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REVIEW AND ANALYSIS OF METHODS FOR ASSESSING DAMAGE TO STEEL STRUCTURES OF LIFTING MACHINES

O.O. Nemchuk[1], A.V. Konoplyov[2], O.H. Kibakov[3], I.P. Lehetska[4]
[1]DSc, Associate Professor at the Department of Lifting and Transport Machines and Engineering of Port Technical Equipment,
Odessa National Maritime University, Odessa, Ukraine,
ORCID ID: 0000-0001-5633-8930
[2]DSc, Head of the Department of Mechanical Engineering,
Odessa National Maritime University, Odessa, Ukraine,
ORCID ID: 0009-0009-9775-6018
[3]PhD, Head of the Department of Transport Machines and Engineering of Port Technical Equipment,
Odessa National Maritime University, Odessa, Ukraine,
ORCID ID: 0000-0001-8339-345X
[4]Lecturer at the Department of Lifting and Transport Machines and Engineering of Port Technical Equipment,
Odessa National Maritime University, Odessa, Ukraine,
ORCID ID: 0000-0002-0858-0770

Summary

Introduction. *In the ports of Ukraine, about 95 000 forklifts are operated, which are registered with the bodies of Derzhhirpromnadzor. In this, the majority of them (72%) developed their normative resource. The average term of their operation exceeds 30 years, and the degree of physical wear and tear approaches 90%. Replenishment of the VPM fleet is carried out mostly at the expense of equipment that was in operation, and the percentage of new equipment does not exceed 20%. It should also be noted that this situation is not the same in different ports of the country. Thus, in the Black Sea Sea Trade Port, the average service life of port transshipment equipment (PPT) is 40 years. At the same time, in the port of Pivdenny, it fluctuates and is no more than 20–30 years.* ***Purpose.*** *Taking into account the current situation, the problem of assessing the residual resource of PPT becomes urgent. It is also necessary to take into account that over-standard operation of VPM increases the amount of repair work and may pose an increased risk in the case of untimely or poor-quality repairs.* ***Results.*** *The problem related to the assessment of the residual resource by port transshipment equipment is considered. There are methods for determining damage to metal structures of cargo-lifting machines. Due to the predominance of disadvantages when using destructive control methods, non-destructive methods are increasingly being used today. They are more promising. The work considers the most used of them.* ***Conclusions.*** *There is no generally accepted approach to determining the damage of metal structures of LM today. At the same time, the existing methods have a number of significant drawbacks, which include the following: most methods are based on the application of destructive control, which entails the violation of the integrity of the examined metalwork, the need for* *subsequent repair of the element from which metal is extracted, resulting in additional costs of time and money; practically absent studies of the main steel grade (09Г2С), of which most of the load-bearing elements of steel structures of lifting machines are made. The most promising methods of damage assessment of LM metal structures are methods of nondestructive testing, in particular, the methods based on the assessment of the hardness parameters of the metal surface layer and coercive force.*

Key words: *evaluation, resource, damage, hardness, coercive force, wear, endurance limit, corrosion damage, destructive methods.*

ОГЛЯД ТА АНАЛІЗ МЕТОДІВ ОЦІНКИ ПОШКОДЖЕННЯ МЕТАЛОКОНСТРУКЦІЙ ВАНТАЖОПІДЙОМНИХ МАШИН

О.О. Немчук[1], А.В. Коноплньов[2], О.Г. Кібаков[3], І.П. Легецька[4]
[1]д.т.н., доцент кафедри «ПТМ та ІПТО»,
Одеський національний морський університет, Одеса, Україна,
ORCID ID: 0000-0001-5633-8930
[2]д.т.н., завідувач кафедри «Машинознавство»,
Одеський національний морський університет, Одеса, Україна,
ORCID ID: 0009-0009-9775-6018
[3]к.т.н., зав. кафедри «ПТМ та ІПТО»,
Одеський національний морський університет, Одеса, Україна,
ORCID ID: 0000-0001-8339-345X
[4]викладач кафедри «ПТМ та ІПТО»,
Одеський національний морський університет, Одеса, Україна,
ORCID ID: 0000-0002-0858-0770

Анотація

Вступ. *У портах України експлуатується приблизно 95 тисяч вантажопідйомних машин (ВПМ), які зареєстровані в органах Держгірпромнагляду. Більшість із них (72%) виробила свій нормативний ресурс. Середній термін їх експлуатації перевищує 30 років, а ступінь фізичного зносу наближається до 90%. Поповнення парку вантажопідйомних машин здійснюється здебільшого технікою, яка була в експлуатації, а частка нової не перевищує 20%. Варто зазначити, що ситуація в різних портах країни неоднакова. Так, у Чорноморському морському торговому порту середній термін експлуатації портової перевантажувальної техніки (ППТ) становить 40 років. Тоді як у порту Південний він становить не більше 20–30 років.* ***Мета.*** *Беручи до уваги ситуацію, що склалася, актуальною стає проблема оцінки залишкового ресурсу портової перевантажувальної техніки. Необхідно також ураховувати, що наднормативна експлуатація вантажопідйомних машин збільшує обсяги ремонтних робіт і в разі несвоєчасних чи неякісних ремонтів може становити підвищену небезпеку.* ***Результати.*** *Розглянуто проблему, пов'язану з оцінкою залишкового ресурсу портової перевантажувальної техніки. Існують методи для визначення рівня ушкодження металоконструкцій вантажопідйомних машин. У зв'язку з переважанням недоліків у разі використання методів руйнівного контролю натепер усе частіше використовують саме неруйнівні методи. Вони є більш перспективними. У роботі розглядаються найбільш застосовувані з них.* ***Висновки.*** *Загальноприйнятого підходу до визначення пошкодження металоконструкцій вантажопідйомних машин натепер немає.*

Наявні ж методи мають низку істотних недоліків, до яких можна віднести такі: більшість методів засновано на застосуванні руйнівного контролю, що спричиняє порушення цілісності досліджуваної металоконструкції, необхідність подальшого ремонту елемента, з якого проводиться виїмка металу, додаткові витрати часу та коштів; практично відсутні дослідження стосовно основної марки сталі (09Г2С), з якої виготовляється більшість несучих елементів металоконструкцій вантажопідйомних машин. Найбільш перспективними методами оцінки пошкодження металоконструкцій вантажопідйомних машин є методи неруйнівного контролю. Зокрема методи, що ґрунтуються на оцінці параметрів твердості поверхневого шару металу та коерцитивної сили.

Ключові слова: *оцінка, ресурс, пошкодження, твердість, коерцитивна сила, знос, межа витривалості, пошкодження корозією, руйнівні методи.*

In the process of LM operation, the state of their metal structures changes. In particular, metal embrittlement, reduction of its endurance limit, corrosion damage, etc. may occur. In order to determine the degree of degradation of physical properties of the metal, destructive and nondestructive methods of control are used [1].

The first ones involve tests of samples cut out of hazardous assemblies of steel structures. These methods have the following drawbacks:

- violation of the integrity of the metal structure;
- weakening of dangerous spots by repair welding;
- the cost of making and testing samples;
- the cost of repairing the damaged sections of the LM metalwork.

An alternative to these methods is non-destructive testing methods [2] which do not have these disadvantages and are therefore more promising. Among them, the most common are methods based on the analysis of the coercive force, hardness of the metal surface layer, acoustic-emission control, etc. The main requirement for the use of any parameter as a criterion in nondestructive testing is its significant, monotonic change in the process of metal degradation.

Let us consider the main methods of nondestructive testing which are currently used to predict the residual life of welded metal structures of LM.

The method of witness samples. According to this method, samples of the same metal as the structure itself are mounted in the most stressed nodes. In this case, the damage in the samples accumulates faster (due to the design features of the sample) than in the base metal. Failure of a specimen witness indicates the accumulation of a critical degree of damage in the node [3; 4]. Damage rate is understood as the value of accumulated fatigue damage, determined on the basis of the linear damage summation hypothesis by the formula:

$$D = \sum_{i=1}^{n} \frac{n_i}{N_i}, \qquad (1)$$

where n_i – current operating time in cycles at the stress level σ; N_i – life to failure at the stress level σ. Obviously, at the initial moment of time $D = 0$, and at the final moment $D = 1$.

The method of integral type sensors. This method is similar to the previous one, but in it the role of witness samples is performed by films of lead or aluminum [3; 4].

They are fixed in the most dangerous places of metal construction LM. As a result of deformation of the metal structure, the sensor is also deformed, and its deformation is plastic, which causes changes in the microstructure of the sensor. According to the state of the film metal, the damage of the LM metal is indirectly assessed. The disadvantages of this method are as follows [5]:

– the operating time of the LM metalwork until the sensors are installed is determined based on the assumption of a uniform intensity of operation, which is rather the exception than the rule;

– the sensor must work together with the metal construction for 8–12 months, which deprives the method of efficiency;

– the sensor is glued to the prestressed steel structure, so the stresses for the sensor and the element of the steel structure will differ by a constant value [6].

The magnetic method is based on the experimentally established dependence between the coercive force value and metal damage caused by changes in its structure. This method was first used to assess the damage of 09Г2С and ВСт3сп5 steels, widely used in crane construction [7; 8]. For the experiment, samples were made, which represented a welded structure of two sheets connected to each other in the joint by semi-automatic welding. The specimens were tested for tensile strength under static loading and for low-cycle fatigue strength under dynamic loading [9]. The degree of accumulated damage was evaluated according to dependence (1).

To obtain a complete picture of changes in the coercive force in different parts of the sample, microslips were made of the base metal, the metal around the weld zone and the weld metal.

The experiment showed that with damage accumulation in the metal, a decrease in the coercive force was observed in all of the above-mentioned areas.

In [10; 11] it was shown that the coercive force depends on: dislocation density, grain size, number of inclusions per volume unit, plastic deformation and internal stresses. Unlike many other methods, in particular tensometry, photoelasticity, etc., the magnetic diagnostics by coercive force react to structural rearrangement, arising residual stresses, as well as mounting stresses. Since the process of damage accumulation in the metal is continuous, the coercive force changes its value throughout the service life of the metal structure. If the quality of welds is satisfactory, it is advised to assess the condition of the joint by magnetic inspection of the base metal at a distance of 10 to 15 mm from the weld. If the weld is wide, the coercive force is checked separately – firstly on the base metal at a distance of 200 mm from the weld, and then directly around the weld and on the weld itself along the axial line. The study found that initially the value of coercive force in the weld is higher than in the base metal. At the same time, damage accumulation processes are faster in the base metal and destruction occurs at the same values of the coercive force. In spite of the mentioned advantages of the method, it also has disadvantages, as described below.

The coercive force [12] has a maximum value in the direction of the principal stresses. In this case, before starting work, it is necessary to know in advance the principal axes of stress in the investigated places. The principal axes can be determined either by calculation or experimentally (by gradually turning the magnetic poles).

The method does not take into account the change in the coercive force depending on the thickness of the metal in question, which requires the creation of tables or calibration charts to bring the values of coercive force, obtained with different thicknesses of metal, to an equivalent value.

The value of the coercive force [13; 14] is sensitive to residual and mounting stresses, which ultimately affect the accuracy of the method.

The method based on the relationship between the hardness of the metal and the degree of its damage. Experimental studies have found that as fatigue damage accumulates, the hardness of the metal surface changes [15]. Generalised results of many studies in this area are contained in [16], which formulated the following laws:

1) in the grains where the maximum stresses act, the hardness increases; with the increasing number of load cycles the volume of the metal, in which a change in hardness is observed, increases;

2) in the most stressed place, the growth of hardness gradually stops and begins to decrease;

3) metal hardness in the adjacent volumes, where the effective stresses are less than the maximum, rising as the number of cycles increases;

4) with further increase in the number of cycles, the hardness in the metal volumes with the maximum stress decreases to the original value;

5) the hardness of specimens brought to failure under different types of cyclic and static loading are very close to each other [17];

6) asymmetry of the loading cycle does not affect the character of hardness distribution along the length of the specimen;

7) increase in stress amplitude at a constant number of cycles leads to the same changes in hardness as an increase in the number of cycles at a constant stress amplitude.

Based on the above laws of hardness change under cyclic loading, we can conclude that the hardness of the metal surface layer can be an objective index, independent of the stress amplitude, average cycle stress, type of loading and changes in proportion to the damage accumulated in the metal.

The possibility of damage assessment based on measurements of metal surface hardness has been considered by many authors. Thus, in [18; 19] the dependence on the hardness of the surface layer of the metal of the welded joint was investigated. It was found experimentally that the hardness of the weld metal and the heat-affected zone is much higher than the hardness of the base metal. With the accumulation of fatigue damage, the hardness value decreases in all three zones. The maximum decrease in hardness occurs in the weld zone.

The dependence of change in hardness value on metal damage, obtained in the work, has a rather gentle part in the range of change in accumulated damage from 0,7 to 1. However, it is this low-sensitivity part of the dependence that is of main interest in evaluating the residual life of steel structures.

It was shown in [20] that the method of damage assessment by metal hardness is insensitive to the transformation of metal structure during cyclic loading. In this regard, it was proposed to use the coefficient of homogeneity and the coefficient of variation of hardness. These parameters made it possible to assess the degree of damage to the metal at the first and second stages of damage accumulation, i.e., before the main crack begins to develop [21]. The homogeneity coefficient turned out to be the most sensitive to the degree of metal damage. Its low level corresponds to a low degree of damage and vice versa.

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