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Detecting illegal tapping locations with free-floating pipers®

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Abstract

In this paper a new method of detecting illegal hot taps will be discussed which uses a free-floating multi-sensor technology called Pipers®. This state-of-the-art device is small (2.2 inch) and floats freely with the liquid, allowing it to be utilized in virtually any pipeline (regardless of any piggability concerns). It can also be deployed during regular operations allowing for deployment without loss or interruption of production and without the need for heavy equipment.

Equipped with both an acoustic sensor and a magnetometer, Pipers® offer two primary avenues for identifying these illegal taps: acoustically and magnetically. The magnetometer measures the magnetic flux which (passively) exists in all steel pipelines and unique signatures in the magnetic flux are used to identify the locations of potential illegal bunkering points. Additionally, any active hot taps (ie theft in progress) can be confirmed by the sound created during illegal hot tapping using the onboard acoustic sensor. The underlying detection method will be discussed, and examples will be shown of illegal taps which were detected and localized.

Keywords: hot tapping. oil theft. inline detection. pipelines

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1. Introduction

Illegal theft of oil from hot taps on pipelines leads to loss of revenue and risks compromising pipeline safety and integrity in pipelines across the world . Detection of these illegal hot taps poses technical, economic, and human challenges which together make solving this problem a difficult undertaking for pipeline operators. From a technological standpoint, the existing tools can be expensive, difficult to run or susceptible to damage from third parties. This can increase the cost of operating a pipeline due to the cost of this monitoring which is required to prevent the installation of these illegal hot taps. Not only does the instrumentation required come at a cost to pipeline operation, but the testing and development of alternatives is expensive and challenging. Additionally, because these hot taps are installed illegally and can happen at any time in a pipeline's life, it puts pressure on pipeline operators to frequently run inspections (e.g. smart pigs) or to install continuous monitoring solutions (e.g. fiber optics). The former is disruptive, while the latter can be subject to sabotage. Thus there is a need for a technology or solution that can provide continuous or frequent monitoring which is economical, tamper proof and reliable. An alternative inline-type screening tool, the Pipers®, seeks to fill in these gaps by providing a technology which is less expensive and simple to deploy, opening up the possibility for frequent or near continuous monitoring of a pipeline without requiring installation of instrumentation on a pipeline. The topic of this paper is devoted to the discussion of this technology and its application for identifying and preventing illegal hot taps.

When examining the currently available methods for detecting and preventing illegal hot taps they all suffer from draw backs. Additionally, thieves are becoming more sophisticated are developing methods to avoid detection, Landstorfer (2019). A simplistic volume balance based approach can help to identify loss of product, but only when the lost oil is in large enough volumes to be detected and can be defeated by re-injecting water into the pipeline making it difficult to detect using typical measurement systems (i.e. SCADA systems). Inspection of a pipeline using a high-resolution MFL tool can be a reliable method for detecting hot taps in a pipeline, but this is expensive, can take a pipeline out of service temporarily, and may not be possible for so-called unpiggable pipelines. This technology can identify hot taps at the time of inspection but provides no protection in the years between these inspections. Further, MFL inspections are not covert activities thieves can abandon existing hot taps or installing new hot taps after inspection if this deployment schedule becomes known. Instrumenting a pipeline with fiber optics or other leak detection systems can provide continuous monitoring solutions, however, these can be subjected to sabotage which can make them ineffective and increase the difficulty and expense of their maintenance.

The tool being presented in this paper, the Pipers®, is a multi-sensor device which makes use of the potential audio signatures (at an active tap) and magnetic signatures left by the creation of a hot tap. The results being discussed in this paper are based on measurements which focus on the magnetic aspects of the identification and localization of illegal hot taps. The tool itself is a 2.2 inch spherical sensor which travels with the flow of the product through a pipeline. This is similar in spirit to an in-line inspection tool in that it travels through a pipeline but does not share the size and piggability constraints of a traditional smart pig since it does not make contact with the pipe wall. The design of the device makes it easier to deploy at a lower cost, does not require operational disruptions, and opens up the possibility of more frequent monitoring of a pipeline. As such, this technology offers a tamper-proof monitoring solution which can be used to detect hot taps in a pipeline system which can help minimize economic losses from these illegal hot tapping activities and increase the safety and reliability of pipelines.

2. Technology Overview

Pipers® are an unconventional pipeline technology which offer several advantages to a traditional smart pig. The device is a 2.2 inch sized ball with several sensors; an inertial measurement unit, magnetic sensor, pressure sensor, and acoustic sensor. Its size and low weight allows for it to be neutrally buoyant in liquids and to either float through liquid pipelines or to be attached to the back of a conventional cleaning pig in gas pipelines.

The Pipers® measure residual magnetization using a 3D digital magnetic sensor to identify metallic features. The residual magnetization can be generated in components and welded joints in the course of their fabrication, when cooled down to ambient temperatures under interaction with weak magnetic fields, or due to irreversible changes of the local magnetization state of components in zones of stress concentration and damage under working. This effect, referred to as metal magnetic memory by, e.g., International Organization for Standardization (ISO), has been used in other industry applications to identify fatigue, cracks and other damage in metallic tools and machinery.

The measured magnetic flux in the pipeline is a combination of magnetic characteristics caused during the pipeline's manufacturing and construction, and over its operational lifespan. Changes in magnetic characteristics can, for example, be used to identify changes in the pipeline's composition and identify different pipeline sections (e.g. schedule changes, differences in material or grade, or changes in construction date). Changes in the magnetic state of a pipeline wall which occur during the installation of a hot tap create observable signatures in the magnetic flux. These changes are especially effective for detecting hot taps when a baseline measurement is available for comparison. By measuring and identifying these magnetic signatures, the Pipers® can be used to identify and locate illegal hot taps in a pipeline.

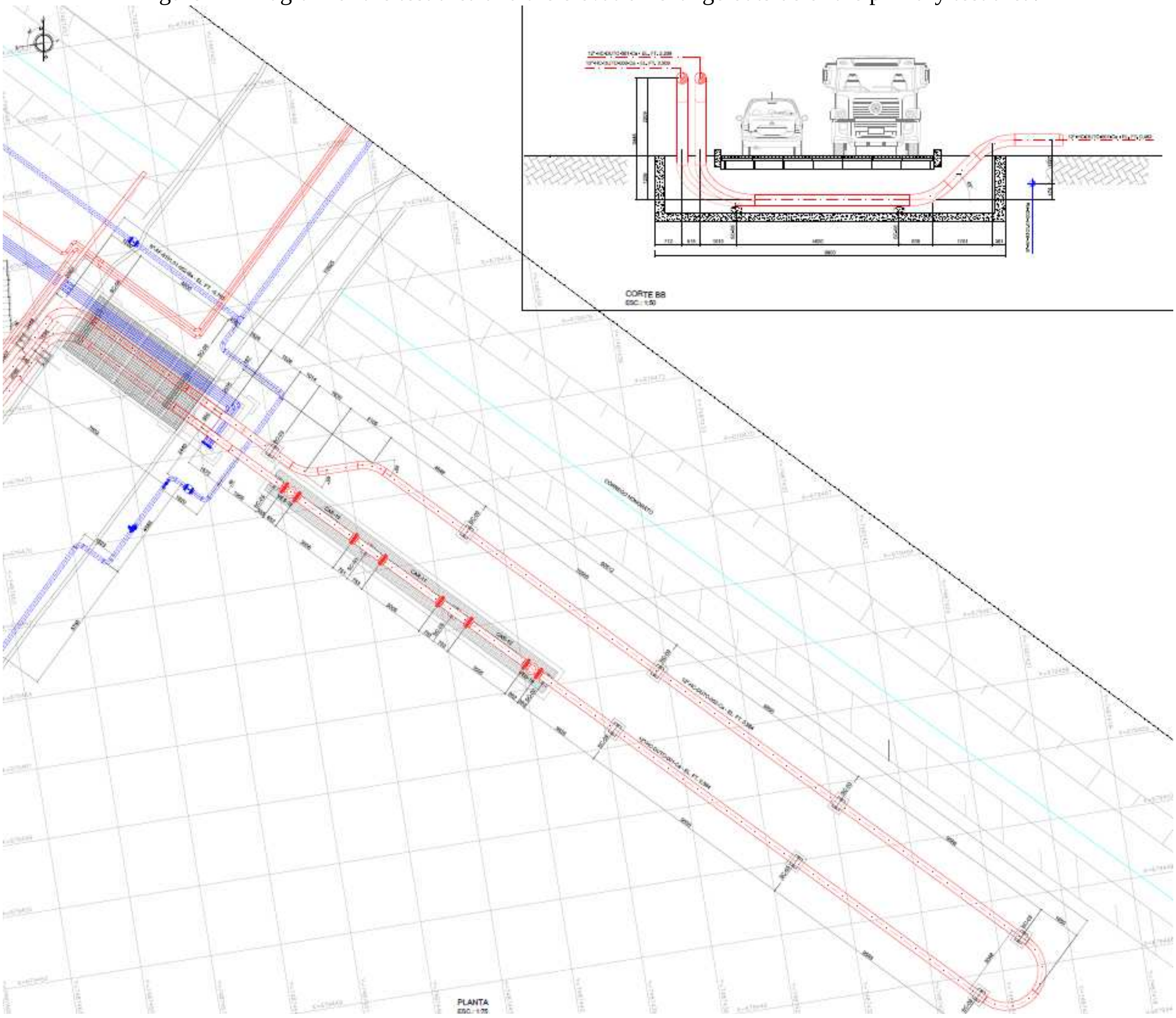
3. Experimental Setup and Procedure

The test described in this paper was conducted at a Petrobras test loop facility in Brazil. The test facility has a 350 m long, 12 inch diameter, steel pipeline loop with multiple hot taps installed. These hot taps come in three different common types with a typical size of half an inch. This project was focused on a 100 m section of the pipeline loop with several hot taps pre-installed and a location where individual spool pieces could be replaced. A technical diagram of this shorter section is shown in Figure 1. This part of the pipeline loop features flanged pipe pieces which were swapped out for "clean" (no hot tap) pipe pieces to establish a baseline measurement. Because this facility is used to evaluate the performance of different hot tap detection technologies, the details of the test (e.g. exact locations, types and sizes of hot taps) are omitted for confidentiality reasons. As a result, the distances reported in this paper have been adjusted to have graphs start at 0 m, but relatively distances are maintained, and some content cannot be presented fully or with all specific details included.

The analysis is focused on this shorter section in the loop and a separate area in the loop with a set of corrosion coupons installed. The 100 m section could be unambiguously identified using the pressure measurements. The area with the corrosion coupons was also easily identified, because these taps were larger and had very pronounced magnetic signatures. The pressure changes used to identify the 100 m test section are caused by elevation changes on both ends of the shorter section: when the pipeline goes down, the pressure goes up, and when the pipeline goes up, the pressure goes down. These pressure increases and decreases are measured by the Pipers® and thus unambiguously identified in the data. These height changes are indicated in the technical drawing in Figure 1 and the pressure measurements of this shorter section are shown in Figure 2.

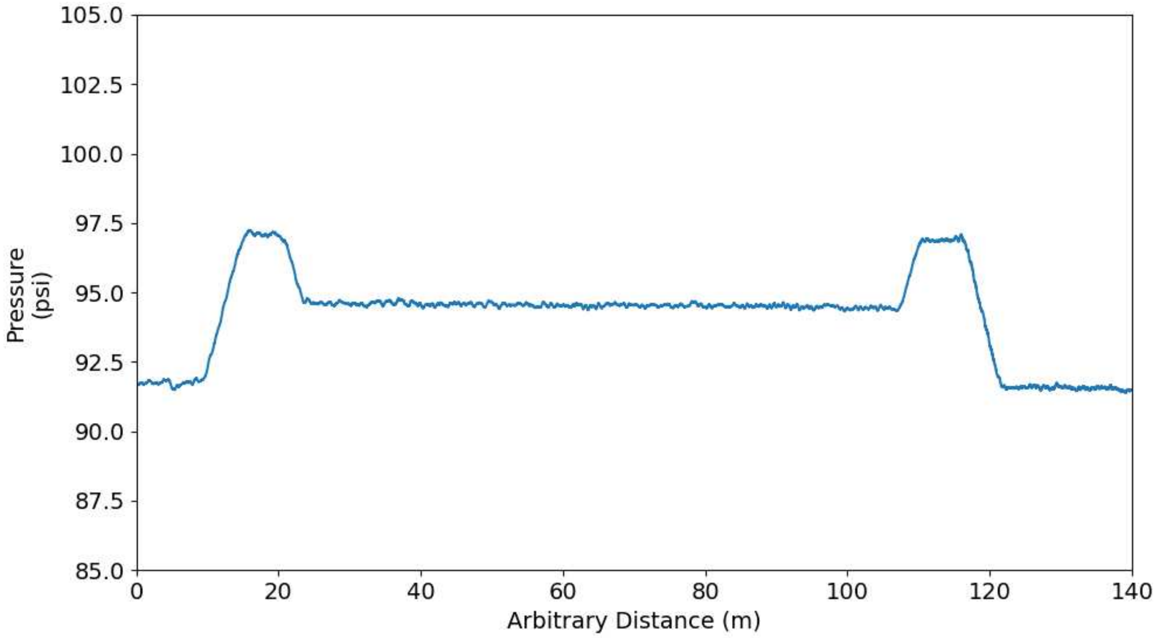
For the actual test program, this loop was screened using the Pipers® in two loop configurations: 1) in its normal configuration where there are multiple hot-taps installed and 2) where one of the pipe pieces with hot taps was swapped with a "clean" piece of pipe (without hot taps). There were four runs in total, two for each pipeline loop configuration and the data collected is presented in the sections which follow.

Figure 1 – Diagram of the test area and the elevation change outside of the primary test area.



Source: technical drawing, reproduced in part with permission from Petrobras.

Figure 2 – Pressure measured by the Pipers®. The height change causes hydrostatic pressure changes which are unambiguously identified in the measured pressure and can be used to align and identify the section of interest.



Source: produced by the author.

4. Analysis and Discussion

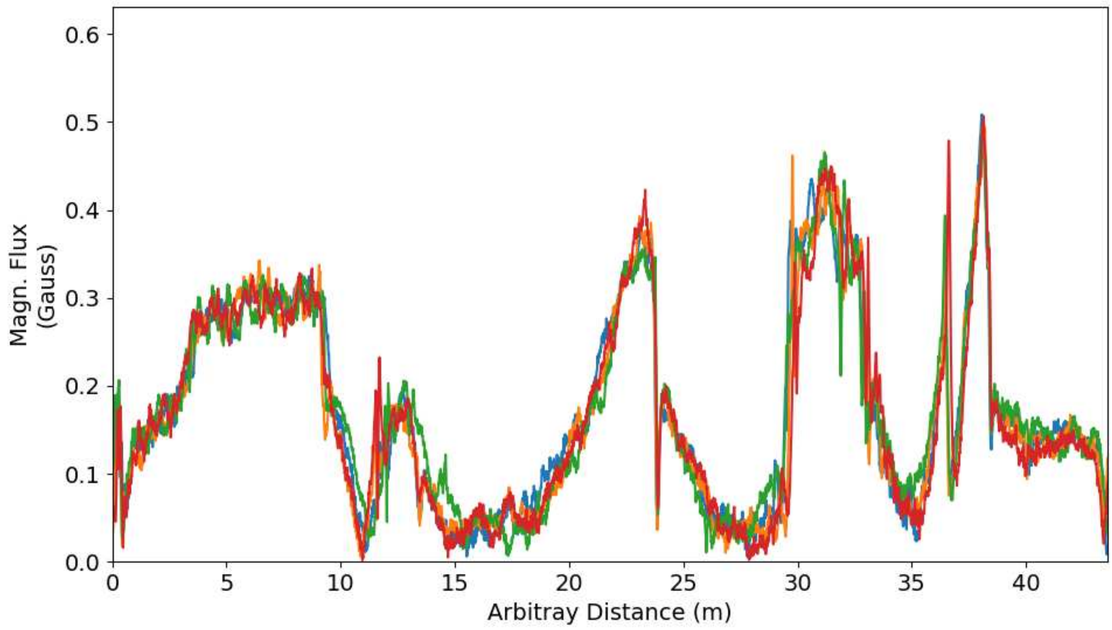
A sample of the magnetic data collected from the four Pipers® in a short section of the pipeline is shown in Figure 3. The data shown here demonstrates two important properties of the magnetic flux measurements in a pipeline: the first is that there is a complex structure in a pipeline and the second is that the data is very repeatable across different runs. This allows for alignment of the data and comparison between subsequent runs. Because of this, any changes in the pipeline due to, e.g., the installation of hot taps can be identified.

In this case, the difference between the first two Pipers® runs and the second two Pipers® runs was the replacement of a single spool piece. Figure 4 shows the data around this swapped spool piece section where the runs without the hot taps are shown in blue (base) and the runs with the spool piece with the hot taps are shown in orange (hot taps) and the grey vertical lines indicate locations of flanges and welds. There is a clear difference in the measured magnetic flux for both configurations and the swapped spool piece section was thus unambiguously identified. While this test represents an extreme case, where a whole section of pipe is removed, it demonstrates the strength of this measurement method for detecting changes to an active pipeline when a baseline measurement is available.

When identifying a hot tap without a baseline available, or to size and characterize an identified tap, the signatures of these hot taps need to be considered. Factors which affect the magnetic flux in the pipe include the physical removal of a portion of metal, the applied physical stresses, the heating and welding of the new pipe onto the host pipeline, and the additional metal from any clamps or supports attached to the pipeline. All of these occur when installing a hot tap and create measurable magnetic signatures in a pipeline. Based on the structure of the magnetic flux in this section (in the magnetic data with the hot taps installed, orange in Figure 4), 5 signatures for hot taps were identified which are indicated by vertical green bands in Figure 4.

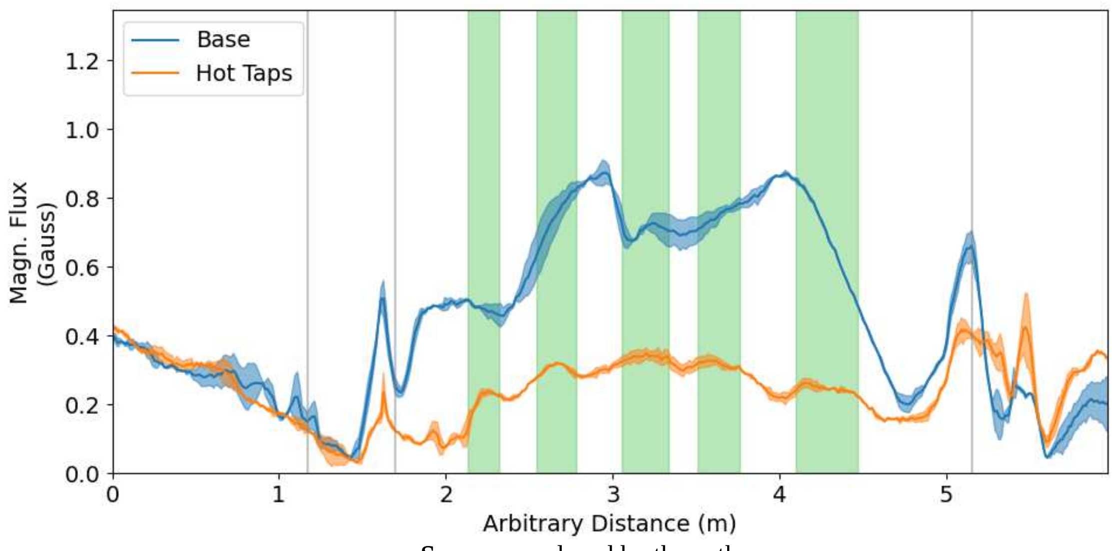
The identification of these magnetic “humps” as hot taps is further supported by the data collected in another section of the pipeline. These taps (in the line for corrosion coupons) were all larger than the simulated illegal hot taps and, for that reason, produced easier to identify signatures in the magnetic flux. The similarity in their structure, however, assists in properly identifying and understanding the signatures at the illegal hot taps.

Figure 3 – Magnetic flux measured in a section of the pipeline during four Pipers® runs, which demonstrates the data structure and repeatability observed in this and other pipelines.



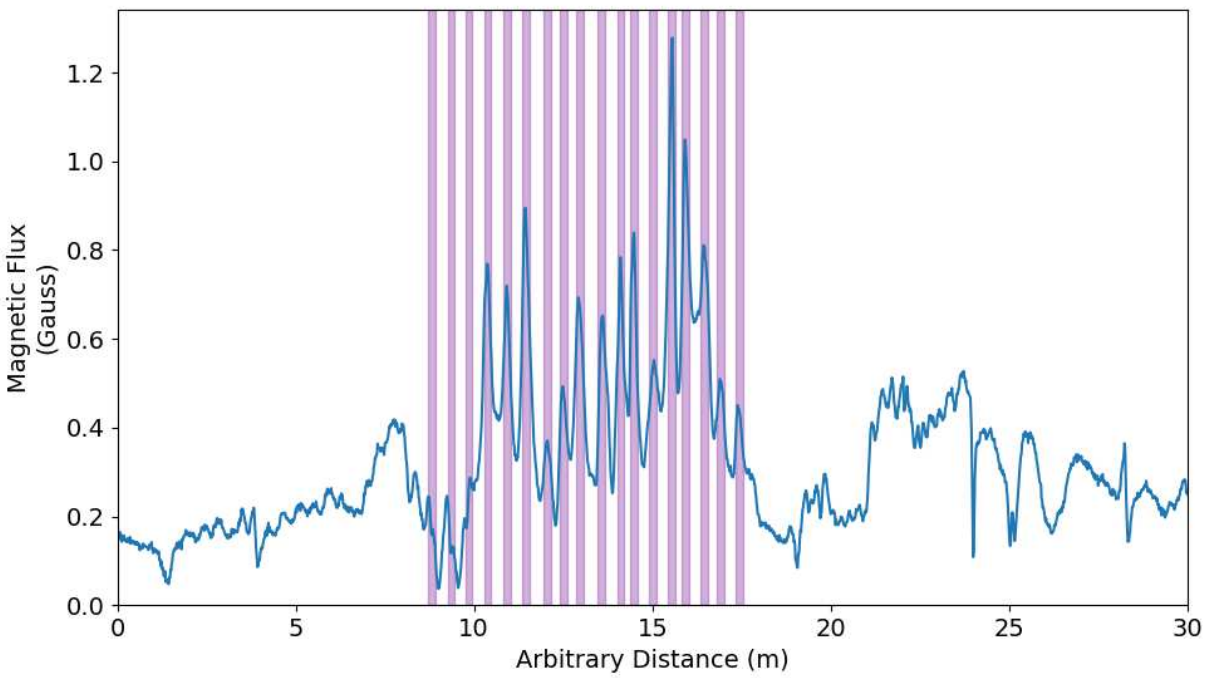
Source: produced by the author.

Figure 4 – Magnetic flux from the spool replacement section. The data in blue is from the runs without the hot taps. The data in orange shows the data from the spool with the hot taps. The vertical green bars indicate the locations of hot taps in the orange data.



Source: produced by the author.

Figure 5 – Magnetic flux measured at the location of 18 installed taps used for corrosion monitoring. The vertical purple bars indicate the individual signatures and locations of the taps.



Source: produced by the author.

As mentioned, in addition to the test area, there were 18, 1.5 inch taps, spaced 500 mm apart, in the line for corrosion monitoring. The magnetic flux at these taps are shown in Figure 5 where the magnetic signatures of the 18 taps are highlighted in purple. These taps have a similar magnetic signature as those from the 100 m section shown in Figure 4 where the tap location also showed an increase hump-like signature in the magnetic flux. Additionally, the Pipers® (which do not directly measure distance) were able to recover this spacing. The calculated spacing between these signatures reported by the Pipers® ranges from of 380 mm to 610 mm, with and average spacing of 500±70 mm, all of which is in agreement with the expected sizes and spacings for these taps. Additionally, it was observed that that the magnetic flux or overall height of these peaks showed variability as a result of the unknown magnetic history or baseline magnetic state of the pipeline. All of them do, however, stand out clearly from the background structure of the surrounding pipe. While the height of these signatures is not consistent, each of these humps does show a similar width (as expected given they area all 1½” diameter) in each of the signatures indicating a repeatability in signature width and overall structure.

In addition to the “simple” type simulated illegal hot taps shown in Figure 4 there were other types of taps in the test loop. These other hot taps had extra metal on the pipeline at the hot tap area and showed more complex structure due to these additional metal components. These other two hot tap types had an extra circular “pancake” piece welded on the pipe where the tap was installed and the other had a full encirclement sleeve at the hot tap installation. The additional metal at these taps had magnetic flux signatures were wider and had more complex structure. This is inline with what was expected based on other magnetic measurements at similar metallic hardware (e.g. sleeves, flanges) in other lines which create similar magnetic signatures. Future tests and screenings of pipelines using the Pipers® are being conducted to further refine the sizing and labelling capabilities of the technology; however, it is confirmed that all the hot taps within these sections were identified by the Pipers® during these tests.

5. Final Remarks

The Pipers® technology was evaluated for its performance in detecting illegal hot taps in pipelines by measuring the magnetic flux in a pipeline with known hot taps at a test loop facility, the data from which can be used to help identify and prevent illegal oil theft. The results of the test show that there is a measurable magnetic signature at hot tap locations and that these signatures are the result of complex changes in the magnetic state of a pipeline caused during the installation of the hot taps. The magnetic flux measured in pipelines does, however, contain complexity which makes analysis during an initial screening difficult. This structure is valuable, however, because it creates unique signatures which can be used to align different runs of a line and creates the opportunity to easily monitor a pipeline over time for illegal by comparing new magnetic measurement to a reference historical profile to identify any differences. For pipelines where illegal third-party damage or theft is a concern, the ease of use and lower cost of the technology will allow for high frequency of monitoring of a line which is also resistant to tampering by third parties.

The magnetic signatures collected in this test loop showed that hot taps appear as hump-like magnetic structures. More detailed and extensive cataloguing of different types of hot taps can be done to better understand what the effect of these hot taps is on the magnetic flux in a pipeline which will allow for better sensitivity, labelling capabilities and accurate sizing of hot taps in the future. The data from this test confirms the basic premise of this measurement technique and shows that the Pipers® are a suitable technology for identifying illegal hot taps in a pipeline and were able to identify all the hot taps within the specified test area in this test loop facility. The use of this technology, therefore, opens up an additional avenue for screening pipelines for illegal oil theft activities and fills a gap in the economics and reliability provided by current technologies such as traditional smart pigging or other instrument-based detection technologies.

6. Acknowledgments

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References

International Organization for Standardization. (2020). *Non-destructive testing — Metal magnetic memory — Part 1: Vocabulary and general requirements*. Geneva, Switzerland: International Organization for Standardization. Retrieved from https://www.iso.org/standard/72146.html

Landstorfer, R. (2019). Illegal hot taping – a case study on how to detect and locate product theft (Vol. 2019, pp. 1–9). Presented at the Pipeline Technology Conference, Berlin, Germany. Retrieved from https://www.pipeline-conference.com/abstracts/illegal-hot-taping-%E2%80%93-case-study-how-detect-and-locate-product-theft