Long-range fields of internal stress and estimation by spectral-acoustic method

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Safe exploitation questions of technical devices of hazardous production facilities (TDHPF) are high-attentioned in the whole world. The present situation in Russia is: more than 80 % of technical equipment works over its working life, and more than 90% of equipment - in power industry. Destroying of technical equipment or its elements can lead to a serious technogenic accidents escorted by human victims and often results in it. That is why the problem of safe exploitation of potential hazardous production ensuring is especially actual. In present this problem resolves to technical engineering procedure complex. Safety can be defined not only by equipment operation level and by opportune leading of maintenance and restore working. Industrial safety and technical diagnostic operation examination becomes the most important term for real technical devices condition of the present moment in time. This way acoustic methods of nondestructive testing are perspective. One of the most important advantages is opportunity of surface defects control in materials using Rayleigh waves (surface acoustic waves - SAW). It is known that microdefecting accumulation inside the different components and assemblies of industrial hazardous production is mostly located in surface layer and SAW method can reveal and define the limiting condition of metal materials.

In our opinion, truth of the trial and research result quality to define the limiting condition can be raised and estimation labour input lowered essentially when opportunity of synergetrics and modern information technologies and nanotechnologies is used.

According to foregoing the object of the present work is researching of thermal stability steel structural-phase condition and welded joints structural-phase condition on different stages of life cycle. It is necessary for limiting condition complex acoustic criterion development.

1. Conceptual model of industrial safety

On the first stage of present research the conceptual model of safe exploitation control was developed and new methodological approach for metal condition estimation and its serviceability based on acoustic method was offered. It has allowed to reveal missing information interrelations between acoustic characteristics and microstructure parameters and to show the quantitative description opportunity for the first time.

The system approach (methodology IDEF0 standart) and structured analysis (Structured Analysis & Design Technique) [2, 3] were used in present work. As it was noticed above, safe exploitation of technical equipment depends of big number of factors, that is why such a main function extraction as “to develop the technical equipment safe exploitation of hazardous industrial objects” is logical. The contextual (parental) diagram or the diagram-ancestor is presented on fig. 1.

The basic interactions (arrow) which activate the basic function are certain and described.

As result a technical equipment working life resource (WLR) (before exploitation on hazardous production facilities) is chosen. Set for this characteristic depends of employed materials, chemical composition, heat treatment condition, physicomechanical properties, and also vector $\{\alpha_1, \alpha_2, ...\alpha_{i,j}...\} = \{\alpha_i\}$ of such a exploitation parameters set as temperature α_1, intrinsic pressure

(for pipe-lines) α_2, r.m.s. voltage level α_3, kind of stressed-deformed condition α_4, corrosive medium α_5 e t.c. ($/\alpha_i$) is conditional index or index of condition of influence of a vector $\{\alpha_i\}$.
As result of present function execution we can hold the exploitation equipment term, but the certain operating time at the set parameters (or at their changes and infringements) to consider. Both of arrows on a block output mean that the resource after the certain operating time can be presented in one of two kinds: residual resource or individual residual resource (RR) ***($/\alpha_i$)*** and after-repair resource (AR) ***($/\alpha_i$)***.
As the after-repair resource appointed term of operation of unit or detail of the technical device after its repair or after replacement is understood. Repair or replacement is conducted in case of exhaustion of detail or unit resource or after its destroying. According to technological and normative documentation requirements technical equipment exploitation (A1) is conducted, with the set of the demanded parameter g_{mp}, when conditions and modes are actual (E). This conceptual model of safe exploitation direction for the first time has been developed and added by new functions, which describe laws of acoustic characteristics change depending on a structural condition, physicomechanical properties and accumulated microdamages, and also developed complex acoustic estimation criterion of a limiting condition of long-term working technical equipment metal.
In opinion of authors mathematical models and limiting condition criterion initial data for development of a definition technique limiting condition of long-term working technical equipment
$$\Omega = \min\{V^{ÀÑ}(g); V^{EÌ}(g)\} < V(g^{òð})$$
V – indirect (instrumental) characteristic index, AC – acoustic characteristics, EM – proximate method limiting condition term. Model decomposition leaded up to stages and phases level of examination execution and acoustic method development. For example one of decompositions, which describes acoustic characteristics determination for estimating the microstructure condition, on fig. 2 represented.
The proved and chosen method of acoustic structuroscopy (AC), physicomechanical properties and also results of metallophysical research of steel (PM) represents initial data for metal condition the acoustic characteristics to determinate. For learning communications between different blocks of developed model special determinations were done.
As at forecasting working capacity, limiting condition determination, residual resource of metal TDHPF macromechanical settlement methods are applied. In practical materials the change of structural-phase condition and accumulation of microdefects have a microlevel to occur. In the present work the electronic-microscopic investigation (research) long-term working metal on different stages of life cycle for limiting condition determination.

2. Substructure character of long-term working metal

At long exploitation of TDHPF by one of the defining factors providing reliable and its accident-free work, the structural condition of steel is. The investigation of damaged bending (flexed section) 12X1MΦ steel of steam line Tom'- Usinskaya state regional power station after 241 537 exploitation hours microstructure character and internal stress in investigated metal to reveal. As have shown, conducted electronic-microscopic researches the high enough dislocation density, equal $(3{,}5\text{–}6{,}5)\cdot 10^{14}$ m^{-2}, in all investigated steam line bending section is contained. With dislocations interaction some types of dislocation substructures are formed simultaneously: mesh dislocation substructure; fragmented one; substructure with high oxidation density; predestruction substructure (microcracks); substructure with micropores in materal [4, 5, 6]. Cracks are observed or on borders of grains in those places where large carbides M23C6 settle down in the form of chains (fig.3, *a*), or in those places of a material in which there is a congestion of large carbides (fig. 3, *b*).

Besides, research of the damaged welded joints of the main steam line of the block №7 on Tom'-Usinskaya state regional power station is executed (steel 12X1MΦ, ∅ 325x43mm after an operating time 198 000 h. at temperature and with a steam pressure 140 kg(f)/cm^2). Irrespective of a place of research basic phase making (matrix) of welded joints of steel 12X1MΦ is the α-phase. Morfologically the α-phase is generally present at various samples in the form of: 1) ferrite grains (least defected part of material); 2) fragmented ferrite; 3) defected ferrite (parts of material with high dislocation density and high bending-torsion of the crystal lattice) and 4) parts of material with microcracks.

It is established, that the scalar density size of dislocations in the basic metal and in metal of a seam is practically identical, and in a zone of destruction (on coast of a crack) size ρ in 1.6 times is less. The size of bending-torsion amplitude of a crystal lattice has the least value in the basic metal. In a zone of thermal influence it is above in 1,7 times. In welded joint the local internal pressure considerably above true breaking points for this steel [5] (local pressure more than at 8-12 time surpass strength). Microcracks in a zone of destruction leads to localization of internal pressure and, naturally, to growth of their size. On the contrary, high fields of pressure engender microcracks, etc. Thus, presence at long-term working basic metal and welded joints of local fields long-range interaction of pressure of greater quantities is one of principal causes of microdefects formation, its growth, development and destruction of potentially hazardous equipment [5, 6].

3. Estimation of a metal condition by spectral-acoustic method

Using acoustic multifunctional spectral system "Astron" the research of damaged elements of power equipment, specified above, and also chromomolybdenumvanadium steel pipes in a various structural condition and with various long durability after greater terms of operation for revealing laws of acoustic characteristics change of depending on microstructure parameters for acoustic criterion limiting condition development.

The analysis of the big number of experiments has shown, that decrease of long durability, increase in term of equipment time operation of a ultrasonic superficial waves delay (SAW) W increases. In some kinds of steel, for example for steel 12X1MΦ, between the damaged structure and a metal microstructure an initial condition 170 nanoseconds (fig. 4) reaches. It is established, to increase in size of local internal pressure fields (average bending-torsion of a crystal lattice) there is a growth of time of SAW delay that explains relaxation of ultrasonic fluctuations sources (concentrators) internal pressure fields, and with decrease in source density, reduction of bending-torsion of a crystal lattice and sizes of local internal pressure fields the relaxation degree of ultrasonic fluctuations decreases also time of a delay of SAW falls.

Results of research show high sensitivity of a spectral-acoustic method definition of microstructure parameters change.

For the damaged welded joints the results received by electronic microscopy method have been compared by a spectral-acoustic method.

Emphasize, that the researches executed by spectral-acoustic and electron-microscopic methods have been lead on the same sample and in the same sections of the destroyed steam line welded joint from steel 12X1MΦ. The SAW delay time measured in the basic metal, a zone of thermal influence and metal of a seam changed in a range up to 80 nanoseconds. Maximal time of a SAW delay was observed on a section of the specimen in a zone of thermal influence and welding metal, the maximal amplitude of local internal pressure fields is fixed, in this zone - the volume fraction of carbide phase δ_{carb} is maximal.

Growth of average local internal pressure fields leads to increase in a volume fraction of material structure hazardous to destruction (sections of a defective α-phase and microcracks). On the other hand, growth of internal pressure leads to increase in SAW delay time that is caused by ultrasonic fluctuations relaxation on sources of internal pressure fields to which we carry grain borders and fragments, particles of carbids on borders and inside of grains and fragments, microcracks.

Proceeding from conceptual model, the analysis of research results the complex (acoustic) criterion of a limiting condition [7] has been developed. For size of a damage level the SAW delay time attitude during the moment of diagnosing W_τ by time of a delay at the metal which has settled the resource (was accepted at presence of microcracks) W_f in view of SAW delay time in metal with an initial structure condition W_0.

The complex criterion of a limiting condition (CCLC) has been expressed as:

$$K_f = \frac{W_\tau - W_0}{W_f - W_0} \cdot \frac{W_f}{W_\tau} \cdot \gamma$$

γ =1,0 – 1,1 – factor considering a controllable element material

The physical sense of criterion consists in the ratio of SAW speeds $W_0^{-1} - W_\tau^{-1}$ with an absolute range of speeds $W_0^{-1} - W_f^{-1}$.

CCLS, expressed in relative units, allows to judge quantitative damage section and to stop operation TDHPF for replacement of a controllable element, proceeding from a parity.

The received criterion has been approved at research is long working of bending and direct sections of steam line and steam cross-over pipes and three destroyed bending power stations and the industrial plant of Siberia. Data of acoustic characteristic measurement give good concurrence to results of metalographic researches [7, 8]. Especially to emphasize, that, having applied the developed method, it is possible to reduce considerably amounts of works at examination conducting.

Conclusions

1. The conceptual model consisting of diagrams, the text and the terminological dictionary, executed in the formalized kind and presented is developed by functions, each of which reflects a real condition of long-term working metal in all stages of life cycle TDHPF.
2. Communications between density of contours of the bending-torsion created by sources of internal fields of pressure, quantity of these pressure and long durability in heatproof chromomolybdenumvanadium steel are established.
3. In metal of long-term working technical equipment of hazardous industrial objects change of a microstructure, accumulation structural damage while in service leads to change of acoustic characteristics. By a spectral-acoustic method it is established, that maximal SAW delay time is fixed in a zone of thermal influence of welding and caused by easing of ultrasonic fluctuations on sources local long-range fields of internal pressure.
4. On the basis of the developed conceptual model, the analysis of results of electronic-microscopic researches, measurement of acoustic characteristics and definition of physicomechanical properties the complex criterion of a limiting condition (CCLC) is developed is long-term working metal of technical devices of hazardous industrial objects.

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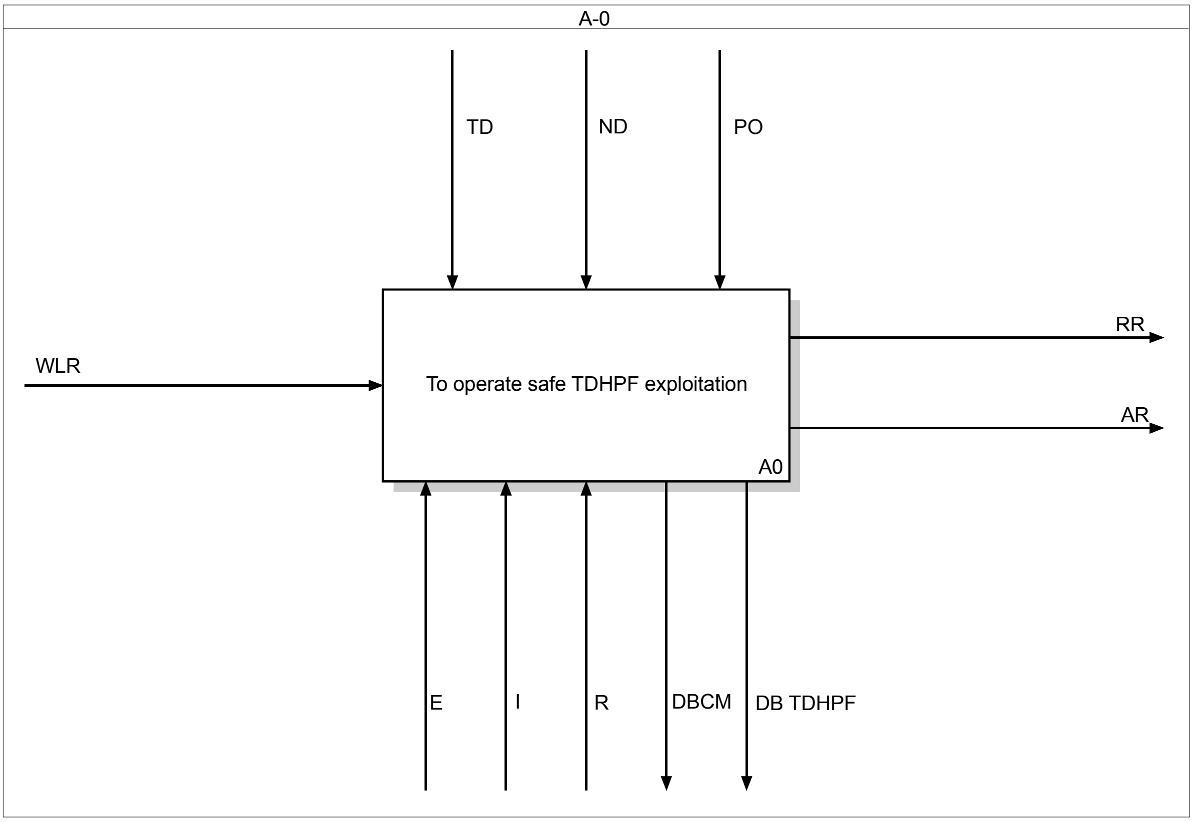

Fig. 1. Safe exploitation TDHPF contextual diagram

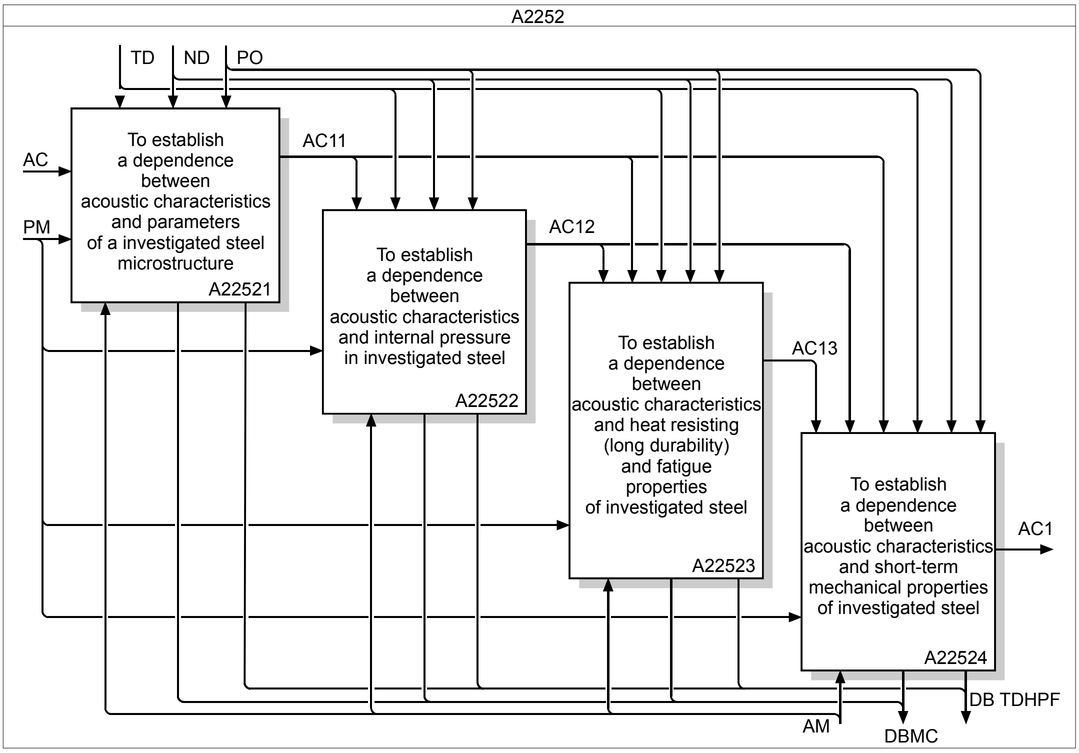

Fig. 2. Determination of investigated steel acoustic characteristics (decomposition of A2252 block)

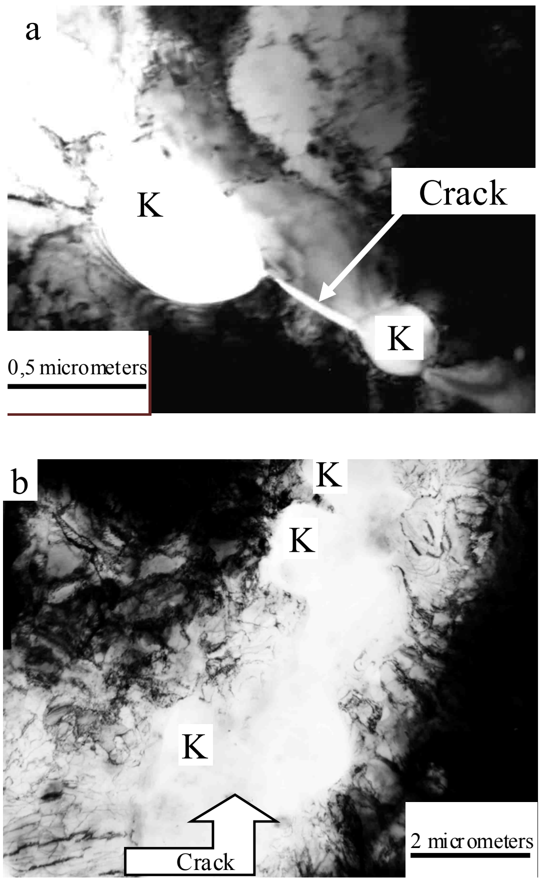

Fig. 3. Cracks between carbides (*a*) and cracks in places of a large carbides congestion (*b*)

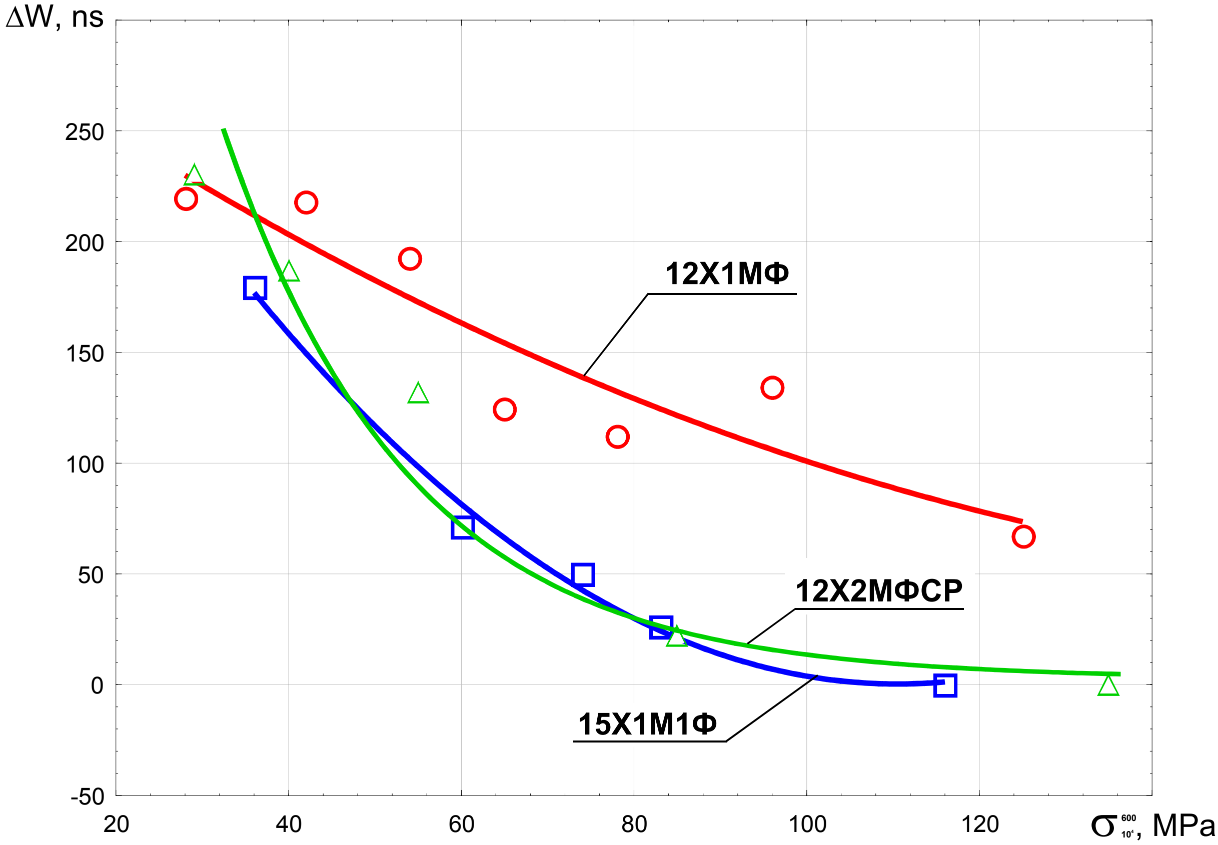

Fig. 4. Communication of investigated steel long durability with SAW delay time