

## “Research Note”

# PRACTICAL IMPLEMENTATION OF MULTI-MOTOR DRIVES FOR WIDE SPAN GANTRY CRANES\*

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**Abstract**– This paper relates to rail mounted wide span gantry cranes and especially to the design of anti-skewing controller. The hereby presented algorithm provides skew elimination according to a simple, efficient and practically applicable method based on two absolute encoders and a skew controller realized in PLC. A safe and reliable operation, even in the case of components failure requires an additional compensator with minimal hardware requirements. Design points are outlined and characteristic results are shown. The proposed solution is experimentally verified in different industry branches.

**Keywords**– Frequency converter, multi motor drive, skew controller

## 1. INTRODUCTION

Wide Span Gantry Crane (WSGC) is an application for load handling in many industry branches: container terminals, cement industry, metallurgy, storage place, etc... The main task in adjustable speed drives design is a safe, multi-axis movement that allows material handling throughout the working area. The most common practical problem expected in these applications is crane skew due to a wide span, especially in outdoor operation.

On most rails, mounted WSGC skewing problem is associated with poor rail conditions, uneven wheel wear, wind influence, wheel slippage or unequal load conditions when the trolley is operating at one end of the crane bridge. The skewing of the crane can cause excessive wheel abrasion and stress, especially to the wheel flanges. It can also produce horizontal or lateral forces that can result in unusual stresses to the crane runway beams and building structure. In reference [1], several solutions for skew elimination using mechanical and/or control measures have been reviewed. There are no detailed design descriptions and experimental results to illustrate the applicability of the proposed solutions. In this paper, we propose a new, low cost solution that can be realized using Field Oriented Control of induction motor drives (FOC) and Programmable Logic Controller (PLC) with Field-bus communication devices, [2-4].

## 2. MAIN POINTS OF SKEW CONTROLLER DESIGN

The crane construction consists of opposite pairs of end truck assemblies (left hand side is named free leg and right hand side is named fixed leg). These are movable along a track and a long transverse support member between the end truck assemblies. Each end truck assembly includes two sets of trolleys and an upper load bar laterally interconnects the two sets of trolleys.

The hardware for skew elimination consists of a PLC with Field-bus communication, two absolute multi-turn encoders, two proximity sensors and four frequency converters for motor supply of trolley

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drives, as shown in Fig.1. On each end truck, one of the converters is the master and the other one, the slave. The master-slave references distribution is modified according to the load sharing principle as described in [5, 6].

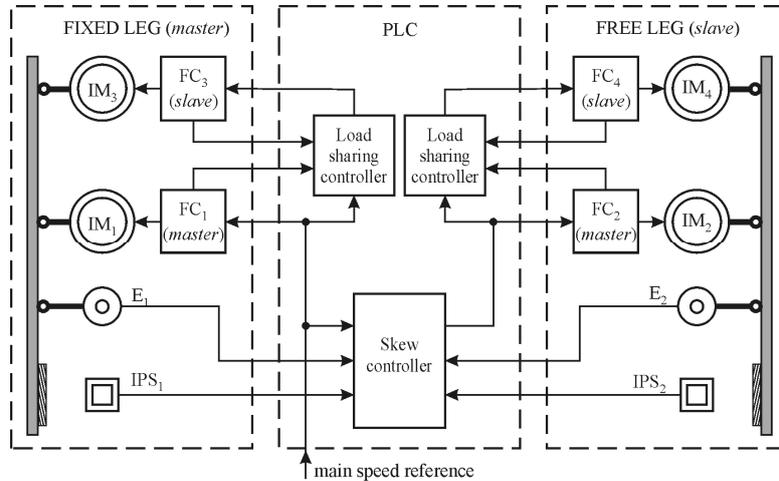


Fig. 1. Block scheme of gantry drive

The main devices for skew tracking are two absolute encoders (E<sub>1</sub> and E<sub>2</sub>) installed on a special, non-tractive wheel (so-called free wheel), in order to avoid slipping. Encoders measure the travelled distance, and absolute position is transferred to the anti-skew control subsystem in PLC, as shown in Fig. 1. The fixed leg frequency converter (FC<sub>1</sub>) is set as a master for gantry drive skew elimination algorithm; while in this case, the speed reference for the frequency converter on the free leg (FC<sub>2</sub>) is modified with the anti-skew controller output.

The control scheme for skew elimination between the master and slave motor of the gantry drive is shown in detail in Fig.2. As can be seen, we propose a simple proportional (P) controller acting as an additional, outer correction loop, which supplies the speed control loop. The speed reference of one motor ( $n_2^*$ ) is updated in relation to the main speed reference ( $n_1^*$ ) with the reference correction value  $\Delta n^*$ . In order to ensure the stable and safe operation of the motors during the large external disturbances and at low speed, when the estimation of electromagnetic torque in speed sensor-less drives lose accuracy, it is necessary to limit the correction value  $\Delta n^*$ .

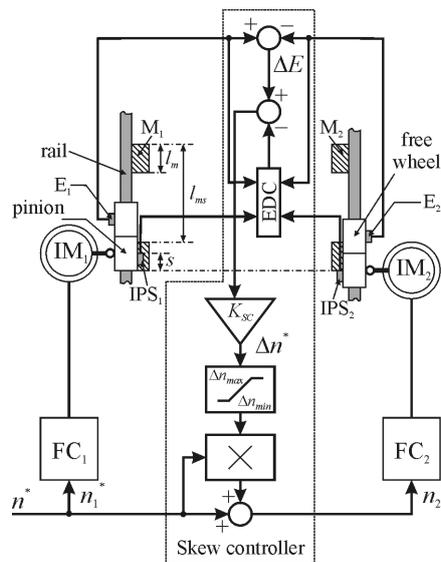


Fig. 2. The principle block diagram of skew controller

The controller output upper and lower saturation limit in per unit value,  $\Delta n_{\min-\max}$ , is set by:

$$\Delta n_{\min-\max} = \pm \frac{1}{n_{\max}^*} \cdot I_p \cdot \frac{s_m}{\pi \cdot D_p} \cdot \frac{1}{t_m} \quad (1)$$

where:

$n_{\max}^*$  - maximum speed reference [rpm],

$I_p$  - pinion wheel gearbox ratio,

$s_m$  - maximum allowed skew [m],

$D_p$  - diameter of pinion wheel [m],

$t_m$  - required time for  $s_m$  elimination [min].

If the encoder position difference  $\Delta E_g$  related to the maximum allowed skew is known, the controller gain  $K_{SC}$  can be calculated by:

$$K_{SC} = \frac{|\Delta n_{\min-\max}|}{\Delta E_g} \quad (2)$$

In this way, the velocity of skew elimination is limited and the drive performance is tailored according to the motor torque values [7].

A reliable operation (even in terms of key components failure - for example encoders) requests an additional external disturbance compensator (EDC) which includes several pairs of position bars (or markers, M) and inductive proximity sensors (IPS). The EDC takes into account all external influences on the position difference of the two encoders: the free wheels diameter difference and an accidental wheel and encoder joint slipping.

The proximity sensors are fitted on the end truck holders, while the position bars are equidistantly mounted along the rails. During the crane movement, proximity sensors detect the moment when the fixed (or free) leg passes above the markers and so register the crane actual skew. Now when both legs are positioned on the markers absolute encoders measure the trajectory difference, as shown in Fig. 2. In fact, this difference is the real skew ( $s$ ) of the crane, determined at each crossing over the markers. If the difference is greater than the length of the markers, it means the crane skew is bigger than allowed. For this reason it is necessary that the length of the markers matches the allowed skew of the crane ( $l_m = s_m$ ).

The distance between successive markers ( $l_{ms}$ ), for the pre-defined length of marker  $l_m$ , can be calculated by expression:

$$l_{ms} \leq \frac{l_m}{\frac{e_{\%}}{100}} \quad (3)$$

where  $e_{\%}$  is the maximum expected linear speed difference between the legs in percent. The value of the speed difference should be estimated based on the static speed accuracy of the drive and the expected maximal deviation in wheel diameter.

The number of marker pairs  $n_m$  mounted along the runway path  $l$  should correspond to the following expression:

$$n_m \geq \frac{l}{l_{ms} + l_m} \quad (4)$$

The limited number of the necessary input data for the calculation and design of the skew controller allows quick adjustment of parameters and the choice of EDC components, and the proposed algorithm makes it suitable for industrial applications.

### 3. CASE STUDY AND RESULTS

In the analyzed example, the WSGC horizontal movement subsystem consists of a fixed and free leg with a distance between them of 64.5 m. The length of the runway rail path is 300 m. The end truck, assembled with a pair of three-phase induction motors (5.5 kW), is supplied from sensor-less adjustable speed drives. The designed rated speed of the crane movement is 16 m/min. The movement is allowed if the wind speed is less than 25 m/s. The loads of fixed and free legs are different, partly because of the asymmetry of gantry, but mostly because of the trolley moving along the gantry. The calculated critical skew of the gantry structure is 100 cm, but during normal operation the maximum allowed skew is  $s_m=50$  cm. The estimated speed difference of the applied sensor-less drives, including the maximum diameter wheel difference of 1 mm, is 1% of the nominal speed. A preview of the gantry drive parameters and controller set-up values is shown in Table 1.

Table 1. Parameter and controller set-up values

parameter values			
$n_{\max}^*$	1455 rpm	$E_{p,rev}$	4096 pulses
$I_p$	394.7368	$D_p$	0.5 m
$I_{fw}$	15.6466	$D_{fw}$	0.5 m
$l$	300 m	$l_m$	50 cm
$t_m$	1 min	$e_{\%}$	1%
skew controller		$K_{SC}$	1/236230
		$\Delta n_{\min-\max}$	$\pm 0.1$
$E_{p,rev}$ - encoder pulses per revolution [pulses/rev], $I_{fw}$ - free wheel gearbox ratio, $D_{fw}$ - diameter of free wheel [m].			

At the beginning, the behavior of the gantry drives without a skew controller was analysed and the main results are shown in Fig. 3. In this case, the load-sharing controllers for the fixed and free gantry leg are applied. Three working sections are noticeable: crane acceleration, steady state operation, and crane deceleration. The encoder measures the motor speed, while torque is estimated from the frequency converters. The measured data are collected in a PLC SCADA system. The observed variables are master motor (IM<sub>1</sub>) speed  $n_1$ , speed difference  $n_1-n_2$  between the master motor (IM<sub>1</sub>) on the fixed leg and the master motor (IM<sub>2</sub>) on the free leg, torque differences between motors on the same leg (IM<sub>1</sub>-IM<sub>3</sub>, IM<sub>2</sub>-IM<sub>4</sub>) and the value of the actual skew ( $s$ ). In this case, as the skew is not controlled, the increase of the value can be seen. During the crane skew, motors (IM<sub>1</sub> and IM<sub>3</sub>) on the fixed leg are more loaded than the motors (IM<sub>2</sub> and IM<sub>4</sub>) on the free leg. In addition, the effects of the load-sharing controller are noticed because the motors on the same leg share loads approximately, i.e. torque difference oscillates about zero value.

The next experiment was performed including the skew controller and under similar operational regimes as in the previous case: acceleration, steady state operation and deceleration. The experimental results are shown in Fig.4. During the crane acceleration/deceleration, due to different loads between the fixed and free leg, the skew can be observed temporarily. The skew controller action eliminates this start-up disturbance in a few seconds. Simultaneously, with the action of a skew regulator, load-sharing controllers provide motor loading in proportion to their rated power. At constant speed operation, the

trolley moves between the fixed and free leg, which causes additional differences in loads, but the proposed controller successfully compensates for these disturbances. In the case of crane deceleration, it can be seen that the characteristic case of the free leg stopping is postponed in order to complete the elimination of skew and for the fine position adjustment.

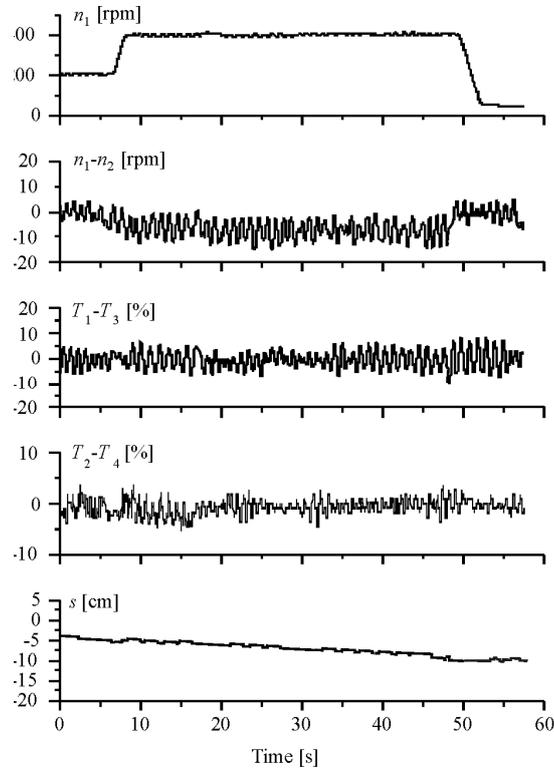


Fig. 3. Behavior of gantry drives without skew controller

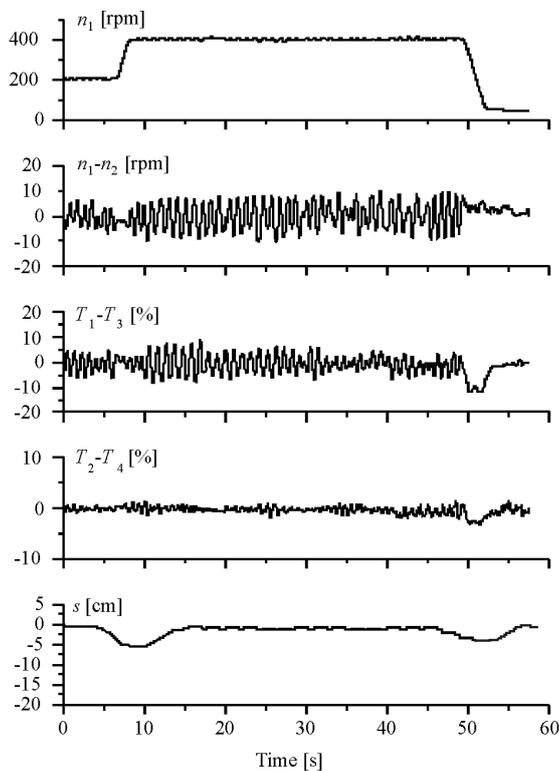


Fig. 4. Behavior of gantry drives with skew controller

#### 4. CONCLUSION

The skew problem in the WSGC crane is solved by modifying the main control software with inexpensive additional hardware components: two absolute encoders and pairs of IPS. The proposed skew controller is designed for a reliable and satisfactory performance drive control of the crane motion. A simple proportional controller in a compensation loop with a limited output, subordinated to the speed controller, realizes the centering and skew elimination. This configuration also enables the realization of the external disturbance compensator, which acts as a skew supervision system.

The efficiency of the proposed skew elimination algorithm can be outlined as follows:

- During acceleration and deceleration the skew is quickly eliminated, no matter of the variable load, which is a function of trolley position;
- The proposed controller is simple for realization in a standard PLC with minimal additional hardware;
- System reliability is improved by EDC, which involves all external disturbances on the encoder position inaccuracy.

The efficiency of the WSGC skew controller is demonstrated by comparing multi-motor drives behavior with and without controller. The extended field measurement and end-users feedback in different industry branches confirmed the satisfactory and reliable operation of the proposed concept.

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