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To cite this article: Huadong Song *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **382** 032021

IOP Conf. Series: Materials Science and Engineering **382** (2018) 032021 doi:10.1088/1757-899X/382/3/032021

Comparative Analysis of In-line Inspection Equipments and Technologies

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Abstract. Considering the global aging of pipelines and demand for new ones in more and more hostile environments, in-line inspection (ILI) based on the Non-Destructive Testing(NDT) was essential for pipeline operating company to protect their asset efficiently. This paper reviewed kinds of state of the art of ILI techniques and equipments, including geometry pig (GP), magnetic flux leakage pig (MFL PIG), ultrasonic pig (UT PIG), electromagnetic acoustic pig (EMAT PIG), eddy current pig (EC PIG), integrated function pig and specific function pig. Through the review of kinds of techniques, different approaches were compared, challenges and problems were highlighted and future research and direction was suggested.

1. Introduction

Pipeline is one of the reliable means for transporting oil, gas, water, and other important resources. A network of pipelines is mostly used for carrying different products especially when long distances are involved. As reported, by United States Central Intelligence Agency World Fact book in November 2015, USA had pipelines that totals more than 2.25 million kilometers as at 2013, China had 86921 kilometres as at 2007, U.K had 39778 kilometers as at 2013, Russia had 256913 kilometers as at 2007, and Canada had 100000 kilometres as at 2007. Some of these pipelines are installed in different environments hence subjected to various challenges, such as corrosion, crack, deformation, External force damage, et al [1].

ILI method is internationally recognized as the most effective way to protect the safety operation of the pipeline. ILI system is a technique used to collect data from internal pipeline, which is a significant part of the pipeline industry integrity management system of promoting safe, efficient and cost-effective pipeline operation [2]. The general ILI system fundamental structure is illustrated in figure 1.

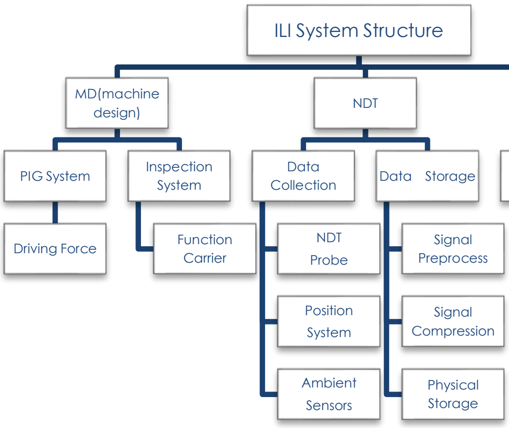

Fig 1. Structure Schematic of ILI System

2. ILI System Based on NDT

In this section, we review the state of the art for ILI techniques and equipments, including Geometry Pig (GP), Magnetic Flux leakage Pig (MFL PIG), Ultrasonic Pig (UT PIG), Electromagnetic Acoustic PIG (EMAT PIG), Eddy Current Pig (EC PIG), Integrated Function Pig and Specific Function Pig. The figure 2 illustrates the pipeline inspection operation procedure and general intelligent PIG types.

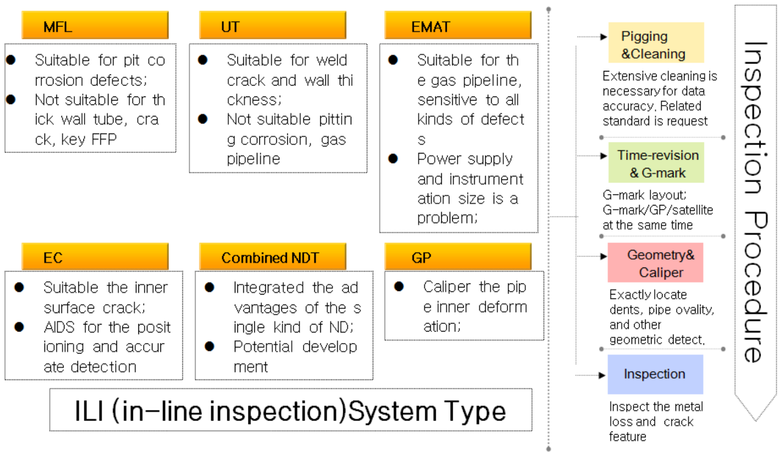

Fig 2. Inspection procedure and intelligent PIG types

2.1. *Geometry PIG (GP)*

According to the procedure of inspection operation, after pigging & cleaning, the GP will be next used to exactly identify and locate pipeline deformation. Information will be vital to judge this pipeline to subsequently implement next more accuracy inspection. The recognition capability by GP include: pipeline ovality, pipeline accessories (valve, three-way, elbow), welds, plain dent, buckle/wrinkles. Some high solution GP even identifies dents with metal loss, bending strains and pipe movement [3].

In general, the GP has more contractility than the other Intelligent PIG because it needs to be characteristic of stronger traffic ability. GP typically classified two types based on operation principle: one type is to depend on the mechanical arm which equipped angle sensor at joint (figure 3a), another depend directly on the large-distance eddy current probe arranged in circle (figure 3b). The former is characteristic of higher accuracy but the latter more tight and robust structure. If the customer need a mapping into GIS or consider the earth movement, Inertial Measurement Unit (IMU) would be often configured.

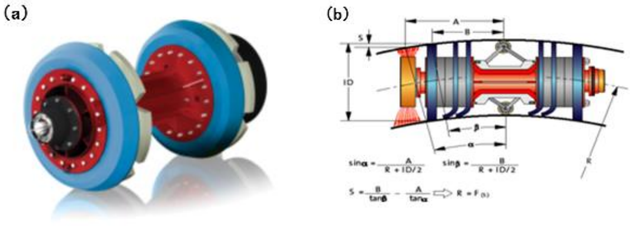

Fig 3. Two types of GP detector

2.2. Magnetic Flux Leakage PIG (MFL PIG)

The main merit of MFL is its ability to operate without the need of pre-processing and the ease to detect defect signal [4]. Moreover, it has capability of easy online detection, high degree of automation for detect many types of defects. Furthermore, it can inspect both internal and external surfaces and it's not affected by transportation media. All of these advantages make magnetic flux leakage inspection the most popular method for in-line inspection.

As a classical NDT method, the principle of the MFL technique is relatively simple. That is, when a strong magnetic field is applied to a ferromagnetic material, any geometrical discontinuity in the test object will cause the field to leak out of the object into the air. The flux leakage can be monitored by a magnetic field sensor and used to estimate the dimensions of the defect. Although the MFL phenomenon is easily understood, the design and analysis of MFL systems involve complicated interactions between the excitation field, leakage flux and the defects in the material. Its main limitation is that eddy current distributed in conductors induced by relative movement between the MFL probe and a specimen alters the profile and intensity of magnetic field leakage and distort the profile of MFL signals [5]. This brings about difficulty in the signal interpretation and description of the defect.

Due to the MFL inspection principle, the traditional MFL based on axial magnet deployment, lack of the sensitive for the axial crack, the circumferential magnet deployment structure have been developed to make a complement for the axial cracks [6]. GEPII new MFL product "TranScan TFI" is just the principle, which is strong suitable to detect the axial flaw including crack.

At Rio international pipeline conference in 2011, T.D. Williamson first introduce SpirALL Magnetic Flux Leakage Tool (Figure 4), which expounds the advantage based on the spiral magnetic leakage structure detect the pipeline, and complement the insufficient of single axial magnetic field [7].


Fig 4. Spiral MFL detector

2.3. Ultrasonic PIG (UT PIG)

Ultrasonic is one of the main areas of traditional NDT methods that uses guided waves and is the primary means of pipeline crack detection. Ultrasonic sensors, typically refers to Piezoelectric Transducers (PZT) or Capacitive Micro-machined Ultrasonic Transducers(CMUT), which converts AC into ultrasonic, as well as the reverse, ultrasonic sound into AC, uses ultra-high-frequency sonic energy to identify discontinuities in materials that are both on and below the surface of the material (such as metals or plastic). When these vibrations encounter interfaces between discontinuous materials, they will be reflected in predictable ways. From the returning signals, mathematically analogize the defect in depth and location of defects on or within the material. Compared with CMUT, conventional PZT are more mature [8]. PZT use coupling in transmitting signals to test specimen [9].

This limits the use of PZT in coating layers or in certain lift-off from the sample under inspection. Figure 5 shows the outline of an UT PIG.

Fig 5. UT detector

2.4. Electromagnetic Acoustic PIG(EMAT PIG)

EMAT are an attractive alternative to standard piezoelectric probes in a number of applications thanks to their contactless nature. EMAT does not require any couplant liquid and are able to generate a wide range of wave-modes [10]. It normally consists of a magnet (either a permanent or an electromagnet) and a wire located above the metal surface and in the magnetic field. When a wire carried an alternating current and held close to a conductor will induce eddy-currents in the conductor. Eddy-currents under the magnetic field is subject to the stress. Under the alternating stress, the stress wave is prone to be generated in the metals. When the frequency is over 20kHz, it will be considered as the ultrasonic wave[11]. On the other hand, the reflected ultrasonic wave will affect the wave vibration, acoustic vibrations inside the conductor move the surface under the receive wire. In the presence of a magnetic field, this motion produces an eddy current in the conductor surface that produces a magnetic field that extends across the air gap to induce a current in the near-by wire connected to a preamplifier.

ROSEN EMAT PIG technology is leading industry, which is featured with high dependable detection and accurate continuous sizing of all critical crack anomalies, coating disbondment as precursor of cracking is reliably detected, pipe diameter covered 12"-48". Figure 6 depicts a Rosen RoDD EMAT equipment.

Fig 6. Rosen RoDD EMAT detector

2.5. Eddy Current PIG (EC PIG)

EC technique is based on the interaction between a magnetic field source and the test material. This interaction induces eddy currents in the test piece. Defects of very small cracks can be detected by monitoring changes in the eddy current flow [12]. Eddy current sensor consists of an excitation coil and a receiver coil. There is a certain distance between the receiving coil and the excitation coil. Receiving coil receives the return magnetic field which passes through the pipe wall. By the changes of magnetic flux the receiver coil can detect pipeline cracks. Rosen used angle sensor combined with EC probe which be intensive spaced to measure the pipeline internal corrosion and dent contour. Deflection principle of detect is shown in figure 7.

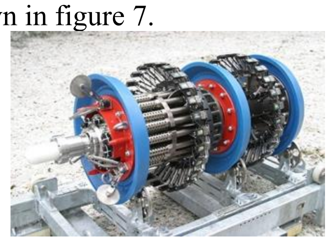

Fig 7. EC detector of ROSEN

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2.6. Integrated Function Pig system

Considering the merits and limitations of different single NDT&E techniques, it is obvious that their appropriate combinations will complement each other thereby giving a better result. Generally there are three major defect types for in-line inspection of pipeline, including deformation, metal loss and crack defects (table1). Every NDT&E technique used in ILI PIG system have its special strengths as it concerns varied defect types. Because of the single NDT limitation to variety detects, composite NDT measurement method is developed. The MFL+UT is most common Integrated Function Pig system. This combined tool absorbs the advantage respectively at MFL superior detection capabilities and UT excellent accurate result [13]. For example, it not only inspects common defects such as corrosion pitting and irregular general corrosion but also accurately sizing large uniformly corroded areas and laminations. Because a single run, additional toll tracking, launching, and receiving pig is not need, which reduces inspection costs and workload. Furthermore, it allows multiple data collection for pipeline integrity, eliminating the need to align manually two data sets.

The state-of-art combined NDT tool is an amazing equipment which be explored by T.D. Williamson. It integrated the pipeline deformation (DEF), spiral high magnetic field leakage (SMFL), magnetic field leakage (MFL), lower magnetic field (LFM), and EMAT. Its structure is illustrated in figure 8. The paper [14] introduced particularly the advantage of this multi-NDT technology in detect the pipeline flaw.

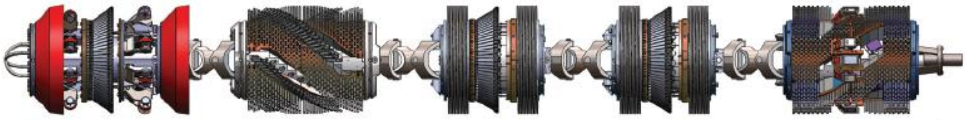

Fig 8. TDW combined pipeline inspection (DEF+SMFL+MFL+LFM+EMAT)

2.7. Specific Function Pig system

For a successful ILI operation, the pipeline suitable situation including cleanliness, through ability, construction standard is important. However, some of the pipes are not suitable for Intelligent PIG because of a variety of reasons. For example, large variable diameter pipe, will often appear in long distance pipeline. If adopt the conventional Intelligent PIG, it is difficult to realize the in-line-inspection. This specific and drastic expanding demand has driven manufacturers of pipeline inspection tools to continuously innovate ILI tools with very high quality of intended functions execution [15]. For example, GEPII SmartScan which claim can be inspect the previously Un-piggable pipeline, ROSEN Multi-diameter which claim suitable to varying diameter. Figure 9 is GEPII Smart-Scan and ROSEN Multi-Diameter.

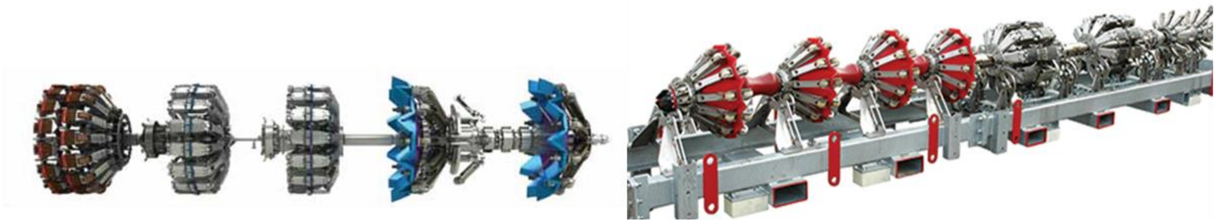

Fig 9. GEPII Smart-Scan and ROSEN Multi-Diameter

The role of health status of pipeline cathode protection to the life of the pipeline's is self-evident. However, related technical to the detection of pipeline cathode protection state is completely in use of external pipe including point designated monitoring or artificial portable devices detection along the pipeline, which is of low efficiency and many factors limit [16]. Hence, a particularly important Specific Functions PIG should be mentioned that from the Baker Hughes CPCM™. They claim that Cathode Protection Current Measurement (CPCM) ILI system is able to collect data and verifies Cathode Protection (CP) effectiveness when in-line-inspection as shown in figure 10.

Fig 10. Baker Hughes CPCM™

3. Comparative analysis of inspection ability between ILI systems

From the above-mentioned, **GP** system has many advantages when it comes to mechanical noncontact measurement of ovality and dents. The main advantage of deformation geometry in detection has shown in table 1. **MFL** system has the advantages of high sensitivity to pit corrosion, operation in hostile environment like high temperature or cold, under water etc. It is also versatile and robust in operation, and can be deployed at low cost. However its limitations includes sensitivity to pipe wall thickness, flow speed restriction, need for permanent magnetization saturation which determines its sensitivity and incapability of crack detection. **UT** system has high sensitivity and long range inspection application like pipeline. It is good for crack, sizing and unlimited thickness of pipe wall. The major limitation is the need for coupling agent and flow restriction that turn down in gas pipeline. **EMAT** system has got the whole advantages of UT and an added merit of operating without need for coupling agent and thickness measurement. While its main limitation is low transduction efficiency, big size senor hence consumes high energy. **EC** system is suitable for inner surface cracks and helps in the positioning and accurate detection. Suitable for wide range of defects regardless of size or material variation. Its limitations include sensitivity to lift-off and slow response at current pig speed. **Integrated Function** system combined the merits of different NDT&E techniques. Multi-NDT technology is developed to inspect multi-defect types such as deformation, metal loss and cracks. However, this method or concept is currently still only applicable to the laboratory stage.

Table 1 detailed the three type defects and give a brief advice on how to choose the intelligent pig according to the detect type. In practice, a success ILI system selection needs to consider more factors, which list in column of consideration parameters.

Table 1. Summary of ILI system inspection ability

Consideration parameters	Meta loss	Cracks	Deformation & Geometry
Gas/ Liquid medium Operation pressure, High-flow velocity Wall thickness, Pipe grade, Internal coat, Multi/Dual-diameter CP system, Ambient	General corrosion, Pitting, Pinholes, Axial groove, Lamination, Wall thinning, Narrow axial external corrosion	Hook/seam weld crack, Hydrogen induced crack, Circumferential crack, Fatigue crack, Shrinkage crack, Lack of fusion, Crack in dents. SCC,	Plain dent, Dents with metal loss, Small dents ID expansions, Buckle/wrinkle, Bend, Bending strain Centerline mapping
Advice of choice	MFL	UT/EMAT	GP /EC

4. Summary

This paper reviewed the ILI techniques and equipments used for pipeline inspection and compared the advantages and limitations of different technologies and systems.

(1) For now, intelligent PIG is the optimal tools for pipeline inspection.

(2) The UT PIG is more suitable for the crack while pitting corrosion is more appropriate to use the MFL PIG.

(3) The EMAT PIG will have an extensive applyment if completely solve the high energy consumption.

(4) Integrated Function PIG combined the merits of different NDT&E techniques, would result in a profound development.

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Acknowledgements
This work was supported by the Major Scientific and Technological Research and Development Project of Shenyang (Y18-1-023).

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