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MECHANICS AND MATERIALS SCIENCE

МЕХАНІКА ТА МАТЕРІАЛОЗНАВСТВО

UDC 539.4

ESTIMATION OF THE STRUCTURAL ELEMENTS DAMAGE BASED ON COERCITIVEVE FORCE MEASUREMENTS REPORT 1. DEVELOPMENT OF THE COERCIMETRIC CONTROL METHOD FOR ESTIMATION OF METAL STRUCTURES DAMAGE DEGREE UNDER MECHANICAL LOADING

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Summary. *Analysis of the known methods of non-destructive testing for diagnosing the technical condition of critical construction elements under operation conditions is carried out by means of detection of the metal service properties degradation and the evolution of the structure and defects of various origins. It is determined that the initial structure evolution in local high-loaded areas in the course of cyclic elastic-plastic deformation results in metal solidity loss with subsequent destruction. It is shown that monitoring of the residual resource of the structure critical elements under operation conditions is usually carried out according to the techniques using special devices and equipment for non-destructive testing, which parameters change characterizes the degradation of metal mechanical properties, that is, the material damage degree. It is determined that the whole process of damage accumulation under operation conditions is divided into two main stages: the stages of cracks origin and propagation, since the laws of processes of plastic deformation and fracture under different load types have a lot in common. The influence of the load type on the origin nature and the accumulated damage type is shown. To estimate the metal damage degree under mechanical loading, non-destructive control method was used, where the coercive force was chosen as the main parameter of diagnosis, as the most sensitive to structural changes and bound by linear dependence with mechanical properties, reflects metal mechanical properties degradation and can serve as a measure of damage accumulation. It is shown that the sensitivity and accuracy of the magnetic properties (coercive force) measurement in the local surface destruction areas depends on the sensor dimensions and metal magnetizing depth. On the basis of conducted researches the developer of the device is proposed to improve the existing structroscope by reducing the dimensions of the sensor for measuring the values of the coercive force and the metal magnetizing depth. The use of improved structuroscope for coercive control under cyclic loading makes it possible to carry out complete diagnostic examination of the current state of structure elements by the same device, and not the combination of defectoscopy with defectometry, as it is done at present.*

Key words: *stroboscope, coercivity, damage.*

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Statement of the problem проблеми. Complex operation conditions of modern facilities for power engineering, petrochemistry, and transport require the application of modern non-destructive control methods capable to provide fail safe operation. Technical diagnostics is an integral part of maintenance. The main task of technical diagnostics is to ensure the safety, functional reliability and efficiency of technical object operation, as well as to reduce its maintenance cost and reduce losses from downtime due to failures and premature repairs. At present methods of technical diagnostics are the most important ones for maintenance support of complex high-tech equipment by its state [1, 2, 3]. This is evidenced by a large number of normative documents, particularly, GOSTs regulating a wide range of problems: from terminology to the classification of technical diagnosis methods of [4, 5, 6].

Analysis of the available non-destructive testing methods. Depending on physical phenomena forming the basis of non-destructive testing, and according to GOST 18353-79 nine methods are distinquished, and according to the rules of the personnel certification in the field of non-destructive testing (PB 03-440-02) of the State Technical Supervision and Control Committee eleven methods such as ultrasonic, acoustic-emission, radiation, magnetic, eddy current, by penetrating substances (capillary and flow detector), visual and measuring, vibration diagnostic, electric, thermal, optical [1, 7, 8 have been already introduced].

Unfortunately, the modern range of non-destructive testing (NT) methods makes it possible to detect only surface and internal defects existing in metal [9, 10]. The processes occurring in the metal during operation resulting in the change of metal physical-mechanical characteristics, including the preceding structure destruction, remain beyond concideration. Nowadays existing known methods of non-destructive testing (radiographic, ultrasonic, magnetic) are designed mainly for the detection and measurement of geometric defects and their location in the investigated object [11, 12, 13]. Also known are Relatively new more universal methods of non-destructive testing which make it possible to measure the structure material stress (deformation) level, detect developing defects, and to determine their coordinates, to estimate the probability of defects risk, as well as to solve other problems while estimating structures technical condition [14, 15, 16].

The disadvantage of the known methods for estimation the technical condition of welded structures by non-destructive methods involves the need for complex flaw detection using several types of NTs, since many of them are merely specific and have certain limitations [15, 17]. Many of the known methods of non-destructive testing have not been widely used, because of the availability of number of unsolved problems of theory and practice, the difficultis in identifying useful interference signals, and the lack of systematic information accesible to a wide range of specialists concerning possibilities of methods, their advantages and disadvantages, rational areas of application [17, 18]. At the same time, while detecting hazardous areas by one of NT methods, it is necessary to carry out mandatory control by other regulatory methods. The known NT methods are quite time-consuming, require surfaces preparation in the investigated hazardous areas, use expensive devices and equipment and availability of qualified specialists.

Damage to metal structures as the result of service properties degradation. While monitoring the technical condition of complex systems and aggregates, the objective timely detection of metal service properties degradation and the evolution of defects with various nature, as well as the organization of defects development control due to the elements aging during operation is one of the most important problems. One of the ways to prevent undesirable effects from the operation of products with damages and defects is to monitor the technical condition of the most dangerous structure element areas with non-destructive testing methods.

The degradation of metal initial mechanical properties, including technological origin under cyclic load conditions is usually associated with damage accumulation processes in the operating time process. Since the degree of accumulated metal structure damages during operation depends on the metal structural state and defects shape and size change, it is possible to estimate their damage degree by non-destructive testing methods responding to structural changes and defect sizes [15, 16].

The microcrack initiation, including operational and technological origin in defect areas, is often considered to be the beginning of the structure bearing capability loss, and its residual resource monitoring is usually carried out using special devices and equipment for non-destructive testing methods, which parameter changes characterize the metal mechanical properties degradation, that is, material damage degree. Bulk and surface defects density, the average distance between them, etc. are often taken as the simplest damage measure [19]. Internal friction, elasticity modulus defect, or difference between modules while stretched or compressed, sound passage speed, electrical resistance, etc. [20, 21, 22] are related as physical parameters correlating with damages. Hence, under cold plastic deformation, metal hardens and causes its physical properties change. The hardened metal stores 5−10% of energy spent on deformation and defects generation in the crystal lattice (the dislocation density increases up to 10^9–10^{12} cm^{-2}) and on elastic distortion of the lattice. The larger deformation degree, the greater strengthening of the hardened metal properties. The deformation degree increase causes strength characteristic growth but plasticity and viscosity decrease. Metal intensively hardens on the initial stage of deformation. Then, with the deformation increase, mechanical properties do not change significantly. While hardening, the hardness and boundary strength increase in 1,5−3 times, and the yield limit in 3−7 times. With the deformation degree increase, the coercive force increases, as well and the magnetic penetration and metal density decrease. When loaded, the electrical resistance of pure metals increases only by 2−6%. For steel, the electrical resistance increase becomes even less significant, and for high carbon steels the resistance decrease can occur as the result of the carbide plates destruction and reorientation. However, in spite of the plasticity lowering, hardening is widely used to increase the strength of the parts produced by the cold forming method. Particularly, the part surface layer hardening increases the fatigue resistance [23, 24].

By origin the defects are divided into production-technological occuring during the product design and manufacture, its assembling and installation, and operational ones, arising after certain product operating time as the result of degradation processes, as well as as the result of improper operation and repairs which were not detected during the product manufacturing and commissioning.

Many structure elements during operation are affected by cyclic loads and temperatures. As the result of cyclic loads impact in the most loaded areas of structural elements, especially in places of stress concentration, there is the elastic-plastic deformation, which causes the change in original metal structure and results in degradation of original mechanical properties. The evolution of the initial structure in local high-loaded areas in the course of cyclic elastic-plastic deformation results in metal weakening with pores and fatigue cracks formation (loss of metal consistency solidity), the development of which results in destruction [25]. In addition, during the product operation time, other defects may occur: fatigue cracks, corrosion damages, cracks formed from single mechanical stresses, mechanical surface damages, etc.

At present, under static and cyclic loads, the whole damage accumulation process is divided into two main stages: the stages of crack initiation and the stage of crack propagation, since the laws of of plastic deformation and fracture processes under different load types have much in common [26, 27, 28].

On the other hand, the stage of crack initiation includes the stages of static and cyclic microyield, the stages of static and cyclic yield (with the occurance of defects of atomic size and the nucleation of cracks having the size of thousand angstroms) and the stage of deformation strengthening with the submicrocracks occurence with the size of approximately 1−2 microns. While stretching the stage of crack initiation is completed reaching the maximum load and neck initiation (Fig. 1). Under cyclic loading, the stage of cyclical hardening (failure), is completed reaching the irreversible damage line (Franch line) (Fig. 2). The damage development in the form of submicrocracs formation [29] is observed at this stage along with deformation strengthening processes just as under static deformation. The stage of the fatigue cracks development is usually described by kinetic diagrams of fatigue failure (the dependence between the fatigue crack growth rate and the stress intensity range).

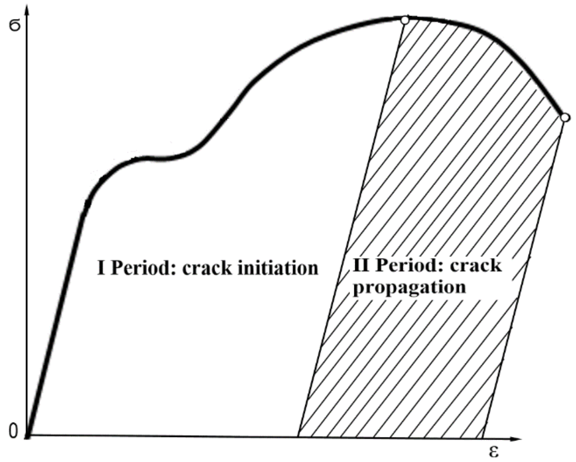

Figure 1. Periods and stages of metal damage during stretching

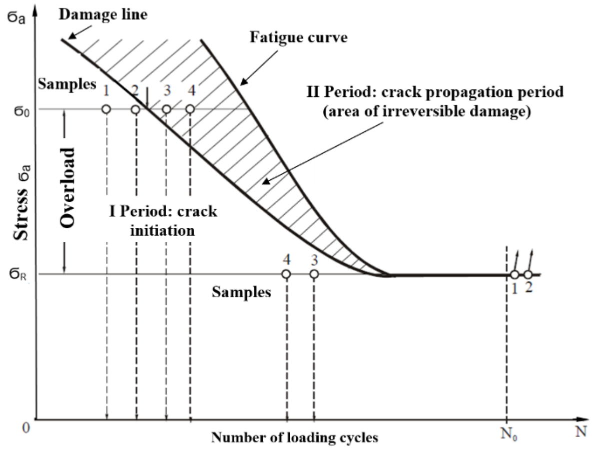

Figure 2. Scheme for defining damage line by Franch

While designing steel structures, designers usually assume metal operation in elastic deformation range and at the same time reducing the action of service loads by different safety factors. But due to the presence in certain structure areas of stress concentrators of different origin conditions for low-cycle elastic-plastic deformation occur in them. It is known [25, 30] that for the low cycle fatigue range the accumulation of two major damage types are typical: low-cycle quasi-static and low-cycle fatigue failure. The cyclic loading is possible under low-cyclic fatigue by effort (stress) amplitude control – «soft load», or by deformation amplitude control – «hard» load. Under the «soft» load, there is simultaneous accumulation of both low-cycle and quasi-static and low-cycle fatigue damages, but the relationship between them depends on the stress amplitude, the load cycle asymmetry, temperature and other factors. Quasistatic destruction in the «soft» load is due to the prevailing process of accumulation of cyclic creep deformation up to critical values that approximately correspond to the relative elongation value δ when stretching with the formation of characteristic «neck», simultaneously with the accumulation of the limited number of fatigue failures. In this case, the cyclic creep curves are characterized by the presence of all three stages: the stage of slow creep, the stage of steady creep and the stage of accelerated creep. The processes of quasistatic damage accumulation due to cyclic creep during the cyclic «soft» load are similar to the accumulation of tensile deformations. Under the «soft» load, the fatigue failure occurs on the background of accumulation of small cyclic creep deformations much smaller than the critical ones (δ), without characteristic «neck» formation and in the absence of the third creep stage as the result of the prevailing process of fatigue crack initiation and development up to the critical values. In case of «hard» loading, damage accumulation occurs only from fatigue and destruction as the result of fatigue cracs initiatin and development up to the critical values without deformations accumulation and damages from cyclic creep. If, for example, we estimate the accumulation degree of metal damage under the «soft» and «hard» loads by relative load (the ratio of the acting maximum stresses $\sigma_{\max}$ to the cyclic conditional yield line $\sigma_{0,2}^{cycles}$), then the damage accumulation kinetics has significant differences (Fig. 3). Monotonous increase of relative load during cyclic operation time is characteristic for the «soft» load, and its stability is characteristic for the «hard» load.

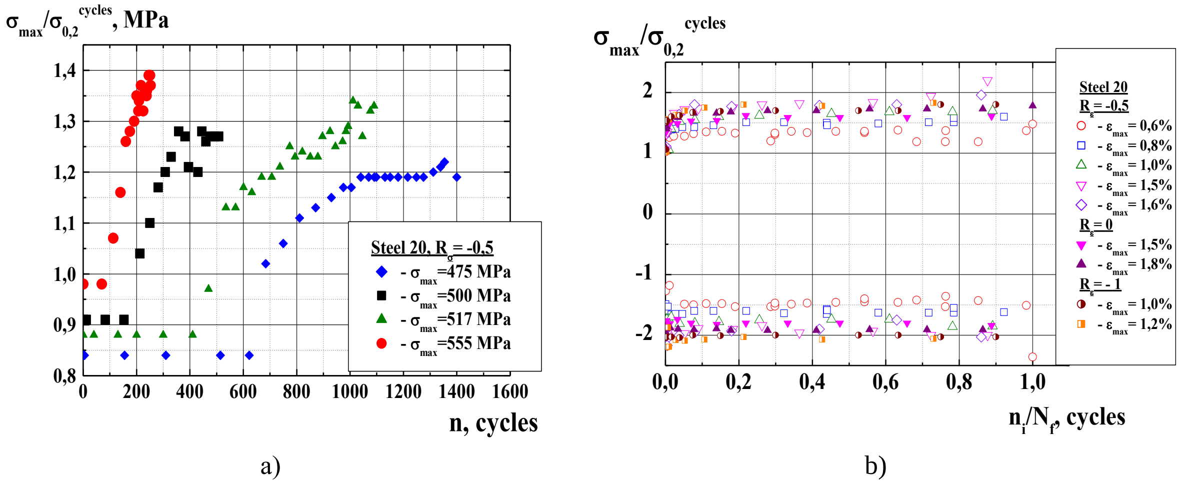

Figure 3. Differences in the nature of the relative load $\sigma_{max} / \sigma_{0,2}^{cycles}$ of metal samples made of steel 20 with «soft» a) and «hard» b) cyclic loading

Substantiation of the method of coercimetric control application for estimation the metal structure damage degree under mechanical stress. Under tension and cyclic deformation, the stress distribution along the product section is very uneven due to the presence of not only roughness and stress concentration, but also plastic deformation of the part surface, which is very heterogeneous both on the surface and in depth and under the conditions of homogeneous stressed state starts earlier than in its core [31]. Carried out experimental investigations proved, for example, [32] that under homogeneous stress state conditions, the surface layer in low carbon steel has yield limit 25% lower than that of the base metal, and according to some other data [33], the yield limit of the thinnest samples is only 20% of the for thick sample size. In this case, the plastic flow passes through the surface, when the core is in elastic state. For these reasons, during cyclic deformation, as a rule, the destruction always begins from the surface in local areas.

Since the coercive force value depends on the deformation level, then in view of the above mentioned curcumstances, the material surface layers under static and cyclic loading begin to deform earlier and accumulate damage than the base metal, which causes the uneven distribution of magnetic properties along the surface and the cross section of the products. In this regard, the accuracy of magnetic properties (coercivity) measurement in local surface areas will depend on the sensor dimensions and metal magnetization depth. Therefore, while studying the mechanical properties of metals by changing the coercive force values in the most damaged local zones of surface layers, it is necessary to use structural (coercimeters) with small-sized sensors of shallow magnetization.

Among the other known non-destructive testing methods, the most sensitive to mechanical loads is the coercive force, which depends on the density change in the the steel dislocation structure under static and cyclic deformation. Therefore, in order to monitor the damage degree of the most dangerous local areas of structural elements during operation, the coercive force was selected as the main magnetic parameter being the most sensitive to structural changes and bound by linear dependence on mechanical properties.

Among the other methods of non-destructive testing, the precise measure of metal structure damage, especially of austenitic stainless (initially non-magnetic) steels, is very advantageous. According to the data obtained in [34], plastic deformation of austenitic steel

AISI 304 increased the value of the coercive force by 10−30 times and the volume of the ferromagnetic phase (α-Fe) by 15−150 times as regards the initial state. However, as further investigations have shown, the initiation and development of pores or cracks (loss of metal consistency) in the mechanical loading process causes significant decrease in the coercive force values under prolonged increase in ferromagnetic phase (α-Fe) volume. It follows that the danger degree of permissible metal deformation of real structures can be estimated by changes in coercive force (metal magnetic properties) size. Such information sensitivity of the coercive force to the processes of metal strength properties change has not yet been determined by other methods of non-destructive testing.

The use of coercive testing under cyclic loading conditions makes it possible to carry out complete diagnostic examination of the current state of structural elements, but not the mixture of defectoscopy with defectometry, as at present.

In engineering practice, ferromagnetic and paramagnetic austenitic steels are widely used in metal-consuming welded structures, which have significant differences in the response of coercive force to mechanical loads.

The response of coercive force to mechanical loads of ferromagnetic steels is related to changes in metal domain structure with arranged domain orientation (from chaotic to directed). At the same time, the coercive force response to the mechanical stresses of paramagnetic in the austenitic steels initial state, which is associated with structural transformations of the original austenite $\gamma \rightarrow \alpha$ into deformation martensitic with finite ferritic-perlite decay, which causes metal magnetic properties change from paramagnetic to ferromagnetic state was determined. Due to the significant physical differences in coercive force response to mechanical loads of ferromagnetic and paramagnetic steels, the main attention in this paper was paid to the experimental investigations contrasting on physical properties in the initial steels state.

In connection with the significant differences in the effect of mechanical load type on the formation of accumulated damage type experimental investigations of the laws of coercive force response on the contrasting load type damaging effects that determine the contrasting types of damage accumulation: quasi-static damage − under static and cyclic stretching (without the influence of fatigue failure) and fatigue damage − in the case of «hard» alternating cyclic deformation (without impact of accumulated damage cyclic creep deformation) at the stages of cracks initiation and development were carried out in this paper.

Coercimetometric control Method. The method of diagnostics the product technical condition consists of carrying out preliminary SSS calculations for determination of the most loaded local metal areas of the structure and further measurement of coercive force values on these surface areas. Since the value of coercive force depends on the magnet pole tip orientation relatively to the acting stress direction, then while diagnosing the product technical condition in the most dangerous local areas, the measurement of *Hc* values on the surface should be carried out in 4 directions when the sensor is rotated through each 45^0 relatively to the previous measurement with further refinement of maximum *Hc* values direction In order to estimate the technical condition of the most dangerous areas during structure operation, it is necessary to monitor regularly the coercive force values with its kinetics construction. The obtained results serve as data for further estimation of product technical condition.

While monitoring the structural elements technical condition by measuring the coercive force values in varying the position (orientation) of the magnet pole tips of the poles of the sensor relatively to the investigated surface, it is possible to determine the most deformed and damaged zones, with the determination of the main stresses direction, and to detect metal non-continuity in the form of pores or cracks (including surface and subsurface). By changing the coercive force kinetics direction during loading process, it is possible to simplify significantly the definition of endurance boundary and establish the stages of damage accumulation: the growth of *Hc* values corresponds to the elastic-plastic deformation (the stages of cracks initiation), and the decrease of their values is associated with the loss of metal consistency with the of pores and cracks occurrence (stages of crack development).

Determination of damage accumulation kinetics staging by means of coercive force at fatigue makes it possible to estimate the cycle life not along the metal fatigue curve (destruction), as adopted in engineering practice, but at the stage of crack initiation along the irreversible damage curve (Franch line), which significantly reduces the risk of destruction. By the size of coercive force on the ascending or descending curve sections it is possible to estimate metal residual strength.

Determination of the values of coercive force on the surface of the product or laboratory sample consists of the magnetization of the metal to saturation, its demagnetization with subsequent magnetization by magnetic field of opposite polarity to neutralize residual magnetism and to measure *Hc* values. Cycle duration for determination of coercive force values is 10 seconds. It should be noted that the change in the orientation direction of the sensor magnet pole tips relatively to the investigated surface affects the coercive force value.

While carrying out the previous investigations the possibility of using coercimetric control, as one of the types of non-destructive methods, for the metal damage estimation during static and cyclic loading, KRM-TS-K2M structurescope equipped with two sensors having 65 mm (D65) measurement base and magnetization depth up to 30 mm and the sensor having 27 mm (D27) measuring base and magnetization depth up to 4 mm (fig. 4) was used. Here the distance between the outer edges of magnet pole tips was assumed as the measurement base.

Figure 4. The photo of KRM-TS-K2M structurescope with sensors having 65 mm (D65 to the right) measuring base and 27 mm (D27 to the left) measuring base

Using structurescope with sensors having 65 mm and 27 mm measuring bases, it was found that the decrease in coercive force measuring base and, consequently, metal magnetization depth, increases the absolute *Hc* values (increases the measurement location) and thus increases the reliability of the data obtained in local areas (Fig. 5). Therefore, the authors proposed the device designer the to develop and manufacture the device with minimum sensor size and low magnetization depth. As the result, the device designer developed and produced improved magnetic KRM-TS-K2M structurescope with the sensor (D12) having 12 mm measuring base and magnetization depth up to 1 mm (Fig. 6).

Data of coercive force *Hc* dependence on the sensor sizes, which also determine the magnetization depth, under cyclic deformation of laboratory sample made of AISI 304 steel, with $\varepsilon_a = \pm\, 0{,}4\%$ deformation amplitude, are shown in Fig. 5. Flat laboratory samples with operating part dimensions 28x14x3.6 mm were used as investigated object. It should be noted that break point of the coercive force kinetics curve according to the number of cycles of low-cycle «hard» load with 0.2 Hz frequency indicates the change in the predominant form of accumulated damages.

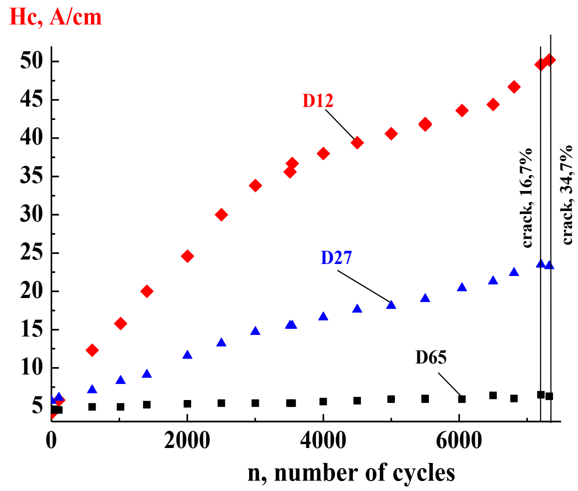

Figure 5. Dependence of *Hc* coercive force value on sensor dimensions the during cyclic deformation of laboratory samples made of AISI 304 steel, with the deformation amplitude $\varepsilon_a = \pm 0{,}4\%$

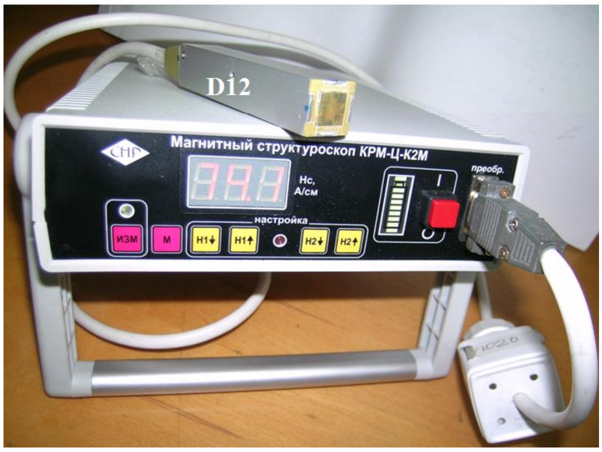

Figure 6. Photo of the magnetic KRM- TS -K2M structurescope the with small-sized non-deep magnetization sensor with 12 mm (D12) measuring base (the sensor is located on top of the device)

Since, under cyclic loading conditions, the destruction, as a rule, occurs from the surface in local zones, then the use of the developed structurscopee with small-sized sensor of shallow magnetization D12 makes it possible to fix the coercive force kinetics, which reflects the metal structure changes and, relatively, the damage accumulation in local surface volumes.

In order to investigate the physical nature of the coercive force response to mechanical stresses, investigations of metal structure change were also carried out by means of measuring the ferromagnetic phase (α-Fe) volume in austenitic steel by Ferritghaltmesser 1.053 Forster ferrite meter.

The use of the developed method for monitoring the most loaded areas in critical structure elements makes it possible to specify experimentally the location of these areas and destruction ones, including determination of initiation stages (elastic-plastic deformation) and the subsequent damage development (the stages of of pores and cracks development) in these areas by the same the device The use of coercimetric control makes it possible to control the product technical condition and have time to determine the type and amount of repairs, their planning and organizing, or at a certain stage of operation, if possible, reduce the level of structure load. Measuring the coercive force values does not require special preparation of the product surface (removal of paint and protective coatings, for example, for sensor D65 having thickness up to 6 mm) and presence of specially trained highly qualified specialists.

The main difference between the proposed method for structural elements diagnostics under operation conditions from other non-destructive testing methods is the possibility of monitoring the technical state of certain most dangerous local metal areas not depending on the type of damage produced at different stages of cracks initiation and development of cracks by simple method using the same not expensive device.

Due to the significant differences in coercive force response to the mechanical loads of ferromagnetic and paramagnetic steels, appropriate experimental investigations, which results are presented in report 2 and report 3 were carried out.

Conclusions. Analysis of the known non-destructive testing methods for diagnostics of technical condition of the structure critical elements under operation conditions by determining the metal service properties degradation and the evolution of the structure and defects of various origins is given.

The experimental substantiation of the possibility to estimate the damage degree of metal structures made of paramagnetic and ferromagnetic steels is carried out according to the results of coercive force measurements.

Significant physical differences in the nature of the response of the coercive force of metal structures made of ferromagnetic and paramagnetic steels to mechanical stresses are specified. The change of magnetic properties during austenitic steel deformation (paramagnetic in the initial state) is due to the given steel tendency to structural transformations (paramagnetic) austenite $\gamma \rightarrow \alpha$ and the occurence of the ferromagnetic phase (α-Fe) formed in austenitic steel (γ-Fe) and consists of martensitic − and ferrite-deformations causing metal transition from paramagnetic to ferromagnetic state. In ferromagnetic steels, during deformation, the magnetization growth is connected with the domain orientation arrangement (from chaotic to directed).

The experimental substantiation of the need to improve the device for expanding its capabilities is made by reducing the sensor base for coercive force values measurement the under mechanical load. It is proposed to the manufacturer to develop and produce the improved device with minimum base for coercive force values measurement.

The improvement of the device sensor made it possible to determine the damage level distribution along the product surface and the kinetics of their accumulation in the most loaded areas of structural elements by means of coercive force values in the metal surface local areas. This given reason during the product make it possible to estimate the damage degree (of different origin) of the metal structure by means of simple non-destructive instrumental method by the same device.

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ДО ОЦІНЮВАННЯ ПОШКОДЖЕНОСТІ ЕЛЕМЕНТІВ КОНСТРУКЦІЙ ПО ВИМІРАХ КОЕРЦИТИВНОЇ СИЛИ ПОВІДОМЛЕННЯ 1. РОЗРОБЛЕННЯ МЕТОДИКИ ВИКОРИСТАННЯ КОЕРЦИТИМЕТРИЧНОГО КОНТРОЛЮ ДЛЯ ОЦІНЮВАННЯ СТУПЕНЯ ПОШКОДЖЕННЯ МЕТАЛУ КОНСТРУКЦІЙ ПРИ МЕХАНІЧНОМУ НАВАНТАЖЕННІ

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Резюме. *Наведено аналіз відомих методів неруйнівного контролю для діагностування технічного стану відповідальних елементів конструкцій в умовах експлуатації шляхом виявлення деградації службових властивостей металу й еволюції структури та дефектів різного походження. Встановлено, що еволюція вихідної структури в локальних високонавантажених зонах у процесі циклічного пружно-пластичного деформування призводить до втрати суцільності металу з наступним руйнуванням. Показано, що моніторинг залишкового ресурсу відповідальних елементів конструкцій в умовах експлуатації зазвичай проводять за методиками з використанням спеціальних приладів і обладнання неруйнівного контролю, зміни параметрів яких характеризують деградацію механічних властивостей металу, тобто ступінь пошкодження матеріалу. Встановлено, що увесь процес накопичення пошкоджень в умовах експлуатації поділяють на дві основні стадії: стадії зародження і стадії поширення тріщин, оскільки закономірності процесів пластичного деформування і руйнування при різних видах навантаження мають багато спільного. Показано вплив виду навантаження на природу походження та вид накопичених пошкоджень. Для оцінювання ступеня пошкодження металу при механічному навантаженні використовували неруйнівний метод контролю, де основним параметром діагностування обрана коерцитивна сила, як найбільш чутлива до структурних змін і пов'язана лінійною залежністю з механічними властивостями, відображає деградацію механічних властивостей металу і може слугувати мірою накопичення пошкоджень. Показано, що чутливість і точність вимірювання магнітних властивостей (коерцитивної сили) в локальних поверхневих зонах руйнування буде залежати від габаритів датчика і глибини намагнічування металу. На основі проведених пошукових досліджень розробникові приладу запропоновано удосконалити наявний структуроскоп шляхом зменшення розмірів датчика для вимірювання значень коерцитивної сили та глибини намагнічування металу. Використання удосконаленого структуроскопу для коерцитивного контролю в умовах циклічного навантаження дозволить проводити повноцінну діагностичну експертизу поточного стану елементів конструкції одним і тим же приладом, а не сумішшю дефектоскопії з дефектометрією, як це має місце сьогодні.*

Ключові слова: *структуроскоп, коерцитивна сила, пошкодження.*

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