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Increasing offshore pipeline integrity via early failure detection using non-destructive testing

Zwiększenie integralności rurociągów podmorskich poprzez wczesne wykrywanie awarii za pomocą badań nieniszczących

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ABSTRACT: Presently, pipelines are one of the predominant methods of transporting oil, gas and petroleum products. Despite the existence of other means of transportation, this is the leading method in oil and gas transportation sector in Azerbaijan due to numerous advantages. Given the paramount importance of this mode of transportation, it is imperative to ensure its uninterrupted and continuous operation. This objective is realized by monitoring and inspection of the internal and external conditions of the pipeline. Two primary techniques are employed for the purpose of monitoring the conditions of pipelines: non-destructive testing (NDT) and destructive testing (DT). Destructive testing constitutes a set of methods for examining the properties of the pipeline material by partially or completely damaging the structure in order to obtain a sample. Destructive testing facilitates the acquisition of more accurate information about the properties of the pipe material thereby enabling the implementation of necessary preventive measures. However, the use of these methods is not always possible, as they require the extraction of a sample, rendering them suitable only in circumstances where the flow of the product has been interrupted. Moreover, the use of these techniques is not viable option in case of offshore pipelines. Conversely, non-destructive testing does not necessitate interruption of the process, thereby enabling concurrent execution of internal cleaning procedures. The use of this method makes it possible to obtain the necessary information about the condition of the pipeline structure without significant interference. A plethora of NDT technologies exists, however, in the offshore environment, the most prevalent one is the use of a pipe inspection gauge (PIG). This technology provides information on the internal condition of the pipeline, including the presence of cracks, corrosion, etc. These devices are typically equipped with specialized sensors, namely ultrasonic and magnetic, to obtain more accurate information about the condition of the pipeline. Each sensor has its own advantages and disadvantages. The present article reviews and analyzes various NDT technologies and types of pipeline inspection gauges with a view to identifying the most effective one for the purpose of inspecting the condition of offshore pipelines.

Key words: pipeline inspection gauge (PIG), ultrasonic, sensor, magnetic, pipeline, diagnostics.

STRESZCZENIE: Obecnie transport rurociągowy jest jednym z najczęściej stosowanych sposobów transportu ropy naftowej, gazu i produktów ropopochodnych. Pomimo istnienia innych środków transportu, ze względu na liczne zalety metoda ta zajmuje wiodącą pozycję w sektorze transportu ropy i gazu w Azerbejdżanie. Ponieważ ten rodzaj transportu ma kluczowe znaczenie, istnieje potrzeba zapewnienia jego ciągłej i nieprzerwanej pracy. Osiąga się to poprzez monitorowanie i inspekcję stanu wewnętrznego i zewnętrznego rurociągu. Istnieją dwie główne techniki monitorowania stanu rurociągów: badania nieniszczące (NDT) oraz badania niszczące (DT). Badania niszczące obejmują zestaw metod służących do badania właściwości materiału rurociągu poprzez częściowe lub całkowite uszkodzenie jego struktury w celu pobrania próbki. Dzięki badaniom niszczącym możliwe jest uzyskanie dokładniejszych informacji o właściwościach materiału rurociągu, co pozwala na podjęcie niezbędnych działań zapobiegawczych. Jednak stosowanie tych metod nie zawsze jest możliwe, ponieważ wymagają one pobrania próbki, a zatem mogą być stosowane jedynie w przypadkach, gdy przepływ medium zostaje wstrzymany. Dodatkowo techniki te nie znajdują zastosowania w przypadku rurociągów podmorskich. Z kolei, badania nieniszczące nie wymagają zatrzymania procesu i umożliwiają równoczesne przeprowadzenie czyszczenia wewnętrznego. Dzięki tej metodzie można uzyskać niezbędne informacje o stanie struktury rurociągu bez istotnej ingerencji w jego pracę. Istnieje wiele technologii przeprowadzania badań NDT, jednak w środowisku podmorskim najczęściej stosowaną jest technologia wykorzystująca tłok diagnostyczny (ang. *Pipe Inspection Gauge* – PIG). Technologia ta dostarcza informacji o stanie wewnętrznym rurociągu, takich jak pęknięcia, korozja itp. Urządzenia te są zazwyczaj wyposażone w specjalistyczne czujniki, głównie ultradźwiękowe i magnetyczne,

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umożliwiające uzyskanie bardziej precyzyjnych danych dotyczących stanu rurociągu. Każdy z tych czujników ma swoje zalety i wady. Niniejszy artykuł przedstawia przegląd i analizę różnych technologii przeprowadzania badań NDT oraz typów tłoków diagnostycznych w celu identyfikacji najbardziej efektywnej metody inspekcji stanu rurociągów podmorskich.

Słowa kluczowe: tłok diagnostyczny (PIG), ultradźwiękowy, czujnik, magnetyczny, rurociąg, diagnostyka.

Introduction

Systems for offshore pipeline transportation of oil and gas are of great strategic, economic and geopolitical importance for most countries. Therefore, ensuring the reliable and safe operation of such systems is the primary objective of operators. Offshore pipelines represent a viable alternative to vessels in the production and transportation of natural hydrocarbons. Pipelines form the fundamental infrastructure of the oil production and refining industry. The classification of these components is determined by various criteria, including installation method, purpose, type and temperature of the transported substance, pressure, etc. Offshore pipeline transportation necessitates constant monitoring of the technical condition and process parameters in order to maintain the working condition and ensure the safe transportation of the product. Gas and oil pipelines are subjected to various loading types (Mustafayev and Nasirov, 2024). These loads encompass both static and dynamic categories. Dynamic loads include loads initiated by waves and underwater currents, thereby resulting in mechanical effects that are both cyclic and impact-oriented. Static loads include loads from hydrostatic pressure, temperature effects, and corrosive effects arising from external natural environmental conditions as well as the aggressiveness of the transported product itself. This phenomenon gives rise to the occurrence of stress-strain states capable of initiating stress-corrosion processes (Saxon, 2012). This form of destruction poses a significant risk for main pipelines, as the manifest immediately during the operational process. Instead, they become evident only when the defect reaches a critical size, resulting in leakage or burst. In the course of maintenance operations, a range of defects may be identified in the same specific area of the pipeline wall. For instance, in areas with wall thinning, the formation of dents can be observed.

The nature of the applied load dictates the extent of volumetric surface defects that manifest on the pipeline. In cases where internal pressure acts as the sole load source and a defect does not induce plastic collapse of the structure, a minor leak can be observed. In the event of a metal defect forming a bridge of residual wall thickness prior to failure, the consequences are significant, often resulting in a large leak or rupture (Witek, 2019).

The volume of oil spills resulting from catastrophic failure leaks from underwater pipelines are the second most prevalent type of oil spill, exceeded in frequency only by spills from tanker accidents (Aleshin et al., 2006). Lapteva (2019) provides statistics on emergency situations on offshore pipelines in the Gulf of Mexico and the North Sea, according to which between 40% and 50% of accidents are attributed to the corrosion of pipeline walls. Spilled oil is one of the most dangerous pollutants of the marine environment. In recent decades, the world's oceans have been subject to numerous catastrophic oil spills (Wang et al., 2020).

The presence of undesirable factors can result in alterations to the dimensions of pipelines, leading to local thinning of the pipe wall and subsequent changes in internal diameter. Consequently, this results in a change in the flow mode of the pumped liquid, which may ultimately lead to the failure of the systems.

A significant proportion of emergency situations that occur as a consequence of pipeline damage can be averted through timely diagnostics and assessment of the pipelines' technical condition. The implementation and execution of appropriate monitoring mechanisms can facilitate the avoidance of financial expenditures associated with the rectification of accident-induced consequences and the restoration of standard operational functionality. Two methods are utilized in order to monitor the condition of the pipelines: destructive testing (DT) and non-destructive testing (NDT).

The assessment of the structural integrity of pipelines is typically conducted through the combination of both methods. However, in the context of offshore pipelines, characterized by elevated levels of inaccessibility and harsh environment, the use of NDT methods is considered optimal for all offshore pipeline systems.

A plethora of non-destructive testing techniques can be used for diagnostics of production pipelines (visual, eddy current, optical, magnetic, radio wave, radiation, acoustic, thermal).

An essential component part of the maintenance of an offshore pipeline is an external visual inspection using a remotely operated vehicle (ROV) deployed from a vessel. ROVs are equipped with sensors and cameras for the purpose of transmitting images from the bottom to a research vessel. They are also equipped with devices for instrumental inspection of pipes (Ageev et al., 2005). The following parameters of the subsea pipeline are determined during the inspection (STO Gazprom 2-2.3-253-2009):

1. Deviations in pipe geometry (corrugations, dents, turning radii etc.);
2. Actual spatial position of the subsea pipeline/crossing;
3. Presence of exposed sections of the pipe;
4. Internal profile of the pipe;
5. Pipe wall thickness and corrosion damage;
6. Image of the inner surface of the pipe.

The most common technology utilised for the purpose of assessing the mechanical integrity of an underwater pipeline is a method that utilizes "intelligent" gauges (Pipeline Inspection Gauge – PIG). These gauges are deployed into the pipeline and move with the flow of the transported fluid. The devices which are installed on the gauges are capable of detecting the slightest changes in the condition of the pipeline. This confirms the absence of mechanical damage and corrosion. It also determines the geographic coordinates to check the displacement of the pipeline relative to the design and original position. Following the acquisition of the required data, a three-step process is initiated for the purpose of evaluating the severity of present flaws or defects. The first step is the calculation of maximum allowable operating pressure for all the identified flaws to determine which ones necessitate repair. The second step pertains to the remedial measures taken in response to the identified flaws. Whereas the last step consists of the estimation of the probability of pipeline failure based on data obtained from the inspection and on corrective measures taken (Witek, 2016).

A significant number of pipeline operators utilize PIGs to inspect the condition of the pipeline. For instance, in order to guarantee the structural integrity of the main oil pipeline Baku-Tbilisi-Ceyhan, a variety of PIGs are used (BP, Environmental and Social Impact Assessment, 2002). An exemplary instance of the use of inspection gauges is their use in the Nord Stream gas pipeline. All PIGs used for internal inspection are manufactured by the ROSEN Group, with a design specifically tailored for the Nord Stream gas pipeline (Lushnikov, 2005). In order to verify the functionality and technical characteristics of the devices, a rigorous testing process is undertaken. This process involves the use of a test pipeline featuring irregularities on the metal walls of the pipes and the concrete coating, as well as pneumatic tests.

In the course of the inspection, three different devices are used for: calibration, cleaning and diagnostics. These devices are capable of detecting potential corrosion and wear points, and measuring pipeline bends using an integrated inertial measurement unit. Furthermore, cleaning can be carried out concurrently with the inspection. The primary control function is executed by a so-called combined "intelligent" device, which is equipped with sensors that monitor the geometry of the pipeline (e.g., dents, bends, buckling), and metal loss in pipeline walls (internal or external corrosion) as well as detect other anomalies (e.g., weld seam defects). The device continuously measures the distance traveled using built-in wheels, which allow the measurements to be compared with a specific point in the pipelines. The device functions optimally at a travel speed of approx. 1.5 m/s; the active control system measures the speed and controls the bypass, which slows down the gauge speed. The device weighs 7.3 tons, and is 6.6 m in length (Energy for Europe. Nord Stream Project, 2005; Lushnikov, 2005). It is equipped with a battery and a high-capacity memory device that records data for subsequent analysis.

The internal geometry module is capable of detecting and characterizing any deviations from the original pipe shape, even if the deviation is less than a millimeter. The device is used to detect changes in the internal diameter, ovality and depression, and record their position (Figure 1). The internal wall surface corrosion sensor is a contactless sensor that scans the surface of pipes for areas with metal loss (Figure 2).

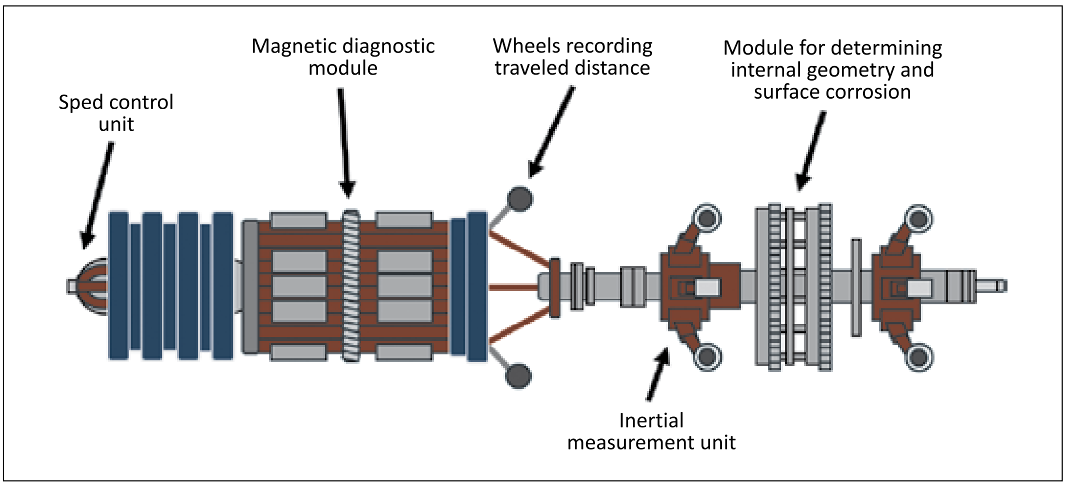

Figure 1. High-resolution pipeline inspection gauge (PIG) (General information about the Nord Stream project, 2013)
Rysunek 1. Tłok diagnostyczny (PIG) o wysokiej rozdzielczości (Ogólne informacje o projekcie Nord Stream, 2013)

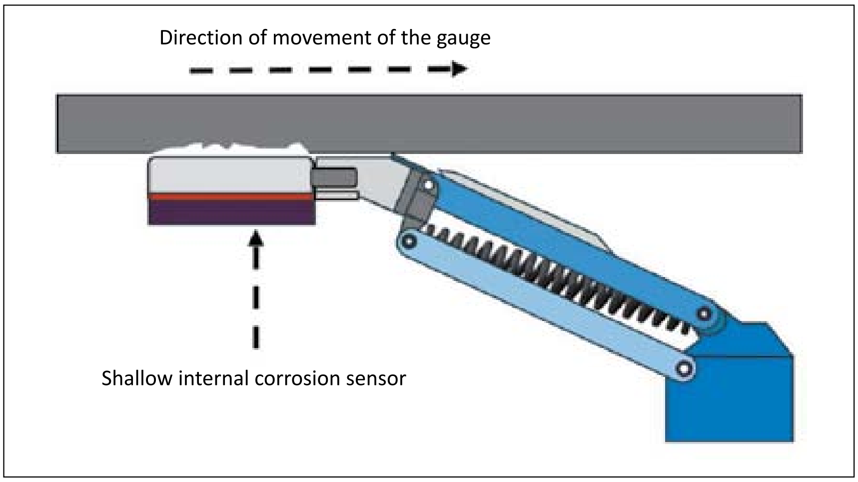

Figure 2. Design of the inner wall surface corrosion sensor (General information about the Nord Stream project, 2013)
Rysunek 2. Konstrukcja czujnika korozji wewnętrznej powierzchni ściany rurociągu (Ogólne informacje o projekcie Nord Stream, 2013)

Minor defects present on the internal surface of pipes lead to a change in the distance between the sensor and the pipe, which is measured by the sensor. One of the types of sensors used in a PIG is a magnetic sensor. The magnetic diagnostic module allows the detection of metal loss or corrosion of the wall of a steel pipe by creating a strong magnetic field that magnetizes the pipe wall, and the electromagnetic sensor records changes in the secondary magnetic field created by the steel pipe. To control the geometry or position of the pipeline, an inertial navigation module is used, which operates on the basis of measuring the force on the internal gyroscopic sensor that occurs when it moves along a curve inside the pipeline. In instances where deviations are observed in geometry or position, measures are taken to stabilize the pipeline, including the use of gravel to prevent the pipe from shifting from its initial position.

Another type of sensors used in pipeline inspection gauges sensor are ultrasonic sensors. Ultrasonic testing (UT) smart PIGs are equipped with ultrasonic transducers that emit sound waves into the pipeline's walls. When these waves encounter variations in material density, they reflect to the transducers. By analyzing these reflections, the PIG is able to construct a detailed image of the pipeline's interior, allowing for precise detection of defects. Ultrasonic PIGs are commonly used for detecting internal pipeline geometry defects and to measure the thickness of pipeline walls (Raczyński and Warnke, 2017).

Research objectives

The objective of this paper is to analyze different types of pipeline inspection gauges (PIG) for subsea pipelines and to select the most suitable NDT method and PIG type for detecting flaws in the subsea pipeline. The selection of the appropriate NDT method and PIG of paramount importance for increasing the lifespan and stability of the pipeline. Moreover, the implementation of more effective non-destructive testing technology has the potential to reduce costs and eliminate potential environmental damage.

Non-destructive testing methods

There are two primary methodologies employed in the testing of pipeline structural integrity and properties. These include non-destructive testing (NDT) and destructive testing (DT).

DT methods necessitate the extraction or cutting of samples directly from the object's structure. Such methods include mechanical testing, metallographic testing, corrosion testing, process testing, chemical analysis and weldability testing.

In the context of destructive testing, the object from which sample is taken is typically rendered inoperable until the sampling points (samples) are restored. However, methods such as hot tapping allow to extract sample without interrupting the operation of a subsea pipeline. Despite the fact that this technology facilitates efficient sampling, its complexity and inefficiency in certain situations means that its use is not as widespread as the use of NDT methods. For instance, in shallow water conditions where the soil is unconsolidated, subject to the influence of waves and underwater currents, visibility can be reduced (due to suspended sediments), even in the presence of artificial lighting (Boran, 1987).

Mechanical testing is one of the main DT technologies. Such methods include tensile, bending, flattening and other types of failure that quantitatively characterize the strength, quality and reliability of connections and structure of the pipeline material itself. Mechanical testing can be classified according to the nature of the loads applied, namely as static, dynamic and fatigue tests (Novozhilov et al., 2015). Destructive tests are often carried out on samples that are welded with the same material and the same welding technology as the welded joints of the original product.

Depending on the operating principle of the testing equipment, all known **NDT methods** in accordance with GOST 18353-79 are divided into the following main types: magnetic, ultrasonic testing, dry penetrant testing etc. (GOST 18353-79). NDT facilitates the assessment of pipeline quality characteristics without compromising their integrity. The primary benefit of non-destructive testing is that it can be carried out without compromising the continuity of the technological process, thereby preserving the economic efficiency of production. The specifics of pipe production have the potential to result in the presence of various defects. Based on such data, proper inspection schedules are developed (Witek, 2018).

The defects primarily manifest themselves as longitudinal marks on the outer and inner surfaces, dents, bumps, cavities etc. Furthermore, defects arising during the manufacturing process, including corrosion and fatigue, have the potential to result in failure.

Magnetic testing methods are based on recording magnetic fields leakage occurring above defects, or the determination of the magnetic properties of the tested materials. In the domain of magnetic testing technologies, the prevalent methods include: magnetic particle testing, magnetograph analysis, flux gate measurement, Hall effect transducer testing, induction testing, and ponderomotive testing.

All magnetic testing methods are used for the purpose of detection of defects, such as discontinuities of metal in ferromagnetic products (Vasin, 1997). In addition to detection of discontinuities in the material, such as cracks, folds, and flakes, magnetic testing facilitates the acquisition of other essential data. Such data can include: the quality of heat treatment, the presence and amount of residual austenite, and magnetic anisotropy.

Furthermore, magnetic testing has the potential to control the process of decomposition of solid solutions and dispersion hardening. In addition, it can be used to ascertain the mechanical characteristics of ferromagnetic steels and cast irons through the changes in their magnetic characteristics. Moreover, magnetic testing can be employed to control the thickness of the cemented or nitride layers, as well as the thickness of the surface hardening layers of products.

Ultrasonic testing is another widely used non-destructive testing (NDT) method. It is used to detect internal defects, cracks, weld integrity and measure the wall thickness of pipelines. Ultrasonic testing is a process that utilizes high-frequency sound waves transmitted into the material. These waves, when transmitted, travel through the material and are reflected when they encounter boundaries, such as the back wall or a defect.

Ultrasonic testing is a widely employed technique for the identification of surface-level and internal defects through the use of high-frequency sound waves. Depending on the setup and scanning method used, it is capable of providing both the depth and size of the detected flaws. The UT method has the capacity to detect even minor defects in the pipeline that may not be visible to the naked eye. It is a highly effective method of measuring wall thickness and detecting changes in material thickness due to factors such as corrosion or wear.

Diagnostics of offshore pipeline systems

Offshore pipeline systems are installed in unique and harsh conditions that impose increased requirements for their safety, reliability and integrity. To achieve the required parameters for the operation of offshore pipelines and ensure their industrial safety and reliability, it is important to monitor their condition in order to detect any abnormalities prior to failures.

The specific features of the design and structure of offshore pipelines are related to their designation, the geographical location of the laying area, coastal conditions and characteristics of the seabed, the strength of sea currents and waves, the shipping timetables and other factors that impose increased requirements for reliability and safety. In order achieve the required parameters for the operation of offshore pipelines and prevent accidents and incidents, it is important to carry out continuous and high-quality diagnostics of the technical condition.

The selection of diagnostic methods and means is determined by the design solutions used in offshore pipelines (e.g., the presence of pipeline inspection gauges launch and reception units, the radius of curvature of the branches, the change in diameter, the type of installation), their service life, natural and climatic conditions, the availability of measuring equipment, transportation capabilities and other factors. The following methods are considered in the majority of normative and technical documentations governing the diagnostics of the technical condition of offshore pipelines:

1. in-pipe technical diagnostics;
2. external diagnostics, determination of the parameters of the technical condition of the offshore pipeline, carried out from the external environment without interrupting the pipeline's operation using engineering and geodetic survey methods, which include:
   a) engineering and hydrographic work performed by a vessel or instrument complex on a towed underwater vehicle based on a side-scan phase sonar, multibeam and

sounding echo sounders using an underwater remotely operated vehicle or divers;

b) engineering surveys on the coastal sections of the pipeline;

c) diagnostics of the coastal sections of the pipeline using non-destructive testing devices.

Diagnostics of offshore pipelines is performed using the following technical means:

- pipeline inspection gauges;
- specialized vessels;
- underwater vehicles (remotely operated underwater vehicles (ROV), towed underwater vehicles, autonomous underwater vehicles; manned underwater vehicles);
- satellite navigation systems;
- hydroacoustic devices;
- hydroacoustic navigation systems.

The implementation of diagnostics involves carrying out external monitoring of the pipeline, as well as internal monitoring of the pipeline condition. External monitoring includes general hydroacoustic photography (macro photography) and detailed monitoring of the pipeline structure (micro photography). Macro photography can be carried out from on board an inspection vessel or using remotely operated underwater vessels (ROV). Autonomous underwater vessels are used as basic equipment for external inspections.

Internal pipeline inspection is carried out to detect flaws, the spatial configuration of pipelines (bends, displacement from the calculated position), the geometry of the pipe shell (ovality, folds), damage to the pipe metal (corrosion, cracks, burrs) and the welded joints. The monitoring of internal defect should be carried out using an in-pipe diagnostic device – a “Pipeline Inspection Gauge – PIG”. Presently, the use of PIGs for conducting internal inspections has become widespread (Figure 3). PIGs are used to identify imperfections on pipeline walls, while moving inside the pipeline under the pressure of the pumped product (oil, gas and gas condensate). The PIG presented in the Figure 3 is equipped with electromagnetic sensors, supporting wheels, equipment for recording and storing in memory the test result data, and power batteries, necessary for its operation (Mogutin et al., 2017; Bussugu, 2019).

PIGs facilitate the concurrent acquisition of data about the spatial configuration of the pipeline and the pipe wall geometry, and the monitoring of the technical condition of the network. This is achieved through the incorporation of non-destructive testing systems (typically magnetic or ultrasonic sensors) into the PIG design.

Flaw detection shells can be used in combination with scraper shells (pistons) designed to clean the inner surface of the pipeline, thus improving the quality of the subsequent flaw detection procedure (Figure 4) (Yashin et al., 2016; Alnaimat and Ziauddin, 2020).

In order to deploy a PIG into the internal space of the subsea pipelines, specialized traps for receiving and launching are utilized (Figure 5) (Yashin et al., 2016; Mogutin et al., 2017). The trap is composed of the following components: a functional pipe, a support frame, pipeline fittings, a shut-off mechanism, a connecting device, control elements, a device for receiving gauges, a gauge passage sensor (Dvornikov, 2018).

Presently, given the paramount importance of accurately assessing pipeline integrity, all PIGs are engineered to exacting standards and operate with high efficiency. There are two main types of PIGs commonly used for pipeline inspection and cleaning:

1. Butterfly type PIG;
2. Wheel type PIG.

Butterfly PIGs are designed with a single flexible disc, frequently referred to as a “butterfly”, which creates a seal against

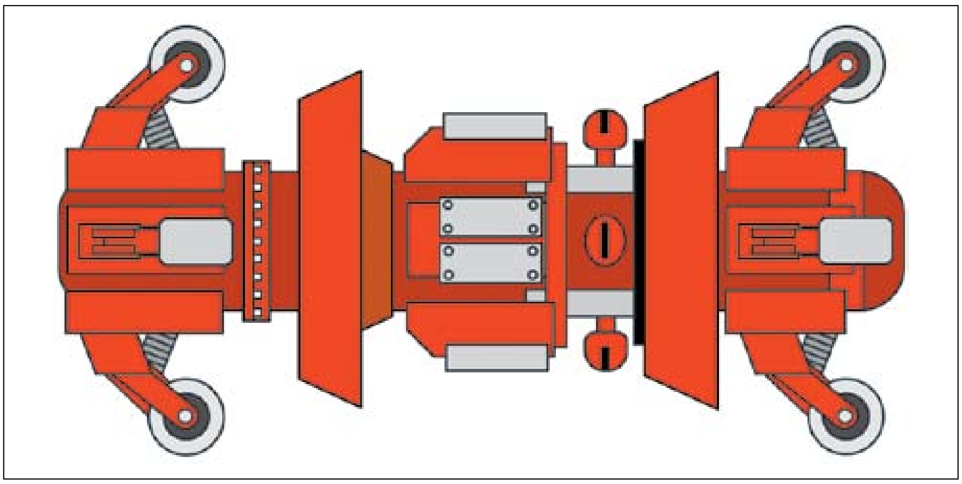

Figure 3. Pipeline inspection gauge for diagnostics of offshore oil and gas pipelines (Mogutin et al., 2017)
Rysunek 3. Tłok diagnostyczny do badania podmorskich rurociągów naftowych i gazowych (Mogutin i in., 2017)

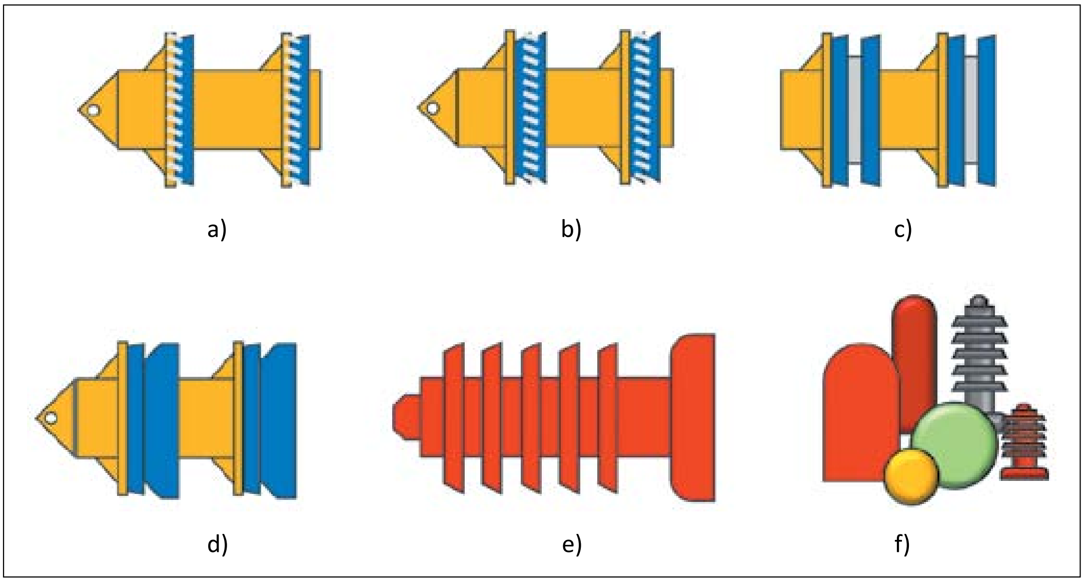

Figure 4. Pistons (tools) for cleaning underwater pipelines (Yashin et al., 2016): a) steel piston "Brush"; b) polyurethane piston with cleaning brushes; c) polyurethane piston with cuffs; d) combined cuff-disk piston; e) solid steel piston; f) cleaning tools

Rysunek 4. Tłoki (narzędzia) do czyszczenia podwodnych rurociągów (Yashin i in., 2016): a) stalowy tłok „szczotkowy"; b) poliuretanowy tłok z szczotkami czyszczącymi; c) poliuretanowy tłok manszetowy; d) tłok kombinowany manszetowo-tarczowy; e) pełny tłok stalowy; f) narzędzia czyszczące

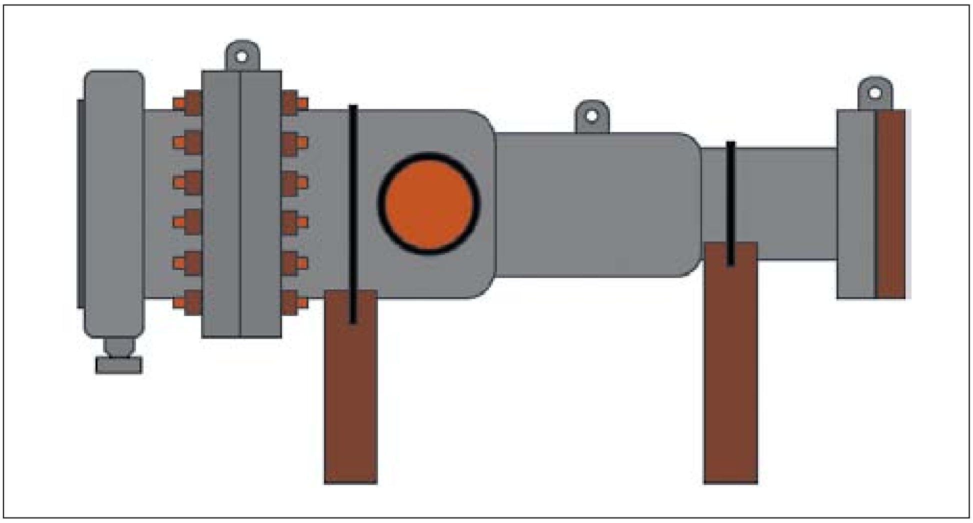

Figure 5. Trap for receiving and launching in-pipe diagnostic tools (Dvornikov, 2018)

Rysunek 5. Przyrząd do odbioru i wprowadzania narzędzi diagnostycznych w rurociągu (Dvornikov, 2018)

the inner wall of the pipeline (Figure 6). The flexible sealing disc of the butterfly PIG is tightly pressed against the inner wall of the pipeline, ensuring efficient cleaning, particularly for light debris and build-up. These types of PIGs are considered to be less expensive to manufacture. However, butterfly PIGs have certain disadvantages. They lack efficiency in instances where heavier debris or wax build-up is present. Such cases necessitate the use of more aggressive cleaning tools.

Wheel type PIGs are equipped with rotating brushes that have the capacity to remove heavy corrosion and wax build-up inside of the pipeline (Figure 7). The design of these types of PIGs is more complicated than that of butterfly ones, which results in a higher cost. Moreover, the use of the PIG's rotating brushes during the cleaning of corrosion and wax has the potential to damage the internal surface of the pipe due to degree of abrasiveness of the tools (O'Donoghue, 2001).

Pipeline industries have a wide choice of pipe inspection tools (PIGs) that have the capability to deliver a high-level report on pipeline features and defects. The internal inspection of subsea pipelines is predominantly undertaken through the utilization of two primary technologies: magnetic flux leakage (MFL) and ultrasonic testing (UT).

It is evident that each technology possesses a distinct set of advantages; however, it is important to recognize that each

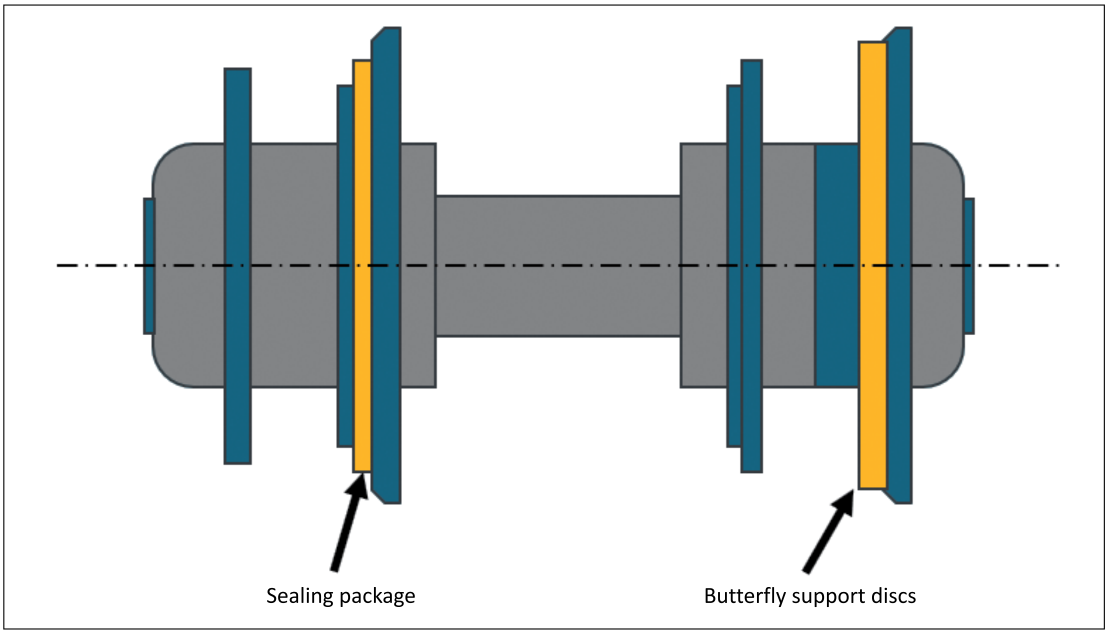

Figure 6. Butterfly type PIG (O'Donoghue, 2001)
Rysunek 6. Tłok typu „motyl" (O'Donoghue, 2001)

technology is also subject to its own limitations. Magnetic PIGs have been shown to be highly effective at detecting metal loss due to corrosion. It has been emphasized by numerous researchers that its effectiveness for corrosion detection is significant. For instance, in the research conducted by Witek (2021), the evaluation of burst pressure and integrity of pipelines was carried out using a magnetic flux leakage inspection tool.

Such devices utilize magnetic fields to detect variations in the metal thickness of the pipeline. They are generally less expensive than ultrasonic PIGs, making them a more cost-effective solution for routine pipeline inspection. Conversely, this type of PIGs has certain disadvantages. For instance, magnetic PIGs are only compatible with pipelines made from ferrous (magnetic) materials, precluding their application to non-ferrous pipelines. Furthermore, magnetic PIGs are unable to provide the level of details on pipeline thickness or structural integrity that ultrasonic PIGs can offer.

Ultrasonic PIGs provide highly detailed and accurate measurements of the thickness of pipeline walls, detecting even small cracks or weaknesses. Unlike magnetic PIGs, ultrasonic PIGs can be deployed in both ferrous and non-ferrous pipelines, rendering them a more versatile option for a wider range of

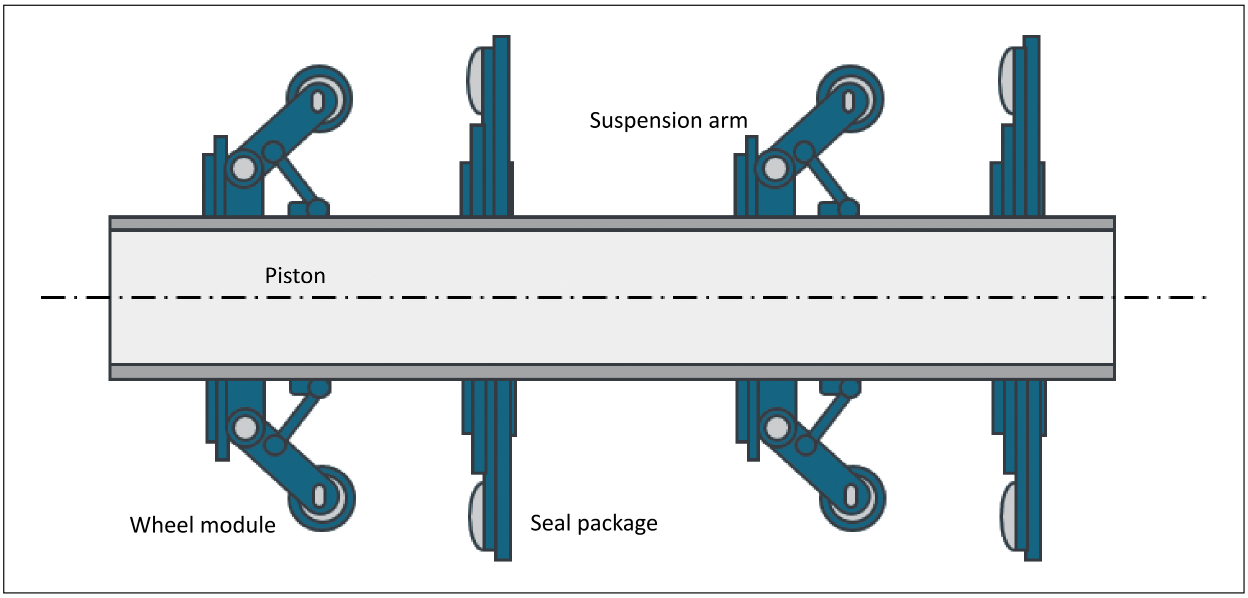

Figure 7. Wheel type PIG (O'Donoghue, 2001)
Rysunek 7. Tłok typu kołowego (O'Donoghue, 2001)

materials. The capabilities of this technology extend to the identification of both external and internal corrosion, wall thinning, cracks, and other structural issues, thereby providing a comprehensive view of the pipe wall imperfections.

However, it should be noted that there is a significant disadvantage of using UT PIGs. The employment of advanced technology and precise measurements has resulted in a higher cost compared to magnetic PIGs. The inspection process using ultrasonic PIGs may take longer compared to magnetic PIGs due to highly detailed measurements and analysis (Pople, 2003).

Conclusion

1. A comparative analysis of extant methods and hardware for diagnosing the linear part of pipelines has been undertaken. This analysis has substantiated the practical feasibility of using inspection devices equipped with both ultrasonic and magnetic sensors in a single design. The recommended design of the inspection device allows for the determination of the pipe wall thickness, metal loss and internal defects in one pass, thereby significantly reducing the costs and time required for additional inspections.
2. The selection of design elements directly related to cleaning the pipeline in the recommended modification should be carried out depending on the type of liquid being transported. Consequently, in instances where the pipe is used for the transportation of heavy liquids, the use of a wheel-type PIG is often more appropriate when compared to butterfly-type PIGs, which are typically utilized for low-density liquids.

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