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Nonlinear PID and Sliding Mode Control applied to a New Generation of Micro-Pump for Small Satellites

E. Hristea, H. Siguerdidjane, A. Arzandé, J-C. Vannier

CentraleSupélec, 91192 Gif-sur-Yvette, France
(emails: {houria.siguerdidjane, amir.arzande,jean-claude.vannier}@centralesupelec.fr)

Abstract: The aim of this paper is to emphasize the studies carried out for the new generation hydrazine pump system in term of nonlinear control in order to simplify the existing controllers that have been designed for this system. It consists of a classical PID structure based on a nonlinear feedback function which allows having a simple control input on the device. Our purpose is thus to implement a relatively simple controller on the new hydrazine pump to make it reliable and cost-effective.

Keywords: Hydrazine pump, non-linear PID control, sliding modes control, small Satellite

1. INTRODUCTION

Satellites launching are more and more numerous and their number do not stop to increase. So, it becomes necessary for engineers to develop some techniques which allow, first to decrease satellite's size and second to attain very long lifetime in order to reduce the costs of launching and of operating of satellites. To obtain these performance many efforts are made on practical and theoretical research related to the space vehicles. In this research work, we are interested in small satellites propulsion system. From now, the consummation of gas is not optimized especially when the tank is running out of gas. As a matter of fact satellites cannot operate whereas the gas reservoir still contains some gas. Indeed, when the level pressure is below a given value, it is not possible to use the propulsion system even though the tank is far from being empty. So a part of the satellite's weight is superfluity. Moreover, the fact that the satellite cannot be controlled increases the risk that the satellite deviates from its orbit. Too much weight and a deviation from an orbit are economically dramatic for a small satellite and must be absolutely avoided.

Therefore, the aim of this paper is to emphasize the studies carried out for the new generation pumps in term of non-linear control in order to simplify the existing controllers that have been proposed for this system. It consists of a non-linear controller which is derived from method based upon sliding mode theory combined with a PID structure. In doing so, it allows having a simple control input on the pump. In previous work, it has been described the technology of the actuator and some non-linear controllers. But, the expression of the command was too difficult for a cost effective implementation.

The paper is organised as follows. Section 2 describes the basic principal of the hydrazine pump. Section 3 is a brief reminder of the modelling which has already been published (Vannier et *al.*, 2005), this is for the reader convenience. Section 4 describes the nonlinear control based on sliding mode method and the PID structure and the results of the numerical simulations. Section 5 gives a simplification in order to implement easily an inexpensive controller on the device.

2. THE MICRO PUMP SYSTEM

2.1 Brief description of the system

The particular structure of the electromechanical actuator has first been presented in (Dugué *et al.,* 2001) and we will briefly describe it here for the sake of completion. The actuator is composed of two parts: the first one is fixed and consists of an electromagnet, supplied through a coil of n turns, placed perpendicular to the magnetic field. Employing an electromagnet opens the possibility to have a magnet with a variable magnetic field. When a current flows through the coil, a magnetic field is built up from which it results a magnetic force. The second one is formed of a moving circular diaphragm, namely a disk of thickness a with a hole in its centre where the pump axis is rigidly fixed. In addition, the actuator structure exhibits a rotational symmetry. The concept of the micro pump is based on the electromagnetic actuator by which it is possible to move the piston forward and backward (due to the fluid pressure) along the pump axis and thus transferring fuel with a desired frequency from a main reservoir to a secondary tank. The position of the running piston, in other words the air gap thickness, in normal functioning mode should be in the range of 0 to a few mm. A simplified scheme is illustrated in Fig. 1.

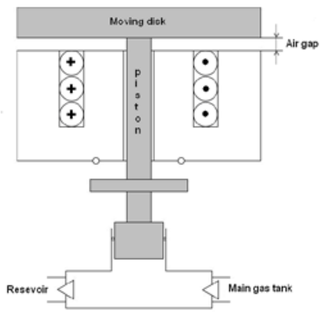

Fig. 1. Actuator scheme

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The magnetic core material of the actuator has been chosen in such a way that the magnetic flux passes through the coil with a sufficiently high frequency for the pump flow as well as a relative good amplitude level of the magnetic field, that is in order to provide the force capable to drive the axis micro pump. All the studies concerning the materials, the calculation of the different forces involved in this system together with the physical constraints, the induced voltages and current levels have been carefully carried out and described in previous work (Dugué *et al.*, 2001) where the reader may also find the explanation of the particular arrangement choice of the system. The resulting prototype of the pump is shown in Fig. 2.

Fig. 2. Prototype of the micro pump

2.2 Mathematical modelling

We can dissociate the system into two coupled subsystems, a mechanical one and an electromagnetic one. By applying the fundamental principle of dynamics, we obtain the equation describing the mechanical dynamics as follows

$$m\frac{d^2x}{dt^2} = -F_{mag}(x,i) + F_f + F_{ext} \tag{1}$$

Where x denotes the air gap, $F_{mag}(x,i)$ is the electro-magnetic force which is a function of the air gap and current through the coil i, F_f is the viscous friction force and F_{ext} represents the external force due to the gas pressure. The electrical subsystem dynamics is given in (2) by applying Faraday's law

$$u = Ri + \frac{d\Phi(x,i)}{dt} \tag{2}$$

Where R represents the electrical resistance of the actuator's coil and $\Phi(x,i)$ is the magnetic flux in the centre of the core. Its total derivative with respect to time is

$$\frac{d\Phi(x,i)}{dt} = L(x,i)\frac{di}{dt} + \frac{\partial L(x,i)}{\partial x}\frac{dx}{dt}i \tag{3}$$

Using the method of the virtual magnetic energy as described in (Vannier *et al.*, 1999) we can express the magnetic force as a function of the inductance $L(x,i)$

$$F_{mag} = \int_0^i \frac{\partial L(x,j)}{\partial x} j dj \tag{4}$$

Using expressions (1) – (4) we can write the dynamical equations of the system in the following nonlinear state-space representation, using $X = [x, v, i]^T$ as state vector

$$\begin{cases} \dot{x} = v \\ \dot{v} = \dfrac{1}{m}\left[-\displaystyle\int_0^i \frac{\partial L(x,j)}{\partial x} j dj - \lambda v + F_0 - Kx\right] \\ \dfrac{di}{dt} = \dfrac{1}{L(x,i)}\left[u - Ri - \dfrac{\partial L(x,i)}{\partial x} vi\right] \end{cases} \tag{5}$$

In the above equation we have used a simple model for the viscous friction $F_f = -\lambda v$. λ is a constant, the external force due to the gas pressure may be modelled as a constant plus an elastic component $F_{ext} = F_0 - Kx$, K is a constant parameter, which approximates the compression of the gas in the pneumatic capacity and also models the elastic constant of a laminar spring which is present in the prototype. From the design of the actuator (Dugué et *al.*, 2001), measurements of the magnetic force, the inductance and the current in the windings versus the air gap are provided. In order to obtain $F(x,i), L(x,i)$ a finite element magnetic analysis was performed and the results are shown in Fig. 3 for the magnetic force, in Fig.4. for the inductance and Fig. 5 shows the partial derivative of the inductance with respect to the air gap.

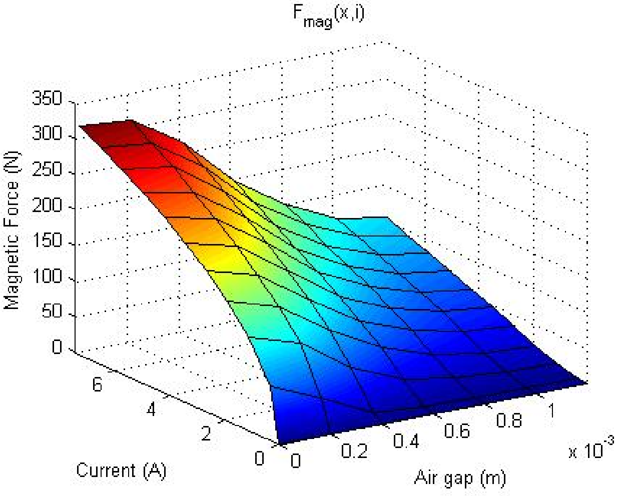

Fig. 3. Magnetic force as a function of air gap and current

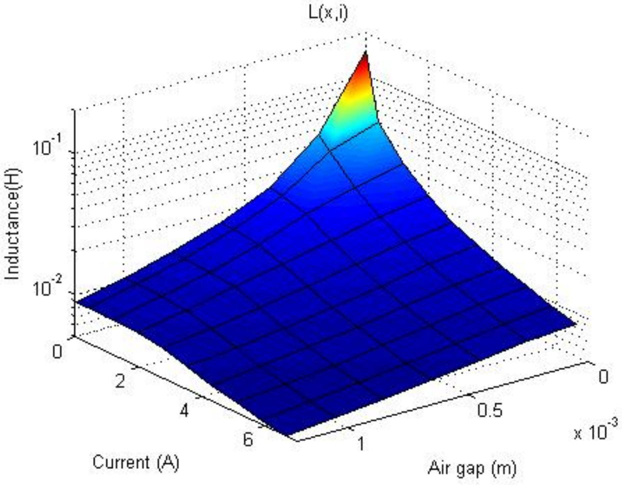

Fig. 4. Inductance as a function of air gap and current