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Experimental study on pipeline internal corrosion based on a new kind of electrical resistance sensor

Yunze Xu [a,*], Yi Huang [a], Xiaona Wang [b,*], Xuanqin Lin [a]

[a] School of Naval Architecture and Ocean Engineering, Dalian University of Technology, Dalian 116024, China
[b] School of Physics and Optoelectronic Engineering, Dalian University of Technology, Dalian 116024, China

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ABSTRACT

In this paper, a ring pair electrical resistance sensor (RPERS) has been developed for an internal-pipeline corrosion on-line monitoring system. The RPERS was divided into six segments along the circumference. The corrosion depth of each segment could be measured by using three alternating excitation currents injected into the sensor from different angles. In order to simulate and monitor the pipeline internal corrosion, a corrosion monitoring system which contained RPERS, wire electrical resistance sensor (WERS), thermocouples and a corrosion coupon was established. First, the corrosion processes in 3.5% sodium chloride solution with the temperature varied from 30 °C to 60 °C were studied. The temperature differences between the inner and outer pipe wall surfaces were measured by the top segment of RPERS. The test results revealed that the performance of RPERS is better than that of WERS in term of metal loss measurement. Then, carbon dioxide mixed with water vapour was pumped into the system with the temperature varied from 50 °C to 80 °C. In the scenarios, top of the line corrosion (TLC) occurred and was monitored by RPERS. The monitoring results demonstrated that the gas temperature and the temperature difference were important factors for TLC in sweet conditions.

1. Introduction

The electrical resistance (ER) sensor technique, also known as electrical coupon technique, has become one of the most important methods for pipeline internal corrosion monitoring [1]. As a result of corrosion process, the cross-section area of the sensor is reduced, leading to an increase in electrical resistance. Based on the change of the resistance, the corrosion loss in metal thickness can be obtained and the slope of the metal loss curve directly corresponds to the corrosion rate. In contrast to conventional electrochemical techniques such as the linear polarization resistance and the electrochemical impendence spectroscopy methods, the advantage of the ER technique on metal loss measurement is that the presence of an electrolyte layer on the metal surface is not inevitable. In that sense, the method can be used in a high resistance medium such as gas and crude oil. Moreover, it can be used for corrosion monitoring of high temperature corrosion and erosion corrosion [2,3].

The traditional ER sensors are almost entirely composed by a corrosion element and a compensation element. The geometry shapes of the elements are usually present in the forms of wire, tube, flush spiral and strip. The corrosion element of the ER sensor is exposed to corrosion surroundings and the compensation element is covered with a protective coating to segregate it from the corrosive environments [4,5]. Through the resistance ratio of the two elements, the temperature interference can be eliminated under ideal conditions. Thus, the metal loss of the corrosion element can be calculated according to its geometric dimensioning. However, in the pipelines with high temperature and pressure, the two elements of the traditional ER sensors may be subjected to different temperature and pressure conditions due to the different locations where they are emplaced. It has been found that a minor difference of 0.25 °C between the corrosion element and the compensation element will cause a significant change in the resistance ratio of 1000 ppm. Although the effect of the pressure difference on the resistance ratio is much less than that caused by the temperature difference, the resistance ratios of typical pipeline steels still undergo obvious changes from 2000 ppm to 4000 ppm per 100 bar [6,7].

In recent years, localized corrosion problems such as bottom of the line corrosion (BLC) and top of the line corrosion (TLC) have become focus issues of the pipeline internal corrosion [8–10].

* Corresponding authors at: School of Naval Architecture and Ocean Engineering, Dalian University of Technology, Linggong Road 2#, Dalian 116024, Liaoning Province, China.
E-mail addresses: xuyunze123@163.com (Y. Xu), wangxn@dlut.edu.cn (X. Wang).

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In general corrosion surroundings, the traditional ER sensors can be sensitive to homogeneous corrosion due to their geometric forms, but the responses of these sensors to localized corrosion are limited [11]. With improvements on the resolution of the electrical resistance measurement, some researchers have tried to use the ER sensors for localized corrosion monitoring in pipelines by changing their forms. Marc Singer [12] has used a new kind of flush head ER sensor for TLC monitoring. However, the monitoring results are dissatisfactory due to the edge effect caused by the pipeline arc. BLC is always caused by sand and corrosion products covering the bottom of the line. The deposit on the steel surface may lead to failures of the corrosion inhibitors and cause serious localized corrosion. The practical corrosion rate of the bottom area in the pipeline is hard to be monitored due to the galvanic effect between the bare steel and the deposit-covered steel [13].

For most oil and gas pipelines, the inner fluids usually endure high temperatures above 50 °C, while the temperature of the outer surroundings is always much lower than the fluid temperature, especially in subsea surroundings [14]. In these scenarios, the temperature differences between the inner and outer pipe wall surfaces exist. Gerstmann [15] found that the temperature differences in sweet conditions may lead to the formation of condensation films on the inner surfaces of the pipelines, which is an important factor for TLC. The outer temperature of the pipe wall surface can be easily measured by arranging the temperature measurement sensor outside of the pipe wall surface. However, it is hard to measure the temperature of the inner pipe wall surface in practice without destroying the pipe wall structure. Due to the unknown temperature difference between the inner and outer pipe wall surfaces, Vitse and Zhang et al. [16,17] established complex thermodynamic models to forecast the condensation rates, but the predicted results still have deviations compared with the experimental results.

The primary purpose of this paper is to present a new kind of ring pair ER sensor (RPERS) for pipeline internal corrosion monitoring. RPERS is composed of two rings, i.e. a corrosion element and a compensation element. The rings are made with an 8 in. X65 pipeline which is usual for subsea installations. The RPERS is divided into six segments and used to monitor the metal losses of these segments in a laboratory system. In the experiment, the temperature difference between the inner and outer pipe wall surfaces is measured by the top segment of RPERS. The metal loss measurement results of RPERS are compared with those obtained from a traditional wire ER sensor (WERS) and a corrosion coupon. In the experimentation of TLC, the metal loss, corrosion rate and temperature difference of the top segment in the pipeline are monitored by RPERS. The relationship of the gas temperature, temperature difference between the inner and outer pipe wall surfaces and corrosion rate is obtained. RPERS also provides a new measurement method for thermodynamic model research within the experiment.

2. Method

2.1. Internal-pipeline corrosion monitoring system

As shown in Fig. 1, the internal-pipeline corrosion monitoring system is composed of three parts: pipeline information detecting section, data acquisition system and data-managing section.

The pipeline information detecting section contains RPERS, traditional WERS, K-type thermocouples and a corrosion coupon. It is the sensitive part of the monitoring system. The sensors provide continuous signals of the internal corrosion conditions and the temperature information in the pipeline.

In the data acquisition system, the ER signals generated from RPERS can be converted to digital signals by an RM3545 micro resistance measurement device whose ER measurement resolution is 10 nΩ. The models of the K-type thermocouples are TP-K01, and the measurement surfaces of the thermocouples are coated with a layer of teflon for insulation. The temperature measurement accuracy of the thermocouples can reach ±0.1 °C in the range of 0–80 °C after having been calibrated in a Julabo FP 51 thermostatic water bath. The temperature control accuracy of the thermostatic water bath is ±0.05 °C in the range of −20 °C to 100 °C. The voltage signals generated from the thermocouples are recorded by NI PCIe-6320 data acquisition card. The ER signals from WERS can be obtained by CMB 1510b. The CMB 1510b is a corrosion data acquisition and storage device which is manufactured by Instituted of Corrosion & Protection of Metals in China. All the signals are transferred to the computer after disposal by a RS232 transition port.

The data-managing section is an operation platform. It is compiled by C# to record and process messages conveyed from the data acquisition system (DAS). All data is saved in the structured query language (SQL) server database.

2.2. The construction and measurement principle of RPERS

As shown in Fig. 2a, RPERS is a part of the pipeline which needs to be monitored. The corrosion element and compensation element have the same inner diameters with the pipeline. The two elements are embedded into the pipeline through a connecting element, which is shown in Fig. 2b. The axial widths of both elements are 10 mm and the initial sensitive wall thickness of the corrosion element is 13.5 mm. The rings are coated with a layer of chromic oxide by plasma spraying except the internal surface of the corrosion element, which is shown in Fig. 2c. The two elements are insulation from other pipe surfaces through the Cr_2O_3 coating on the contact surfaces and the insulation resistance is higher than 1 MΩ among each element at a voltage of 50 V. A better temperature and pressure compensation effect can be provided as the compensation element and the corrosion element are coaxial concentric placed in the pipeline. The monitoring results of the localized corrosion, i.e. BLC and TLC, will be closer to the actual situations than traditional flush head ER sensors since the arc of the corrosion element is the same as the pipeline to be monitored.

RPERS can provide two monitoring functions, i.e. the monitoring of the localized corrosion in pipelines and the measurement of the temperature difference between the inner and outer pipe wall surfaces. The two functions are introduced as follows.

For localized corrosion monitoring, each element is divided into six segments using electrodes 1, 3, 5, 7, 9 and 11, as shown in Fig. 3. Segment 1 is between electrodes 1 and 3, segment 2 is between electrodes 3 and 5 and the other segments are dealt with the same approach. These electrodes are also used for voltage measurements. The resistance values of the segments on the corrosion element are represented by R_i^{cor} ($i = 1, 2, 3, \ldots, 6$), respectively. The resistance values of the segments on the compensation element are represented by R_i^{comp} ($i = 1, 2, 3, \ldots, 6$), respectively.

The six segments may suffer different temperatures or corrosion environments due to the different locations and flow regimes in the pipeline. Galvanic current may generate in RPERS and cause a measuring error [18]. To eliminate the additional potential caused by the galvanic current in the ring, the square excitation current waves are injected into the ring pair for ER measurement. The amplitude of the current is 1 A and the measurement period for each signal is 241 ms. In a measurement period, the voltage signals V_+ and V_- caused by the positive current I_0 and negative current $-I_0$ are measured. Then the average voltage $\bar{V}$ used as the final measurement result can be calculated by:

$$\bar{V} = \frac{V_+ + |V_-|}{2} \quad (1)$$