Main Pipelines Corrosion Monitoring Device

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Abstract. The aim of the article is to substantiate the technical solution for the problem of monitoring corrosion changes in oil and gas pipelines with use (using) of an electromagnetic NDT method. Pipeline wall thinning under operating conditions can lead to perforations and leakage of the product to be transported outside the pipeline. In most cases there is danger for human life and environment. Monitoring of corrosion changes in pipeline inner wall under operating conditions is complicated because pipelines are mainly made of structural steels with conductive and magnetic properties that complicate test signal passage through the entire thickness of the object under study. The technical solution of this problem lies in monitoring of the internal corrosion changes in pipes under operating conditions in order to increase safety of pipelines by automated prediction of achieving the threshold pre-crash values due to corrosion.

1. Introduction

Nowadays oil and gas industry gives more and more attention to the safety of production, transportation and storage of oil and gas worldwide. It’s important both for the human beings and their environment. At the same time, despite the development of methods and ways of ensuring industrial safety in oil/gas industry and success achieved, oil and gas pipeline accidents and failures are still a problem, and the associated environmental problems still occur [1].

So, research in protection against corrosion [2] [3] and creating devices for the pipeline corrosion control are quite urgent [4] [5] [6] [7] [8] because of a significant number of accidents due to pipeline corrosion. The possibility to determine the critical corrosion level and changes in a pipe on the basis of instrumental and analytical forecast [9] allows not only to provide well-timed replacement of pipeline sections but also to substantiate the use of specialized electrical, chemical or mixed corrosion prevention methods.

The main methods of gathering information about the corrosion changes in the linear part of oil / gas main pipelines are smart pigging and electrometric measurements with subsequent instrumental survey of the condition of metal and pipe insulation at the inspection points. Pipeline pigging is the most informative method for obtaining data on the extent of damage in the pipeline inner walls but only 40% of gas pipelines are prepared to pass the corrosion detection pig. Besides, the main pipeline is out of service while pigging. Electrometric measurements are aimed at determining the main indicator of corrosion – the corrosion rate, expressed as weight loss of metal per unit area per unit time Kм,г/(м²·year) or a rate of corrosion penetration per time unit KГ,мм/year [10] [11]. Automated
remote corrosion monitoring on the basis of the electrometric measurements is able to only monitor external corrosion processes and therefore it is not accurate enough to perform predictive analytics [12] [13].

The main problem of monitoring corrosion changes in pipelines is the difficulty of measuring the thickness of ferromagnetic conducting pipes directly when under service. Primary data collection devices must ensure continuous monitoring of a wall thickness corrosive wear in automatic mode without using the pipeline pigs and digging. As such smart transmitter the main pipeline corrosion monitoring device [14] can be used.

2 Method and structural scheme

The essence of technical solution is that the drive (exciting) and measuring inductance coils covering the pipeline are placed at the most deteriorated section of the main pipeline. So, the pipe acts as a magnetic conductor of a transformer eddy-current transducer (eddy-current probe), and EMF induced in the measuring coil will depend on the pipe parameters and its thickness in particular. Periodic EMF measurements, accumulation of measured values in digital memory and comparison with design/target values make it possible to determine the residual life of a pipe wall and to predict the moment of dramatic loss of wall thickness up to failure.

The technical implementation of the device involves using two drive inductance coils (exciting coils) connected in series in Helmholtz arrangement and measuring coil placed between them; frequency-tunable test-signal generator, pipe temperature sensor and digital computer. The EMF induced in a measuring coil is pre-amplified by a broadband amplifier and is filtered by a tunable bandpass filter to increase noise immunity and protect from random interference.

Figure 1. gives the main pipelines corrosion monitoring device block diagram.

The main pipelines corrosion monitoring device (Figure 1) includes a digital computer consisting of central processor 1, random access memory 2, read only memory 3, analog-to-digital converter (ADC) 4 and input/output port 5; tunable harmonic oscillator 6, broad-band amplifier 7, narrow-band tunable filter 8, first 11 and second 13 driving coils, measuring coil 12 and digital temperature sensor 9.

After placing the measuring and drive coils on a pipeline (winding can be performed together with pipe insulation) the monitoring device is set up, it involves production of harmonic oscillations in a given frequency range (e.g., 20 to 2000 Hz). The choice of frequency range is determined by the necessity of penetration of the magnetic field into the depth of the pipe wall. Frequency tuning of a test signal is performed by a central processor. Voltage, proportional to the EMF of mutual induction is amplified by a broadband amplifier and fed to a narrow-band filter which is frequency tuned along with the generator. Next, the current or peak stress voltage value is converted into digital code and stored in RAM of a digital computer. As specific conductivity of structural pipe steel of depends on its temperature, together with the measurement of output voltage, measurement of the pipe temperature by the digital sensor takes place. The measured temperature is stored in RAM. The operating mode of the device is periodic, short-time or continuous. Data exchange with external devices is provided upon request of external devices or without the request via the programmed time intervals. The device supports interface Ethernet, Modbus protocols, as well as data transfer using a cellular GPRS.
3. Numerical modeling

Next, the calculation of EMF using the formula (1) is performed for the same frequency range for which the measured data were obtained,

\[
\dot{E} = -j\pi\mu_0\omega w_{u_b} \frac{j_{w_b}}{l_b} R_u^2 \left(1 - \eta + \eta \mu_a \mu_{\text{eff}}\right),
\]

where \(j\) – the excitation (drive) current; \(l_b\) – length of the exciting (drive) coil; \(w_u, w_b\) – the number of turns in the measuring coil and the exciting coil; \(\omega\) – angular (circular) frequency of harmonic excitation signal; \(\mu_u\) – relative magnetic permeability of pipe steel; \(\mu_{\text{eff}}\) – effective magnetic permeability, which determines the degree of attenuation of the magnetic flux due to eddy currents; \(\eta = \left(\frac{R_i}{R_u}\right)^2\) – the fill factor defined by the ratio of the cross sectional area of the test object and tube of magnetic flux, linked with the measuring coil; \(R_i\) – the external radius of the pipe; \(R_u\) – the radius of the measuring coil.
Figure 2 shows approximate graphs of the calculated by the formula (1) and measured EMF induced in the measuring winding.

![Graph showing EMF vs Frequency](image)

**Figure 2 –** The dependence of the EMF induced in the measuring coil upon the frequency of the harmonic excitation signal.

To monitor corrosive changes in the pipe wall it’s necessary to periodically measure the voltage induced in the measuring winding in the same frequency range as that used in setting up. After that the calculation by the formula (2) is carried out, and with that the value of specific conductivity $\sigma$ is corrected taking into account the pipe temperature at the time of measurement. One must try to achieve coincidence of the measured and expected graphs by changing the pipe wall thickness of a tube in calculating equations. According to several cycles of measuring the thickness of the pipe we construct a regression model that makes it possible to predict the moment of the wall thickness loss to pre-failure condition. The results of the automatic control of the pipeline internal corrosion changes can be transferred to the operator or radio modem via the input/output port.

The eddy currents density is maximum at the surface of the object in circuit, with a diameter close to the diameter of the exciting coil and decreases to zero on the axis of the eddy-current probe and at $r \to \infty$. Eddy current density also decreases with depth of the test object. For approximate estimation of the penetration depth of the electromagnetic field of surface eddy-current probe one can use the formula for the depth of penetration $\delta$ (m) of a plane wave:

$$\delta = \frac{2}{\sqrt{\omega \mu_0 \sigma}},$$

where $\omega$ – angular (circular) frequency of the excitation current of eddy current probe; $\mu_0$ – absolute magnetic permeability, H/m; $\sigma$ – specific electrical conductivity of the test object material, Cm/m.

Figures 3, 4 present the results of calculating the penetration depth of the electromagnetic wave into a conductive medium, calculated according to the formula (2).

The value $\delta$ corresponds to the attenuation of the magnetic field by a factor of $e$ compared to the value of magnetic field intensity on the surface of the object.
As follows from the content of the Figures 3, 4 at the operating frequencies of the monitoring device (80–200 Hz) penetration depth is sufficient for the control of corrosion processes in pipes with up to 2 cm wall thickness.

4. Conclusions.
The pilot studies of the main pipelines corrosion monitoring device have been carried out; the studies confirmed the possibility of detecting local and extensive pipe defects, including the inside of a pipe, in a wide range of experimental conditions.

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