Conceptual model of resource assessment of fuel and energy complex long working equipment on the basis of structural criteria

A N Smirnov¹ and N V Ababkov ²
¹ Professor, Department of Engineering Technology KuzSTU, Kemerovo, Russian Federation
² Associate Professor, Department of Engineering Technology KuzSTU, Kemerovo, Russian Federation

E-mail: n.ababkov@rambler.ru

Abstract: The main approaches to the technical diagnosis and assessment of residual life of potentially dangerous equipment FEC, currently in use. A new conceptual model resource assessment of parts and units of fuel and energy complex. On the issue of technical diagnostics are considered in complex positions.

Introduction
Currently, over 80% of Russian industrial equipment worked his expected life for the fuel and energy complex (FEC) – more than 90%. And the destruction of the technical devices or their components may result and lead to major technological catastrophe with human victims. It is therefore particularly relevant is the task of providing (control) the safe operation of potentially dangerous equipment [1–3].

There are many complex physical and chemical processes related primarily to the collapse of part of the pearlite microstructure, coagulation and spheroidization carbide formation of micropores, or wedge-shaped microcracks in the metal during long-term operation of equipment FEC at high temperatures and pressures.

The decay rate of the microstructure formation and growth of micro depends on the temperature and the operating pressure, in addition, an important role has the number of starts and stops of the equipment.

Highly topical issue of developing new effective methods to assess the resource elements of technical devices based on the evaluation of structural-phase state and the strength characteristics of the metal power equipment after prolonged use. More widespread receives concept based on "prediction and prevention" instead used the concept of "find and fix" [4].

There are a large number of theoretical and experimental studies to evaluate resource efficiency, reliability, durability and other characteristics of long working metal potentially dangerous equipment currently. The fundamental work of schools academics Makhutov N.A. [5] and Mitenkov F.M. [6] are of particular note among of them.

Makhutov N.A. and Gadenin M.M. consider questions of a technical diagnosis of residual life and security in terms of assessing the risks of dangerous conditions, which are defined as the product of the probabilities of their occurrence in the corresponding damage arising from reserves of strength, stability, resource, survivability in statistical or deterministic setting [5]. In other words, the analysis...
methods of mathematical statistics and probability theory is subjected to large amounts of data on a particular hardware. On the calculation of added analysis of possible equipment damage from an accident. According to these calculations carried ranking objects by hazard class.

The concept of residual life assessment of equipment and systems of nuclear power plants are developed by Mitenkov F.M. et al [6]. The definition of the actual model of operation (FME) and the physical law of damage accumulation $\omega$ is at the heart of this concept:

$$\omega = \sum \frac{\Delta V}{V_f};$$

where $V$ – volume fraction of defects, $V_f$ – critical volume fraction of defects.

From Eq. 1, the use of a physical law of damage accumulation accounts for only a fraction of defects that can detect modern methods and means of nondestructive testing. The concept of residual life assessment of equipment and systems of nuclear power plants are not talking about changing the structural and phase state of the metal in the process of long-term operation.

As we know, no technique, no algorithm for calculating the residual resource does not take into account the changes that occur in the metal structure in the long-term operation of technical devices of hazardous production facilities. As an example, the calculation of resource drums high-pressure boilers. According to regulatory documents [7] resource drums high-pressure boilers is determined by the value of the accumulated damage to the metal (2):

$$A = 2 \frac{n_{ss}}{N_{ss}} + 0,08 \frac{n_{ss}}{N_{hs}} + \frac{n_{ss}}{N_{h}} + \frac{40n_{ss} + \omega \tau}{N_{f}},$$

where $n_{ss}$ – the number of start-stop drum; $N_{ss}, N_{hs}, N_{h}, N_{f}$ – number of cycles for the start-stop mode, heat stroke, hydro and temperature fluctuations, respectively; $\omega$ – frequency thermal cycling drum during the operation of the boiler at steady state; $\tau$ – time between the drum.

The Eq. 2 shows that the extension of the resource drums high pressure boiler is taken into account only the factors relevant to the modes of operation of the equipment. Structural changes in the metal for long term use are not included.

**Theoretically part**

The authors propose a slightly different approach to equipment life assessment based on structural factors.

It is obvious that the total time of the safe operation of the equipment (3) consists of equipment operating time before the survey (current state) $\tau_{cur}$ and further operating time before reaching the limit state $\tau_{res}$ (residual life):

$$\tau_{l.s.} = \tau_{cur} + \tau_{res},$$

There are complex physic-chemical and structural changes in metal equipment, spent a long time in a complex stress conditions, often in hostile environments (before the survey). The structure is an important indicator of the metal is characterized by its performance. All kinds of thermal effects and loads are recorded in memory of the metal at the time of diagnosis, which was exposed to the metal, since its fabrication and finishing a certain period of operation (in our case – $\tau_{cur}$).

It is very important to understand and appreciate these changes. However, structural-phase state of the metal after hours ($\tau_{cur}$). Is one side of the issue. On the other hand, to assess the real resources must also take into account the macro defects (sometimes they are valid, often they are not eliminated, but just missed), resulting in the manufacture, repair, equipment operation during $\tau_{cur}$. These defects have a significant impact on the accuracy of the estimates of the resource.

The current state of the equipment at the time of diagnosis characterizes the ratio of its current condition of $K_C$ in this case, which can be represented as
where \( K_{\text{str}, \text{c}} \) – structural metal ratio in the current state, \( K_{\text{op}} \) – coefficient taking into account operating modes (temperature, pressure (load), cyclicity, environment) \( K_{\text{def}} \) – coefficient taking into account the presence of defects in workmanship, installation and repair of the base metal and welded joints. \( K_{\text{str}, \text{c}} \) determined by the nature of changes in the structural-phase state and the internal stress fields, the redistribution of sources of stress fields and their density. \( K_{\text{str}, \text{c}} \) can be expressed as a function of parameters of the structure in the form of

\[
K_{\text{str}} \rightarrow f(\sigma_{\text{in}}, \tau, \rho_{\pm}, \rho, \mu, d_{\text{gr}}, \gamma_{\text{c}}),
\]

where \( \sigma_{\text{in}} \) – the amplitude of the internal stress, MPa; \( \tau \) – shear stresses; \( \rho_{\pm} \) – excess dislocation density; \( \rho \) – scalar dislocation density; \( \mu \) – source density fields of internal stresses; \( d_{\text{gr}} \) – grain size; \( \gamma_{\text{c}} \) – coefficient taking into account the size and nature of the distribution of carbide phases in the metal.

For each class of materials we are developing engineering methods for calculating the structural factor. For earlier [8] studied the authors proposed structural steels factor which is fulfilled in the long running heat-resistant steels of fuel and energy complex at all stages of the life cycle (from the initial state to the ultimate state and destruction, which has the following form

\[
K_{\text{str}} \rightarrow f(\sigma_{\text{in}}, \tau, \rho_{\pm}, \rho, \mu, d_{\text{gr}}, \gamma_{\text{c}}),
\]

The structural factor must be determined on equipment operated in difficult stressful conditions at high voltages and temperatures, cyclic and shock loads in corrosive environments, in periods of routine maintenance (specified period of diagnosis, developed a certain period).

To determine the actual condition of the equipment, except for the structural factor must be considered and modes and installation, repair and metallurgical defects, and accumulated operating defects, and already the basis upon which the coefficients. Therefore, to determine the need to define the \( K_{\text{c}} \), \( K_{\text{def}} \) and \( K_{\text{op}} \).

The operating conditions of the equipment, \( K_{\text{op}} \) can be represented as a coefficient that depends on the number of cycles (\( N \)), pressure or load (\( P \)), temperature (\( T \)), corrosive environments (\( L \)).

Hence \( K_{\text{op}} = K_{N} K_{P} K_{T} K_{L} \) the numerical values of the coefficients are presented in the table.

\[
K_{\text{def}} = K_{\text{met}} K_{\text{rep}} K_{\text{inst}}
\]

The values obtained experimentally.

**Table.** Symbols and values of the coefficient

| №  | Symbol of the coefficient | Value of the coefficient | Condition                              |
|----|---------------------------|--------------------------|----------------------------------------|
| 1. | \( K_{T} \) – ambient temperature | 1.0                      | Operation in stationary mode at design parameters |
|    |                            | 1.2…1.4                  | Significant violations temperature regimes, overheating |
|    |                            | 1.1                      | Slight temperature changes              |
| 2. | \( K_{N} \) – cyclic recurrence | 1.0                      | Calculated modes, start-stop            |
|    |                            | 1.2…1.3                  | Violations cycling modes                |
|    |                            | 1.05…1.1                 | Minor violations                        |
| 3. | \( K_{L} \) – aggressive environment | 1.0                      | Calculated environment                  |
|    |                            | 1.2…1.4                  | Aggressive (major changes), unplanned environment |
| №  | Symbol of the coefficient | Value of the coefficient | Condition                                      |
|----|--------------------------|--------------------------|------------------------------------------------|
|    |                          |                          | Minor violations of environment parameters    |
| 4  | $K_p$ – pressure or load | 1.0                      | Estimated operating modes                      |
|    |                          | 1.2…1.4                  | Significant variations in pressure or load     |
|    |                          | 1.05…1.1                 | Low pressure drop or load                      |
| 5  | $K_{inst}$ – installation defects | 1.0                      | No visual defects welds normalized hardness    |
|    |                          | 1.3                      | Unrepaired defects mounting form welds, hardness, kinks, bends (on the verge of admission) |
|    |                          | 1.05                     | Minor defects (valid), small dents, scratches, allowable weld defects |
| 6  | $K_{met}$ – defects of metallurgy | 1.0                      | The suggested structure, normal mode of heat treatment, the hardness in the normal |
|    |                          | 1.1                      | Large metallurgical defects, bundles, nonmetallic inclusions, stripes, polishing defects, etc. |
|    |                          | 1.05                     | Slight defects                                 |
| 7  | $K_{rep}$ – repair defects | 1.0                      | No defects                                      |
|    |                          | 1.1                      | Removable repair defects, weld shape, hardness, bending |
|    |                          | 1.05                     | Removable, allowable defects                   |

As previously mentioned – $K_c$, the coefficient that characterizes the technical condition of the object of control at the time of inspection. While maintaining at least a relative constancy $K_{op}$ and $K_{def}$ and throughout the life of the equipment and in the first approximation can be written

$$\frac{\tau_{res}}{\tau_{cur}} \approx \frac{K_{1,s} - K_c}{K_c}, \quad (7)$$

where $K_{1,s}$ – coefficient of the technical status of the equipment at the time of the limit state. It requires a highly individual approach, but given the level of exploitation and accumulation of defects in the same equipment at close lifetime. The determination of this factor analysis was performed on the basis of operating conditions (calculated coefficients $K_{op}$ and $K_{def}$).

The structural factor limiting state was evaluated by the results of the research base metal and welded joints of equipment overage. From the Eq. 7, having a small mathematical transformations and substituting in the formula calculation results and research, we get the desired result – the remaining time of the equipment.

$$\tau_{res} = \frac{\tau_{cur} (K_{1,s} - K_c)}{K_c}, \quad (8)$$

The authors created a database on equipment FEC of Kuzbass, have a lot of research on the study of mining equipment at present. The proposed methodology has a significant disadvantage in the complexity of determining the structural criteria. Necessary to satisfy the costly electron microscopy studies.
There are several ways free from this drawback. The most promising is the development of non-destructive evaluation of physical methods of structural changes. For a number of steel (such as Cr-Mo-Va steel), we have developed acoustic and magnetic structural damage assessment criteria [8–10]. There is the need to perform standard electron microscopy studies for each grade of steel, but in any case (to avoid large errors).

For practicing engineers developed an atlas of histograms, by which, with the knowledge of the structural factor, the operating conditions of equipment (after an analysis of the repair and maintenance documentation) expert finds the histogram lifetime (resource) of the technical device.

This methodology does not exclude holding standard NDT methods, they complement the results of our tests, at their expense introduced clarifying amendments to the corresponding coefficients.

**Conclusion**

1. The main approaches to the technical diagnosis and assessment of residual life of potentially dangerous equipment FEC, currently in use. It is shown that the existing methods and techniques of assessment of the resource does not take into account the behavior of the structural-phase state, methane (decay of the structure, changes in local internal stress fields) of both primary and weld metal during prolonged operation in difficult and stressful conditions in hostile environments.

2. A conceptual model for evaluating the long-term resource working metal objects FEC, based on the study of the evolution of structural and phase state of metal. The structural factor taking into account the nature of changes in the basic parameters of the structure of metal in the process of long-term use, which together with the regime coefficients and imperfection makes it possible to reliably estimate the share of thermal power equipment.

3. For various FEC equipments held a range of additional studies involving non-destructive research methods are developed and the coefficients of the histogram using which increase the reliability of resource estimates.

The work is financially supported by project RSF №14-19-00724

**References**

[1] Kljuev V V 2012 Degradacija diagnostiki bezopasnost (Moscow: Spektr) p. 128.

[2] Smirnov A N, Vasil'ev A G and Shevelev E V 2000 Ocenka stepeni povrezhdennosti dlitel'no rabotajushhego metallja jungerooborudovaniya akusticheskim metodom Vestnik Kuzbasskogo gosudarstvennogo tehnikeskogo universiteta 5 p 46.

[3] Smirnov A N and Ababkov N. V 2010 Kompleksnyj podhod k ocenke rabotosposobnosti jelementov jenergeticheskogo oborudovaniya Ezvestija Samarskogo nauchnogo centra RAN, T. 12 №2 (2). – pp 520–524.

[4] Smirnov A N 2004 Strukturajna povrezhdennost' stalej i ee ocenka spektral'no-akusticheskim i jelektrono-mikroskopicheskim metodami Kontrol'. Diagnostika 4 pp. 13–18.

[5] Mahutov N A and Gadenin M M 2011 Tehnicheskaja diagnostika ostatchnogo resursa i bezopasnosti (Moscow: Spektr) p. 187.

[6] Mitenkov F M, Kajdalov V B, Korotkih JU. G and etc. 2007 Metody obosnovanja resursa jadernyh jenergeticheskikh ustanovok (Moscow: Mashinostroenie) p. 448.

[7] SO 153-34.17.442-2003. Instrukcija po porjadku prodlenija sroka sluzhby barabanov kotlov vysokogo davlenija.

[8] Uglov A L, Erofeev V I, and Smirnov A N 2009 Akusticheskii kontrol’ oborudovaniya pri izgotovlenii i ekspluatatsii (Moscow: Nauka).

[9] Ababkov N V, Kashubskij N I, Knjažkov V L, Knjažkov A F, Kozlov JE V, Koneva N A, Makarov N M, Murav'ev V V, Popova N A, Smirnov A N, Fol'mer S V 2011 Diagnostika, povrezhdajemost’ i remont barabanov kotlov vysokogo davlenija (Moscow: Mashinostroenie) p. 256.

[10] Smirnov A N and Ababkov N. V 2013 Kriterii ocenki sostojanija i resursa dlitel'no rabotajushhih barabanov kotlov vysokogo davlenija Svarka i diagnostika 4. pp. 55–58.