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Event Discrete Control Strategy Design of Overhead Crane embedded in Programmable Logic Controller

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ABSTRACT: *The main objective of this article is a control strategy for a crane. Specifically, reduce as load oscillations during their displacement trajectory, in order to ensure the safety of the operators and the own load carried during the displacement. Moreover, as overhead cranes are most often complete and difficult to be mathematically modeled, seen in the industrial process, Classic Control Systems techniques based on Proportional, Integral and Derivative Controllers (PIDs) embedded in Programmable Logic Controllers (PLCs)). The general proposal of this article is a system, instead of C.E.S(Continuous Event System) and D.E.S(Discrete Event System), able to control the dynamic effect of the load and of the production of the prototype in a reduced scale, through a Programmable Logic Controller.*

Keywords *- Industrial Processes, Crane Control, PID Control, Programmable Logic Controllers*

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I. INTRODUCTION

The Crane is an equipment used by several industry segments to carry out the lifting of loads for a certain period of time, the main objective of this project is that in an industrial environment it helps the transport of loads, reducing the physical efforts preventing wear, aiming at the health and avoiding diseases acquired at work. The cranes present a serious problem with the angular movement that the load performs during its displacement, this movement known as pendulum effect is decisive when we deal with the risks that this causes to the people, the structure and the own load transported. It is considered that these balances, in addition to hindering the transport and positioning of these loads, also endanger the health and life of the operators, as well as the integrity of the equipment and cargo, which are often of great economic value. The main objective of this paper is to raise the model of the proposed plant seeking to reproduce the behavior of the crane system, evaluating the performance of the system through model-based analysis, designing and simulating Proportional Integral and Derivative (PID) controllers to maintain control of the oscillation of the load during the transport process of the same, to construct a small scale prototype of the crane, for tests and tests of the automatic control developed.

II. THE OVERHEAD CRANE SYSTEM

In this section we present the crane system that was developed. This system consists of the gantry, formed by two parallel bars, that performs the translation movement on the X - axis, the carriage that performs the movement on the Y - axis the winch that performs the suspension movement of the load on the Z - axis. movements on the $X, Y\ and\ Z$ axes are performed by electric motors, which designate the torque needed to move the load. The crane was designed according to the project, as shown below.

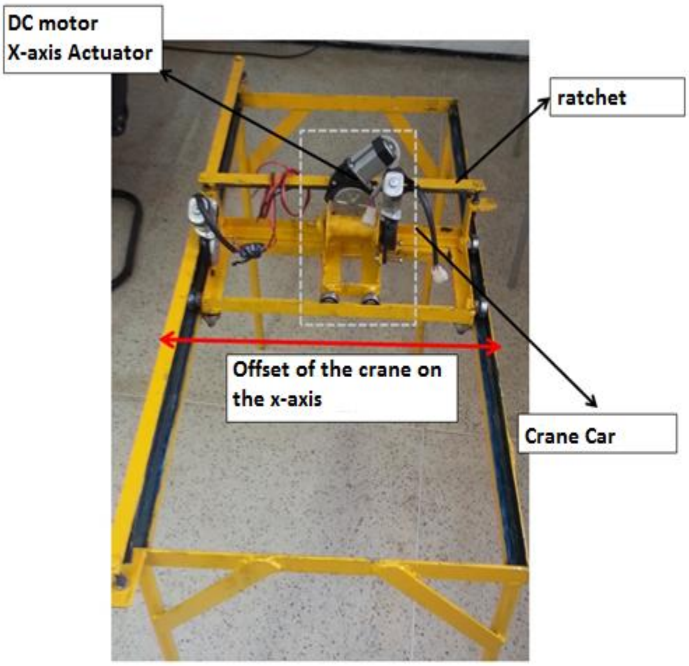

Figure 1-Detail of the carriage and displacement of the crane on the X axis

A [1], study was carried out on a linearization of crane systems, in order to solve the problem of stability control during a car movement, not read simple pendulum model.

Model obtained according to an analysis made by [2] and [3]; Cable length remains constant in Z, Model of overhead crane in XY plane; Subsystems $(x-\gamma)$and $(y-\beta)$

$$\left(\frac{\partial T}{\partial \dot{q}_k}\right) - \left(\frac{\partial T}{\partial q_k}\right) + \left(\frac{\partial V}{\partial \dot{q}_k}\right) = Q_k \quad (1)$$

Punctually the expression is given by: $L = T - V$,

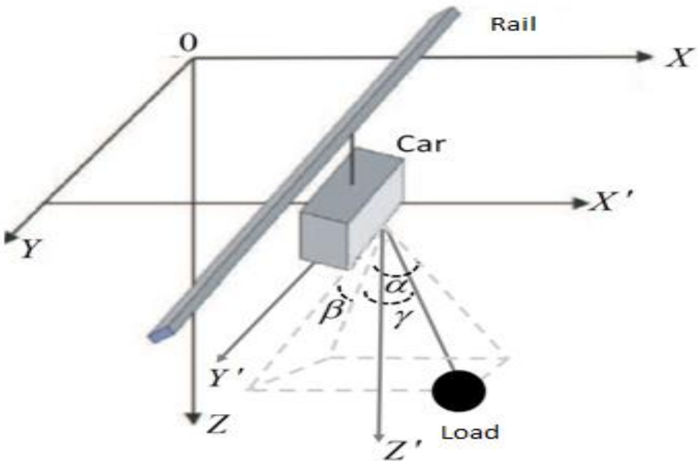

Figure 2-Body diagram free of a crane with three degrees of freedom

$Modelos(x-\gamma)\ and\ (y-\beta)$

$$A_{(x-\gamma)} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & a_{22} & a_{23} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & a_{42} & a_{43} & 0 \end{bmatrix} B_{(x-\gamma)} = \begin{bmatrix} 0 \\ b_{21} \\ 0 \\ b_{41} \end{bmatrix} \ A_{(y-\beta)} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & a_{66} & a_{67} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & a_{86} & a_{87} & 0 \end{bmatrix} B_{(y-\beta)} = \begin{bmatrix} 0 \\ b_{62} \\ 0 \\ b_{82} \end{bmatrix} \quad (2)$$

$$TF_{u_1(x)} = \frac{1.618s^2 - 6.662e^{-33}s + 31.75}{s^4 + 0.4036s^3 + 36.06s^2 + 7.919s} \quad TF_{u_2(y)} = \frac{5.466s^2 - 2.286e^{-30}s + 107.2}{s^4 + 1.363s^3 + 75.16s^2 + 26.75s}$$
$$TF_{u_1(\gamma)} = \frac{3.236s^2 + 1.825e^{-16}}{s^3 + 0.4036s^2 + 36.06s + 7.919} \quad TF_{u_2(\beta)} = \frac{10.93s - 7.737e^{-15}}{s^3 + 1.363s^2 + 75.16s + 26.75} \tag{3}$$

III. CRANE CONTROL PROJECT

It was analyzed by MATLAB & Simulink-MathWors® environment, Dynamic behavior analysis based on models and representation by transfer function, Analysis in Open Loop and Closed Loop, Step response $u(t)$, Stability analysis, $TF_{u_1(x)}$ and $TF_{u_1(y)}$ poles and zeros $(x-\gamma)$ and $(y-\beta)$, present similar answers, subsystem approach $(x-\gamma)$.

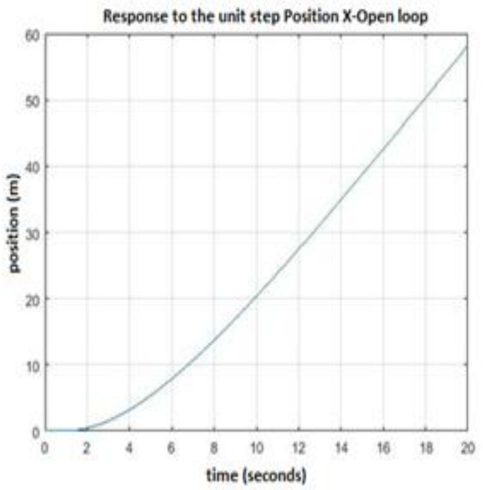

Figure 3: Response to the level of the open-loop Y position.

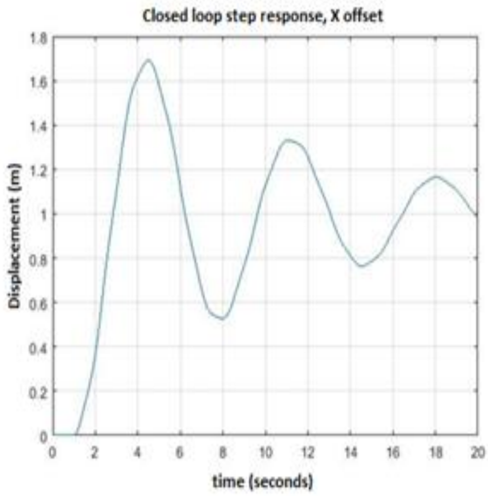

Figure 4: Response to the step of the X position in closed loop.

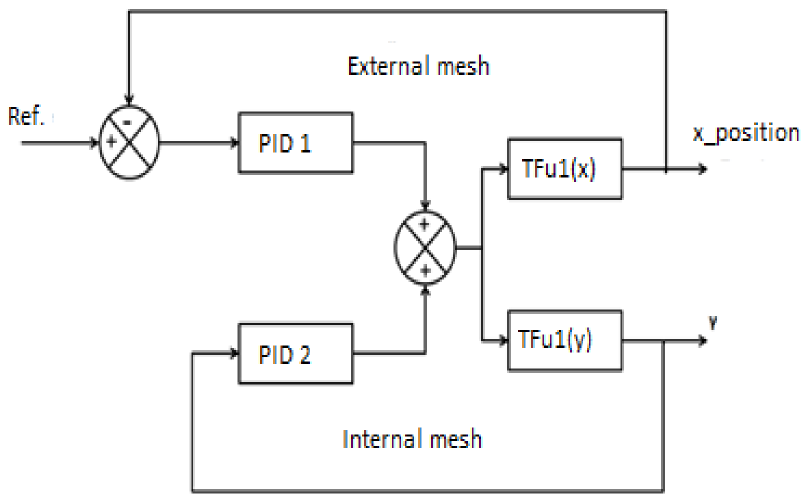

Figure 3-PID control strategy, problem $(\mathbf{x}-\boldsymbol{\gamma})$.

- Cable length is fixed in Z;
- The angular variation module $|\Delta\gamma|$and $|\Delta\beta|$ should be a maximum of 10 degrees or 0.1745 $radians$;
- The Overshoot must not exceed 20%, the accommodation time must not exceed 10 seconds and the control effort of the controlled system must comply with $\pm 2\ Vdc$ saturation due to the operating voltage limit of the DC motors.

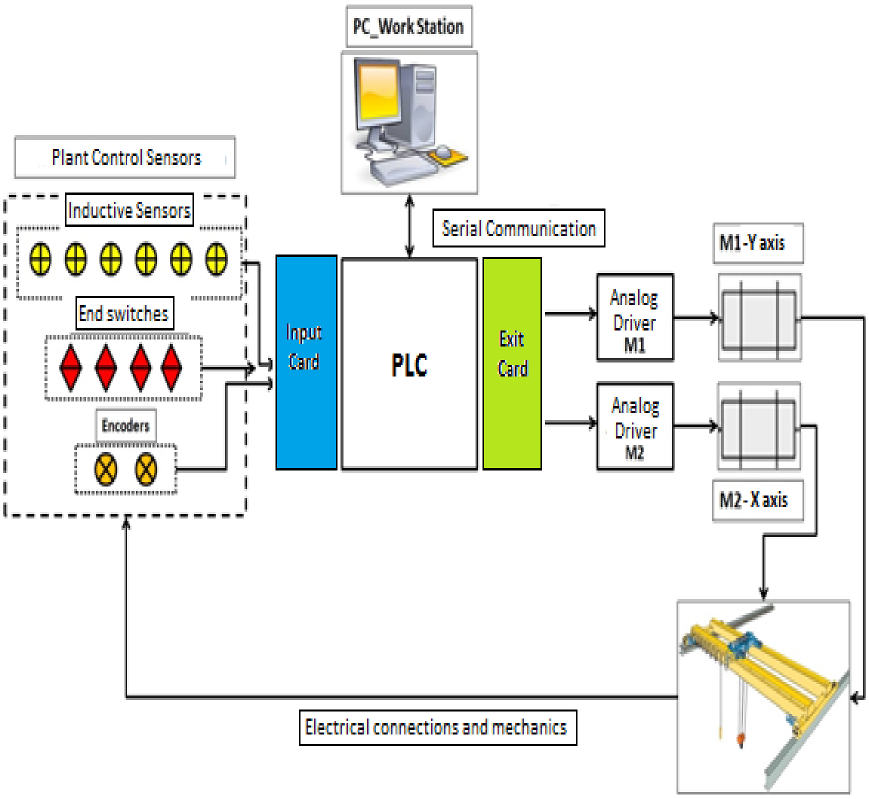

Figure 4: Diagram of connections and assembly of the crane

The control of the crane's automatic drive commands uses a Rockwell © MicroLogix ™ 1200 1762-L24BWA CLP, with 14 (24 V_{DC})digital inputs and 10 (ten) digital relay outputs (24 V_{DC}), with possibility of expansion of up to 6 (six) digital and analog I/Os cards depending on the current demand of each card. The X_0 and X_1 ports of the PLC input card were used to connect the encoders that sense the position of the rail on the Y axis and the carriage on the X axis. These ports are high and were configured via the HSC (High Speed Channel) function with a sampling period of $25\mu s$, so that the encoder pulse count could be read correctly.

Two types of sensors were used basically to perform the task of scalar positioning of the rail and crane car in the quadrants, the other to signal the presence of object (load) in one of the six operating quadrants of the Positioning Sensor bridge of the Track and Car of the Crane.

In order to make the scalar position sensing in the car and rail set in the XY plane, ROTARY type LPD3806 - 60BM - G5 - 24C, (24 V_{DC})and 20 Khz sampling frequency were used, with a resolution of 400 $pulse/revolution$ and the plant actuators used to perform the crane movements are Mabuchi DC motors, eight-tooth 12 V_{DC} gear, 6 A rated current and 16.9 Nm torque.

The operating area of the crane was divided into six zones, called quadrants I through VI, as shown in the table below.

Quadrant (k) = (Number of pulses in $X(k)$, Number of pulses in $Y(k)$) for $k = 1,2 \dots ,6$ where k is the number of quadrants.

Table 1 Events and actions of the control in SED of crane

	EVENTS					
	CHARGE QUADRANT I	CHARGE QUADRANT II	CHARGE QUADRANT III	CHARGE QUADRANT IV	CHARGE QUADRANT V	CHARGE QUADRANT VI
ACTIONS	M2_LEFT (ON)	M1_LEFT (ON)	M2_LEFT (ON)	M1_LEFT (ON)	M2_LEFT (ON)	M1_ RIGHT (ON) & M2_ RIGHT(ON)
	ENCODER 02 = 1195 pulse	ENCODER 01 = 4824 pulse	ENCODER 02 = 1195 pulse	ENCODER 01 = 2559 pulse	ENCODER 02 = 1195 pulse	FC_01_X(ON) & FC_01_Y(ON)
	M2_LEFT (OFF)	M1_LEFT (OFF)	M2_LEFT (OFF)	M1 _LEFT (OFF)	M2_LEFT (OFF)	M1_ RIGHT (OFF) & M2_ RIGHT(OFF)
	M1_LEFT (ON)	M1_ RIGHT (ON) & M2_ RIGHT(ON)	M1_LEFT (ON)	M1_ RIGHT(ON) & M2_ RIGHT(ON)	M1_ RIGHT(ON) & M2_ RIGHT(ON)	
	ENCODER 01 = 4824 pulse	FC_01_X(ON) & FC_01_Y(ON)	ENCODER 01 = 2559 pulse	FC_01_X(ON) & FC_01_Y(ON)	FC_01_X(ON) & FC_01_Y(ON)	
	M1_LEFT (OFF)	M1_ RIGHT(OFF) & M2_ RIGHT (OFF)	M1 _LEFT (OFF)	M1_ RIGHT(OFF) & M2_ RIGHT(OFF)	M1_ RIGHT (OFF) & M2_ RIGHT (OFF)	
	M1_RIGHT(ON) & M2_RIGHT(ON)		M1_ RIGHT(ON) & M2_ RIGHT(ON)			
	FC_01_X(ON) & FC_01_Y(ON)		FC_01_X(ON) & FC_01_Y(ON)			
	M1_RIGHT(OFF) & M2_ RIGHT(OFF)		M1_RIGHT(OFF) & M2_ RIGHT (OFF)			

Each of the six quadrants is directly monitored by an inductive sensor, which is intended to signal presence of charge or not in the quadrant. The movement of the car and the rail on the X and Y axes are monitored by individually coupled encoders on the motors of each axle, where it is possible to position the car and rail on any of the six operating quadrants by the pulse ratio of the encode of each motor and the displacement in meters in the X and Y axis. As shown in Fig. 07 and 08 below.

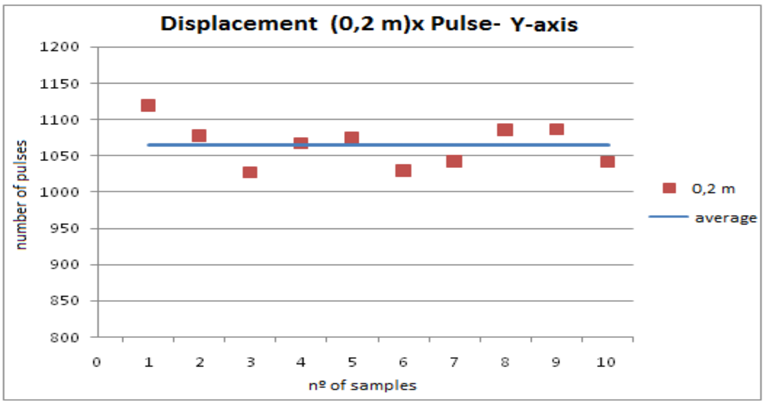

Figure 5: Relation of pulses x displacement in the Y axis - (20cm)

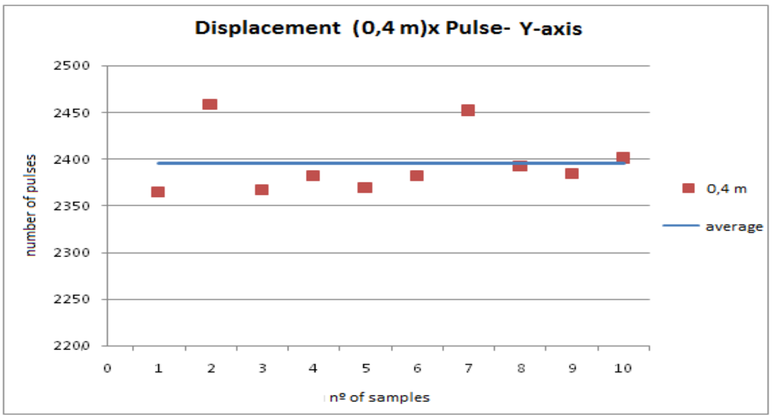

Figure 6: Relation of pulses x displacement in the Y axis - (40cm)

IV. EXPERIMENTS

The results presented are obtained from four tests with the crane. These tests served to survey the relationship between the number of encoder pulses of each of the axes, with the displacement in centimeters of the car and rail respectively and with the travel time according to the Table below.

Table 2 Relation of pulses vs. displacement of the car in the Axis *X*

Pulses vs. Displacement on X-axis		
n	0.10 m	0.20 m
1	871	1548
2	881	1549
3	847	1548
4	854	1549
5	860	1547
6	847	1550
7	854	1550
8	883	1552
9	871	1551
10	786	1549
Pulse Average	855	1549

Table 3 Relation of the displacement of the car in X vs. time

Displacement vs. X-axis time		
n	0.10 m	0.20 m
1	1.75	2.84
2	1.5	2.9
3	1.53	2.85
4	1,59	2.82
5	1.5	2.82
6	1.68	2.93
7	1.42	3.09
8	1.69	2.79
9	1.51	2.77
10	1.47	2.84
Average in seconds	1.56	2.87

Table 3 Relationship of pulses vs. rail offset on Y-axis

Pulses vs. Displacement on Y-axis				
N	0.20 m	0.40 m	0.60 m	0.80 m
1	1119	2364	3738	5144
2	1077	2458	3746	5144
3	1027	2367	3784	5076
4	1067	2382	3788	5102
5	1074	2369	3809	5071
6	1029	2382	3745	5126
7	1042	2452	3785	5089
8	1085	2392	3753	5089
9	1086	2384	3758	5113
10	1041	2401	3788	5073
Pulse Average	1065	2395	3769	5103

Table 5 Rail displacement ratio in Y vs. time

Displacement vs. Y-axis time				
N	0.20 m	0.40 m	0.60 m	0.80 m
1	2.34	4.06	6.29	8.55
2	1.75	4.21	6.48	8.49
3	1.56	4.22	6.36	8.47
4	1.81	4.17	6.39	8.58
5	1.86	4.22	6.39	8.55
6	1.88	4.23	6.27	8.53
7	1.81	4.18	6.41	8.55
8	1.9	4.14	6.46	8.66
9	1.76	4.19	6.29	8.52
10	2	4.18	6.46	8.52
Average in seconds	1.87	4.18	6.38	8.54

The Ladder follows the control strategy described in the flowchart shown in Fig. 9 below.

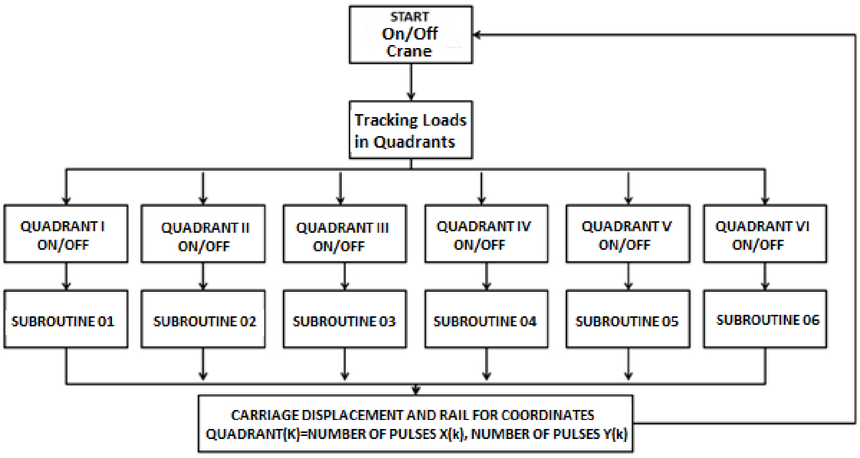

Figure 7: Flow diagram of control strategy for Ladder implementation

V. CONCLUSION

In this article, the system information proposals through four tests, to obtain the relations of pulses versus displacement of the car in the X axis and of the rail in the Y axis, as well as displacement relations versus time of the car and rail, whose results are demonstrated. Finally, a strategy of automatic control of the system was developed, based on DES (Discrete Event System). For a deployment of the control strategy, the Ladder code to be shipped in a CLP was developed. The study of the dynamics of the crane showed the system to be unstable by nature and that an oscillating characteristic of the load angle interferes with the displacement dynamics of the as expected, of the PID controller in S.C.V (System Continues Variables) designed with the purpose of limiting the variation of the angle and minimizing its effect on the dynamic displacement of the system, showing itself in conformity with the pre-design requirements and taking the system to the desired operating point, small-scale prototype of the crane, proved to be very robust and with excellent operation; a strategy of automatic control in D.E.S. and effective and the Ladder developed from prominence, was able to execute of efficient form the automatic control of prototype.

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