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ORMEN LANGE PIPELINE INSPECTION – A CLIMB TO SUCCESS

Ryan Fenwick, ROSEN, Newcastle Upon Tyne, UK

Andy Studman, Shell International, Aberdeen, UK

Dave Cockfield, Pipeline Innovations, Newcastle Upon Tyne, UK

Abstract

This paper presents a case study of a complex inline inspection (ILI) activity with multiple significant challenges that required innovative solutions to achieve an outcome of a safe and successful activity within required schedule and budget.

The Ormen Lange gas field, operated by A/S Norske Shell, is located in the southern part of the Norwegian continental shelf approximately 120km north-west of the Nyhamna gas and gas condensate processing plant in Gossa Island, Norway. The water depth in the field area ranges from 800m to 1,100m.

The development, which has been in operation since 2007, consists of 20 wells with 4 subsea templates connected to a 30-inch 240 km production pipeline in a looped configuration to enable round trip pigging using processed gas from Nyhamna.

The processed gas from Nyhamna is exported via the 42-inch/44-inch 1,166km Langeled pipeline, to the Easington gas terminal in the United Kingdom. The condensate is stored in underground caverns and offloaded to tanker vessels.

Ongoing risk-based integrity assessment determined that ILI by intelligent pig was required in 2023 to determine if the corrosion control systems in place were working as intended and determine the actual integrity status of the pipeline.

Challenges included:

- Significant deferment associated with shutting in production to conduct pigging operations requiring an approach of flawless planning and execution.
- Multiple key stakeholders involved, including external licence partners, who all required to satisfy themselves that the activity was being properly planned and executed.
- Uncertainty over the potential volume of solids present in the pipeline system, meaning the design of a progressive cleaning pigging programme initially had to cater for both the low end (10Te) and high end (210Te) estimates, before this uncertainty could be reduced.
- Large elevation profile change (1100m) during pig transit to and from the subsea templates and Nyhamna terminal with associated liquid hold up with potential for process upsets due to mobilising large liquid slug volumes during pigging operations.

Given the above challenges, an approach whereby the pipeline operator, plant operator, pipeline service contractors and stakeholders worked together in a highly collaborative, transparent and structured manner was key to a safe and successful outcome.

The campaign consisted of:

- A significant pre-execution planning phase covering all aspects of shutdown, restart, preparation for pigging, procedure generation, equipment preparation, debris and flow modelling, pig selection, risk assessment and contingency planning.
- A high velocity flush of the pipeline using dry gas to displace liquids from the pipeline system.
- Upfront deployment of Pipeline Innovations' Pathfinder foam bodied caliper pig to confirm piggability of the pipeline and give key information on location and amount of solids accumulated in the system separately to the main ILI campaign.

- A cautious and iterative progressive pigging programme which included the use of the ROSEN active cleaning tool which utilised a combination of high differential pressure and Venturi effect to emit a high velocity jet of product in and around and in front of the pig.
- Detailed and comprehensive flow assurance modelling for Mono-Ethylene Glycol (MEG) dosage, liquid buildup in between runs, and prediction of pig velocity were applied to all runs.

This paper describes the step-by-step approach which resulted in a close to flawless cleaning, bore proving and ILI of the Ormen Lange pipeline system completed in October 2023.

Introduction

Pipeline Operation:

A/S Norske Shell operates two subsea pipelines, each 30-inch diameter and 120 km in length, located off the west coast of Norway. These pipelines transport a mixture of natural gas and gas liquids from the Ormen Lange subsea field to the Nyhamna onshore processing facility. From Nyhamna, the processed gas is transported through the 42-inch/44-inch 1,166km Langeled pipeline to the United Kingdom.

Figure 1: Ormen Lange & Langeled Pipelines

Pigging System: Each pipeline is equipped with launcher/receiver stations, to conduct round trip pigging operations via a subsea pigging loop equipped with a subsea pigging valve. The system can be configured for bi-directional pigging operations. Dry export gas is used as the pigging medium supplied from the Nyhamna plant. Pigging operations requires subsea production to be shut in.

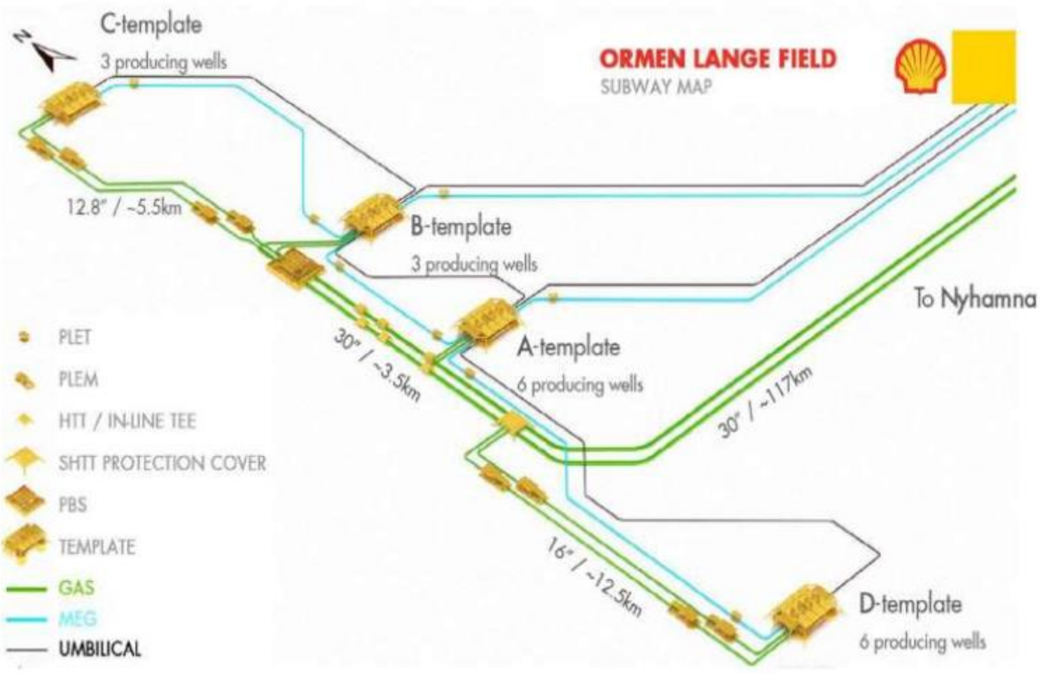

Figure 2: Ormen Lange Field Layout

Pigging Frequency and Historical Inspection:
Operational pigging of the pipeline system for flow assurance and internal corrosion control reasons is typically not required as these are managed by other barriers however periodic ILI by intelligent pig is required undertaken primarily to detect and size any metal loss features that could be present as a result of the internal and external corrosion control barriers being not fully effective. The pipelines were last subjected to ILI during the commissioning phase in 2007.

Sand Fines and Debris Accumulation:
Sand fines produced from the subsea wells had been observed in the slug catchers (Pipeline A and pipeline B) during routine cleaning operations. Inspection of the debris from both slug catchers revealed approximately 10-14 tonnes of material, comprising 90% reservoir fines and 10% ferrous corrosion products.

Uncertainty in Fines Transport Mechanism:
There was significant uncertainty regarding the transport mechanism of sand fines within the pipelines due to variations in pipeline profile and gravitational effects. Initial process design experiments suggested that fines would be transported by liquids within the pipeline. However, subsequent modelling predicted that up to 105 tonnes of sand deposits could have accumulated in each pipeline, resulting in a potential high case total accumulation of up to 210 tonnes across both pipelines. This volume if present and not well mitigated presented a high risk of creating a total blockage during pigging operations resulting in a high adverse consequence of a lengthy unplanned pipeline outage. This was considered by Ormen Lange stakeholders as an unacceptable outcome.

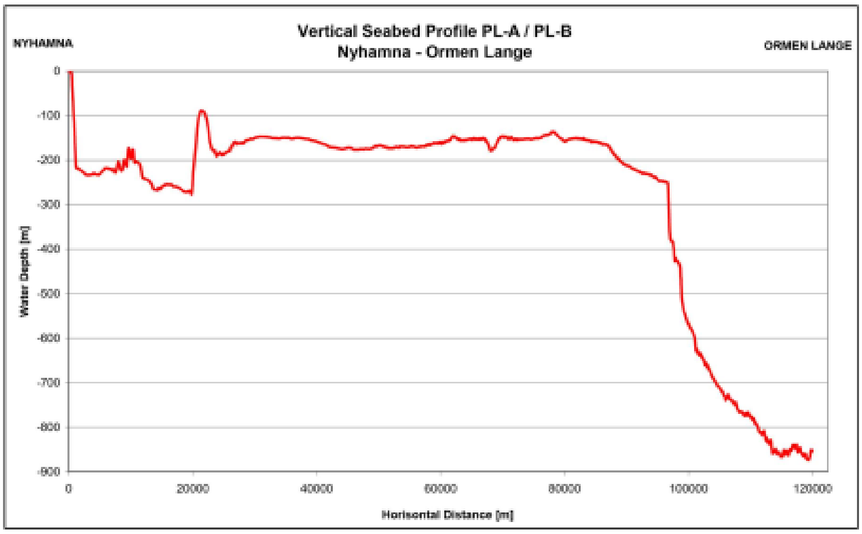

Figure 3: Vertical Seabed Profile Ormen Lange Pipeline

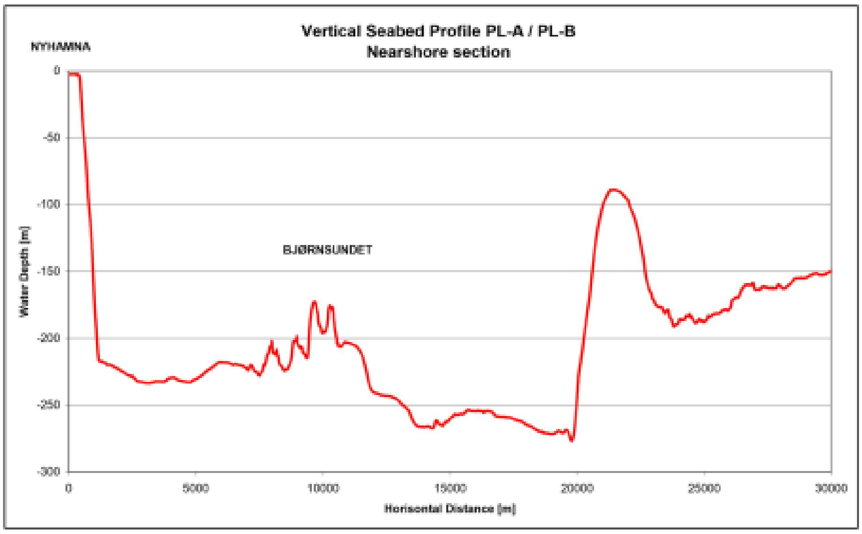

Figure 4: Vertical Seabed Profile Nearshore Section

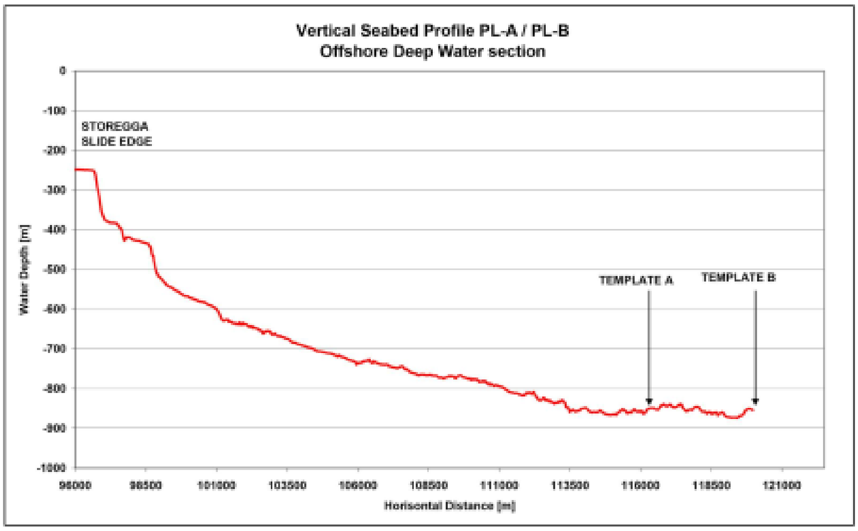

Figure 5: Vertical Seabed Profile Offshore Deepwater Section

Pipeline Wall Thickness and Operational Control:

The two 30- inch pipelines have a constant internal diameter (ID), but the wall thickness varies along the subsea sections, ranging from 29.5 mm to 35.5 mm nominally. Since production is shut-in during inspection campaigns, and pigging is undertaken with export gas, flow rates are fully controllable throughout the operation.

Shell Norske Requirements for Inspection:

The client, A/S Norske Shell, requested ILI of both pipelines using a combination of Magnetic Flux Leakage with Axial magnetisation direction (MFL-A) and Internal Eddy Current (IEC) technologies. The following key objectives were specified:

- Safety: Zero, incidents, accidents or near misses during both planning and execution phases.
- Environmental Protection: No adverse environmental impact arising from pigging operations.
- Cost and schedule: Execution of the campaign with minimal production deferment to minimise operational and loss of production costs.
- Quality: Data acquisition to meet Pipeline Operator's Forum (POF) Specifications and requirements for in-line inspection of pipelines, POF 100, November 2021.

To operationalise these objectives the execution team developed and applied a number of key mindsets including "Apply rigorous project management", "Set ourselves up for flawless execution" and "Run as many pigs as required, but not one more than that" and "Contingency planning is essential".

General Approach

At the outset, it was recognised the project would be highly challenging due to a combination of factors that included shutting in production to conduct pigging operations, significant pipeline elevation profile that could present a risk of pig velocity excursions, potential presence of large volumes of solids, presence of liquids, and uncertainties on operability of pigging facilities such as pig traps and valves given around 16 years had elapsed since the last pigging campaign. These challenges required a structured and rigorous project management approach to identify the relevant risks and put in place suitable plans to mitigate risks to the required level of As Low As Reasonably Practicable (ALARP). Several workshops were conducted between A/S Norske Shell, ROSEN, and Prism Energy, resulting in the development of the following general approach:

- Dynamic High-Velocity Flushing: Use of high-velocity flushing to ensure effective removal of debris and fines prior to inspection.
- Debris Quantification: Implementation of procedures to quantify the volume and composition of debris removed during pigging operations.
- Bypass Design on Pigs: Integration of bypass mechanisms on the pigs to enhance cleaning efficiency and facilitate progressive pigging.
- Run Modelling: Development of detailed operational models to predict pigging performance, flow dynamics, and debris transport mechanisms.
- Contingency Procedures: Establishment of contingency plans to address potential operational challenges, including pig tracking, retrieval, and mitigation of any unforeseen issues during the campaign.

The approach was designed to ensure safe, efficient execution of the pigging campaign while minimising deferment and achieving A/S Norske Shell's inspection requirements.

High Velocity Flush

The pipeline system was configured to utilise dry gas for high-velocity flushing. This setup aimed to mobilise and then transport as much liquids and solid debris as possible from the pipeline prior to pigging. Reducing the liquid content of the pipelines was required to prevent flooding the slug catchers during the first pig run. Whilst the intent of the high-velocity flow was to mobilise and transport liquid and fines it was not feasible to accurately quantify the amount of solid debris transported out of the pipeline system as the slug catchers were only equipped to measure liquid returns.

Debris Quantification

To address concerns regarding debris accumulation and the potential risk of pigging issues, a comprehensive approach was adopted to better understand and manage debris in the pipeline. The initial methods and subsequent steps were as follows:

1. **Initial Method - Sound Wave Analysis**:
   The first method employed involved using “Pressure Pulse” sound wave technology to introduce a negative pressure wave into the pipeline system and then measure the time taken and the changes in amplitude in the reflected return pressure wave signal to qualitatively estimate the thickness and approximate location of any debris. This technique proved inconclusive on this application due to practical difficulties introducing a sound wave, the long pipeline length and presence of multiphase fluids which limited the accuracy of solid qualification. These results, whilst not useful, were also not unexpected and deemed still worth trying as relatively low effort.

2. **Second Method - Debris Mapping with Pathfinder Foam Caliper Tool:**
   A further method was undertaken using the Pathfinder foam-bodied caliper tool from Pipeline Innovations Limited. Constructed from medium density foam the Pathfinder is a soft bodied tool for measuring pipeline geometry, internal diameter, detecting and measuring dents, ovality, debris mapping and assessment. By design it is able to negotiate reductions in diameter of up to 40% providing a relatively low-risk solution for pipeline proving especially where previous pigging history is limited or there are known concerns with piggability. It was selected for its minimal aggressiveness and the option to run it undersized, 98% of the nominal pipeline ID, to enhance operational safety and assure pipeline piggability. The Pathfinder incorporated a fixed forward bypass to create a low volume high velocity flushing effect to prevent debris accumulation in front of the tool and mitigate any potential for pipeline

blockage. To aid with tracking, the pigs were manufactured with embedded permanent magnet packs in the nose cone and provision for electromagnet transmitters was included.

Figure 6: 98% Foam Pig Post run

Initial Foam Pig Run:
A dummy Pathfinder foam pig, sized at 676 mm (98% of the pipeline ID of 690 mm), was run first to prove piggability. The dummy Pathfinder is identical in construction to the operational Pathfinder but is run without the embedded sensor system and electronic data pack being installed. Upon receipt, the condition was reviewed and assessed. This provided assurance to confirm or otherwise safe passage of the operational Pathfinder.

The undersized dummy Pathfinder was run at an average velocity of 4.4 m/s, though the velocity increased with pressure drop across the pipeline. The pig body sustained minor superficial damage, leading to the decision to proceed with the Pathfinder pig.

Pathfinder Foam Pig Run:

The full-size operational Pathfinder, with an outer diameter (OD) of 717 mm, was launched and received with a run time of 27 hours and 20 minutes and an average velocity of 2.44 m/s. The pig was equipped with 12 bypass holes (50 mm each), to mitigate any potential for debris build up in front of the pig. The pig was received in good condition with no damage and minimal wear. Data acquisition was 100% and of excellent quality.

Figure 7: Pathfinder post-run

Results and Analysis:

Analysis of the data collected from the operational Pathfinder run confirmed the minimum internal diameter in accordance with pipeline end termination (PLET) connector drawings. Data indicated approximately 56m³ of debris was present between 50 km and 123 km, predominantly in Pipeline A. It was considered that 56m³ was a worst-case scenario due to envisaged potential for Pathfinder to bulldoze a proportion of debris for a period before riding over it which effectively would then measure this proportion as new (additional) debris. No credit was taken for this potential effect as it could not be confirmed or quantified.

Based on these findings, a recommendation was made to reverse the pig run direction for the campaign from A to B to B to A, thereby minimising the distance of transportation of debris and preventing transfer of the higher amounts of debris present in Pipeline A into Pipeline B.

Cleaning Pig Program Design

Following an extensive engineering review, the cleaning campaign was developed with the following components and procedures:

Pig receiver configuration:

- To take account of potential for large volumes of solids that could present a risk of pigs not fully entering the pig receiver and practical difficulties removing pigs it was decided to route returns from pigging through the pig tap bypass line direct to the slug catcher and then "squeezing in" the pig once it was detected to have arrived at the barred tee. This has the advantage of assisting reliable pig receipt and minimise delays retrieving pigs and the disadvantage that solids would not be present in the receiver as input to decision making.

Initial Cleaning Phase:

- Bi-Directional Gauge Pig: The campaign commenced with a bi-directional gauge pig designed to be reversed at low differential pressure (DP) if necessary. This feature allows for pipeline flow reversal in the event of a blockage, thereby reinstating production. A ROSEN Pipeline Data Logger (PDL) was attached to monitor significant DP buildup. The purpose of the PDL, equipped with accelerometers and gyros, was to assist in correlating tool location and identifying debris accumulation based upon data collected throughout the campaign.
- Bypass and Magnet Packs: Bypass mechanisms, similar to those used in Phase 1 with foam pigs, were incorporated to enhance debris flushing in front of the pig. Magnet packs were doubled to improve the removal of corrosion products. Undersized full guides were selected to reduce the risk of excessive wear.

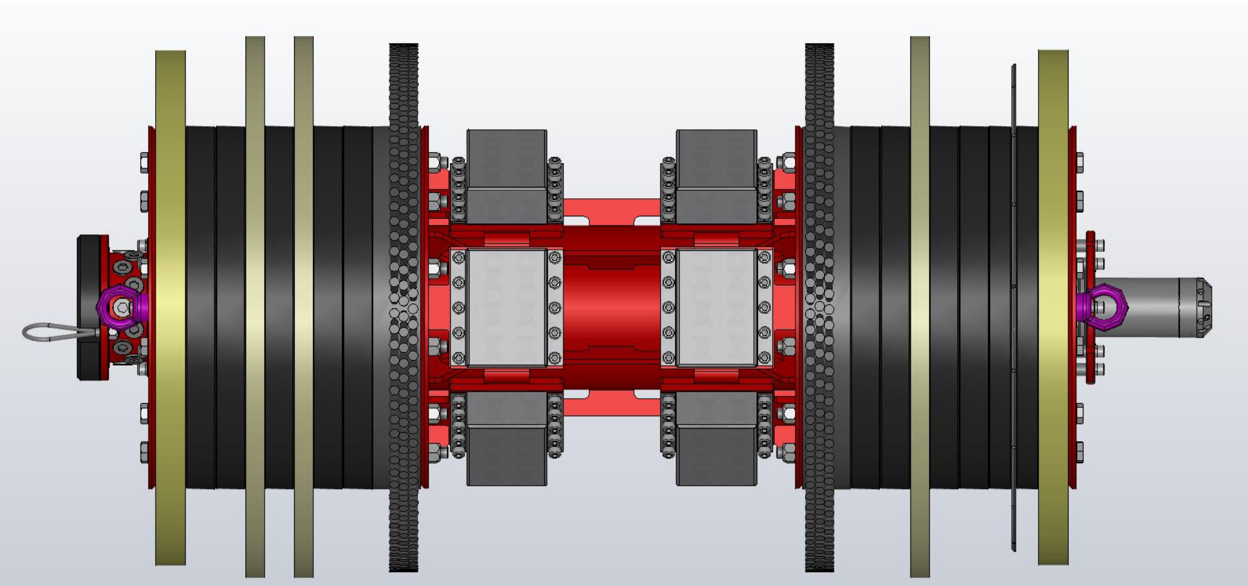

Figure 8: Gauge Pig

Medium Aggression Cleaning:

- Brush - Mag Cleaning Pig and Bulldozer Pig: The purpose of medium aggression cleaning pigs was to clean the pipeline effectively to a level where it would be considered sufficiently safe to proceed to running more aggressive pigs. Oversized discs were provided in order to offer higher aggression options. 4.2% bypass was installed on the pigs to maintain a high flushing effect. Data from the PDL was utilised for comparisons between cleaning runs, specifically for evidence of debris accumulations, which would present as DP spikes and potentially stop / start behaviour.

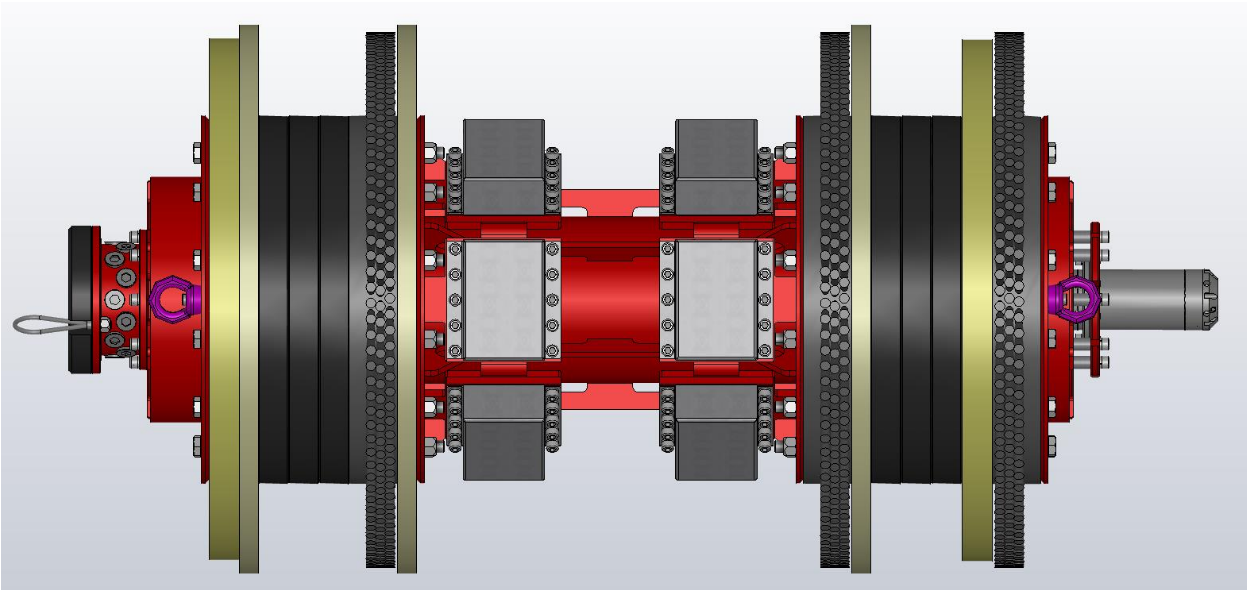

Figure 9: Brush - Mag Cleaning Pig

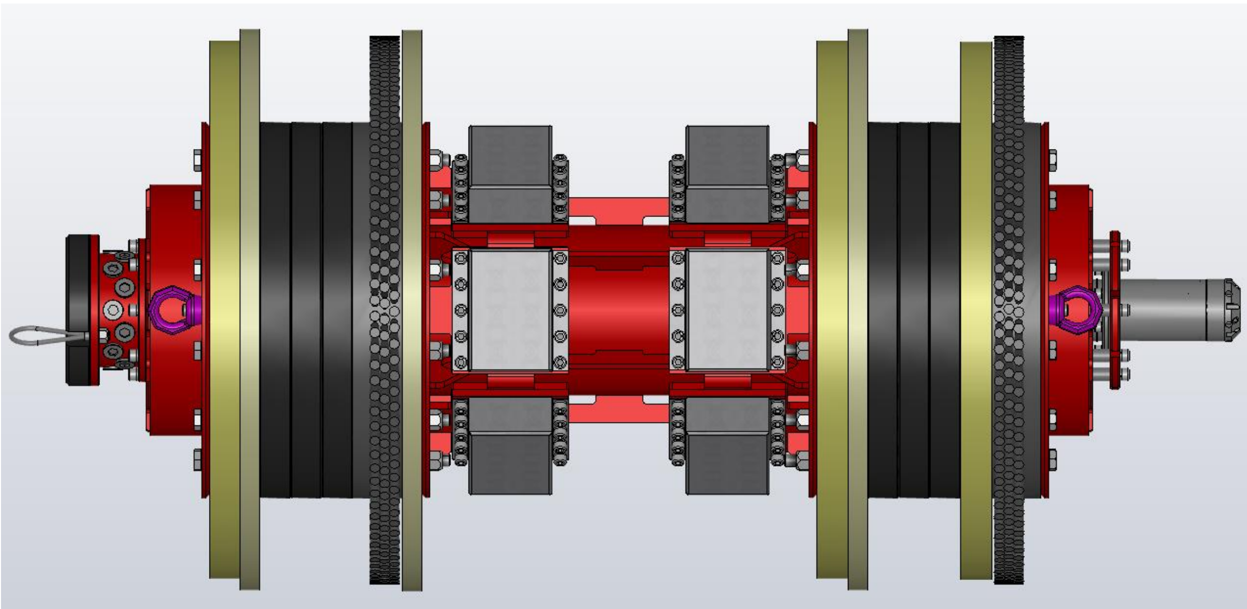

Figure 10: Bulldozer Pig

High Aggression Cleaning:

- Heavy Duty Cleaning Pig (HDCP): The HDCP features a dual-module setup with descaling cups and magnets to ensure thorough removal of corrosion scale and debris. This setup is aimed at achieving the highest quality data for subsequent inspection.

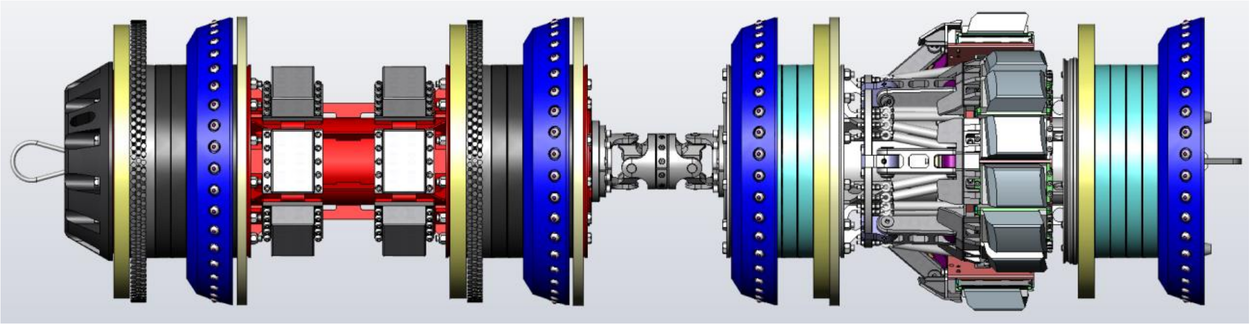

Figure 11: HDCP

- Active Cleaning Tool (ACT): The ACT [1] utilised a bypass path to create a suction effect, enhancing its ability to transport fine solids from the pipe wall. This pig generates a high-velocity jet from the front, assisted by brushes and cups, to prevent sand accumulation. This technology, although established in the industry, was utilised for the first time in a Shell pipeline.

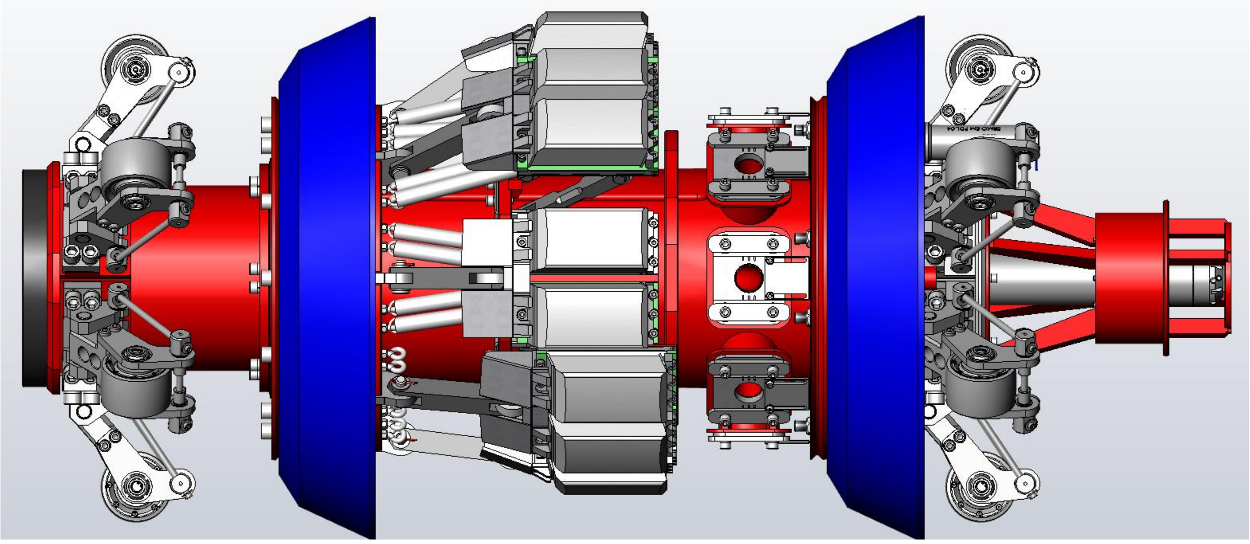

Figure 12: ACT

Decision-Making Support:

- A decision-making flowchart was created to guide the campaign's operational decisions, the chart demonstrated the data driven approach which would inform the decision-making process. This structured approach was designed to ensure thorough cleaning and inspection of the pipelines, optimising performance and data quality while minimising operational risks.

AS Norske

Execution

Gauge Pig Operation Summary - September 17th

The gauge pig was successfully launched with the following operational parameters:

- Flowrate: 17 MSM^3/D
- Pressure: 83 bar

Operational Details:

- The gauge pig was successfully received after a run time of 18 hours and 57 minutes. As described earlier flow was directed through the mainline tee to avoid potential clogging of the receiver with excessive solids, preventing the receiver from being isolated.
- The pig was then squeezed into the receiver and removed.

Condition and Observations:

- The gauge pig was assessed to be in good condition with minimal wear and limited debris accumulation.
- Due to contamination and potential of Health, Safety, and Environmental (HSE) risks to personnel, the receiver required flushing. This contamination made precise debris quantification challenging and increased reliance on pig behaviour data recorded by the Pipeline Data Logger (PDL) for assessing debris levels.

Figure 13: Gauge Pig Post-run

PDL Data Analysis and Decision

The PDL data from the first gauge pig run did not reveal any significant DP spikes that could not be accounted for by known pipeline features. Based on this analysis, the decision was made to continue with the cleaning program as planned.

Figure 14: PDL Recorded Differential Pressure

Subsequent Cleaning Runs

Following the gauge pig run, the brush-mag cleaning pig and the bulldozer pig runs were successfully completed. Both runs were completed without any damage to the pigs or evidence of excessive DP according to the PDL data. These results indicate successful execution of the cleaning operations to date. As such a decision to progress the cleaning campaign onto the higher aggression pigs was taken.

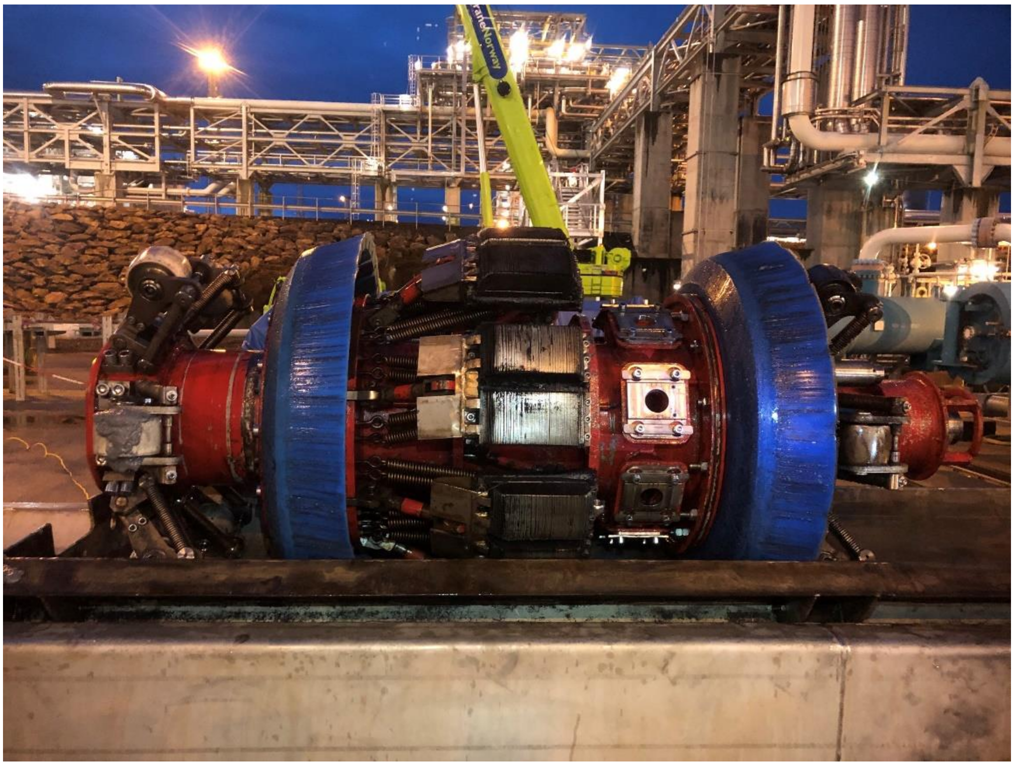

Figure 15: Run 4 ACT Post Run

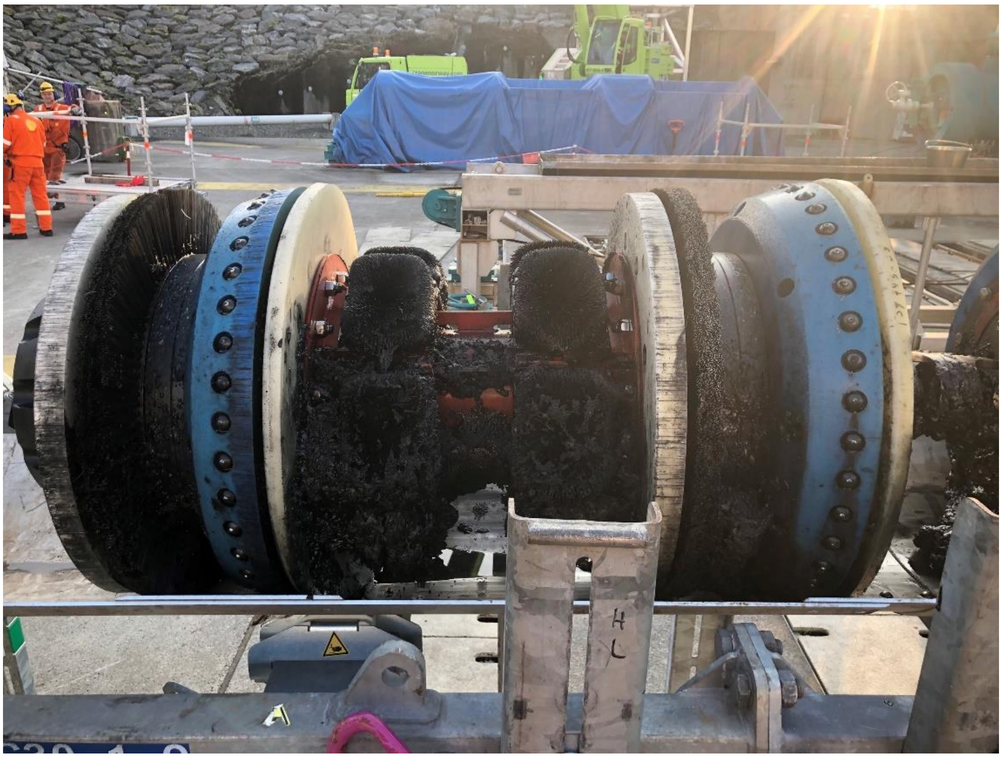

Figure 16: Run 5 HDCP Front Module Post-run

Figure 17: Run 5 HDCP Rear Module Post-run

Due to an observed increase in ferrous debris collected on the magnets, repeat runs of the ACT and the HDCP were requested. This additional cleaning as deemed necessary to address the higher levels of ferrous debris and ensure optimal pipeline condition and inspection accuracy.

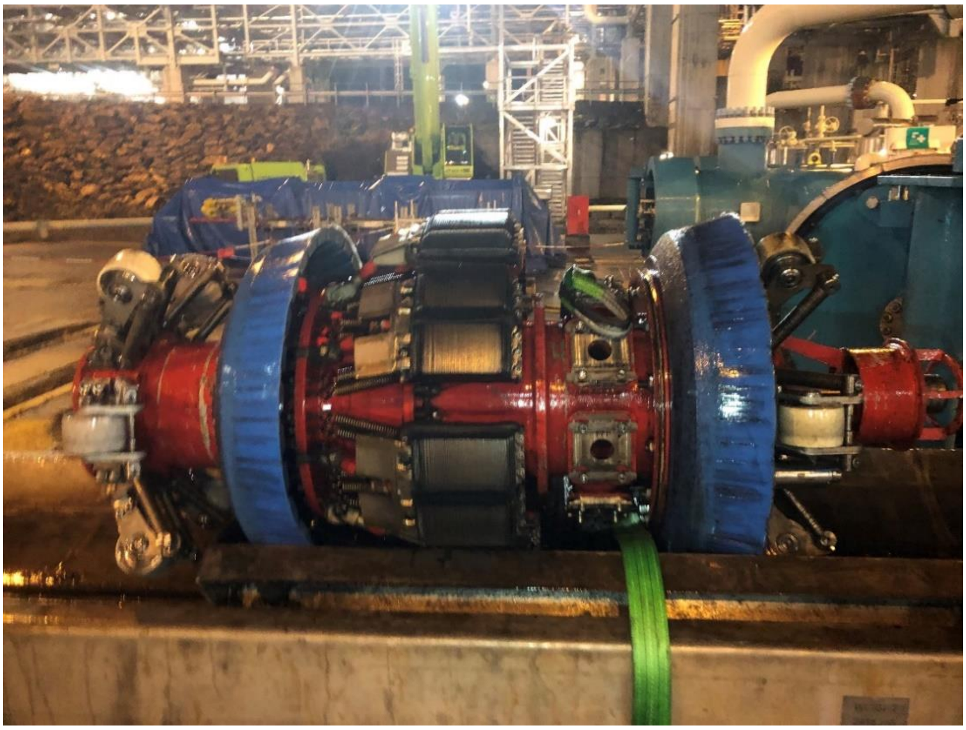

Figure 18: Run 6 ACT

Figure 19: Run 7 HDCP

Decision to Proceed with MFL A + IEC Inspection

Following a decrease in the amount of ferrous debris recovered the decision was made to proceed with the MFL A + IEC inspection. This decision was based on the improved condition of the pipeline and the reduction in debris, indicating readiness for the next phase of inspection.

MFL+ IEC Inspection Execution

On October 1, 2023, the ROSEN RoCombo MFL-A + IEC) ILI tool was successfully run through the pipeline. The results from the ILI run were utilised to determine the integrity of the pipeline following the completion of the cleaning campaign.

The evaluation of data from the ILI enabled A/S Norske Shell to verify that the primary threat of internal corrosion was being well managed. The data subsequently enabled Shell to update the integrity assessment of the pipeline, (taking account of other relevant data as well such as ongoing subsea external inspection campaigns, testing of the safeguarding systems etc) and concluding it was suitable for safe continued operation.

In addition the ILI results provided A/S Norske Shell and stakeholders confidence to proceed with future field development plans, including a subsea compression project.

Demonstrating degradation mechanisms such as corrosion was being well managed was therefore a key factor to extend the service life of the pipeline and support future further investment decision making.

Figure 20: MFL-A / IEC Inspection Tool

Keys to Project Success

Summary of Pigging Activities and Project Execution

The successful execution of the pipeline inspection project was influenced by several key factors and activities, as detailed from the pigging vendor's perspective:

Project Planning

- **Norske Shell Project Governance:** Despite technically being a large maintenance scope, project governance was discussed at kick off and it was decided to appoint a Decision Executive (DE), Business Opportunity Manager (BOM) and Project Manager. Assurance reviews were conducted prior to each gate, which ensured the project received the correct focus for the associated risk.
- **Stakeholder Management:** Stakeholder management was key to success of this project, and in particular regular & transparent engagement with the licence partners. The partners were kept regularly informed of progress and risk management throughout the project life cycle and invited to participate in key workshops.
- **Pre-Inspection Preparation:** The pipeline inspection had been anticipated for some time, with complexities introduced by significant quantities of sand combined with “Ormen Lange Black Stuff” (OLBS) found in the slug catchers. These factors increased challenges to the cleaning campaign.
- **Debris Characterisation**: AS Norske Shell conducted studies to understand the characteristics of the debris - its type, quantity, and potential likely location. This baseline assessment was crucial input for assessing and then addressing the debris challenge.
- **Vendor Selection and Contracting**: ROSEN was selected to assist AS Norske Shell with the pipeline inspection, leveraging their expertise, project execution capabilities, and advanced pigging technology. Contracting was streamlined by appointing a single vendor responsible for both cleaning and inspection. Use of sub-contract services and complimentary technologies such as Pathfinder Innovations Ltd which informed the proceeding pigging campaign.
- **Collaborative Workshops:** Initial collaboration included a pigging workshop with representatives from project management, engineering, flow assurance, and site execution. The workshop facilitated the development of a pigging program outline and emphasized the need for data-driven decision-making.
- **Ongoing Coordination**: Weekly meetings between key Shell and ROSEN personnel were held to address challenges, develop the pigging sequence, and manage risks. Stakeholder management was key, culminating in a “pigging on paper” exercise at the Nyhamna site, which enabled common understanding of roles, procedures, sequencing and contingency plans, paving the way for flawless field execution.

Data-Driven Decision Making

- **Initial Campaign Steps:** The campaign began with opening the subsea pigging valve followed by a system flush to transport liquids and potentially some solids out of the pipeline system. Next step was running an undersized dummy Pathfinder foam pig run for pipeline proving. The subsequent operational Pathfinder foam bodied caliper tool provided crucial data on pipeline bore and anticipated debris volumes, supporting the prediction of presence of debris.
- **Flow Assurance Optimization:** ROSEN’s flow assurance engineers collaborated with Shell flow assurance and pipeline engineers to define optimal operating conditions for each cleaning and inspection tool. This included the setup of bypass mechanisms to prevent debris buildup and ensure efficient pig tracking. Additionally, a dynamic pipeline model was run using real-time data (e.g. pressures and flow rates) to track the pig location during pigging.

- **Pipeline Data Loggers (PDL):** Solid-bodied cleaning tools were equipped with PDLs to detect anomalies such as pig stops or high differential pressures, which could indicate blockages or process upsets.
- **ILI Tool Inspection:** The ultimate goal was to perform an inspection using the ROSEN ILI tool to acquire data in line with the stated specification and therefore suitable for assessing the integrity of the pipeline system. Flow assurance was integral to optimizing the operating conditions and bypass settings for the ILI run. Following data collection, ROSEN's evaluation team worked with Shell’s integrity team to confirm the quality and acceptance of the inspection data.

In summary, the project’s end success is considered to have been underpinned by an approach of meticulous planning, effective collaboration, data-driven decision-making, all contributing to a successful pipeline inspection and cleaning campaign. Contingency planning, (including stuck and stalled pig scenarios) although not required to be utilised, also contributed to stakeholder confidence and support that the activity could proceed.

Key Observations

Project Preparation and Execution:

Comprehensive project preparation contributed to a flawless execution by all parties involved, ensuring smooth operations throughout.

Conservatism vs. Efficiency:

The project successfully balanced conservatism with efficiency, maintaining a safe cleaning program capable of identifying significant debris without introducing excessive conservatism that could adversely affect the project schedule.

Risk Management:

The implementation of bypass mechanisms and high flow rates effectively mitigated potential risks associated with debris accumulation and pipeline blockage.

Risk Assessment and Mitigation:

Stuck Pig workshops and Hazard Identification (HAZID) sessions were crucial in identifying potential issues. These proactive measures allowed for effective engineering solutions or mitigations to be put in place.

Team Collaboration:

Open and honest communication among all stakeholders—client, contractor, and team members was pivotal in resolving conflicts early and ensuring the successful outcome of the project.

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Ormen Lange Partners:

ORMEN LANGE PARTNERS: Shell, petoro, equinor, ORLEN UPSTREAM NORWAY, vår energi
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Rosen: Christopher Woodley, Charles Ofosu, Gareth Smith, Ashwin Pinto

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[1] A NEW CLEANING APPROACH FOR BLACK POWDER REMOVAL. By, Dr Hubert Lindner, ROSEN Technology & Research Center, Lingen (Ems), Germany. 2006.