Rapid Identification of New Hot Taps in Pipelines Using Remnant Magnetism

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Abstract

The theft of oil from pipelines using illegal hot taps is a major issue that not only costs oil and gas companies upwards of millions of dollars but can lead to dangerous loss of containment. By volume, thefts in Nigeria alone are as high as 100,000 to 400,000 barrels of oil a day. In Mexico, the annual loss of revenue from illegal hot tops is estimated at more than $1 billion dollars.

Early stage detection is key to ensuring pipeline safety and to avoid costly and environmentally damaging incidents. INGU's Pipers® are a multi sensor, miniaturized inline inspection tool that can be deployed easily and at low cost, either free floating in operational lines or mounted to a pig. Pipers® include a magnetometer onboard, allowing it to measure magnetic flux signatures from remnant magnetism in the pipeline walls and any installed metallic features.

Illegal hot taps are external modifications that produce a measurable difference in the magnetic flux of a pipeline. The difference is due to the creation of a hole in the pipeline wall, as well as from additional metallic materials installed on the pipeline's exterior. After establishing a baseline screening, all subsequent Pipers® deployments readily detect changes in magnetic signatures, leading to the identification of the presence and location of a hot top.

By measuring changes in the magnetic flux between subsequent inspections, external modifications to a pipeline can be identified and localized. This presentation discusses the analysis techniques, as well as showcases examples of how remnant magnetism can be used to rapidly identify illegal hot taps during repeated screenings of a pipeline.

Introduction

Theft of oil from illegal hot taps impacts revenue, and compromises pipeline safety and integrity across the world. The detection of hot taps poses technical, financial, and human challenges, which together make solving this problem extraordinarily difficult for pipeline operators. From a technical standpoint, existing detection tools are difficult to run and are susceptible to damage from those involved in the crime. From a global financial standpoint, Ernst & Young estimates illegal and fraudulent activities cost oil and gas companies US$133 billion annually (Ernst & Young, 2015), (Desjardins, 2017), (Ralby 2017). The costs associated with monitoring for this activity can be significant. The instrumentation required, as well as the testing and development of alternatives are expensive and the results can be uncertain. Hot taps can be installed at any time in a pipeline's lifespan, putting pressure on operators to regularly run costly and disruptive inspections (e.g., smart pigs) or to install continuous monitoring solutions (e.g., fiber optics) that can be vulnerable to sabotage. There is a need for a reliable, tamper proof, and economical solution to this problem.

When examining the currently available methods of detection and prevention of illegal hot taps, we see many draw backs. Criminals are becoming more sophisticated in developing methods to avoid detection (Landstorfer, 2019). A simple volume balance-based approach can help to identify the loss of product, but only when the volumes are significant enough to be detected. Still, measuring volumes can fail when water is injected into the pipeline in order to fool existing measurement systems (i.e., SCADA). Inspection of a pipeline using a high-resolution MFL tool can be a reliable method for detecting hot taps, but it is expensive, imposes downtime, and is unable to reach all assets (e.g., unpiggable pipelines). Importantly, MFL technology can only identify hot taps at the time of inspection, there is no protection between inspections. Further, MFL inspections are not covert activities. Thieves can abandon existing hot taps or install new hot taps after inspection if the deployment schedule becomes known. Instrumenting a pipeline with fiber optics or other leak detection systems can provide ongoing protection, but only if they are not subject to sabotage, which renders them ineffective and, ultimately, expensive to maintain.

The Pipers® solution being presented in this paper is a multi-sensor, inline inspection tool that makes use of both audio and magnetic signatures left by the installation of an illegal hot tap. The results presented in this paper focus on the effectiveness of magnetic signatures for the identification and localization of hot taps. Pipers® are a 2.2-inch spherical sensor systems that travels within operational pipelines. The miniature size and buoyancy of Pipers® allows it to overcome the piggability constraints of a traditional smart pig, since it does not make contact with the pipeline wall. The design of the device makes it easier to deploy, at a lower cost, and it does not require operational disruptions. Importantly, Pipers® open up the possibility of more frequent monitoring, making it possible to rapidly detect new hot taps within the system. The dynamic nature of this solution makes it tamper proof and highly reliable, minimizing financial losses, and increasing safety and reliability.

Remnant Magnetism and Magnetic Flux Measurements

The Pipers® measure residual or remnant magnetization using a 3D magnetic sensor to identify metallic features and assess the pipeline wall condition. The residual magnetization is the magnetization in ferromagnetic materials, such as pipe pieces 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., the International Organization for Standardization (ISO), has been used in other industry applications to identify fatigue, cracks and other damage in metallic tools and machinery.

From this it follows that the measured magnetic flux in the pipeline is a combination of magnetic characteristics caused during the pipeline's manufacturing, construction, and installation, 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). Taking advantage of this effect allows changes in the physical state of the pipeline to be identified by analysing the measured magnetic profile of a pipeline and to screen for significant damage and other anomalies within a pipeline.

The installation of a hot tap is a significant modification to a pipeline which requires removal of a portion of the pipe wall and installation of metallic components on the pipeline's exterior. This causes changes in the magnetic state of a pipeline wall which creates observable signatures in the magnetic flux. When a baseline measurement (without the hot tap) is available for comparison, this change can be more unambiguously identified with an increased detection sensitivity, thus providing an especially effective method for detecting hot taps. By measuring and identifying these magnetic signatures, the Pipers® can be used to identify and locate new hot taps in a pipeline.

Case Study

This paper discusses a case study where an 8.5 km 22 inch crude-oil pipeline was surveyed using the Pipers® in a hot-tapping intervention scenario where a new hot tap is introduced at an unknown location along the pipeline to validate the Pipers® hot tap detection capability. The pipeline was inspected four times in total; two times (run 1 and run 2) prior to the hot tap installation and two times (run 3 and run 4) after the hot tap was installed on the pipeline. The time interval between the first two (pre-installation of the hot tap) and the last two runs (post-installation of the hot tap) was 14 days.

The basic concept of hot tap detection (or any other metallic anomalies that arise during the operation of a pipeline) is to establish an initial baseline and in subsequent inspections identify deviations from this baseline. This methodology works because the magnetic flux measured by Pipers® is highly repeatable over subsequent runs. To illustrate this, the magnetic flux data from the four inspections is shown in Figure 1 for a sample section.

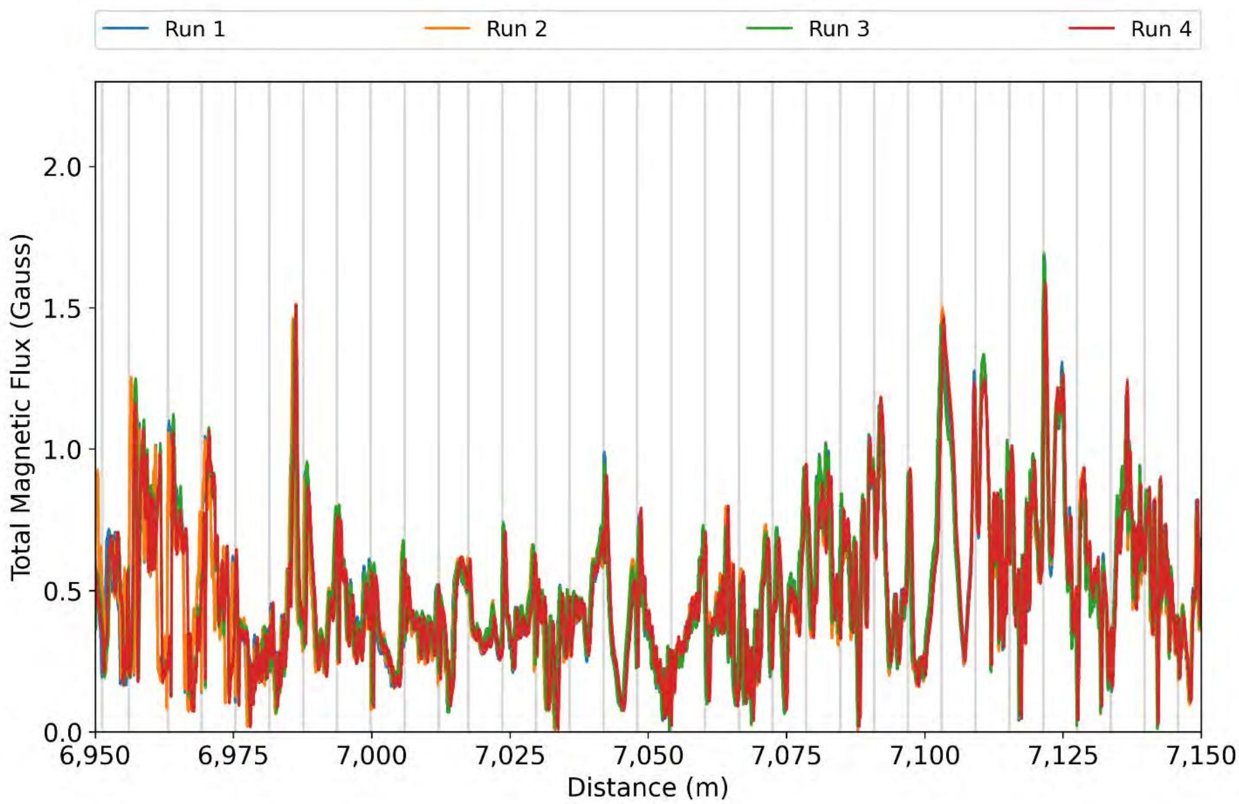

Figure 1: The total magnetic flux measured in a section of the pipeline during the four Pipers® runs, which demonstrates the data structure and repeatability observed in this and other pipelines. The vertical grey lines identify the weld locations.

This example clearly demonstrates two important properties of the magnetic flux measurements in a pipeline: the first is that there is a complex magnetic flux structure in a pipeline and the second is that the data measured by the Pipers® are repeatable across different runs. The repeatability of the Pipers® data 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.

Since there are different factors that can affect the magnetic flux measurements between subsequent runs, the detection and differentiation of hot taps from the other factors is done by detecting a change in the baseline that resembles a known unique magnetic signature for the hot tap. 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.

To identify observed changes in the magnetic features as hot taps, and to characterize and size these features, the different shapes introduced in the magnetic flux by these features needs to be considered. A test was done previously where the Pipers® were used in a test loop facility to evaluate the capability of detecting hot taps. The results of this test were previously presented at the Rio Oil & Gas conference, and provided supplementary information on the types of hot taps, and magnetic signatures of hot taps during that test. The results from the Pipers® during the test were verified and confirmed to be correct. Three previously seen signatures for different hot taps include a simple case where an increased broad peak or convex structure is seen in the magnetic flux, where the structure change occurs for the whole width of the hot tap. A data example of this simple case was shown in the beforementioned paper where a spool replacement with these hot taps were installed and is reproduced in this paper as Figure 2.

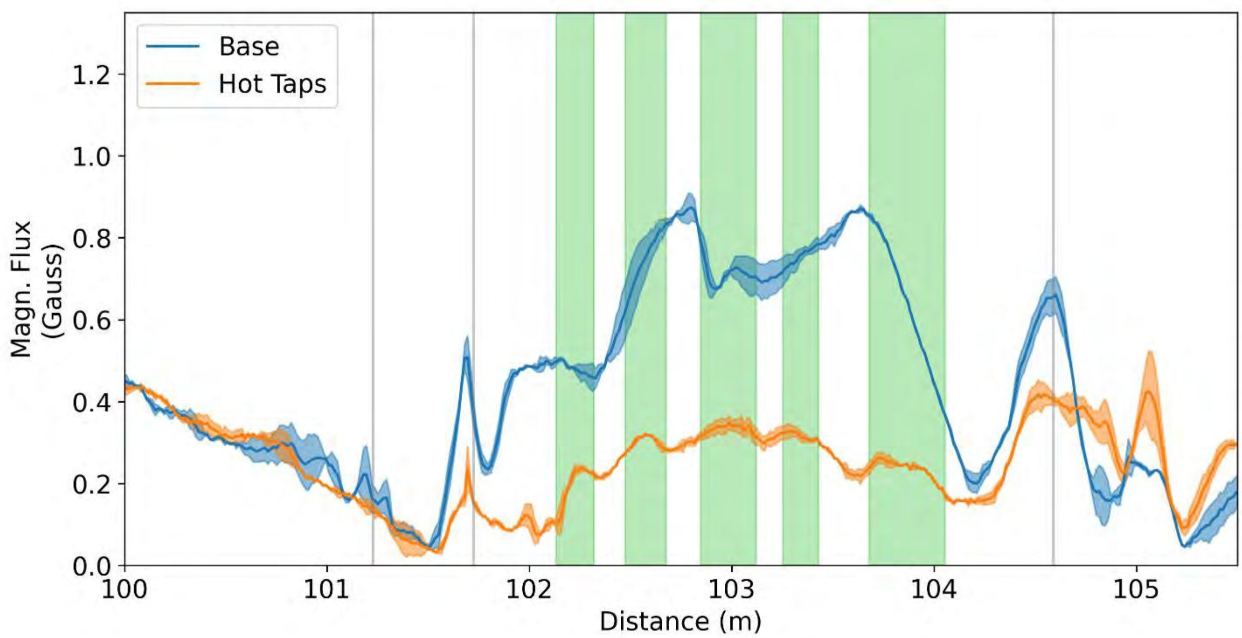

Figure 2: Magnetic flux from a spool replacement section. The data in blue is from the runs without the hot taps. The data in orange shows the data from the spool with the hot taps. The vertical green bars indicate the locations of hot taps in the orange data.

The five hot taps identified in the test are representative of the simple case, with the fifth hot tap having an additional circular metallic piece. The additional metallic piece has a broader magnetic signature compared to the other four installed hot taps. The other two signatures showed more complex structure due to additional metal components on the hot tap area; one type has a full encirclement sleeve at the hot tap and the other type has an extra piece of metal shaped like a saddle and fits the contour of the pipe that is welded on the pipe where the tap was installed. The additional metal at these taps had magnetic flux signatures that were wider and had more complex structure. This is in line with what was expected based on other magnetic measurements at similar metallic hardware (e.g., sleeves, flanges) in other pipelines which create similar magnetic signatures. These signatures are used as templates to identify and compare if a change in the magnetic baseline is due to the installation of a hot tap. To determine the location of a hot tap once the magnetic signature is found, the data from all sensors is used in sensor fusion algorithms to create a distance scale.

In this case study, a magnetic baseline was determined by surveying the pipeline prior to the installation of hot taps. A precise and accurate distance scale is generated by utilizing the identified girth welds and fittings in the magnetic flux data with known information provided in a pipe tally. The post-installation runs were then directly compared to the magnetic baseline, where a search for deviations in the magnetic baseline was done. Any deviations from the baseline are then processed for any magnetic signatures that resemble factors or features that could cause changes in the magnetic flux. Figure 3 shows the data around the section where the new hot tap was identified in the screenings post-installation of the hot tap. The grey vertical lines indicate locations of welds, and the vertical green bars indicate the location with a clear difference in the measured magnetic flux both in the axial and total magnetic flux.

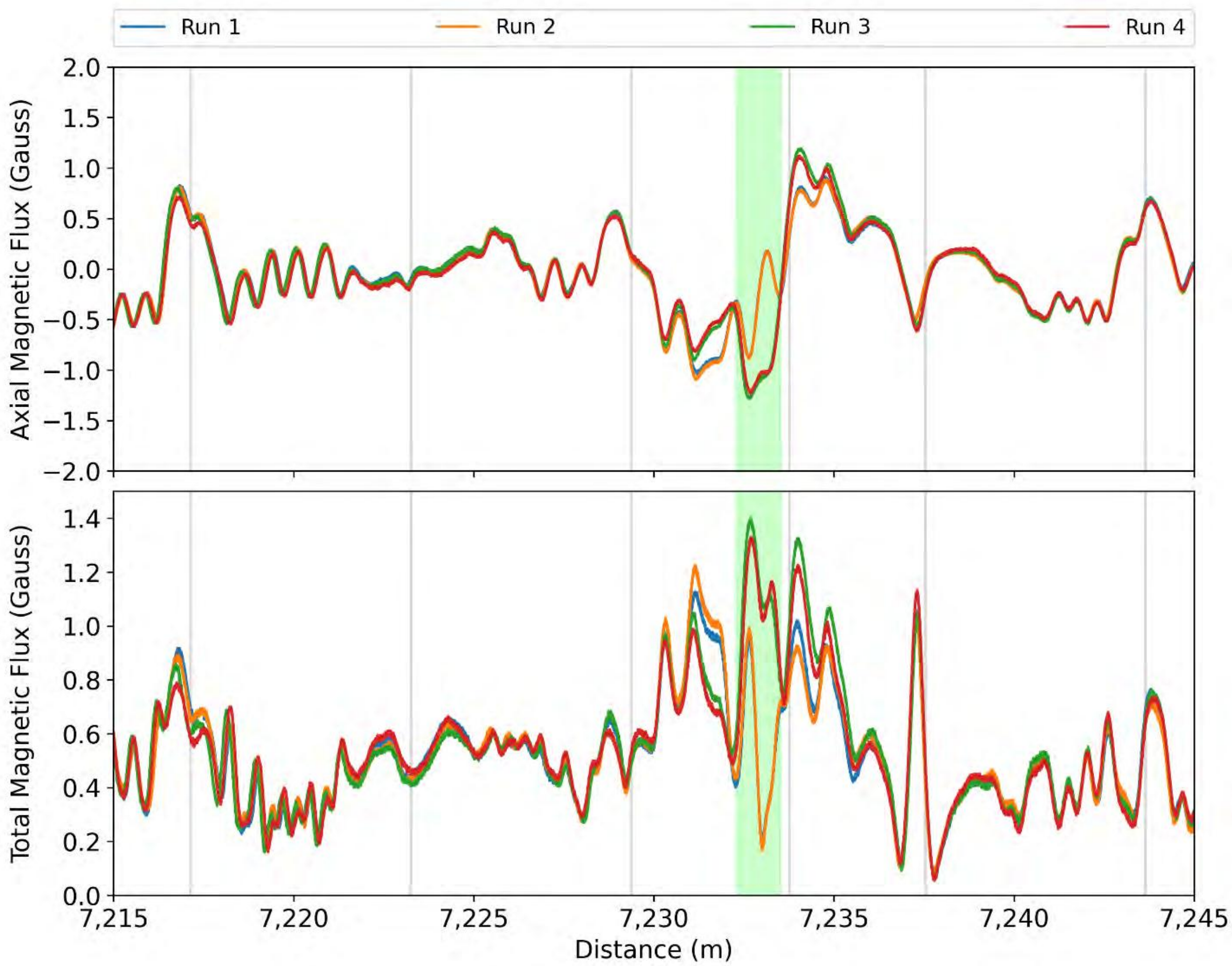

Figure 3: The axial and total magnetic flux measured by the four Pipers® in a section of the pipeline where a new hot tap was identified. The first two runs of the Pipers® were screened before the new hot tap installation, and the last two runs were screened after the installation. The vertical grey lines indicate locations of welds, and the vertical green bars indicate the location of the hot tap installation.

A magnetic signature was found within a spool piece approximately 7.23 km into the 8.5 km pipeline that appeared to follow more of a broad peak and convex structure as well as having a change in magnetic flux in the adjacent regions due to the installation process of the hot tap. The broad peak structure is identical to the mentioned simple case for a hot tap and was unambiguously and rapidly identified when comparing the runs pre-installation and the runs post-installation. The location of the identified hot tap was then sent to be verified.

It was confirmed that the location of the new hot tap installed within this section of the pipeline was correctly identified by the Pipers®. Future tests and screenings of pipelines using the Pipers® are being conducted to further refine the sizing and labelling capabilities of the technology; however, the results of this case study demonstrate the strength of this measurement method for detecting changes to an active pipeline when a baseline measurement is available.

Conclusion

Pipers® technology was evaluated for its effectiveness in detecting an illegal hot tap by measuring the magnetic flux in a pipeline. A baseline screening was conducted, after which a hot tap was installed. Following subsequent deployments, data streams were compared. The results 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, resulting from the installation of hot taps. The magnetic flux measured in pipelines does, however, contain complexity which makes analysis during an initial screening difficult. These complex structures are, however, valuable, because they create unique signatures, which can be used over time to identify tell-tale differences. For pipelines, where illegal third-party damage or theft is a concern, the ease of use and lower cost of Pipers® technology allows for higher frequency, tamper free monitoring.

The magnetic signature collected in the test pipeline showed that the hot tap appeared as a broad peak magnetic structure. 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, which in time will allow for greater sensitivity labelling capabilities and accuracy. Data from the test screenings confirms the basic premise of this measurement technique and shows that Pipers® are suitable for, and capable of, identifying new hot taps in a pipeline. The use of this technology opens up a new avenue for screening pipelines for criminal activity related to oil theft and fills an important gap in affordability and reliability among current technologies.