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MODELING AND CONTROL OF A GANTRY CRANE SYSTEM

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Abstract: *Gantry cranes are a well-known system for transportation of large equipment in the industry. The automation of the transport process is necessary to improve the productivity inside a plant, as a large period of time in the production process is occupied by the transport of the raw materials. Replacing human operator with automatic control ensures lack of sway in the load and a maximum speed of transportation, as it will be shown in the experimental part.*
Key words: *gantry crane, control, modeling, reference profiling, anti-sway.*

1. INTRODUCTION

The cranes are machines which are used for moving loads from one point to another in a minimum time so that when the weight reaches the destination there is no sway of the load. Usually a trained human operator makes this operation. During handling, the weight can make swinging motions. If the swinging exceeds a certain limit it is necessary to counteract the movement or even to stop the whole process until the weight settles. Both operations are time consuming, slowing down the production process. Therefore, many researchers searched methods to stop the sway.[1]

Crane operations can be divided into five stages as follows: gripping, lifting, transportation from one point to another, down and release. The operation that consumes the most time in the transport cycle is the transport. There are research directions regarding the full automation of the process but most of the researches are made to lower the time when the weight is transported from one place to another.

Usually the controller attached to the crane has to ensure the control of two phenomena: cart translation in order to get the most accurate positioning of the load and the sway control, in order not to let the weight oscillate. In the papers mentioned above, both the cart positioning and the sway control is made simultaneously, but there are researches that separate the two phenomena, using two feedback controllers.[2] The controller used for the translation movement can be a classic PD control or a fuzzy control.[3] Similar, fuzzy control can be used for anti-sway movement, as well as delayed position feedback controller.

Trajectory optimization is the process of designing a trajectory that minimizes or maximizes some measure of performance within prescribed constraint boundaries. While not exactly the same, the goal of solving a trajectory optimization problem is essentially the same as solving an optimal control problem.[4]

2. MODELING OF A GANTRY CRANE

The mathematical models of the systems can be obtained based on analytical approaches (using physics laws) or by experimental approach. Concerning the analytical approach, dependencies between the physical variables of the system are determined, mathematical equations are obtained such as algebraic equations, differential, partial derivatives, finite differenced equations etc. Determining the mathematical model implies using both theoretical and experimental procedures; high efficiency is obtained using the both procedures sequentially.

The experimental approach has as purpose obtaining a mathematical model based on measuring the input/output signals. A priori knowledge of the process is used, obtained based on theoretical analysis or by previous measurements then the input and output signals are measured and through an identification procedure the link between the measured variables is established. The inputs may be the ones from normal functioning or can be introduced artificially.

For a gantry crane system the model is determined using Lagrange formalism. In figure 1, a schematic of the gantry crane is presented.

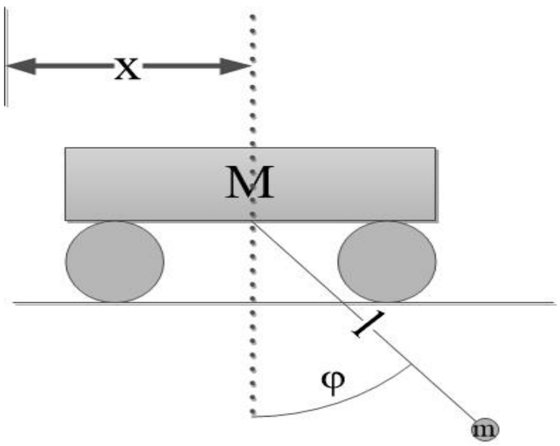

Fig. 1. Gantry crane schematic

The kinetic energy is determined by equation 1.

$$\mathrm{T} = \frac{1}{2}M\dot{x}^2 + \frac{1}{2}m(\dot{x}^2 + 2\dot{x}\dot{\varphi}l\cos\varphi + \dot{\varphi}^2\dot{l}^2) \quad (1)$$

The potential energy is given by equation 2.

$$V = -mgl\cos\varphi \quad (2)$$

Building the Lagrangian accordingly to [5] the following equations of movement are obtained:

$$(M+m)\ddot{x} + ml(\ddot{\varphi}\cos\varphi - \dot{\varphi}^2\sin\varphi) = F \quad (3)$$

$$\ddot{x}\cos\varphi - \ddot{\varphi}l - g\sin\varphi = 0 \quad (4)$$

The equations show the dependency between the cart acceleration and the weight angle. It is proven that the sway is only influenced by the length of the wire or rod and by the acceleration of the cart.

Considering the swing of the weight nonexistent during the movement (therefore the angle φ is zero) and taking into account the small angles approximations, we can approximate the state space equation as shown in equation 5.

$$\frac{d}{dt}\begin{bmatrix} x \\ \dot{x} \\ \varphi \\ \dot{\varphi} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & \frac{mg}{M} & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & -\frac{g}{l}(1+\frac{m}{M}) & 0 & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \varphi \\ \dot{\varphi} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{M} \\ 0 \\ -\frac{1}{Ml} \end{bmatrix} F$$

$$y = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \varphi \\ \dot{\varphi} \end{bmatrix} \quad (5)$$

Using Matlab environment, the equations were implemented and the mathematical model was compared with a simulation of the physical model made in SolidWorks. In figure 2 the comparison between the simulated system and the mathematical model is shown.

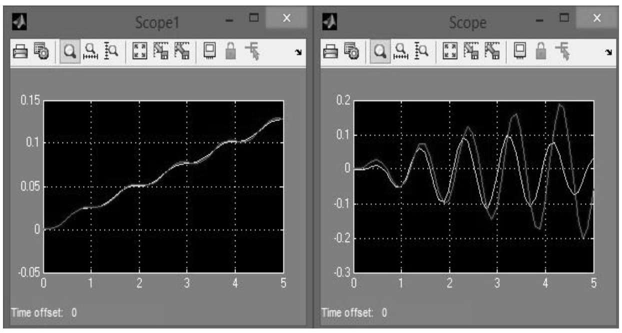

Fig. 2. Simulation and mathematical model output

On the left side of the figure, the positions determined by the equation and by the simulation are identical. On the right side the angle output of the mathematical model is similar with the simulated output, thus validating the mathematical model.

Having the mathematical model we can now develop control strategies that may be afterwards implemented on the real system.

3. CONTROL OF A GANTRY CRANE

To prove the relation between the cart acceleration and the weight swing, an experimental stand is created to permit the control and command of a cart on a translation axis and to be able to read the angular position from an encoder. Therefore the system in figure 3 was proposed.

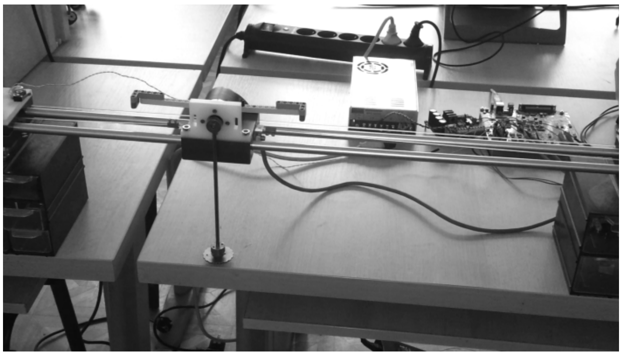

Fig. 3. Experimental setup

A Bühler motor is chosen and a wire transmission is developed. At full power, the cart's speed is 0.37 m/s. The power supply delivers 24V and 14.6A, ensuring the necessary power for the motor. For the motor command an EM160 motor driver is used, that is specially designed for positioning systems. Having installed the quadratic control, it has the possibility to accelerate and to break in both directions. For the angle measuring system an Elcis I44EA industrial encoder is used.

The encoder can deliver 10000 impulses on a full rotation, ensuring a very good resolution in order to track the sway of the weight. For the data acquisition a DaqBoard 3000USB was used. The board ensures two encoder ports and many digital and analogical inputs and outputs in order to gather data from the system and to send the command to the driver motor.

A graphical user interface was built for the data to be plotted and for manually command the system. The system response for a step signal is presented in figure 4. As it can be seen, the weight oscillations amplify at the end of the positioning.

As it can be seen, the reference and position overlap exactly, but at the start of the movement the weight oscillates very much (10 degrees).

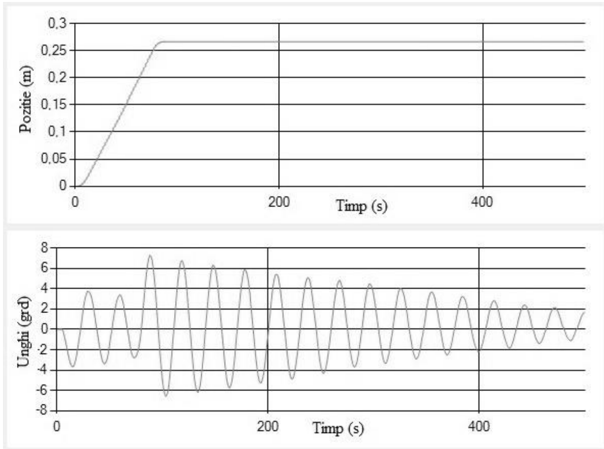

Fig. 4. Amplified oscillation of the weight

In order to achieve a good reference following, a feedforward control was applied.

Applying the controller to the system, the system behaved as shown in figure 5.

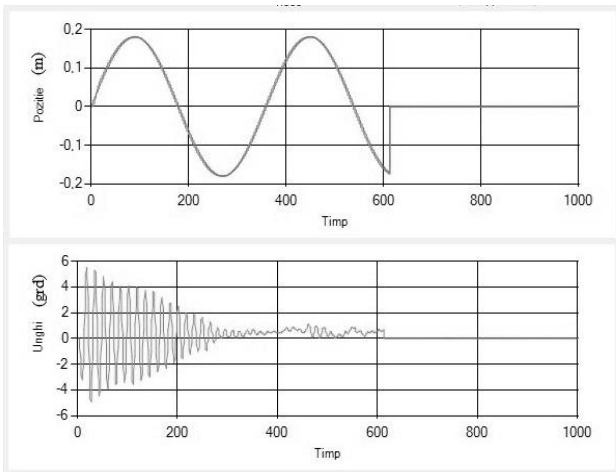

Fig. 5. Sine reference and angle output

Therefore a trajectory of the acceleration was imposed.[6] Designing a trapezium shaped acceleration reference is necessary due to the fact that step signal acceleration induces shock in the system. In figure 6, as it can be seen, the amplitude of oscillation if a trapezium shape is imposed is of only 0.8 degrees.

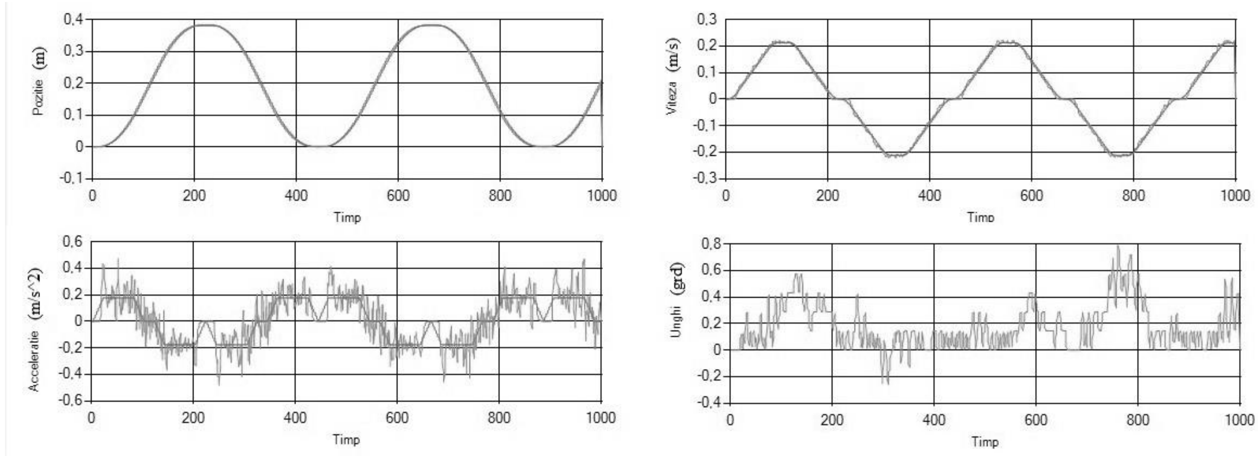

Fig. 6. Trapezium imposed trajectory on acceleration

4. CONCLUSIONS

Gantry crane systems are used in almost every transportation operations of a company. Improving operating times by making the transportation process autonomous is a good way to reduce the dead time in the production process. Trajectory optimization is a good way to avoid the shocks inserted by acceleration and provide good results as shown in the experimental part. Imposing a trajectory on acceleration improves the operating times and lowers the oscillations of the weight.

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Modelarea si controlul unui sistem de tip macara portal

Rezumat : Macarale portal sunt un sistem bine-cunoscut pentru transportul de echipamente grele în industrie.Automatizarea procesului de transport este necesară pentru a îmbunătăţi productivitatea în interiorul unei fabrici,deoarece o perioadă mare de timp din procesul de producţie este ocupat de transportul materiilor prime. Înlocuirea operatorului uman cu control automat asigură lipsa oscilatiilor echipamentului transportat şi o viteză maximă de transport, aşa cum se va arăta în partea experimentală.

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