Engineering Failure Analysis 60 (2016) 40–56

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Stochastic modelling of perfect inspection and repair actions for leak–failure prone internal corroded pipelines

Chinedu I. Ossai *, Brian Boswell, Ian J. Davies

Department of Mechanical Engineering, Curtin University, GPO Box U1987, Perth, WA 6845, Australia

ARTICLE INFO

Article history:
Received 24 June 2015
Received in revised form 5 October 2015
Accepted 16 November 2015
Available online 17 November 2015

Keywords:
Markov modelling
Lifecycle phases
Weibull distribution
Failure probability
Inspection and repair cost
Corrosion wastage time

ABSTRACT

To enhance the performance of any facility, reduce cost and failure probability involves proper inspection and repair decisions. To be able to establish the cost of repair and inspection of corroded pipelines at different stages of the corrosion defect depth growth, Markov modelling technique was adopted. This model formulated an inspection and repair technique, which has the potentials of aiding policy makers in maintenance management of internally corroded pipelines. The transition states were determined using the Remaining Useful Life (RUL) of the pipelines whilst Weibull distribution was used for calculating the corrosion wastage rates at the lifecycle transition phases. Monte Carlo simulation and degradation models were applied for determining future corrosion defect depth growth, in a bid to establish periodic inspection and repair procedures and their costs. Data from an onshore pipeline inspected with Magnetic Flux Leakage (MFL) in-Line-Inspection (ILI) technique was used to test the validity of the model. The results obtained indicate that the model has practical applications for inspection and repairs of aged-internally corroded pipelines.

1. Introduction

Utilization of pipelines for transportation of oil and gas from production fields to refineries and loading terminals has resulted in the deterioration of the pipelines over time. This deterioration, which is caused predominantly by corrosion [1–3], results in pipe-wall thinning and reduction in reliability [4–5]. Although corrosion inhibitors and biocides have played a significant role in the reduction of the rate of pipe-wall thinning [6], the problem of pipeline corrosion, especially, internal ones, has significantly impacted the operations and maintenance cost of oil and gas companies as it accounts for over 50% of the downtimes in the industry [7–9].

The need to establish optimal inspection and repair policy is vital for risk quantification in operating oil and gas pipelines, hence, the reason why numerous researchers have worked on different aspects of risk optimization models for corroded pipelines [4–5,10–13]. Gomes et al. [14] addressed inspection and maintenance optimization of corroded pipelines by using Monte Carlo simulation to sample and evaluate expected number of failures and repairs. These authors determined an optimal inspection and failure cost based on their model. The work of Wang and Zarghamee [15] also focused on estimating the reliability of corroded pipelines using finite element analysis and Monte Carlo simulation. This research, which determined the retained strength of corroded pipelines at different defect sizes was aimed at establishing the fitness-for-service of corroded pipelines. And also establish the optimal inspection and maintenance schedules that will ensure the safety of operations. Hasan et al. [16] also used Monte Carlo simulation and First Order Second Moment (FOSM) method to establish the failure probability of internal corroded oil and

* Corresponding author.
E-mail addresses: ossaic@gmail.com (C.I. Ossai), b.boswell@curtin.edu.au (B. Boswell), i.davies@curtin.edu.au (I.J. Davies).

http://dx.doi.org/10.1016/j.engfailanal.2015.11.030
1350-6307/

gas pipelines, after analysing the remaining mechanical hoop strength capacity of the corrosion defects. Sahraoui et al. [11] on their part proposed an inspection and maintenance policy, which was based on an imperfect inspection by considering the probability of corrosion defect detection and wrong assessment of defect sizes. These researchers had an ultimate aim of ensuring that the reliability of corroded pipelines is determined to a high degree of accuracy. Other researchers [13] approached corroded pipeline maintenance optimization for general corrosion, pitting corrosion and stress corrosion cracking from the point of failure frequency and the associated consequences of failure to health, safety and environment. They also optimized maintenance intervals in order to minimize cost. Again, Zhou [17] evaluated the reliability of corroded pipelines under the influence of internal operating pressure. The author modelled the reliability with respect to corrosion induced failures as — small leakage, large leakage and rupture.

Since corrosion is a function of uncertainties associated with the operating environment of the pipelines, it is always necessary to monitor the variability of the environment, materials and technique used for acquiring the data used for predicting the growth of corrosion defects of Pipeline [18–19]. To establish the deterioration arising from these external and internal constraints in a pipeline, a hierarchical Bayes framework, which used multi-level generalized least square was adopted for estimating corrosion defect growth while modelling the uncertainties in the operability of the material and environment [18]. Similarly, in order to optimize the service life of structures, a 2-stage inspection based maintenance management framework was used [20]. This technique, which considers deterioration defects and sizing error of detection of the defects, has the potentials of minimizing lifecycle cost of structures and optimizing the inspection intervals.

Optimal maintenance and repair planning involves the establishment of the acceptable failure probability level for the corroded pipelines, in consideration of cost. This also involves checking alternative inspection and repair policies, in order to establish the most appropriate for the expected pipeline reliability. Since the retained strength of corroded pipeline has direct link to the corrosion wastage at a given time, failure limit functions — leakage, burst and rupture have been established by different authors in consideration of stochastic corrosion growth rate [10–12]. Hence, managing corroded pipelines effectively entails, understanding the expected time of leakage, burst and rupture failures, as the corrosion wastage changes over time.

From the foregoing discussion, it can be seen that much has been done on reliability management of corroded pipelines. However, to the best of the knowledge of the authors, there has not been notable research on inspection and repair optimization, in consideration of stochastic, probabilistic risk quantification. This situation motivated the authors to carry out such research using Markov modelling, Monte Carlo simulation and degradation modelling by focusing on the stochastic behaviour of corrosion defect depths. First order Markov chain modelling will be used in this paper for proposing the model, seeing that it has been used for establishing the effect of corrosion defect depth growth on corroded pipelines and other facilities by other researchers [21–25]. The successful use of first order Markov chain modelling in different research areas such as corrosion has also made it an established principle for solving real life problems that requires sequence modelling, control tasks, machine learning and stochastic modelling.

This paper, therefore, aims to utilize information about corrosion wastage times to estimate inspection and repair procedures for internally corroded pipelines, subjected to failure by leakage. As such, inspection and repair planning is expected to be done in consideration of the corrosion wastage times of the pipelines at the lifecycle transition phases — introduction–maturity, maturity–ageing, ageing–terminal, terminal–failure and failure–leakage. The objective of this research is to model stochastically, leak-prone pipeline failure by considering a different inspection and repair alternative association with the corroded pipeline and estimate the cost. Even though numerous research works have been carried out on different aspects of inspection and maintenance cost models for corroded pipelines, the consideration of the lifecycle phases of corroded pipelines in inspection and repair cost determination that is considered in this research is novel. Although we have assumed a perfect inspection that results in a non-significant measurement error of corrosion defects, it is important to note that the model developed in this research has a higher potential of cost savings for inspection and repair actions requiring leak failure. This is because other researchers have considered the threshold defect depth that will trigger inspection and repair of corroded pipelines as 50% [26] whereas this paper has taken this defect threshold as 80% in consideration of ASME standard [27]. Again, this research also considered the failure probability of the pipeline at different lifecycle phases in the determination of the survival probability, which is vital for estimating the inherent risk at any lifecycle phase of a corroded pipeline. It is also expected that the knowledge of the inspection and repair cost developed in this research will be useful for determining the future cost of pipeline integrity management as corrosion defect depth grows.

2. Markov modelling concept

A Markov Process is a stochastic system which has future events only depending on current ones without reference to previous events. This peculiarity makes a Markov Decision Process (MDP) to be memoryless since the impact of previous events on future occurrences is not recognized in predicting the future events [28–29]. The growth of corrosion defects of a pipeline has a typical memoryless system since the future corrosion defect growth rates and initiation locations on the pipeline do not depend on the previous corrosion defect sizes or spots. This is because the growth rates of existing corrosion defects and new corrosion defect initiation, depend on the characteristics of the operational parameters [2,19,30–32] that fluctuate with time and location on a pipeline. The interaction of the operating parameters and the pipeline material and specific behaviours of the corrosion process — stable and meta-stable states of a localized corrosion such as pitting [23,33] also stochastically influence corrosion defects and contribute to the memoryless behaviour. The undependability of future corrosion defect depths on previous ones is the reason for the randomness of