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Robotic Inspection Technology – Process and Toolbox

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ABSTRACT

Pipeline systems deteriorate progressively over time. Corrosion accelerates progressively and long term deterioration increases the probability of failure (fatigue cracking). Limiting regular inspecting activities to the "scrapable" part of the pipelines only, results ultimately into a pipeline system with questionable integrity. The confidence level in integrity 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 ROSEN robotic inspection concept is based on a modular toolbox principle. A variety of modules are available to be applied as needed. The tool box principle is proven to be more reliable and efficient for resolving specific inspection tasks then an universal "all purpose" robot. Quality Function Deployment (QFD) analysis has enhanced the choice for an efficiency technology for the robotic solution.

The word "robotic" means autonomous control and interaction of the features: Recognition - Strategy - Motion - Decision Ability - Memorize and Control. Application of the latest micro-electronics enables interactive application of the different individual systems with established communication systems, e.g. utilizing Bluetooth technology. ROSEN paid particular attention to the robustness of such autonomously operating units to fulfill the demanding reliability requirement. The QFD analysis concentrated both on appropriate strategies for navigation and inspection.

The initial goal is to offer a tool box type service that can be configured for any specific inspection requirement and just may be ultimately carry out maintenance tasks.

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 program
   This must be achieved economically, reliably and safely.

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

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.

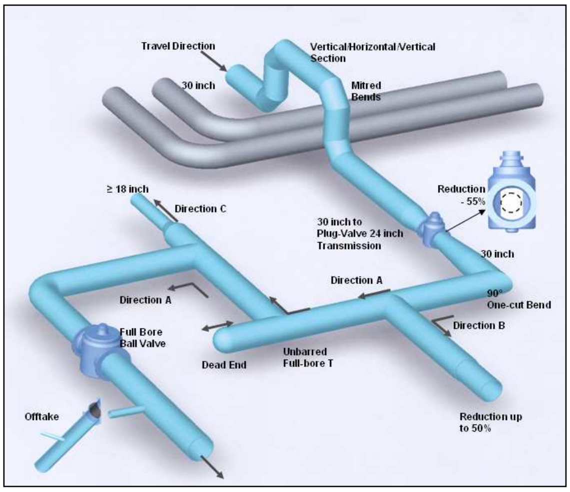

Figure 1. Typical piping configuration as design basis for the ROBOT

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 chosen inspection 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).

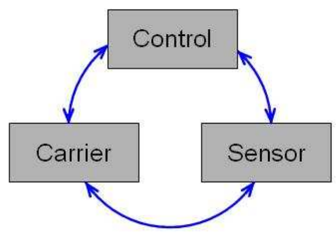

Figure 2: The Basic Modular Concept

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.

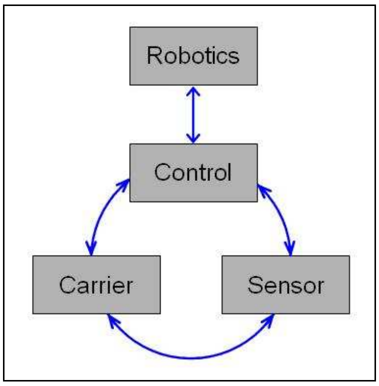

Figure 3: The Modular Robotic Inspection Concept

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

- 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, Vent-lines
- 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

Sensors Requirements

- Permanent Transmitter
    - Tracking the Robot
    - Communication
- Modular NDT – Sensory
    - Electro Magnetic Acoustic Transducer (EMAT)

- Ultrasonic (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

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

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).

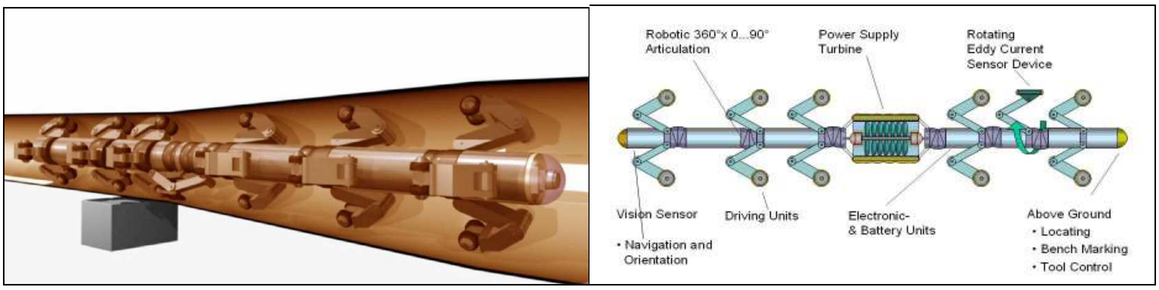

Figure 5: Final concept of the Robotic Inspection Tool

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”.

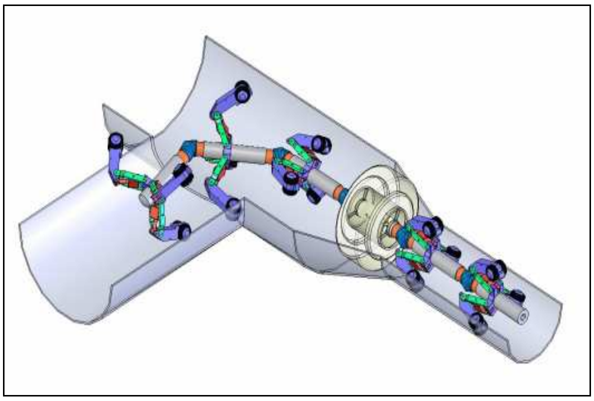

Figure 6. Ro*Bot* entering Off-Take. Shown is also the use of the Power-Generation-Module (expanded to maximize turbine driving flow)

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

REPORTING

The reporting of inspection findings is handled by ROSOFT, our software program.
It has been designed 17years ago and is still considered the most modern software package for integrating inspection data seamlessly into client's integrity management systems.

In spite of being considered modern, ROSEN has started a development program to renew ROSOFT. The improvements over the years have taken its toll on the flexibility of the operating system. A new operating system has now been chosen and after completing the estimated 25manyears investment in software engineering, a new "state of the art" software package will be available (in about 2years) linking easily accessible inspection information with program driving the Asset Integrity Management Systems.

Without going into too much detail, this will be vision for this software package:

THE SOFTWARE WILL ASSESS THE INSPECTION DATA INTELLIGENTLY
AND
WILL GUIDE THE USER TO AREAS OF REQUIRED ATTENTION.

This will be a huge step forwards from: "the software allows you zoom wherever you want to zoom into."

INTERMEDIATE STEPS BY SPIN-OFF-PROJECTS

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. Two of these are briefly introduced in the next subsections

Robotic Survey System (RSS)

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

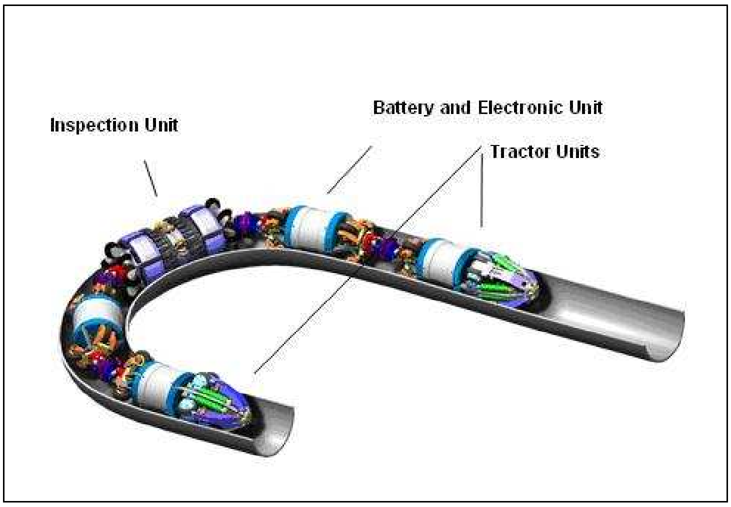

Figure 7. Robotic Survey System (RSS). Optimized for autonomous inspection of vertical venting pipelines.

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).

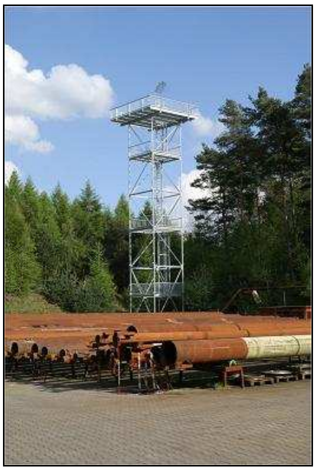

Figure 8: RSS test facility at ROSEN Technology and Research Centre (RTRC), Germany.

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.

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 be available.

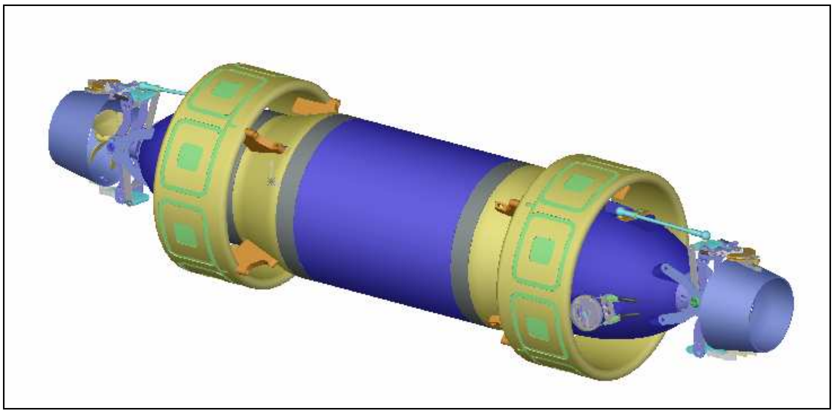

Figure 9. Ro*Float*: Free swimming leak detection tool

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

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

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 simular techniques and methods are partly 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 pipleines.