Evaluating Pipeline Integrity: The Impact of Non-Intrusive Isolation Tools and the Advantages of Two-Way Communication

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ABSTRACT

Abstract #1 Evaluating Pipeline Integrity Following Non-Intrusive Isolation Tool Deployment

Pipeline isolation plays a critical role in ensuring safe and efficient maintenance operations, particularly in high-consequence areas (HCA) where a release of product containment has the potential to cause great harm to the public or damage to the environment.

To create a robust physical barrier within the pipeline, well-established isolation technologies utilize gripping elements, commonly referred to as grips in down-hole packer technologies, to anchor the tool securely to the pipeline's inner wall, and a sealing element to isolate the pipeline pressure.

Despite its efficacy as an isolation tool, there has been debate regarding the potential for the grips to induce surface changes in the pipe's inner wall. Such changes could, in theory, alter the pipeline's mechanical properties, especially under sour service conditions where there is heightened risk of sulphide stress cracking (SSC).

To address these concerns, the isolation tool's manufacturer conducted extensive testing, alongside a third party, to evaluate its impact on pipeline integrity.

The study involved rigorous testing on multiple pipe sections with and without seam welds, focusing on three key parameters: (i) the penetration depth of the grips' teeth into the pipe wall, (ii) changes in macro- and micro-hardness values due to teeth penetration and (iii) the formation of micro-cracks at the base of the teeth indentation marks.

The results suggest that even under repeated deployments, the use of this isolation tool does not compromise pipeline integrity or contribute to the risk of SSC. The results were independently verified by a third-party institution, further validating the tool's reliability and safety in operational environments. This comprehensive approach ensures that the findings are robust, applicable to real-world scenarios and contribute valuable insights into pipeline safety and integrity management.

This paper will discuss the scope of testing, the methodology used, the suite of tests performed, the data gained from these tests and the results.

Abstract #2 Enhancing Pipeline Integrity: Integrating Remote Monitoring Enables Two-Way Communication with Non-Intrusive Isolation Tools

In the complex and demanding environments of subsea and offshore pipeline operations, ensuring the safety and integrity of critical infrastructure is paramount. The ability to precisely control and monitor non-intrusive isolation tools is essential, particularly during valve repair or replacement on offshore platforms, where depressurization of the entire pipeline can be costly and environmentally detrimental.

This paper explores the innovative combination of non-intrusive isolation tools with a tether less two-way communication system, which allows for remote activation, isolation, and monitoring of pipeline isolations. By using extremely low-frequency electromagnetic signals, this system enables precise two-way communication through pipeline walls up to 65 mm (2.56 inches) thick, a feature especially valuable in subsea or buried applications where physical access is limited. The remote communication capability allows operators to monitor key parameters such as annulus pressure, pipeline temperature,

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and the integrity of isolation barriers in real-time, ensuring that the isolation is maintained without compromising safety or operational efficiency.

Furthermore, this integration provides significant advantages during valve replacement operations, where localized pipeline isolation can minimize production downtime and loss of product through flaring or venting of the pipeline, thereby reducing environmental impact and associated costs. The combination of non-intrusive double block and monitor technology with advanced communication systems offers a robust solution that satisfies both regulatory requirements and operator concerns, enhancing the safety, reliability, and efficiency of pipeline operations.

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INTRODUCTION

Pipeline isolation is a natural and fundamental part of intervention activities in a pipeline system. Local pipeline isolations have brought great benefits over traditional intervention methods in pressurized systems. These isolations are deployed for various purposes, in many different locations and across the entire lifespan of such systems, with their primary task being to locally isolate an area or sector of the pipeline system from the pressure and contents within. Safe and efficient isolation operations have been and should continue to be the fundamental premise of all plans made to intervene into such operating pipeline systems. In areas where the consequence is high, there is the potential of causing great harm to the public or damage to the environment. While traditional approaches to completely decommission the systems are considered the safest methods before intervention, they may also be the most time consuming and costly option. In-line isolations are proven to be both a safe and viable option in most pipeline intervention activities, enabling work to be completed that was previously not viable with traditional methods (whether the reasons were technically, economically or risk related). Executing local isolations as a replacement for large scale, temporary full decommissioning and recommissioning methods could even lower the safety risk associated with operation of and intervention in pressurized pipeline systems.

This paper discusses three aspects of pipeline isolation and in-line isolation methods to address questions and concerns that can originate from the pipeline owner's and operator's perspective.

- The load effects on the pipe wall when grippers are used to anchor the isolation tool in place,
- The marks left in the pipeline from the gripping system and any long-term effects on the pipe wall.
- The through wall communication system used to verify and control the isolation, including the isolation tool's electronic control system and the associated externally capable remote control and monitoring system.

Both the tool's traditional gripping to the pipeline and the through-wall communication system plays a pivotal role in both the current and future applications of these isolation techniques. Recent developments and isolation cases demonstrate the robustness and versatility of such isolation tools and techniques.

Safety of isolation – barrier definition

When personnel are working on or exposed to an isolated section of a pressurized pipeline system, the worker's safety is directly affected by the effectiveness of the isolation set. When breaking containment of an isolated and depressurized section of the pipeline, safety depends on the effectiveness of the barriers established to protect against residual or reintroduced pipeline pressure, as well as the controls and redundancies built into the isolation system. Two barriers are often the minimum requirement and are described in internationally recognized codes, recommended

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practices, and various reports, including: HSG253, DNV-ST-F101, DNV-RP-F113, ASME31.8, API 6D (valves), API 521, OSHA, ISO 10418, NFPA 56.

It is clear from the consensus of these documents that there has to be two barriers and there also must be an independency between the two barriers. This principle repeats across the literature and should be considered a key requirement. No single failure of a seal or a component should have the potential of jeopardizing the entire isolation. Here, different isolation systems use different technical solutions to obtain barrier independency, but this is also based on different interpretations of what constitutes "independent barriers". This paper discusses the principles that should apply for obtaining the required independency of the barriers as well as critical features added for an effective verification and control of the isolation.

In-line isolation technologies have been used to facilitate partial depressurization of pressurized pipeline systems. Their primary task is to protect the personnel working directly on the depressurized pipe section from exposure to the hazardous pressure and content of the pipeline. When a traditional decommissioning and recommissioning activities of the entire system are done to fully remove the pressure and locally remove the content to allow for a safe intervention, one can argue this is the safest option. In some cases, this option may be found unfeasible, in particular when large pipeline networks need intervention and isolations, or that the overall risk picture remains unchanged, due to the extent of the work scope. When alternatives to these traditional methods have been needed, the use of in-line isolation technologies have chosen as safe and reliable double block isolations that also, in most all cases, are obtained significantly faster and cheaper.

The latest technology enables remote access via satellite or 4G cellular communication to the in-field wireless through-pipe-wall communication system installed locally to communicate with the isolation tool. This enables a new level of flexibility and continuous status reporting for not only the in-field technicians and project team, but also the customer or other involved contractors.

Design of barriers

This section addresses two different in-line isolation tools, characterised by "intrusive" or "non-intrusive," and how the double barrier principle is obtained and verified.

A design with two barriers and a system that enables verifying the performance of both, is the only way for true compliance to the mandatory and fundamental requirement for safe isolations. There are several methods of reaching this requirement. Often the focus is drawn to the term double block and bleed, (DBB) where the bleed should ensure no leakage through the primary barrier reaches the secondary barrier. This means that the void between the barriers must be designed so it routes any leaking medium to a safe location away from the work area being isolated. In addition to DBB there is a term double block and monitor (DBM). DBM satisfies the requirement for safe isolation by having two barriers that work independently from each other, though both barriers shall have the

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capacity to hold the entire isolation pressure on their own. The failure modes of one barrier shall not affect the other. The pressure contained for continuous monitoring of the integrity shall be kept to a small volume.

When in-line isolation tools are non-intrusive they have two barriers that are anchored to the pipeline wall through sets of grippers, which have teeth that grip into the inner circumference of pipeline wall. The tools are set in a straight section of pipe without any tap or port to vent the pressure between the barriers. In case an isolation method like this should comply to the DBB principle, then a sufficient bleed would either mean to connect and open a vent through a preinstalled or tapped fitting to the pipeline at the set location or to connect a hose or tubing directly to the isolation tool inside the pipe, running backward through the pipeline to a safe area outside the pipe where the pressure and content from a potential leak of the primary seal into the annulus can be released. This "connected" type of bleed is limited to tethered tools, pulling the vent hose behind it as it is moved into and along the pipeline toward the isolation location. This is in many ways impractical and introduces a possibility that the vent line will be damaged or disconnected during the installation of the isolation system. When in-line and non-intrusive tools are used they should instead follow the double block and monitor (DBM) principle. Using this isolation method, the integrity of both seals is verified sufficiently before intervention and isolation status is monitored throughout. This enables any changes to be detected and reported.

Intrusive in-line isolation tools are typically deployed through a tapped branch connection that is either preinstalled or made at the desired intervention location as shown in figure 1. The isolation barriers are inserted through this tap and installed inside the pipeline upstream or downstream of the branch line.

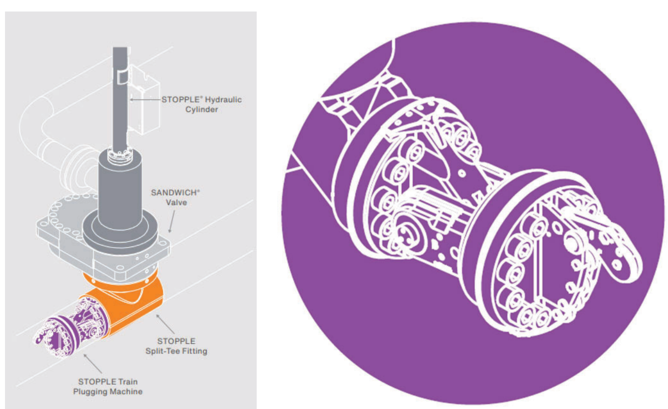

Figure 1: STOPPLE® Train inline isolation tool

The two barriers are in a way dependent on the same mechanism for insertion and retention; should a bleed port be incorporated in this set up it either has to be established as a separate tap directly in the pipeline, between the barriers, or as a bleed feature through the tool itself, but the requirement is that a bleed line is integrated through the second barrier and the insertion mechanism.

 https://doi.org/10.52202/078572-0022

Barrier designs may vary between tool suppliers, but common to all is that the isolation loads, which is the axial force from the pressure being isolated, are retained in the branch connection/fitting the isolation tool is attached to and deployed through, and little or no load goes into the pipeline wall itself. Before studying this further we must look at how isolation loads are secured for non-intrusive in-line isolation tools.

Non-intrusive tools use a system of grippers that expands and engages with the pipe-wall and retains the loads through small indentations from the gripper teeth. One of the typical (and natural) concerns is that these gripper systems could change the material properties of the pipe, resulting in a situation where the isolation tool may experience the lack or total loss of grip at load and move in the pipeline. Another concern is that marks from the tool damage the pipe in some way. The short answer to both is no; Both non-destructive examination (NDE) and destructive testing (DT) have proven that the pipeline suffers no damage from these marks, and marks left in the pipeline wall are superficial in nature and are even smaller than the acceptable tolerances for anomalies allowable in pipeline sections during manufacture.

In addition, the field-proven performance of the TDW SmartPlug® tools shows no loss of grip in any of the inline isolation tools deployed, spanning across 25 years of service and close to 400 successfully completed double barrier isolations.

As mentioned in the introduction above, a key principle is to also ensure the anchoring to pipe wall comply to the redundancy principle. If the isolation depends on just one anchoring point and the tool fails to grip the pipe wall, the operation can be jeopardized. A better solution is to have independent anchoring to different points of the pipeline, which complies with the requirements in international codes. Having two isolation modules that are physically separated, and located at different positions in the pipeline, increases the overall safety significantly. This is confirmed by theoretical evaluation/calculation.

Where isolation tools have sufficient differential pressure across the barriers, the barriers are not dependent on the activation mechanism at all and have achieved an exceedingly high reliability (low probability of failure). However, where the isolation pressure is insufficient to provide enough activation force, each barrier may be dependent on the activation mechanism. Having separate activation mechanisms with no shared components will also significantly improve the probability of success, as opposed to a system with a single activation mechanism.

In traditional intrusive designs, the isolation tool is anchored through the fitting used for seal insertion. This typically results in the isolation loads being transferred into the fitting and the pipeline as axial forces and bending moments, particularly at the hot tap fitting. While this may not always pose a concern, certain cases may require additional support to maintain the stability and integrity of the overall isolation system. Even when structural strength is sufficient, challenges can arise from

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flexibility—or the lack thereof—within the equipment stack, including the plug insertion tool and valve. A stable system is essential to ensure that pressure is consistently retained, and the seal remains uncompromised, avoiding issues caused by structural bending or movement.

PROVING THE SAFETY OF IN-LINE ISOLATION TOOLS

This section presents testing performed by TDW to verify that sufficient grip is created during an isolation at the same time as the stress and any indentation created does not affect the integrity of the pipeline.

Safety of inline isolations - anchored to pipeline wall

Inline isolation tools that are secured through grips to the inside pipe wall depend on a certain indentation of the teeth into the pipe wall's material. This indentation is small, in the range of 0.1-0.2mm, which is considered superficial according to most pipeline manufacturing requirements and tolerances. This indentation is still important, however, since its absence will reduce the anchoring capacity to that of pure friction. Even though the tools are creating only small indentations with limited depth and magnitude, TDW has verified the effects through significant testing.

The first question is whether insufficient indentation in the pipe can increase the possibility of losing grip. This could cause the isolation tool to move under the differential pressure loads.
The second is the possible adverse effect the tools grippers may have on the pipeline, meaning that the indentation marks could reduce the material's natural resistance toward cracking and possible sour service compatibility.

A third effect to be verified is the fact that the loads induced in the pipe wall could become too high for the overall capacity of the pipe wall, and yield the pipe or, worst case, even burst the pipe. The loads that are induced in the pipe from the tool are radial loads from the seal and a combined radial and axial load from the grippers.

TDW has successfully completed tests that prove:

- The loads during isolation are well controlled and correctly predicted through the simulations and calculations performed,
- Anchoring to the pipe wall leaves superficial grip marks and minimal material changes that do not cause risk to future operations, including repeat isolations of the same location and sour service aspects.

Testing loads in pipe

In-line isolation tools induce loads into the pipeline wall to create sealing and ensure gripping. The radial and axial loads from a plug module at differential pressure will include a hoop stress. For safe utilization of the pipe material's capacity, pipe stress calculations must use maximum limits set for

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these loads by recognized codes, such as DNV-ST-F101 and DNV-RP-F113. These calculations establish the allowable isolation pressure, which is influenced by two key factors: the inherent capacity of the pipeline and the specific load characteristics of the plug design being used.

The key factor that affects the grippers' loads into the pipeline is the gripper wedge mechanism. Theoretical calculations are performed to predict the loads that the tools induce in the pipeline for every project during the preparation and assessments before each isolation.

During several projects using the SmartPlug isolation tool, strain gauges have been attached to test pipes to measure the exact elastic expansion in the pipe as a response to the loads formed by the tool and the internal pressure. This has been done as a verification that the measured strain corresponds to what the theoretical calculations are predicting. Engineering has used strain gauges to validate new designs that affect the tool's proven gripping mechanism. This was done recently when tool designs were optimized to meet a project scope, which was to reduce the pipe stress level at a requested isolation pressure.

An isolation was requested for a 30-inch subsea pipeline at 165 bar, where the initial calculation fell short in fulfilling the limits for pipe stress. The tool was redesigned to reduce the load input into the pipe. Both the gripping mechanism and the packer was redesigned. To qualify the design and verify simulations and calculations performed, strain gauges were attached to two different test rigs with different pipe ID, pipe wall thicknesses and material quality. This was done both to confirm that the target was met using two independent data sets and to compare the readings from two different test rigs.

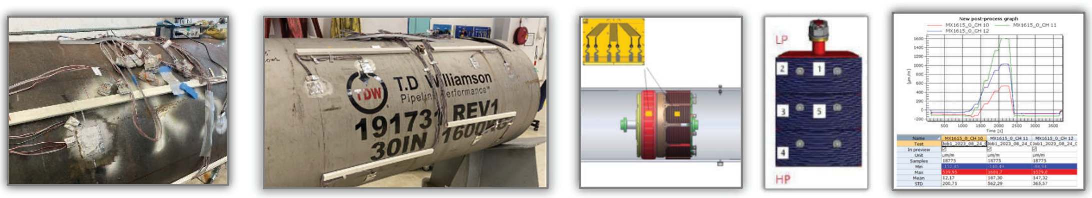

Figure 2: Images from project reporting for the strain measurement.

Similarly, a 24-in tool was designed for the same purpose and sized for thin-walled onshore pipelines. This design was subjected to tests in a thin wall test rig (8mm WT). The test rig was also equipped with strain gauges around the circumference and in the axial direction.

The objective of both tests was to verify that the measured loads in the pipes matched the predicted loads from the theoretical calculations and to determine how the distribution of strain in the pipeline due to the actual loading from the tools' geometry would correlate to the results of an FEA analysis based on a 3D model.

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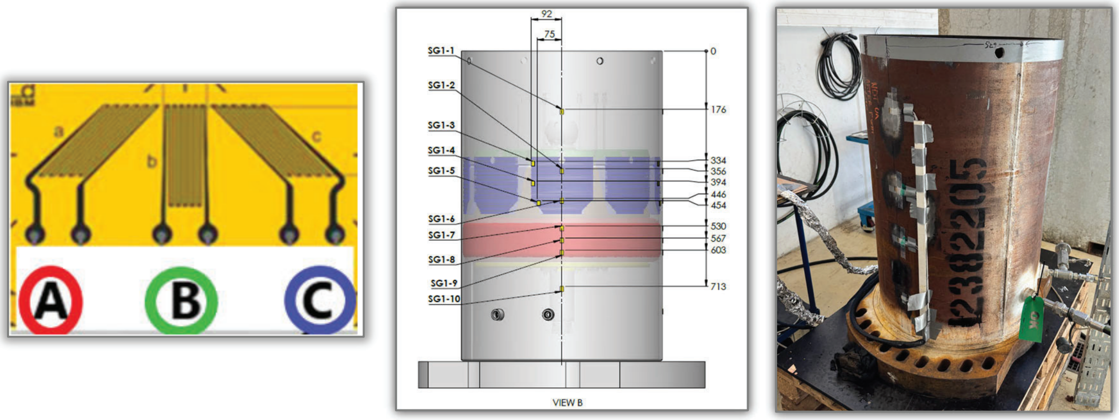
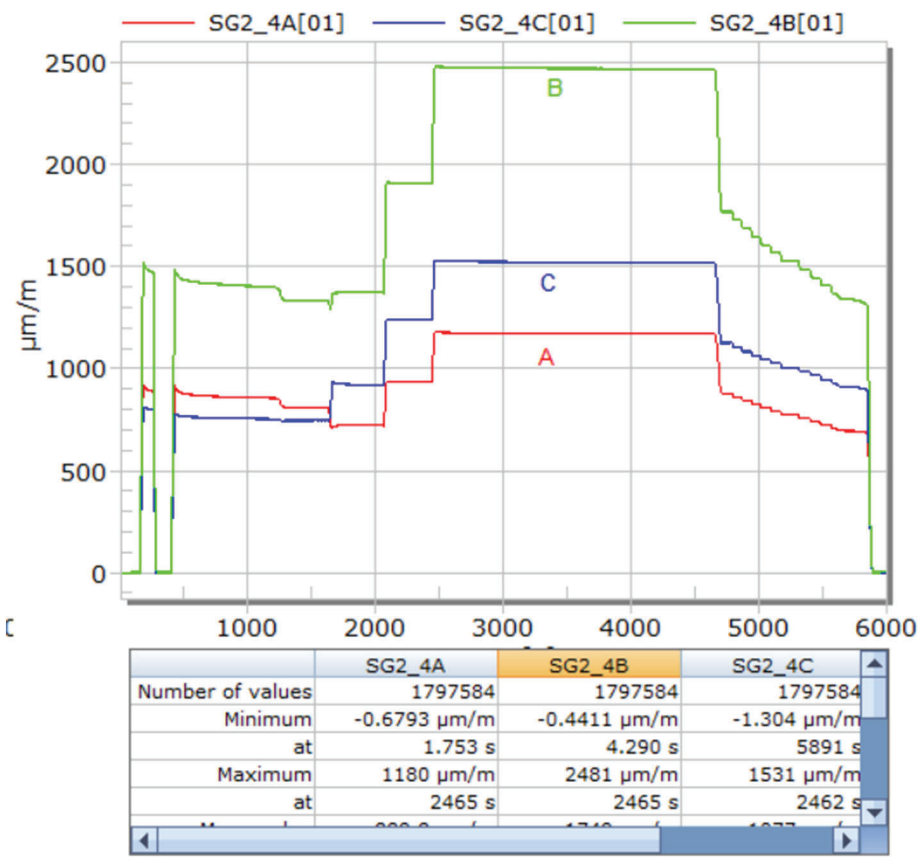


Figure 3: Three-axis strain gauges placed on the 24in test rig



	SG2_4A	SG2_4B	SG2_4C
Number of values	1797584	1797584	1797584
Minimum	-0.6793 µm/m	-0.4411 µm/m	-1.304 µm/m
at	1.753 s	4.290 s	5891 s
Maximum	1180 µm/m	2481 µm/m	1531 µm/m
at	2465 s	2465 s	2462 s

Figure 4: Graph - raw strain gauge data obtained during testing

A total of 20 strain gauge sensors with three-axis/channels per strain gauge were used to thoroughly map the strain in the 24-in test rig. Several iterations were done, including one attended by an onshore gas transmission pipeline network owner/and witnessed by DNV as a third party.

https://doi.org/10.52202/078572-0022

In sum, this testing concluded that the predicted strains per pipe stress calculation for this test rig corresponded with the strain measured on the test rig. Some localized loadings showed higher strain response in certain places but that is a natural response on the outer surface of the pipe from the factors of a slightly oval test pipe and the load pattern from the grippers on a thin wall pipe. The FEA analysis of the 3D model of the same components confirms that the extent of the strain is limited to shallow surface loads, not affecting the bulk of the wall thickness and the mid-wall (membrane) strain/stress.

Testing gripping to pipe

Achieving a predictable grip to pipe wall is fundamental in verifying that a change in design has not affected the gripping capacity of the isolation tool in non-ideal conditions. For such conditions choosing a test material and test method is critical to reveal or verify the limit for gripping. In several different projects where updated designs were built and tested to confirm lower pipe stress gripping to pipe wall was also tested. Qualifying this is required as the radial load from the grippers is reduced and the overall anchoring is changed. Testing was planned to verify gripping in different type of pipes and pipe materials. Three plug designs — 24-in, 30-in and 42-in — were tested using pipe material with hardness representing X60, X65 and X70 carbon steel pipelines with standard quality and a SuperDuplex material pipe with significantly higher hardness (~30HRC) than the maximum allowable hardness of X65 and X70 pipe (<< max 22HRC). All the test rigs were had the hardness measured on the inner surface where the grip was applied.

- Small scale testing was also done to confirm gripping in high alloyed materials like Alloy 625/Inconel.
- The tests were done at pressures between ambient pressure (tool activation loads only) and up to 358bar.
- The position of the plugs in the test pipes was recorded using digital calipers.
- The grip marks in the pipe were inspected after the tool was removed from the test rig.
- Tests confirmed the limits for gripping, meaning that under the incorrect conditions, typically a combination of excessively high pipe hardness and excessively low radial (clamping) force, a tool will not lock to the pipe but slide.

In sum, the testing provided relevant information to confirm the slip line theory and concluded that the current and updated designs for the TDW in-line isolation tools safely anchor the tool to the pipe -wall with minimal tooth indentation and with good margin to the condition that causes loss of grip. This applies to the standard X- qualities of pipeline material, but also higher alloyed pipelines like SuperDuplex and Alloy 625/Inconel.

https://doi.org/10.52202/078572-0022

Figure 5: Photographs from the different test rigs used for gripping validation testing.

Testing for possible damage to pipe

While the previous section focused on the safety of gripping through teeth embedment into the pipe material, the counter question would be if these permanent marks made into the pipe wall represent any of several risks:

- The work hardening of the material itself could possibly initiate a micro-crack that could propagate into pipeline rupture over the course of a pipeline's life cycle.,
- The cold working could accumulate hardness and lead to lack of grip if the tool were set at the same location more than once.
- The increased hardness at the groove made by the tooth tip could affect the pipeline's sour service resistance.

Based on the testing TDW has performed and summarised in a separate paper, TDW can safely claim that none of the above listed risks is considered a real risk when standard TDW inline isolation tool designs are selected to isolate different pipelines (carbon steel, SuperDuplex and Inconel qualities) with standard pipeline properties.

Using non-intrusive, in-line technology to isolate pipelines under sour service conditions is a safe, common practice. However, one concern is that these isolation tools might damage the inside of the pipe when their gripping mechanism (grips) engages against the pipe wall. The perception is that the marks left on the pipe wall have the potential to compromise the pipeline's integrity. Specifically, the question is whether repeatedly setting the tool at the same set location leads to surface work hardening and/or the initiation of microcracks at the bottom of each grip mark which could make the inner surface more susceptible to sulfide stress cracking (SSC) or cause a situation where the pipe would not be able to support the grips, leading to tools sliding.

The proprietary SmartPlug isolation tool allows pipeline sections to be isolated at or close to operating pressure. The tool is remotely controlled and bi-directionally piggable. Its basic configuration consists of two pigging modules and two isolation plug modules. When the SmartPlug tool is set, the hydraulic activation cylinder's contraction causes the packer to expand (and seal against

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the pipe inner surface) and the grippers to engage with the wall of the pipe. The radial (outward pointing) force from the slips causes the teeth to slightly embed into the pipe wall surface.

At the request of a pipeline operator, TDW performed and commissioned an extensive series of tests to determine if the repeated setting of a 36-inch SmartPlug tool had any effect on the inner wall of a section of pipe. The testing was performed with the grips purposely set to straddle the seam weld and, in the heat-affected zone (HAZ) next to the seam weld, also using loads simulating previous plug set operations in the client pipe during 2007 + 2015.

NDE baseline tests were done to verify that the pipe was free from any critical defects before testing started, and the results showed no evidence of critical surface discontinuities.
After testing was completed, the pipe was sectioned, and an extensive series of non-destructive evaluation (NDE) and destructive tests analysed the pipeline material looking for “flaws” or “defects” initiated or further developed during the tests (by the teeth indentation or the hoop stress).
All tests were conducted on a 6-meter section of pipe supplied by the operator.

Destructive Testing

During testing, a plug module was set and unset eight times in the test pipe, under conditions simulating the customer’s operational scenario and cyclic loads (2007 and 2015 isolations).
The plug module was set in one of two ways: either the slips straddled the seam weld, or the slip edge was placed directly on the heat-affected zone (HAZ) adjacent to the seam weld of the pipe. After testing the pipe coupons (segments) were cut from each test location. The position of each coupon in the original pipe was recorded and photographed before further testing.

This destructive testing determined the:

- **Extent of tooth penetration into the inner pipe wall**.
  The depth was measured from 20 indentations left by the tool’s teeth on the pipe wall. Most (80%) of the marks ranged from 0.1 to 0.25 millimetres, with a maximum depth of 0.38 millimetres. The deepest marks were found in the cap weld, where the initial contact between the teeth and the pipe was more intense.

- **Changes in macro- and micro-hardness from repeated setting of the slips at the same location.**
  Macro-hardness values (Vickers HV10) were measured at 1.5 mm (the NACE standard) and 0.75 mm depth from the surface. Macro-hardness values at 1.5 mm depth were less than 250 HV10, meaning they conformed to NACE MR0175/ISO15156-2 and indicated little to no effect from slip loadings, even after multiple settings and pressure cycles. Levels taken at 0.75 mm depth from the surface (50% of the NACE standard) showed an increase

https://doi.org/10.52202/078572-0022

from standard values but also a significant reduction from micro-hardness values taken nearer the surface at 0.05 to 0.725 mm depth.

Eight cycle tests conducted indicated no accumulation of surface hardening, suggesting that while repeated sets would further displace metal, there was no significant impact on the macro-hardness values.

- **Risk of Initiation and propagation of micro-cracks at the base of the tooth indentation.** Microscopic analyses indicated no micro-cracking at the root of the tooth indentation. Because the rest of the pipe material has low residual stresses, it is unlikely that if micro-cracks occurred, they would propagate through the pipe wall. Micro-hardness values (Vickers HV 0.05) ranged from 180 HV to 350 HV.
  Eight cycle tests in the same pipe bore area resulted in no significant increase in hardness. Sub-surface micro-hardness values showed a significant downward trend as the distance from the edge increased.

Findings

While tooth marks on the surface can elevate surface hardness, the values rapidly decrease to acceptable levels, typically at a depth of between 0.125 and 0.5 mm. The pipe zones that hardened during teeth penetration were small and not expected to influence the sour service capability of the pipe. There was no evidence of micro-crack formation at the base of the tooth indentation.
Based on these findings, TDW and the involved client's pipeline and material-technical authorities concluded that the SmartPlug tool's impact on the pipe wall after multiple deployments was superficial and unlikely to increase susceptibility to SSC.

An independent third party created the test report.

COMMUNICATION TECHNOLOGY

Introduction to SmartTrack™ and through-wall ELF communication

In the late 1990s, TDW designed and developed its SmartTrack™ system, operated in conjunction with its proprietary SmartPlug® tool for onshore and offshore, in-line pipeline pressure isolation. The SmartTrack system is based on through-wall communication via extremely low frequency (ELF) signals that remotely track and monitor the isolation tool and allow the activation/deactivation of the SmartPlug tool. The technology has advanced and evolved over time and is now also a viable alternative to traditional pig tracking and monitoring technologies, as in-line tools can be fitted with the SmartTrack transponder and is functional in any pipeline and its components, onshore, offshore topside, or subsea.

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The SmartTrack system's two-way (bi-directional), through-wall communication takes place between the tool's transponder and an externally located transceiver. Each transponder that is an integral part of the tools control system or mounted to the in-line tool as a separate transponder unit is assigned a unique ID code. As it moves through the pipeline, the transponder emits a unique signal that is picked up by transceivers situated near or on the exterior of the pipeline. The signals are then relayed to a user interface, allowing the pig/tool to be easily identified as it moves through the pipeline system. Depending on the conditions and equipment used, signals have been received from pipelines buried at depths of up to 3 meters and from transponders with a separation distance of up to 5 meters. The general limit of wall thickness for precise communication is tested and confirmed to be 2.56in (65mm), though the system has achieved communication through 4.33in (110mm) wall thickness with careful engineering and planning of how the equipment is installed in the field.

One of the unique features of the SmartTrack system is that transponder settings, such as signal frequency, ping rate and signal strength, can be remotely adjusted during operation if operational conditions change or if battery life needs to be conserved. This feature is particularly useful in long-term, delayed operations or operations put on hold due to adverse weather conditions. In such cases, the unit can be remotely deactivated and set to dormant mode, then reactivated when required by the operator. In the dormant mode, the measurement functions are deactivated, and power is conserved, extending battery life significantly (by several months/years depending on which equipment).

Any part of the SmartTrack system external or internal to the pipeline can be supplied as an ATEX/IECEx/UKEx certified product for use in Zone 1. This allows the communication equipment and isolation tools to be utilized without a hot work permit. This severely reduces the amount of risk assessment work having to be performed to issue the permits in the field.
Each individual SmartTrack unit has an individual coded signals which ensures security and communication with the correct identifiable unit (a SmartPlug control system or an individual pigs tracking transponder).

The use of SmartTrack to control and monitor a SmartPlug® inline isolation tool.

More than 380 offshore pipeline isolation operations have been performed with the SmartPlug in-line isolation tool. Activation, monitoring and tracking of the tool has been done with the SmartTrack system in all cases, and the SmartTrack system has proven to be safe and reliable even in challenging environments. The through wall communication allows the technicians on the job site have control of the tool throughout the planned sequence of the operation.

Due to the diversity of pipeline design and the different repair scopes, isolation operations vary in how they are implemented and executed. Some stages of the operation are common. The main usages of two-way communications in an in-line isolation operation include:

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Status prior to running the tool

Before loading into the pig trap, the SmartPlug® tool can be wirelessly interrogated to verify status of internal hydraulics, valve packs, communications systems, etc. This avoids having to open any connections in a field environment.

Figure 6: Tool status prior to loading

After loading the SmartPlug® tool into the pig trap and pressurizing the pig trap to line pressure, a final verification can be made that all systems are satisfactory before initiating the steps of the operation that affect the production operation of the pipeline. (e.g. opening valves and the SmartPlug® entering the pipeline flow, or the start of a shutdown of the pipeline production).

Pig tracking

Standard use of the tracking part of the system. Transceivers can be placed at strategic points along the route, or a handheld transceiver can be used to follow the pigging progress depending on the pigging speed. (Sections of the pipeline with more challenging pigging, such as valves, tees, or sharp direction change, where tracking would be required are areas where the pigging speed would be reduced.) Accurate and reliable tracking data is critical during pigging of an inline isolation tool.

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Figure 7: Pig tracking with handheld SmartTrack transceiver

Pin pointing

When a tool is tracked to its intended isolation location, knowing its exact position may be required. Pinpointing the location is performed using the same communications equipment as tracking during pigging. In pinpointing mode, the location of the tool can be identified to +/- 1 inch.

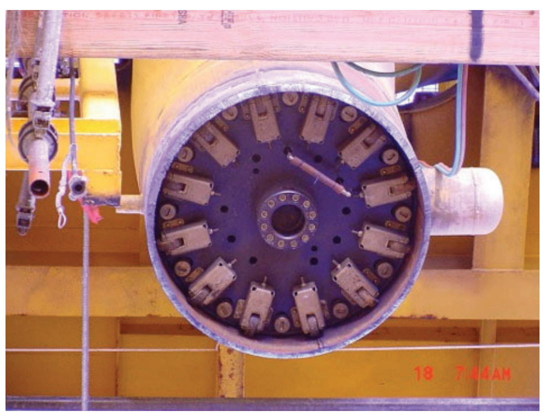

Figure 8: Pipe cut 4in from 36in SmartPlug® isolating 950psi

Status and activation of tool

With the isolation tool in place at the intended activation location, the SmartTrack system is used to receive a verification of the tool status. In the unlikely event that the tool has malfunctioned during pigging, it is beneficial to identify this before activation. As there is no opportunity to visually inspect the tool within the pipeline, identification of damage can be done by reading the sensors within the

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tool. This status also provides a baseline for the pressure and temperature conditions prior to the isolation.

Tool activation is initiated through the SmartTrack system then the control system of the in-line isolation tool reports back when it has performed the requested task. The activation of the SmartPlug® tool is performed using automated sequences. If a sequence has for any reason not been performed or has not achieved its desired outcome the system will report this. The supervisor can then evaluate the information and take the necessary steps to fault find and bring the tool back to the required status.

Evaluation of the tool status before issuing isolation certificate

Isolating pipeline content is a critical operation. Before issuing an isolation certificate and handing over the isolated pipeline to the client, the SmartTrack system is used to receive the data needed to evaluate the safety and integrity of the isolation. This is more than just identifying that there is no passing pressure across the tool. Pipeline pressures, temperature within the pipeline, hydraulic pump run time and, internal pressures of the tool's hydraulics are all recorded and can be compared to historical values and pre-tested conditions.

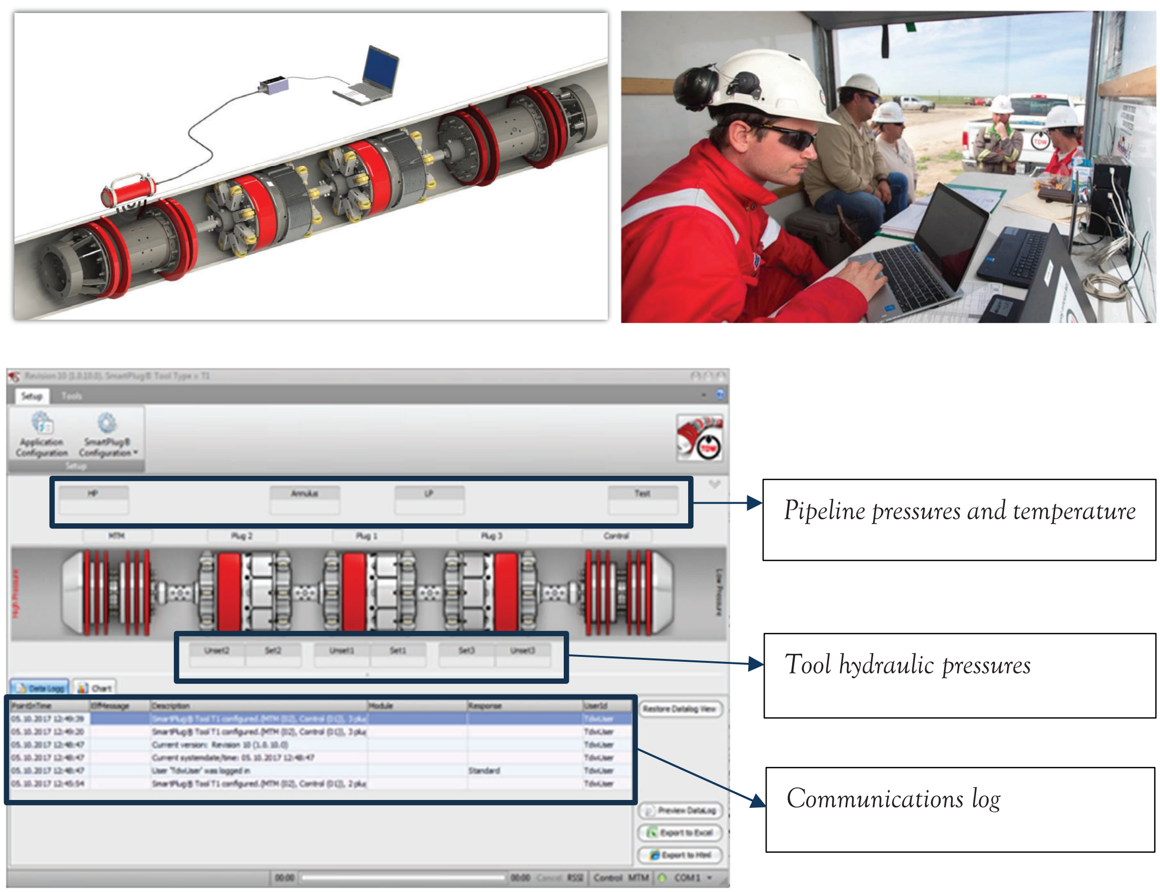

Figure 9: Graphical user interface of a SmartTrack system

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Verify the integrity of the isolation, the tool performance and supply of pressure readings

With the isolation tool in place, the primary role of the SmartTrack system is to provide the monitoring of the pressure between the two independent barriers of the SmartPlug® tool to verify the integrity of both barriers throughout the isolation period. In addition, the sensors on the tool can supply additional pressure readings. During both isolation and hydrotest, especially if a leak test of a valve using the volume between the valve and the hydrotest module of the SmartPlug tool. In the last situation the operator of the pipeline will often not have the ability to connect a pressure sensor to the pipeline at the required location. So, the only solution is to use the SmartPlug® sensors. All the SmartPlug® sensors are verified against calibrated sensors during the factory acceptance test of the SmartPlug® tool done prior to the operation.

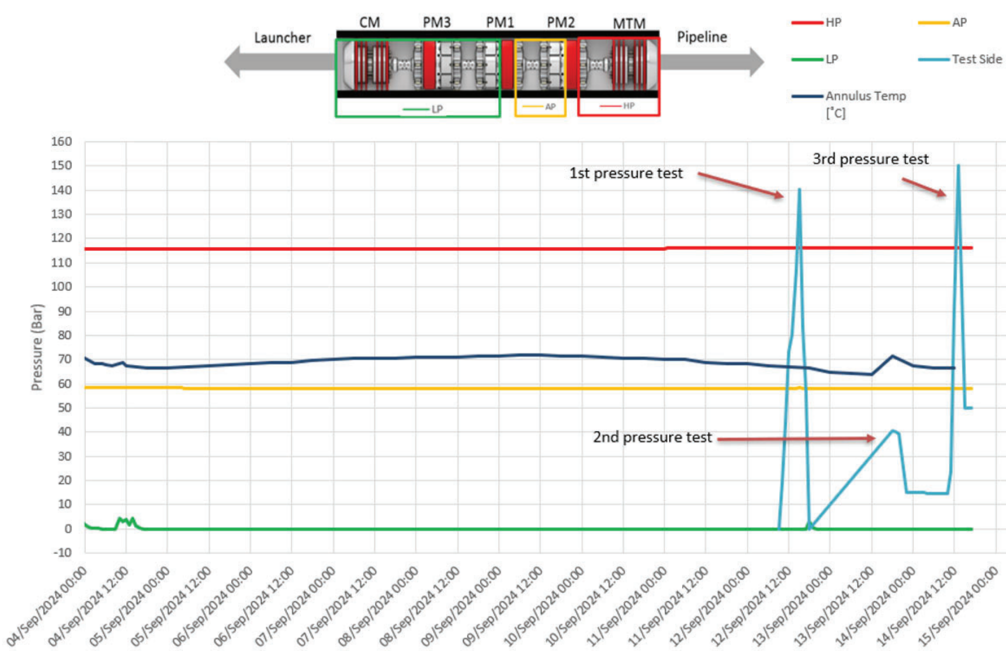

Figure 10: Output graph from SmartTrack user interface showing pressure test.

Remote communication (4G/Sat.coms)

The SmartTrack two-way communication system is used to communicate between the tool inside the pipeline and the communications equipment immediately outside the pipeline. During pipeline operations, there can be many reasons for wanting to utilize the communication data from a location that is not close to the pipeline. To achieve this TDW further developed a wireless solution for use from the field, through cellular 4G or satellite communication networks, allowing a limitless worldwide connection and the ability for TDW operators to monitor the isolations from anywhere, only dependent on access to the global networks. This figure illustrates the two options.

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Figure 11: Example of a 4G cellular and Satellite communication setup.

The driving factor for utilizing remote technology varies from operation to operation. The factors can be split into main groups:

Safety

- The isolation may be close to or have risks associated with the location. Examples of this could be exposure to the elements or unsafe travel route to and from the work site.

Efficiency

- Making the operation more cost-efficient by reducing the number of technicians having to mobilize to a remote location.
- Reducing the amount of personnel on board a vessel or offshore installation.
- Avoiding having to run cables from the isolation to the monitoring location (e.g. crossing a busy road, or heavy equipment being moved around the job site).
- Allowing the sharing of real time data to multiple locations so parties from different companies or other affected assets (connecting pipelines, downstream plants etc) can make decisions based on the same real time data.
- The longer the isolation time the larger the gain can be from implementing remote monitoring.

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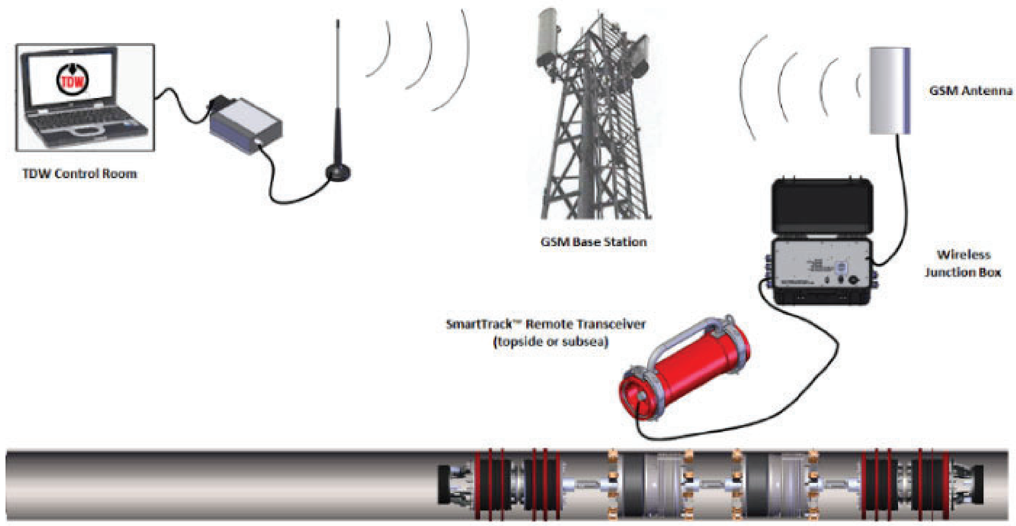

Figure 12: Using remote monitoring instead of running cables

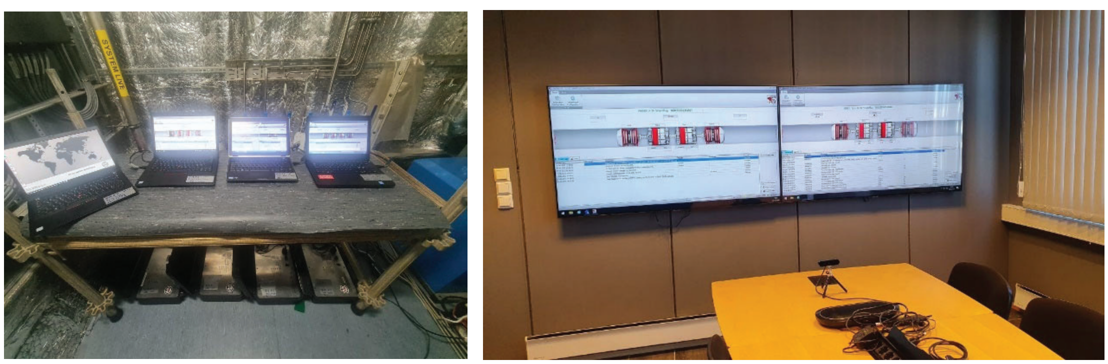

Figure 13: Office mirroring field by remote monitoring.

The remote monitoring system TDW has developed brings flexibility and adaptability to how TDW can solve field operations in the safest, most efficient way for our customers. To date the system has been successfully used on 23 operations.

SUMMARY AND CONCLUSION

This paper highlights the advancements and rigorous validation of non-intrusive in-line isolation tools as a safe, efficient, and reliable method for pipeline repair and maintenance. By addressing industry concerns, it aims to desensitize scepticism surrounding the use of gripping mechanisms and their potential impact on pipeline integrity. Extensive testing confirms that tooth indentations from

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grips are superficial, well within manufacturing tolerances, and do not compromise pipeline material properties or long-term performance, even under demanding conditions like sour service.

A cornerstone of in-line isolation technology is the use of zero-leak, independent, and rigorously tested barriers. These barriers provide redundancy, ensuring that no single failure point—such as a hinge point or seal defect—can compromise the isolation. The dual-barrier approach, validated against industry standards and best practices, reinforces safety by preventing leaks under high-pressure and high-temperature conditions, offering unparalleled reliability during critical pipeline interventions.

Another vital advantage is that no axial loads or stress are transferred into the fitting or branch line, reducing the risk of damage to the pipeline's structural integrity during isolation. This approach is particularly beneficial for complex configurations or operations in high-consequence areas where safety and precision are paramount.

Finally, the integration of through-wall communication systems like the SmartTrack™ technology marks a significant innovation in monitoring and controlling isolation tools. Through wired or remote options such as 4G cellular and satellite communication, operators can achieve real-time, two-way communication for precise activation, monitoring, and diagnostics of isolation tools. This capability enhances operational safety, reduces costs, and supports decision-making by providing actionable insights from anywhere in the world.

In conclusion, non-intrusive in-line isolation tools represent a proven and robust solution for pipeline maintenance, balancing operational efficiency with uncompromising safety and reliability. By combining state-of-the-art gripping systems, zero-leak barriers, load-free fittings, superior seal performance, and advanced communication technologies, these tools redefine best practices for pipeline integrity management. This approach not only meets industry demands but also inspires confidence in the continued adoption of these innovative solutions across varied and challenging pipeline environments.

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