Practical Solutions for Unpiggable Pipelines – From In-Line Inspection to Robotic Applications

By: Wolfgang Krieg, Corporate Manager Marketing, ROSEN Group

Pipeline inspection with intelligent In-Line Inspection (ILI) tools have been established in the industry for decades. The quality and the value of ILI services for evaluating the integrity of pipelines are undisputed. Recent advances in the capabilities of these tools to negotiate variations in pipeline diameter have led to an optimism that eventually every pipeline can be inspected internally for mechanical damage, corrosion or cracking.

Low-flow or low-pressure situations in gas pipelines can be addressed with special low-friction and steady sealing units without the need for tethered or self-propelling actuation. Multi-diameter, telescoping pipelines or plug valves can also be addressed with current tools. The required expertise to develop and deploy these tools increase from conventional ILI technology towards bi-directional, tethered, low-flow /low-pressure, or complex multi-diameter tools.

Still, many pipelines cannot be inspected, even with these enhanced technologies. Single-point access pipelines, laterals, or empty pipelines are examples. Most of these so-called unpiggable pipelines have never been cleaned before which is also a challenge for internal inspection. These pipelines must be inspected from a self-propelled motion platform. ROSEN has developed a modular Robotic Survey System (RSS) which can be adapted and equipped with the required inspection technology. The system is targeted for pipeline sizes from 8" to 20". Another system, the RoHelix tool, has been developed for the inspection of large diameter pipelines greater than 36". The tool can be launched in a conventional manner or assembled inside the pipeline when a manhole is the only access point. Both tools carry various MFL inspection sensors. The latest developments in Eddy Current (EC) and Electro-Magnetic Acoustic Transducer (EMAT) technology can both be configured to be sensitive not only to cracking but also to corrosion and mechanical damage. This will eliminate the adverse friction effect associated with Magnetic Flux Leakage (MFL) method.

The paper will describe the operational specifications for each family of the inspection devices currently provided by ROSEN to meet the requirements of challenging pipelines as well as the anticipated specifications for the RSS and the RoHelix inspection system. Currently a field test program is under way, and findings from this program will be presented.

1. Introduction

Pipelines are proven to be the safest way to transport and distribute gases and liquids. Regular inspection is required to maintain that reputation. Today, a large part of the pipeline systems can be inspected with "standard" In-Line Inspection (ILI) tools. Since first use in the early 1960's, the ILI tools have been significantly developed and improved. Challenges of the early days of pipeline inspection, such as high speed in gas lines, tight 1.5D bends, dual-diameter, heavy wall thickness, high pressure and -temperature, multi-diameter, long distances, etc., have been resolved and modern ILI tools are able to cope with these challenges.

But to date, a large portion of the pipelines are classified as unpiggable. This is for several reasons:

1. No access, meaning launcher and receiver are missing
2. Installation, such as plug valves, 90° miter bends, dead ends, off-takes, etc. (picture 1)
3. Low- or none flow
4. Cleanliness of the pipe

The developments described in this paper are based on a "step by step type" method. ROSEN uses this method successfully by providing the industry with innovative technologies over the last 30 years.

The industry looks for means to inspect these in-accessible pressure holding piping systems, vernacular also call unpiggable pipelines. The inspection of these lines should be done preferably without interruption of 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. For several reasons, the preferred metal loss inspection technology is therefore Magnetic Flux Leakage (MFL).

In many cases unpiggable situations have been resolved over time which is summarized in picture 2, the "Unpiggable Timeline".

2. Closing the Gap – ILI Solutions for "Unpiggable Pipelines

As mentioned above, reasons why pipelines are classified as unpiggable are numerous; however, it can be concluded that the "Singing-and-Dancing" solution for unpiggable pipelines is not a single tool, but rather a project by project driven tailored solution.

2.1 Low-Flow / Low-Pressure Tools

One possible solution is a tool for low-flow / low-pressure gas pipelines. The graph in picture 3 shows the required differential pressure versa the pipe diameter.

As shown in picture 3, MFL ILI tools with a diameter of ≥ 24" need a line pressure of 30 bar (435 PSI) to inspect a gas pipeline without major issues. Small diameter MFL tools need even higher pressure, for example the minimum pressure for the inspection of a 8" line is 25 bar (363 PSI).

But what about the inspection of lines with lower pressure? Special MFL tools have been developed to overcome this challenge; the so called Low-Flow / Low-Pressure (LFLP) tools. The goal of this development was to optimize the friction of the whole tool to a minimum and keep the performance specification at the standard level. The pressure required to propel a LFLP tool should be a 1/3 of a standard MFL tool.

Getting the tools from the launcher to the receiver is not the main challenge in low-flow / low-pressure lines. The speed excursions which normally occur during the inspection runs in low-flow / low-pressure lines are usually caused by obstacles, such as excessive girth welds, bends, dents, diameter changes, etc. The tool stops at this obstacle, as the pressure (force) is not high enough to move the tool over it. After a certain time, the pressure behind the tool builds up and forces the tool over the obstacle. In some cases, tool speeds of over 30 m/s (67 mph) are reached, whereas most MFL ILI tools have a maximum speed specification of 5 m/s (11 mph). Furthermore, after the tool starts to move again, the head pressure in front of the tool is low, therefore, the tool slows down significantly or comes to another stand still. This kind of speed excursion impacts the performance specification of the ILI service, in many cases, the data quality is not acceptable and data analysis is impossible.

A key for low-friction is the optimization of the magnetizer. Magnetization through an air-gap and yokes with front- and rear wheels showed the best performance during computer simulation. A prototype magnetizer confirmed the results in pull-test. A 3D drawing of a 12" magnetizer unit is shown in picture 4.

The second task was the optimization of the friction from the cups. Computer-simulations and pull-tests showed that the best performance can be achieved with sealing cups in the front of the tool and with special wheel supported ? on the rest of the tool. picture 5 shows a 12" LPLF tool with the final setup.

The LFLP tools have been successfully deployed around the globe, providing solutions for applications before classified as “unpiggable”.

2.2 Multi-Diameter Tools

Another challenge for pipeline in-line inspection are multi-diameter pipelines. Most of these pipelines are classified as unpiggable due to unavailability of suitable technologies.

Most of the multi-diameter pipelines have not been designed as such, but over decades operators decided to connect two or more pipelines of different diameters to fulfill their system requirements. Also, conscious decisions have been made to build multi-diameter pipelines. One example is the Asgrad offshore pipeline in Norway. The initial design was a single 42" diameter pipeline. However, due to the water depth of over 200 meters, a 42" ball valve, which was required for the launching facility, was not available off the shelve. The development of such a valve would have cost in excess of 100 million US$ and would have added extra risk to the project. Therefore, they decided to use an existing offshore ball valve. The biggest one they could find was 28". As a result, the Asgard pipeline now starts in 28", which runs for a few hundred meters, and transitions into 42" in diameter.

As no ILI technology for the Asgard pipeline was available, the operator decided to have one built; a 28" to 42" multi-diameter MFL tool.

This was in the early 90th and since then a number of multi-diameter inspection tools, mainly for geometry and metal loss inspection, has become available. Key challenge for such tools is a special low-friction and steady sealing unit which can cover the specified diameter range. Picture 6 shows such a sealing unit.

Over the past 10 years several multi-diameter tools have been developed, built and successfully deployed in a multitude of projects. Picture 7 shows a typical multi-diameter MFL tool and picture 8 shows a list of available multi-diameter high-resolution geometry and MFL metal loss tools.

The multi-diameter tools have also applications in single diameter unpiggable pipelines. Pipelines with plug valves can be easily inspected with these tools, provide the same or even higher performance specification than single diameter high-resolution geometry or MFL metal loss ILI tools.

2.3 Bi-Directional Tools

Another application for ILI tools is the inspection of pipelines which have only access from one end. Loading lines normally go from the onshore facility, such as a tank farm, to an offshore buoy or to a pipeline end manifold. These lines are usually inspected from the onshore location. The tool is pumped towards the buoy or pipeline end manifold. A few feet before it reaches the installation the flow is stopped and afterwards the flow is reversed. This will bring the tool back to the onshore launcher.

For this kind of applications special Bi-Directional (BiDi) ILI tools have been developed, covering geometry and MFL metal loss inspection services (see picture 9). No need for expensive tethered self-propelled tools.

Some of the world's +4.8 million pipeline kilometers (+3 million pipeline miles) contain rather strange fittings. One of them is ball valves which have the option to launch a cleaning tool. Picture 10 shows such a valve.

This kind of ball valve offers a cost-efficient solution for regular pipeline cleaning. The cleaning tools are launched into the valve, while? the valve is closed and the door can be opened. After the door is closed, the valve is open and the tool is launched with the flow. The next downstream ball valve has the same functionality and is used as a receiver. At one end of the ball valve, a steel mesh is installed to stop the tool. The ball of the valve can be rotated by 360°, hence it can be used as launcher and receiver.

If only one valve is installed, the cleaning is normally done with a BiDi cleaning tool. The tool is launched as described above. Once the end of the pipeline has been reached the flow is reverted and the tool is pumped back to the ball valve.

In the past, these ball valves have been used for cleaning only. With the new small and short BiDis, these lines can now be inspected with ILI tools. MFL metal loss and geometry inspection services are available. Picture 11 shows the new 10" BiDi tool.

3. Robotic Tools

Since modifying unpiggable pipeline systems for in-line inspection is often not practical and costly, ROSEN has started the development of self-propelled inspection tools for unpiggable pipeline systems. Self-propelled ILI tools are available, however, mostly as tethered applications. Tethered inspections are usually limited in inspection length and number of bends which can be passed. Therefore, a different approach has been taken.

The robotic tool has to fulfill the following basic functions:

- Entering into the piping system without permanent traps
- Finding its way around the piping system
- Inspecting the entire piping system
- Collecting inspection data from every square inch of the pressure holding pipe wall with the chosen inspection technology
- Coming back out

In view of the variety of piping system configurations as well as the variety of different possible corrosion processes, a versatile system has to be chosen. That versatile system is based on modular components from which a tool can be put together as required for specific job.

In order to fulfill the basic requirements of entering into the piping system, finding its way around autonomously and acquiring inspection data, a highly sophisticated robotic tool is mandatory.

This robotic tool comprises of three integrated yet independently encapsulated modules responsible for sensor, 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 (picture 12).

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 that there are three main advantages in putting this simple and basic concept persistent into action:

- Improved flexibility to adapt tools with regard to inspection aims and individual pipeline requirements
- Improved reliability through the ease of use of component tests and well defined interfaces
- Highly focused and efficient Research & Development (R&D) process due to an optimized structuring of research fields

With the stated requirement of inspecting traditionally “unpiggable” pipelines, 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.

A brief overview of the challenges and obstacles that are 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 resulting in 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
  - Allows 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
- Entering 90° off-takes
- Capability for expressive NDT to > 50% of nominal ID
  - Includes multi-diameter pipelines
  - Support lines, foff-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 Testing (UT), Laser
  - Visual Inspection
  - 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 optional 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 RSS (picture 13) 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" to 12" was tested. For this purpose a 25 meter (82 feet) high test facility was built up (picture 14). After the successful testing of the 10/12" robotic prototype the following robotic systems have been developed, tested and successfully deployed.

3.1 RoHelix- Metal Loss Self-Propelled Inspection Tool

The RoHelix is based on MFL. The RoHelix uses transverse technology to induce a magnetic field perpendicular to the pipeline longitudinal axis. The RoHelix tool detects and sizes narrow longitudinal flaws such as notches, crack like features, gouging and channeling corrosion (see picture 15).

Longitudinal pipe magnetization has difficulties detecting narrow longitudinal features. With the transverse magnetization of the RoHelix tool, narrow longitudinal defects can now be clearly detected and accurately measured.

Key technology advantages:

- Based on reliable and proven high-resolution MFL technology
- Full circumferential coverage with high detection accuracy and only 3 yokes due to rotation of the yokes
- Self-propelled tractor and sensor unit in one body
- Single entry to the pipeline
- Capable of safely negotiating 1.5D bends
- Bi-directional
- Autonomic (only batteries) or tethered (external cable with communication) operation possible
- Reliable in various media (water, gas, crude oil and dual-phase products)

3.2 Robotic Survey System (RSS) – Generation 2

The autonomous self-propelled RSS can be equipped with for example a high-resolution UT inspection unit (see picture 16). The modular design permits the easy adaptation of alternative inspection carriers for corrosion defects, mechanical defects, manufacturing defects, welding defects and crack defects.

The RSS is being specially designed for inspecting challenging pipelines. It can carrier different measurement systems and is capable of driving vertical and passing 1.5D back to back. Most significantly it is able to operate within a pipeline requiring no medium to drive it.

Key technology advantages

- High reduction passing
- Tight bend passing capacity
- Multi-diameter capacity
- Extremely high driving force enables vertical climb
- Self-adapting tractor drive and sensor unit in one body
- Intelligent and redundant on-board mission control
- Single entry to the pipeline
- Capable of safely negotiating 1.5D bends
- Bi-directional
- Autonomic (only batteries) or tethered (external cable with communication) operation possible
- Reliable in various media (water, gas, crude oil and dual-phase products)
- Stand alone sensor carriers (Shallow Internal Corrosion, UT, EMAT, etc.)

3.3 Robotic Pipe Scanner (RPS)

ROSEN's RPS is a reliable and effective tool for managing the integrity of above-ground pipes such as product lines, flow lines, firewater lines and other pipes in which traditional in-line inspection cannot be performed. Unique magnet and sensor designs ensure high sensitivity and accuracy. The unit is designed to bypass pipe support structures and other installations (see picture 17).

The RPS is based on MFL, a well-established, robust inspection technology with a proven record of sensitivity and accuracy. ROSEN's unique embodiment of the technology ensures the best possible results in every performance category.

Key technology advantages

- Accurate, robust and reliable
- Rapid and efficient inspection speed
- Real time data analysis and reporting
- 360° coverage, internal/non-internal discrimination
- High magnetic levels ensure accurate feature classification, accuracy and sensitivity
- Tool design ensures ease of operation and flexibility
- Tool can negotiate pipe supports and other installations

4. Conclusion

This paper has presented the requirements on the techniques and methods capable to inspect unpiggable pipelines.

Further developments of existing ILI technologies have closed the gap between piggable and unpiggable pipelines.

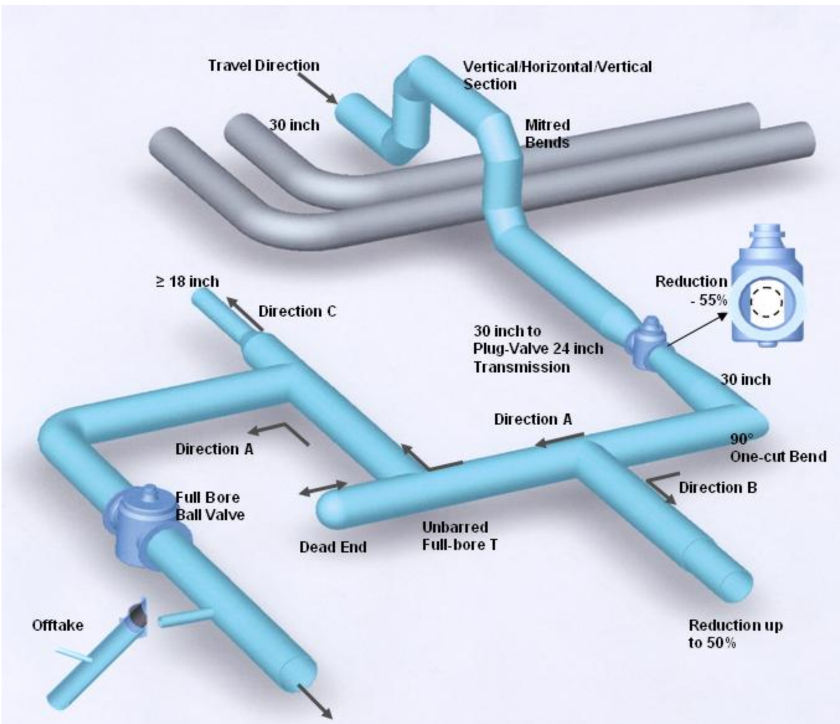
The ROSEN Robotic Inspection tools combine high maneuverability and autonomy with the flexibility in bringing a large variation of NDT techniques safely through the pipeline.

Spin-off projects with similar techniques and methods are partly developed, improved and being tested.

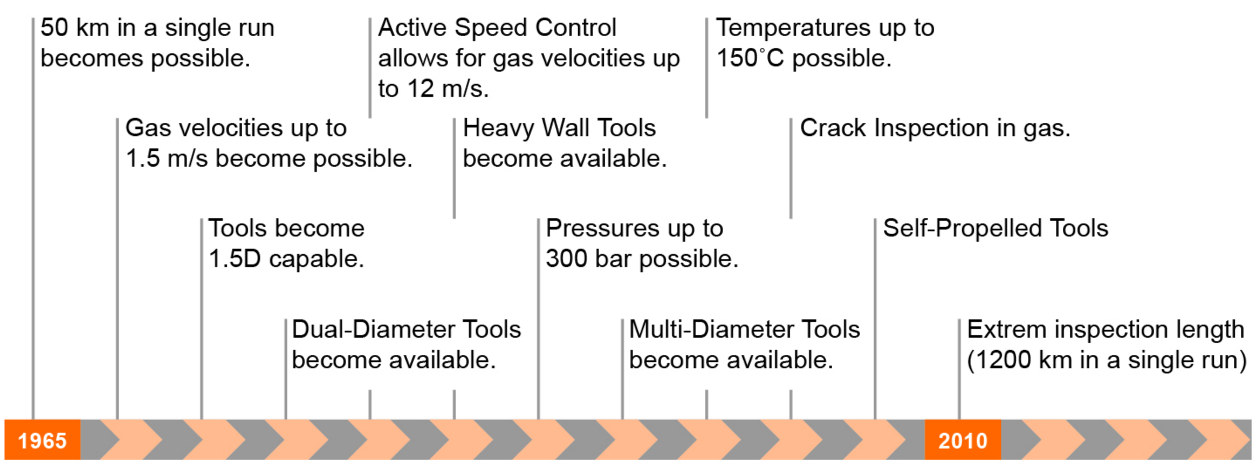
Finally, considering the introduced techniques, structures and processes established by ROSEN, the robotic modular approach can be identified as a natural, evolutionary step to enable regular inspection in up to now unpiggable pipelines.

5. Pictures

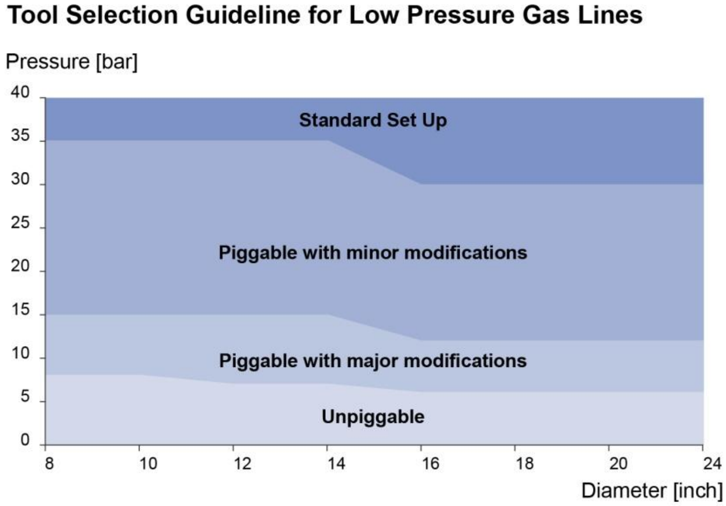
The following pages contain the pictures referred to in the text.



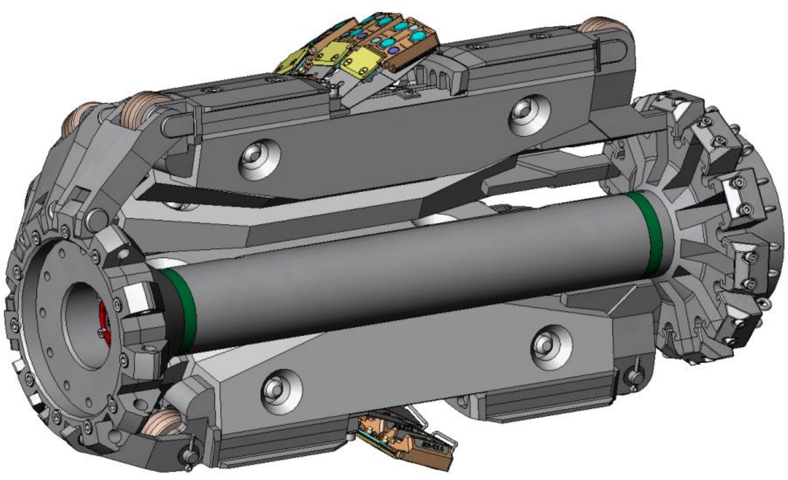
Picture 1: Unpiggable installations



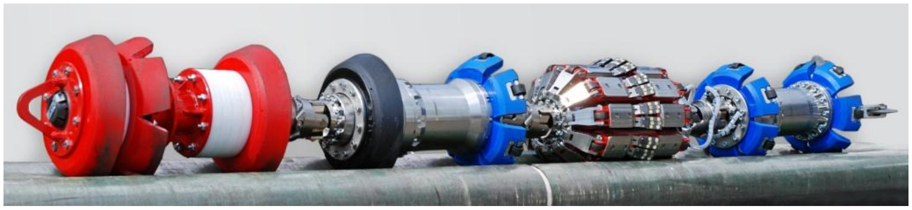
Picture 2: Unpiggable timeline



Picture 3: ROSEN ILI MFL tool selection guideline



Picture 4: 12" LFLP magnetizer unit



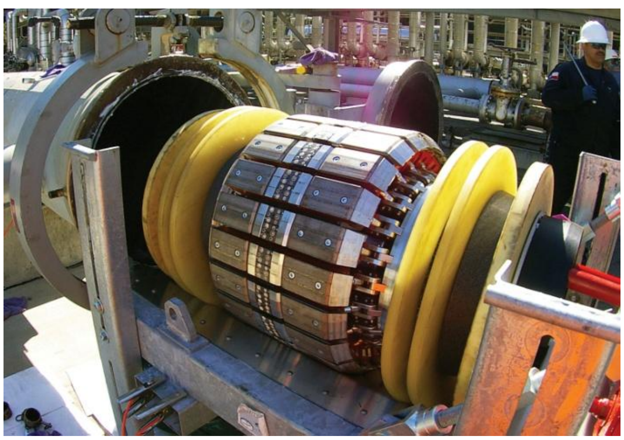
Picture 5: 12" LFLP MFL tool

Picture 6: Multi-diameter sealing unit

Picture 7: 32-42" multi-diameter MFL tool with speed control

ILI Tools				
Class	ID-Min [in]	ID-Max [in]	Passage Ratio	Min Bend
12/18"	10.7	18.0	60%	1.5
14/18"	11.3	18.0	63%	1.5
14/20"	11.8	19.9	59%	1.5
18/24"	15.4	24.0	64%	1.5
24/28"	21.8	27.6	79%	5
26/30"	22.1	29.8	74%	1.5
30/36"	26.3	35.8	73%	1.5
32/42"	27.2	42.0	65%	1.5

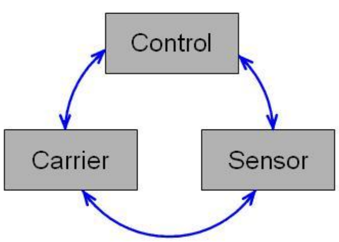
Picture 8: Available multi-diameter high-resolution geometry- and MFL metal loss ILI tools



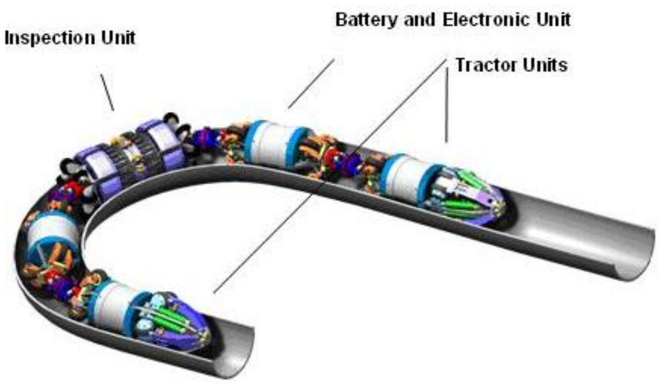
Picture 9: 24" BiDi ILI tool

Picture 10: Ball valve with cleaning tool launcher / receiver

Picture 11: 10" MFL metal loss BiDi tool



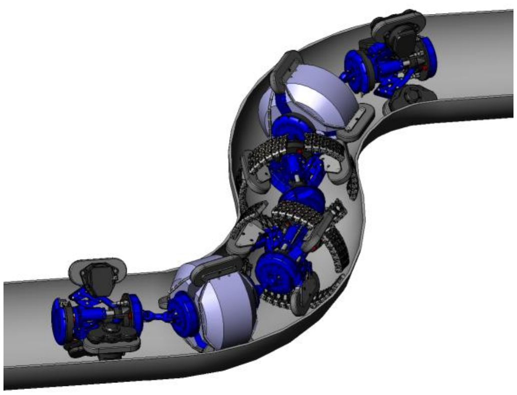
Picture 12: The basic modular concept

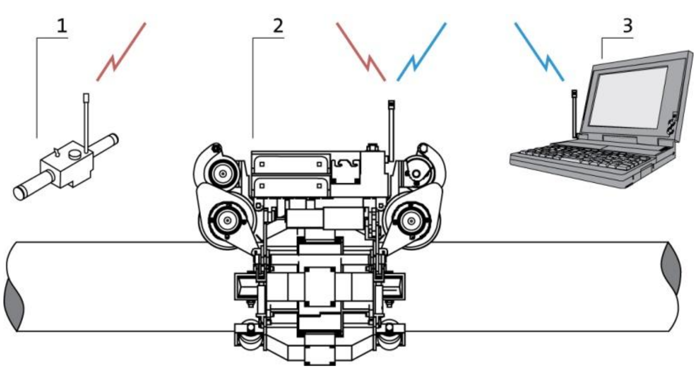


Picture 13: RSS – self-propelled metal loss inspection tool

Picture 14: RSS test facility


Picture 15: RoHelix –self-propelled metal loss inspection tool


Picture 16: RSS Generation 2



Picture 17: On-site performance equipment
1 Remote control panel for manual operation and data evaluation
2 Self-propelled inspection tool installed on the pipeline
3 Visualization notebook