UDC 620.197:621.774

Metrological Aspects of Pipe Corrosion Resistance Estimation in the Electric Power Installation

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The potential metrology errors that appear when estimating the state of corrosion-resistant pipe surface, namely roughness, indices of general and pitting corrosion are analyzed. It is shown that for determination of technological manufacturability of high-duty pipes with enhanced corrosion resistance it is necessary to follow the possibilities of surface microrelief 3D - analysis. It will enable to describe the surface in the initial state and in the process of service as well as to work out methods to remove disadvantages.

Keywords: PIPE, SURFACE, MICRORELIEF, PITTING CORROSION

Introduction

The problem of limited durability of pipes applied in thermal and atomic engineering becomes more urgent each year. A considerable economic benefit achieved at successful solution of this problem is mentioned in numerous publications on this subject. Many investigations and design projects in this area are focused on raise of durability and operate reliability of pipes used as constructional elements of electric power plants: zirconium alloy covers of fuel elements of atomic furnaces, stainless steel and titanium alloy pipes applied on thermal and atomic power stations for vapor condensation and heating of feed water, various carbon steel boiler tubes.

The patent survey shows that the most of scientific publications are oriented on creation of new corrosion-resistant Zr-alloys [1]. The actuality of this trend is explained by rather early fracture of fuel element covers due to the formation of local corrosion centers. It is assumed that atomic furnace performance and expenditures connected with nuclear-fuel reprocessing can be increased and lowered respectively due to raise of corrosion stability of fuel elements.

The problem issues related to durability of condenser and preheating pipes as well as their economic value are studied in details in [2]. It is noted that in this area the key problem of operate reliability of electrogenerating plants is insufficient operational durability of pipes. And in [3] it is mentioned that corrosion failure is related to the whole complex of technology factors featured for current manufacturing method of these pipes.

Stress corrosion problem in pipes used in various heat exchangers is not solved yet. In particular, the project presented in [4] is devoted to this problem. The authors consider that more thorough knowledge of stress corrosion mechanism in the pipes will allow its effective control. It is reported that implementation of this project will provide only in the USA annual energy saving above 20×10^6 Btu at simultaneous decrease of greenhouse gas atmospheric emissions more than 300 thousand tons [5].

With some share of simplification it is possible to assert that solution of this problem needs a system approach and can be observed as a consecutive solution of the following problems:

- reliable description of initial pipe surface condition and revealing of technological possibilities to improve it;
- estimation of local corrosion center

topography in the initial stage of formation,

- definition of corrosion change dynamics in a time while in service;
- forecasting of achievement of critical level failure value proceeding from service conditions.

The solution of such problems requires proper measuring devices for collecting and processing great volumes of information with the use of up-to-date software. First of all, it is necessary to have reliable data on topography of surfaces subsequently subjected to corrosion environments.

Results and Discussion

<u>Method of internal pipe surface microrelief assessment</u>

When producing high-duty pipes, methods of their internal surface condition estimation are crucial. This problem is considered in [6]. There are a number of contradictions in the present standards which cast some doubt on reliability of results of microrelief estimation, and set parameters of pipe surface condition almost cannot affect their operational properties, including corrosion resistance.

Parameter R_a determined proceeding from the possibilities of pipe production process is taken as a basis in most present standards and specifications regulating the condition of pipe internal surface. As applied to shell-type zirconium alloy pipes, this parameter is within the limits from 0.3 to 1.5 microns in various standards.

In Ukrainian and Russian specifications on stainless steel coiled tubing applied in electric power plants this parameter is at the level $\leq$ 1.5 microns. At the same time, as applied to stainless steel pipes used in food, pharmacological, semi-conductor and other industries that require especially high sterility, this parameter is within the limits $\leq$ 0.3 microns. It is necessary to note that such pipes are not produced currently neither in Ukraine nor Russia. Prescribed parameter R_a defines necessity of using strip chart recording based on stylus method developed in 30s of the last century. It consists in the application of thin needle moving across a surface and observing its deviations. Subsequently this technique was essentially improved and applied till now. A number of additional parameters are obtained at profile diagram processing.

Not talking about adequacy of parameter R_a, we note that this parameter is mentioned not to cover corrosion resistance of metal surfaces as well as potential errors which can appear as a result of wrong measurement direction in a number of publications. In particular, necessity to choose measurement orientation which should be carried out perpendicularly to direction of the main deviations of surface is ignored when estimating a microrelief of internal pipe surface. However, in many cases scanning is carried out in the longitudinal direction. As a result, there are significant errors. They are caused by longitudinal topography clearly observed in hard-wrought pipes shown in **Figure 1**. In these cases the measurement path passes through crests or dimples of surface, and the real results are distorted and do not cover its real structure.

At the same time, the measurements in the transverse direction showed that R_a values exceed this parameter stipulated in current specifications in more than 10 times, and electrolytic potential measurements of stainless steel pipes from such surface are close to carbonaceous grades [3].

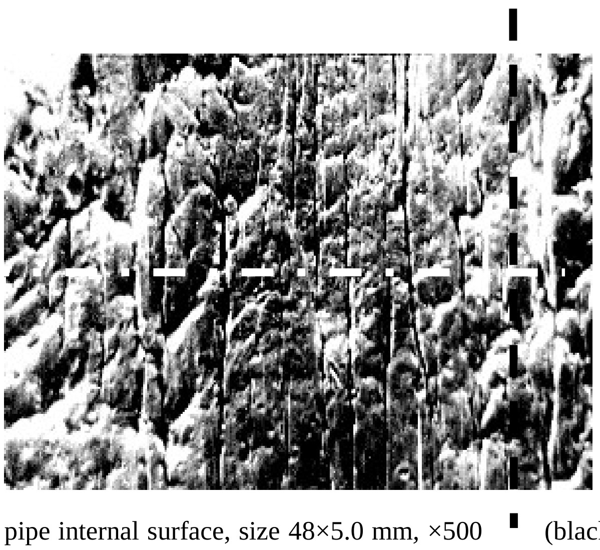


Figure 1. Dot area of cold-rolled pipe internal surface, size 48×5.0 mm, ×500 (black dotted line - longitudinal orientation of measurement path, white dotted line - transverse orientation)

Other potential reason of metrological errors is selection of measurement path length, cut-off step and characteristics of filters.

The standardized values of these parameters are formulated as applied to stationary profiles with clear-cut components formed mainly during mechanical operation - machining, milling, polishing. Plastically deformed surfaces have absolutely other structure of deviations, a considerable amount of casual components in the form of local ravines which can become the potential corrosion centers and further fracture. Out-of-roundness profile of pipe internal surface presented in **Figure 2** is indicative of this.

One more serious lack of strip chart recording is impossibility to reveal the local pits which are the elements of pitting corrosion. It is caused by sizes of contact sensor (needle) and software used in up-to-date profilographs.

Potential errors of corrosion parameters and corrosion stability evaluation

Methods of corrosion parameters and corrosion stability evaluation are defined by standard GOST 9.908-85.

In this document, the continuous corrosion value is recommended to define as weight loss per unit surface area. However, it is well-known that at action of corrosion environments the surface peaks are intensively etched at the initial stage and only after a while local pits appear. It is still not clear how to divide these components as applied to the surfaces with casual components, for example characteristic for pipe internal surface. This moment is a potential source of metrological error.

Other reason of potential errors is corrosion spot square definition method. It is recommended to apply planimeter for these purposes, and if such measurement is impossible, a square of corrosion spot is computed. At the same time, evaluation of corrosion spot square in the internal pipe surface by means of the planimeter is completely eliminated due to profile cross-section curvilinearity. And generally corrosion spots have a free shape and their approximation will inevitably lead to significant errors.

Recommendations on pitting corrosion evaluation also have problems. In particular, it is underlined that the maximum depth of pitting corrosion is defined by:

- "measurement of the distance between plane of mouth and bottom of pitting after removal of corrosion products by mechanical indicator with mobile needle-shaped stylus in cases when pitting size allow stylus to reach pitting bottom". Permissible dimensions of the indicator are not specified.
- "microscopically, measuring the distance between plane of mouth and pitting bottom (double focusing method) or on the crosscut metallographic specimen at corresponding amplification".

In this case, estimation error will be related to pitting sampling subjected to measurement. Cross profile of cold-wrought pipe internal surface is illustrated in **Figure 3**. Other sections of the standard also have such drawbacks. Out-of-date requirements of pitting corrosion resistance test methods of corrosion resistant steel and alloy

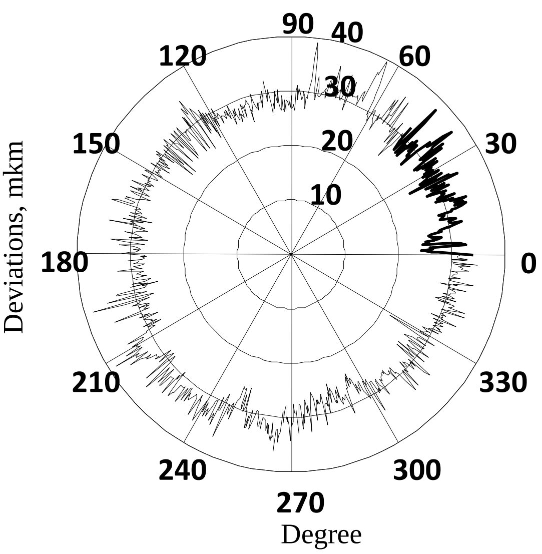


Figure 2. Out-of-roundness profile of cold-rolled pipe cross-section 25×1.65 mm, steel X18H10T

of current standard 9.912-89 are also beneath criticism. It is recommended to use the average conditional rate of pitting corrosion as evaluation method in given GOST. This rate is defined as a change of metal weight from sample surface unit per time unit. At the same time, it is not clear what is better at equal rate: a great number of small pittings or less of deep pittings? All mentioned conditions are often not considered [7] which can inevitably lead to erroneous results.

Possibilities of 3D - surface analysis

Every year 3D – surface analysis becomes more widespread. The international standard “Surface texture: Terms, definitions and surface texture parameters” has been put in action recently. This standard is necessary because of rapid development of nanotechnologies that need high accuracy evaluation. At the same time, mass production of optical profilographs and corresponding software capable to process great volumes of measuring information has been started.

Standard ISO/25178-2 regulates: signs of surface structure**,** terms used for its parameters definition, classification of measurement methods, nominal performance of contact and contactless measurement**.** This standard introduced new parameters.

Examples of using pipe internal surface 3D - analysis

Some examples of using 3D - analysis as applied to estimation of high-duty pipe quality are presented below.

Estimation of surface uniformity

Pipe making methods from zirconium alloys provide application of spray acid etching at the final stage of the process. Defects formed in the internal surface during rolling are removed. To estimate its efficiency the microscope pictures of Zr1Nb alloy pipe internal surface are made at different amplification.

Processing of obtained pictures provided determination of entropy values of gray-scale pictures. According to [8] entropy is a statistical characteristic of random nature which can be used to describe the structure of image. Entropy value was defined using expression - sum (p.*log2 (p)), where p - bar diagram of picture deviation.

Obtained results are presented in **Table 1.** It is possible to draw a conclusion that noticable change

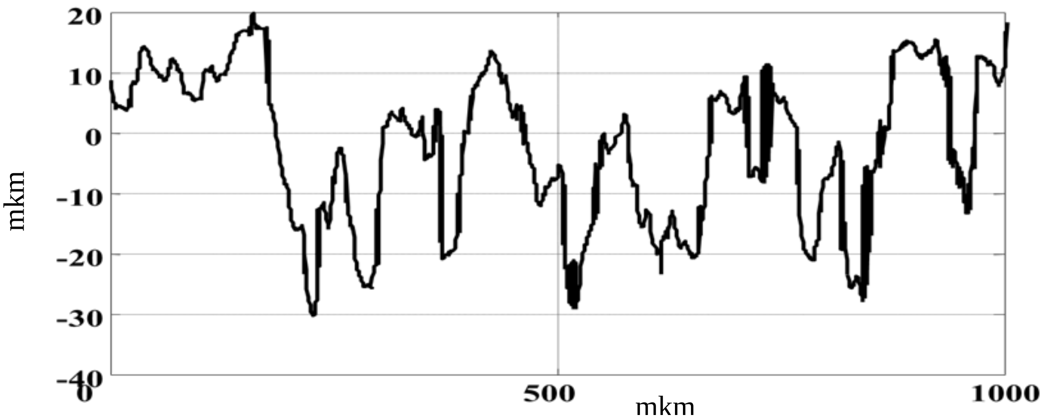


Figure 3. Deviation of cross profile of pipe internal surface 25×1.65 mm

Table 1. Entropy of pipe internal surface 17 x 1.9 mm, alloy Zr1Nb

Surface characteristics	Surface condition					
	After rolling			After heat treatment and etching		
	× 200	× 500	× 1000	× 200	× 500	× 1000
Measurement	0.65	0.26	0.13	0.65	0.26	0.13
Image size, mkm	345×546	15×0220	75×110	337×550	14×6220	72×110
Entropy	55.9	48.4	47.6	45.5	43.6	45.42

of surface inhomogeneity occurs in macroareas and is almost constant on the local sections.

Interconnection between microrelief and microstructure

Other instance of successful 3D - analysis application is interconnection between microrelief of pipe internal surface and metal microstructure. A number of publications cover interconnection between metal microstructure and its corrosion properties, including [9]. The pictures of microrelief and microstructure of Zr1Nb alloy pipe 9.1×0.7 mm are shown in **Figure 4** to understand the mechanism of such regularity as applied to zirconium alloy.

Further we estimated the standardized autocorrelation functions (ACR) for deviations relating to both secants. ACR diagrams are illustrated in **Figure 5**. ACR pattern shows the periodicity of microstructure and microrelief. Spectral concentrations shown in **Figure 6** are defined to determine amplitude-frequency characteristics of deviations.

Determination of contact areas

At metal flow the formation of surface microrelief depends on the contact between tool and deformable metal. In general, the formulation this problem is similar to determination of corrosion center square.

Initial picture of pipe internal surface in the grey shade scale obtained by means of scanning microscope is shown in **Figure 7** at amplification × 1000. The size of analyzed section is 90×122 micron.

The same section is shown in **Figure 7 a** in binary aspect with white contact zones. Digital processing of binary image showed that the contact area was approximately 37 % from the total surface of analyzed section.

It is quite obvious that estimation of total square of contacts using GOST 9.908-85 is not real in similar cases.

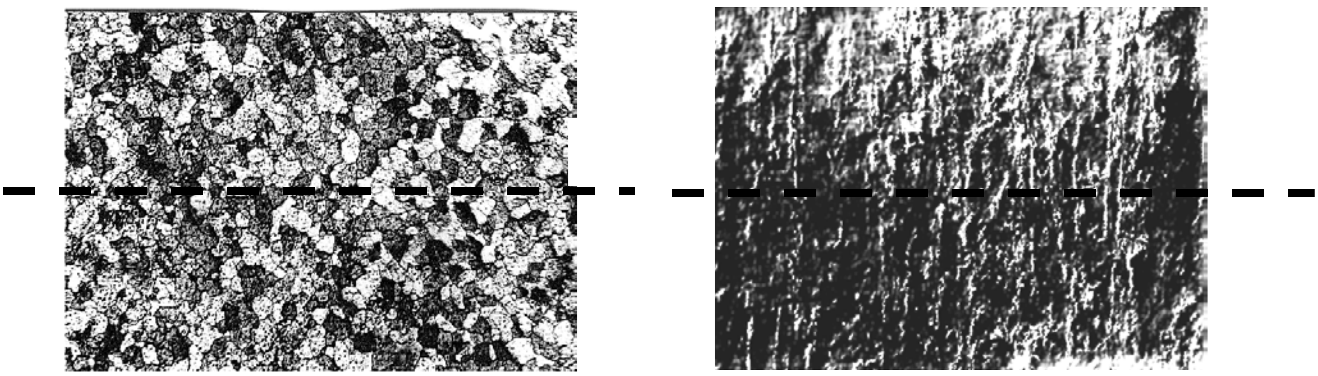


Figure 4. Microstructure × 400 (a), microrelief × 200 (b) and secants of pipe internal surface 9.1×0.7 mm, alloy Zr1Nb

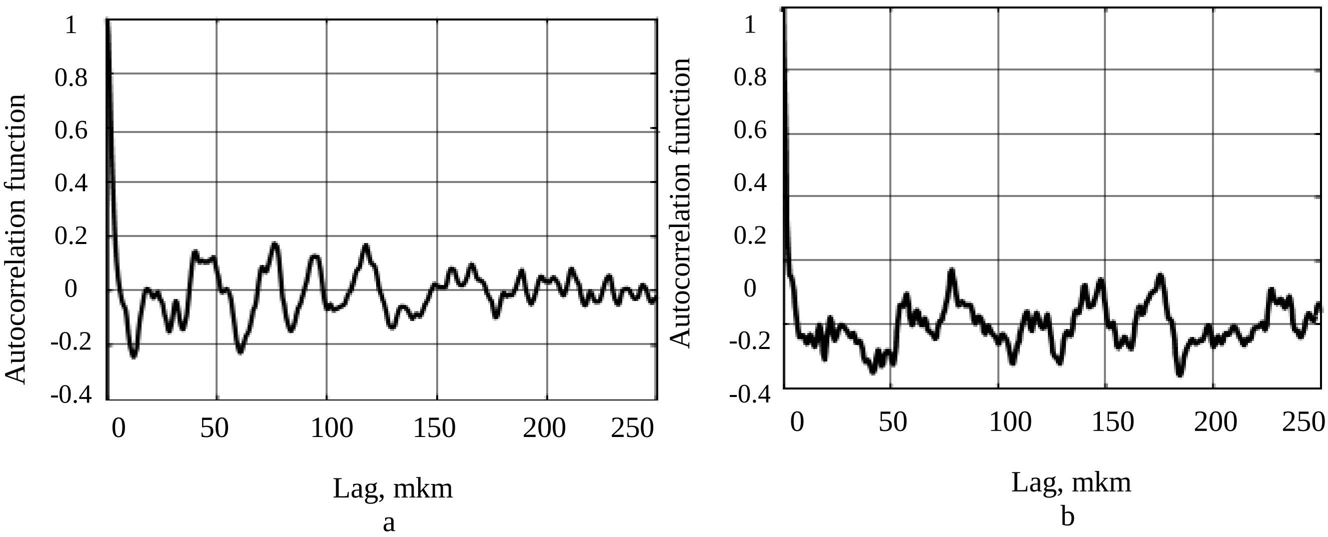
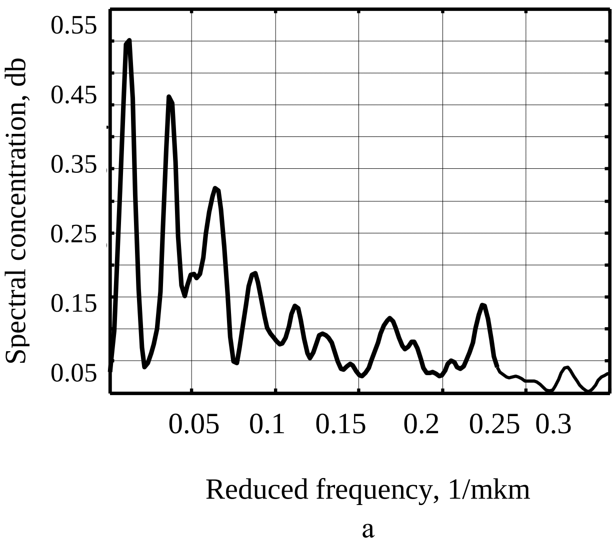


Figure 5. ACR of profile deviations relating to secants of microstructure (a), microrelief (b)



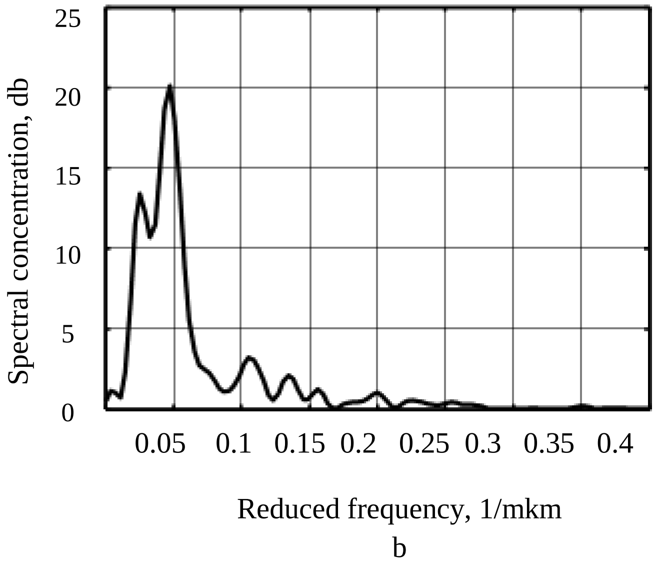
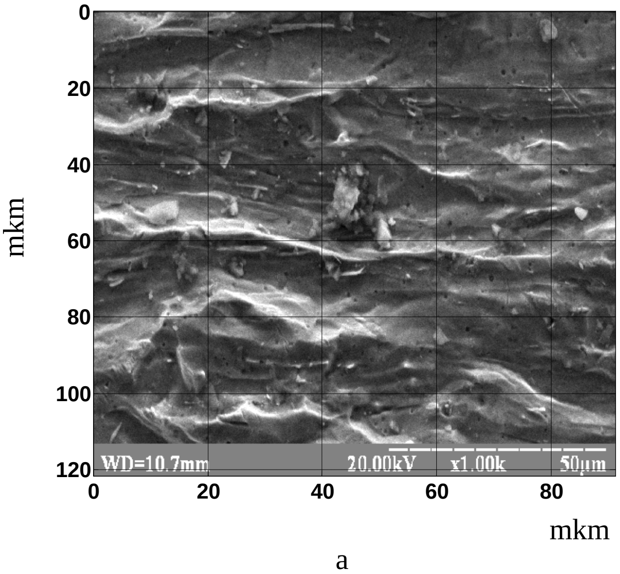


Figure 6. Spectral concentration of profile deviations relating to secants of microstructure (a), microrelief (b)



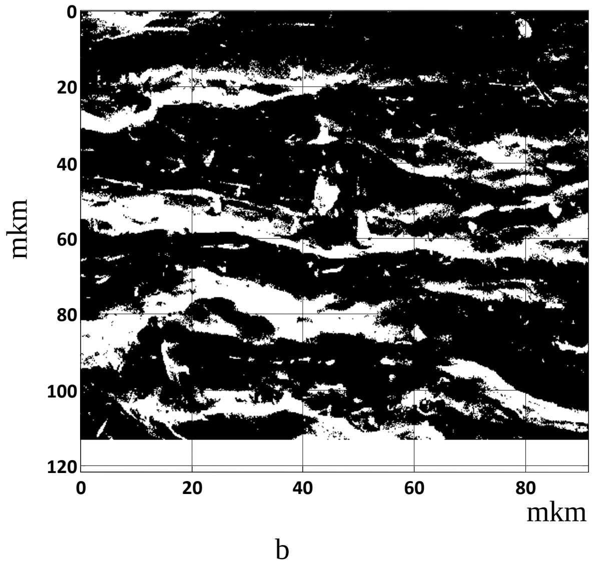


Figure 7. Pipe internal surface 25×1.5 mm in gray shade scale (a) and in the binary image (b), amplification × 1000

Conclusions

The estimation method of high-duty pipe internal surface microrelief applied today is associated with considerable metrological errors.

Estimation methods of total corrosion resistance and parameters of pitting resistance based on GOST 9.908-85 and GOST 9.012-89 are out-of-date and do meet the modern requirements.

To increase qualitative level of investigations in this area, it is necessary to follow the standard ISO/25178-2 that recommends surface microrelief 3D - analysis.

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* Published in Russian

Received October 26, 2010

Метрологические аспекты оценки коррозионной стойкости труб, используемых в энергетических установках

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Проанализированы потенциальные метрологические погрешности, возникающие при оценке состояния поверхности коррозионностойких труб, а именно шероховатости, показателей общей и питтинговой коррозии. Показано, что для установления технологических возможностей производства труб ответственного назначения с повышенными антикоррозионными свойствами необходимо руководствоваться возможностями 3D – анализа микрорельефа поверхности. Это позволит достоверно описать поверхность в исходном состоянии и в процессе эксплуатации, а также выработать пути устранения недостатков.