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Research articles

Estimation of effect of hydrogen on the parameters of magnetoacoustic emission signals

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ABSTRACT

The features of the magnetoacoustic emission (MAE) signals during magnetization of structural steels with the different degree of hydrogenating were investigated by the wavelet transform. The dominant frequency ranges of MAE signals for the different magnetic field strength were determined using Discrete Wavelet Transform (DWT), and the energy and spectral parameters of MAE signals were determined using Continuous Wavelet Transform (CWT). The characteristic differences of the local maximums of signals according to energy, bandwidth, duration and frequency were found. The methodology of estimation of state of local degradation of materials by parameters of wavelet transform of MAE signals was proposed. This methodology was approbated for investigate of state of long-time exploitations structural steels of oil and gas pipelines.

1. Introduction

Pipeline transport is traditionally considered economically most profitable and technologically most advanced among other systems. During transporting of large volumes of products (oil, gas etc.), ensuring of the reliability of trunk pipelines with aim prevention of failures and accidents is very important problem [1,2]. The main reason of failures during operation of the oil and gas pipelines is corrosion which is manifested in the thinning of the pipe wall, stress corrosion cracking, hydrogen embrittlement, corrosion fatigue cracking [3,4]. Among the particularly dangerous factors of corrosion-mechanical fracture, one must take into account the aggressive role of hydrogen, which can cause uncontrolled fracture of the structure over a short period of time. The most vulnerable parts in terms of their damage and fracture, especially in the conditions of hydrogenation of metal are the welded joints [5]. On the other hand, the composition of the transportation medium (oil, gas) and the conditions of exploitation of the pipelines produce the conditions for such hydrogenation and, accordingly, the danger of fracture caused by the phenomenon of hydrogen embrittlement.

In order to ensure the uninterrupted and safe supply of oil and gas products, it is necessary maintain the pipeline systems in good working order and to monitor their technical condition. Thus, the problem of methods development for monitoring the state of the pipe and diagnostic both the linear part and the single units of the technological equipment is very important. Traditional methods of non-destructive testing (NDT) are mainly oriented to find defects and determining their geometric sizes. The method of acoustic emission (AE) is the most widely practiced and well-developed among the methods of NDT for detection of operational defects such as cracks [6]. But the traditional AE method for detection of the cracks calls for of the application of an external load to the control object. Sometime this load for growth of small defects in the object may be much more than its optimal operating modes. Therefore, for the local diagnostics of ferromagnetic elements of structures and products, the phenomenon of generation of magnetoacoustic emission (MAE) signals under the influence of an external magnetic field is used [7,8]. It is possible to develop methods for efficient detection and quantitative evaluation of the degree of degradation of structural materials, particularly, under the influence of the hydrogen-mechanical factor, by combining the parameters of the MAE signals with known physical phenomena.

MAE is unique technique due to possibilities of measuring high levels of stress and detecting structure defects [8]. In the literature, the results of research of the effect of many factors on the parameters of the MAE signals are presented widely. A large number of publications are devoted to the study of dependence of parameters of the MAE signals versus residual stresses [9–11], microstructure

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features of ferromagnetic materials [12–14], microhardness of materials [13], frequency of magnetization of the external magnetic field [15–17], modes of heat treatment [18,19], applied stresses and plastic deformation [20,21] etc. The effects of demagnetizing and stray fields [22], anisotropy [23], irradiation [24], hydrogen [25] and another factors on MAE has been investigated.

But the spectral parameters of MAE signals have received little attention. Edwards et al. [26] have established that the amplitude and frequency of the MAE depends on the specimen geometry and the modes of treatment. Augustyniak et al. [27] have studied the effect of magnetizing frequency and sample geometry on MAE properties for the different grades of steel. The spectrum of MAE signals was studied using a time-resolved Fourier analysis. The results show that the fast Fourier transform spectra are much more strongly affected by the thickness of the sample than by the material properties and the magnetizing frequency. For the thin sample ($h = 3$ mm) the low frequency component are practically absent, while for the thickest one ($h = 10$ mm) the content of the components from the frequency range 100–200 kHz is similar to that of the 200–300 KHz. The obtained spectra are qualitatively similar for the all magnetizing frequencies (triangular, 0.28 Hz–13.1 Hz).

The MAE signals are described by the stochastic processes theory. The importance feature of the MAE signals is a variation of frequency spectrum in the time domain. Therefore, the wavelet transform is effective to use for analyzing spectral parameters of MAE. Takuma et al. [28] have described a method for the stress measurement by wavelet transform of the MAE signals. The wavelet coefficients in the time–frequency coordinate plane illustrate the characteristic features of the signals. Therefore, the authors showed that the stress of a structure's member parts can be evaluated by monitoring coefficients.

Some authors have used the wavelet transform method for processing the Barkhausen noise (BN) voltage signals. So, using wavelet analysis Spivak et al. [29] have defined the average duration of BN of amorphous $Fe_{78}B_{12}Si_9Ni_9$ alloy – 10^{-4} s. Miesowicz et al. [30] have presented a new approach to BN signals processing for detection of fatigue crack. BN signal from mild steel samples under axial fatigue is investigated using fractal signal processing, particularly wavelet variance method. The results show that the method can detects the crack initiation in metallic structures that is importance for diagnostic of the state of structural elements.

By literature review, the MAE signals were analyzed using the dependence of the some parameter of signals (for example amplitude or intensity) on some properties of the object and the experimental conditions. For higher efficiency of the MAE method, it is necessary to improve the methods of signal processing.

In this paper, the method of estimation of local degradation of material by means of parameters of the wavelet transform of the MAE signals is proposed.

2. MAE method: Background and verification

2.1. Theoretical background of analyze of the MAE signals by the wavelet transform

"The wavelets" is total name of a family of the mathematical functions which are localized in time and frequency. The wavelets are generated in the form of translocations and dilations of a fixed function called the mother wavelet [31]. The important property of the wavelets is the possibility to investigate of signals having time-dependent spectral characteristics. The decomposition of such signal on a set of the wavelets (functions) makes it possible to realization of the local analysis. We can see the signal frequencies evolution during the duration of the signal and compare the spectrum with other signals spectra.Although, the most important information of the signals mainly belongs to the low-frequency domain, the decomposition process of the approximation component may lead to the loss of information located in the high-frequency domain [32]. Therefore for investigation of the MAE signals the wavelet packet transform (WPT) was used. In the WPT a wavelet detail component is also further decomposed to obtain its own approximation and detail components. Thus, when a signal is decomposed into J levels using wavelet packet, $0 \sim f_{\max}$ is decomposed equally into

$$0 \sim \frac{1}{2^J} f_{\max}, \frac{1}{2^J} f_{\max} \sim \frac{2}{2^J} f_{\max}, \ldots \frac{2^J - 1}{2^J} f_{\max} \sim f_{\max},$$

totally 2^J wavelet components [33].

Choose of the mother wavelet and number of decomposition levels depends on the features of the investigated signal. The performance and the length of the filter should be considered so as not to affect the quality of waveform after wavelet transform [34]. The symN wavelets are also known as Daubechies' least-asymmetric wavelets. The construction of the Symlet wavelet is similar to that of the Daubechies wavelet. However, the Symlet wavelet has better symmetry for the reduction of the reconstruction phase shift. After studying of the properties of different wavelets [34,35], the sym8 wavelet with approximate symmetry, compact support, and biorthogonality is selected as the wavelet base to decompose of the MAE signals (Fig. 1).

Since the frequency of discretization of the MAE signals is 2 MHz, the maximum frequency present in the signal is 1 MHz. The number of levels was set to three (Fig. 2) that correspond to

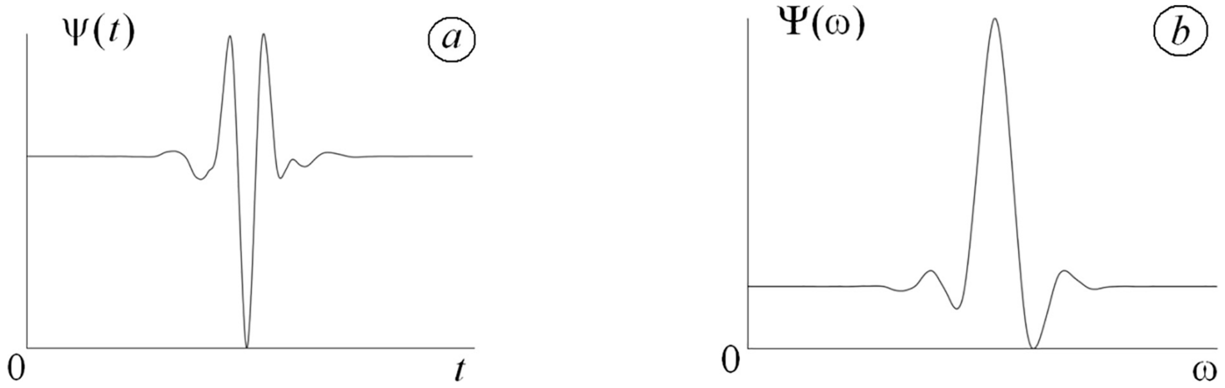

Fig. 1. Wavelet function $\psi(t)$ (a) and scaling function $\Psi(\omega)$ (b) of sym8 wavelet.