XXIV Symposium *Vibrations in Physical Systems,* Poznan – Bedlewo, May 12-15, 2010

Magnetic Levitation of a Light Cylindrical-Shape Mass with Control of Damping of the Transition-State Vibrations

Paweł OLEJNIK
Department of Automation and Biomechanics, Faculty of Mechanical Engineering of the Technical University of Łódź, 1/15 Stefanowski St., 90-924 Łódź, Poland
olejnikp@p.lodz.pl

Jan AWREJCEWICZ
Department of Automation and Biomechanics, Faculty of Mechanical Engineering of the Technical University of Łódź, 1/15 Stefanowski St., 90-924 Łódź, Poland
awrejcew@p.lodz.pl

Abstract

Development in the direction of future applications of fast and accurate position control systems used in optoelectronics, computer hardware, precision machining, robotics and automobile industry stimulates high engagement in creation of non-conventional implementations [1, 2]. The work presents a numerical analysis devoted to that domain basing on a non-contact (frictionless) fixing of some cylindrical-shape's mass in an alternating magnetic field. These considerations precede identification of electromagnet parameter and created by it magnetic field in the real experimental realisation of the problem shown on a photo in Fig 1. The mass levitates in field generated by the electromagnet's system sourced by voltage of 12V. Next to the numerical algorithm of voltage feedback there has been even used a modified PID control [2] of transition state's oscillations of the levitated light mass that are recorded until it reaches the stable equilibrium position. Results of the experiments have been presented on time-history charts of $h(t)$ displacement measured between themselves faced surfaces of the electromagnet's core and surface of the levitated mass.

Keywords: decaying vibrations, magnetic levitation, numerical control, experimental rig

1. Introduction

Magnetic levitation is a known topic and can be realised in some ways [3, 4] but the most visual effects can be observed after utilization of an electromagnet made of superconductor.

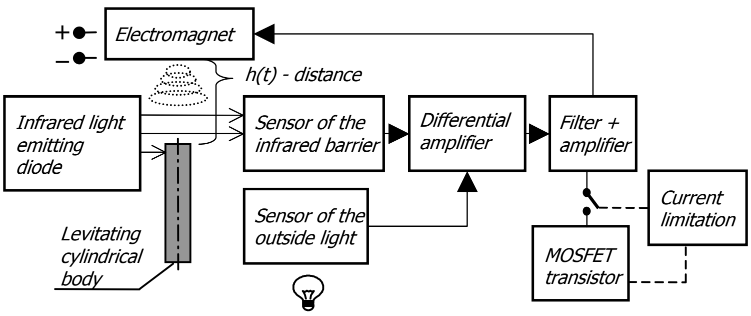

Figure 1. A schematic block diagram of the hardware, signal connections and the levitating solid body.

In a simpler way of creation of a system for examination of levitation's phenomenon one can use a system with infrared light's sensor that traces position of the levitated mass (barrier) placed in the magnetic field generated by the electromagnet.

For the purpose of the experiment presented here the role of sensor is played by the infrared light barrier that monitors actual position of the cylindrical mass. A schematic view of the experiment is shown in Fig. 1.

2. The Analysed System

Electronic part of the system uses two light-sensitive resistors of which the first one acts together with infrared light-emitting diode as a simple barrier tracing the cylindrical solid body's position. Because of existence, in the surrounding space, of many infrared light emitting sources like sun or light bulbs (producing disturbance signals to the barrier) the second one measures the amount of light coming into the system from surrounding space. When the barrier's sensor is partially illuminated (a result of covering of it by the levitating body) then a voltage difference appears and is inputted to the differential amplifier for generation of another value of voltage sourcing the electromagnet's circuit. Experimental realisation of the diagram presented in Fig. 1 has been shown in Fig. 2.

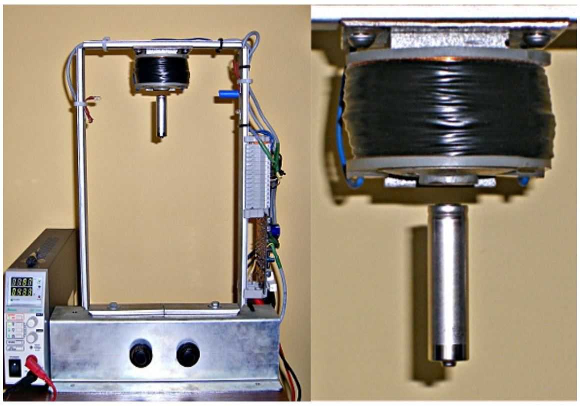

Figure 2. Experimental setup of the control system of the levitating cylindrical light mass (constructed by Piotr Jędrzejczyk, student of the second degree studies at the Faculty of Mechanical Engineering).

The system shown in Fig. 2 can be modelled (in a simplified dimension) by the dynamical system of three first-order differential equations (1) describing motion of the mass levitating in magnetic and gravitational fields and the voltage equation for the electric circuit with alternating current. One distinguishes the following meaning of the system state's vector $\boldsymbol{x}$: $x_1 \rightarrow h$ displacement of the levitating mass measured downward from the electromagnet's surface, $x_2 \rightarrow dh/dt$ corresponding velocity of the displacement, $x_3 \rightarrow i$ electric current in the electromagnet's electric circuit.

$$\dot{x}_1(t) = x_2(t),$$
$$\dot{x}_2(t) = g - \frac{k}{m}\left(\frac{x_3(t)}{x_1(t)}\right)^2 + u(t)\,|_{1case}, \qquad (1)$$
$$\dot{x}_3(t) = \frac{1}{L}\big(v(t)\,|_{2case} - Rx_3(t)\big),$$

where electrical and physical constants are as follows: L =0.002H is the coefficient of inductance, R =0.29 Ω – the coefficient of resistance, k =10^{-4} kg·m^2/C^2, C – the magnetic flux, m = 0.0226 kg – mass of the levitating body.

3. Two Cases of the Numerical Control

Voltage $v(t)$ and force excitation $u(t)$ are the two control signals. They are considered in two separate cases, namely: 1) $u(t)$ is a feedback from position h in the system with *PID* controller having the transfer function $PID(s) = k_P+(s+k_I)/s+k_Ds$ inserted to the first axis of the block diagram shown in Fig. 3, while $v(t)$, a voltage source remaining constant at 12V; 2) the time-dependent control input voltage in Laplace representation $V(s) = -((k_1+k_2s+k_3s^2)H(s) - k_1h_0)$ to the analysed dynamical system working as the plant in the closed-loop control system with feedback from full state-vector (numerical model of the control strategy has been shown in Fig. 4). Disturbances coming from any external light sources have been neglected.

Both presented numerical models include characteristics of operation of the infrared light barrier $IRR(t) = 1-b_{IRR}h(t)^{-2}$. This approximation with b_{IRR} dumping (sensitivity) constant measures the amount of the infrared light transferred from the emitting diode to the light-sensitive resistor with presence of the levitating body working as the barrier.

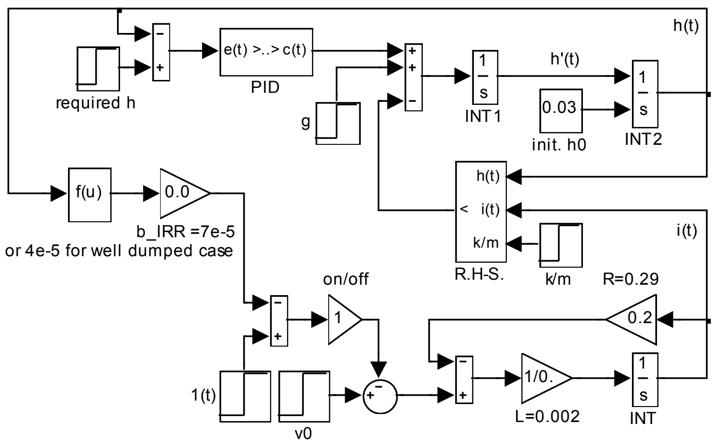

Figure 3. Feedback from displacement of the levitating mass in *PID* control for k_P = 250, k_I = 800, k_D = 13.

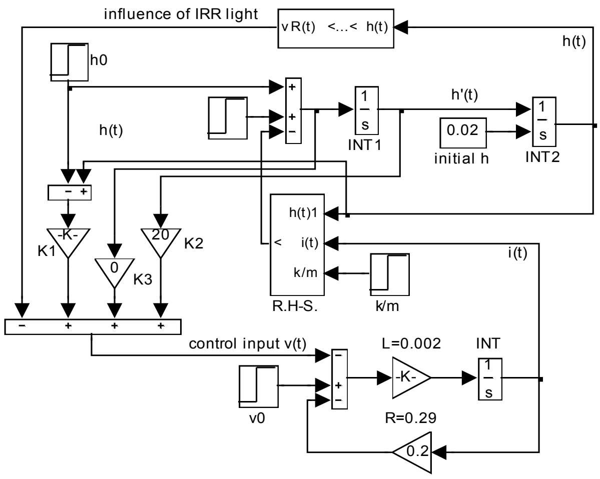

Figure 4. Closed-loop input voltage control with a usage of full state-vector feedback for $k_1 = 10^3$, $k_2 = 20$, $k_3 = \{0.0, 0.2\}$ in a model made in Simulink.

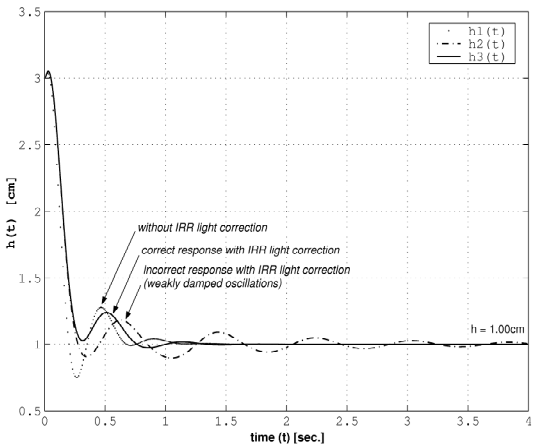

Figure 5. Time-histories of $h(t)$ obtained from the diagram shown in Fig. 3 for different values of the infrared light's barrier factor $b_{IRR\{1,2,3\}}$ = {IRR off, $0.7 \cdot 10^{-4}$, $0.4 \cdot 10^{-4}$} in the closed-loop position feedback control and for $h_0 = 3$cm.

In Fig. 5 there is visible a well-founded effect of introduction of the infrared light barrier. The case, for a short interval of values of the IRR factor has been described as the correct one being more realistic in relation to the motion of mass *m* observed on the experimental rig. Conducting this experiment one tries to hang the mass at height h_f =

1cm with the initial condition $h_0 = 3$cm. It is visible that the mass is quickly attracted to the steady-state position but it is achieved in a different manner.

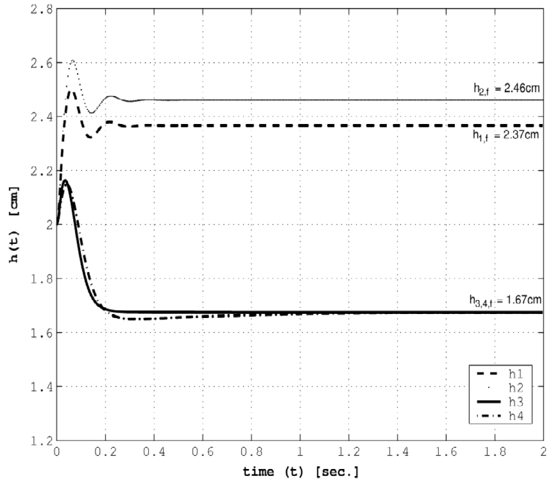

Figure 6. Time-histories of $h(t)$ evaluated from the diagram visible in Fig. 4 for different values $b_{IRR\{1,2,3\}}$ = {7, 0.7, 22.2}$\cdot 10^{-4}$ corresponding to $h_{\{1,2,3\}}$ (for $k_3 = 0$), respectively. Infrared light's sensitivity factor $b_{IRR\{4\}} = b_{IRR\{3\}}$ (for $k_3 = 0.2$), and $h_0 = 2$cm.

Frictionless oscillations in the transition to stable position can be pretty damped (see Fig. 6) with the use of the second case of the control strategy that bases on a feedback from the full state's vector as it has been shown in Fig. 4. For a different initial position ($h_0 = 2$cm) of mass m there is visible a quicker (because of voltage but not external force feedback as examined in the first approach) and better dumped attraction of the mass to the steady-state position. With respect to application of a different method of control (with a control with feedback to the voltage time variable input v) the whole system is characterized by a slightly different dynamics so the position of convergence changes with assumption of bigger values of $b_{IRR\{1,2,3\}}$ ={7, 0.7, 22.2}$\cdot 10^{-4}$. Factor $b_{IRR\{3\}}$ is the highest available here and the control nicely fixes the levitating mass at $h_3 = 1.67$cm. At this position the stabilized voltage sourcing the electromagnet equals 13.66V. Time-history of h_4 in Fig. 6 is the unnatural effect of the non-zero coefficient of feedback from acceleration ($k_3 = 0.2$, see Fig. 4). Desired position is achieved in about 1.2 sec., and it confirms, the vector component of feedback from acceleration is not necessary in this application.

4. Conclusions

Dependently on the presence of IRR light's barrier and values of its sensitivity factor (b_{IRR}) there can be distinguished various shapes of the step response. The convergence is quite fast and well-damped when the IRR light's correction exists, and moreover, takes a correct value of its significance. A choice of the incorrect value of b_{IRR} reflects in bringing the mass into a small-amplitude weakly-dumped oscillations around its desired steady-state position. At some conditions such effect of oscillations is observable on the real laboratory rig and is undesirable when one needs to fix the levitating mass at a constant height. Therefore, the introduced feedback from the infrared light barrier with mass *m* working as the armature of the electromagnet makes sense. Better shapes of characteristics of the transition to steady-state responses have been confirmed by the second strategy. They are faster, more stable, and no oscillations have been reported after examination of system parameters. Magnetic field has allowed for elimination of any kinds of friction that are usually necessary in various realisations of fixings. Our experimental investigations will turn to identification of electro-magnetic parameters of the whole mechatronic system and the associated magnetic field. It should help in improvement of numerical adequateness of the presented approach as well as improvement of the tested strategy of control.

Acknowledgments

This paper has been financially supported by Master Program of the Foundation of Polish Science and the grant of the Ministry for Science and Higher Education for years 2010-2012.

References

1. J. Ackermann, *Robust control,* Springer-Verlag, 1993.
2. M. Aliasghary, et al., *Sliding mode control of magnetic levitation system using radial basis function neural networks,* IEE XPlore, RAM (2008), 467-470.
3. A. Green, K.C. Craig, *Robust, design, nonlinear control of magnetic-levitation systems*, Journal of Dynamics, Measurement and Control **120**(4), (1998), 488-495.
4. A. Piłat, *Active magnetic suspension and bearing. Modeling and simulation*, InTech Education and Publishing, Vienna, (2008), 453-470.

Lewitacja Magnetyczna Lekkiej Masy o Kształcie Cylindrycznym z Kontrolą Tłumienia Oscylacji Stanu Przejściowego

Rozwój w kierunku przyszłych aplikacji szybkich i dokładnych układów pozycjonujących stosowanych w optoelektronice, sprzęcie komputerowym, obróbce precyzyjnej, robotyce czy też przemyśle samochodowym wzmaga wysokie zaangażowanie w tworzenie implementacji niekonwencjonalnych. Praca przedstawia analizę numeryczną dotyczącą tego obszaru zastosowań bazującą na bezkontaktowym podwieszeniu pewnej przewodzącej masy o kształcie cylindrycznym w zmiennym polu magnetycznym. Rozważania te poprzedzają identyfikację parametrów elektromagnesu oraz wytworzonego przez niego pola elektromagnetycznego na rzeczywistym stanowisku doświadczalnym pokazanym na fotografii na rysunku 1. Masa lewituje w polu magnetycznym generowanym przez układ elektromagnesu zasilany napięciem 12V. Algorytm numeryczny obok sprzężenia napięciowego zawiera także zmodyfikowaną kontrolę typu *PID* oscylacji w stanie przejściowym lewitującej masy o mały ciężarze poprzedzającym osiągnięcie przez nią stabilnego położenia równowagi. Wyniki tych doświadczeń pokazano na wykresach czasowych przemieszczenia $h(t)$ zmierzonego pomiędzy skierowanymi do siebie powierzchnią rdzenia elektromagnesu i powierzchnią lewitującej masy.