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Control of a non-linear vacuum system through a PID controller

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Abstract

In this work obtaining and validating of a mathematical model of a plasma nitriding vacuum system is presented. The developed model is based on the analogy of a vacuum system with an electrical circuit. The model was performed with the aim to use it for the design and implementation of a Proportional Integral Derivative control algorithm. It has been demonstrated that this algorithm, which is based on the simulation on MATLAB Simulink, is suitable to the pressure control in the nitriding vacuum chamber.

Keywords: Vacuum system; system modelling; electrical circuit analogy; MATLAB Simulink; PID algorithm.

1. Introduction

Plasma nitriding is a technique based on glow discharge electrical phenomena, which is commonly used to improve the surface properties of several components and metallic parts used mainly in equipment and industrial machinery. Through this thermo-chemical treatment it is possible to increase the life time of these

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parts by increasing the surface hardness, the wear resistance and in some cases the corrosion resistance according with Dutrey et al. [1].

Plasma nitriding process is characterized to be a clean technology because the use of a N_2 / H_2 glow discharge at vacuum pressure. David Pye [2] mentions that additional to this advantage, this process promotes the minimum volumetric distortion of the pieces as well as the high control of the processing parameters to obtain specific characteristics on the surface of the pieces.

The process is carried out in a vacuum chamber with a controlled atmosphere of Nitrogen (N_2) and Hydrogen (H_2) in a range of $1.33x10^2$ y $1.33x10^3$ Pa. The work piece is heated about 500°C and it is maintained constant during the process. Pessin et al. [3] indicate that in these conditions a plasma discharge is performed by the application of a pulsed voltage of direct current about 800 V of amplitude between the chamber (anode) and the work piece (cathode).

Chirino Ortega et al. [4] mention that the stability of the vacuum pressure in the processing chamber is critical because the plasma discharge characteristics depends on it and Shoaib, et al. [5] relate this pressure with the mechanical properties obtained on the work piece.

This is why it is necessary to add a pressure control system in the chamber to regulate the pressure for different conditions of gas flow of entrance. To implement a control algorithm for the system is required to have an approximation of the model of it and after that, proceed to design the controller based on the validated model; the modeling of a system to design a closed loop control is essential in the theory of control.

There are mainly three ways to obtain a model: a) by physical laws, b) by parameter identification methods and sometimes c) by both techniques: Passino-Yurkovich [6]. To use physical laws is necessary to know the system, its components and the mathematical relationships between them, nevertheless sometimes is difficult to obtain the model when disturbances exists, belonging to the process or not. By the other hand, in agreement with Rodriguez-López [7] the parameter identification requires to obtain experimental input and output data to apply one of the existing methods such as least square and its variants, stochastic approximation, instrumental variation, and so on.

In this work the model of the vacuum system of a plasma nitriding process and the design of a digital PID controller is presented. The equipment of the nitriding process was designed and currently it is under construction in the Corporación Mexicana de Investigación en Materiales, COMIMSA.

The model was obtained using a technique based on the comparison between an electrical network and the vacuum system components used by Pasquino et al. [8]. This method takes into account the similarity between the laws of voltages in an electric circuit and the pressures in a vacuum system, and it has the advantage of the existence of many programs of circuit analysis according with Ernst [9].

To finalize the control loop, a digital PID algorithm was implemented to the control elements: a butterfly valve moved by a step motor and a roots vacuum pump varying its speed. The main idea of this work is to demonstrate that with an appropriate and validated mathematical model of the system, it is possible to use it for the design of a simple controller.

2. Design

With the aim to obtain the system model, the basic principles of the electric circuit and the vacuum system have been analyzed.

2.1. Electrical circuit

The main components of an electrical passive circuit are the resistive, capacitive and inductive elements and a power supply. When the circuit is energized, an electrical current flows through the elements, in the