SYSTEM IDENTIFICATION VIA ARX MODEL AND CONTROL DESIGN FOR A GRANITE BENCH AT SIRIUS/LNLS*

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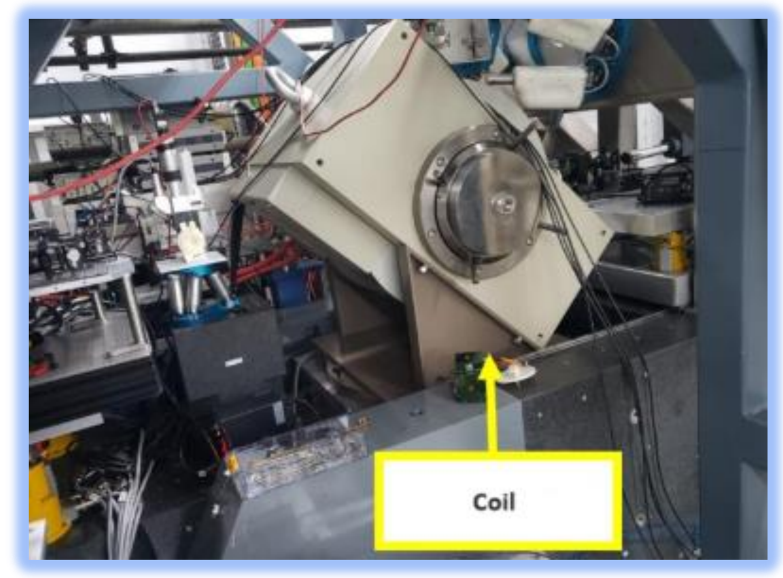
Abstract

Modern 4th generation synchrotron facilities demand mechatronic systems capable of fine position control, improving the performance of experiments at the Beamlines. In this context, granite benches are widely used to position systems such as optical elements and magnetos, due to its capacity of isolating interferences from the ground. This work aims to identify the transfer function that describes the motion of the granite bench at the EMA Beamline (Extreme conditions Methods of Analysis) and then design the control gains to reach an acceptable motion performance in the simulation environment before embedding the configuration into the real system, followed by the validation at the beamline. This improvement avoids undesired behaviour in the hardware or in the mechanism when designing the controller. The bench, weighting 1.2 tons, is responsible by carrying a coil, weighting 1.8 tons, which objective is to apply a 3 T magnetic field to the sample that receives the beam provided by the electrons accelerator. The system identification method applied in this paper is based on the auto-regressive model with exogenous inputs (ARX). The standard servo control loop of the Omron Delta Tau Power Brick controller and the identified plant were simulated in Simulink in order to find the control parameters. This paper shows the results and comparison of the simulations and the final validation of the hardware performance over the real system.



Expectations

The main expectation of this work is to provide a method to find control gains in order to stabilize critical systems, such as the granite bench at the EMA Beamline – one of the most critical granite benches due to the weight of the scientific equipment that it carries. Guaranteeing a stable movement in terms of transient and stationary motion is ubiquitous to preserve the integrity of the mechanism. Also, the development of a methodology to tune the controller responsible by guaranteeing such unprecedent safety applications is essential when dealing with critical scientific equipment, as the validation in the simulations environment avoids the test of gains that belong to a specific numeric range that can be dangerous to the system.

Hardware and Signals

In a summarized way, the block diagram that represents the system is:

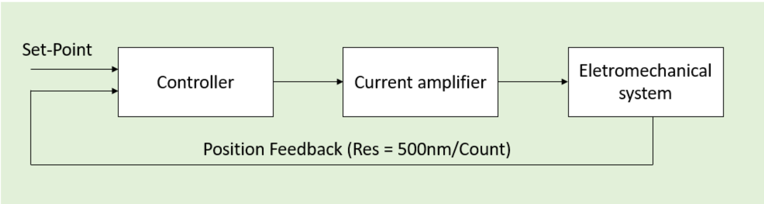


Figure 1: Representation of system (hardware + eletromechanical).

Inside the PBLV and the motor, the two currents have 90º between each other. The general amplitude is configurable by the user using the native PBLV** code. The general amplitude – which will be called as I_g – keeps the following relation the same during all motion:

$$\sqrt{I_a[k]^2 + I_b[k]^2} = I_g$$

By acquiring the two currents, it is possible to build an complex current $I[k]$ – in which j is the imaginary unit – that has the following format in the k-th instant:

$$I[k] = I_a[k] + j \cdot I_b[k]$$

Note the modulus of $I[k]$ is equal to I_g, $\forall k > 0$. In the k-th instant, it is possible to build an extra variable – which will be called in this work as *electric angle* – , which can be represented by the following relation:

$$\varphi[k] = \tan^{-1}\left(\frac{I_b[k]}{I_a[k]}\right)$$

*** PBLV: Power Brick LV Controller, the hardware responsible by controlling the bench.*

Identification: ARX Model

The autoregressive model with exogenous inputs can be expressed by the following generic transfer function:

$$y[k] = \frac{B[q]}{A[q]} u[k]$$

Indeed, they have the following format:

$$A(q) = 1 - a_1 q^{-1} - a_2 q^{-2} - \cdots - a_m q^{-m}$$
$$B(q) = b_1 q^{-1} + b_2 q^{-2} + \cdots + b_n q^{-n}$$

Note the functions $A(q)$ and $B(q)$ have orders m and n, respectively. Their coefficients are meant to be estimated. Also, the operator q representes a delay:

$$u[k]q^{-n} = u[k-n]$$

Identification: parameters estimation

To cover a calculation example of the parameters estimation, let it be assumed that $m = 2$ and $n = 1$. Then:

$$A(q) = 1 - a_1 q^{-1} - a_2 q^{-2}$$
$$B(q) = b_1 q^{-1}$$

Bringing the delay operator to the discrete time, the relations turn into:

$$y[k] = a_1 y[k-1] + a_2 y[k-2] + b_1 u[k-1]$$

This equation represents a causality between the input and the output, as it depends only on past values. For example: in the instants $k = 3$ and $k = 4$, the relation is, respectively:

$$y[3] = a_1 y[2] + a_2 y[1] + b_1 u[2]$$
$$y[4] = a_1 y[3] + a_2 y[2] + b_1 u[3]$$

The identification by the application of the ARX model must find the coefficients a_1, a_2 and b_1 that represent as good as possible the behavior of the plant. If the last relation is extrapolated to a set of N samples, starting by $k = 3$, it can be written in a matrix form:

$$y[3,4,\ldots,N] = \begin{bmatrix} y[2] & y[1] & u[2] \\ y[3] & y[2] & u[3] \\ \vdots & \vdots & \vdots \\ y[N-1] & y[N-2] & u[N-1] \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ b_1 \end{bmatrix}$$

In which y and u are data acquired by the controller. The relation can be expressed by:

$$y = \Psi \Theta$$

In which Ψ is called regressors matrix and Θ is the vector of coefficients to be determined. To properly find the coefficients vector, the pseudo-inverse matrix is necessary: (in which Ψ' is the transpose of the matrix Ψ)

$$\Theta = (\Psi'\Psi)^{-1}\Psi' y$$

Experiment

Apply a smooth movement using controller's IDE

Collect data and bring to Matlab

System identification via ARX model (automatic function provided by Matlab)

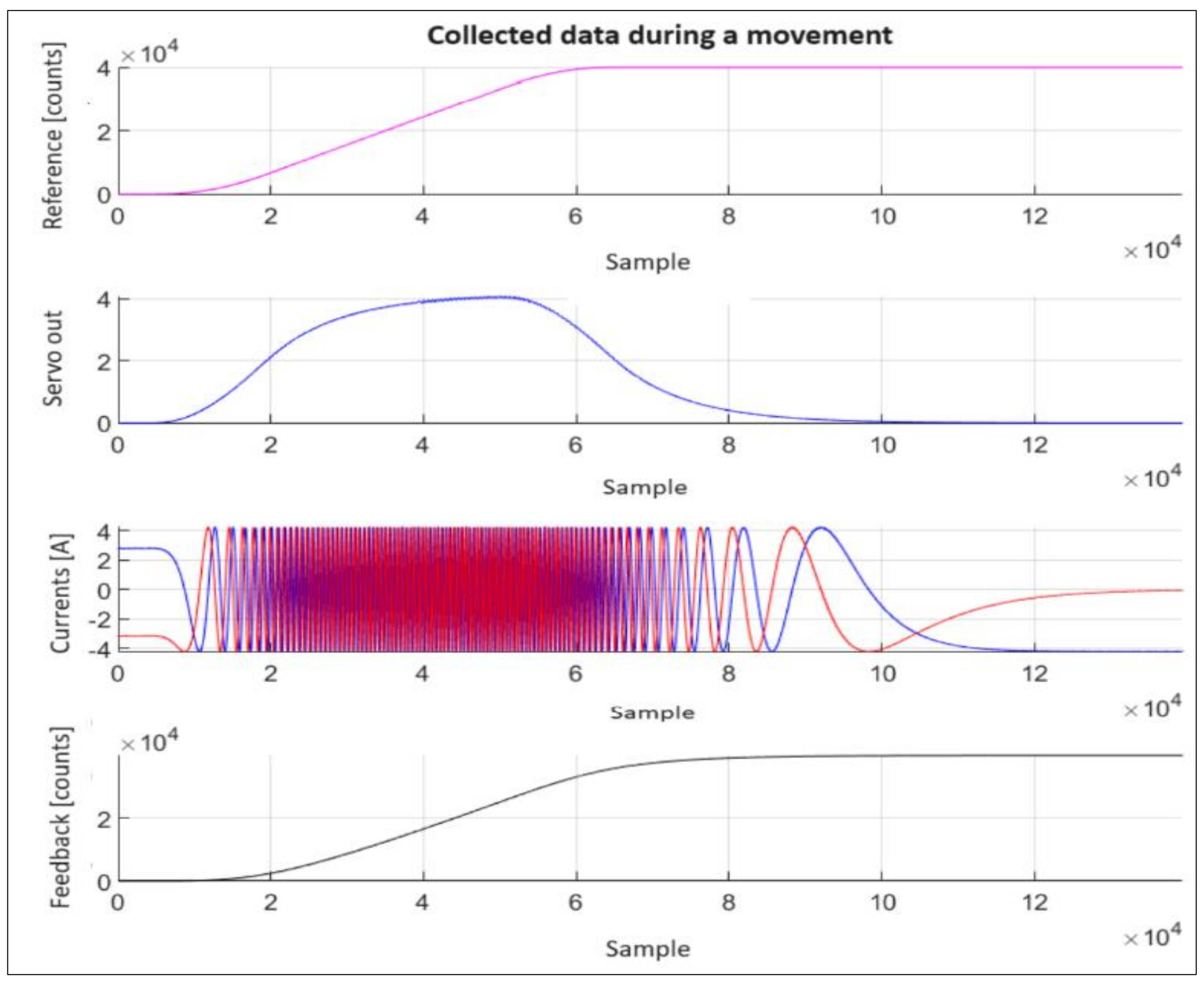


Figure 2: Experiment to collect data: currents, servoOut and feedback.

Controller design

Bring controller and identified plants to Simulink

Test several gains and choose the best

Simulation with best gains found in Simulink

Embed gains into PBLV

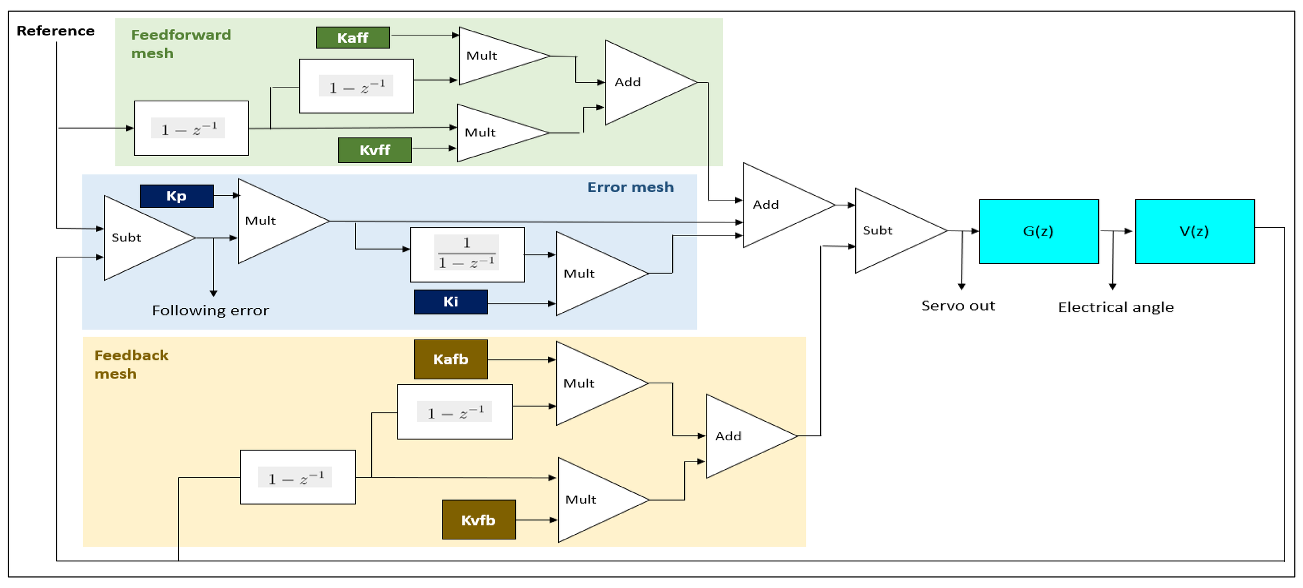


Figure 3: Block diagram containing controller and identified plants.

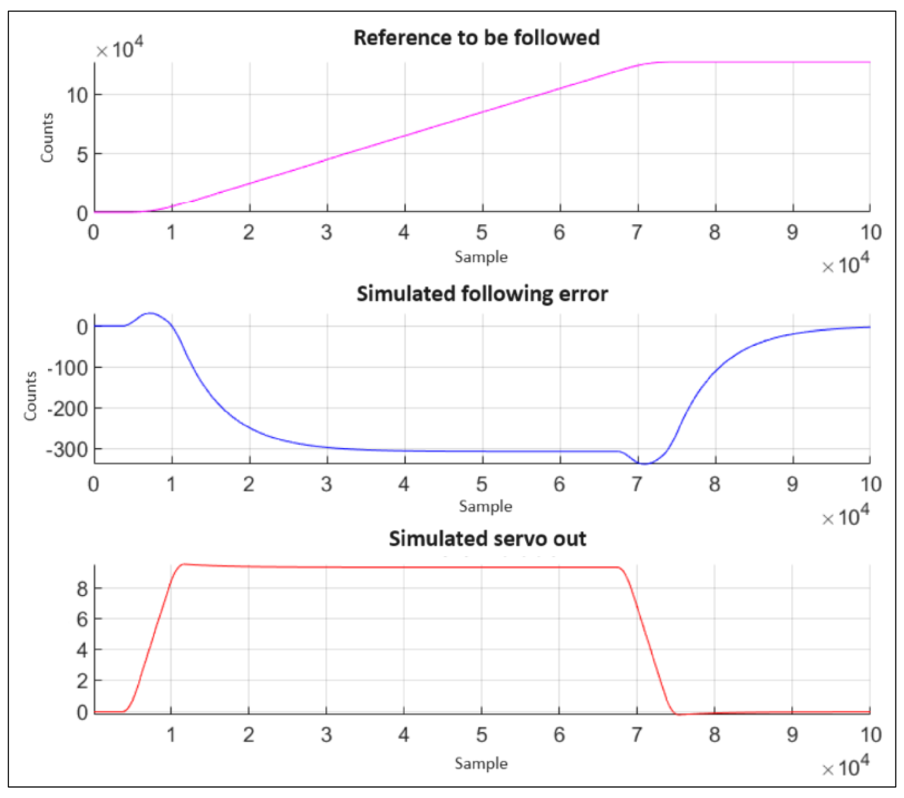


Figure 4: Simulated results after controller design.

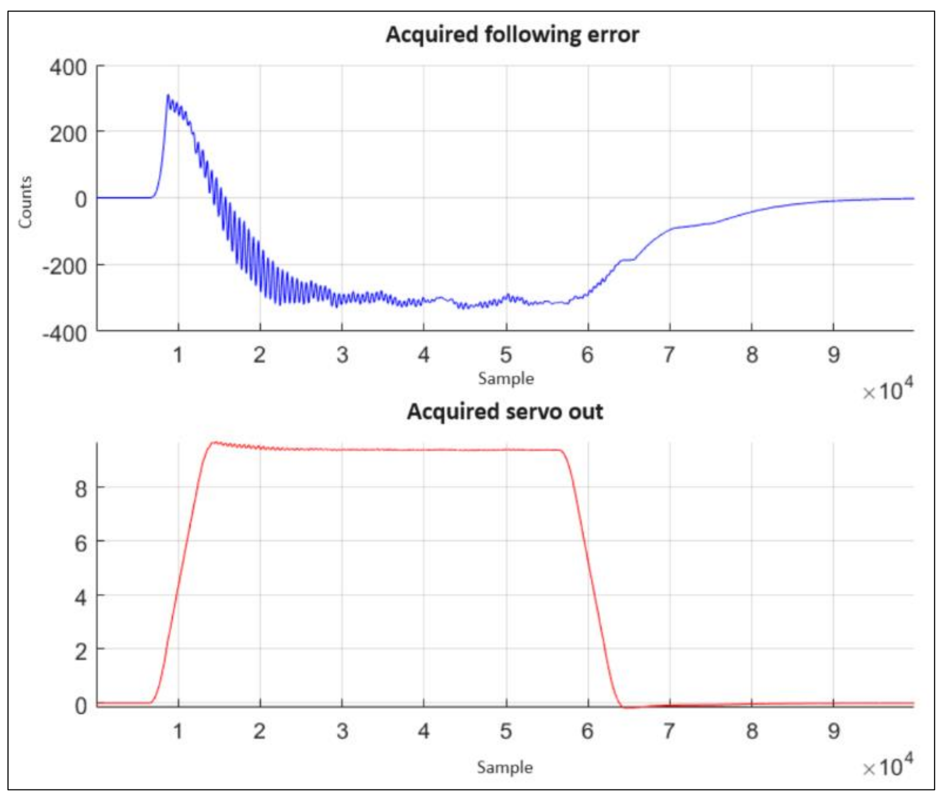


Figure 5: Real acquired results.

Acknowledgement

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