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Robotic Inspection Technology for Unscrapeable Pipelines

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ABSTRACT

In-Line Inspection tools are limited to scrapable pipeline sections only. Corrosion and cracking do not have this limitation. Not inspecting them would result into operating pipelines sections with questionable integrity. The confidence level in the integrity of these systems will drop below acceptance levels. Unscrapeable pipeline sections are usually short but they are quite often in-accessible and inhibit the entire rest of the pipe of being inspected. In view of the fact that the internal geometry of those pipeline sections is not designed to let In-Line Inspection devices pass, a robotic approach is required.

The robotic approach is as challenging as simple

- ¾ Get in there without disturbing the flow.
- ¾ Be able to reach all places of interest.
- ¾ Apply the required inspection technology.
- ¾ Bring back the required inspection data.

ROSEN faces these challenges with a modular toolbox principle. This is mandatory, as a universal "all purpose" robot would not be reliable and efficient in resolving the postulated inspection task.

Achieving this leap forward ROSEN runs a development program containing several Projects to undertake the necessary big steps in different R&D areas, while minimizing the risk of creating undesirable market solutions. In this paper we inform you of its present status.

INTRODUCTION

Pipelines are proven to be the safest way to transport and distribute Gases and Liquids. Regular inspection is required to maintain that reputation. The larger part of the pipelines system is accessible by In-Line Inspection Tools but this access is limited to the section in between the launching and receiving traps only. Unfortunately, corrosion does not have this limitation.

The industry looks for means of inspecting these in-accessible pressure holding piping systems, preferably, without interrupting the operations. It is a fact that sufficiently reliable and accurate inspection results can only be obtained by direct pipe wall contact/access. If that is not feasible from the outside, we have to go inside.

Since modifying pipeline systems for In-Line Inspection is mainly not practical, ROSEN pursues development of ROBOTIC inspection services for presently in-accessible pipeline systems. We started a multi million dollar investment program for achieving this leap forward and this paper explains the present status of the program.

The development is based on a “step by step type” method. ROSEN uses this method successfully by providing the industry with innovative technologies over the last 25+years and our two main aims are:

1 Develop and improve on non destructive testing (NDT) services limiting disruption of producing operations to a minimum for early detection, defining and accurate sizing of anomalies that may ultimately threaten the integrity of pressure holding facilities

2 Report the results such that they fit seamlessly into any integrity management programThis must be achieved economically, reliably and safely.

Our long term vision on systems and commitment to reliably working components is summarized as:

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COMPONENTS FOR TOMORROW MUST FIT INTO SYSTEMS AFTER TOMORROW

We present the basic technique for developing the final solution as well as the structures and methods we applied for the entire Research & Development (R&D) process. In addition, auxiliary type services that were developed simultaneously will also be presented.

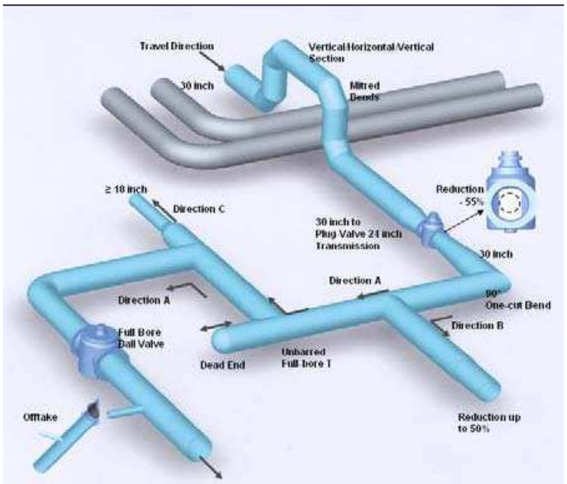

Figure 1. Typical piping configuration as design basis for the ROBOT

THE ROBOTIC TOOLBOX SERVICE CONCEPT

The ROBOTIC inspection service consists of two basic components, the inspection ROBOT for acquiring data from the pipe wall and the processing of the inspection findings and reporting it

The Robotic Tool

The ROBOTIC tool has to fulfill the following basic functions:
1 Enter into the piping system without permanent traps
2 Finds its way around the piping system (see figure 1)
3 Map the location of the entire piping system
4 Collect inspection data from every square centimeter of the pressure holding pipe wall with the choseninspection technology
5 Come back out

In view of the variety of piping system configurations as well as the variety in different possible corrosion processes, a versatile system had to be chosen. That versatile system is the box type concept with modular components from which a tool can be put together in which ever way required for specific jobs.

In view of the above, it is clear that a very high form of autonomy is required for this type of applications. We probably know that the piping systems have tremendous internal geometry variations but do not know to which extent.

THE TOOL THAT GOES IN THESE PIPING SYSTEMS HAS TO FIND OUT AND DEAL WITH IT

The Inspection Findings

The inspection findings have to be reported such that they can be seamlessly integrated into any integrity management system. Seamlessly means that any of the following programs should be able to use the reported inspection findings without manual interception:

- fit for purpose
- risk assessment
- GIS data bank
- remaining lifetime predictions
- corrosion growth estimates
- repair suggestions
- increased maintenance
- etc. etc.

MODULAR COMPONENTS

In order to fulfill the basic requirements of entering into the piping, finds its way around autonomously and acquire inspection data, a highly sophisticated ROBOTIC tool is mandatory.

This ROBOTIC tool comprises of three integrated yet independently encapsulated modules responsible for sensory, control and mechanic functionality. To keep the focus on the essential aim of inspecting the pipeline, mechanic modules are simply called "carrier" meaning a carrier for sensor and electronic technology (Figure 2).

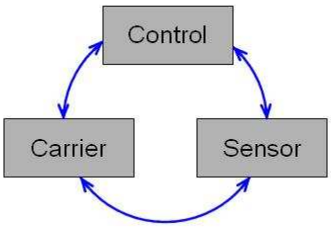

Figure 2: The Basic Modular Concept

A tool may be equipped with several different sensor modules at one time. This flexibility makes it possible to perform a crack detection and geometry inspection within one survey as an example. Many other combinations are also possible.
The past proved there are three main advantages in putting this simple and basic concept persistent into action:

1. Improved flexibility to adapt Tools with regard to inspection aims and individual pipeline requirements.
2. Improved reliability through the ease of use of component tests and well defined interfaces.
3. Highly focused and efficient Research & Development (R&D) process due to an optimized structuring of research fields as well as a simplified cooperation's with R&D partners (Centre Suisse d'Electronique et de Microtechnique SA, *CSEM*; Fraunhofer Institute Biomedizinische Technik, *IBMT* ; Southwest Research Institute of Texas, *SwRI*).

With the stated requirement of inspecting traditionally "un-inspectable" pipelines to be reached, more is required from the existing Carrier, Sensor and Control modules than just extending their functionality or making them more flexible.

A truly ROBOTIC control system is required for controlling as well as coordinating the complex system functionally.

The Robotic Component

Therefore, it became obvious that strategies for controlling, sensor usage and tool movement are indispensable. As a result, it was decided to extend the modular toolbox approach with a Robotic component as shown in Figure 3.

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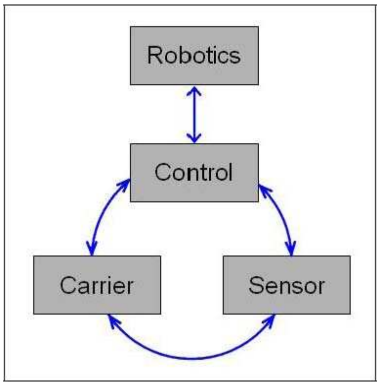

Figure 3: The Modular Robotic Inspection Concept

This toolbox concept enables a flexible, reliable and optimized framework capable of adapting to the individual pipeline environments and to the actual inspection targets. The R&D process was accelerated by applying well tested and proven control module structures.

The application of the ROSEN "SMART – Box" is an example. This concept was developed and applied more than 5 years ago. It is a "plug and play" electronic component that is field programmable and can be applied in all of our equipment for any technology (MFL, Eddy Current, UT, Navigation, etc.). The SMART – Box component fits the structurally designed frame work applicable to all of our inspection tools.

A new design of the complete loop "Carrier-Sensor-Control" was not necessary, as the robotics module "supports" extended control with strategies which are explained in the next section. The robotic control toolbox maintains it modularly in two fundamental ways - functional (as being built up by modularized software components) and physical. Both are incorporated within the ROSEN "SMART – Box" concept as pictured in Figure 4.

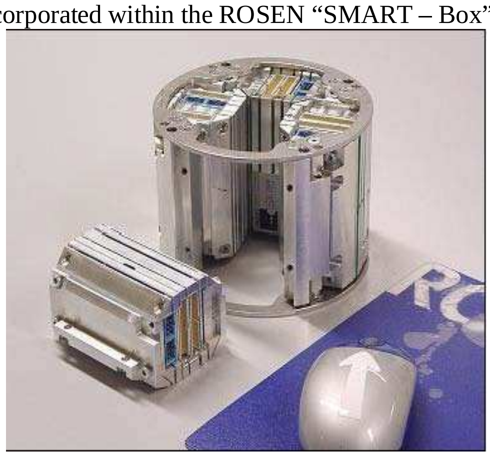

Figure 4. Modular components for data acquisition, recording and processing (ROSEN "SMART Boxes")

REQUIREMENTS ON THE ROBOTIC INSPECTION TECHNOLOGY

A brief overview of the challenges and obstacles present in many pipeline systems provides the foundation for the requirement of a Robotic Inspection Technology. The last section developed the structural concept that is believed to be optimal for building up such technology ending with the modular Robotic Inspection Concept. This next section builds upon the named challenges and the structural concept of the robotic system in order to clearly define the requirements of each of the previously identified modules.

Carrier Requirements

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□ • Self Propelled
□ o Allow inspections independent from the flow of the medium
□ o Tool is enabled to enter and leave the pipe at the same point
□ o Capability of Dead-End inspection
□ • Bi- Directional
□ o Necessary for free, independent tool movement.
□ Enter 90° Off-Takes
□ • Capability for expressive NDT to > 50% of nominal ID
□ o Includes mutli-diameter pipelines
□ o Support lines, Off-takes, Vent-lines
□ • High Product by-pass
□ o Ease travel against the flow
□ • Launching and receiving through same 90° Hot-Tap entry points
□ o Improving efficiency by reducing operational costs
□ o Improved safety relative to 45° Hot-Tap entry points

Sensors Requirements

□ • Permanent Transmitter
□ o Tracking the Robot
□ o Communication
□ • Modular NDT – Sensory
□ o Electro Magnetic Acoustic Transducer (EMAT)
□ o Ultrasonic (UT), Laser
□ o Visual
□ o Eddy Current (EC)
□ • On board Power Generation Module
□ o Increases inspection time and range
□ • Inertial Measurement Unit
□ o Mapping the pipeline
□ o Allows path finding strategies under consideration of an existing pipeline map

Robotic Control Requirements

□ • Wireless Above Ground Remote Control
□ o Needed for training the Robotic system controllers
□ o Needed for option manual control
□ • Path finding
□ o Local Strategies: How to pass / enter bore valves, dead-ends, take-offs, vent- and support lines
□ o Global Strategies: How to inspect the entire environment with regard to expected findings, medium in the pipe, pipeline trajectory and inspection purposes
□ • Sensor Usage
□ o Strategies for enhanced scanning of critical findings
□ o On board selection and utilization strategies for additional sensor modules

THE ROBOTIC INSPECTION TOOL (Ro*Bot*)

The requirements on the Carriers, Sensors and Control Modules have given rise to a highly flexible and maneuverable solution (Figure 5).

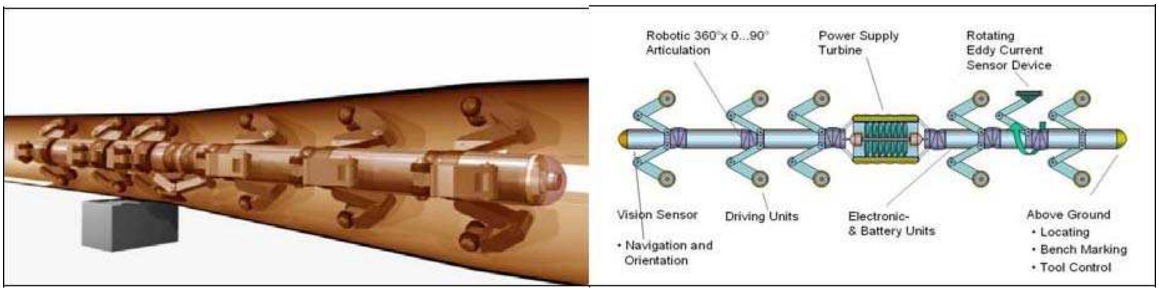

Figure 5: Final concept of the Robotic Inspection Tool

The Heart of the Carrier Module consists of up to 30 independent acting robotic axes, including novel automotive articulated joints. These joints were designed to freely direct the robot in any plane.

Local path finding strategies for tasks such as entering a 90° Off-Take (Figure 6), are responsible to ensure that the interaction of all included axes and modules runs smoothly. These local strategies are developed during an initial process of both, supervised and autonomous learning.

Global path finding inspection strategies depend on individual pipeline requirements. A strategy could be to follow an uploaded trajectory with help of the navigation system using on-board inertial measurement unit (IMU). Another, simple strategy would be to enter only off-takes with internal diameters between 12” – 18”.

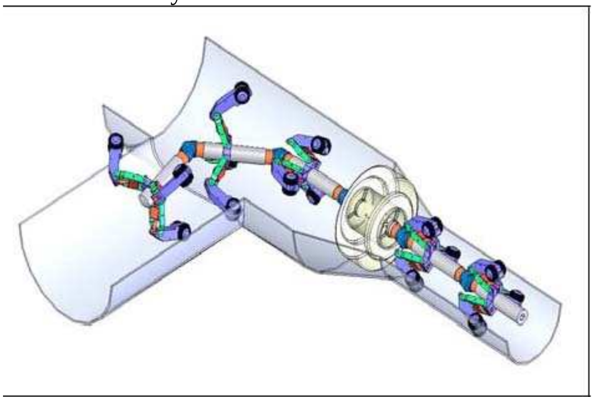

Figure 6. Ro*Bot* entering Off-Take. Shown is also the use of the Power-Generation-Module (expanded to maximize turbine driving flow)

Features of the ROSEN Robotic System (Ro*Bot*)

- Autonomous and self propelled
- Bi-Directional, self adapting tractor drives, Single Entry and Exit Point
- Novel, automotive articulated joints, designed to freely direct from 0° - 90° in the plane
- Collapsible to 45% of nominal ID
- Modular Design of Carrier, Sensors and Control
- Intelligent and redundant on board mission control
- Wireless connection for manual interaction and training
- Optional Retina Vision (3-dimensional imaging)
- On board navigation by Inertial Measurement Unit (IMU)
- On-Board Power generation
- Fail safe System

INTERMEDIATE STEPS BY SPIN-OFF-PROJECTS

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The “RoBot” project places great demands on Research & Development. Papers can be written only about path finding – or inspection strategies and theses of how to implement them by intelligent algorithms would be worth to produce. However these are useless without a carrier- and sensor design that is capable of meeting the demanding conditions of an operating pipeline system. The challenge of developing this Robotic System is to undertake big steps in the many R&D areas, while minimizing the risk of creating undesirable market solutions.

Incremental R&D minimizes this risk by splitting the whole project up into clear and controllable tasks. This process is supported by our modular toolbox concept. Modules can be separated and partly developed independently within familiar and tested environments. As a result, some innovations are researched and developed within Spin-Off-Projects, with less complexity than the whole Ro*Bot* project. Three of these are briefly introduced in the next subsections

Robotic Test System (RTS)

This spin - off is one major intermediate step to the final robotic system, Ro*Bot*.

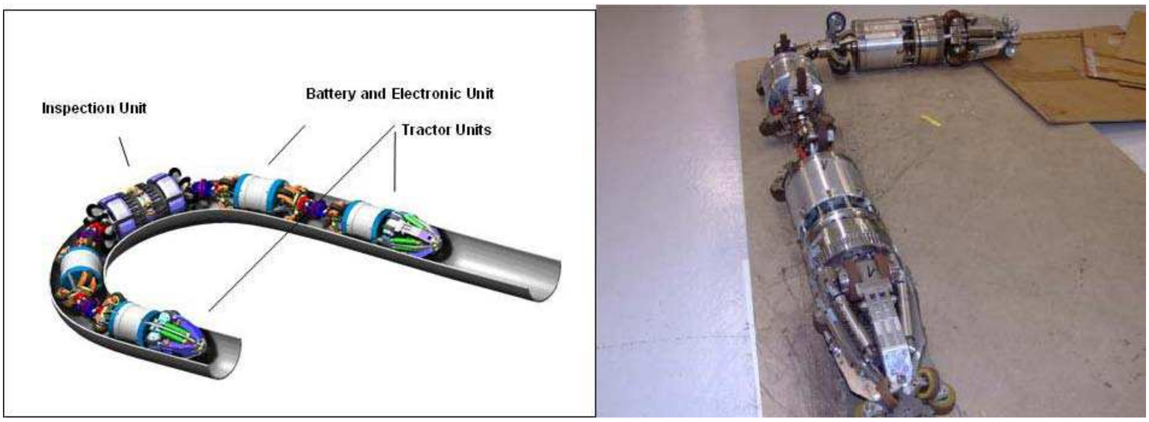

Figure 7. Robotic Test System (RTS). Optimized for autonomous inspection of vertical venting pipelines.

The RTS (Figure 7) is optimized for inspecting vertical venting pipelines. Therefore two tractor – units capable to create extremely high driving forces had to be developed. A prototype for diameters from 10”-12” was tested at the ROSEN Technology and Research Centre (RTRC) in Lingen, Germany. For this purpose a 25 meter high test facility was built up (Figure 8).

Figure 8: RTS test facility at ROSEN Technology and Research Centre (RTRC), Germany.

Features of the RTS are

- Autonomous self Propelled Robotic Test System with bi-directional & self-adapting tractor drive

- High Magnetizing MFL Inspection Unit for accurate feature detection & sizing
- Extremely High Driving Force, enables vertical climb
- Single entry- and exit point
- Passage of Pipeline Installations and Fitting (Y’s, T’s etc.)
- Wireless above ground remote control

Among other parts, the Robotic Control Modules used in the RTS are the same being used in the final Ro*Bot*. This approach allows ROSEN to develop necessary experience with robotic strategies.

Free Swimming Leak Detection Tool (Ro*Float*)

Ro*Float* is designed for leak-detection and localization in water pipelines. The tool is an autonomous swimming vehicle. It is able to detect small leakages by acoustic emission (hydrophones). Also several sensor modules like visual, eddy-current and ultrasonic will are available.

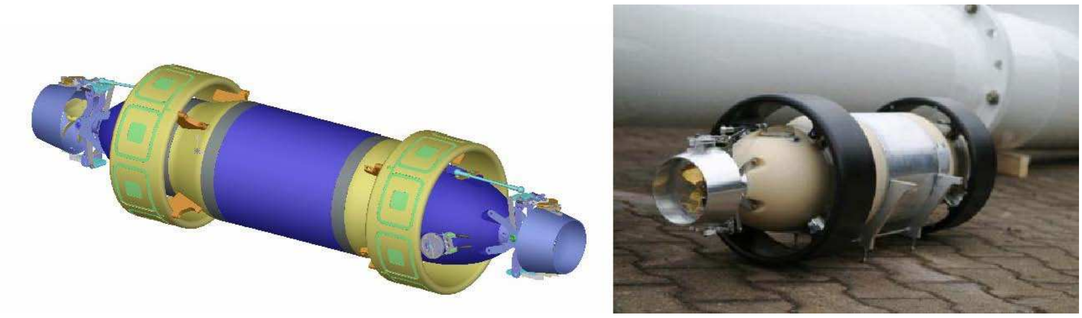

Figure 9. Ro*Float*: Free swimming leak detection tool

Ro*Float* helps to create knowledge and to gain experience within areas of

- autonomous acting vehicles
- usability of additional sensor systems
- combinations of sensor systems
- reactive inspection strategies and technologies

Amongst other electronic and sensor modules, the Robotic Control Module of Ro*Float* is the same as used in RTS and in Ro*Bot*.

Self Driven MFL – Tool

Based on the Magnetic Flux Leakage technique, this self driven tool was constructed to inspect the pipeline while rotating. This allows covering 100% circumference with just three sensor arrays. As a result the tool is lightweight while covering a diameter range of 36” to 40”

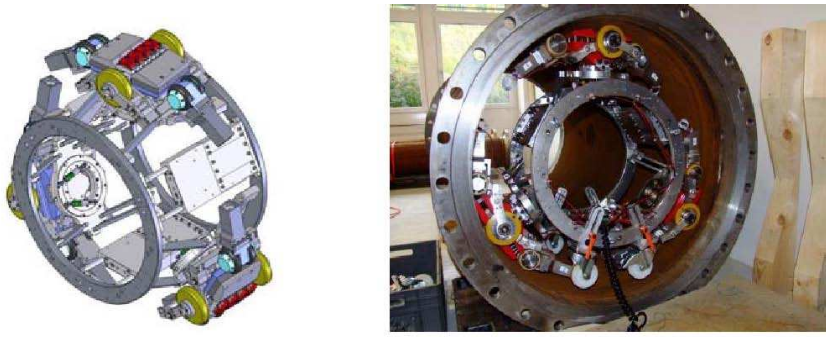

Figure 10. Self driven corrosion detection tool

Again robotic modules already used in RTS, Ro*Float* and Ro*Bot* are parts of this development.

CONCLUSION

This paper has presented the requirements on the techniques and methods, capable to inspect up to know un-inspectable pipelines.

The modular toolbox approach, extended by a Robotic Control component was shown to be a consistent solution. This modularity does justice to the complexity of the necessary R&D, as well as to the flexibility and usability of the final robotic system.

The ROSEN Robotic Inspection Tool (Ro*Bot*) combines high maneuverability and autonomy with the flexibility in bringing a large variation of NDT – techniques safely through the pipeline.

Spin-Off-Projects with similar techniques and methods have been developed, improved and are being tested. Two of them were briefly introduced. Once again the modular toolbox concept supports this process. Spin-Off-Projects minimize the technical risks in performing extensive R&D with robotic systems. Moreover they support desirable solutions by keeping the focus on the market.

Finally, considering the introduced technics, structures and prozesses established by ROSEN, the Robotic Toolbox approach can be identified as an natural, evolutionary step to enable regular inspection in up to now un-inspectable pipelines.