



TECHNICAL PAPER

“Multi-diameter Pigging in Challenging Applications”

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Introduction

FTL Technology conceived, designed and developed the patented VariPig in 1998 working closely with Statoil on project Åsgard.

In the intervening years FTL Technology has been involved in many projects where VariPig has been deployed in multi-diameter pipeline systems. Early projects were concerned with Ready for Operation (RFO), which then developed into; camera vehicle, progressive cleaning, gauging, bi-directional dewatering, decommissioning and carrier vehicles for UT inspection technology.

The VariPig system is well proven and the time from project concept to actual deployment is short, when compared to a specially designed pig. VariPig has become almost the ‘pig of choice’ in large diameter differential multi-diameter pipelines.

This paper outlines some of the most challenging applications that FTL Technology have encountered, details the functionality of VariPig and how the multi-diameter technology has developed since its initial conception and use on the Åsgard project.

Section one - VariPig Overview

Background

FTL Technology developed the patented multi-diameter VariPig unit in response to a design study, which called for a pigging system that could successfully negotiate a large diameter change in a long distance subsea gas transmission pipeline [1].

The Åsgard project comprised of a 42" transport pipeline from the processing terminal near Kårstø, Norway connected to a 28" subsea export riser base. In total the pigging distance was 710km [2].

During pre-commissioning and commissioning of the Åsgard pipeline, the VariPig was operated from large to small diameter, i.e. 42" to 28". The operation required the VariPig assemblies to flood, clean and gauge prior to hydro-test and then de-watering.

In a normal operational task a pre-loaded cassette would be lowered to the seabed for pigging from the 28" subsea manifold to the 42" onshore platform at Kårstø, the reverse of the RFO tasks.

Figure 1, shows the 42" x 28" VariPig after a successful dewatering operation. The VariPig had to be capable of maintaining pigging functions in both 42" and 28" pipelines.

An initial design study identified the following system requirements:

- Near centreline running in all diameters
- Low running friction
- Differential drive pressure to be kept as low as possible
- Ability to accommodate auxiliary components such as magnet packs, gauging plates, and electronic packages



Figure 1 – Åsgard 42" X 28 VariPig

Multi-diameter pipelines

Subsea pipelines with large diameter changes are becoming more common in today's environment. Often new lines are tied in to existing infrastructure, creating pigging challenges and requirements for multi-diameter capable systems.

Design Considerations

Standard guided pigs typically use polyurethane guide discs to support the pig. Due to the wear associated with this design, the polyurethane seal discs are usually required to be a large percentage oversized to compensate for guide disc wear over the length of the pigging run.

The oversized seal discs can have an adverse effect on pig performance, and can require a high drive pressure to push the pig through the smaller sized pipeline of a dual diameter system due to the increased volume of material, which results in high friction between the seal disc and internal pipeline wall.

Typically a standard guided pig is only capable of small percentage diameter changes. Figure 2, indicates that anything above a 10% diameter increase would require careful analysis of whether a standard guided pig configuration was suitable. Depending on the nominal diameter of the smaller pipe, it is possible that anything above a 20% change in diameter would require a wheeled pigging unit to have the best chance of successful completion [3].

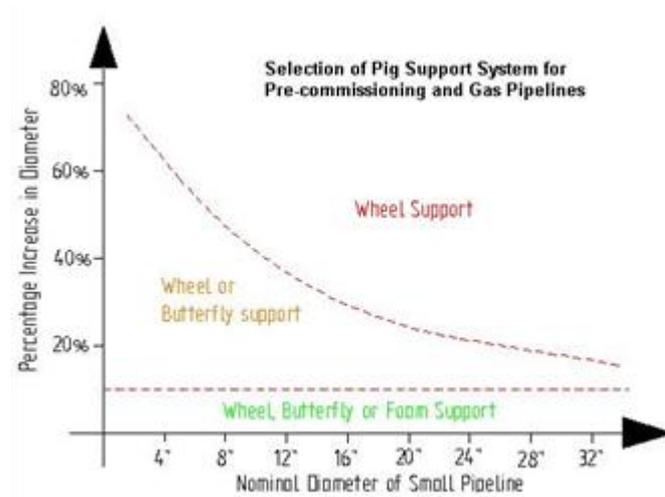


Figure 2 – Pig Selection Criteria

As an alternative to conventional guided pigs, an independent suspension system is able to hold the pig in a controlled position and reduce the amount of percentage oversize of the seal disc. However, the potential wheel loading due to the vehicle weight means it is difficult to achieve centreline running and typically it is only possible to be within 6% - 10% of the pipe centreline. This results in a requirement for the seal discs to be oversize so they can compensate for the pig alignment and reduce the possibility of a seal disc flipping.

Design Criteria

During the development of the Åsgard project a design criteria was established. The design was based on the considerations of the pigging technologies that were available at the time.

- Multi-diameter – The ability to change from a nominal diameter to a larger or smaller diameter but also the ability to function at diameters in-between these two limits.
- Centreline running – The suspension system must run on or as near to centreline as possible in both diameters, allowing the seal discs to be configured for optimum performance and provide a high seal disc flip pressure.
- Low differential drive pressure – Less pressure to drive the unit around the pipeline and lower operating cost.
- The ability to accommodate auxiliary components such as; brushes, magnet packs, electronic components, etc.

VariPig Function

Suspension Unit

The VariPig suspension unit contains a central piston to which all the arms are linked. Figure 3, shows the central piston and connected suspension arms.

The linked system ensures that if one arm is compressed and constrained by a restriction or feature within the pipeline, the central piston will force all the other arms to follow the restriction geometry, keeping the VariPig on pipe centreline.

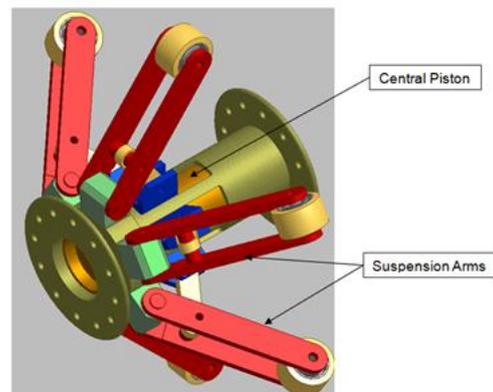


Figure 3 – Connection of Suspension Arms to Central Piston

Figure 4, shows the suspension arms opening in unison while negotiating a concentric reducer.

The central body of the suspension unit contains a spring system, which provides a reactive force greater than the weight of the VariPig assembly, creating a self-supporting system.



Figure 4 – VariPig Negotiating a Reducer

The interconnected system is able to offer a multi-diameter capability; when negotiating a diameter change from large to small the arms will close down, causing the spring to compress. When entering a larger diameter, the spring force will push against the piston, causing the suspension arms to open out and follow the pipeline geometry. In addition to this, the linked system will keep VariPig on centreline when in either diameter.

Interconnection of the link arms, through the piston, allows the suspension system to maintain its centreline position while negotiating through the pipeline, even if only two arms are in contact with the pipe wall. This offers an advantage when passing features, such as an off-take that is not fully barred or spanning a wye piece, as the suspension arms will remain constrained. This removes the potential of a suspension arm opening up into the off-take and becoming damaged as could be the case with some independently sprung systems where the suspension arms are independent of each other. Figure 5, shows a VariPig passing through an off-take, the non-constrained arms remain in the same geometrical diameter as the internal pipe wall.



Figure 5 – Passing a Tee Junction

Figure 6, shows a mounting block which connects the suspension arm to the main body and is offset in relation to the central VariPig body. The offset causes VariPig to induce a rotational movement when negotiating through the pipeline. The rotation encourages even seal disc wear and can increase the permissible pigging distance that is achievable.

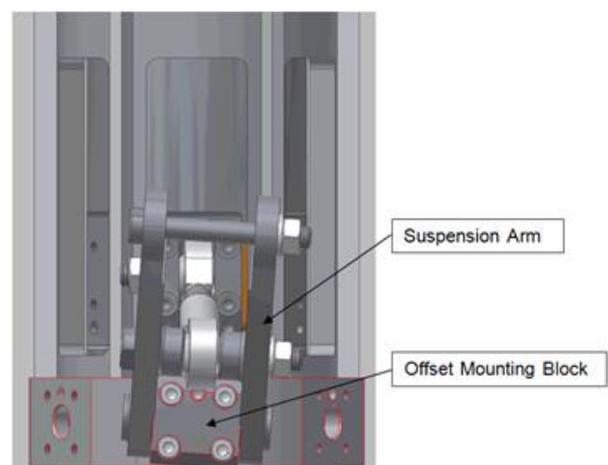


Figure 6 – Mounting Block Offset



Figure 7, shows a seal disc that has travelled through a 750km system, an even contact band is visible around the outer diameter of the sealing disc.



Figure 7 – Even Seal Disc Wear

Testing and extensive project experience has demonstrated that the suspension system is able to hold VariPig within 0.2% of pipe centreline. The ability to provide accurate centreline running means the seal discs are no longer required to be oversized to compensate for the high degree of wear associated with a traditional guided pig design. The seal discs can be optimized to suit a diameter just greater than the internal pipeline wall, providing an effective seal and reducing the friction generation between components.

Due to the support system that the suspension unit provides and the ability to optimize the sealing disc design, VariPig is able to operate with a consistently low differential drive pressure in pipeline diameters. Typically this can be approximately 0.2 Bar in a straight pipeline section. For RFO operations this can allow a reduction in the compressor spread required to drive the VariPig around the pipeline system compared to, a polyurethane guided pig where friction levels are increased.

Wheels assemblies

Figure 8, shows typical wheel assemblies that are utilized on the VariPig system. These have been extensively tested and verified on an internal test rig, completing many hours of successful testing. The test rig is also able to simulate weld bead impact and elevated operational temperatures, providing realistic pipeline conditions.



Figure 8 – Wheel Assemblies



The wheel assembly comprises of a metallic hub to which a specially formulate, heavy duty tyre material is moulded. Internally to the hub, there are rolling element bearings which are able to cope with a high load capacity. A spindle passes through the bearing and connects the wheel assembly to the VariPig suspension arm.

The tyre material offers good resistance to mechanical wear but is also able to offer a degree of compliance, absorbing the shock impact from a weld bead. The material is able to dissipate heat effectively during operation, reducing the risk of wheel failure.

Seal discs

The seal discs are important components of the VariPig system. The discs must provide effective sealing in both large and small diameters to ensure effective drive is maintained. In addition to sealing, the larger disc must also fold down, when passing from large to small diameters. Figure 9, shows a VariPig in a smaller diameter pipeline with the large disc folded down, reducing the contact of the sealing edge with the pipeline wall.



Figure 9 – Folded Seal Disc

The folding of the larger diameter seal disc is achieved by the use of buckle inducers, shown in Figure 10. The optimum buckle inducer position is obtained by computer analysis, defining its location on the seal disc. The careful positioning of buckle inducers causes the seal disc to fold down in a controlled manner when negotiating from larger to smaller diameters.



Figure 10 – Buckle Inducer



Figure 11, shows a buckled disc which has folded into a uniform pattern, the buckle inducers are visible in between the folds of the disc. In this diameter the smaller seal disc is now taking up the pressure from the drive media.

This method of folding ensures minimal contact of the larger drive disc with the pipeline wall when passing through the smaller diameter, ensuring that the seal disc has an unworn sealing surface when reaching the large diameter. Controlled folding of the sealing disc in this way creates a stress on the rear of the sealing disc which causes it to spring open when transitioning into the larger diameter, creating a seal against the pipe wall.



Figure 11 – Controlled Seal Buckling

Section Two – Case Histories

Following on from the successful completion of the Åsgard project, the VariPig system has been used for other challenging multi-diameter operations.

Detailed here are some of the interesting and challenging projects that have been completed.

UK North Sea – 24" X 32"

A major pipeline operator required the use of a dual diameter data acquisition pig for a 24" x 32" pipeline system.

The initial pipeline was 125km of 24" section followed by 340km of 32" section, a total pigging length of 465km. Features within the pipeline included 3D bends, valves and full bore tees, additionally the 32" section featured a symmetrical wye piece.

A dual module VariPig assembly was developed to negotiate the pipeline. Each module was connected via an articulation joint. The assembly carried data acquisition equipment with the rear module having brush units for debris removal from the pipeline wall.

Careful design was required to ensure that the VariPig was able to traverse the distances in both diameters, negotiate all the pipeline features including the symmetrical wye piece without stalling but also be compact enough to pass around 3D bends.

Figure 12, shows the final VariPig.



Figure 12 – 24" X 32"

UK North Sea - 20" X 14"

Recent projects have included work on a project where a pipeline diameter needed to be reduced to accommodate reduced operational flow. A pigging consultant carried out a design study on pigging options and recommended that VariPig was a viable option to traverse the proposed 20"x14" pipeline system, as an interim solution to ensure continued running of the pipeline.

The length of pipeline to be pigged was 5kms and included 5D bends and production Tees in the 20" section. The medium being transported was oil with sand. The change in internal diameters of the pipeline equated to 49%. Operational cleaning was the reason for pigging.

During the early pigging runs it was discovered that the temperature experienced in the pipeline was higher than first expected. With this information to hand the seal disc concept and material was reviewed and improved to include higher integrity elastomers. Following these changes the VariPig traversed the pipeline without mechanical issues 23 times utilizing a fleet of 4 pigs, before the pipeline was converted to 14" throughout. During this period additional brushes and a data logger was also able to be added to the VariPig platform.

An image of the final pig is shown in Figure 13.

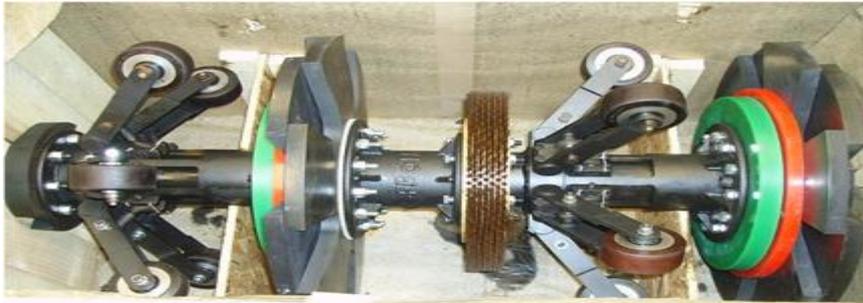


Figure 13 – 20" X 14"

Multi-Diameter - 26" X 20" X 26"

One of the main areas in which VariPig is extensively used is in Ready for Operation (RFO) in subsea applications for flooding and dewatering. In a recent project FTL Technology designed and built a VariPig platform suitable for:

- 1) Flooding in a 26" x 20" x 26" pipeline system
- 2) Dewatering in a 20" x 26" x 20" pipeline system

VariPig was chosen following full scale pig comparison trials that demonstrated VariPig to be the most suitable design for the RFO activities.

Lengths of pipeline pigged were 16kms and 41kms and the pipelines included Tees and 3D bends.

Both operations were carried out successfully at very low differential pressure and with very limited reconfiguration, which allowed the same VariPig to be used in both the flooding and dewatering operations.

The multi-diameter VariPig is shown in Figure 14.



Figure 14 – Multi-Diameter VariPig

Pipeline De-commissioning

VariPig is increasingly being used in pipeline decommissioning and to allow pipeline repair. In the case of repair, VariPig is also used for dewatering following the repair.

As the VariPig design is already well proven, new sizes of VariPig can quickly be designed and built to promptly facilitate repair situations. So when timescales are short and there is limited time to develop a new pigging system VariPig allows for fast track pig deployment.

In a previous decommissioning and repair project VariPig was utilized in a pipeline system with multi diameter bores of $\varnothing 650$ and $\varnothing 710$ over a distance of 146km. Media involved included hydrocarbons and MEG. In addition to Tees and 5D bends in both diameters, a dent in the pipeline caused a restriction of $\varnothing 618$ in the $\varnothing 710$ pipeline. Additionally a check valve was required to be pigged in both directions.

VariPig performed satisfactorily in both the decommissioning and dewatering operations, Figure 15, shows the final VariPig.



Figure 15 – Pipeline De-commissioning

Atlantic & Cromarty VariPig De-commissioning Project

FTL Technology, completed a de-commissioning project on behalf of Qserv, to facilitate the closure of the Atlantic and Cromarty pipeline in the UK North Sea.

The original commissioning of the pipeline took place from onshore at the St. Fergus Terminal north of Aberdeen to sea-bed, decreasing from large diameter 18" to small diameter 16". The de-commissioning was carried out from sea-bed to onshore at St. Fergus (16"-18"), to allow all contamination to be collected onshore. This posed a problem as the pig had to do the majority of work in 78kms of the smaller diameter, before reaching the last 3kms which was the large diameter.

VariPig was deployed with a specially configured train of three, incorporating a revised sealing package. This was developed to lessen the risk of leaving contamination in the pipeline, reduce the effect on the

seals of the extended period in the smaller diameter, and to maintain a full seal within the large diameter.

The VariPig train was deployed with a 50/50 MEG and sea water mix as the media to propel the first two VariPigs and chemically treated seawater for the last VariPig. To reduce time and cost for the operation an existing 16" launcher was utilized. During the operation, due to limited slug catcher facilities, the VariPig train was frequently paused and re-launched in the pipeline whilst hydrocarbon and ferrous debris was cleared.

The pipeline was pigged at low velocities with approximately the first 30kms distance at 0.35m/s and the remaining distance at between 0.08m/s and 0.05m/s. The pipeline included full bore tees in both diameters and a subsea manifold, which was 15mm smaller than the 16" pipeline.

On completion the VariPig train was received back into the pig trap for demobilisation, allowing the pipeline to be capped off and successfully de-commissioned. Figure 16 shows VariPig being removed from the receiver.



Figure 16 – Atlantic & Cromarty

Section Three – The Long Term Flexibility of VariPig

VariPig offers the potential to become a long term re-usable and re-deployable asset.

One example of this is, over the course of several years a VariPig base unit supplied to Statoil, Norway, initially used on the Alve pipeline, has been reconfigured for alternative operations in different pipeline systems.



The projects focus around the Norne FPSO and its associate pipelines Alve, Urd, Marulk and Skuld. Detailed below are the case histories of all four projects and how VariPig was modified to suit the requirements of the differing pipeline systems.

Alve [5]

The Alve pipeline in Norway is a 16km flow line, which required flood and subsequent dewatering operations. As there was no pig launcher present on the subsea Alve manifold, all operations needed to be completed from the Norne FPSO vessel. Figure 17, shows a field schematic.

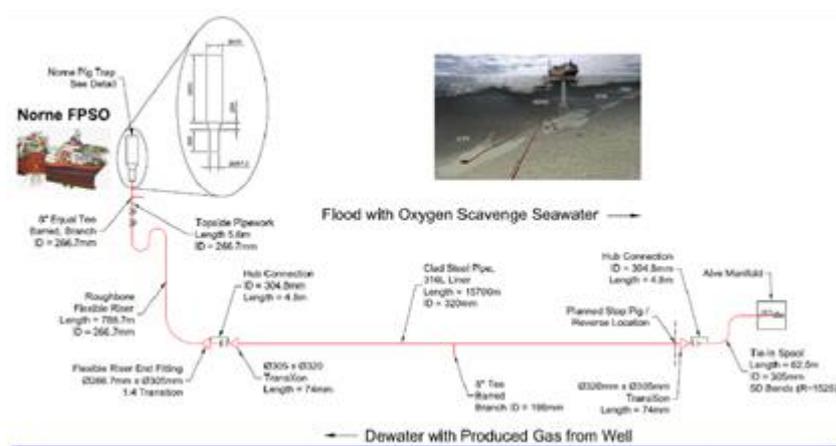


Figure 17 – Alve Field Schematic

The nominal diameters of the pipeline were 10" x 12" x 13", however there were a number of diameters in between these limits which required coverage by the seal discs.

A four pig train was launched from Norne, oxygen scavenged seawater was used to propel the train through the system. When just upstream of the manifold the first pig in the train would be stopped and reversed back through the system with Nitrogen and gas. The pigs were required to provide a high degree of sealing as there were concerns that any gas bypass would cause a hydrate risk.

From the pipeline detail and advised parameters provided by the operator a list of requirements were established:

- Fully bi-directional with a high sealing efficiency when travelling in both directions
- High sealing efficiency with minimum bypass though all components within the system, reducing the risk of Hydrate formation on the return to Norne
- Able to cope with low flow rates, 0.03m/s to 0.08m/s
- The required drive pressure in all pipeline features to be a maximum of 7 Bar
- Seal disc flip pressure to at least 5 times the drive pressure

A two module pig was developed, the final design is shown in Figure 18. Due to the bi-directional requirement, the wheel units face one another and are connected together via a central flange. The

suspension arms on each unit are linked with an external spring mechanism; however, front and rear modules are independent of each other.

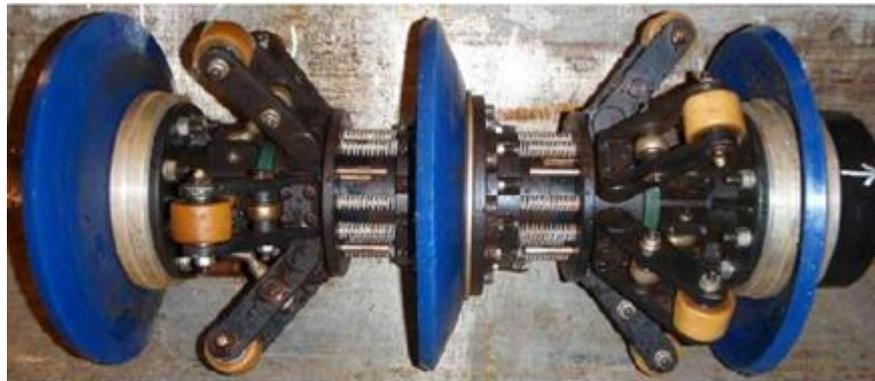


Figure 18 - Alve VariPig

The spring mechanism allows the suspension arms to move in a vertical orientation, rather than in an arc as with a traditional VariPig. This allows the VariPig to pass pipeline features in both directions without the suspension system locking up when passing a Wye or off-take.

The ability of the pig to negotiate the pipeline on centreline meant that the sealing package could be optimized to provide efficient sealing. The sealing disc was designed with a diameter just greater than the largest internal pipeline bore. Only single non-buckling seal discs were used, with the idea being that the disc can cover several smaller diameters before it finally buckles.

A central seal disc was included to prevent the possibility of a leak path when travelling through a 5D bend, Figure 19. The central seal disc would maintain drive in the event of bypass around the front or rear seal discs.

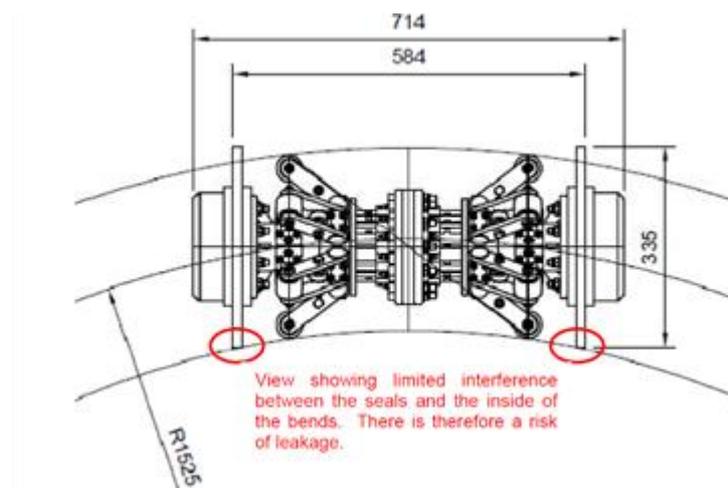


Figure 19 – Potential Leak Path

Following completion of the Alve project the pigs were refurbished before being placed into storage.

Urd

The Urd project required pipeline de-commissioning prior to the replacement of an existing flexible riser, in operation on an 11km production oil line, Figure 20 shows the field schematic.

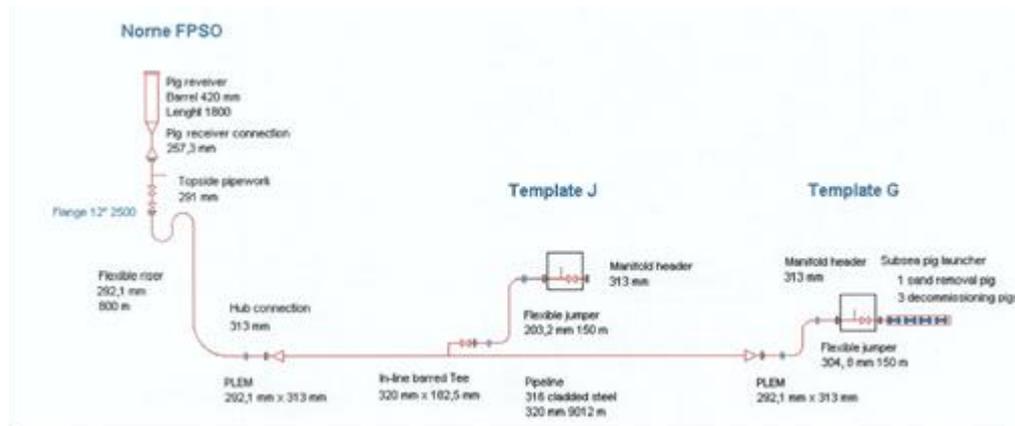


Figure 20 – Urd Field Schematic

The bi-directional pigging system utilized on the Alve pipeline, was reconfigured for use as a uni-directional pig travelling from subsea launch to topside receipt.

The existing layout of the pig, in its bi-directional configuration, was not suitable for use in the temporary subsea launcher. The internal diameter of the launcher header required the VariPig suspension units working range to be increased to provide support at launch.

To allow for VariPig to negotiate the temporary launcher and pipeline, the front suspension unit was rotated 180°, aligning the units in a more traditional arrangement. The VariPig seal components were replaced to suit the Urd pipeline diameters.

The pigging operation utilized four VariPig assemblies in a de-commissioning pig train. VariPig one and two were launched initially for sand/debris removal and received in the pig receiver, Figure 21, shows the pig

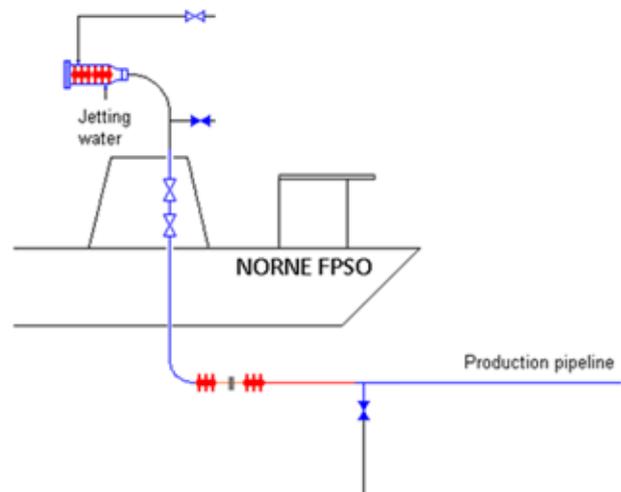


Figure 21 – VariPig Locations After Sand Removal

locations after the initial VariPigs were received. The topside pig receiver was unable to store more than two pigs so the third VariPig was pumped into the flexible riser which was subsequently removed with the VariPig in place.

Figure 22, shows the new riser installed with the fourth VariPig having remained in the pipeline prior to change out.

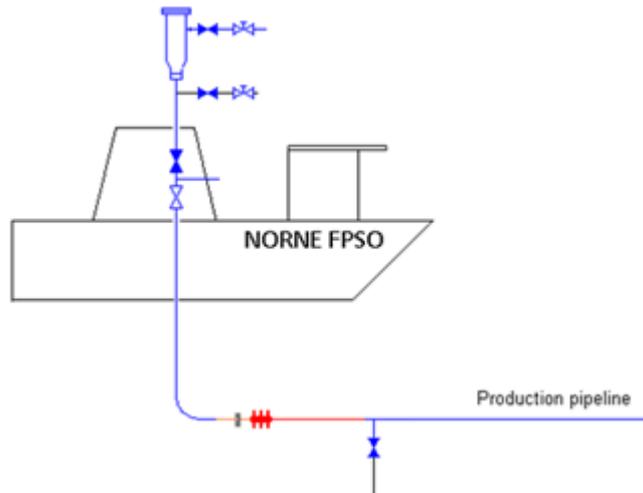


Figure 22 – New Riser Installed

The riser was pressure tested before the final VariPig was pumped up to the receiver on Norne FPSO topside, Figure 23.

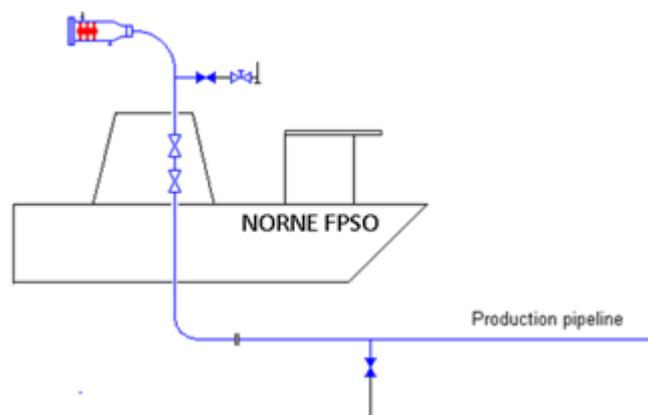


Figure 23 – Final VariPig Returned to Norne Topside

Figure 24 shows the Urd VariPig after operation.



Figure 24 – Urd VariPig

Marulk

The Marulk 11km 10" pipeline was the third pipeline, connected to the Norne FPSO, to make use of the VariPig assemblies from the Alve project. Several changes in internal diameter were within the pipeline system and a flexible riser onto Norne. Figure 25 shows the field schematic.

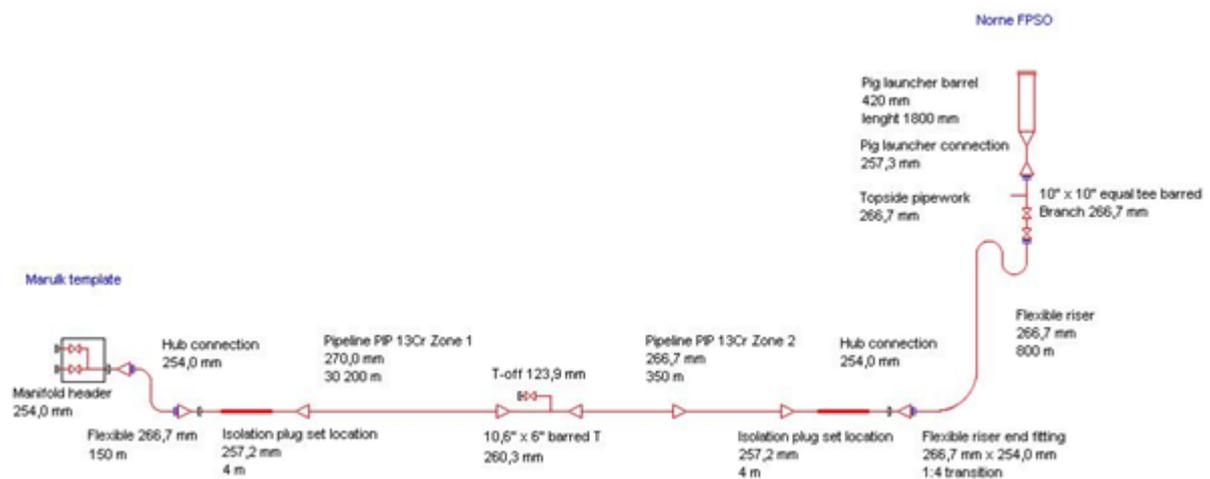


Figure 25 – Marulk Field

As with the Alve project the VariPig was required to carry out a bi-directional operation from the Norne FPSO to the Marulk subsea template and return.

The percentage change in pipeline diameters were reduced compared to Alve requiring the VariPig suspension units to be modified to restrict their working range and a reconfiguration of the seal packages.

The VariPig train of four pigs was pumped from Norne to the Marulk template. Following completion of operations, and to dewater the pipeline, the VariPig train was pumped back successfully to Norne, with the last pig being propelled with Nitrogen.

Figure 26, shows the Marulk VariPig after successful project completion.



Figure 26 - Marulk VariPig

Skuld

A number of years after the original Alve project, the same VariPig base structure was used for a RFO pigging requirement on the 25km Skuld 14"x12" pipeline.

The operations required the VariPigs to be launched and received using subsea facilities.

Various changes in pipeline diameter were within the system with small diameter back-to-back bends in a PLET.

The operation was uni-directional but as a contingency the same bi-directional configuration was maintained. The diameter range required an adjustment of the suspension units working range and reconfigured seal packages.

A VariPig train of two pigs was pumped successfully into the subsea receiver.

Following successful deployment the four different VariPig assemblies were subsequently refurbished and preserved awaiting their next utilisation.



Conclusion

VariPig offers the ability to function in multi-diameter pipelines. The design of the suspension unit offers true centreline running, low differential drive pressures and seal package optimization.

Through planned design VariPig was able to pass challenging pipeline features, such as tight bends, tees and wye pieces.

The adaptability of the VariPig system has allowed the same base unit to be utilized on several pipeline systems with some basic design changes. This provides the operator with a reusable, re-deployable asset, reducing the total cost of ownership.



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