Improvements of an inspection technique for unpiggable pipeline diagnostics from above ground

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Abstract

There are thousands of unpiggable and challenging pipelines running through Europe alone. The integrity management of these pipelines requires nondestructive evaluation techniques, which can be applied without introducing inspection tools into pipelines. Pipeline diagnostics shall, therefore, be executed from above ground. Indirect approaches such as DC Voltage Gradient (DCVG) survey or External Corrosion Direct Assessment (ECDA) can be used for this purpose. However, such approaches are characterized by distinct limitations, i.e., properties of soil (DCVG), or necessity of reference excavations (ECDA). Consequently, the latterly mentioned techniques can only be used for external corrosion and coating damage detection and not for information about a metal loss in the pipe wall.

The presented Above Ground Inspection Technique (AGIT) has been developed to overcome limitations of DCVG, ECDA, and In-Line Inspection (ILI). Thus, AGIT is capable of localizing and categorizing external and internal metal losses in unpiggable pipelines. All crucial information of the pipeline will be given to the customer through only one inspection run. The Electromagnetic Pipeline Testing GmbH (EMPIT) holds all exclusive rights and assets of AGIT.

At first, the physical basics and technical principles of AGIT will be explained. Briefly spoken, the technique is based on above ground measurements of the magnetic field of a buried pipeline under test. Metal loss defects in the pipeline wall become detectable through AGIT as they result in measurable changes of the magnetic field at different frequencies.
In addition to the magnetic field data, the pipeline's depth of cover, the test current in the pipeline, and the chainage along the pipeline will be stored and used for further evaluation. Moreover, information on coating holidays based on registered local leakages of the test current and the presence of metal objects in the close vicinity to the tested pipeline will be highlighted and presented to our customers.
Secondly, a review of performed inspection runs, including a comparison of detected features and their validation through excavations, is presented. It has been proved that AGIT demonstrates a high level of reliability in detecting pipeline defects
Lastly, the goals, approaches, and test results of improvements, achieved by a new development of the AGIT, including the method itself, the field inspection unit, and the evaluation procedure, will be discussed.

1. Introduction

Oil, gas and, water pipelines are indispensable for product transportation in all countries of the world. The greatest proportion is made of steel and slow expansion of oil and gas infrastructure is adding pressure to existing, aging infrastructure. The majority of the pipeline network, in industrialized countries, was built between the 1950s and 1970s. The risk of pipeline failure due to corrosion and other external effects is higher than it was ever before. Consequently, reliable solutions for mitigating this risk are needed.
Nowadays, most of the pipelines are operated under cathodic protection (CP) as an anti-corrosion measure, but nevertheless, a lot of undesired environmental factors are present, which lead, despite CP, to corrosion of pipelines. Their integrity is the most important factor for a safe environment, secure production, and transportation. To prevent the dangerous influence of corrosion on pipeline integrity, different inspection techniques have been introduced to the market. The mainly used ones are: (i) water pressure test, (ii) inline inspection (intelligent pigging) [1], (iii) DC voltage gradient survey (DCVG) [2], (iv) current mapping (CM) [3], and (v) External Corrosion Direct Assessment (ECDA) [4]. Inline inspection is the only method that provides direct information about the condition of the pipeline wall. However, not all pipelines can be inspected using intelligent pigs. The main limitations of inline inspection are (i) the inability to work with varying inner diameters of pipeline joints; (ii) the inability to pass through sharp bends and tees, and (iii) the inherent lack of pig launches/receivers in pipelines. Also, mandatory cleaning of the pipeline prior the inline inspection takes additional time and raises inspection costs. Other techniques either deliver only “passed” / “not passed” assessment (hydrostatic pressure test) or merely identify coating damages, which might lead to corrosion and therefore need costly excavations for physical verification with direct access to the pipe wall.

As an alternative to indirect survey techniques for unpiggable and challenging pipelines, the herewith-presented Above Ground Inspection Technique (AGIT) shall be used. After only one inspection run the AGIT inspection delivers information about internal and external metal loss, girth weld locations, depth of coverage, and coating defects. The inspection is performed from above ground along the Right Of Way (ROW) of the pipeline without any influence on the transportation mode of the inspected line. Simultaneously, GPS coordinates of desirable points will be defined and stored. In this way, not only mapping of the pipeline is realized, but also precise localization of faults is possible and our costumers save money and time.

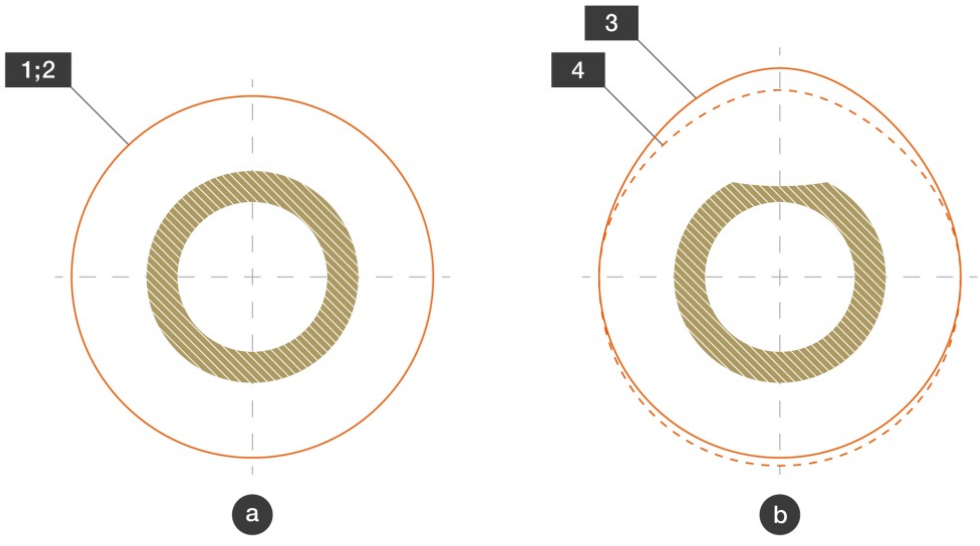
2. Physical principles of the inspection technique

The inspection technique [7] is based on measurements from above ground of the AC magnetic field, which will be induced around the inspected pipeline by a specially generated test current. This test current will be conducted into the pipeline wall via two electrical contacts on the edges of the inspected range. The current contains several harmonic components with frequencies ranging from a few to a few hundred Hertz. The chosen frequency range is caused by the electromagnetic properties of the pipeline steel. The magnetic field, induced by this current is surrounding the pipe. Due to the skin effect, the current density distribution in the pipeline wall, along the pipe radius, is frequency-dependent. The higher the frequency is the higher is the current concentration under the outer surface of the pipe’s wall. The harmonic components

with lower frequencies are flowing through the whole wall cross-section, whereas the harmonic components with higher frequencies are flowing mainly through the thin layer under the outer surface of the pipe. Due to the fact that the pipe is made of ferromagnetic steel, another physical effect plays a crucial role for metal loss recognition. This is the stray magnetic flux from the pipe wall. Similarly to the current, the magnetic field distribution in the pipe wall towards the radial direction is also frequency-dependent. Due to the relatively high magnetic permeability of steel, the magnetic field density in the pipe wall is much higher than outside the wall. In case of a metal loss in the pipe wall, the magnetic field appears (strays) from the wall over the defect. This leads to a corresponding deformation of the surrounding magnetic field. This effect is also frequency-dependent. The deformation of the magnetic field will be registered by the AGIT inspection system and later recognized when the data is evaluated.

When considering two different situations “with” and “without” metal loss in the pipe wall, a difference in the magnetic field curves shape becomes evident. In case of a pipe without any metal loss (cf. **Fig. 1*a***), the surrounding magnetic field lines *1; 2* for some but the same field density is circular and independent to the frequency of the test current. However, a different situation takes place if a metal loss fault is present (cf. **Fig. 1*b***). In this case, the surrounding magnetic field lines are egg-shaped and their shape is frequency-dependent. The lowest frequency *3* and the highest frequency *4*, which have the same field density like the corresponding field lines in **Fig. 1*a***, illustrate this.

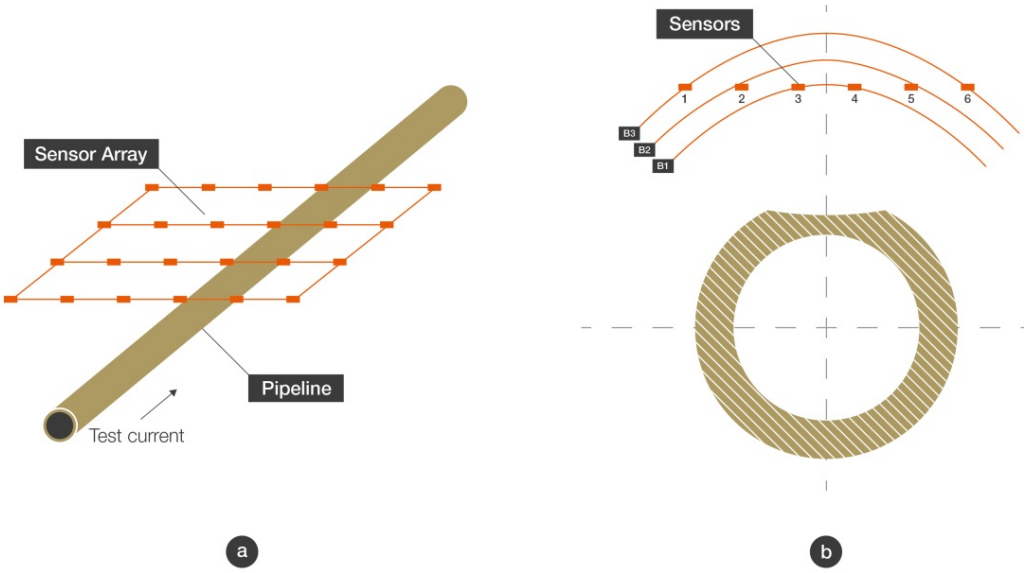
Fig. 1. Magnetic field lines for the same field density at the lowest (cf. *1*, *3*) and the highest (cf. *2*, *4*) frequencies; (*a*) – pipe without metal loss; (b) – pipe with metal loss.



The frequency-dependent deformation of the magnetic field lines exists not only in case of an outer metal loss, as shown in **Fig. 1**, but also in case of an inner metal loss. If a metal loss fault lies in another clock position, the magnetic field lines deformation is also present and thus allows AGIT to recognize the fault at all clock positions. When using both, the measurement and the comparison of the magnetic field outside the pipe at different frequencies, it is possible to clearly differentiate between the situations

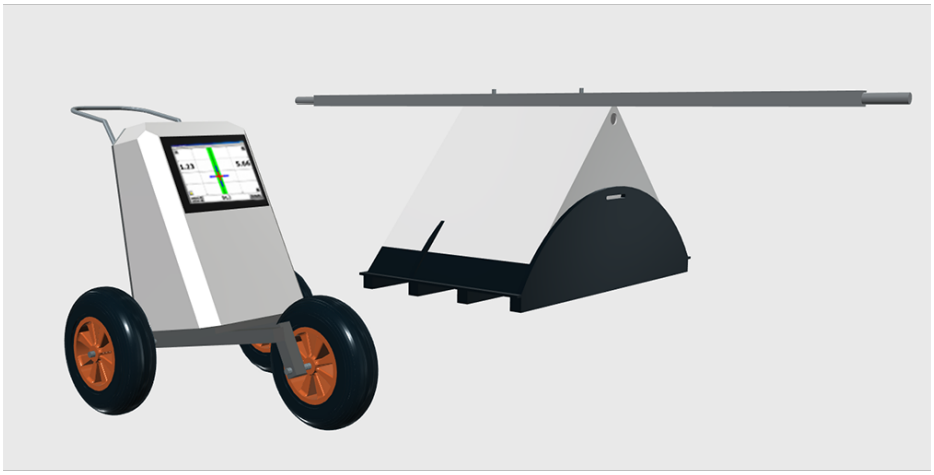
"*with* metal loss" and "*without* metal loss". This is the basic principle of the AGIT method.

Fig. 2. (*a*) Sensor Array in the measuring position over the pipeline; (*b*) sensor line in the measuring position ($B_1 > B_2 > B_3$) over a metal loss defect.



Instead of using just one sensor, the AGIT inspection system uses six sensors in one line, which is perpendicular to the pipe. This allows the determination of both, the depth of coverage, and the actual current flowing through the pipe. Additionally, a higher sensitivity of the system is achieved. For a higher productivity of the inspection, four sensor lines are used, which are placed next to one another in the inspection direction along the pipe. In this way, a 6 x 4 matrix of sensors is built – the so called Sensor Array (SA) (see **Fig. 2*a***). The AGIT sensors measure the pipeline's surrounding magnetic field above ground (see **Fig. 2b**).

Fig. 3. The AGIT system; Data Collector Module (left) and Sensor Array (right)



The output signals from the sensors are transferred to the Data Collector Module (DCM) where they are digitized, stored and used for the determination of the pipeline

position related to SA and the actual test current in the pipeline. The DCM is equipped with a display, which is used to show graphically the actual pipeline position (depth of coverage and displacement). This supports correct orientation of the SA above the pipeline at every step of the inspection.

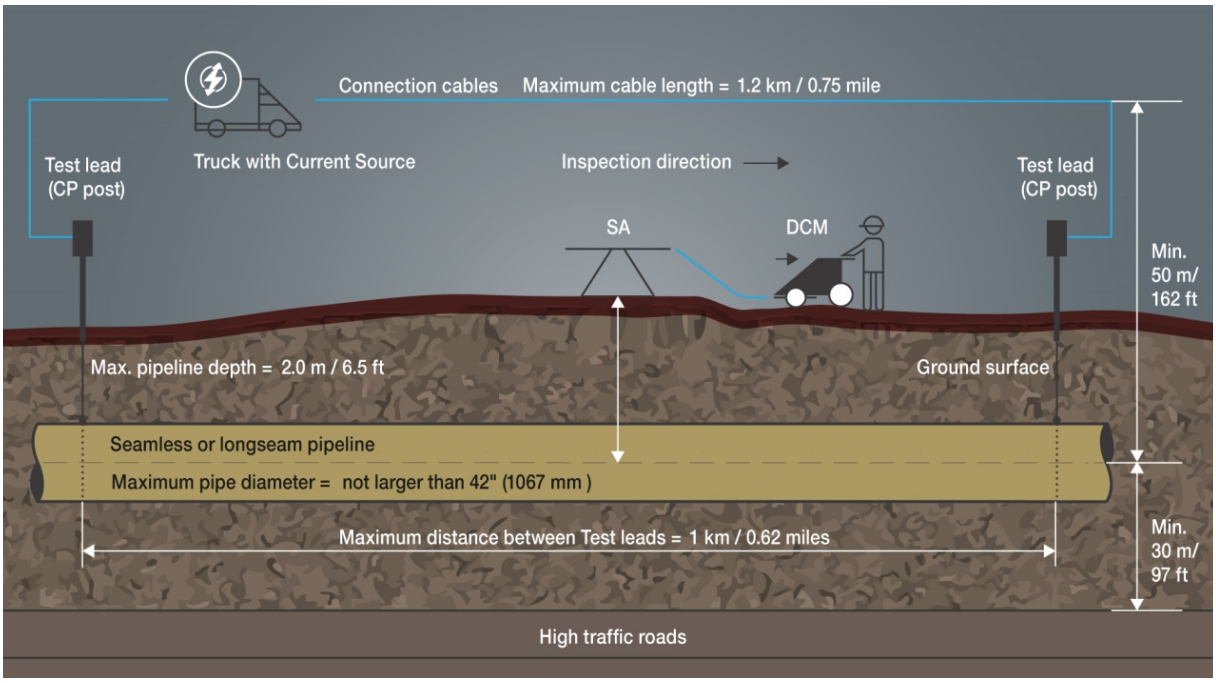
The complete field unit of the AGIT system contains the SA and the DCM (**Fig. 3**).
Thereafter, the stored magnetic field data will be evaluated at EMPIT´s office. For the evaluation, an analysis algorithm is used, which is based on 2D comparison and digital filtering of magnetic field data for all used frequencies of the test current. This algorithm also includes current-independent analysis because the test current can slightly change at every moment and at every location during diagnostics. For this purpose, specially developed evaluation software is used. The digital filtering in the software allows an essential reduction of different kind of interferences from outside, like distorting magnetic fields from power lines, moving vehicles etc. Finally, the output of this analysis will be data about metal loss, girth weld positions, depth of coverage, and current leakage through the coating. All the information will be summarized in a final report and presented to our customers.

3. Field experience with the AGIT inspection system

The AGIT inspection system has been used for hundreds of kilometres of pipeline diagnostics. All buried steel pipelines are eligible for diagnostics. Neither the type of coating nor the transported product has an influence on the quality of measurements. AGIT has been used to inspect oil, gas, chemical, water, jet fuel, and brine pipelines and has detected internal and external corrosion metal loss faults, blisters, dents, gauges, mill defects, and pipe deformations in those. Over 90% of the defects diagnosed with the AGIT system have been verified by contact non-destructive testing of excavated pipelines on positions of found faults. Therewith the technique has proven its reliability to the market hundreds of times.

The system is certified for the inspection of pipelines ranging from 3” to 42”. When inspecting such pipes, the response threshold for defects starts at 20% metal loss. The AGIT inspection system can be used on both, seamless and longitudinally welded pipelines. Spirally-welded pipelines can also be inspected by using an additional filtering algorithm.
An AGIT inspection begins with the deposition of the connection cable between the AGIT Current Source (CS) and the pipeline connection points. As connection points, different contact possibilities can be used: available CP (cathodic protection) posts, above-ground parts of the pipeline or built-in valves, as well as the pipeline itself, in case of excavation holes, which allow direct contact to the pipe. For one range only two contacts are necessary. The inspection will be performed between these two contacts (see **Fig. 4**).

Fig. 4. Schematic presentation of the AGIT inspection



After contacting and laying out the connection cable, a quick functional test is carried out. Then, the actual inspection begins. The starting point is one of the two connection points. The monitor of the DCM shows a live-report of the depth of the pipeline, the exact position of the SA, the inspection current, and the positioning of the SA over the pipeline. The analysis of the magnetic field data and the calculation process take approx. 6 sec. During this time, the system is not moved. Afterwards, the SA and DCM will be moved 1 m further to the next inspection step. The storage of the data happens after every step. The assembly of the sensors in the SA allows a seamless capture and analysis of the magnetic field data and allows the inspection crew to archive an average productivity of 800 m per day (depend on the surface over the pipeline).

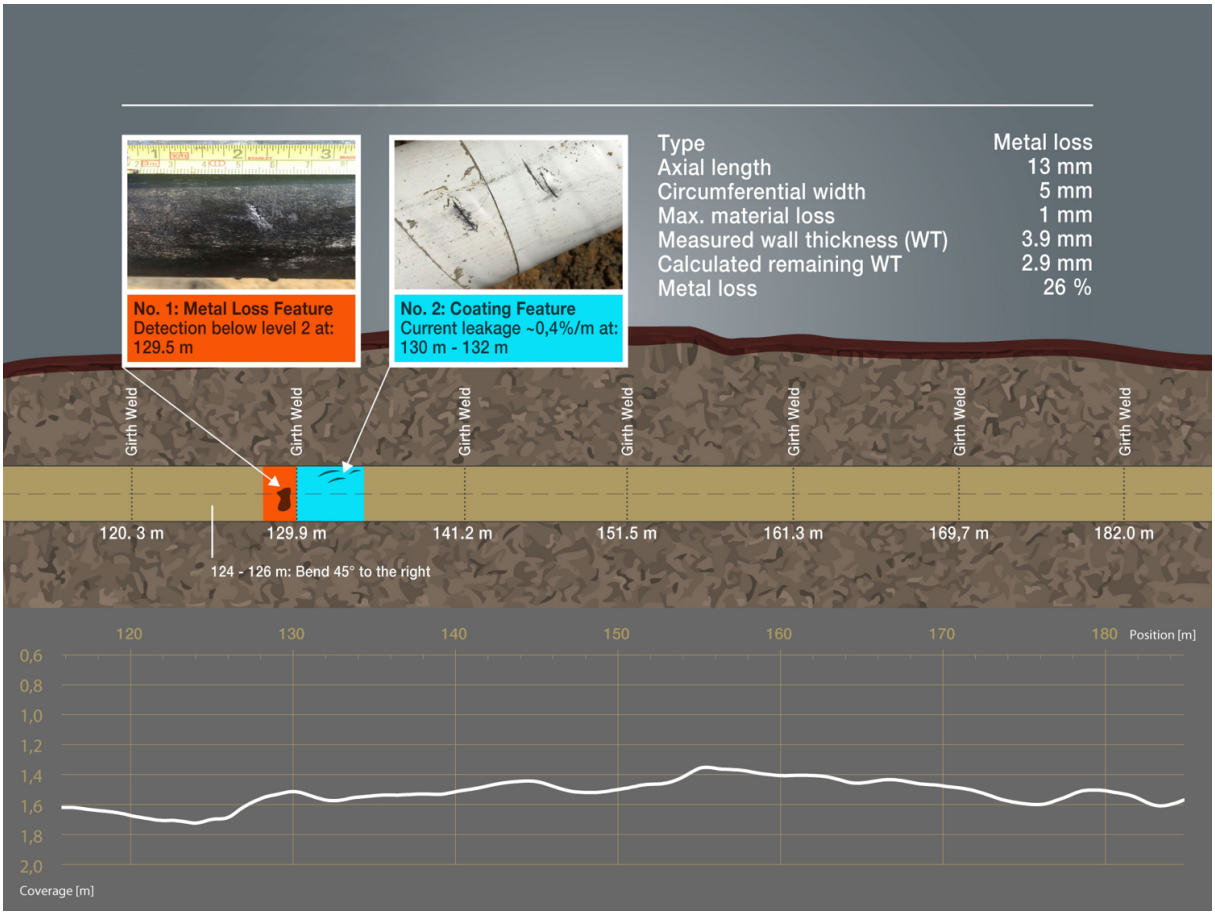
The AGIT inspection can be used for nearly all challenging buried pipelines, also piggable pipelines can be inspected with the technique. If a pipeline is piggable, AGIT can be used for regular monitoring in ranges where intelligent pigging has indicated small defects which have not been repaired yet. In this case, AGIT is an inexpensive alternative to verification excavations for monitoring. In ECDA, AGIT can also be used to estimate possible metal losses before a suspicious range of a pipeline will be dug out.
The terrain inspected has ranged from plane field and forest to cities. Also, parallel pipelines have been inspected and field experience has shown that a distance greater than 60 cm has no influence on the quality of measurements.

4. Further developments and improvements of the AGIT inspection system

Since last year, EMPIT has started intense experimental research in the field of sensitive magnetic field measurements driven forward by a highly skilled and engaged team to further develop the inspection technique. This team is led by Dr. Guennadi Krivoi, who is EMPIT´s head of R&D. The long period of field experience with AGIT inspections has shown that it would be highly beneficial to pipeline operators if AGIT

could recognize smaller metal loss faults. This is due to the fact that in some cases, depending on the operation pressure, wall thickness, and pipe diameter, critical dimensions of defects are below AGIT's reference defect. The reference defect has the dimensions of 50 mm x 50 mm x 50% of metal loss and can be detected with a probability of detection (POD) not smaller than 96%. Thus, further developments and improvements of the AGIT inspection technique are based on the following goals: (i) better reduction of electromagnetic interference from outside in the "normal" industrial environment, (ii) better sensitivity for recognition of smaller defects, and (iii) better definition possibilities of dimensions of the faults. Therefore, a clustering matrix will be introduced where at least 3 or 4 clusters with defect dimensions will be defined. Additionally, the system will be operated by two instead of three people and better day productivity up to 1000 m shall be reached in the future. The first step of the goals has been archived and tested in the field and laboratory. Through the implementation of a newly developed analog to digital converter, the usage of an improved algorithm for data analysis after the diagnostics, improved sensor calibration, and the improved stability of the current source, not only the influence of electromagnetic interferences has been significantly reduced, but also smaller defects have been detected in the recent past. Below, an example of found defects on a gas pipeline is shown (**Fig. 5**). Detection of such defects is made possible through recent improvements.

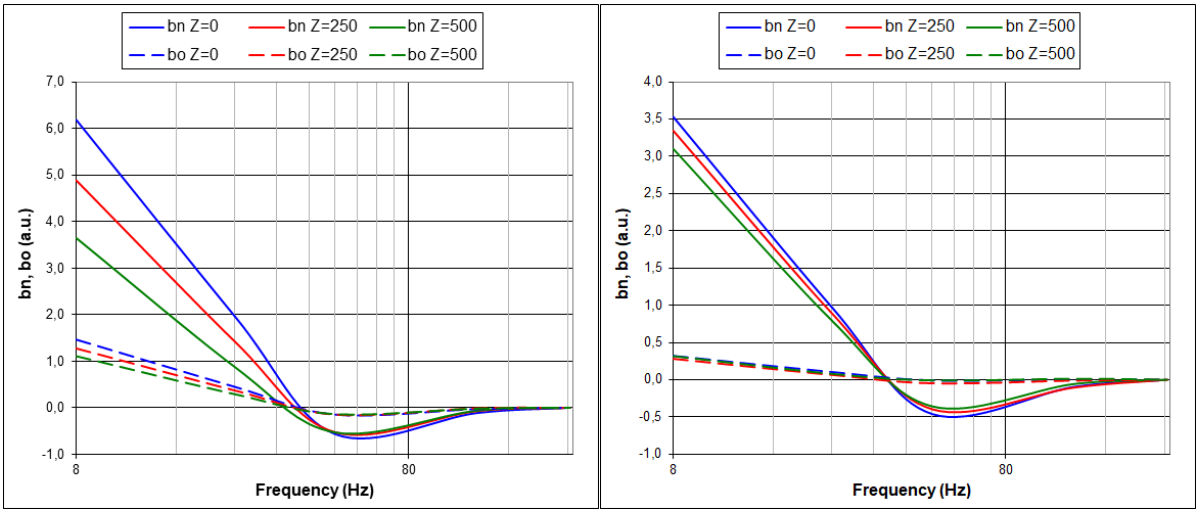
Fig. 5. Sample of recently detected defects.



In order to achieve the second step of the development, 3D modeling of the magnetic field around the pipe was extensively done.
After this step was successfully completed, the output parameters of the actual and future (next generation) configurations of the AGIT system were simulated. The configurations are based on the output magnetic field data from the 3D modeling. As a defect indicator, the so-called output parameter *b* will be used. It combines quotients of magnetic field values computed for positions of particular sensors. On this way, the output parameter is test-current-independent and responses only to deformation of the magnetic field lines caused by metal loss faults. The comparison of the simulated output parameters *b* of both variants of the AGIT system (*bn* for the "new" and *bo* for the "old" variant) is presented in **Fig. 6**. The simulated case was a 16" steel pipe with the outer defect dimensions of 50 mm x 50 mm x 50% metal loss.

The graphs in **Fig. 6** show the output parameter *b* as a function of the frequency at two different values of the pipe depth (pipe depth is the distance between the axis of the pipe and the sensor line). Coordinate *Z* is along the pipe axis; *Z* = 0 means that the sensor line is positioned over the middle of the defect, the other *Z* values show the axial displacement in mm of the sensor line from this "zero" position.

Fig. 6. Output parameters *b* (*bn* for the "new" and *bo* for the "old" variants) of the AGIT system for different values of pipe depth: (*a*) 1m, and (*b*) 1.5 m.



a) *b)*

It can be seen, that the maximum value of the output parameter *b* of the new configuration is 6 to 7 times bigger than old configuration. This fact guarantees a better resolution of the new configuration for small defects and consequently the possibility of defect clustering. The next step in the development is prototyping and experimental investigation of the AGIT system's new configuration on pipes with artificial and natural defects at the company facilities. Afterwards, field tests are planned to be executed and EMPIT is searching for eligible test lines at the moment. Lastly, the use of new measurement components promises a reduction of the needed measurement time per meter and leads to a better productivity of inspections.

5. Conclusion

AGIT is an above-ground inspection technique, which is currently used on gas, oil, fuel, and water pipelines. It is a technique built for challenging pipeline diagnostics whilst remaining truly non-destructive. The transportation of the product through the pipeline can continue normally during the inspection. The preparation for the AGIT inspection is simple and does not require cost-intensive launches and the prior cleaning of pipelines. The best sensitivity of the AGIT method can be achieved under field conditions for buried pipelines which depth is below 1.5 m. The detection of defects does not depend on their clock position.
Modelling of the magnetic field around the pipe, with defects and later simulation of the response of the currently used and further developed AGIT system, have shown that the new configuration of the inspection system will be more sensitive to smaller defects and allows to develop clustering of metal loss faults in terms of their dimensions.

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