

## Inline Inspection from an Operator's Point of View

### *Strategic Insights*, Volume VII, Issue 1 (February 2008)

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*Strategic Insights* is a bi-monthly electronic journal produced by the Center for Contemporary Conflict at the Naval Postgraduate School in Monterey, California. The views expressed here are those of the author(s) and do not necessarily represent the views of NPS, the Department of Defense, or the U.S. Government.

#### Abstract

E.ON Ruhrgas operates a gas transmission network with a length of more than 11,300 km. Following a review of existing pigging results in 2003, the criteria for intelligent pipeline pigging were revised based on experience from previous pig runs. It was found that inline inspection is an efficient tool for monitoring the integrity of high-pressure gas pipelines, thus helping to ensure safe and reliable operations.

Based on the results found, E.ON Ruhrgas decided to use inline inspection to examine all piggable pipelines greater approx. 20 km in the E.ON Ruhrgas pipeline grid over a period of approx. five to seven years. The good technical condition of the pipelines allows E.ON Ruhrgas to organize the pig runs mainly based on economic and strategic criteria.

The results of current inspections are an important input to the company's pipeline integrity management system (PIMS) for piggable pipelines. The necessary pipeline measures can be planned and implemented in an economic manner thanks to the very good quality of the magnetic flux leakage (MFL) results. Also, it is possible to prepare an electronic pipeline log based on the data obtained from the pig runs. Excavation costs can be brought down if the geographic locations of pipeline components and detected features are known and the geographic data can serve as a basis for the GIS system and pipeline surveillance by air.

Long-term cooperation with a selected pipeline pigging company makes it possible to exploit synergies and organize an ambitious pigging program in an economic and efficient manner.

#### Introduction

E.ON Ruhrgas is one of the leading gas companies of Europe. The company buys natural gas from domestic and foreign sources and sells it to distribution companies, industrial customers and power stations in Germany as well as to customers in neighboring countries. E.ON Ruhrgas operates a gas supply network that is more than 11,300 km long. The total compressor capacity installed is 908 MW and the storage capacity amounts to 5.1 billion cubic meters. The company's main task is to ensure secure and continuous gas supplies to its customers in line with their patterns of demand. This requires an efficient and sound pipeline system that is maintained and operated based on technical and economic criteria. In a first step, the condition of the pipeline needs to be evaluated to ensure an economic approach. One way of doing this is intelligent

pigging. The paper describes why E.ON Ruhrgas decided to use this method and how it is applied.

## Inline Inspection Concept

The pipelines of E.ON Ruhrgas built after 1962 are generally considered to be suitable for pigging based on the current state of the art. Newly built pipelines are usually inspected by a caliper pig and subjected to hydrostatic testing and even stress testing in most cases to detect and remedy major fabrication and/or construction defects. The pipelines are provided with cathodic protection on the day of commissioning. During the first three years of operation, intensive measurements are made to check the pipelines for coating holidays and proper functioning of the cathodic protection system. The pipelines are also surveyed (walking surveys, mobile surveys, surveillance by air) as stipulated under the regulations applicable<sup>[1]</sup>.

E.ON Ruhrgas and the relevant project companies introduced intelligent pigging in 1996. In 2003, all results obtained for the approx. 2,600 km of pipe inspected were reviewed with the objective of establishing a predictable pattern that helps the company to say when pig runs are necessary. It was found that metal loss can occur despite a cathodic protection system that functions properly:

- In casing pipes where the protective current does not reach the product pipe.
- Under disbonded coating where the coating has separated from the pipe and prevents the protective current from reaching the pipe, allowing conditions to develop that accelerate corrosion rates (water, oxygen).
- Under anti-buoyancy concrete saddles where the protective current does not reach the pipe.
- At locations where pipelines have been damaged by third parties or where the pipeline operator failed to detect construction defects during or directly after the construction period and metal loss did not occur until several years later.

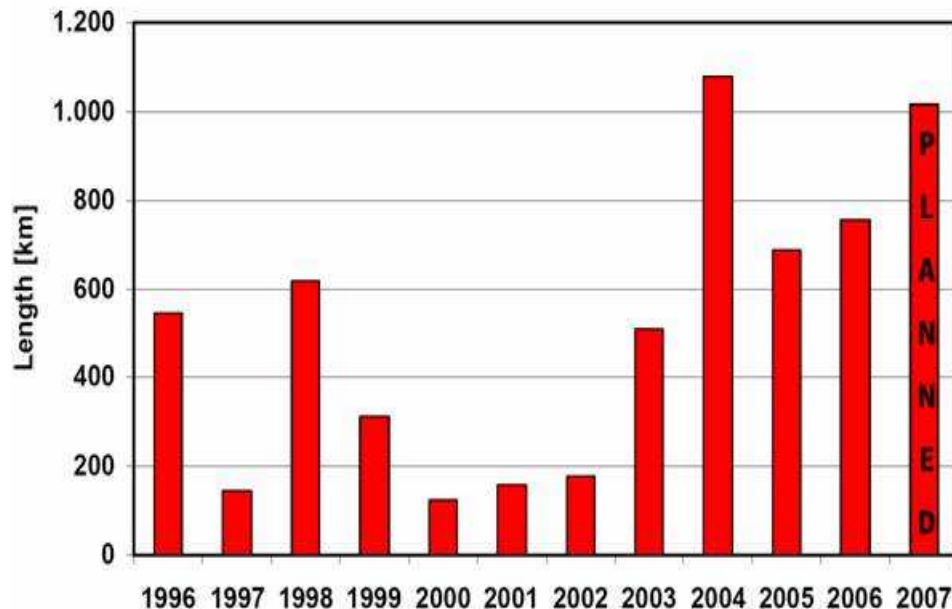
It was also found that stress testing is not a criterion in favour of or against intelligent pigging because the mechanisms mentioned above do not show until corrosion has reached a certain stage or because the defects have possibly not yet existed when the stress test was made as, for example, in the event of third party interference or hidden construction defects. Any such corrosive damage can only be detected by intelligent pigging.

Based on the inspection results obtained for the period from 1996 to 2003, E.ON Ruhrgas therefore decided to apply the intelligent pigging method for inspecting its transmission network in line with the current state of the art and economic criteria. The condition assessment program was to start with pipelines greater approx. 20 km. Of course, the program also covers shorter pipelines where special circumstances indicate inspection priorities.

## Pigging Program of E.ON Ruhrgas

In 2004, E.ON Ruhrgas introduced a pigging program for the inspection of approx. 5,000 km of its pipelines. The pipelines have diameters from DN 200 to DN 1,200, pressure stages from 67.5 MOP to 100 MOP and lengths from 8 km to 240 km. The pipelines also include some dual-diameter lines (e.g. 28"/32", 36"/40", 40"/44", 42"/48") and three 32"/36"/40" multi-diameter lines that are particularly challenging for the gas supplier and pipeline integrity company in terms of pig availability and pig run organization. [Figure 1](#) shows the pipeline lengths that E.ON Ruhrgas inspected by intelligent pigging in the period from 1996 to 2006.

**Figure 1: Annual Pipeline Lengths Inspected by Intelligent Pigging**



As is obvious from the figure, the annual length of pipeline inspected was as high as 1,080 km in 2004 when the new pigging program was introduced. The average length of approx. 325 km valid for the period from 1996 to 2003 has increased to approx. 840 km today.

In practice it was found that the pipeline length that can be inspected in a year is limited by two factors. First, not more than approximately 15 pipeline sections can be tested for their integrity in a year. Second, the time and organization input required for inspecting very long pipelines limits the total length that can be examined in a year to approx. 1,100 km. Another important factor is the complex nature of the pipeline system to be inspected or the number of invalid runs to be expected. In 2005, the pipeline length inspected by pigging was therefore only 690 km because, among other things, the integrity program included the very challenging dual- and multi-diameter pipelines.

Thanks to the overall good condition of its pipelines, E.ON Ruhrgas is free to organize its integrity program mainly based on economic criteria. Immediate line pigging jobs are not necessary at this point of time.

## **Organization of Pig Runs and Line Pigging**

### **Pigging Services**

The E.ON Ruhrgas pipelines to be inspected are natural gas pipelines which usually carry dry natural gas. Sometimes the lines also contain unwanted material such as pipe dust, construction debris, welding electrodes, particularly after re-routing measures, or small quantities of condensate. The pipelines must therefore be cleaned with a magnetic cleaning pig to prepare for inline inspection. Brushes are not used as deposits on the inner pipe walls are not to be expected. The cleaning pig is fitted with a caliper plate to determine and document whether the inspection tool can safely pass through the pipeline. Experience from the past few years has confirmed that one or two cleaning pig runs are sufficient in preparation for intelligent pigging.

After the cleaning pig, a caliper pig is sent through the line. The results of the caliper pig run are only analyzed to the extent necessary for confirming that the passage through the pipeline is free. A full analysis of the results may be necessary if the intelligent pig detects dents or ovalities in the line.

Basically three types of pigs are currently used for intelligent pigging: MFL inspection tools, ultrasonic inspection tools or electromagnetic acoustic transducers (EMATs). They are available in diverse designs and in combination with mapping and caliper modules. The tools are selected depending on their suitability for use in gas lines and the defects expected. The main pipeline defects expected are metal loss, weld anomalies, dents and manufacturing defects. Both MFL tools and ultrasonic tools are tools suitable for this purpose.

E.ON Ruhrgas uses MFL inspection tools as ultrasonic pig inspection in a gas pipeline requires liquid batches. This would cause problems with respect to the pig run and operation of the gas line. The EMAT is a crack detection tool suitable for use in gas pipelines. But E.ON Ruhrgas has used the EMAT only for test purposes so far as the EMAT development status still needs some input and cracks are not defects that occur frequently.

Another additional valuable service that can be performed together with pigging is mapping. For this purpose, a mapping module with a gyrocompass is usually connected to the intelligent pig. Above-ground markers (AGMs) are provided along the line at defined distances (e.g. max. 2 km). They are installed on top of the pipeline and their positions are recorded. As the pig travels through the pipeline, an AGM detects its magnetic field and stores its traveling time to the relevant AGM. Using the information of the inertial measurement unit installed in the pig, the exact position of each weld, valve, branch or other component as well as of each feature detected is subsequently calculated. Based on the information obtained, an electronic log book is prepared for the pipeline inspected. It is not possible in any other way to prepare such an electronic log book with the same information density and at the same costs. The operator benefits from this information in manifold ways.

The mapping information:

- serves to establish or consolidate a GIS system;
- helps to reduce excavation costs as the size of the building pits is minimized;
- is used for automatically scanning the pipeline corridor with the airborne CHARM laser system[2].

## Tendering

Tendering is based on the POF specifications[3] that are expanded to include company-specific requirements (e.g. the E.ON Ruhrgas safety requirements). The E.ON Ruhrgas specifications contain the pipeline questionnaires for the lines to be inspected. The specifications also list in detail the responsibilities of the contractor and of E.ON Ruhrgas based on the condition assessment plan of a pipeline inspection company. The approach ensures that the responsibilities for pig transportation and cleaning and the provision of auxiliary facilities are clearly defined. The specifications also define in detail the accuracy and format requirements for the mapping data as the POF requirements are not very specific in this respect.

E.ON Ruhrgas specifies the deadlines, contents and formats for the preliminary and final reports to be submitted by the pipeline inspection company. These elements are essential to ensure prompt processing of the inspection results at E.ON Ruhrgas. For example, the preliminary report must contain information about the AGMs triggered during the pig run as this information is important with respect to the mapping accuracy that can be achieved later. Early information about problems allows the company to take prompt action. The format specified for the pig run

reports and mapping data is based on an E.ON Ruhrgas-specific format that is compatible with the in-house PIMS and allows the large data volumes to be entered to the company's Electronic Data Management System (EDMS).

The pipeline inspection companies are requested to quote their prices separately for the cleaning pig and intelligent pig (mobilization, MFL inspection, mapping, report). The terms quoted for the cleaning pig should be flexible as the number of pig runs required may vary.

The entire pipeline inspection package negotiated by E.ON Ruhrgas for the period from 2004 covers approx. 5,000 km of pipelines. The services were quoted and negotiated as optional items. As a result, E.ON Ruhrgas is free to buy inspection services on an annual basis without having to re-negotiate prices. At the same time, E.ON Ruhrgas has a reliable planning basis for the period for which the price terms are valid.

### Planning and Line Pigging

As network utilization is constantly increasing, it has become more and more important to have a detailed and consistent integrity program plan. E.ON Ruhrgas therefore appointed a person from the company's Pipeline Technology Centre of Competence as project manager. He heads the pipeline integrity project team and manages all measures centrally. He receives the operations-specific information he needs from the engineers on site who are operationally responsible for the pig runs to be made in their operations areas. The project team of E.ON Ruhrgas is rounded off by experts from the in-house Materials and Corrosion Technology Centre of Competence, staff from the Operations, Dispatching and Purchasing Departments and from PLEdoc, a mapping and documentation service provider.

The organizational approach is to use own staff for higher-value services and award contracts to pipeline integrity companies or other sub-contractors for work that can reasonably and economically be performed externally. External services include the design and provision of cleaning pigs, transportation and cleaning of pigs, insertion of pigs into the launch trap and removal of pigs from the receiver trap as well as assistance with pig tracking. E.ON Ruhrgas uses its own staff for all services for which it is responsible as the operator pursuant to the German Energy Industry Act<sup>[4]</sup> and the High-Pressure Gas Pipeline Regulation<sup>[5]</sup>, e.g. launching of the pig from the trap.

The pipelines to be inspected by pigging in a year are agreed internally in the autumn of the preceding year. The Dispatching Centre examines the flow situation to be expected and determines the time windows available for the pig runs. E.ON Ruhrgas then plans the pig runs based on the time windows specified, keeping the number of mobilizations to a minimum. Equal-diameter pipelines are therefore inspected together in one mobilization period. The time schedule determined is then promptly agreed with the pigging service contractor to ensure early booking and availability of the pigs required.

The necessary measures are organized in such a way that equal-diameter sections are first cleaned and then inspected by caliper and intelligent pigs. This approach ensures minimum on-site time for both the pigs and the service staff whose number varies depending on which type of pig is used. Other factors influencing the time schedule are other operational measures that need to be taken into account and, above all, pig availability. Planning must also take into consideration preparatory measures on the pipeline, for example, welding or flanging on of pig traps.

The AGMs for the mapping pig run are installed in line with defined criteria. Courses are provided for staff from the Operations Department to train them in pig tracking, AGM handling and safety issues relevant to line pigging. E.ON Ruhrgas organizes on-site visits together with the pipeline integrity company to examine the conditions on site. Pipeline books and a list of geographic

information are also made available. Sufficient space for inserting the pig in and removing it from the trap, suitable workshops and washing stations as well as the locations and adequate dimensions of pig traps are of particular importance in this context.

A couple of days before the pig run takes place, E.ON Ruhrgas works out a detailed pipeline shut-off report for the inspection planned. The report includes all necessary switching measures for the pipeline grid, responsibilities, persons involved as well as a pig tracking plan. The pig run is made by the person responsible for the pigging measure (operations engineer) pursuant to Guideline GL 273-501[6]. The operations engineer is supported by staff from the Operations Department and employees of the pipeline integrity company. The pig run is documented in a report that includes, among other things, the time schedule, liquids and solids removed as well as any features detected.

**Figure 2: Processing of Pig Run Results at E.ON Ruhrgas**



[Figure 2](#) describes how the pig run results are processed. The preliminary report is to be submitted within five days from the date on which the intelligent pig run was made. E.ON Ruhrgas checks the report for complete MFL data, the number of AGMs triggered and any significant pipeline flaws that may require immediate action. The final report is to be submitted within two months from the date on which the intelligent pig run was made. It is evaluated internally by the Cathodic Protection and Materials Technology Departments using existing information from the Operations Department and the general history of the pipeline. The MFL data are entered to a special software program and ranked for further processing based on cathodic protection and strength aspects. Following further automatic and manual processing, the following features are evaluated:

- Reduced wall thicknesses in the base material and weld area,
- Circumferential weld anomalies,
- Dents,
- Corrosion rates, metal loss depths and areas,
- AC interference,
- Metal loss in bends and casing pipes,
- Moreover, the mapping data are analyzed.

In the next step, the E.ON Ruhrgas expert departments discuss the results with the Operations Department. The measures recommended are summarized in a list that is appended to the

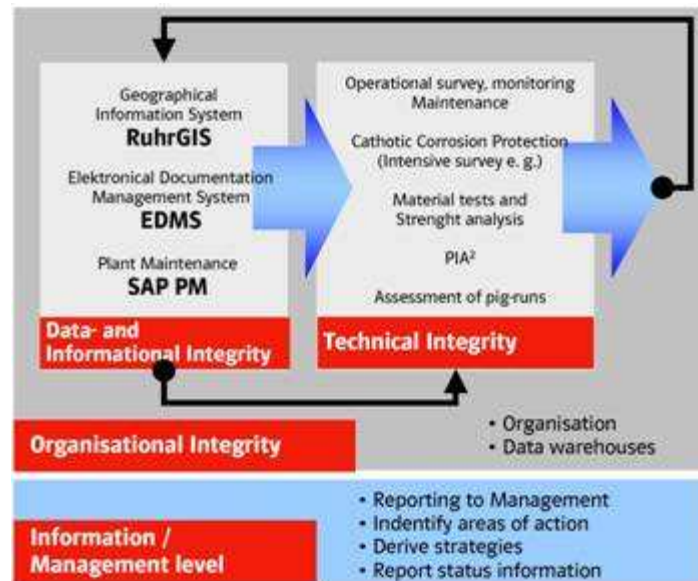


internal pipeline integrity report. The remedial action agreed is taken within a defined period of time and certified by an expert, if required.

## Integration in PIMS

The entire pigging process starting with the selection of the pipelines to be inspected is controlled and documented by the PIMS (Pipeline Integrity Management System)<sup>[7]</sup> of E.ON Ruhrgas. The PIMS is a tool that links technical, management and organization information (Figure 3).

Figure 3: Definition and Characteristics of PIMS



The system defines the condition assessment processes and sub-process interaction and links the data processed. Technical pipeline integrity is confirmed based on the expert knowledge of the Pipeline Technology Centre of Competence and Operations Department. For this purpose, the processes mirror measures in the fields of operational monitoring and maintenance, cathodic protection, material and strength analyses as well as measures to assess current pipeline conditions, e.g. by means of intelligent pigging. Data and information integrity is ensured by including the relevant process parameters in the RuhrgasGIS geographical information system, the EDMS and the SAP PM.

The system makes it possible to describe the condition of specific pipelines or classes of pipelines for reports to the company's management or work on future strategies.

## Experience

### Project Implementation and Technology

The project of inspecting an average length of approximately 870 km of natural gas pipelines annually over the past three years and cooperation with a selected pipeline integrity company were handled very efficiently by the project team. Some weak points were identified when the project started but they were eliminated by appropriate action. At first, a special focus was on responsibilities and interaction between the pipeline integrity company and the E.ON Ruhrgas project team. It was soon found that established contacts and recurring procedures in planning, project implementation and analysis of the results obtained were great advantages.

Communication between the project team members and the pipeline integrity company as well as communication among the staff of the pipeline integrity company was not satisfactory in the beginning. The situation improved when regular meetings of the project team members and management meetings were introduced to discuss technical innovations and organizational issues in addition to the project under way.

Also, a customer communication platform was introduced that was essential in ensuring efficient communication between E.ON Ruhrgas and the pipeline integrity company. The customer communication platform is an Internet-based software application that allows the project team members to communicate by e-mail and access project-relevant information. It also serves as a common project server and describes the project status. An automatic function for monitoring dates makes it possible to directly remind project members of their tasks via e-mail. The messages can be escalated, if required, to ensure that critical tasks remain in the focus.

When the difficulties encountered during project implementation were analyzed, it was found that in 2004, the first project year, problems occurred with the MFL fleet. The problems were caused by defective charging devices or safety valves, deficient data storage or electrostatic charging. The cleaning and caliper pig runs, on the other hand, did not involve any problems. In 2005, the inspection program included very challenging dual- and multi-diameter pipelines. The success rate of the MFL runs was excellent in that year while the caliper and mapping pig inspections required additional input. In 2006, E.ON Ruhrgas and the pipeline integrity company benefited from the experience gained in the previous years and implemented the integrity program without any problems.

All in all, it can be said that initial difficulties were solved efficiently by appropriate measures so that the ambitious goals set for the project in terms of costs, quality, time schedule and safety standards were fully achieved. Appropriate measures included organizational adjustments of the project management at the pipeline integrity company, improved spare parts inventories, pressure testing of pig trap components and stringent quality checks. Also, an important factor that contributed to the project's success was the enormous flexibility of all persons involved.

## **Caliper and MFL Results**

Experience over the past three years has confirmed that the use of caliper pigs is fully justified. The MFL pig sometimes detects dents in the pipeline without specifying dimensions. It is an economic approach in these cases to have the caliper pig runs analyzed and have a closer look at the dents mentioned in the MFL report. Often, the strength characteristics of the relevant pipeline sections are good so that costly confirmation digs and examinations on site can be avoided.

The quality of the defect data listed in the MFL reports is very high. In many cases defects listed were found immediately when the line was excavated and uncovered and the defect dimensions determined by the pig were fully confirmed. The E.ON Ruhrgas Operations Department and Pipeline Technology Centre of Competence therefore consider intelligent pigging a very valuable inspection method.

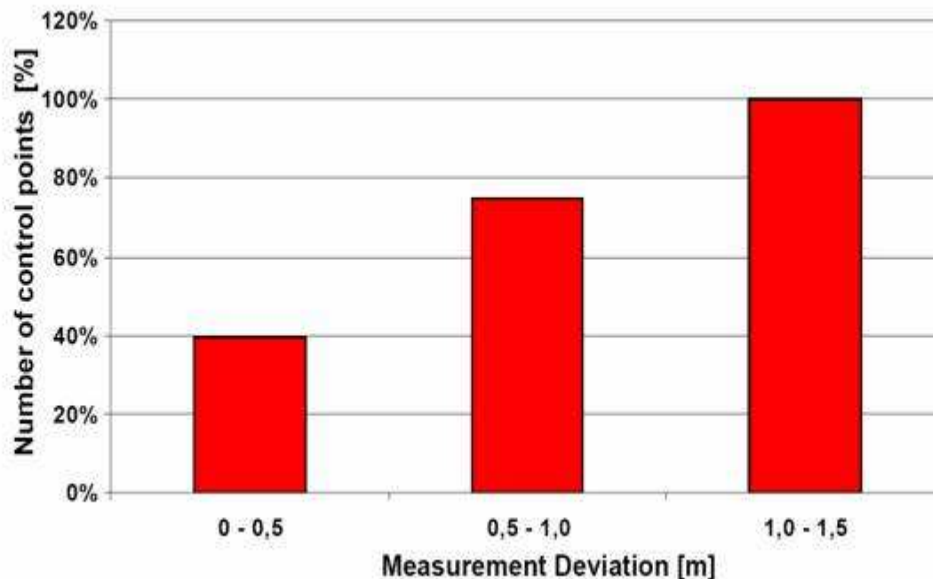
## **Quality of Mapping Data**

The original accuracy requirement E.ON Ruhrgas specified for pipeline position mapping was +/- 0.5 m for a three-dimensional coordinate. The AGM reference points were to be mapped with an accuracy of at least 0.1 m and the distance between AGMs was to be limited to 2 km. But it became obvious in practice that the requirement specified could not be met with the current state of the art. Today, an accuracy of +/- 1m is usually specified for a three-dimensional coordinate with a confidence level of 90 percent and an AGM spacing of, for example, 1 km.



E.ON Ruhrgas reviewed the mapping accuracy of a pig run made in 2003 based on reference points mapped after the pig run was made. [Figure 4](#) shows the cumulated measurement deviations (only position, two-dimensional) determined as the differential between the coordinate from the pig run report and the coordinate measured on site.

**Figure 4: Cumulative Frequency of Reference Points [%] vs. Measurement Deviation in 2-D**



For approximately 40 percent of the coordinates examined, the measurement deviation is less than 0.5 m. As the percentage of coordinates examined increases in a linear fashion, the measurement deviation reaches 1.0 to 1.5 m for 100 percent of the coordinates examined. The measurement deviations would even be higher for three-dimensional coordinates.

Many technical optimizations were made and the pig run itself was optimized. Today, the pipeline integrity company commissioned by E.ON Ruhrgas delivers an average position accuracy of approx. 1 m (two-dimensional) with an AGM distance of not more than 2 km. This means, the accuracy requirements for the location of defects in the field or for proper operation of the CHARM system are met.

It is not possible to determine the covering layer above a pipeline with the measurement accuracies achievable today. Theoretically, the coverage is determined by deducting the vertical coordinate of the inline inspection tool from the vertical coordinate of the ground level (determined, for example, by air surveys). But the measurement deviations described above can lead to very erroneous results. For example, a sufficiently covered pipeline with a real cover of 1 m could be interpreted as having no cover at all if the measurement deviation is approx. 1.5 m.

The current mapping accuracy for inspections of E.ON Ruhrgas pipelines has been achieved thanks to technical innovations and improvements in program planning and implementation. For example, new AGMs were introduced in 2006. The time drift is considerably lower than for the previous model. This helps to significantly reduce, in particular, axial measurement deviations. Also, AGM sensitivity to the magnetic field of the pig was improved considerably so that the number of non-triggered AGMs is now negligible. In the past, measurement deviations were often high because many AGMs were not triggered and, as a result, the number of reference points was low. Other measures taken to minimize measurement deviations include photo-documentation of AGM locations, training of staff to improve AGM handling, introduction of rules to determine optimum AGM position or reduced AGM distances where possible.

## Conclusion

Intelligent pigging is a valuable inspection method also for pipelines that were directly provided with cathodic protection when they were commissioned. The method complements quality assurance during construction, stress testing, caliper pig inspection, intensive surveys and operational monitoring. The inspection results serve as an important basis for the company's PIMS. The necessary pipeline measures can be planned and implemented in an economic manner thanks to the very good quality of the MFL results. Also, it is possible to prepare an electronic pipeline log based on the data obtained from the pig runs. Excavation cost can be brought down if the geographic positions of pipeline components and detected features are known and the geographic data can serve as a basis for the GIS system and pipeline surveillance by air. Long-term cooperation with a selected pipeline integrity company makes it possible to exploit synergies and organize an ambitious pigging program in an economic and efficient manner.

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