



SKEW CONTROLLER FOR RAIL MOUNTED WIDE SPAN GANTRY CRANES

Nebojša Mitrović, Vojkan Kostić, Milutin Petronijević, Borislav Jeftenić*, Bojan Banković

University of Nis, Faculty of Electronic Engineering, Nis, Republic of Serbia

* University of Belgrade, Faculty of Electrical Engineering, Belgrade, Republic of Serbia

Abstract: *In this paper controlled electrical gantry drives of rail mounted wide span gantry cranes are analyzed, with special attention to skewing problem. Presented algorithm provides skew elimination on the simple, efficient and practically applicable method based on of two absolute encoders and skew controller realized in PLC. The algorithm is experimentally verified at several places in industry and characteristic results are shown in this paper.*

Key Words: *rail mounted wide span gantry crane, skew controller.*

1. INTRODUCTION

Rail mounted wide span gantry cranes frequently skew due to poor rail conditions, uneven wheel wear, wheel slippage or unequal load conditions when the trolley is operating at one end of the crane bridge. Skewing of the crane can cause excessive wheel wear and stress, especially to the wheel flanges. It can also produce horizontal forces at right angles to the rail which can result in unusual stresses to the crane runway beams and building structure. This often results in differing diameters of drive wheels, which subsequently cause the crane to skew [1,2,3].

Reason for writing the paper is wide span gantry crane accident in sugar factory, as a consequence of skewing. Authors of this paper had an assignment to design all electrical drives on the crane and especially to solve the problem of gantry drives as cause of breakdown. In this paper concrete mode of skew elimination for gantry drive is described. Suggested solution concept is exactly confirmed with experimental results.

2. CASE STUDY OF SKEW CONTROLLER DESIGN

In analyzed example, the whole drive of crane movement consists of fixed and free gantry legs. The distance between fixed and free leg is 64.5m. The length of runway rail path is 300m. Legs have drives on both of their ends with three phase induction motor power of

5.5kW. Therefore, for drive of the whole gantry four motors are used. Maximal speed of movement is 16m/min. Movement is allowed if the wind speed is less than 25m/s. Construction of the gantry is lattice, to decrease the influence of wind, and for the given span elasticity is expressed. Loads of fixed and free legs are different, partly because of asymmetry of gantry, but mostly because of the trolley which is moving along the gantry with loaded belts. Calculated critical skew of gantry is 1m, and adopted maximal allowed skew is 50cm.

Skew elimination is realized by suitable PLC, two absolute encoders, two proximity sensors (with six pairs of markers 50cm in length) and four frequency converters for motor supply of gantry drives, as shown in Fig.1. On each leg one of the converters is master and the other one is slave. The difference of their references is consequence of load sharing between motors on that leg. The principle of load sharing on the same leg is described in [4,5,6].

For the cause of skew tracking two absolute encoders are used (one for each leg). The encoders are installed on the special wheel which is not tractive (so called free wheel), in the cause to avoid slipping. Encoders measure the traveled path, and the information is forwarded to the regulation subsystem which is realized in PLC. The master converter on the fixed leg is chosen to be the master converter for gantry drive, while in this case, the master converter on free leg is slave for gantry, Fig.1.

On the basis of travelled paths difference, the skew controller generates the total reference speed component, as the consequence of skew. Control scheme for skew elimination between the master and slave motor of gantry drive is shown in Fig.2. Starting point at design of skew controller is that the motor which lag should be accelerated to overtake the motor on the other side in order to eliminate the skew. As shown in Fig.2, the speed reference of only one motor (n_2^*) is updated, in relation to the main speed reference ($n_1^* = n_1^*$). Reference correction Δn^* is proportional to the difference of absolute encoder position ΔE . Regulator gain K_{SC} can be calculated by (1):

$$K_{SC} = \frac{\Delta n^*_d}{\Delta E_g} \quad (1)$$

where Δn^*_d is the desired reference speed correction in relation to main speed reference for given absolute encoder position differences ΔE_g .

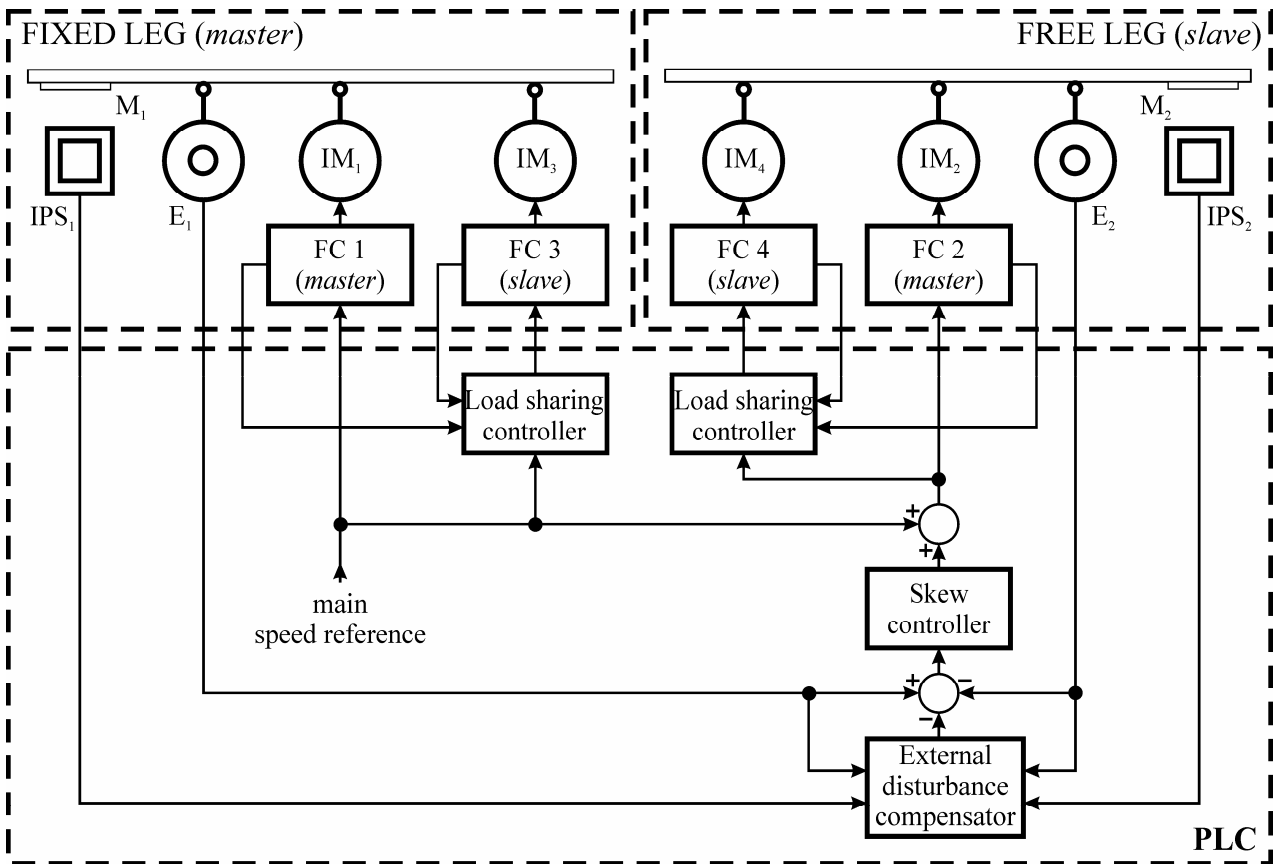


Fig. 1 Block scheme for gantry drive

In order to ensure the stable operation of the motors during the large external disturbances, especially at low speed when estimation of electromagnetic torque in speed sensorless drives loses accuracy, it is necessary to limit the correction value Δn^* .

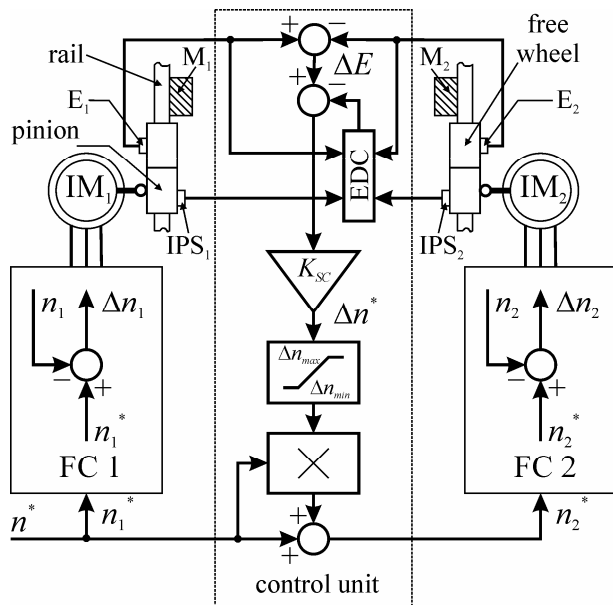


Fig. 2 The principle block diagram of skew controller

Actual skew is achieved as the difference of position between two encoders with respect of the correction

from the external disturbance compensator. External disturbances compensator (EDC) respects all external influences on the position difference of two encoders: the difference in the wheel diameter, wheel and joint encoders slipping.

The biggest external disturbance, slipping of driving wheels, is eliminated by mounting encoders on free wheels. Position "a" in Fig.3, represent term of skew (s) as distance between reference point and normal on movement direction. Pairs of markers (M) and proximity sensors (IPS) are needed for the realization of the disturbance compensator. Proximity sensors are fitted on legs, while the markers are mounted and equidistantly disposed along the rails. During the movement of the crane, proximity sensors serve to detect presence of the markers and to register the moment when fixed (or free) leg passes above markers. In the general case, crossing over the markers of the fixed and free leg is not simultaneous. By absolute encoders the trajectory difference is measured till the moment when both legs are positioned on the markers, as shown in Fig.3 position "b". In fact, this difference is the real skew of the crane, determined at each crossing over the markers, and represents the output of the external disturbance compensator. If the difference is greater than the length of markers, that means the crane skew is more than allowed. For this reason is required that the length of markers matches allowed skew of the crane. Number of markers that should be mounted along runway is

estimated on the basis of the static speed accuracy of the drive (especially for speed sensorless drives) and maximal deviation of wheel diameter (geometrical imperfection of the construction). In our case, the distance between markers is 50m.

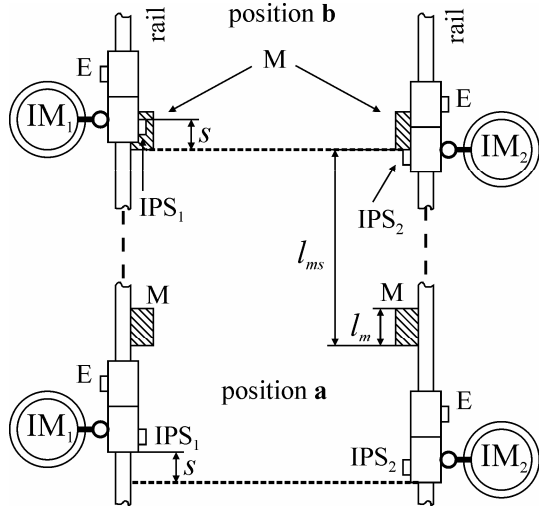


Fig. 3 Principle of external skew regulator

Distance between successive markers (l_{ms}), for adopted length of marker l_m , can be calculated by expression:

$$l_{ms} \leq \frac{l_m}{\frac{e_{\%}}{100}} \quad (2)$$

where $e_{\%}$ is maximal expected linear speed difference between the legs in percent. Number of marker pairs n_m for the length of runway rail path l can be estimated by:

$$n_m \geq \frac{l}{l_{ms} + l_m} \quad (3)$$

Per unit upper and lower limiter saturation value in Fig.2, $\Delta n_{\min-\max}$, is adjusted by:

$$\Delta n_{\min-\max} = \pm \frac{1}{n_{\max}^*} \cdot I_p \cdot \frac{l_m}{\pi \cdot D_p} \cdot \frac{1}{t_m} \quad (4)$$

where:

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

I_p - pinion wheel gearbox ratio,

D_p - diameter of pinion wheel [m],

t_m - maximal allowed skew correction desired time [min].

By assumption $\Delta n_d^* = |\Delta n_{\min-\max}|$ and ΔE_g as number of encoder pulses which represent the length of marker, controller proportional gain K_{SC} is easily obtained by equation (1).

In the Fig.4, the behavior of gantry drives without skew controller is shown. Therefore, in this case load sharing regulators for fixed and free gantry leg are included. Initial crane skew is near 10cm. From the load sharing aspect, motors torque, and torque difference on the same side should be observed. Estimated motors torque are obtained from the frequency converter. Mechanical computation, performed by SAP software package, shows that the skew influence is manifested differently on the motors torque on fixed and free leg.

Skew influences on the motors torque is shown in the Table 1. Increasing tendency of skew is noticed, Fig.4. In this case, skew is value that can't be controlled.

Fig.4 confirms the data given in the Table 1. During crane skew, motors (IM_1 and IM_3) on fixed leg are more loaded than the motors (IM_2 and IM_4) on the free leg. Also, the effects of the load sharing controller can be noticed because the motors on the same leg approximately share loads, i.e. torque difference oscillate about zero value. The amplitude oscillation depends on load sharing gain controller and its limiter settings.

Table 1. Torques during the skew

Skew [m]	Free leg torque [Nm]	Fixed lag torque [Nm]
0.1832	5.33	152.55
0.3664	10.66	305.102
0.549	15.99	457.65
0.732	21.32	610.2
0.915	26.65	762.75

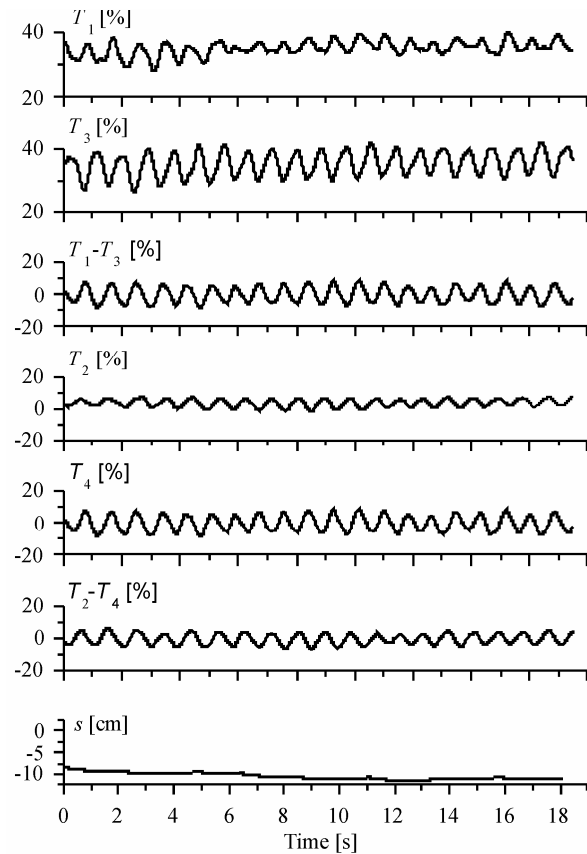


Fig. 4 Behavior of gantry drives without skew controller

Fig.5 shows experimental results including the skew controller. Gantry drive relevant parameter and controller set-up values are shown in Table 2. Three working sections are noticeable: I) crane acceleration, II) steady state operation and III) crane deceleration. Observed variables are: master motor speed, estimated speed difference between master motor on fixed leg and master motor on free leg, estimated torque differences between motors on the same leg and actually skew.

In the first section, during crane acceleration due to different load between the fixed and free leg (trolley position, conveyor belts ballast) skew in transient is

noticeable. According to absolute encoders position difference, there is regulator tendency to cut down or eliminate skew. Simultaneously, with action of skew regulator, effect of load sharing controller is active.

Table 2. Parameter and controller set-up values

parameter values			
n_{max}^*	1455rpm	$E_{p,rev}$	4096puls.
I_p	394.7368	D_p	0.5m
I_{fw}	15.6466	D_{fw}	0.5m
l	300m	l_m	50cm
t_m	1min	$e_{\%}$	1%
load sharing controller		skew controller	
K_{LS}	10	K_{SC}	1/236230
$\Delta n_{min-max}$	$\pm 0.02 \cdot n_{max}^*$	$\Delta n_{min-max}$	± 0.1
$E_{p,rev}$ - encoder pulses per rev. [pulses/rev], I_{fw} - free wheel gearbox ratio, D_{fw} - diametar of free wheel [m].			

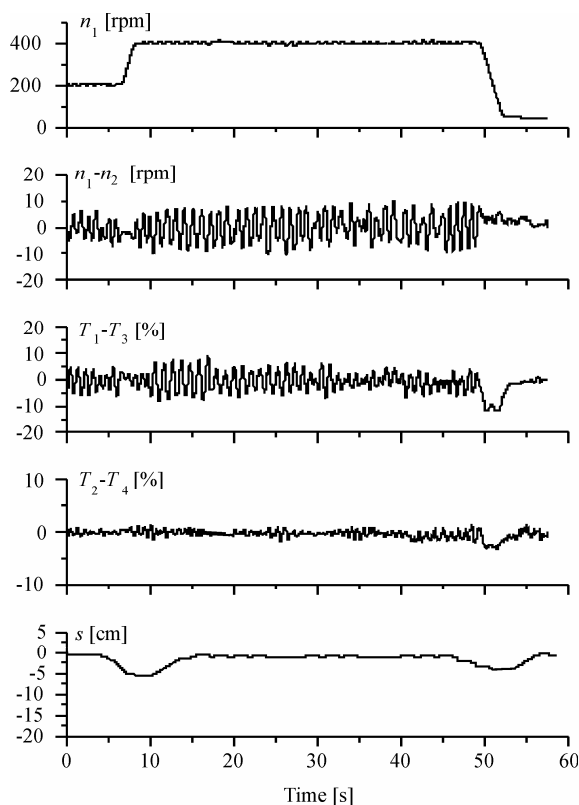


Fig. 5 Behavior of gantry drives with skew controller during accelerate - steady state - decelerate period

In the second section drive operates at constant speed. During the operation, trolley that moves between fixed and free leg, is active. Efficiency of algorithm can be seen from a several aspects:

- skew during the acceleration is rapidly eliminated, no matter of the variable load as function of trolley position and load of conveyor;
- load sharing controller provides equal load distribution with respect to adjusted proportional gain and limiters value.

In the third section, during crane deceleration similar statements are valid. It is evident that before final crane stopping, adjustment between legs is happening

3. CONCLUSION

Presented results show how the delicate problems of controlled multimotor drives, which call into question the stability of the whole system and its work in general, can overcome at the simple and inexpensive way. On concrete example of rail mounted wide span gantry crane considered problem is skew elimination.

Applying modern converters and the appropriate algorithm realized in PLC, reliable solution for skew elimination is shown. The solution is applicable in speed sensorless drives where information about the speed and load torque are estimated from frequency converters.

The skew problem is solved by software, and for hardware implementation only two encoders are needed. This configuration also enables realization of external disturbance compensator. On exactly predefined positons, the main task is to provide skew supervision and adjustment of controlled value.

The core of the system is PLC that communicates with the frequency converters and other devices over Profibus protocol. Information interchange between PLC, frequency converters and encoders enables simple realization of suggested algorithms.

5. REFERENCES

- [1] Busschots F., Belmans R., Geysen W., "Application of field oriented control in crane drives", Proc. IEEE-IAS, Annual Meeting, Dearborn, Michigan, USA, September 28-October 4, 1991, pp. 347-353.
- [2] Backstrand, J.E., "The application of adjustable frequency drives to electric overhead cranes," Industry Applications Society Annual Meeting, 1992, Conference Record of the 1992 IEEE 4-9 Oct. 1992, vol.2, pp.1986 – 1991.
- [3] A. K. Paul, I. Banerjee, B. K. Snatra, N. Neogi, "Application of AC motors and drives in Steel Industries", Fifteenth Natinal Power System Conference, Bombay, December 2008, pp.159-163.
- [4] Rockwell Automation, "Load Sharing for the 1336E-PLUS II AC Drive", Publication number 1336E-WP001A-EN-P, June 2000.
- [5] Jeftenic B., Bebic M., Statkic S., "Controlled multi-motor drives", International Symposium on Power Electronics, Electrical Drives, Automation and Motion, SPEEDAM 2006, Taormina (Sicily) - ITALY, 23-26 May 2006 , pp. 1392-1398.
- [6] Jeftenic B., Bebic M., Jevtic D, "Load distribution for mechanically coupled drives", XI International Symposium on Power Electronics, Ee 2001, Novi Sad, Serbia, Oct.31-Nov.2, 2001, pp.197-200.