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ROBOTIC INSPECTION TECHNOLOGY – PROCESS AND TOOLBOX

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Abstract

Pipeline deterioration grows progressively with ultimate aging of pipeline systems (on-plot and cross country). This includes both, very localized corrosion as well as increasing failure probability due to fatigue cracking.

Limiting regular inspecting activities to the "scrapable" part of the pipelines only, will ultimately result into a pipeline system with questionable integrity. The confidence level in the integrity of these systems will drop below acceptance levels. Inspection of presently un-inspectable sections of the pipeline system becomes a must.

This paper provides information on ROSEN's progress on the "robotic inspection technology" project.

The robotic inspection concept developed by ROSEN is based on a modular toolbox principle. This is mandatory. A universal "all purpose" robot would not be reliable and efficient in resolving the postulated inspection task. A preparatory Quality Function Deployment (QFD) analysis is performed prior to the decision about the adequate robotic solution. This enhances the serviceability and efficiency of the provided technology.

The word "robotic" can be understood in its full meaning of Recognition - Strategy - Motion - Control. Cooperation of different individual systems with an established communication, e.g. utilizing Bluetooth technology, support the robustness of the ROSEN robotic inspection approach.

Beside the navigation strategy, the inspection strategy is also part of the QFD process. Multiple inspection technologies combined on a single carrier or distributed across interacting container must be selected with a clear vision of the particular goal.

1. Introduction

A large percentage of the pipeline networks around the world are routinely inspected using conventional and well established in-line technologies. However, there remains a large portion of the pipe network unable to be inspected using these classical techniques. This result was most likely due to cost considerations and the not as stringent regulatory environment of the past. As a result, there are only two ways to inspect pipelines which up to now are consider "un-inspectable": through modification on the pipeline or through existing inspection technologies. In most cases the first option has to be rejected by cost and operational reasons. So it is on ROSEN as a leading inspection company, to purse the second option.

Many older pipelines or flow and product lines were designed without consideration for ease of inline inspection. Figure 1 provides an overview about the main obstacles making it virtually impossible to inspect the system with regular tools. Even though it is very unlikely to find all of these restrictions in one pipeline, any combination of these can render a pipeline incapable of being inspected.

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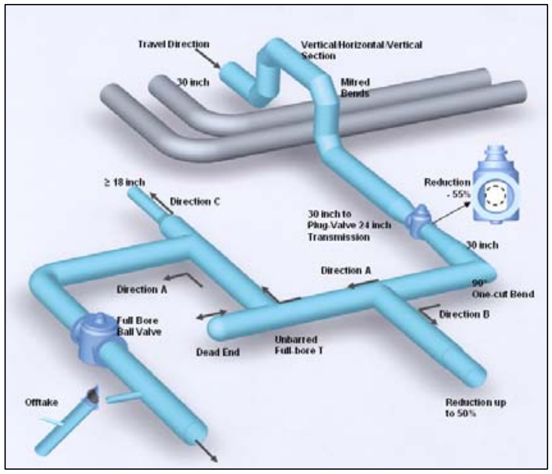

Figure 1. Overview of possible pipeline obstacles

Nevertheless the industry must face the challenge of building tools capable of passing as many of these types of obstacles as possible. Clearly a general solution is required to provide the same inline capabilities as traditional techniques minimizing the modification requirements necessary to complete the task. While thinking about the right solutions, it is very important not to loose out of sight the actual purpose: Putting the techniques of non destructive testing (NDT) into action in order to make reliable conclusions about the pipeline integrity while guaranteeing efficiency and highest level of safety. To be successful, fundamentally new, innovative developments, based on well-founded experience in regular inline inspection are needed.

2. The Robotic Toolbox Concept

ROSEN approaches these challenges by using decades of operational and technical experience to extend the existing modern inspection tool fleet with highly flexible and independent acting systems.

With the declared goal of secure and efficient adoption of NDT technologies in the pipeline area, even this additional flexibility will not end in an "all purpose tool". Therefore, ROSEN has established and developed modular technologies to meet these goals.

2.1 Modular Inspection Techniques

The existing ROSEN inspection technology is comprised up of 3 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).

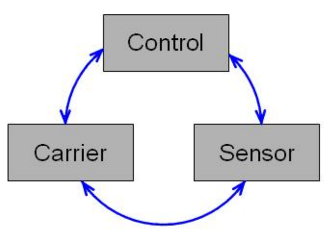

Figure 2: The Basic Modular Inspection Technology Concept

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:

I. Improved flexibility to adapt Tools with regard to inspection aims and individual pipeline requirements.

II. Improved reliability through the ease of use of component tests and well defined interfaces.

III. Highly focused and efficient Research & Development (R&D) process due to an optimized structuring of research fields as well as a simplified cooperations with R&D partners (Centre Suisse d'Electronique et de Microtechnique SA, *CSEM*; Frauehnhofer Institut 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. With the growing needs in functionality and complexity, there also arises an enormous demand for controlling as well as coordinating of the entire system.

2.2 The Extended Toolbox

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.

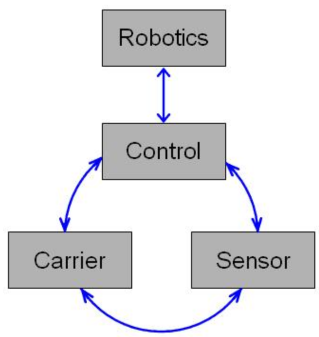

Figure 3: The Modular Robotic Inspection Concept

This toolbox concept enables a flexible, reliable and optimized framework capable of adapting to the individual pipeline environments and to the actual inspection targets.

Moreover the R&D process and resulting time schedules can be accelerated on account of reusing well tested and proven control module structures. 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 modularity 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.

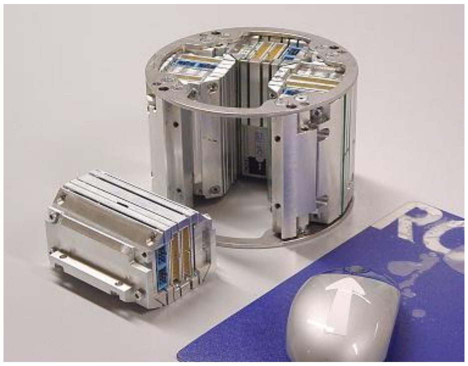

Figure 4. Modular components for data acquisition, recording and processing (ROSEN "SMART Boxes")

3. Requirements on the Robotic Inspection Technology

We introduced this paper with an overview of the challenges and obstacles present in many pipeline system that provide 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.

3.1 Carrier Requirements

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

3.2 Sensors Requirements

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

3.3 Robotic Control Requirements

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

4. 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).

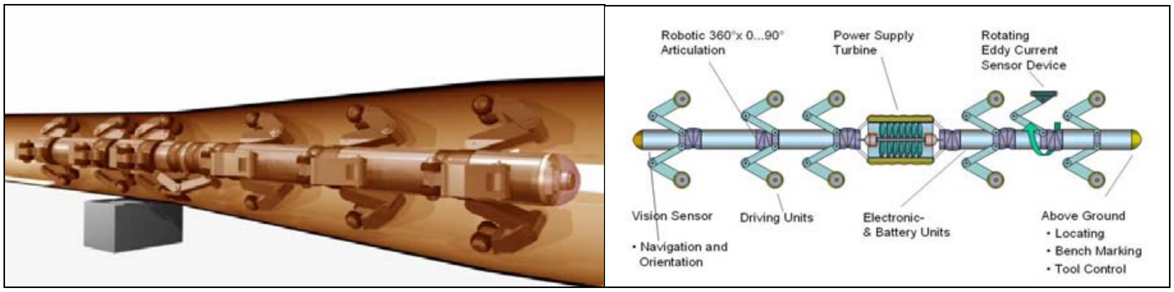

Figure 5: Final concept of the Robotic Inspection Tool

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.

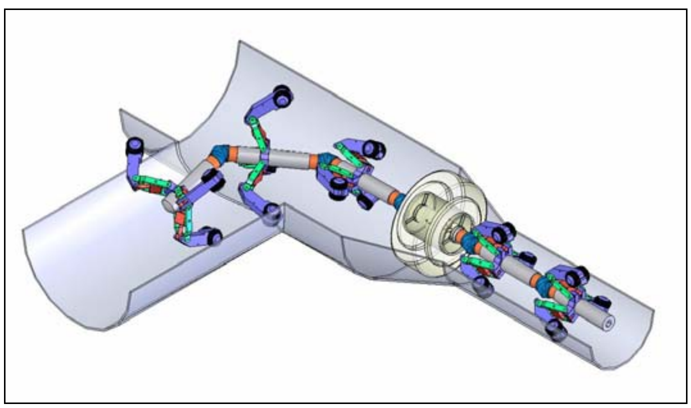

Figure 6. Ro*Bot* entering Off-Take. Shown is also the use of the Power-Generation-Module (expanded to maximize turbine driving flow)

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

4.1 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 Inertial Measurement Unit (IMU)
- On-Board Power generation
- Fail safe System

5. Intermediate Steps by Spin-Off-Projects

The “RoBot” project places great demands on Research and 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. Two of these are briefly introduced in the next subsections

5.1 Robotic Survey System (RSS)

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

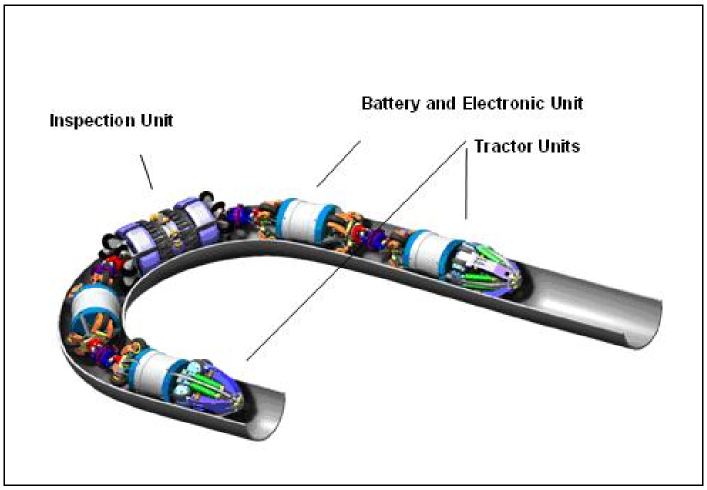

Figure 7. Robotic Survey System (RSS). Optimized for autonomous inspection of vertical venting pipelines.

The RSS (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).

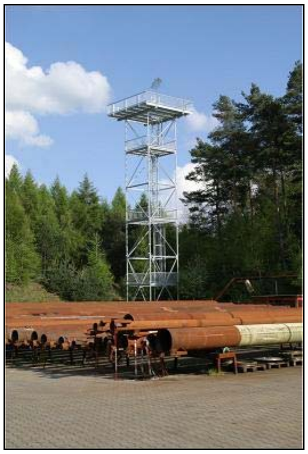

Figure 8: RSS test facility at ROSEN Technology and Research Centre (RTRC), Germany.

Features of the RSS are

- Autonomous self Propelled Robotic Survey 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 RSS are the same being used in the final Ro*Bot*. This approach allows ROSEN to develop necessary experience with robotic strategies.

5.2 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 ultra sound will be available.

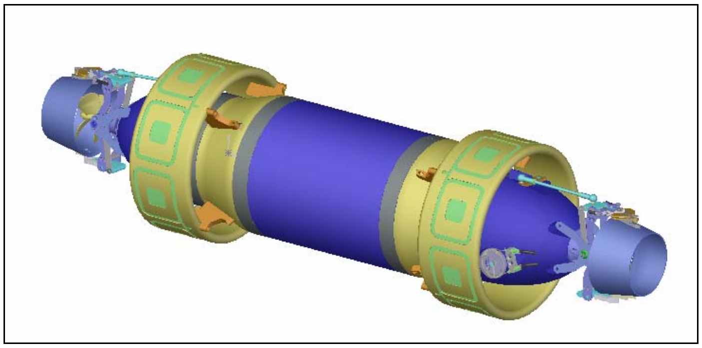

Figure 9. Ro*Float*: Free swimming leak detection tool

With regard to the final Robotic Inspection 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

The Robotic Control Module of Ro*Float* is the same as used in RSS and Ro*Bot*

6. Conclusion

This paper has presented the requirements on a tool, capable to inspect pipelines that are up to now not inspectable by traditional inspection technologies. It became obvious that these can be fulfilled only by the modular toolbox approach, extended with a Robotic Control component.

This modularity does justice to the complexity of the necessary R&D processes, as well as to the flexibility and usability of the final robotic system.

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

Needed techniques and methods are partly developed, improved and tested within Spin-Off-Projects. Two of them were briefly introduced. Once again our modular toolbox concept supports this process. These 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.