3D Tower Crane as a mechatronic tool for education

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***Abstract*—The paper presents a laboratory model of the 3D tower crane. The arm of the crane is approx 1.2m long and the model is approx. 1.5m heigh. The crane is equipped with three DC motors that control: the rotary movement of the tower, the movement of the trolley and up and down movement of the load. The model is equipped with an unique unit for measuring an angle position of the load. The paper contains description of some mechanical solutions as well as results of chosen experiments. Some aspects of appliance in education are discussed.**

Keywords-component; 3D crane, mechatronic model, real-time control,

I. INTRODUCTION

The laboratory model, presented in the paper was designed and constructed on the basis of the experience, gained by the authors during designing and building up a mechatronic models of a gantry crane and a 3DOF manipulator[5][6][7]. The aim was not to build a copy of any existing industrial equipment, although received a laboratory model reflects many of the phenomena occurring during a transport of a suspended load [2][3].

Cranes type of the tower, in opposite to the gantry cranes work mainly outdoor, where cargo is moved at high altitudes, or when a terrain is rough, and even moving. The most often it is used in: building construction sites, ports and vessels.

A work of cranes is seriously dependent on weather conditions, especially on a wind speed. Extremely difficult place to work are vessels, where in addition to a strong wind come also disturbances caused by the rocking board of a ship [4].

Presented the laboratory model allows to familiarize with: a complexity of controlling such object, designing, developing, implementation and testing control algorithms in real time. The RT-DAC board [9] allows to execute algorithms in the MATLAB&Simulink environment in real time. The results of the experiments may be observed directly on MATLAB scopes. The system also allows to test real time control parameters by the possibility of setting a sampling time, and the frequency, the control is generated

II. GENERAL OVERVIEW

Figure 1 presents a general view of the model. The crane may hoist or lower a suspended payload and also to move the payload along the rail and around the basis. The crane is controlled in real time in the MATLAB & Simulnk environment. A control PC computer is equipped with an analog-didgital borad (RT-DAC USB [9]) that mediates in an exchange of data between the controlled object and a controller running on the PC machine. Digital outputs of RT-DAC are connected to the crane power interface, where the calculated by the control algorithm value of control is converted into a PWM type voltage signal and then distributed to an appropriate DC motor.

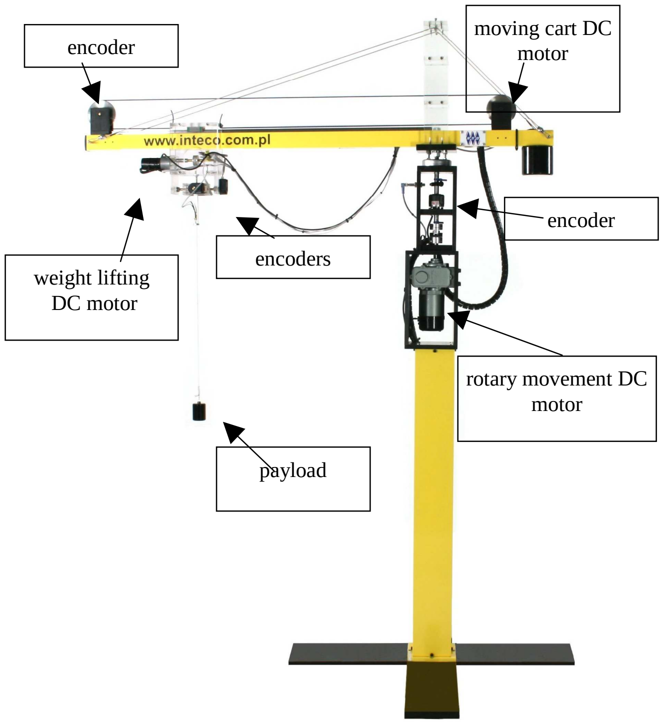

Figure 1 Tower crane – general view

An electric drive consists of three DC gear motors. The motors: weight lifting and moving the cart are mounted on shafts equipped with other gearboxes changing rotary to plane motion. There are also two encoders (measuring rotary position) placed on the shafts. Other two encoders are placed in the trolley mechanism for measuring in two planes a deviation of the rope from the vertical position. The third gear motor is placed directly inside the crane body. The shaft, transfering torque from this motor is equipped with the sixth encoder that measures rotary position of the crane arm with respect to the basis. The crane is equipped with three limit switches to prevent the construction from damages caused by fault control.

The presented crane is not a copy of any existing industrial object. It is a very good tool: for research purposes, for examination of phenomena that occur during movement of a suspended payload and for designing control algorithms assuring a safe transport. Safe means resistant to disturbances like violent gusts of wind or sudden appearance of an obstacle.

A. *Trolley drive*

The RH158 gear motor (Figure 2) has been chosen as a trolley drive. The motor, equipped with a gearbox 76.84:1, gives 50 Ncm maximal torque [10]. The rotary motion is converted into the flat movement by another gear that pulls a steel link connected to the trolley.

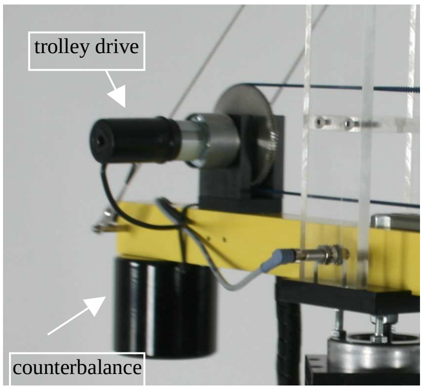

Figure 2. Tower crane – trolley drive

B. *Trolley*

A mechanism for measuring a deviation of the payload is mounted in the trolley (Figure 3). It consists of two shafts connected similar like in the Cardan coupling. Both shafts have mounted encoders for measuring angles of deviation in two planes.

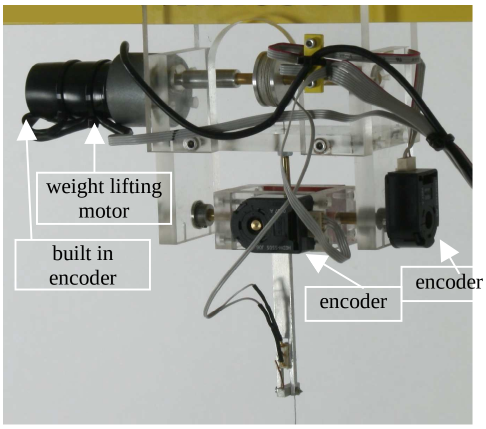

Figure 3. Trolley

In the upper part of the trolley, above the mechanism, there is a weight lifting motor (Type RH158-2S). Rotation of this motor (length of the rope) is measured by the built in two-phase Hall-effect 90° encoder. The rope goes exactly through the center of the mechanism. A deviation of the payload forces a deviation of the mechanism, that is noticed by the encoders.

C. *Tower*

A construction of the crane tower presents Figure 4. Parvalux motor: PM10MIW has been used as a drive of the crane rotary movement.

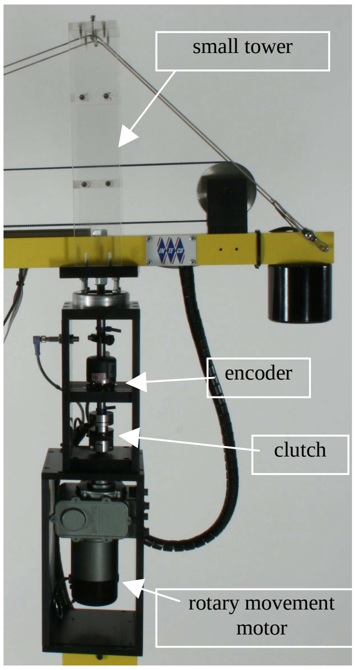

Figure 4. Tower

Its maximal torque is equal to approx. 11Nm. The motor is mounted inside the construction of the tower. The torque is transmitted by the shaft (diameter 12mm) to the arm. The motor is connected to the shaft by the clutch (Figure 4). There is also an encoder mounted on the shaft for measuring an angle position of the arm. The shaft is connected with the arm rigidly. The small tower (Figure 4) assures a rigidity of the arm.

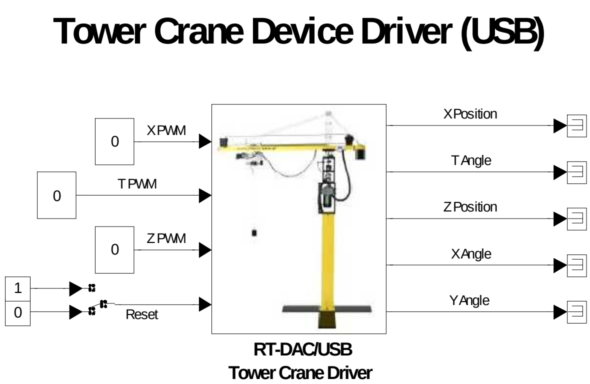

Figure 5. MATLAB&Simulink environment

III. EXPERIMENTS

The crane is controlled in the Matlab&Simulink environment. It was prepared a driver for experimental purposes (Figure 5). The driver has three inputs: XPWM – for control the trolley motor, TPWM – for control a crane rotary movement, ZPWM – for control the weight lifting motor. The control values may vary from 0 to 1. The value 0 refers to no control, value 1 means full control. The control is PWM type. A value between 0 and 1 refers to the fill factor of the control square wave. The switch “Reset” sets the encoder counters to value 0. It is used for calibration purposes.

There are five outputs available for a user: X Position – position of the trolley in reference to the length of the arm, T Angle – angle position of the arm in reference to the crane basis, Z Position – length of the rope with a suspended payload, X Angle – angle deviation of the payload in the arm plane, Y Angle - angle deviation of the payload in the plane, directed perpendicularly to the arm.

A. *Payload movement*

A simple connection of the X Angle and Y Angle signals to the Simulink tool: Scope, makes able to observe in real time movement of the payload in the X Angle vs. Y Angle plane. Figure 6 presents results of an exemplary experiment with an oscillating payload. Small crosses on the figure denote measured points.

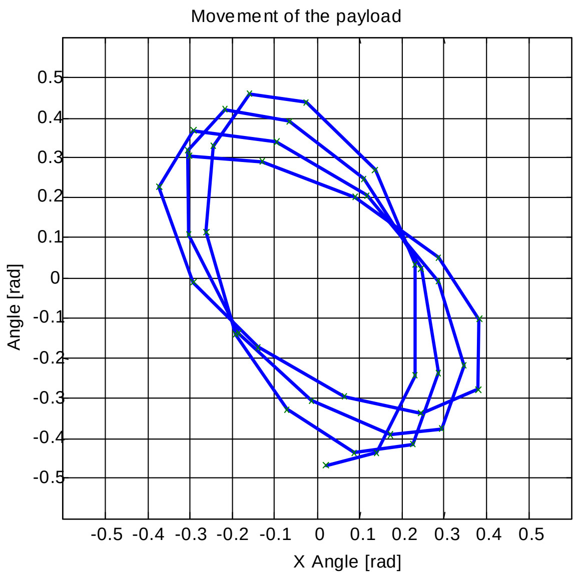

Figure 6. Movement of the payload

B. *Control experiment*

The driver of the crane looks like a typical Simulink model therefore a construction of the controller is intuitive for person familiarized with the MATLAB&Simulink environment (Figure 7.). In the presented experiment, only the x axis is fed by the control signal, values of the GainT and GainZ elements are set to zero. A controller is a type of two position block with a hysteresis. A width of the hysteresis defines a precision of keeping the object position near a desired value. In this case it is a trolley position along the arm. When the trolley goes beyond a specified position, the controller changes the control to the opposite value. When the trolley changes its position, the payload is moving freely. Some signals are connected to the Scope. Figure 8 presents the chosen signals that were observing in real time during the experiment. As the width of the hysteresis is set to 0.3 (the lower value is equal 0.1 and the upper 0.4,) the trolley changes its position among these values. When the trolley position overcrosses the value 0.4m, the

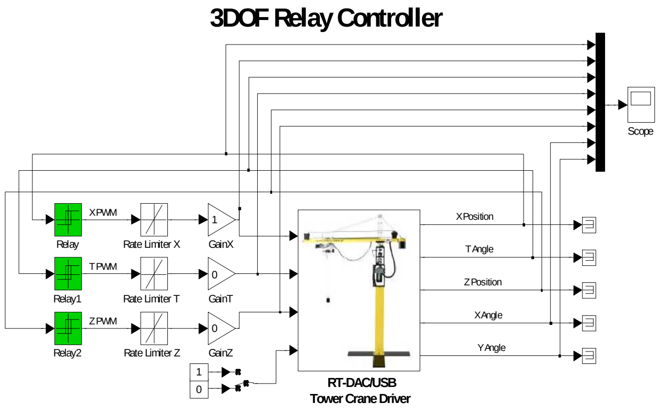

Fig. 7. Relay controller

control is changed from the value 0.5 to –0.5, and when the trolley position achieves the value lower than 0.1m, the control is changed from the value -0.5 to 0.5. During these changes, oscillations of the payload are increasing or decreasing randomly. There is no control algorithm dumping the oscillation activated.

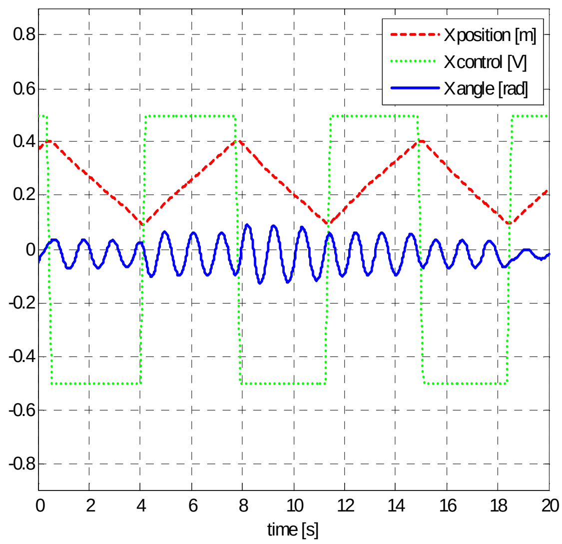

Figure 8. Results of the experiment

IV. EDUCATIONAL ASPECTS

As the system is equipped only with the position sensors (digital encoders), students during a construction of the control algorithms meet a problem with lack of a velocity signal. The simple solution in a form of the element differentiating the position signal, early shows its disadvantages, especially when the system moves slowly. To achieve a better performance, students must think about other solutions, like e.g. observers.

The system also reveals the phenomenon of elasticity of the shaft, coupling the PM10MIW motor and the arm. It is observed in the form of small oscillations of the arm in a final phase of a rotation movement.

A mathematical model of the tower crane it is not a trivial case. Mathematical aspects of modeling a behavior of the crane give a lot of opportunities to study various methods of modeling physical objects for control purposes[8][1]. The basic problems, the students faces:

- modeling of the PWM type control signal and its reference to the force control,
- modeling of the motor equipped with a gearbox,
- modeling of static and viscotic friction,
- designing an LQ controller basing on a linearised model,
- dumping payload oscillations,
- developing strategies of a save transport of the payload,
- comparing the payload deviation measure system to alternative methods, e.g. accelerometer implementation.

According to mathematical equations [8], a movement of the oscillating payload can not be decomposed into two planes: X, and Y. A deviation of the payload in the X plane influences on the payload movement in the Y plane. Experiments show, this effect can be omitted only when the deviation of the payload is lower than approx. five degrees.

V. Conclusions

The tower crane was designed to serve as an educational system. It is connected in it:

- scientific and technical environment MATLAB&Simulink
- system for control in real time, consisting of software parts and hardware
- modern electromechanical solutions like: measuring position sensors, proximity sensors, DC motors, gearboxes, couplings, bearings including thrust bearings.

The whole is a complex mechatronic system, allowing a successful practice with students of many scientific problems in the field of automation, robotics, modeling, identification, electronic, mechanical and first of all, the theory of control.

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