DESIGN, TESTING AND DEVELOPMENT OF A CAMERA PIG TO SUPPORT THE CLEANLINESS ASSESSMENT OF PIPELINES FOR CCUS

Author(s):

Edward Bartlett – Pipeline CCS and Leak Prevention System Custodian, ENI

Shaun Peck – Global Support Engineering Manager, EV Offshore Ltd (EV)

Introduction

ENI's Liverpool Bay (LBA) region is located in the UKCS (East Irish Sea) and is made up of five oil and gas producing installations: Douglas, Hamilton, Hamilton North, Lennox and Conwy.

Following the planned cessation of hydrocarbon production (late 2024/early 2025) the LBA region is to undergo a field decommissioning exercise, followed by a repurposing project which will see the LBA field being used for CCUS (Carbon Capture Utilisation and Storage) to support the wider UK Hynet project.

As part of the ENI LBA region repurposing project, a series of pipeline flushing and decommissioning activities are to be carried out across the offshore assets, including the subsea pipeline network, to support the project readiness activities.

It is recognised that pipeline cleanliness is paramount for the CCUS operation to be successful, therefore intensive pipeline cleaning is required.

To assess the level of pipeline cleanliness during pigging campaigns, it was recognised that the most effective way to assess the pipeline internal surface would be via camera to visually record the extent of any debris. This not only serves a purpose to assess the level of cleanliness at the time of pigging, but also supports the requirements for the final pipeline cleaning prior to CCUS operation.

The Challenge

Due to a gap in the pigging market EV were contacted by '*Baker Hughes Process & Pipeline Services Limited'* with the outlined premise of requiring a piggable camera, which could be used to visually record the internal surface of a pipeline to support the ENI repurposing activities.

The problem and therefore its solution made a successful inspection challenging due to:

- Schedule a challenging 6 week delivery timeline across the months of U.K. vacation.
- Design, build and test a successful system reliably and without error or delay.
- Deliver reliable camera images at the top tool speed, and at constant speed.
- Pipeline constraints dictating the design and form factor of the inspection tool.
- Pipeline cleanliness and pigging fluid turbidity.

In addition to the listed array of technical challenges the project had a very tight schedule. The challenges of schedule refer to the time between contract award and execution date. There was a 6 week window across the, less than ideal, summer holidays for this to be completed prior to acceptance testing. This on its own would be a major driver in the direction of the tool design, construction and would define the major building blocks.

One of the technical challenges of cameras entering the pipeline logging space is the speed of travel of the tool. Typical downhole tool logging tool speeds are within the region of 4m/minutes. The requirement from ENI for this operation was initially to log at 30m/minute. It was critical due to the application that the images gained had good clarity and that ‘motion blur’ did not affect the quality of the data obtained. In addition, the tools successful transition through bends and obstructions was key as these areas were possible areas where cleaning may not have been as effective and therefore needed to ensure the transition through these areas was smooth and at a constant speed to allow the best possible visuals.

The form factor of the tool would be driven by the pipeline ID and minimum bend radius to be encountered. EV looked to utilise as much of the existing hardware from the current downhole tools as possible. The restriction with downhole tools is usually the tool OD (commonly 1 $^{11}/_{16}$”) and the makeup tool length. Therefore, the hardware is usually long and thin and therefore very different to the conventional geometry of a pipeline pig.

With a tool design completed and the challenges solved, the issue of fluid clarity and pipeline cleanliness would be the next challenge. The camera would need to be optimised for worst case conditions, to ensure that debris/contamination from the pipeline internal surfaces didn’t impact the results. As the camera would be tuned to look through a fluid column much larger than is the norm in downhole operations, the operational procedures would also need to be created to ensure the camera was conveyed in the cleanest fluid medium possible.

The Solution

The schedule dictated that much of the hardware would need to be taken from current EV tools and existing material stock.

This instantly drove decisions around the optical elements of the tools which have long lead-times. EV employs a number of custom optics to enhance the visuals from the system, to ideally quantify the results gained and also to minimise the effects of the harsh environments worked within.

Electronically the system would be based upon EVs Optis® Infinity system (Figure 1). This allowed existing electronics to be used with minimal functional changes. The majority of the changes would be surrounding adapting to the form factor of the tools.

Figure 1 – EV Optis® Infinity

The design was developed wherever possible, in conjunction with a highly supportive supplier network, to utilise existing CADCAM programs to decrease the associated lead time (Figure 2).

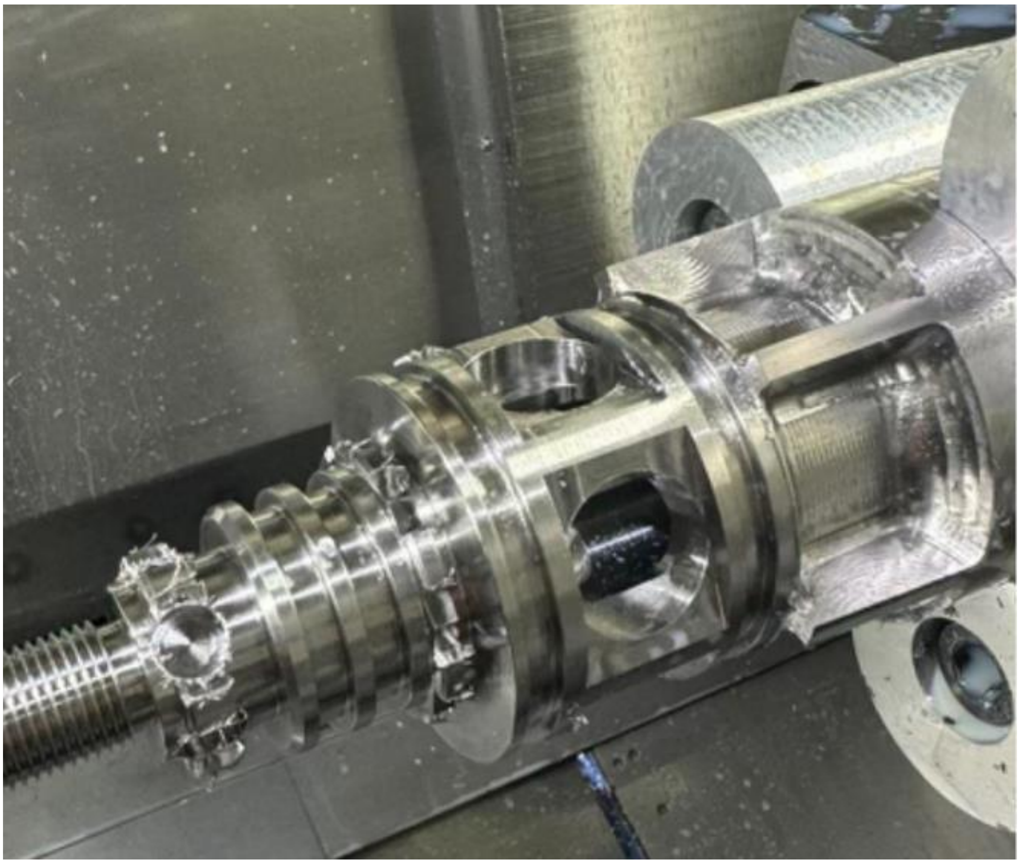

Figure 2 -Multi Camera Pig Body Machining

Optimising the camera to adapt to the increase of speed which the tool would be travelling at was a critical factor and a balancing act with what was possible with the available hardware, the constraints of sizing and compromises of camera functionality. As part of the development, EV utilised a piece of test equipment which had been commissioned for a slightly different purpose, to assess for a phenomenon known in the downhole sector as stick ‘n’ slip, this is when the downhole tool will be subject to irregular stop and start motions due to friction forces in high deviation wellbores (Figure 3).

Figure 3 – EVs Horizontal Test Pipe Facility

This test system is a 40ft section housing a linear actuator which the camera systems can be fixed within and ran at varying speeds within varying fluid turbidity.

With this, EV were able to optimise the camera operating parameters to give clear unblurred images at speeds up to 0.5m/s. The conditions within pipeline are relatively benign with regard pressure and temperature compared to the 125ºC and 15kpsi the downhole cameras usually work in. This gave us the opportunity to push certain parameters harder than would normally be allowable to overcome issues at higher speeds and more challenging fluid conditions (Figures 4 & 5).

Figure 4- Optis® Infinity Ran at 0.2m/s without Optimisation

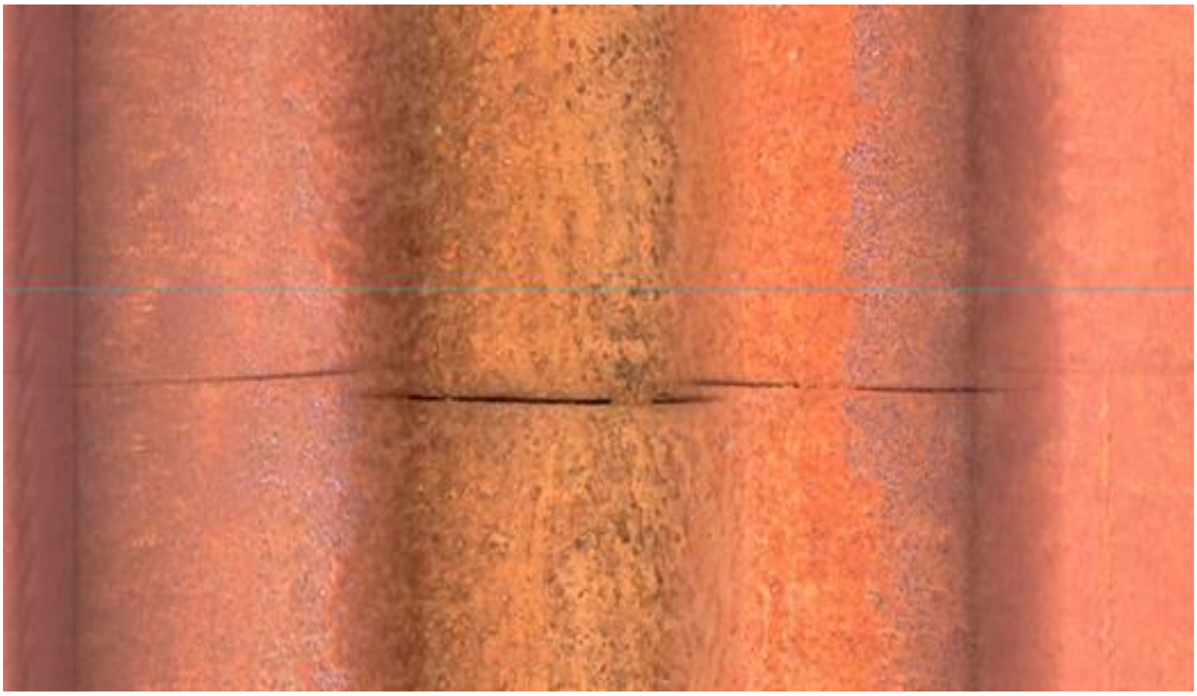

Figure 5- Optis® Infinity Ran at 0.5m/s with Optimisation

As detailed, the constraints of time and the requirement to give best in class images had led EV to decide upon the route of using the electronic basis from the Optis® Infinity System. With this and the pipeline information known, the tool had to split into sections giving a maximum body OD of 114.3mm and a maximum tool module length of 500mm. With this in mind the tool was split into 3 modules as detailed below (Figure 6). Whilst the direction of travel was still unknown, due to the complicated electrical interactions between PCBs and the maximum allowable cable length for signals to be sent without effecting tool performance we ended up with a Multi Camera Pig Module housing the camera optics and lighting. A Memory Pig Module which housed the PCBs to both operate and store the data from the Multi Camera Pig. The Memory Pig Module was also the place where the tool would be programmed with the recording intervals, light intensities and other key camera parameters set. The final of the three modules would be the Power Pig Module which would house a custom Lithium Battery Pack which was also designed and manufactured within the very short time window.

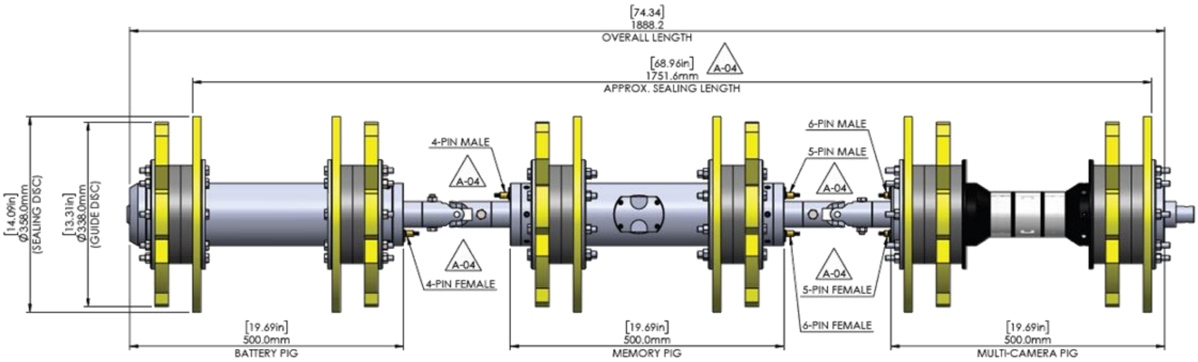

Figure 6- PigCam® Modular Design

The final piece of the puzzle was adapting the design and operational procedure to work within the potentially challenging conditions, where the pig train could remove debris from the pipeline internal surface and contaminate the pigging medium.

Having a low fluid turbidity plays a critical part of any successful downhole camera run and would be even more critical for this application. Generally, within the downhole space, a conventional 1 $^{11}/_{16}$" tool in >4" ID casing, would look through 1" of fluid. In the case of Pig Cam® the tool would be looking through >4" of fluid.

Optimising the lights within Pig Cam® was another way to help the camera performance in less than ideal fluids. The thinking here is similar to that of the lights you select when driving your car. Full beam is ideal when driving in clear, dark conditions where you wish to see further down the road but are next to useless when driving in fog as you are then met with a wall of white, a few feet in front of the car. With Pig Cam®, we gave the option prior to testing effectively of 'full beam' lights perpendicular to the camera body axis but also 'fog lights' with a wide light pattern with as little light as possible perpendicular to the camera body axis.

Due to the nature of the pig, there was a high potential for debris to be removed from the pipeline wall during the pig run, this would likely obscure the optics without the correct optical elements being used. To mitigate this, sapphire rings were utilised, which have additional surface treatment to allow contamination to fall away to the low side of the pipeline and stop any grease or fluid films adhering.

Result

Approximately 6 weeks after project commenced, site testing was carried out in a custom test loop at Propipe's Hartlepool facility. The test loop was constructed to reflect the pipeline geometry including the same pipeline ID and minimum bend radius (Figure 7). Successful testing was subsequently required to provide the final tool assurance prior to execution.

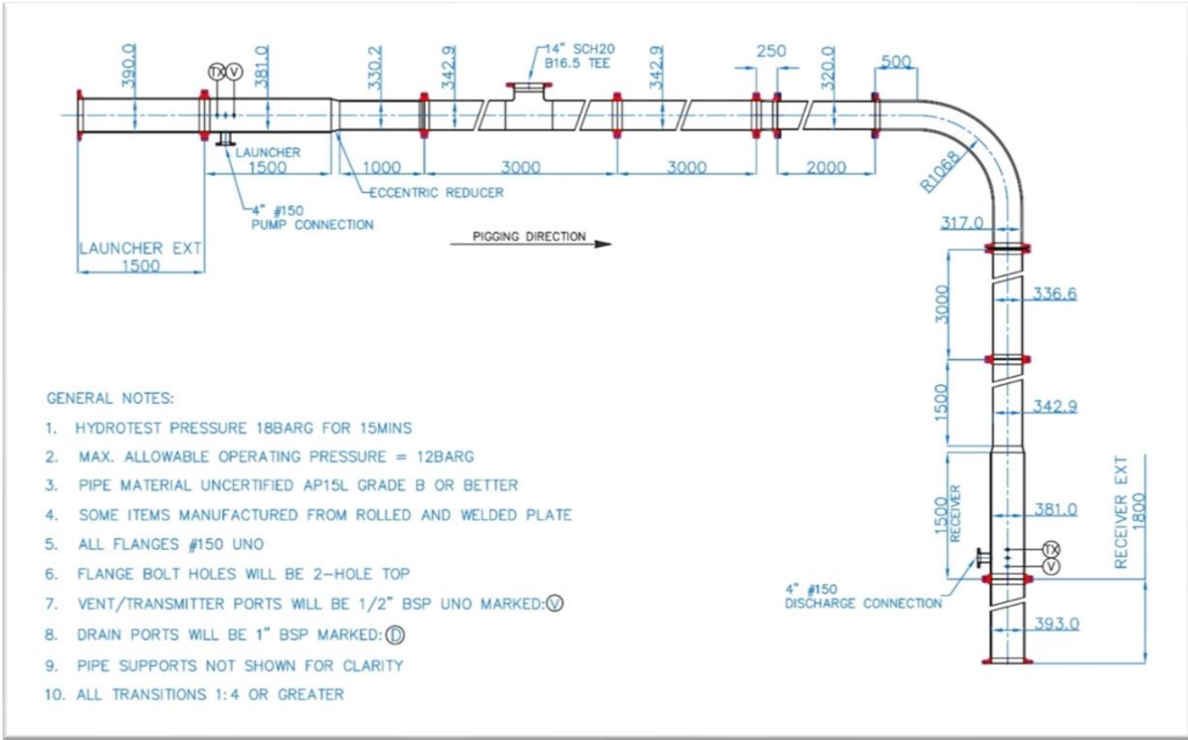

Figure 7- Propipe 14" Test Loop

The outlined objectives for testing included:

- To prove piggability of the system - could the pig maintain a constant speed and navigate the required bends.
- Position of the camera module - with fluid turbulence likely to impact the visual results, confirm whether the camera being at the front or rear of the train was critical.
- Light Level - with a number of highly reflective surfaces both on the camera system and within the pipeline what would be the optimum light level.
- Speed of travel - what was the optimum speed of travel and what camera setting fitted this speed best.

In total there were 9 runs carried out through the test loop:

Runs 1-3 focused on the piggablity of the tool, including the launch and receipt operation, and how the tool traversed the test loop bends. During runs 1-3 the pig speed was 0.17m/s, and the camera was positioned as the forward pigging module, the results showed lots of turbulence as the pig train pushed through the fluid (Figure 8). The key takeaway from these runs were:

- There was lots of fluid turbulence impacting the camera images.
- There was contamination settlement on the sapphire windows.

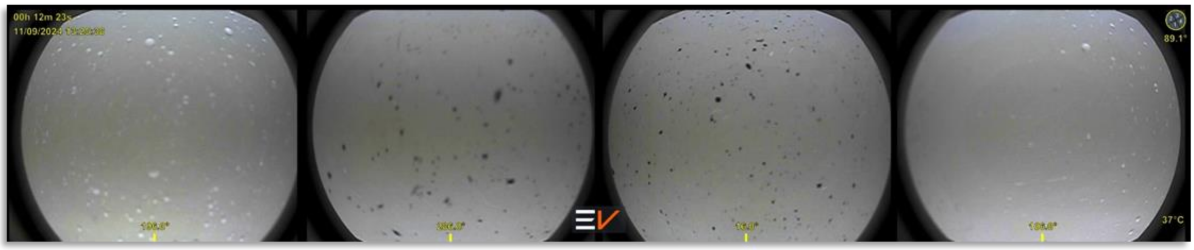

Figure 8- Showing Turbulence and Contamination on windows

Runs 4-5 were again at 0.17m/s but this time the Battery Pig Module was placed at the front of the train (Figure 9). The key takeaway from these runs were:

- Having the camera effectively towed led to much improved images, greater clarity and less turbulence.

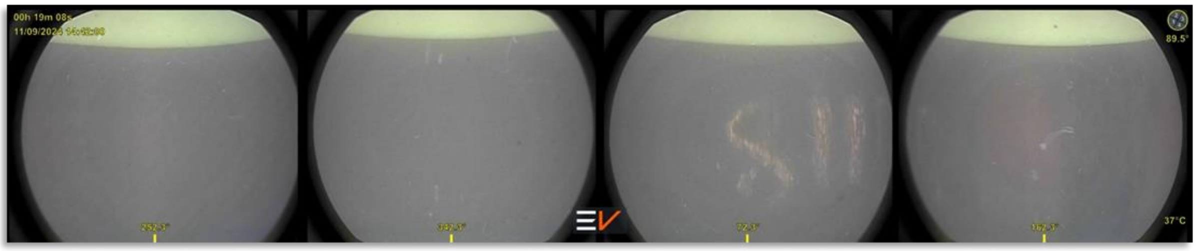

Figure 9- Internal pipe detail visible

Run 5 onwards, the goal was to improve the visuals via camera control and using all the experience of cameras EV have gained over 20 years of imaging in harsh environments (Figure 10 & 11). These included:

- Increasing the contrast by pulling out the blacks in the image.

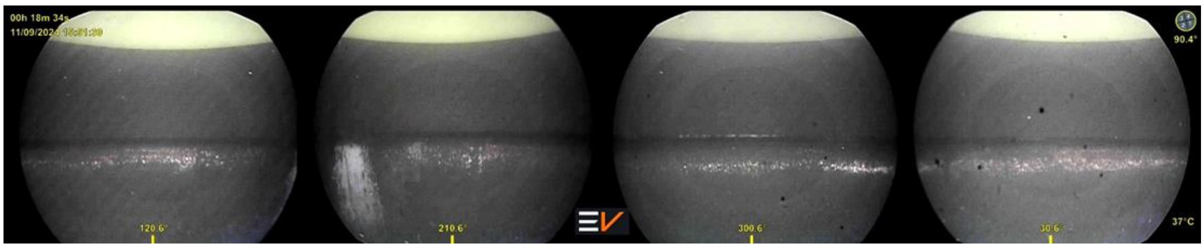

Figure 10- Higher contrast levels but lots of internal relections visible.

- Removing all areas of ‘bare metal’ from the camera module therefore removing internal reflection.
- Moving the sealing disks away from the camera so that the camera was focussed on the pipewall and the colour range wasn’t being affected by the sealing disks

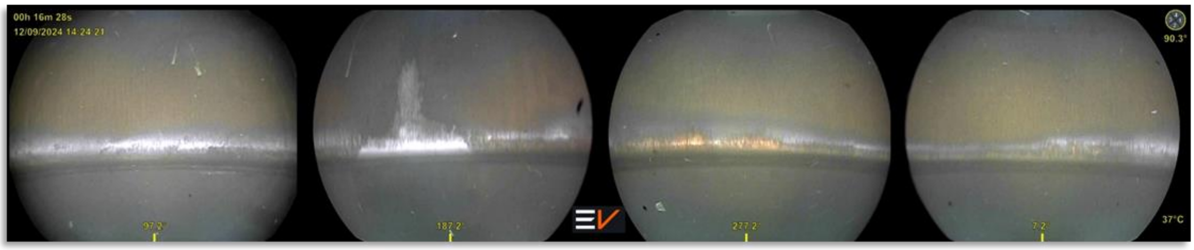

Figure 11- Run 9, ran at 0.2 m/s

Upon completion of the test runs, successful testing was confirmed and concluded that:

- The pig traversed the pipeline without issue. The custom cable joints worked without issue and didn't cause any hang up issues. Looking at the camera with the pipe open ended, it was possible to see as the camera passed the bends and minimal fluid bypass.
- The camera performed much more favourably being at the back of the train. Also moving the disks and changing the material from yellow to black gave favourable results. Using a surfactant more suited to water conditions on the optical windows led to far less contamination sticking.
- The lighting of the camera worked best being ran at maximum with all angle of lights lit. Light reflection from the metal surfaces resulted in internal reflection on the image, this was dramatically improved by blackening.
- With the correct settings and camera location, the tool was able to image well at speeds of 0.17m/s and the revised upper limit of 0.2m/s.

The quality of the final data sets was such that an idea of scale of defects or anomalies could be given. EV's proprietary dimensioning software was used and examples are shown below (Figure 12).

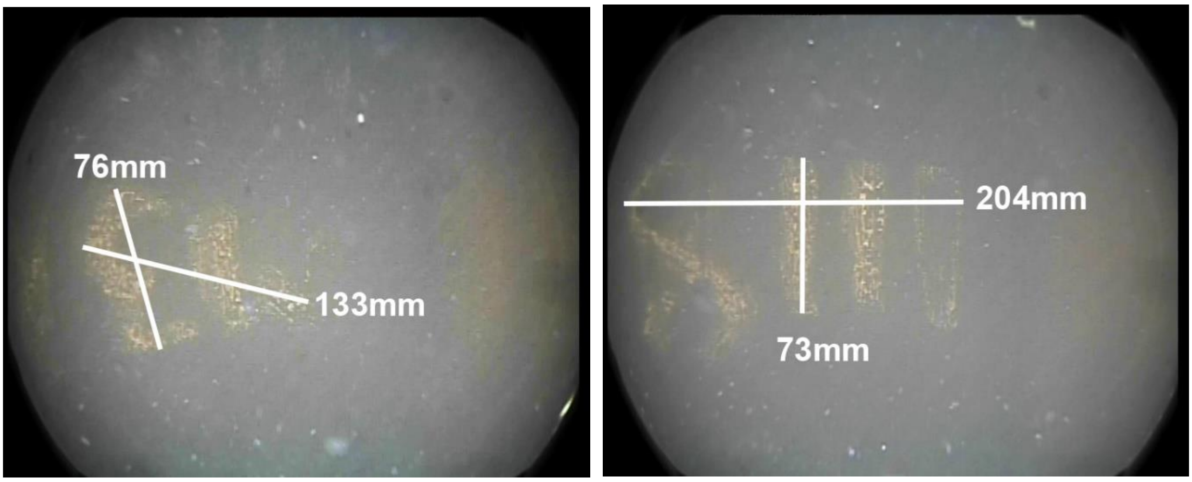

Figure 12- Dimensioning Examples

Finally, as a potential deliverable to ENI, EVs stitching software was used to generate the image stitch, showing a section from the test loop (Figure 13).

As can be seen this gave a very clear image of a section the pipeline ID.

- Image stitching improves the image clarity by analysing a feature over a number of captured frames and creating a composite image using the best parts from each frame.
- Within this Image processing, techniques are used to locally enhance contrast and automatically detect the key areas of interest.
- This isolates the camera movement from particulates to create a static image and reduces the interference from particulate seen in a video.

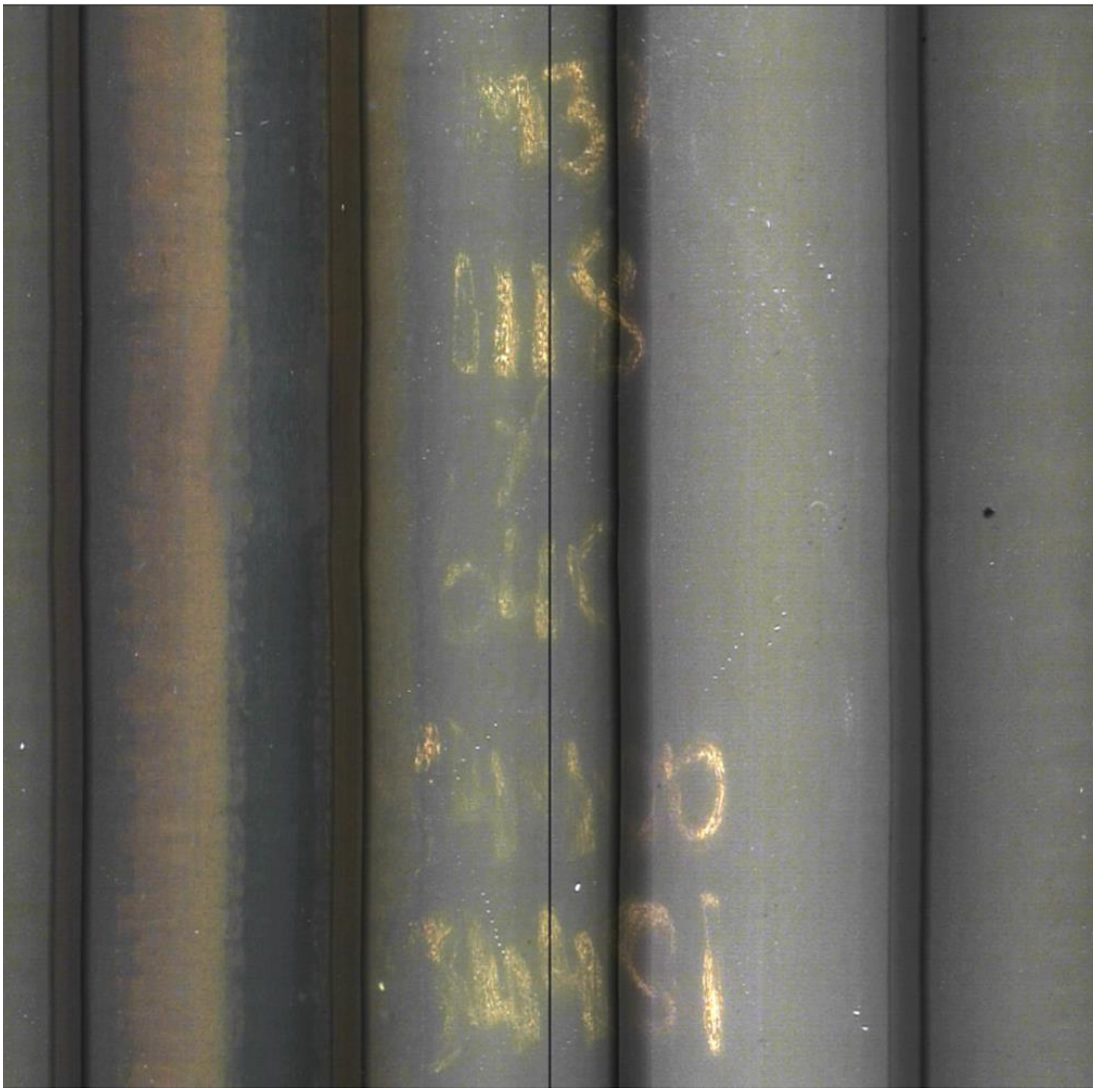

Figure 13- Stitched Image at 0.2m/s

Conclusion

Despite the very tight 6 week project schedule, a project was executed and verified delivering a viable solution to meet the ENI challenge and requirement to assess the level of pipeline cleanliness during pigging campaigns via camera to visually record the extent of any debris. This not only serves a purpose to assess the level of cleanliness at the time of pigging, but also supports the requirements for the final pipeline cleaning prior to CCUS operation.