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THE ELECTROCHEMICAL METHOD APPLICATION OF IN-SERVICE DEGRADATION CONTROL OF PORT CRANES STEELS

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Summary. *Long-term service of marine port cranes causes a deterioration of mechanical properties of their structural materials, especially plasticity and brittle fracture resistance. Therefore it is important to control not only defects accumulated during service, but also a state of metal using non-destructive methods. The electrochemical approach could be effective for this purpose. Two parameters – mechanical (impact strength) and electrochemical (polarization resistance) were used as sensitive to port cranes steels degradation. Impact strength was evaluated using specimens cut across the steel rolling direction and polarization resistance was calculated on the base of polarization curves obtained in 3% NaCl. The clear downward trend for the both, electrochemical and mechanical, informative parameters has been given. The method was applied in the field conditions for a prediction of the steel impact strength of the operated port crane.*
Key words: *port cranes, in-service degradation, mechanical properties, electrochemical characteristics, non-destructive control.*

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Introduction. There are over 1100 port cranes in Ukraine [1], and more than 90 % of them are operated over the normative service life. Age of certain cranes reaches 40 years and more, which increases a number of accidents. Therefore, it is important not only to reveal operating defects but also estimate actual mechanical properties of metal. Our previous researches [2, 3] indicated that just the characteristic of brittle fracture resistance (impact strength *KCV*, obtained by Charpy testing) among studied mechanical properties is decreased the most sharply for a number of marine port structures. This parameter is important for ensuring the integrity of metal structures, so its prediction by the methods of non-destructive control is especially relevant to the problem solving. It is proposed to use electrochemical approaches basing on a fact that certain electrochemical properties of a corroded metal depend not only on the aggressiveness of corrosive environment, but also on structural and stress-deformed state of a material [4]. It was shown [5] that polarization resistance R_p as the electrochemical parameter of corrosion resistance of a metal is sensitive to in-service degradation of the port structures steels. Consequently, this characteristic, decreasing together with impact strength of steel during its long-term service, serves as the informative parameter of metal degradation. Therefore, a possibility for a prediction of brittle fracture resistance *KCV* of steel by a change in its R_p value, using correlation between the mechanical and electrochemical parameters, is perspective. The aim of the work – to build the correlation between polarization resistance and impact strength for different parts of the port cranes as the basis for non-destructive control of a metal state of marine loading-unloading structures under operation, and to approve it in the field conditions.

The object and engineering peculiarities of electrochemical measurements in the field conditions. The objects of diagnostics were the cranes of the type «Albrecht» (symbolic notation A1, A2?…A3 and A4) and «Sokil» (S1, S5) operated during 36–45 years. In view of a high risk of crack-like defects development and, consequently, brittle fracture, the following parts of the cranes were studied: back shelf of trunk, back shelf of boom, lever upper shelf of mobile counterbalance and back shelf of column. Metal surfaces which are diagnosed by the

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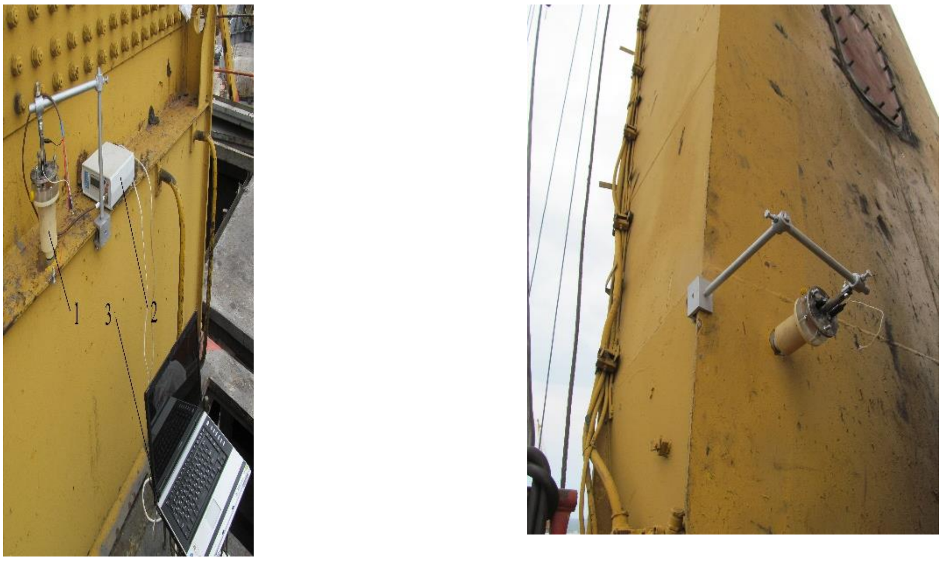
electrochemical method should satisfy the following requirements: placing in space – horizontal, vertical, or under a corner (except for position «ceiling»); surface roughness should not exceed R_a = 1,6 mkm; size of area for setting of an electrochemical cell should be not less than 30 mm in diameter. The following two parts of the crane A4 were chosen for determination of polarization resistance of the steel (Fig. 1): horizontal shelf, which is practically not loaded under operation, and vertical one, as the most loaded. Metal area, where the cell was kept, was prepared in the following manner: clearing a surface from dirt and coating, polishing, degreasing with acetone and alcohol; drying out by filtration paper and washing with distilled water.



a) b)

Figure 1. The examples of binding of the electrochemical cell to a horizontal (a) and a vertical (b) shelf of the crane A4: 1 – electrochemical cell with the corresponding electrodes; 2 – portable potentiostat; 3 – laptop with the proper software

The method of polarization resistance consists in slow polarization of the investigated metal from the corrosion potential to both anodic and cathode directions, not more than 30 mV in each side, and measuring the corresponding current. Dependence „polarization potential E – polarization current j" is linear in such potentials range for many systems metal–environment. Polarization resistance in this case is determined as a ratio of potential shift ($E_2 – E_1$) to current increment ($j_2 – j_1$). However linear area often exists on polarization curve only in very narrow range of potentials or is fully absent. In this case an inclination a tangent to polarization curve in a point which corresponds to corrosion potential E_{cor}, determines a value of polarization resistance:

$$R_p = (E_2 - E_1) / (j_2 - j_1). \quad (1)$$

The developed portable electrochemical complex consisting of a portable universal rider electrochemical cell with the chloride-silver reference electrode and the auxiliary platinum electrode, a portable potentiostat and a laptop, was used to carry out the electrochemical investigations. A peculiarity of the cell construction was the following. It was made of teflon and it had opening (16 mm in diameter) which cuddled up hermetically to a metallic surface using a rubstrip.

3% NaCl solution, which was imitated aggressive salt water, was served as a corrosion environment. Polarization curves (dependences of current of cathode and anodic electrode reactions on potential of polarization) were registered in the potentiodynamic mode at a potential sweep rate of 1 mV/s.

Research results. The correlation between R_p and *KCV* for specimens cut along rolling direction is given in [5]. However the analysis of impact strength results has shown more essential drop of *KCV* values for specimens cut across rolling direction due to operation (Fig. 2). It concerns especially the minimum values and indicates an essential heterogeneity of steel properties after degradation. For example, impact strength for the steel of the arrow of the crane A1 as a result of operation reduced in 5 times, that corresponded to brittle fracture resistance of martensite structure of quenched carbon steel. Therefore in this work the correlation between impact strength and polarization resistance as the basis for an evaluation of a metal state was built using *KCV* values obtained for the cross cut specimens.

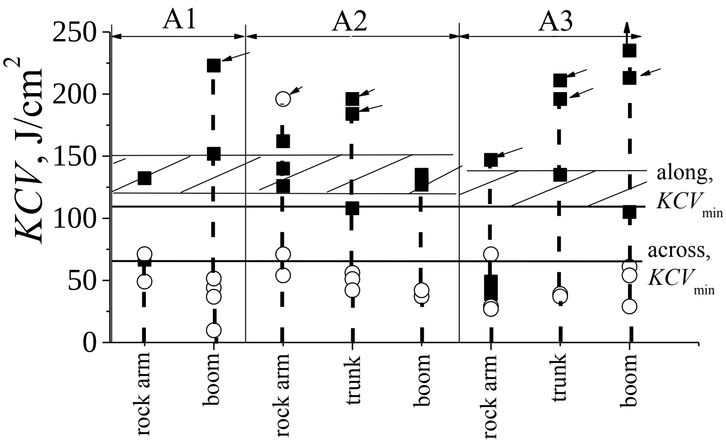


Figure 2. Impact strength *KCV* of the port cranes «Albrecht». The hatched areas correspond to the scattering of *KCV* values for the metal initial state

The obtained values of polarization resistance R_p^e and impact strength KCV^e of the steels of the different portal cranes units indicate a substantial decrease of these characteristics as a result of its long-term service (Table 1). The impact strength drops more essentially, therefore it could be considered as the most conservative informative parameter of in-service degradation of port cranes steels.

Table № 1

Mechanical and electrochemical properties of port cranes steels

Crane	Years of service	Unit	KCV^e, J/cm^2		KCV^e / KCV^0	R_p^e, Ohm·cm^2	R_p^e/ R_p^0
			min	aver.	aver.		
Initial state (St 3sp steel)			-	-	1	925	1
A1	45	Rock arm	48.5	58.0	0.89	879	0.95
		Boom	10.5	31.0	0.47	611	0.66
A2	38	Rock arm	54.0	62.0	0.95	870	0.94
		Trunk	41.5	50.0	0.77	722	0.78
		Boom	35.5	38.5	0.59	675	0.73
A3	40	Rock arm	27.0	42.0	0.64	777	0.84
		Trunk	37.5	38.0	0.58	657	0.71
		Boom	29.0	43.0	0.66	712	0.77
C1	39	Boom	49.0	61.5	0.95	827	0.89
C5	36	Boom	41.0	51.0	0.78	733	0.79

It should be noted that the correlation given in [5] between the mechanical and electrochemical parameters reflects their changes with service time in relative values. Therefore, the initial values of the proper parameters are necessary for the correlation obtaining. In this case the value of impact strength of steel St 38b-2 for the initial state KCV^0 of 65 J/cm^2 was taken as the maximum value for crane steels with taking into account the strain hardening. Concerning the R_p parameter, the value measured for St3sp steel (analogue of St 38b-2 steel) was accepted for the initial state. It means that the R_p relative change was calculated on the basis of the results of in-laboratory and field measurements (Table 1, Fig. 3).

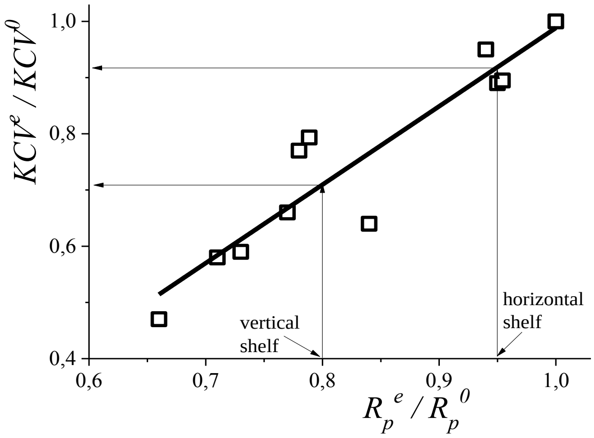
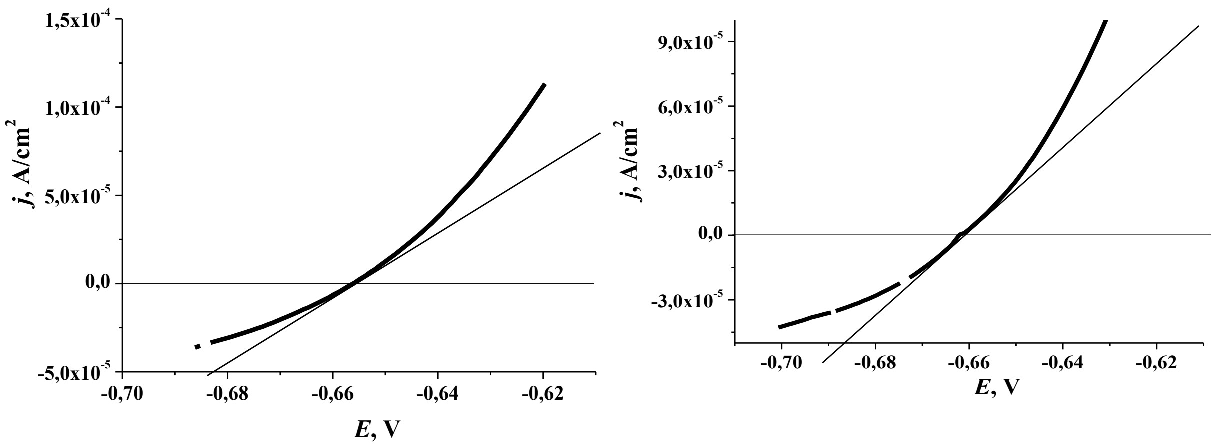


Figure 3. Correlation between relative changes in impact strength and polarization resistance (KCV^e, R_p^e – values for the steels after service; KCV^0, R_p^0 – for the initial state) for the different parts of the cranes. The levels R_p^e, obtained for the crane A4, are shown by arrows

Regardless of data variation, there is a clear tendency to decreasing of the both (electrochemical (R_p) and mechanical (KCV)) informative parameters of materials state (Fig. 3). A significant relationship between these parameters was revealed: the correlation coefficient R of 0,859 was considered satisfactory. Verification of meaningfulness of this correlation by the critical values of correlation coefficient revealed that it had nonrandom character. The approximation equation of the built correlation is obtained by the regressive analysis using the least-squares method:

$$KCV^e/KCV^0 = -0{,}41 + 1{,}39\cdot(R_p^e/R_p^0). \quad (2)$$



a *b*

Figure 4. Polarization curves for the crane A4 steel: *a* – horizontal shelf; *b* – vertical shelf

The variance analysis of this correlation revealed its high reliability (0,975). Therefore this dependence can be assumed as a basis of non-destructive electrochemical method of diagnostics of mechanical properties degradation of port crane steels.

The results of the electrochemical measurements in the field conditions on the port crane A4 are presented on the Fig. 4 for two tested positions: horizontal and vertical shelves. Two values of R_p were obtained as a result: 740 and 883 Ohm·cm^2 (Table 2). It allowed to calculate the ratio R_p^e/R_p^0, then the values KCV^e/KCV^0 were determined using the correlation (2), and finally the corresponding KCV^e values were found (Table 2, in numerator).

The proposed approach was verified by the Charpy testing of the specimens cut from the investigated units of the crane A4. The data obtained by the mechanical tests (Table. 2, in denominator) were in a good agreement with the predicted ones which are somewhat underrated comparing to the experimental values. It means that the proposed method provides the conservative estimation of the impact strength values, while their ratio is the same for the both tested units.

Table № 2

Polarization resistance in 3% NaCl solution and impact strength of the crane A4 steel

Material	R_p, Ohm·cm^2	R_p^e/R_p^0	KCV^e/KCV^0	KCV^e, J/cm^2
Horizontal shelf	883	0,95	0,916	59,5/64
Vertical shelf	740	0,80	0,707	46/50

Conclusions. The clear downward trend is revealed for the both, electrochemical and mechanical, informative parameters of in-service degradation of the steel of different portal crane parts. The graphic dependence between these parameters is built; the corresponded approximation equation is obtained and it is satisfied with a reliability of 0,975. A significance of interaction between the electrochemical and mechanical informative parameters estimated by the correlation coefficient showed its satisfactory closeness. Meaningfulness of this interaction by the critical values of correlation coefficient was clarified, it has not casual character. The obtained approximation equation is assumed as a basis of the non-destructive electrochemical method for a diagnostics of impact strength of steels. The engineering approbation of the proposed electrochemical method is performed on the crane A4, as an example, for a diagnostics of the mechanical properties in-service degradation of marine port cranes steels.

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УДК 534.134

ЗАСТОСУВАННЯ ЕЛЕКТРОХІМІЧНОГО МЕТОДУ КОНТРОЛЮ ЕКСПЛУАТАЦІЙНОЇ ДЕГРАДАЦІЇ СТАЛЕЙ ПОРТОВИХ КРАНІВ

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Резюме. *Тривала експлуатація морських портових кранів спричиняє погіршення механічних властивостей їх матеріалів, особливо пластичність та опір крихкому руйнуванню. Тому важливо виявляти не тільки експлуатаційні дефекти, але й стан металу, використовуючи неруйнівні методи. Електрохімічний підхід може бути ефективним для цього. Два параметри – механічна ударна в’язкість і електрохімічний поляризаційний опір – використано як чутливі до деградації сталей портових кранів. Ударну в’язкість визначали на зразках, вирізаних поперек напряму вальцювання, а електрохімічний опір визначали на основі побудованих поляризаційних кривих у 3%-ому розчині NaCl. Отримано чітку тенденцію до зниження обох – електрохімічного і механічного інформативних параметрів. Метод застосовано в польових умовах для прогнозування ударної в’язкості сталі портового крана, що знаходиться в експлуатації.*

Ключові слова: *портові крани, експлуатаційна деградація, механічні властивості, електрохімічні характеристики, неруйнівний контроль.*

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