The technical condition assessment and the resource of safe operation of technological pipelines using electromagnetic-acoustic effect

M G Bashirov, E M Bashirova, I G Khusnudinova and N N Luneva

Ufa State Petroleum Technological University, Branch of the University in the City of Salavat, Russian Federation

E-mail: ilvina011@mail.ru

Abstract. The combined use of the electromagnetic-acoustic effect and a mathematical model of the dynamics of the stress-strain state of technological pipelines in the form of a transfer function to increase the reliability and accuracy of estimating their residual life, taking into account the degradation of the metal structure during operation has been justified.

1. Introduction

Failures of technological pipelines at oil and gas facilities often lead to their depressurization, which, in turn, can be complicated by explosions and fires. In technological pipelines there are stress concentrators and mechanical heterogeneities, leading to the gradual accumulation of damage in the metal. In addition, the process of the appearance of local elastic deformations in the metal occurs under the action of a working environment and elevated temperatures and pressures. The combined effect of all factors can lead to structural failure. It is necessary to develop methods for assessing the technical condition of technological pipelines, based on the identification of defect parameters at the early stages of their development, when degradation processes begin in the metal structure that can cause sudden destruction of the pipeline [1-3].

Changes in the structure of steel grade 10 steel during static tensile tests are presented in the images obtained using the Mvizo MET-221 microvisor (figure 1).

Figure 1. Changes in the structure of steel grade 10 steel during static tensile tests, 100 times increase.
As can be seen from the research results, damage is accumulated in the process of loading steel samples. This is accompanied by a change in the mechanical, acoustic, and magnetic properties of the material, and these properties can vary in this case in different directions [5-7]. In recent years, considerable attention has been paid to the development and application of non-destructive methods for assessing the technical condition of products based on the electromagnetic-acoustic (EMA) effect, which allow generating acoustic waves in the monitoring object and reading information about its technical condition. It should be noted that for the integral assessment of the technical condition of objects characterized by a set of parameters, mathematical models of their dynamics based on the transfer function are beginning to be applied. In connection with the above, it seems promising to conduct studies aimed at the combined use of the EMA effect and mathematical models of the dynamics of the stress-strain state of metal in technological pipelines, which would significantly improve the safety of these objects based on more reliable and accurate examination of their technical condition and residual life [8-9].

2. Materials and methods

The test object under research is presented in the form of a “black box”, the probing signal generated by the EMAT is fed to its input, and the response is the bottom signal reflected from the opposite surface of the object. The current state of the object is described by its transfer function, the parameters of which change when the properties of the object (mechanical, acoustic, electrical, magnetic) change (figure 2). Changes in the structure of the metal of the object, the nucleation and development of the damage are reflected in its transfer function, therefore, analysis of the parameters of the transfer function allows us to identify these changes.

![Figure 2. The structural diagram of the system "EMA converter - control object".](image)

Figure 3 shows the response signals - bottom signals obtained using the EM2210 EMA device when testing samples of steel grades St3sp and 09G2S.

Using a computer program for the temporary impulse response characteristic of the EMA signal, the transfer function of the control object is identified [9].

The most informative component of the transfer function is the polynomial of its denominator - the characteristic polynomial (characteristic equation).
a) no load  

b) under tension with a force of 250 kp

Figure 3. Bottom (reflected) EMA signals obtained using the EM2210 device when testing a sample of steel grade St3sp.

It is possible to evaluate not only the stability of the system, but also the stability margin according to the coordinates of the characteristic equation roots marked on the complex plane.

Figure 4. Migration of the coordinates of the characteristic equation roots with increasing static load: a) for the St3sp sample, according to State Standards (GOST) 1497-84, type No. 1; b) 09G2S, according to GOST 1497-84, type No. 1.

According to the root stability criterion for a stable (workable) automatic control system, all real roots and real parts of the complex roots of the characteristic polynomial must be negative.

3. Experimental research

By tracking the change in the values of the characteristic polynomial roots or, more clearly, by tracking the migration of their coordinates on the complex plane, you can track the change in the operational properties of the test object, determine the limit state and assess the residual life of safe operation (figure 5) [10].
Figure 5. Assessment of the current technical condition and resource of the pipeline according to the coordinates of the characteristic equation roots.

For an integral quantitative assessment of the state of the control object, the area of the complex plane region was used, beyond which the characteristic polynomial roots should not exceed with the given operational properties of the object [11].

The purpose of experimental research is to identify patterns of the relationship of informative EMA parameters with the operational properties of the metal of technological pipelines.

Based on the analysis of the range of steels used in the manufacture of oil and gas technological pipelines, St3sp, 10 and 09G2S steel grades were selected for experimental studies and flat-type specimens were manufactured with various geometric dimensions according to GOST.

4. Result

In addition to the standard software of a personal computer and tablet, the ScanView EMA software of the EM2210 thickness gauge from Oktanta LLC and computer programs were used to approximate the EMAP response signal, identify the transfer function of the control object, and calculate the roots of the characteristic polynomial.

To implement the proposed method for assessing the technical condition and resource for the safe operation of technological pipelines based on the EMA effect, a hardware-software complex has been developed consisting of a device (utility model patent No. 169803) and software (state registration certificate for a computer program No. 2018617490).

The methodology provides for the sequential execution of the following operations:

- measurement of metal thickness;
- placement of an electromagnetic-acoustic converter (EMAT) on the surface of the process pipeline (figure 6);

Figure 6. Placement of EMAT on the surface of the process pipeline.
registration of the time sweep of the EMA response signal (bottom signal Y (s)) to a pulsed electromagnetic effect on the monitoring object (probe signal X (s)) and storing the results in digital form;

- approximation of the EMA response signal and identification of the transfer function of the control object using a computer program;

- using computer programs, the values of the roots of the characteristic equation are calculated and their coordinates are plotted on the complex plane. On the complex plane for a particular steel grade, the area of the specified operational properties is indicated, the boundaries corresponding to the limiting state of the pipeline metal are highlighted. The boundary values of the characteristic equation roots for a particular steel grade are determined by the calibration dependencies.

5. Conclusion
The reliability of determining the technical condition of expertise objects depends to a large extent on the methods and means of non-destructive testing and diagnostics used - the more perfect these methods and means, the earlier developing defects can be detected. The early detection and the removal of defects reduces the likelihood of failures and accidents.

Acknowledgments
We are grateful to the management of the companies “Russian Laboratory” , “Salavat” for the opportunity to conduct research with an electromagnetic - acoustic thickness gauge EM2210. For attention to the work and for assistance in the search for devices, we are sincerely grateful to V.L. Talaev, Energy Advisor to the General Director of “Neftekhimremstroy Ltd.” and the general director of “NPO” Oktanta Ltd. ” Avilov D.E.

References
[1] Sun B, Wang J, Li Z-L, Qin Y, Liu S-Z and Tomker D 2017 Modified modal strain energy method for analyzing the dynamic damping behavior of constrained viscoelastic structures Journal of Engineering Science and Technology Review 10(5) 174–80
[2] Bashirov M G and Mironova I S 2015 Integral criteria development for technical state and lifespan assessment of machine assembly in oil and gas industry SOCAR Proceedings 1 46–55
[3] Bashirov M G, Kuzeev M I, Kuzeev I R and Yunkin A I 2004 Electromagnetic method of diagnosis in problems of operation safety assurance and evaluating the service life of equipment at petrochemical and petroleum-processing plants Bezopasnost’ Truda v Promyshlennosti pp 49–54
[4] Ibragimov I G and Vildanov R G 2007 Measuring stresses in welded joints by the remagnetisation loss method Welding International 21(2) 139–41
[5] Ibragimov I G and Vildanov R G 2005 Measurement of stresses in metallic structures by method of reversal magnetization losses Zavodskaya Laboratoriya. Diagnostika Materialov 71(2) 29–31
[6] Vildanov R G 2004 A study of a remagnetization loss sensor Measurement Techniques 47(3) 259–63
[7] Kovshova Y S, Kuzeyev I R, Naumkin E A, Makhutov N A, Gadenin M M 2015 The influence of quasi-static loading regimes on the strength of vessels operating under pressure Inorganic Materials 51(15) 1502–07
[8] Strizhak V A, Pryakhin A V, Balabanov E N, Obukhov S A and Efremov A B 2012 Features of the construction of the sensor for the emission and reception of acoustic pulses of electromagnetic-acoustic method for controlling stress-strain state of the wheel rim Magnetic phenomena 164–77
Bashirov M G, Bashirova E M, Khusnutdinova I G 2019 The dynamic identification of the technical condition of pipelines on the basis of the analysis of the temporal characteristics of electromagnetic-acoustic signal *IOP Conference Series: Materials Science and Engineering*, **511**(1) 12042

Khusnutdinova I G and Bashirov M G 2017 The use of electromagnetic-acoustic method for estimating the stress-strain state of the metallic elements of power equipment *Key Engineering Materials* **743** 463–7

Bashirova E M 2005 Evaluation of the limiting state of the metal equipment for processing of hydrocarbonic raw materials with application of an electromagnetic method of control (Ufa)