Non-contact and non-destructive testing of unpiggable pipelines from the ground surface

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For large parts of the buried pipeline network, referred to as unpiggable pipelines, there is no simple and established procedure for assessing the integrity of the pipeline. The Current Magnetometry Inspection (CMI) method described below detects localised pipe wall anomalies from the ground surface without direct contact with the pipeline. The case studies presented here demonstrate the added value of CMI for assessing the condition of unpiggable pipelines. To date, more than 1,000 km of pipeline have been inspected using the method. The success rate for verifications is over 90 %.

Introduction

Over the past century, a network of pipelines covering thousands of kilometres has been laid worldwide for the transport of gases and liquids. With the increasing age of the pipelines, the recurring inspection of pipeline safety is becoming more and more important. In addition, as hydrogen is integrated into the existing energy infrastructure, the need arises for a transport network that can reliably withstand the reactive gas mixtures containing hydrogen.

Currently, the most reliable way to check the safety of buried pipelines is to inspect them from the inside using intelligent pigs equipped with ultrasonic or eddy current probes that move through the pipeline with the transport medium. Nowadays, modern long-distance gas pipelines are usually equipped with the necessary pig traps and fittings during construction. However, large parts of the existing pipeline network are considered unpiggable due to their construction. According to estimates, about half of these pipelines are currently not piggable or are only piggable with great effort. For other transport media, the proportion is often much higher. The drinking water network, for example, can be considered unpiggable as a whole. Making pipelines piggable often involves major reconstruction work and is therefore extremely capital-intensive in many cases.

The common protection practice for unpiggable pipelines is to coat them with insulating materials, usually bitumen-based for older pipelines, plastic-based for newer ones, in combination with cathodic corrosion protection (CCP). Especially in the case of bituminised pipes, the local effectiveness of the CCP is checked by Close Interval Potential Surveys (CIPS). Direct Current Voltage Gradient (DCVG) can be used to detect local coating faults. However, neither CIPS nor DCVG allow the condition of the pipe wall to be assessed. Consequently, a direct statement about the integrity of the pipeline is not possible.

The method of Current Magnetometry Inspection (CMI) has the potential to fill precisely this gap. CMI can be used to make a direct statement about changes in wall thickness or anomalies in the pipe wall. In addition, the technique allows a simultaneous evaluation of the coating condition independent of the condition of the pipe wall. In the following, the physical principles of CMI as well as experiences with the CMI inspection system are presented. The results of the inspections of the long-distance gas pipeline (FGL) 101 of the pipeline operator ONTRAS Gastransport GmbH and several pipelines of Dow Olefinverbund GmbH demonstrate the added value of a CMI inspection compared to the common practice of CIPS and DCVG. As a practical example of the inspection of non-coated drinking water pipes, experiences in the network of the Swiss water utility company SWG are presented.

Physical basics

CMI is based on the AGIT technology certified by TÜV Süd. The inspection procedure enables the combined inspection of the pipeline integrity as well as of the coating of pipelines made of ferromagnetic materials. The condition assessment of the pipe wall is based on the analysis of anomalies in the magnetic vortex field generated by an energised ferromagnetic pipe. The underlying physical effects are the skin effect and the magnetic leakage flux. The skin effect leads to a frequency-dependent current distribution in the pipe wall. At high frequencies, the majority of the current flows near the outer pipe surface, while at low fre-

quencies the current flows evenly through the entire pipe wall. In the case of an intact pipe with a homogeneous pipe wall, the magnetic field lines run circularly around the pipe at all frequencies (***Figure 1***).
Anomalies in the geometric shape or in the pipe wall lead to measurable changes in the magnetic field. The magnetic field lines, which are circular in an intact pipeline, deform in the case of frequency-dependent anomalies and take on an oval shape (***Figure 2***). In this way, the CMI method can be used to localise different types of anomalies such as wall erosion due to corrosion, cracks, defective girth welds as well as geometric deformations such as dents and bulges. Detection of metal loss is possible from a wall erosion of 20 % of the wall thickness.
Regardless of the condition of the pipe wall, CMI provides the basis for determining the coating condition. This is achieved by magnetic field and stress gradient formation. As a result, the size of the coating defects can be evaluated relative to each other. The smallest detectable coating damage is 1 cm^2.

Inspection system

The CMI inspection system consists of three components: signal generator, field rover (***Figure 3***) and data centre. The signal generator is responsible for the reliable and safe provision of the inspection current with frequency components ranging from a few hertz to the kilohertz range. Intelligent optimisation procedures are used to adjust the inspection current to the local geometric and electromagnetic properties of the pipeline and the environment. The current is fed into the pipeline via electrical contact points at the edges of the section to be inspected. Usually, the CP posts of the existing CCP infrastructure are used for this purpose. A schematic representation of an inspection setup can be seen in ***Figure 4***. For the pipeline operator, this means that almost no preparatory measures are required. The inspection is carried out without contact and without influencing the operation of the pipeline.

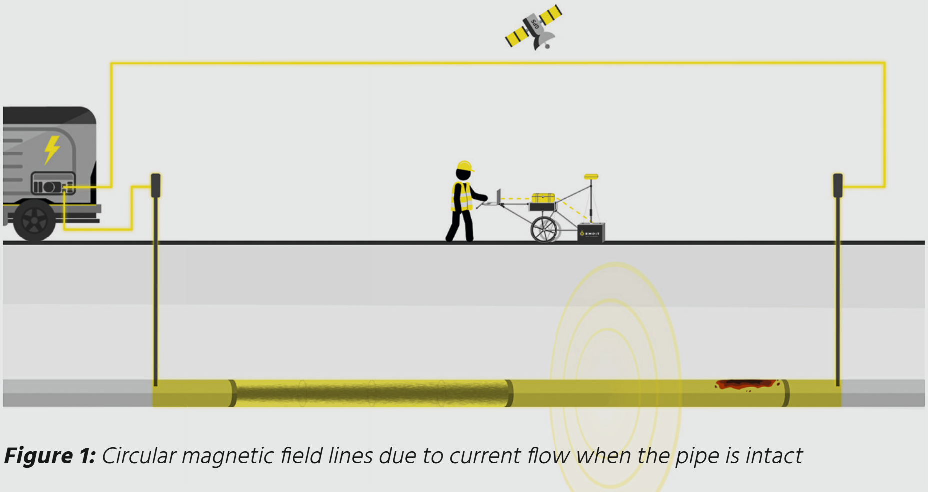

Figure 1: *Circular magnetic field lines due to current flow when the pipe is intact*

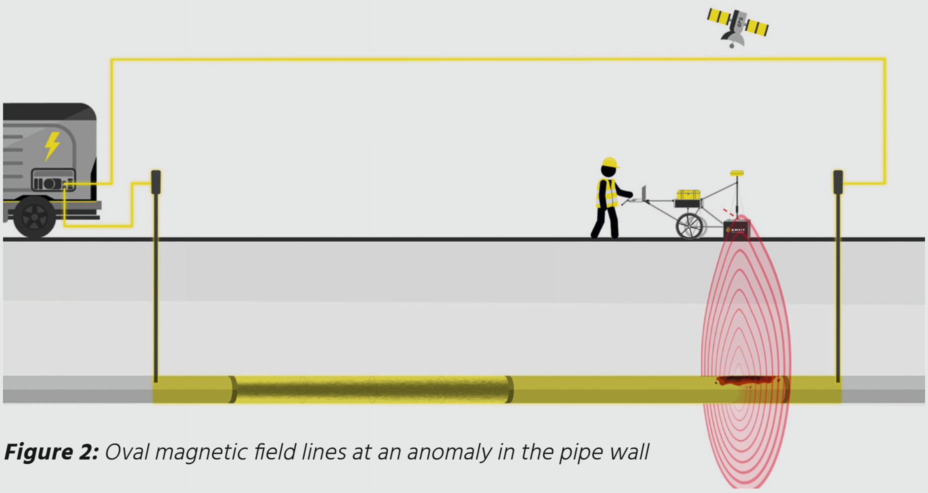

Figure 2: *Oval magnetic field lines at an anomaly in the pipe wall*

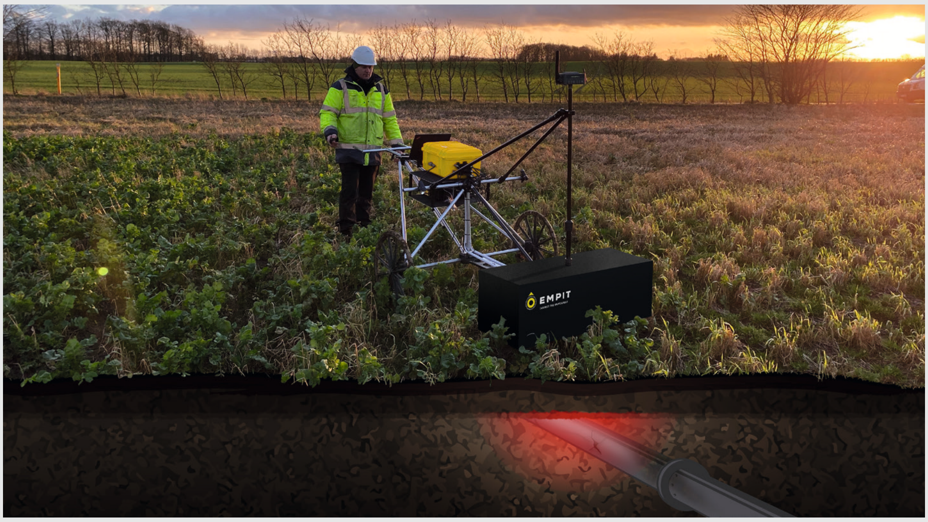

Figure 3: *The Field Rover of the CMI Inspection System*

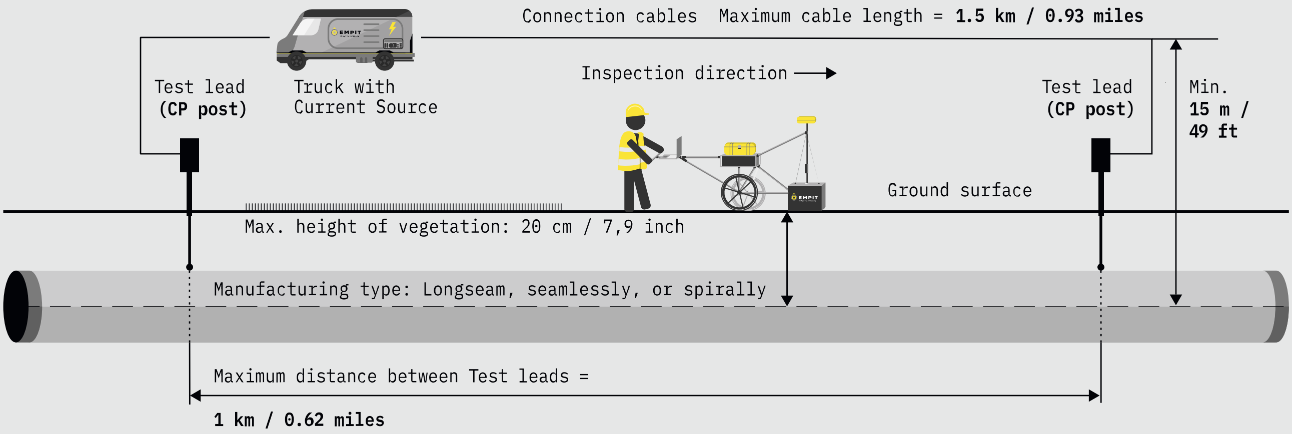

Figure 4: *Structure of an inspection*

The field rover is equipped with a variety of three-dimensional magnetic field sensors that record the induced AC field with nanotesla resolution. Analogue and digital filtering provide the basis for effective noise reduction. Essentially, digital signal processing algorithms ensure that the pipeline signal is clearly separated from environmental noise during inspection. High-precision RTK-GNSS systems are integrated into the field rover for centimetre-precise pipeline location and three-dimensional mapping. The digitised magnetic field values are validated in real time and transmitted to the data centre for further analysis. Using digital filtering, machine learning and clustering algorithms, the positions of pipe wall anomalies, coating defects and the local disturbance level are determined there. The coating condition output parameters in dB µV and the magnetic susceptibility allow an evaluation of the detected anomalies.

Inspection of the FGL 101

The FGL 101 of ONTRAS Gastransport GmbH is a DN 600 gas pipeline in Germany that was commissioned in 1969. The pipeline is cathodically protected and the local effectiveness of the CCP is monitored by regular CIPS. Due to its construction, the FGL 101 cannot be pigged. Prior to the CMI inspection, there was no known information about the pipeline's integrity, the positions of the girth welds or of the pipeline geometry, especially of the bend radii. The aim of the inspection was to create a digital pipe book that would include this information.
In October and November 2019, EMPIT GmbH carried out a CMI inspection for the first time since the com-

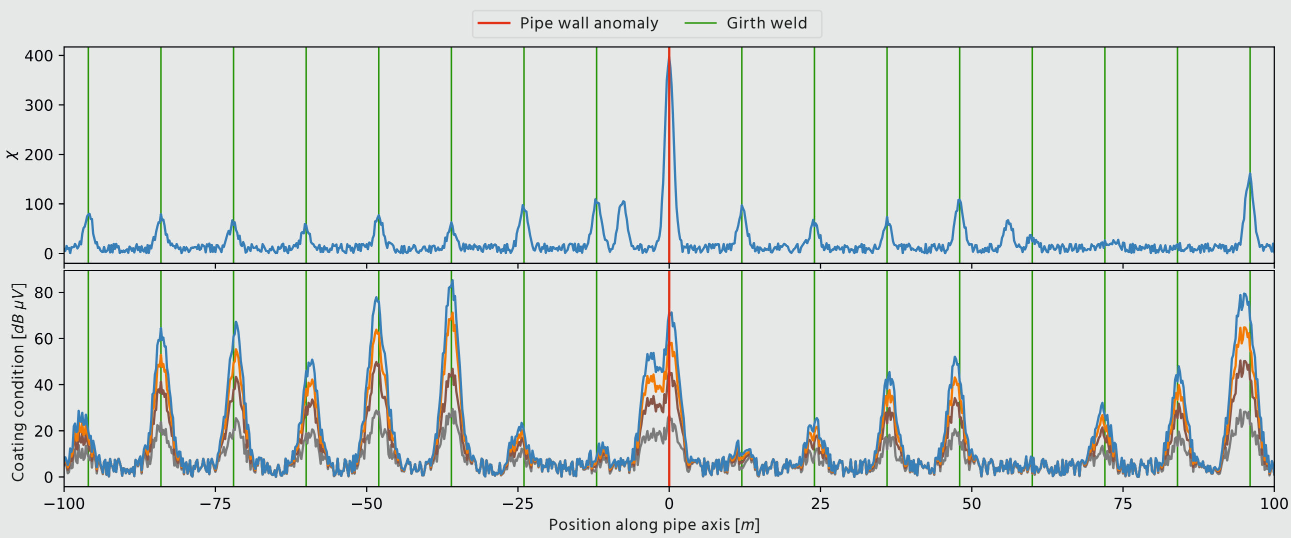

Figure 5: *Extract from the results of the CMI inspection FGL 101*

Figure 6: *Girth weld anomaly detected with CMI (left) and coating holiday (right)*

missioning of the pipeline on an approx. 30 km-long section between gate valve 1 and gate valve 9. In the inspection report, anomalies in the pipe wall and in girth welds were listed in addition to coating holidays. In this pipe, the anomalies with the highest rating were girth weld defects (cf. ***Figure 5***). These were also classified as such in the final report sent and verified in October 2020. X-ray and ultrasonic tests were carried out on the exposed pipe wall. All anomalies detected by EMPIT were confirmed. A total of six girth welds were found that needed to be repaired.

The excavations were also used to validate the condition of the coating reported by EMPIT. As a result, all the coating holidays listed in the report could be verified. The relative sizes in dB µV also matched the dimensions of the faults in reality (cf. ***Figure 6***).

Inspection at Dow Olefinverbund GmbH

In the period from September to October 2020, EMPIT GmbH carried out inspections on a total of four pipelines in the Teutschenthal brine field and storage site for Dow Olefinverbund GmbH. The aim of the inspection was to verify the integrity of the pipeline and the subsequent acceptance by the TÜV. The pipelines are parallel transport pipelines for thick brine, thin brine and diesel with diameters between DN 80 and DN 350 installed in 1997-1998. The entire pipeline network of the brine field and storage site is under local cathodic corrosion protection (LCCP).

The results of the inspection showed that the approx. 10 km-long pipelines are in an almost anomaly-free condition. The probability of failure of the pipelines was increased in only two places. Coating holidays in combination with pipe wall anomalies were detected, just as later excavations verified. The position +51 m in ***Figure 7*** shows the pipe wall and coating defects shown in ***Figure 8***. At the end of 2020, EMPIT was able to further develop its pipe integrity model. In this final report, recommendations for action were formulated for both locations. The result: repair of the defects is not necessary. The responsible authorities at Dow Olefinverbund GmbH nevertheless decided to carry out excavations at both positions in order to be able to conclusively assess the performance of CMI. Both the positions of the coating holidays and the pipe wall anomalies were confirmed in the course of the excavations (cf. ***Figure 8***). The acceptance by TÜV Süd confirmed the overall good condition of the pipeline and that the anomalies found did not affect pipeline safety.

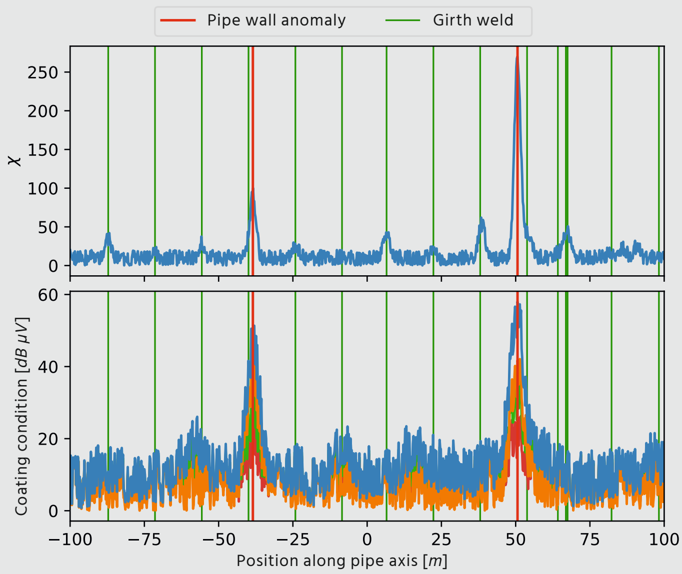

Figure 7: *Plot of the detected anomalies*

Figure 8: *Coating holiday and underlying pipe wall anomaly (position +51 m in Figure 7)*

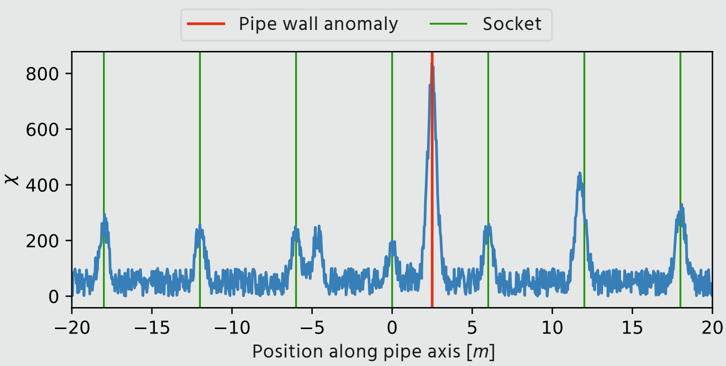

Figure 9: *Verified anomaly with 95 % metal loss*

Inspection of drinking water pipes at SWG

EMPIT GmbH has been inspecting the entire network of the city of Grenchen, Switzerland, since 2018. By means of a continuous inspection cycle, it has now been possible to assess the condition of approx. 20 % of the drinking water pipeline network. Various imminent pipe bursts could thus be prevented and an action plan has been created internally, which allows rehabilitation measures to be prioritised with precision. The success rate of the verification of detected damages is almost at 100 % and the city of Grenchen has reported significantly fewer pipe bursts in the city since beginning to use CMI.

Outlook

The CMI method presented here has the potential to assess the integrity of many buried unpiggable pipelines from the ground surface for the first time. In the inspections presented of the long-distance gas pipeline FGL 101 of pipeline operator ONTRAS Gastransport GmbH as well as several Dow Olefinverbund GmbH pipelines, pipe wall, girth weld and coating holidays could be reliably detected and verified. Thanks to CMI, SWG was able

Figure 10: *Two detected defects in the town of Grenchen, Switzerland*

to evaluate its ageing infrastructure and thus reduce costs and plan measures.
EMPIT GmbH, which is one of the 100 most innovative companies in the German SME sector, is currently testing the conversion of magnetic susceptibility to the magnitude of the mechanical stress in the pipe wall. The first practical projects are underway and the necessary decisions can be made, for example, on the basis of the ASME B31 criteria. This allows pipeline operators to easily integrate CMI results into their Pipeline Integrity Management Systems (PIMS) and consequently to efficiently and cost-effectively plan measures for the safer operation of their pipelines in the future.

KEY WORDS: unpiggable, condition assessment, non-destructive testing technology

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