Journal of Petroleum Science and Engineering 133 (2015) 771–775

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

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

A novel smart caliper foam pig for low-cost pipeline inspection – Part B: Field test and data processing

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ARTICLE INFO

Article history:
Received 9 June 2014
Accepted 30 September 2014
Available online 2 December 2014

Keywords:
oil pipeline
pigging
utility pigs
pipeline integrity

ABSTRACT

Pipe in-line inspection by "intelligent" pigs is a fundamental oil and gas industry practice but still considered as an exceptional operation. In fact, the instrumented pigs used for such purpose are expensive and delicate tools with non-negligible risks of sticking inside the pipeline, thus making their deployment rather rare. In Part A of this paper we presented a novel smart foam pig, with sensing capabilities analogous to those of a multi-channel caliper pig, but characterized by very low operating risks due to its high capability to negotiate restrictions and its very low likelihood of creating obstructions, hence encouraging more frequent pipeline inspection campaigns. The present Part B discusses the results of the pig field tests. The processing and visualization for interpretation of acquired raw data are carried out through a dedicated software. A comprehensive analysis of the data acquired on two test campaigns on an 8 km pipeline in Italy is reported and the comparison with information gathered adopting a commercial In-line Inspection (ILI) pig is discussed.

1. Introduction

In the oil and gas industry, pipelines are unquestionably the most economical transportation method both for crude and refined products, in particular for long-range transfer (Trench, 2001). Nevertheless, they are intrinsically vulnerable to third-party damages, weather/environment threats, degradation factors and aging issues which may include possible initial construction defects.

Pipeline integrity management practices and pipeline maintenance procedures must therefore be accurately and effectively pursued to avoid accidental leakages. For instance, periodic non-destructive inspections to ensure proper cleaning to avoid obstructions and to assess both internal and external pipeline integrity are usually performed (Kishawy and Gabbar, 2010; Menon, 2011). Cleaning pipeline inspection gauges, commonly called pigs, and instrumented In-line Inspection (ILI) pigs (Tiratsoo, 1999; Quarini and Shire, 2007; Kishawy and Gabbar, 2010; Menon, 2011) play a key role in pipeline infrastructure management.

The former are used to remove debris and wax accumulations inside the pipe, while the latter are used to inspect the pipeline status through data recording of one or more of its specific characteristics, which are monitored adopting different kinds of sensors. Caliper pigs measure the inner diameter and shape of the pipeline in order to detect deformations (Beller et al., 2006; Zhang and Yan, 2007; Vieira et al., 2008; Pipeline Innovations Ltd; Weatherford MultiCal). ILI pigs are far more expensive and more fragile than cleaning pigs, requiring more stringent operating conditions and involving higher risks of stuck-pig events.

In Part A of this paper ("A novel Smart Caliper Foam pig for low-cost pipeline inspection – Part A: Design and Laboratory Characterization") we described the development, fabrication and preliminary laboratory testing of a new, low-cost and low-risk caliper foam pig, which represents a halfway device between classical cleaning and ILI pigs, totally novel in the present scenario of pigging protocols. The new tool embeds special sensors and low-cost electronics conceived to detect, locate and size inner diameter changes, defects and significant roughness anomalies. The use of a foam vector enables

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http://dx.doi.org/10.1016/j.petrol.2014.09.038
0920-4105/

the pig to negotiate substantial restrictions preventing operational problems in case of getting stuck along the pipe. Two identical prototypes have been fabricated and assembled. Laboratory tests, reported in Part A, showed suitable robustness and capability of application to inner diameter changes and surface corrosion measurement. The present paper discusses the results of the field tests carried out in an 8 km pipeline in Trecate (Novara, Italy). The acquired data have been processed using a fully custom-developed software, also described here, which allows easy interpretation and direct comparison with the data provided by a commercial Caliper pig launched in the same pipeline during the same inspection campaign.

2. Field tests

The field tests were conducted at the Oil Center Plant of Trecate (Fraz. St. Martino, Trecate, NO, Italy), property of eni E&P Division.

Pipeline characteristics and conditions of use for the test are as follows: (1) pipeline diameter: 12 in. (max/min known ID 292.20 mm); (2) pipeline length: 8165 km; (3) thrust: liquid water; (4) working pressure for the test: about 2 bars; (5) average dragging speed for the foam PIG: 1.1 m/s; (6) mission duration: about 2 h.

Two structurally identical 12 in. smart foam pig prototypes were launched in 2 separate tests on consecutive days, under the same operating conditions, to fulfill a twofold experimental verification of the required mechanical robustness, of the repeatability of the measurement and of the proper operation of the onboard electronics.

After preliminary verification of the pipeline conditions by launching a traditional (non-instrumented) foam pig and the installation of a suitable catch basket in the arrival trap, the first prototype was launched: Fig. 1 shows two stages of the launch of the first prototype before starting the water flow.

Fig. 2 shows the first prototype just after its recovery from the trap, about 2 h after the launch. Apart from the natural abrasion on the outer surface of the foam vector and of the steel nuts probes (consumed for about half of their height), all the mechanical parts of the prototype were undamaged and still fully operative at the end of the mission. The electronics were still active and positively responded to the switching-off imposed through the magnetic sensor integrated in the printed circuit board (PCB). All seals via o-ring for the PCB disc protection (one on the cap of the USB connection and two concentric around the hub of the PCB disc for inwards and outwards) demonstrated perfect tightness under the test conditions.

The next day, the second prototype was launched under the same conditions as the first. At the end, i.e. after pig retrieval, all components were found intact and preserved the original and correct installation position, as in the first test. Again, the sealing of the o-ring on the cap of the USB connection and around the central hub of the PCB disc-holder was confirmed. Thanks to the positive result of the twofold test under the same conditions, the quality and reliability of the mechanical design of the prototype has been satisfactorily validated.

The same day, a Service Company performed its run with a single-channel Caliper pig, equipped with a mechanical measuring system (designed to sense the internal pipe diameter), an odometer and an internal locator unit (see scheme in Fig. 3). The locator unit consists of a short-range locator designed to find the pig position in case of a pig-stuck event.

3. Software interface

A fully customized software has been developed for pipeline data analysis. Raw data acquired during the pig run and stored on a solid state memory on board can be downloaded into a PC through the USB connection. Data is then converted by the software to both numerical and graphical data, enabling further post-processing and direct defect recognition. Fig. 4(left) reports an example of how the deformation data is visualized in the software's user interface. Each trace of the graph corresponds to the signal sensed by one of the strain-gauge embedded in the pig's arms. Fig. 4(right) explains this relation: the green plot corresponds to the arm pointed in green, which underwent a sensible deformation (expansion) while passing by the dimple located just after the pipe entrance, clearly visible in figure.

From deformation data the software is also able to detect the concentric welds at the junction between two consecutive pipes (approximately 10 m one from another). Other data provided are the pig's roll and tilt, obtained processing the signals generated by a three-axis accelerometer embedded in the PCB, which are crucial to identify the instantaneous pipe sector inspected by each arm. In Fig. 5 the full screen of the software is presented, which includes vertical marks corresponding to the detected pipe junctions, the three accelerometer signals (red, white and blue traces in the upper part of the diagram) and two views of the pig that show roll, tilt (pitch) and an overstated representation of the arms' deformations instant-by-instant.

From the data it is possible to easily recognize the following pipeline characteristics by simple visual inspection: (1) horizontal and vertical curves; (2) valves, T-junctions, concentric welds and traps; (3) obstructions and bumps; (4) cracks and dimples; (5) ovalizations and concentric diameter restrictions; (6) depth/altitude variations through integration of accelerometer data; (7) pig location.

Fig. 1. Launch of the first prototype of Smart Foam pig.