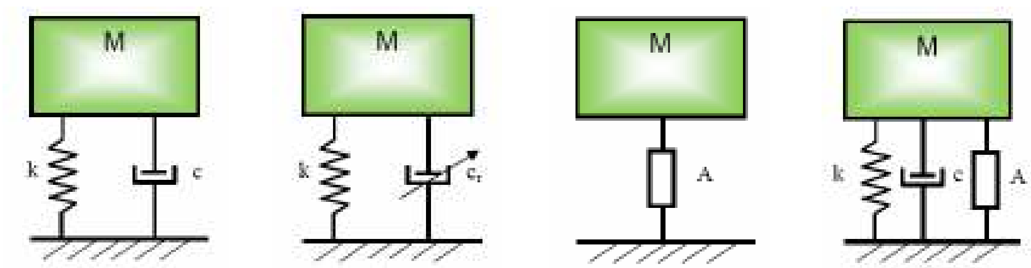
The vibration reducing process should take into account both the fulfillment of the operation conditions for the equipment representing the vibration source and the minimization of the negative effects the vibrations produce on the human body and surrounding environment.

It is nowadays admittedly the significant benefits of the vibrations reducing level: increased lifetime for products and systems, increased operating parameters for equipment, machines and tools, reduced noise and enhanced working conditions. Once identified the vibration source, the first step should be the system redesign and optimization by using the most convenient damping solutions.

Starting from the present situation, a research team form *Transilvania* University of Brasov has performed a thorough study for developing advanced models and systems for human body protection to vibrations, having the financial support from the Romanian National Council for Scientific Research (project A-393 CNCSIS). This paper presents the solution proposed by the authors regarding the design of a hand-arm vibration control system, based on fuzzy logic controller.

2. DIFFERENT TYPES OF VIBRATION CONTROL

Considering the type of structure and the type of vibrations the structure is subjected to, several control strategies may be adopted for vibration control [3]: a) – passive, b) – adaptive-passive, c) – active and d) – hybrid, Fig. 1.
The simplest, cheapest and most used solution is the *passive control*: the system consists of a mass *M*, a spring *k* and a damping element *c*. The vibrations level is reduced by energy dissipation as heat. The major drawback is related to their low performance due to the inability to adapt to perturbation or structural changes under operation conditions.



a) b) c) d)

Figure 1: Types of vibrations control strategies: a) – passive, b) – adaptive-passive, c) – active and d) – hybrid [3]

The *adaptive-passive control* system differs from the previous one by the damping element which is adaptable. The important advantages are given by: robustness, reliability, fully adaptive, do not induce addition energy in the system, need for low energy external sources as energy supply (i.e. batteries or accumulators), allow for applications of unconventional solutions.
The *active control* gives a very good adaptability but at a significantly higher price then the previous two systems. It consists of an inertial mass *M* and an actuator *A* which represents the real time regulator element for the vibration level. Still, its use on large scale is limited due to the following reasons: high complexity of the embedded systems, high cost, relatively reduced performance improvement comparing to the passive and adaptive-passive solutions, not straightforward programming, frequently need for adjusting of the electronic sub-system. However, during the last years, the development of the semiconductors industry and the progress registered in digital signal processing allow for rapid advance in the field of active control systems which are considered more and more as an alternative solution.
The hybrid control is a combination of passive and active control; the forces generated by the active system are more reduced since the vibration control is partly taken over by the passive system. The main advantage is the control energy – lower than in the case of active control but higher than the case of adaptive-passive control, since the forces generated by the actuator correct the forces developed in the passive devices, according to the selected control strategy.
The study of the different types of control strategies and systems leads to the conclusion that, except for the passive control, the other types need to identify the relation between the measured variables and the forces involved in the control process, according to the selected control strategy. Consequently, the control efficiency depends on the precision of the analytical model which describes the structure dynamic behavior and of the control devices. If a strict relation is considered between the monitoring variables and the forces generated for reducing of vibrations level, problems may occur related to the system reliability. The problems occur due to the high number of interventions in the control process per time unit or due to effects that negatively influence the structure dynamic behavior. Moreover, the above mentioned analytical relation between variables may be too complex to be precisely monitored by the control elements.
All these problems lead the attention of specialists toward unconventional methods for control strategies implementation, based on artificial intelligence, such as neural networks or fuzzy logic. The solution presented in the following paragraph takes into consideration these present trends.

3. THE ADAPTIVE-PASSIVE CONTROL SYSTEM

The design of the hand-arm vibration control system starts from the definition of the functions it has to fulfill: 1 - to acquire the information related to the vibrations – aiding the sensors; 2 - to process the data and take decisions – using the microcontroller; 3 - to command the system damping control for reducing the vibration level. As a result of the study of different control systems for vibration absorbers – passive, adaptive-passive and active, the adaptive-passive solution has been chosen, Fig. 2. It combines the feasibility features of the passive control with the adaptability of the active control, using relatively small energy sources outside the system. At the same time, the solution may be implemented at a significantly smaller cost as the active control system.

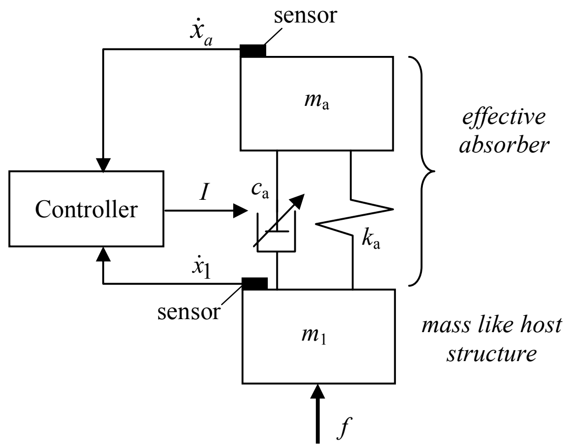


Figure 2: Adaptive - passive vibration absorber [4]

From the operational point of view, the adaptive-passive systems are divided in three categories [5]:

1 - Systems controlling the stiffness by the change of the controlled system eigenfrequency in terms of excitation value and/ or the frequency response function; this is done in order to eliminate the possibility of resonance irrespective of the excitation frequency. It is achieved by coupling / decoupling of elastic joints of different sub-assemblies of the controlled system.

2 - Systems controlling the inertial mass by the change of the controlled system eigenfrequency in terms of excitation value and/ or the frequency response function; this is done in order to eliminate the possibility of resonance irrespective of the excitation frequency. It is achieved by coupling / decoupling of additional masses of the controlled system.

3 - Systems controlling the damping by increasing the dissipated energy; this is achieved by coupling of additional damping elements which allow the controlled change of the dissipation capacity so that the response of the system to the excitation has minimum value. This category is used for the new vibration control system proposed and described in paragraph 4.

For all three cases described above, as for the passive control, the control forces are generated by the controlled mechanical system. The optimum stiffness, inertia or damping is real time selected, by a feedback process based on the information acquired from the sensors that measure the excitation and/ or the system response level. Therefore, the adaptive-passive control systems need for operation low energy supply (exterior to the controlled system).

4. MODELING AND SIMULATION

The proposed system uses piezoelectric sensors for signal acquisition, a fuzzy controller for signal processing and a magneto-rheological fluid absorber. The piezoelectric sensors are efficient, with simple construction and have a relatively low cost; the magneto-rheological absorber has the important advantage of a highly reaction time, which allow a real time control; the fuzzy controller is suitable for this type of applications, easy to program and giving reliable results.

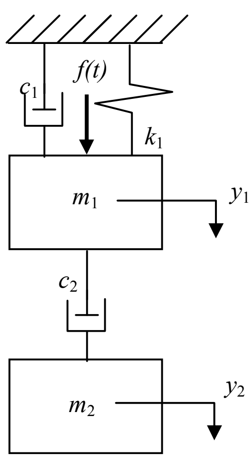


Figure 3: Dynamic model of the proposed system for hand-arm vibration control

The dynamic 2 degrees-of-freedom model consists of the masses m_1 and m_2, absorbers c_1 and c_2, and the spring, k_1, Fig. 3. It is described by the following system of equations:

$$\begin{cases} m_1\ddot{y}_1 + k_1 y_1 + c_1\dot{y}_1 + c_2(\dot{y}_1 - \dot{y}_2) = f(t) \\ m_2\ddot{y}_2 + c_2(\dot{y}_2 - \dot{y}_1) = 0 \end{cases}, \quad \textbf{(1)}$$

which can be written as:

$$\begin{cases} \ddot{y}_1 = \dfrac{1}{m_1}\cdot\left[f(t) - k_1 y_1 - c_1\dot{y}_1 - c_2(\dot{y}_1 - \dot{y}_2)\right] \\ \ddot{y}_2 = -\dfrac{1}{m_2}\cdot c_2(\dot{y}_2 - \dot{y}_1) \end{cases} \quad \textbf{(2)}$$

The system simulation has been performed using Matlab-Simulink. For the force *f(t)* a Dirac function has been generated.

For the Fuzzy controller, the membership functions defined are presented in Fig. 4 and Fig. 5. The input variable is considered the displacement of mass 2 and the output variable is the current intensity, I, which will influence the damping of the magneto-rheological absorber.

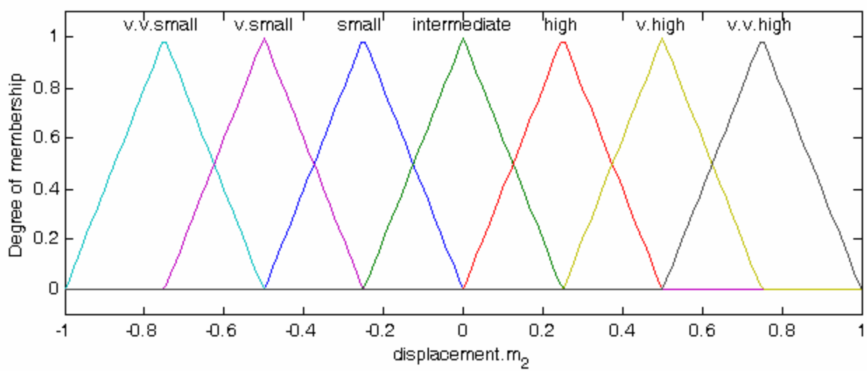


Figure 4: Membership function for input variable

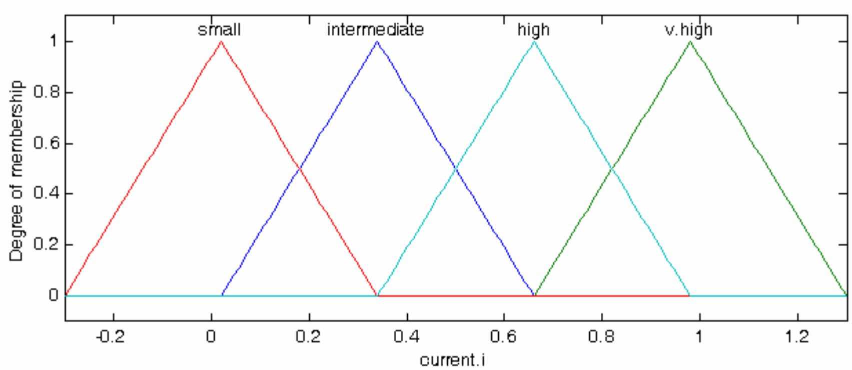


Figure 5: Membership function for output variable

The following rules have been defined:

1. If(*displacement.m_2* is v.v.small)then(*current.i* is v.high)
2. If(*displacement.m_2* is v.small)then(*current.i* is v.high)
3. If(*displacement.m_2* is small)then(*current.i* is v.high)
4. If(*displacement.m_2* is intermediate)then(*current.i* is v.high)
5. If(*displacement.m_2* is high)then(*current.i* is high)
6. If(*displacement.m_2* is v.high)then(*current.i* is intermediate)
7. If(*displacement.m_2* is v.v.high)then(*current.i* is small)

The block diagram of the state-space equations is presented in Fig. 6 – for the uncontrolled system and in Fig. 7 – for the adaptive-passive controlled system.

The adaptability feature of the adaptive-passive control systems depends on the control strategy. Another important advantage is that, unlike the active control systems, they do not determine the controlled system instability – in the sense of limited input – unlimited output.

In the last years these systems are more and more appreciated by the specialists due to their ability to combine the best anti-vibration properties of the passive and active systems, so that they reach and even pass the active systems performances related to the controlled reducing vibrations level process for a large range of structural dynamic loads.

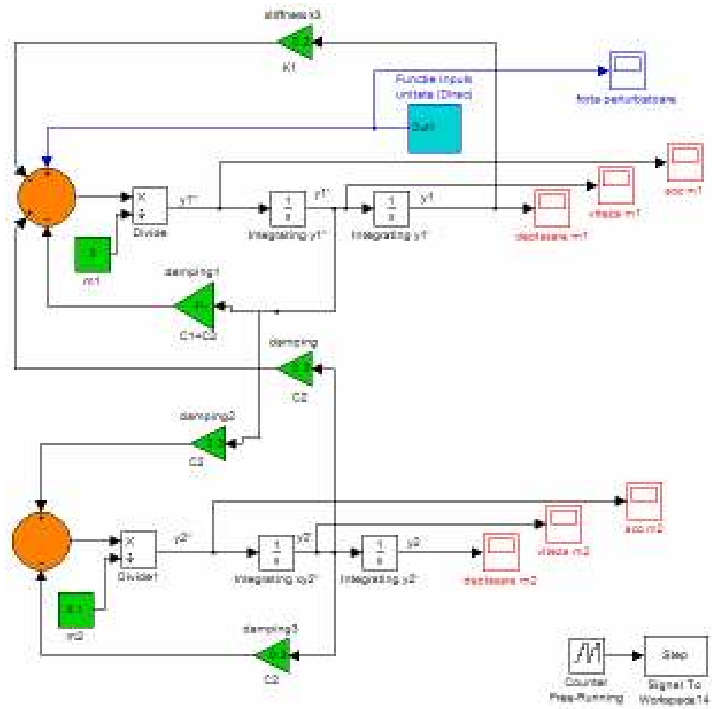


Figure 6: The block diagram of the state-space equations describing a 2 dofs uncontrolled system

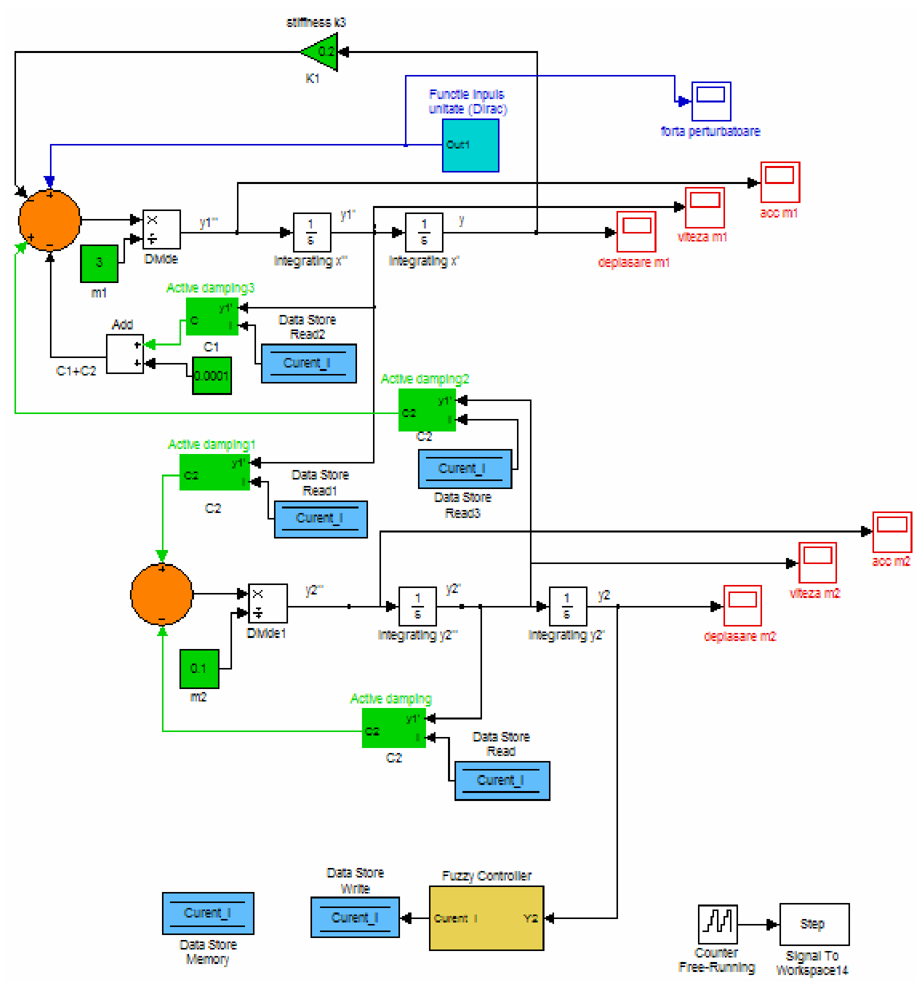


Figure 7: The block diagram of the state-space equations describing a 2 dofs system controlled with a Fuzzy controller

The results are presented in Fig. 8, for mass m_1 and Fig. 9, for mass m_2, in both cases: without control and with the use of a Fuzzy controller.

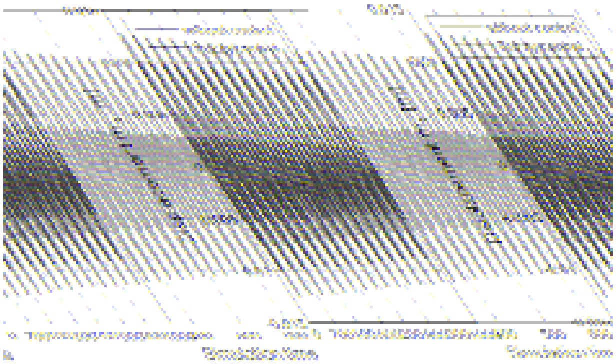


Figure 8: Displacement of mass m_1

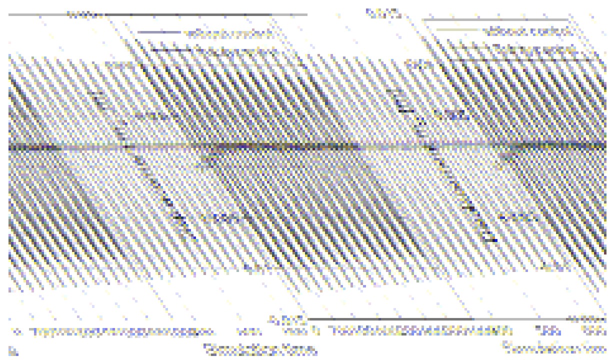


Figure 9: Displacement of mass m_2

5. CONCLUSION

The results obtained by simulations lead to the conclusion that the adaptive passive control system based on fuzzy controller may represent a solution for the hand-tool manufacturers interested to redesign their products for vibration level reduction. The piezoelectric sensors are efficient, with simple construction and have a relatively low cost; the magneto-rheological absorber has the important advantage of a highly reaction time, which allow a real time control; the fuzzy controller is suitable for this type of applications, easy to program and giving reliable results. At the same time, the solution may be implemented at a significantly smaller cost as the active control system.

6. ACKNOWLEDGEMENT

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