SIMPLIFYING PIPELINE INSPECTION.
THE INTEGRATION OF ADVANCED EDDY CURRENT SENSORS ONTO CONVENTIONAL FOAM PIGS.

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Abstract

Pigging tools for pipelines are typically dominated by cleaning pigs at one end of the spectrum and intelligent pigs at the other. The cleaning pigs are simple, low cost tools that are deployed by onsite technicians and pose little operational risk to the pipeline Operator. Their simple design and construction, especially with foam pigs, mean there is little risk of them getting stuck in the line, mobilisation costs are low and they can be deployment & retrieved using standard facilities. Intelligent pigs on the other hand are complex tools that need to carry the NDT sensors and electronics / power modules in a configuration that allows for optimum inspection capability while maintaining good Piggability. The use of Intelligent pigs require significantly more planning in terms of logistics and operations, the use of specialist personnel for deployment and the processing of data. The impact to production and the cost of inline inspection is significant and subsequently ILI tools are only deployed in a pipeline every few years, therefore data can be infrequent. I2i Pipelines have pioneered the development and integration of advanced electromagnetic inspection sensors onto conventional cleaning tools for the regular inspection of pipelines. The innovative pigs bring together the best capabilities of both types of tools, the ease of use, the low risk and the low cost of a cleaning tool coupled with the advanced NDT sensors normally associated with more expensive ILI tools. The result is a fully capable range of inspection tool that can be deployed regularly by onsite engineers to inspect pipelines for corrosion and cracking, trend inspection data and to capture any changing conditions within the pipeline. This paper will look into the technical challenges, applications and operational advantages of deploying inspection technology with routine cleaning operations.

Introduction

Simple, low cost inspection solutions for pipeline pigging operations are going to take centre stage in the pipeline services industry over the next few years. Oil Companies and Pipeline Operators are facing increasing pressure to reduce operational costs and increase value as the financial squeeze due to the low price of oil takes hold. There is also a strong operational need within the industry to design in-line tools that can be launched quickly and easily to look at frequency effects within a pipeline during its operational life. Pipeline inspection activity needs to remain high as maintaining existing, ageing, infrastructure will become more important as investment in new fields are put on hold in this challenging economic climate.

At the start of 2015 i2i Pipelines embarked on a project to embed advanced NDT sensors into existing utility pig design during the manufacturing process, to make simple utility pigs smarter, so data collection could become a regular, simple and low cost activity. Collecting inspection data on a regular basis is not something the pipeline industry has been able to do until now, due to the costly and disruptive nature of full inspection activities. A typical pigging programme will involve a cleaning programme with either foam or mandrel (utility) style pigs followed by an inspection run with either MFL or UT. The process is disruptive and costly to the client and subsequently is only carried out infrequently. There was a clear demand by pipeline operators and the opportunity to develop a low cost inspection solution that would allow inspection to take place during the cleaning phase prior to launching a full ILI tool. The reduced impact to production operations, the ability to collect data while cleaning and the subsequent cost savings could be significant.

The Discovery project started by i2i was to determine if inspection sensors could be safely and effectively embedded into foam pigs to give inspection data on internal pipe wall defects. The results of the project are detailed in this paper and show that foam pigs can now carry out effective pipeline inspection and gives pipeline operators another valuable option for the inspection of pipelines.

NDT selection

After studying the manufacturing processes used for foam pig manufacture i2i selected an eddy current sensor design for the build of the foam pigs. I2i designed a specific electromagnetic sensor specifically for the foam pig build and one that could be integrated without interfering with the manufacturing process. The NDT method needed to be able to inspect in multiphase and dry gas conditions as the foam pigs would be deployed in all pipelines rather than a specific medium. Electromagnetic or Eddy current inspection technology has several advantages over other inspection methods for this type of application as it can be deployed in both multiphase and dry gas environments. Eddy current also has the additional advantage of being able to image through non-conductive coatings so the pipeline would not have to be cleaned prior to inspection, which was a key factor in the whole application of the technology.

Ultrasonic methods were not considered due to the liquid couplant needed for dry gas pipelines and the level of cleanliness required for the technique to get any suitable results.

MFL technology was ruled out due to the difficulty in embedding magnets inside a foam body. Initial trials showed that the magnets would pull out of the foam when inserted into a pipe.

The Discovery Foam Pig project

The Discovery foam pig project was to stay as close to the original concept of the foam pig as much as possible. The idea was to embed sensors and electronics without changing the material selection or build process as much as possible and for all intense and purpose the final tool was to look and behave as a traditional foam pig with the added benefit of inspection sensors.

The build of the tool would involve a waterproofed array of sensors embedded into the fabric of the foam during manufacture and would be coupled to a pressure housing inserted into the centre of the foam via a pressure rated cable and connector. The sensor head was to be designed and priced to be a disposable item as it was highly likely the foam pig would get damaged during a pigging run. The pressure-housing cavity in the middle of the foam would allow the pressure vessel to be extracted and used inside another foam body of different pipe size if required. This design concept is shown below.

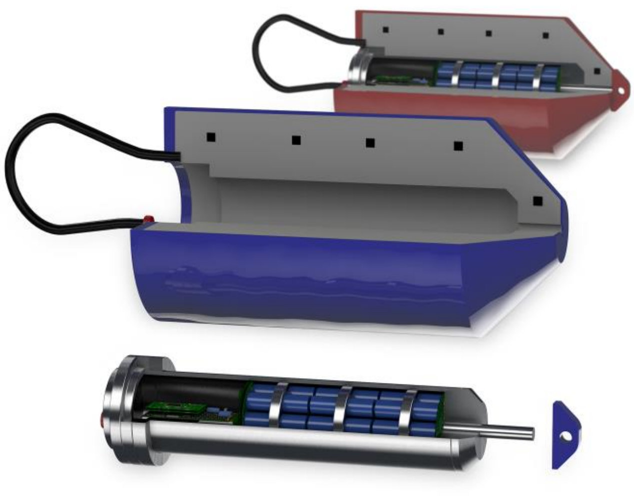

Image 1: Concept view of the Discovery foam pigs. The pigs are made with a cavity to house the electronics pressure vessel, which can be interchanged between new sensor heads.

The sensor array would be connected to the pressure housing with a pressure rated connector and cable. This same connection port at the back of the pressure vessel would allow for the programming of the electronics prior to an inspection run and the download of stored data after the inspection run was complete.

The pressure vessel would house the bespoke processing electronics and rechargeable battery unit. The housing would also hold a pressure sensor, Inertia measurement unit and temperature sensor for data logging and geographical mapping.

The manufacture of the Discovery foam pig would take place in several stages:

Firstly, the inspection sensors were embedded in a PU coating to ensure they were waterproof. Any water ingress onto the sensors would make them redundant and distort the signal. Once the sensors are waterproofed they are then placed inside the foam pig cast towards the end of the cast body. The first generation sensor arrays where in a helical array to allow for extension if the foam pig should encounter a partial blockage. This design was problematic, not only to waterproof the sensors but also positioning them into the mould during manufacture. The process was time consuming and there was considerable scope for misalignment.

The foam pig cast is prepared as normal with the addition of a pressure housing cavity plug positioned in the centre of the cast prior to pouring the foam. Once the foam is poured and set the plug can be removed to leave a void for the pressure housing.

1st Generation

The first generation of Smart foam pig included a helical design of sensors running diagonally within the foam was to allow for the extension of the pig if it changed shape as it negotiated partial blockages or multi diameter pipelines.

A cavity was left for the pressure vessel to be inserted into the centre of the foam. The pressure vessel was then connected to the front of the foam pig with threaded bar and washers.

Image 2: 1st Generation foam pig. Sensors arranged in helical array. No PU cup was included in the design at this stage.

The helical shape of the sensors was also very difficult to wire together and made it difficult to manufacture the foam pig. The shape did allow for 100% inspection coverage but the difficulty in manufacture and assembly did not make this a viable option for future development.

This helical design would only be considered in future bespoke builds where the tool was being designed for a specific multidiameter pipeline application.

The first generation prototype was run in the Montrose test loop on several occasions over the summer of 2015. A number of design flaws where highlighted very quickly. The first major flaw was the lack of strength in the nose section of the foam pig to retain the pressure vessel.

Image 3: Failures occurred when the internal pressure vessel blew through the nose of the foam. The foam body alone is not strong enough to hold the pressure vessel in place. This is especially the case for smaller diameter tools.

The pressure vessel surface area was nearly equal to that of the foam body and as the pressure increased behind the pig the PV forced itself through the foam pig body.

2nd Generation Prototype

The 2nd generation of Discovery pigs built on the failures of the first designs and included a hard PU cup moulded into the nose of the foam pig during manufacture. This standard PU disk would be bolted onto the front of the internal pressure vessel holding it in place as the pig was pushed through the pipeline. A pigging disk was also bolted onto a flange at the rear of the pressure vessel. This rear disk would help a uniform drive of the pig through the pipeline. The combination of front PU cup and rear disk was a significant improvement to the overall design and allowed the internal pressure vessel to remain in place during the deployment.

Figure 4: 2nd generation foam pig with PU disk bolted to the rear flange of the internal pressure vessel.

The external PU coating on the foam pig did suffer excessive damage during the deployment due to the extra weight of the 20kg pressure vessel.

Figure 5: 2nd generation prototype. Damage to the outer PU coating due to the extra weight of the internal pressure vessel.

3rd Generation

The 3rd generation design included a number of subtle improvements that allowed the foam pig to travel around the loop with minimal damage. The design included a circular sensor array that was more securely embedded into the foam body, coupled with the front PU cup and rear disk, it gave the foam pig much needed support to counteract the extra weight of the pressure vessel. This particular design also include a 2nd external cup to the front of the disk to help drive the pig with the extra payload.

Image 6 shows a typical 3rd generation Discovery foam pig with the external PU coating cut away to show the position of the sensor array embedded into the body of the foam pig. The circular sensor array is much easier to manufacture and embed within the foam.

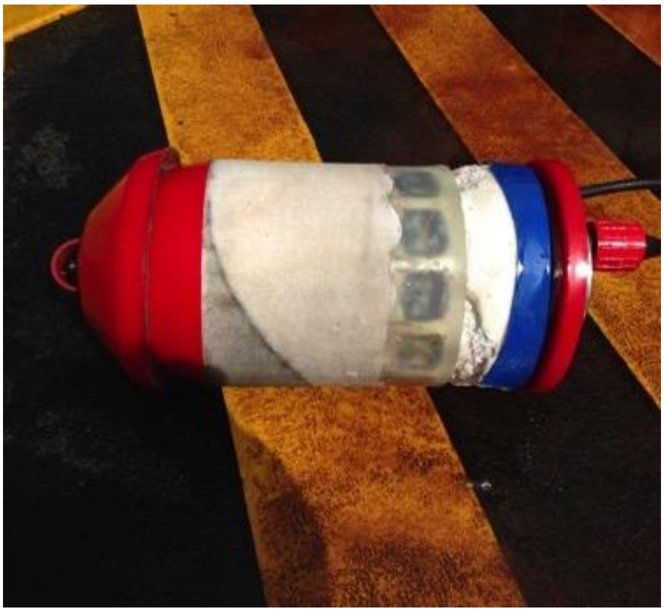

Figure 6: Sensor array in a circular belt design.

Test facility

The test facility used during the Discovery project was the 10” 1km pipe loop at the Petrofac training facility in Montrose. The test loop is the most realistic test facility in the UK as it has dedicated launch / receive chambers as well as a pressurised system that allows the tools to be pushed around the loop within inhibited water. The speed the tools can be pushed around the loop can vary between 1-3m/s.

Image 7: The 1km test facility in Montrose

The test pipework is made up of a series of welded and flanged joints covering 1km with 8 bends and 2 road crossings.

Inspection Data

Inspection data from the foam pigs was as expected from the laboratory trials. The sensors worked from a stand off of approx. 20mm from the pipe wall. The pipeline features were uniform and repeatable along the entire length of the pipeline with signals repeated on several inspection runs.

The signal amplitudes from the weld and flange reflections, an important indication of how the sensors were positioned within the foam body, were even over the 1km of pipeline showing that the sensors were secure in place and the foam acting as a stable platform.

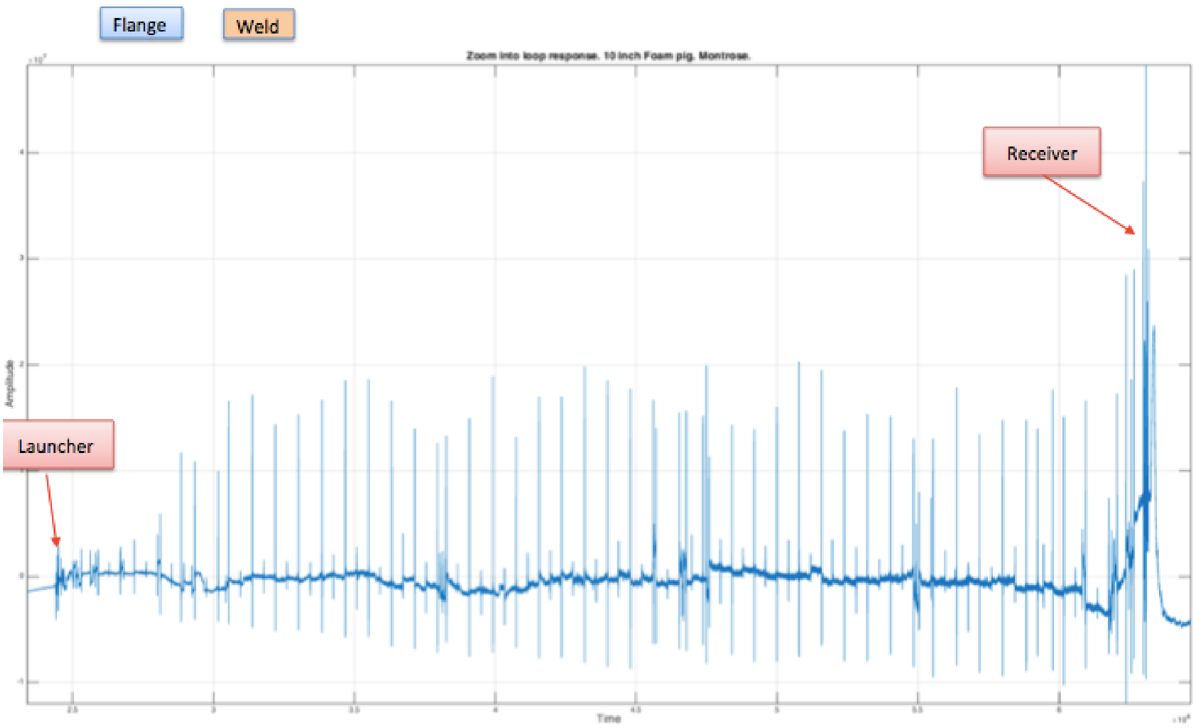

Figure 8: 1 km of data from the Montrose test loop

Image 9: The 1km of data is broken down into shorter sections to show the signal responses in more detail.

The signals in image 9 show the uniform reflections from all the pipeline features in the 1 km including the bends, welds and flanges. The back to back bends that make up the road crossing are clearly visible in the first section of the image 9.

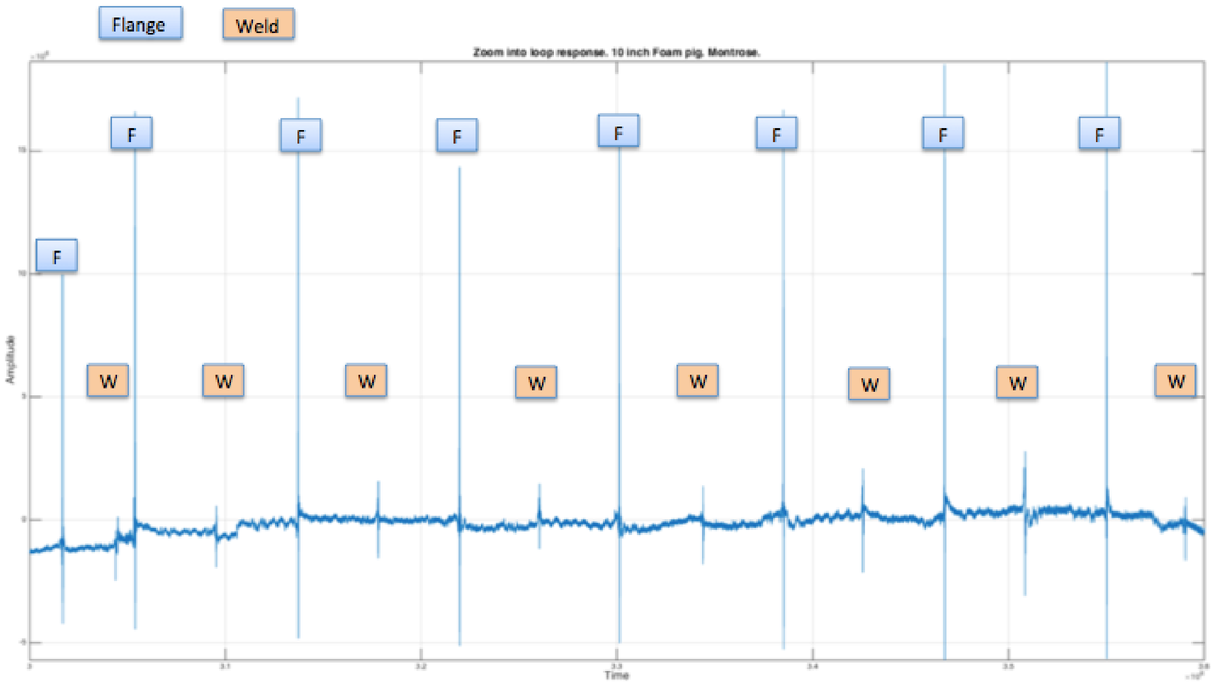

Figure 10: Shows the uniform signals along the straight sections of the pipeline

The signals in image 10 show how the foam pig can operate as a stable inspection platform to get good signal reflections for the pipeline features. This is an important consideration for the Pipeception signal recognition software that has been developed to automatically process these signals as part of the Discovery project.

Advantages

The advantages of embedding electromagnetic sensors into foam pigs can be significant, not just in that it offers an innovative and cost effective alternative to conventional inspection pigs but it offers a potential new strategy for the inspection of pipelines. Some of the advantages are listed below.

- Internal corrosion and fatigue cracking can be detected
- Internal inspection can be part of routine maintenance & cleaning operations
- Suitable for inspecting flexible pipelines – foam pigs can be less aggressive in the pipeline.
- Deployment has little or no impact on production
- They can negotiate complex geometry, reduced pipe bore and multi-diameter pipeline
- The can be launched & received from conventional facilities – all tools are < 1.3m in length
- They can inspect in multi-phase or dry gas environment
- Longitudinal as well as circumferential cracks can be detected – tested on lab pipe sample only
- Pressure, Temp & Velocity can be accurately profiled along the pipeline
- Innovative sensor mapping technology replaces conventional odometer

Conclusions and way forward

The advantages of combining advanced sensors with a simple foam pig design can be significant. If manufacturing procedures can be followed and the foam pigs can be constructed in a way that allows them to take the extra weight of the internal pressure vessel then the foam pigs can become a new inspection option for pipelines. Low cost, low risk, easy to mobilise and delivering inspection data on internal corrosion and cracking.

Simplicity of design and operation of in-line inspection tools is an important step in the evolution of pipeline inspection, especially in this new era of low oil prices. There needs to be a reversal in the trend of making things more and more complicated as simple tools with advanced sensors can be just as effective in detecting internal anomalies.