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Review

A review on pipeline integrity management utilizing in-line inspection data

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ABSTRACT

Pipelines are widely used in transporting large quantities of oil and gas products over long distances due to their safety, efficiency and low cost. Integrity is essential for reliable pipeline operations, for preventing expensive downtime and failures resulting in leaking or spilling oil or gas content to the environment. Pipeline integrity management is a program that manages methods, tools and activities for assessing the health conditions of pipelines and scheduling inspection and maintenance activities to reduce the risks and costs. A pipeline integrity management program mainly consists of three major steps: defect detection and identification, defect growth prediction, and risk-based management. In-line inspections (ILI) are performed periodically using smart pigging tools to detect pipeline defects such as corrosion and cracks. Significant advances are needed to accurately evaluate defects based on ILI data, predict defect growth and optimize integrity activities to prevent pipeline failures, and pipeline integrity management has drawn extensive and growing research interests. This paper provides a comprehensive review on pipeline integrity management based on ILI data. Signal processing methods for defect evaluation for different types of ILI tools are presented. Physics-based models and data-driven methods for predicting defect growth for pipelines with different categories of defects are discussed. And models and methods for risk-based integrity management are reviewed in this paper. Current research challenges and possible future research trends in pipeline integrity management are also discussed.

1. Introduction

Thanks to the advantages of safety, efficiency and low cost, pipelines are widely used in transporting large quantities of oil and gas products over long distances. Pipelines may suffer from different types of defects such as corrosion, fatigue cracks, stress corrosion cracking (SCC), dent, etc. These defects, if not properly managed, may result in pipeline failures including leak or rupture, which could lead to very expensive downtime and environment hazards. There are many pipeline incidents every year around the world, and three of the North America pipelines incidents in 2016 resulted in over 2,000 metric tons of oil and gas leak and spill. Integrity is the top priority for pipeline operators to ensure reliable and safe operations of pipelines, to increase productivity, reduce cost, prevent damage to the environment, support future projects, etc. It is essential to find effective ways to monitor, evaluate and assure the integrity of the pipeline, and reduce the risk of leaks and rupture.

For pipelines, we need to ensure safety, security of supply and compliance with relevant codes and legislation. Procedures and practices are implemented to protect, manage and maintain the integrity of pipeline systems. Due to the significant severity of pipeline failures, the core of pipeline integrity management is to keep pipelines in safe operating conditions. Pipeline integrity tools

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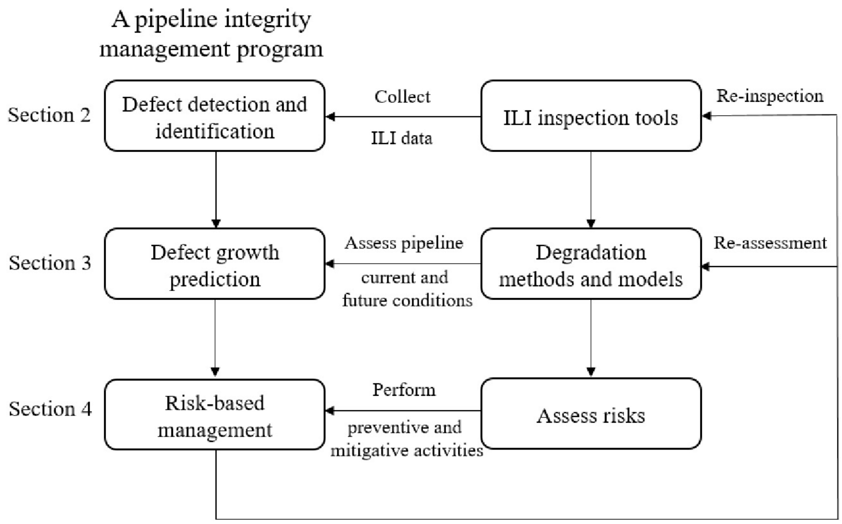

Fig.1. A flowchart for a pipeline integrity management program

are developed to improve business performance, manage risks as well as ensure compliance. Proper pipeline integrity management can reduce both the probability and consequences of failure and increase the pipeline companies' benefits, by properly assessing and managing the defects. Pipeline integrity program monitors and predicts defects and thus adjusts when, where, how, and what actions need to be taken, such as inspection, maintenance and repair. A good pipeline integrity program should be able to manage risk successfully, prevent failure from occurring, control damage effectively, and reduce the overall cost.

A pipeline integrity program generally consists of three major steps:

(1) Defects detection and identification, to obtain defect information through inspection, monitoring, testing and analysis techniques.
(2) Defect growth prediction, to predict defect growth based on damage prediction models and the collected data.
(3) Risk-based management, to recommend optimal inspection, maintenance and repair policies and activities.

Defect information is collected using detection and identification tools. Pipeline companies can gather defect information through walking along the pipelines by technical personnel, hydrostatic testing, in-line inspection (ILI), nondestructive evaluation (NDE), etc. ILI tools are currently the most widely used inspection technology for detecting and inspecting various types of pipeline defects. In this paper, only ILI tools will be discussed and other detection techniques will not be covered. Defect growth prediction is to predict defect growth and when a pipeline failure will occur. There are different kinds of threats to pipeline integrity, such as metal loss, cracking, dents, third party damage, weld, etc. Study on different defect prediction models is the foundation of effective integrity management. The last step, risk-based management, will determine proper inspection intervals, and maintenance and repair actions. The management models will also influence the first step and the second step by possibly changing the inspection actions and defect status. The aim of an integrity program is to achieve accurate defect prediction and balance the reliability and costs in an effective way. Fig.1 shows a flowchart for a pipeline integrity program, and the section numbers in this paper for the three key steps.

Some reported studies considered the design stage as a part of pipeline integrity management process. It is true that pipeline integrity management is a lifecycle approach which involves the design phase, and better design practices typically lead to better pipeline integrity assurance. Study on behaviors of different threats in pipelines as well as inspection and maintenance activities can also give a good feedback to the pipeline design stage. Palmer and King [1] and Antaki [2] provided detailed introductions to the pipeline design stage. Bai and Bai [3] introduced life cycle cost modeling for the design stage of pipeline integrity management. In this paper, though, we will not cover the pipeline integrity design stage, and will focus on detection, prediction and management methods and models during the operation stage.

Pipeline integrity management has drawn extensive and growing research interests, and a large number of studies have been published in conference proceedings and academic journals on methodologies, models and applications. This paper reviews the research studies on pipeline integrity management based on ILI data, with an emphasis on models and methods developed for more effective defect detection, prediction and management. Some published reviews discussed topics related to some subsections of this paper [4–9], with some of them emphasizing failure mechanisms of one type of defect, while some focusing more on applications and practices. Compared with the published reviews, this paper gives more comprehensive and detailed discussions on the methods and models used in the pipeline integrity management framework, and provides an overview on strategies for inspecting, predicting and managing all major pipeline threats. Pipeline integrity management framework and some related case studies were also presented in [10–14]. Legal issues and demands for pipeline integrity programs were discussed in [15]. Pipeline integrity management guidelines are developed by American Petroleum Institute (API) [16], which conducts studies on petroleum industry and provides standards for oil and natural gas industry.