THE MAGNETIC DIMENSION

Samir Takillah PhD, Mehdi Laichoubi M.Eng, and Hamza Kella Bennani PhD, Skipper NDT, France, explain how a new magnetic contactless technology can be used to inspect buried pipelines that are difficult to access.

Frequent inspections of oil and gas pipelines are critical to ensure their operational safety, to protect people and the environment. A significant portion of the global network, estimated at 30%, cannot be inspected through traditional techniques, i.e. inline inspection (ILI). The alternatives currently available on the market are not satisfactory either from an efficiency or from an operational standpoint. Skipper NDT has therefore developed a novel, contactless magnetic technology, with proprietary and patented field protocols designed to ensure operational safety while optimising maintenance costs. On one hand, it aims at identifying stress concentration zones as well as metal defects on pipelines, such as dents and corrosions. On the other hand, it precisely geolocates the pipeline network. The results observed in real field

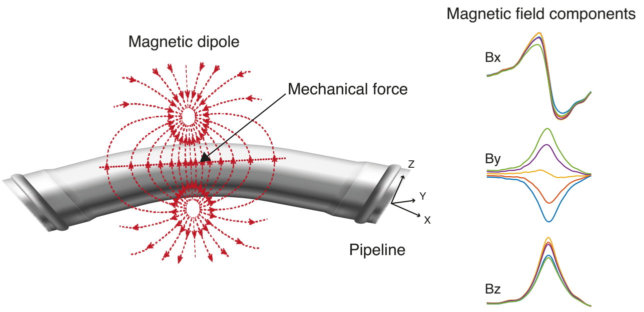

Figure 1. **Magnetic dipole is observed above stress concentration zones.**

Figure 2. **Tailor made flexion bench.**

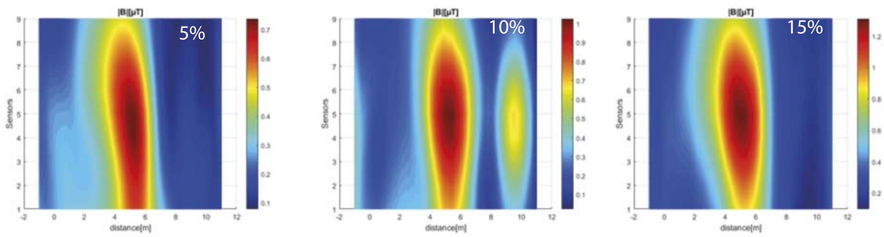

Figure 3. **Distribution of the magnetic field obtained with bench test along the pipe axis.**

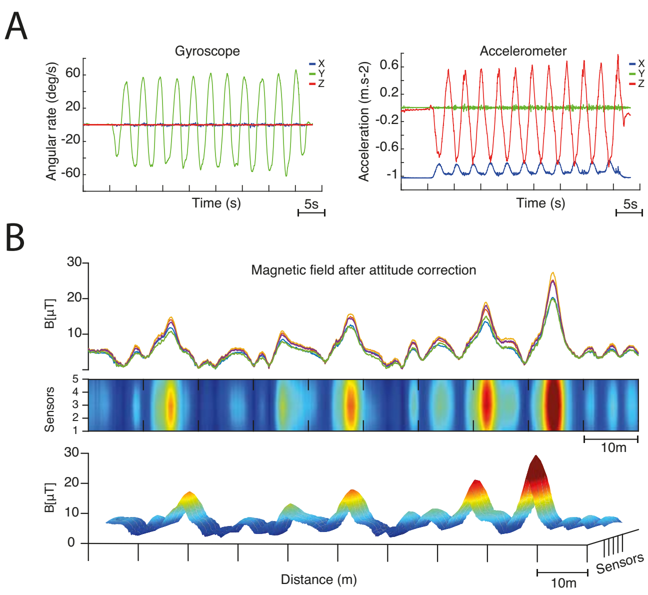

Figure 4. **Panel A: The angular rate and acceleration evolutions before and after correction. Panel B: Distribution of the magnetic field along the pipe axis after attitude correction.**

conditions were confirmed by an R&D programme launched in collaboration with the French energy majors TOTAL and TEREGA.

Skipper NDT magnetic contactless technology

Villari effect

Magnetic non-destructive testing technologies have received a great deal of interest and are extensively adopted to ensure the operational safety of pipelines. Over the last few decades, this subject has been investigated by many researchers and several techniques have emerged, including magnetic flux leakage (MFL), magnetic Barkhausen noise (MBN), magnetoacoustic emission (MAE), and stress induced magnetic anisotropy (SMA). Unlike approaches which may be ascribed to active magnetic test methods, in which a strong magnetic field is applied, the large standoff magnetometry (LSM) method is considered a passive one. It uses the natural surrounding magnetic field as stimulus to locate stress concentration zones as well as potential metal defects on pipelines. This disruptive technology, optimised by Skipper NDT through four years of R&D, is based on the inverse magnetostrictive effect, also known as the Villari effect. An applied stress causes a change in magnetisation of ferromagnetic materials (Figure 1). This change can be remotely measured in the magnetic field surrounding the steel pipeline, using magnetic sensors capable of detecting weak magnetisation changes. The LSM technique offers several advantages; non-intrusive, above ground inspection combined with a precise geolocation of the structure including its depth of cover.

Laboratory results vs numerical simulation

In order to confirm the performance of its technology, Skipper NDT has built a tailor-made non-magnetic 15 m rig station to acquire labelled magnetic data in a controlled environment (Figure 2, panel A). This test bench is used to assess the impact of several influencing parameters on the surrounding magnetic field, such as the standoff or the defect's spatial position.

To isolate and quantify the magnetic signature of metal anomalies we first acquired the signal from defect free tubes to obtain their initial magnetic state. Anomalies were then created either through chemical attacks for corrosion or mechanical pressure for dents in order to better represent the reality of the field. A flexion bench was tailor made to machine dents of various depths (5%, 10% and 15%) (Figure 1). After the metal defects were created, the tubes were measured again. The introduction of anomalies caused a clear and visible change in their magnetic response at 90 cm (Figure 2). These observations are of great importance for the deployment of LSM technology.

In parallel to these experiments, Skipper NDT has developed its finite element magneto-mechanical models used to generate a library of magnetic signatures for various pipeline anomalies. The results are used to improve the efficiency of the algorithms to automatically identify metal defects of various types. The data obtained during laboratory experiments were compared against those obtained with Skipper NDT's finite element model. The results are encouraging, and the algorithms fit well with experimental tests.

Proprietary field protocols and tools

Pre-processing algorithms

Skipper NDT's engineering team has developed and implemented a suit of algorithms in order to filter and interpret the data acquired in the field. The aim is to reduce any potential interferences and magnetic noises to ensure an optimal data interpretation (Figure 4). Data is processed as follows:

- A notch filter is applied in order to eliminate the surrounding 50 Hz.
- An individual magnetic calibration is performed on sensors.
- The data acquired from the sensors is compensated with the calibration measurements.
- An attitude correction corrects/minimises any involuntary disturbance from the Skipper NDT device orientation, mainly due to the terrain's irregular nature (Figure 7).
- The local earth magnetic field is subtracted from our magnetic measurements.
- The magnetic signals are then calculated in the local coordinate system.
- Finally, GPS co-ordinates and kilometer points are associated to each magnetic point of interest.

Figure 5. Skipper NDT device/inspection machine.

Cart/inspection machine

In terms of hardware, the Skipper NDT team has patented a field inspection machine (Figure 5). It contains five high

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resolution fluxgate magnetometers, an IMU, a GNSS and multiple sensors to assist the data processing algorithms. The machine is operated by a Skipper NDT field operator who moves the device above the pipeline. The operator

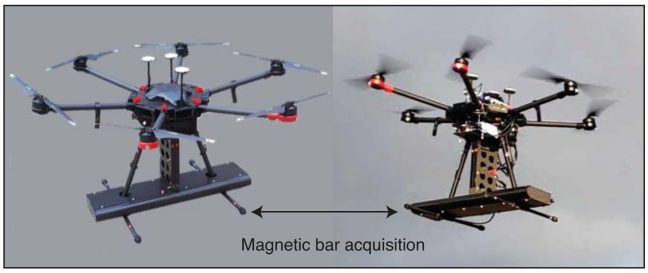

Figure 6. Drone with SKIPPER NDT's embedded LSM technology.

Figure 7. Skipper NDT operator moving the device on random landform.

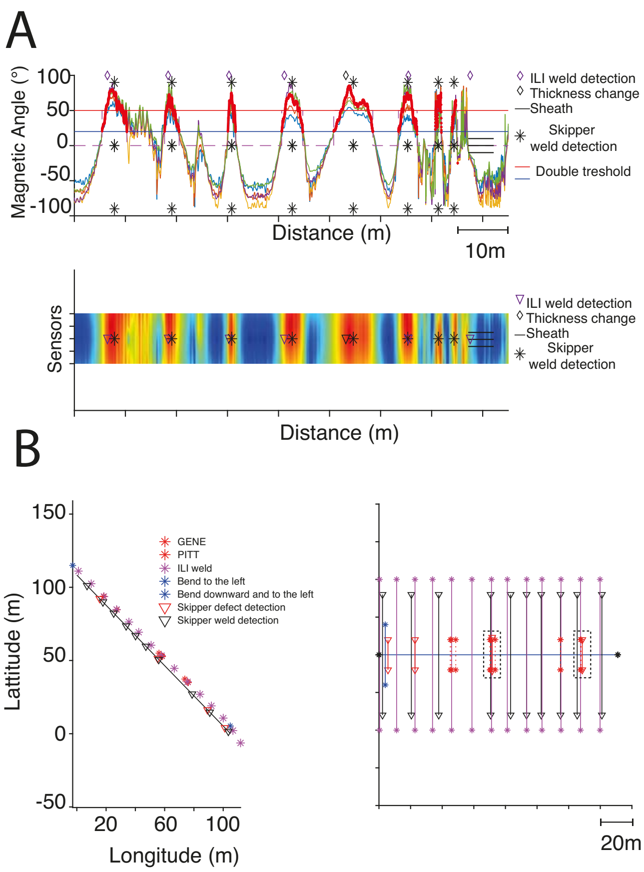

Figure 8. Panel A: Comparison of welds coordinate between ILI and LSM. Panel B: Comparison of corrosion defects between ILI and LSM.

reports potentially unwanted events during the acquisition (such as the presence of road crossing or metallic objects nearby). According to the use case, the device can be towed by a four-wheel drive vehicle. It is important to note that there is no modification whatsoever of the pipeline's normal operational conditions.

Skipper NDT embedded LSM system on a drone

Skipper NDT will be releasing in the second half of 2020 a drone version of its field inspection machine (Figure 6). With the same embedded equipment, this system will enable accurate magnetic recording via drone. The first application will be pipeline mapping services. This will allow us to operate when the right-of-way is not negotiable or hazardous.

Services and field applications for integrity management

Predictive maintenance service

The non-piggable pipeline network across the world is extensive, at over 1.5 million km. The integrity of these buried structures is paramount to their operational safety and for maintenance cost optimisation. Predictive maintenance techniques are designed to help determine the condition of in-service pipelines in order to estimate when maintenance should be performed. The LSM technology can achieve this without interfering with the pipeline operations.

Application

The acquisition protocols and data analysis tools allow Skipper NDT to extract the 'useful magnetic signal' from the data acquired on the field. Corrosion defects are identified through several characteristics and unique parameters that allow for a robust data interpretation. At the end of this phase, Skipper NDT compiles a list of magnetic anomalies classified as potential defects. This step is achieved after extraction of unwanted events inherent to the field acquisition (crossed networks, for example) or mechanical stresses generated by bends and welds. For the latter, the magnetic signal has generally a distinct shape which allowed us to isolate it and integrate it into our automatic detection tools. The results show a good match with those obtained with traditional inspection techniques (ILI) (Figure 8, panel A).

The gradient of the magnetic field is calculated after elimination of events linked to magnetic anomalies. The peak of the post-processed signal is present in the vicinity of metal losses. As shown in Figure 8, panel B, the processing chain results lead to satisfactory and encouraging metal loss detection. Defects with the following dimensions (155 mm x 294 mm x 10 mm), (135 mm x 449 mm x 28 mm), (21 mm x 26 mm x 37 mm) were detected with a high degree of precision in the field. As for false positive indications, they are usually due to welds (poorly detected) or bends perpendicular to the ground. The false negatives are marginal and negligible. The system detects and interprets magnetic anomalies that will provide additional data points to existing integrity managements systems. The events that the LSM technology is able to identify are:

- Repairs (flanges/plidco).
- Illegal tapping (represented by a tee on the test bench).
- Dents.
- Corrosions.

Cost optimisation

Maintenance costs represent a significant capital expenditure for pipeline operators who require technologies to improve the security of their networks and at the same yield cost-efficiency. The average cost of a defect investigation is approximately €15 000. As an example, a national incumbent gas pipeline operator has an annual budget for unpiggable pipeline inspections of €20 000 000. Given the current 95% failure rate they report, the financial impact translates into a €19 million/y financial loss due to useless excavations. This amount represents 5.4% of their net operating income, leading to the requirement for more efficient technologies.

Mapping service (excavation)

The precise geolocation of pipeline networks is crucial for oil and gas pipeline operators. While locating the position of a buried pipeline seems to be an easy task, its precise geolocation is sometimes prone to errors. According to the Common

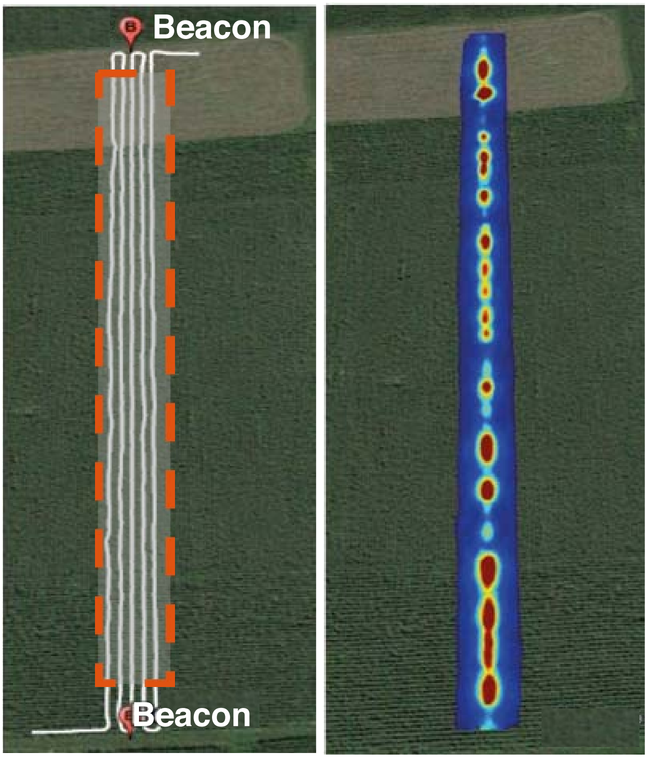

Figure 9. 180 m x 10 m inspected area (orange dashed lines) and its magnetic field map highlighting the pipeline position (coloured surface). White lines on the left picture represent the path of the inspection tool.

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Ground Alliance (CGA), improperly located or undetected subsurface utilities has resulted in 1906 injuries, 421 fatalities, and US$1.7 billion in damages during the last 20 years.[1] Several techniques are available: ground penetrating radar, sonic surveying, AC signals. All these options have their advantages and limitations, especially when right-of-way is not negotiable. Skipper NDT has developed its own method for precisely and continuously acquiring the latitude, longitude and depth of cover (DOC). To achieve this, the magnetic field is recorded above the surface to come up with an accurate magnetic map.

Application

A surface area was mapped using our protocol. In this case, the inspected area was 180 m x 10 m, containing an 8 in. pipeline buried at 1.1 m on average. It led to a magnetic field map where pipeline signature stands out (Figure 9). The signal is then automatically processed with a dozen algorithms to both clean the data and trace the line with decametric accuracy. The given result is a precise geo-positioning of the line of interest in all spatial directions (latitude, longitude and DOC), as shown in Figure 10. The performances of our location in this case study have been evaluated with respect to a reference line established by land surveyors using traditional methods (Figure 11). Skipper NDT's technology offers several advantages over existing methods:

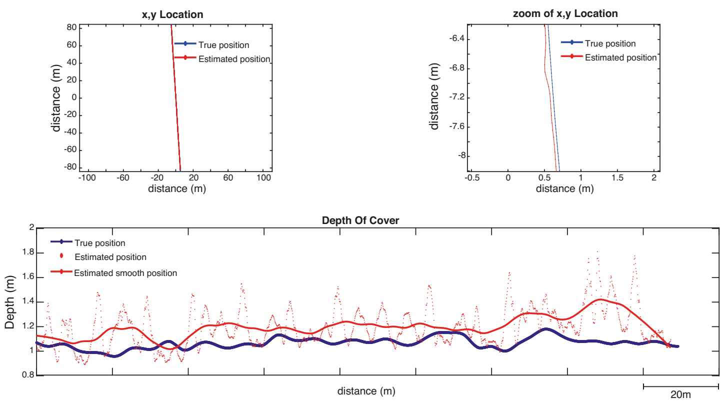

Figure 10. Predicted location of the pipeline on the surface and DOC in metres.

- Detection can be performed regardless of the terrain conditions.
- Technique works on all soil conditions and for both small and large pipeline diameters.
- Positioning is given in absolute co-ordinates.
- It can measure depth-of-cover.
- The detection of the pipeline is continuous along the line, which means that the number of data points is not a limit (1 position/cm in this case).
- High accuracy: 6.8 cm and 13.04 cm for mean lateral accuracy and mean DOC accuracy respectively, in this example.

Cost optimisation

In terms of pipeline geolocalisation, existing methods can map on average 2 km per day, given the field's logistical constraints. The Skipper NDT technology can map up to 6 km per day, hence a 3-fold cost efficiency. Furthermore, the technology used is less prone to human errors (based on algorithms) and safer for field operators.

Conclusion

Skipper NDT's LSM technology offers a precise detection service of anomalies on buried metallic structures. Furthermore, it allows for a decametric geolocation of these tubular structures including DOC. Each magnetic inspection is subject to an automatic data processing protocol. A full review of the results is then carried out by Skipper NDT's team of data analysts. The company's pipeline integrity experts assist integrity managers to better assess field operational risks and thus have a more cost-efficient maintenance programme. Skipper NDT's LSM technology has generated tangible field results backed by a robust and ambitious R&D programme launched in conjunction with two French energy majors, TOTAL and TEREGA. It constitutes a reliable tool for pipeline integrity management. Its deployment is simple and does not require any interruption or operational modifications; therefore it is cost-efficient and easy to deploy.

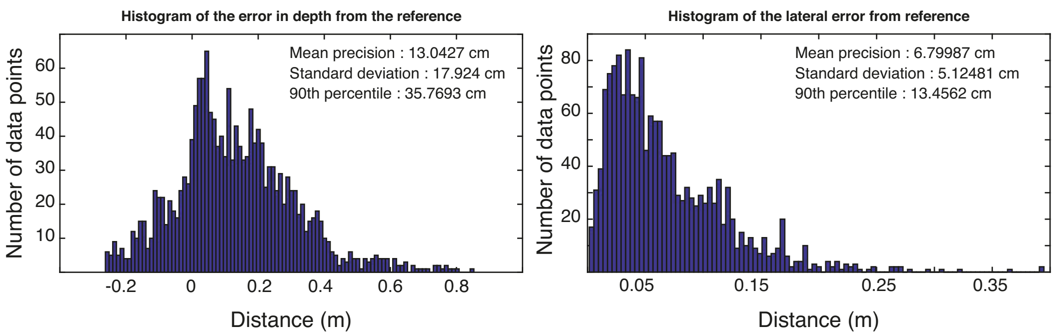

Figure 11. Histograms of the performances compared to the referenced line. Left histogram for lateral precision, and right histogram for DOC precision.

References

1. Common Ground Alliance, Damage Incident Reporting Tool Report 2015, https://commongroundalliance.com/sites/default/files/publications/DIRT_Analysis_and_Recommendations_2015_Report_Final.pdf
2. https://www.pipeline-conference.com/abstracts/large-stand-magnetometry-lsm-buried-pipelines-inspection-experimental-study-influence-dent