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Trajectory of the Overhead Crane

Leonid Martovytskyi[1], Vasyl Glushko[1], Zoya Shanina[2], Roman Frolov[3], Dmytro Kozak[4], Olena Cherkashyna[5], Olena Syvachuk[3]
[1] PhD in Technical Sciences
[2] PhD in Mathematics and Physics
[3]Senior Lecturer
[4]Teacher
[5]Research engineer
National UniversityZaporizhzhia Polytechnic
64 Zhukovskoho str., Zaporizhzhia, Ukraine, 69063
ORCID: 0000-0002-6839-1840, 0000-0002-8109-6950, 0000-0002-7640-2589, 0000-0001-9967-0220,0000-0003-0617-539X, 0000-0002-9747-0070

Today and in the future, overhead cranes are and will continue to be an extremely important component in various industrial operations, especially in the context of Ukraine's reconstruction and integration into the European Economic Area. Currently, the approach to hoisting cranes as secondary machines designed to perform only auxiliary handling operations has changed. Modern cranes, especially special cranes, are increasingly being used to perform basic technological operations. An area that has long been a subject of interest is machines that can independently manage all crane operations and thus operate autonomously using end-to-end digitalisation.

The highest level of digital technology in cranes is the creation of robotic cranes capable of autonomous operation with an operator in a remote control room or even working according to a programmed scope of work, i.e. the creation of automated robotic cranes (ARCs) that are integrated with artificial intelligence technology and can perform tasks autonomously or remotely, controlled by operators. The popularity of automated robotic cranes is growing, especially in the heavy lift and transport logistics industry.

The consumer characteristics of the robotic crane imply high structural perfection of all its components operating in the industrial robotmode and a level of controllability that meets modern technologies.

The main goal of increasing the efficiency of crane operation can be achieved by improving and digitising the crane's operation cycle, which includes long-range navigation of cargo transportation and positioning, precise manoeuvring, and cargo gripping.

The overall goal of improving the safety of special cranes is to remove anyone from dangerous proximity to the load and enable workers to safely adjust the load through the entire crane cycle. This can already be achieved by converting cranes to remote and automatic control through the complete digitalisation of all crane operations. The conversion of cranes to remote and automatic control can significantly improve the safety and efficiency of crane operations and opens up opportunities for further increasing crane productivity.

The new concept of digitalisation and automation in the crane industry does not necessarily imply that everything old must be removed and replaced with new. New and fundamentally different special cranes should be integrated into the existing, well-established process, gradually replacing partially worn, obsolete equipment with useful and advanced upgrades. The process continues until all equipment that has reached the end of its standard service life is replaced.

It is economically feasible to use existing crane equipment following comprehensive and contemporary modernizationin the updated production environment.This assertion stems from the observation that a significant portion of the bridge fleet, notably, possesses a metal structure, which constitutes the most costly and crucial element of a crane, typically maintaining a predictably serviceable condition.

In order to substantiate the feasibility of converting an operational overhead crane into a robotic counterpart, it is imperative to conduct an analysis of the trajectory accuracy and positioning of the crane movement mechanism. This aspect, often the most challenging in terms of ensuring precise positioning, warrants meticulous examination.Achieving full controllability and precise positioning of the crane along the longitudinal coordinate of the overhead crane is easily attainable provided that the trajectory of its movement is clearly defined.However, as evidenced by the experiment results, the trajectory of the crane's movement may deviate significantly from the ideal programmed path, even with the absolute geometric precision of the crane runway and the elimination of misalignments and tilts in the crane running wheels.This can be explained by the uniqueness of manufacturing each specific crane, the inheritance of technological and design deviations, even within normative limits, the cumulative effect of which leads to a synergistic impact during operation.The specific behaviour of each individual crane in a particular production environment is difficult to identify and even more difficult to eliminate.

Despite the uncertainties arising from a multitude of inherited design, technological, and acquired operational deviations, each individual crane must be meticulously controlled with high precision in positioning. This necessitates a robust, or at the very least, adaptive control system.

When overhead cranes move along tracks in real manufacturing conditions, there is a deviation from the straight-line trajectory of the crane's movement.The linearity, or adherence to ideal movement, can be assessed by the magnitude of deviation of the geometric center of the bridge from the programmed path ΔX, as well as the angle of bridge torsion φ at each moment of movement (Fig. 1).

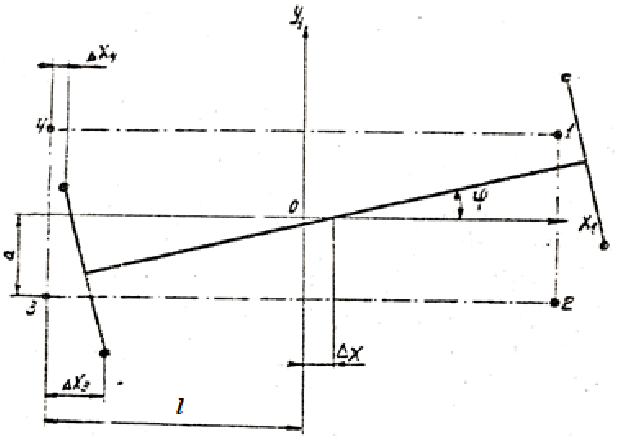


Figure 1 – Scheme for determining the lateral displacement and skew angle of a crane

The nonlinearity of the trajectories of overhead cranes is accompanied by oscillations of their centres relative to the ideally straight path. All of this results in the emergence of noticeable lateral forces acting on the wheels alongside the crane runway rails. These lateral forces cause wear on the wheels and rail heads, affecting the metal structure of the crane, especially the end beams.

For the purpose of studyingthe trajectory of the crane, non-contact lateral displacement sensors for the crane and a non-contact displacement sensor-recorder were developed and utilizedat National University Zaporizhzhia Polytechnic. Fig. 2 illustrates the layout of the lateral displacement sensors 2, displacement recorder sensors 1, and magnetic markers 3.

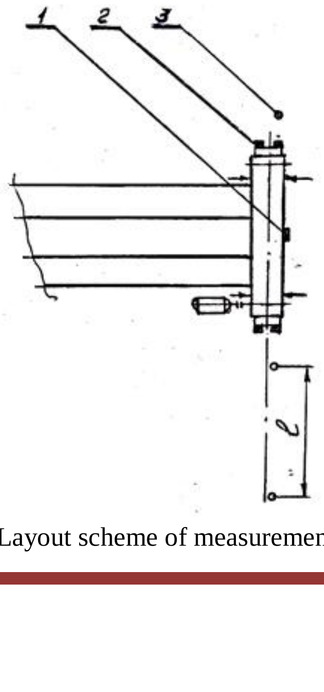


Figure 2 –Layout scheme of measurement sensors

The experimental investigations were conducted ona special overhead crane operating at one of the metallurgical plants with a lifting capacity of $Q = 20/5\ t$with a span of $L = 16{,}5\ m$.

An inductance coil 1 wound on a steel core attached to a bracket 2, which was installed under the lower plate of the end beam 3, was used as a path marker (Fig. 3).During the crane's movement, the coil passed over permanent magnets 4 installed on the crane runway beam at a specified interval l. The current pulse induced in the coil was recorded.

To determine theskew angle of the crane φ and the lateraldisplacement ΔX of its centre, it is sufficient to know the lateraldisplacements ΔX_3 i $\Delta X_4$of the wheels of one end beam (Fig. 1). These displacements were registered by non-contact sensors based on the principle of changing the transformation ratio when the inductance of the transformer windings changes. The sensor (Fig. 4, a) consists of a bracket l, on which two magnetic cores 2 are mounted, which are made of E-shaped transformer iron. The function of the closing plates is performed by the cranerunway rail (Fig. 4, b). Each magnetic core is equipped with a coil, which has an excitation and a measurement winding.

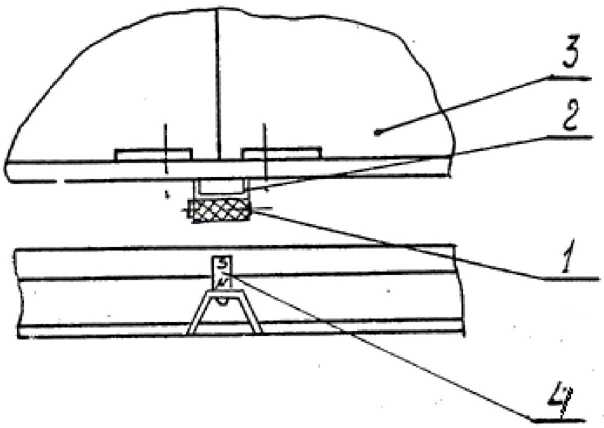
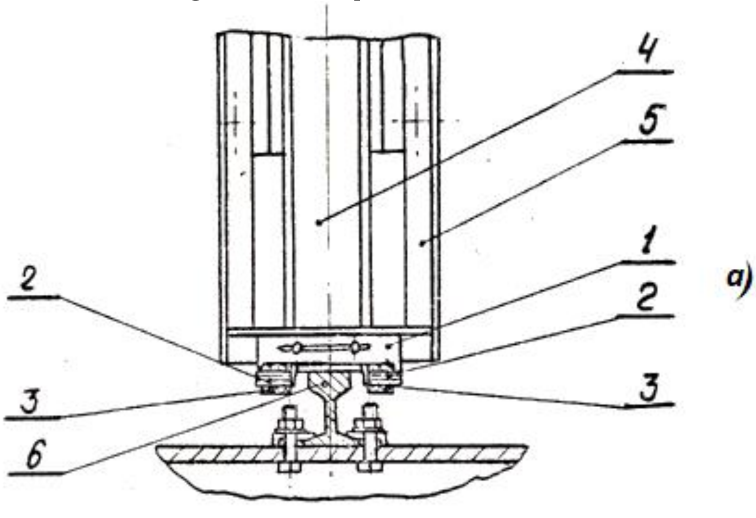
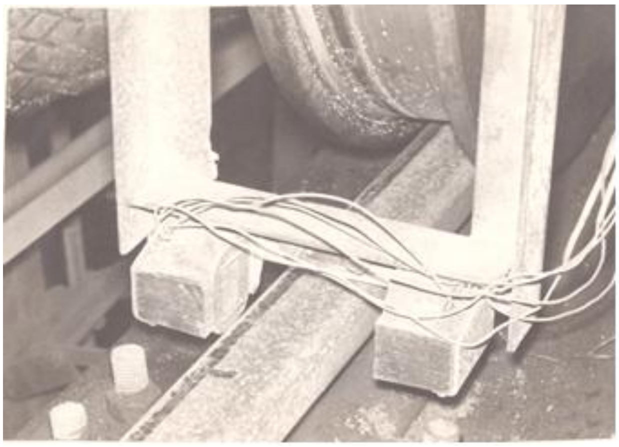


Figure 3 – Crane path detection sensor





b)

a) scheme of the sensor; b) general view of the sensor
Figure 4 – Crane lateral displacement sensor

The distance between the magnetic cores is 2...4 mm greater than the distance between the flanges of the running wheel 4. The bracket 1 itself, which has an oval groove, is attached to the wheel shield with two bolts. The groove allows the bracket with the coils to be moved during adjustmentand final installation of the sensor symmetrically relative to the flange of the wheel according to the template. The magnetic field of the coils with magnetic cores is closed through the rail, and therefore the transformation coefficientof each coil depends on the distance to the rail. The sensitivity of the sensors depends on the supply voltage, the magnitude of which is limited by the heating of the windings. Calibration of the lateral displacement sensors was performed with a set of probes. During this process, the sensors exhibited a non-linear characteristic.

As an example, in the fragment of the crane's trajectory record (Fig. 5), the work of the crane displacement registration sensor is shown under the number 1, while the displacements of the wheels of one end beam from the straight trajectory are indicated under the numbers 2 and 3. This analysis considers both forward motion of the crane (to the left of the vertical) and reverse motion (to the right).

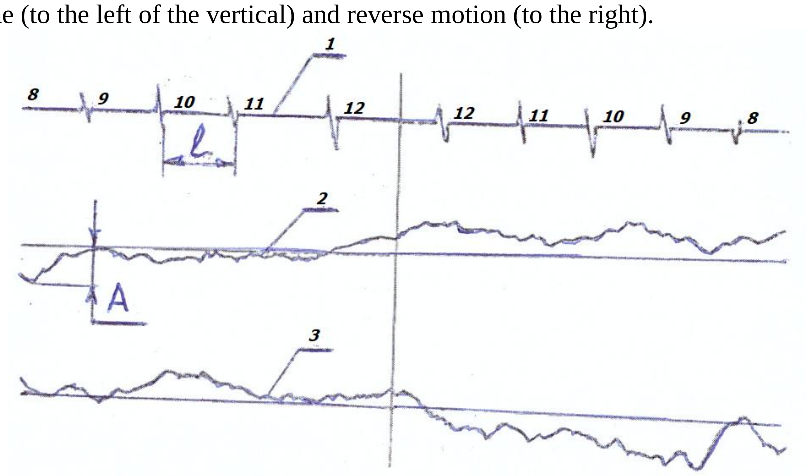


Figure 5 – Fragment of the crane movement trajectory registration

In practice, one of the methods used for self-adaptation of the trajectory of overhead cranes involves the use of conical crane running wheels.

When studying the influence of the conical shape of the cranerunning wheels on the trajectory of its movement, there arose a need to alter the conical profile.The adjustment of the wheel conicity was performed on the crane runway beams using a specialized apparatus, allowing for the machining of the crane's wheels without dismantling them. The crane's movement mechanisms were utilized as drives during the machining process.

The apparatus (Fig. 6), consisting of a carriage and a cutter, was secured to the crane runway beam using a clamping plate and a tightening bolt. In this process, bolts for fastening the crane runway were utilized. The carriagewas supported by four adjustable leadscrews, which allowed for the adjustment of the cutter's position in height. To ensure the free rotation of the crane's drive wheels, the crane was lifted on jacks.

The conicity was achieved by rotating the carriagebefore turning. The cutting feed was performed by moving the cutting tool in the tool post, while the longitudinal feed was controlled by the carriage. Using the crane movement controller, the necessary rotation frequency of the machined wheels was set to achieve the optimal cutting speed.

The proposed method can be used not only for machining wheel surfaces but also for turning brake pulleys without dismantling them, directly on the crane.

The elimination of dismantling parts and the utilization of crane mechanisms as drivesfor turning significantly reduces labour costs and repair time for crane mechanisms.

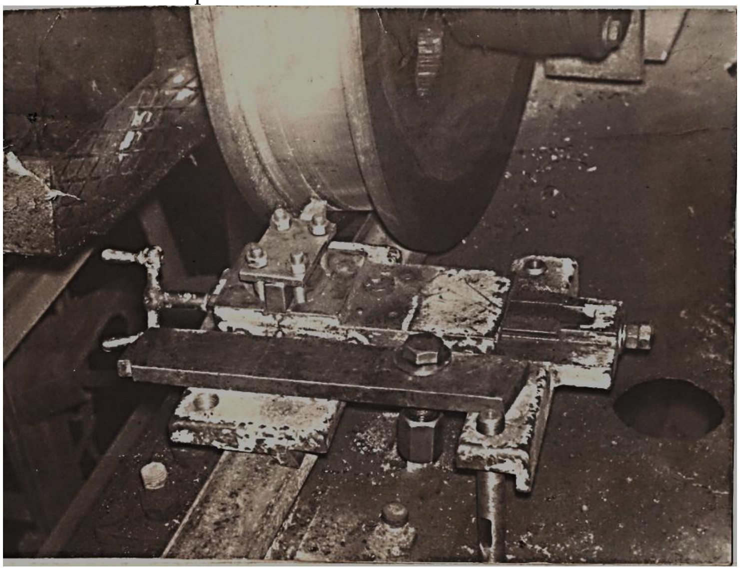


Figure 6 –Apparatusfor turning the rolling surfaces of crane wheels without dismantling them

With a separate drive, the conical running wheels centre the crane on the crane runway tracks during movement and compensate for the difference in the rotational speeds of the drive motors, which arisesdue to uneven drive resistance on the drive wheels.

In order to experimentally evaluate the effect of drive wheel conicity on crane motion self-adaptation, simulations were conducted for three crane motion modes:

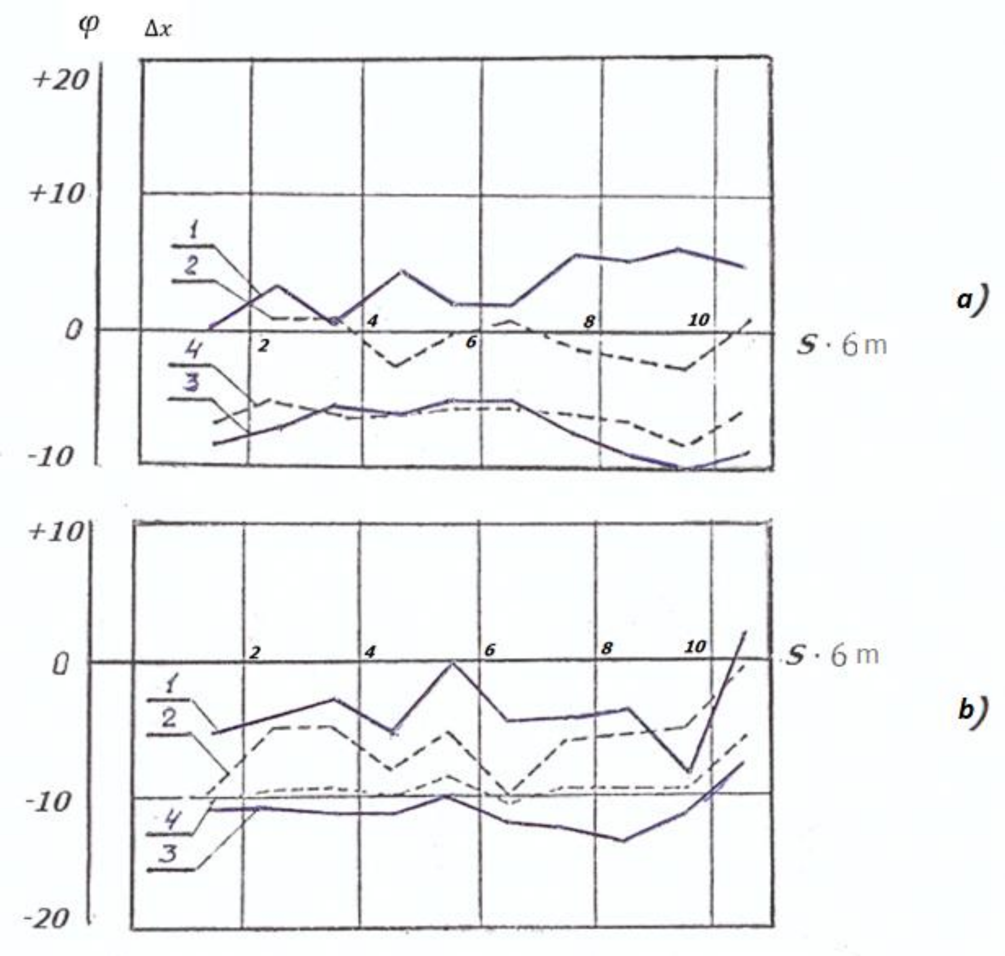
- with cylindrical wheels;
- with conical drive wheels with a conicity of 1/20;
- with conical drive wheels with a conicity of 1/10.

The experiments were held while the crane was moving forward and backward on the same section of crane runway.

Average values of the parameters Δx i φ during the movement of a crane with cylindrical and conical (with a conicity of 1/20 and 1/10) wheels are presented in Table 1. Graphically, these values along the entire path of movement are displayed in Fig. 7.

Table 1 – Average values of the parameters Δx i φ during the crane movement

Direction of movement of the crane	Cylindrical wheels		Wheels with a 1/20 cone		Wheels with a 1/10 cone	
	Δx, mm	$\varphi \cdot 10^{-4}$, rad	Δx, mm	$\varphi \cdot 10^{-4}$, rad	Δx, mm	$\varphi \cdot 10^{-4}$, rad
Forward	-7,10	+3,42	-6,00	-0,25	-5,00	-0,23
Backward	-10,7	-3,08	-8,78	-5,92	-8,31	-6,37



——is for cylindrical wheels; ------ is for conical wheels;
a) represents forward movement; b) represents backward movement; 1, 2 – tilt angles of the crane φ, 10^{-4} rad; 3, 4 –displacement of the crane centre Δx, mm
Figure 7 –Movement parameters of a crane on wheels with different rolling surfaces

Conclusion

The experiment results indicate that a crane with conical drive wheels exhibits greater stability during forward motion compared to a crane with cylindrical wheels. This stability is achieved due to the moment of force generated by the inclination, which depends on the conicity of the wheels. However, during reverse motion, the stability of the crane deteriorates, which can be attributed to the specific advantages and disadvantages inherent to each individual crane.

The set of sensors for tracking the crane's trajectory has demonstrated its effectiveness and can be recommended for use in feedback loops of automated crane motion control systemsas a sensitive adaptive system in the subsequent digitalisation of robotic crane control.

References

[1]. KozlovV. V. (1984) *Dinamikaupravleniyarobotami* [Dynamicsofrobotcontrol]/ [KozlovV. V., MakarychevV. P., TimofeyevA. Z., YurevichYe. I.]. Moscow: Nauka. (inRussian)
[2]. Kazak S. A.(1968) *Dinamikamostovykhkranov* [Dynamics of overhead cranes]. Moscow: Mashinostroenie. (in Russian).
[3]. Rigatos G., Busawon K. (2018) Robotic manipulators and vehicles: control, estimation and filtering.Cham. Switzerland: Springer.
[4]. Latombe J. (1991) Robot motion planning.Kluwer, Boston.