A NON-INTRUSIVE METHOD USING INDUCED PRESSURE WAVES TO TRACK MOVING OBJECTS WITHIN PIPELINES

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Abstract

A new live pig tracking methodology is proposed with field proven operational data. The new proposed method allows tracking from one end of pipeline. Additional sensors are not required along the route and a transmitter system is not required on the pig. The method can be applied to any object in a pipeline.

Tracking is based on analysis of induced pressure waves within the conduit. Data such as pig position, velocity and estimated time of arrival can be calculated. The method discussed has recently been successfully used to track pipeline pig location on a large diameter offshore pipeline project in eastern Europe. The pipeline had a stuck pig from recent precommissioning activities. The location of the pig was unknown. It was also unknown if the pig was stuck or still moving slowly.

InnerVue™ pressure wave technology was mobilised to the site. An initial analysis confirmed the location of the pig. A further analysis a short time later confirmed the pig was not moving. A remediation plan was put in place to retrieve the pig and pressure wave technology was used to track the location of the pig during its recovery.

Through successive testing, the live pig velocity was calculated and from this an estimated time of pig arrival. The pig arrived in the pig receiver within minutes of the predicted arrival time. Live tracking provided confidence to the pipeline operator that the remediation methods were going to be successful and allowed optimization of subsequent commissioning activities.

Introduction

November 2019 saw the dawn of a new era in real-time pig tracking when Halliburton Pipeline and Process Services successfully validated a live pig tracking method based on patented transient wave theory, the foundation of their unique InnerVue™ suite of services.

A negative pulse InnerVue™ Survey is best described as being similar to a sonar response technique. A controlled hydrodynamic wave is induced into a pressurised pipeline system and the position of a significant flow impairment can be determined by identifying reflexes visible in the recorded data trace. This method is suitable for use in both fluid and gas systems, though the analytical approach for either is very different.

With a focus on this application in gas systems, it is imperative that the acoustic velocity of the medium being transported in the pipeline is known as accurately as possible. Largely based on ideal gas theory and adiabatic propagation, unrestrained acoustic velocity is calculated and thereafter extrapolated into a restrained velocity profile specific to the pipeline. Characteristics are adjusted to reflect the operating parameters of the pipeline at the time of surveying; flow, pressure, and temperature all impact the density and compressibility of the gas. This has a direct effect on relative bulk modulus and the equivalent speed of sound at any given point in the system, which in turn, in addition to the considerations taken toward the specific shape of the wave generated, render the transit of any pulse within the pipeline as totally unique.

In 2019 Halliburton Pipeline and Process Services successfully executed an extensive pipeline precommissioning campaign in eastern Europe. During the proceedings a lost-pig occurrence prevented completion of the dewatering workscope of one of the 18” pipelines. Halliburton Pipeline and Process Services were appointed to carry out an InnerVue™ survey to locate the lost pig. The successfully deployed survey provided critical information necessary to develop a pig recovery plan once discovering that the lost pig was located 16.5km from the platform. Working closely with the EPC and Field Operator, a reverse pigging operation, involving Halliburton managing a combination of specialist services onshore, offshore and remote deepwater, was conducted to recover the pig.

A foam pig was launched from a deepwater pig launcher and travelled towards the platform. The propellant was nitrogen gas supplied from a membrane spread transferring N2 gas via twin gathering pipelines. A crossover at the subsea manifold presented a serious challenge to accurate pig location which traditional methods were not able to overcome.

Pig tracking specific InnerVue™ surveying was performed on board the production platform throughout the reverse pigging operations. In live conditions, pressure waves were transmitted through the system in real-time allowing live monitoring of the now-found-pig location. Once the foam pig reached this location, both pigs in unison began moving towards the platform. Surveying continued throughout and provided a real-time location, speed and estimated time of arrival.

The next phase of InnerVue™ Live Pig Tracking development is underway. It focuses on a commercialized practical solution deployable as an integrated offering with the flexibility to enhance pigging operations no matter the scenario or stage of the asset life.

Theory

In this section, the theory behind the utilisation of InnerVue™ pressure wave monitoring is explained. For tracking of objects, it is key that the acoustic velocity of the medium being transported in the pipeline be known as accurately as possible. To calculate the acoustic velocity of the pipeline contents, the following factors must be known: pipeline internal diameter (mm), pipeline wall thickness (mm), Young’s modulus (Pa), fluid density (kg/m^3), fluid bulk modulus (Pa), and fluid viscosity (cP).

The fluid characteristics need to be adjusted to reflect the operating parameters of the pipeline, as flow, pressure, and temperature can all impact the density of a fluid, which in turn affects the bulk modulus. From these characteristics, the acoustic velocity in an unrestrained fluid (relative speed of sound) can be calculated theoretically utilising the Newton-Laplace equation as per Rowlinson and Swinton (1982) and shown in Equation 1.

$$c_{fluid} = \sqrt{\frac{K}{\rho}} \tag{1}$$

Once this unrestrained acoustic velocity is known, a modified hooks law formula as per Chilingarian, Robertson and Kumar (1987) and shown in Equation 2 can be used to combine it with the pipeline characteristics to define the restrained acoustic velocity.

$$c_{system} = c_{fluid}\sqrt{\frac{1}{1+\frac{ID}{WT}*\frac{K}{E}}} \tag{2}$$

Object tracking is predicated on the premise that if the velocity of the pressure wave travelling in the pipeline is known and the time it takes to traverse the pipeline to the object can be recorded, then the location of the object can be determined as per Bird (2015) using Equation 4.

$$blockage\ distance = acoustic\ velocity\ x\ (\frac{time}{2}) \tag{4}$$

Objects can be tracked by repeatedly introducing pressure waves into the pipeline and monitoring for the response wave. Object velocity can monitored by introducing pressure waves at set intervals. Calculating distance travelled over a given time interval allows calculation of average object velocity and subsequently, pig estimated arrival time.

Data Collection

There are two requisites for data collection for analysis—that a pressure wave can be generated within the pipeline and there is a tie-in point for the data to be recorded. A data logger is connected to the pipeline at a point close to the pressure pulse generation point to record the changes in pipeline pressure caused by the pressure wave reflecting from objects in the pipeline. The use of an ultra-high-speed data logger recording at an equivalent 4,000 data points per second (dps) with a sensitivity of 0.15% ensures a high level of accuracy can be achieved, a reasonable indication of which would be one data point being referenced every 250 mm along the length of the system.

When the object tracking operation is ready to perform the data logger is set to record the pipeline pressure. A pressure wave can then be generated, and the pressure variations monitored and recorded, as per Figure **1**.

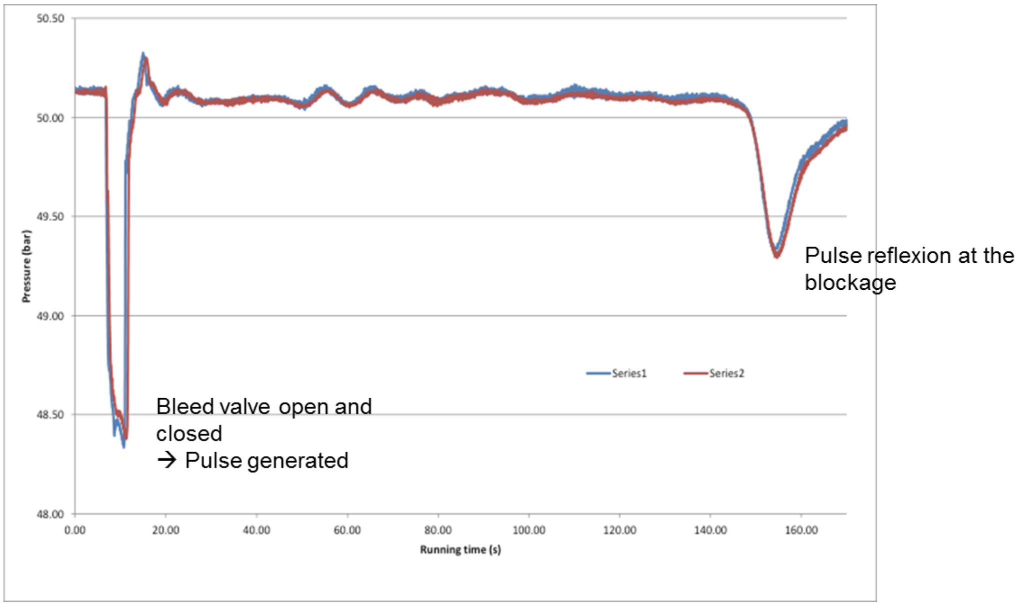

Figure 1. Typical Response Pressure signature

Figure **1** shows a pressure wave being created at approximately 10s. A reflex from this pressure wave is clearly seen at approximately 155s.

Pressure waves can be produced at set intervals to allow real time tracking. Data can be captured on the data recorder and automatically processed with real time location, object velocity and estimated time of arrival live streamed to a web portal or similar.

In situations where there is low confidence in the known fluid parameters and therefore the theoretical acoustic velocity, a calibration measurement may be possible if a system containing the same fluid is available. This could be the system to be surveyed if it contains a feature, such as a tee, which can be identified on the pressure trace. A measurement taken from this system will allow calculation of an accurate acoustic velocity using the equations detailed above.

Object Tracking Pulse Generation

To generate the pressure wave, a mechanism needs to be in place to allow the generation of a pressure pulse by bleeding off a small volume of fluid from the pipeline. This could be from the rapid opening and closing of a bleed valve with pipework routed to a safe vent location, as shown in
Figure **2**.

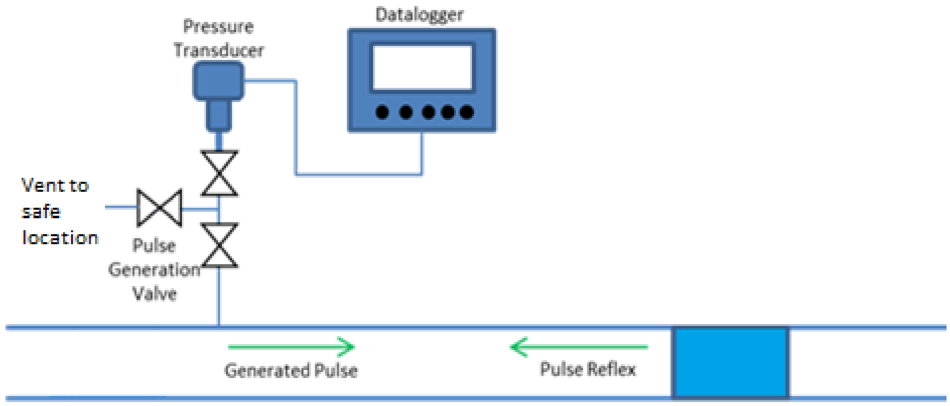

Figure 2. Typical blockage location data collection setup.

The pulse generation valve can be a manual valve operated by personnel or an automated actuated valve. With an automated valve, pressure waves can be produced at known intervals allowing continuous monitoring of object location.

Analysis

The data sets are analyzed using proprietary software to identify the pulse generation point and reflex, as shown in
Figure **3**.

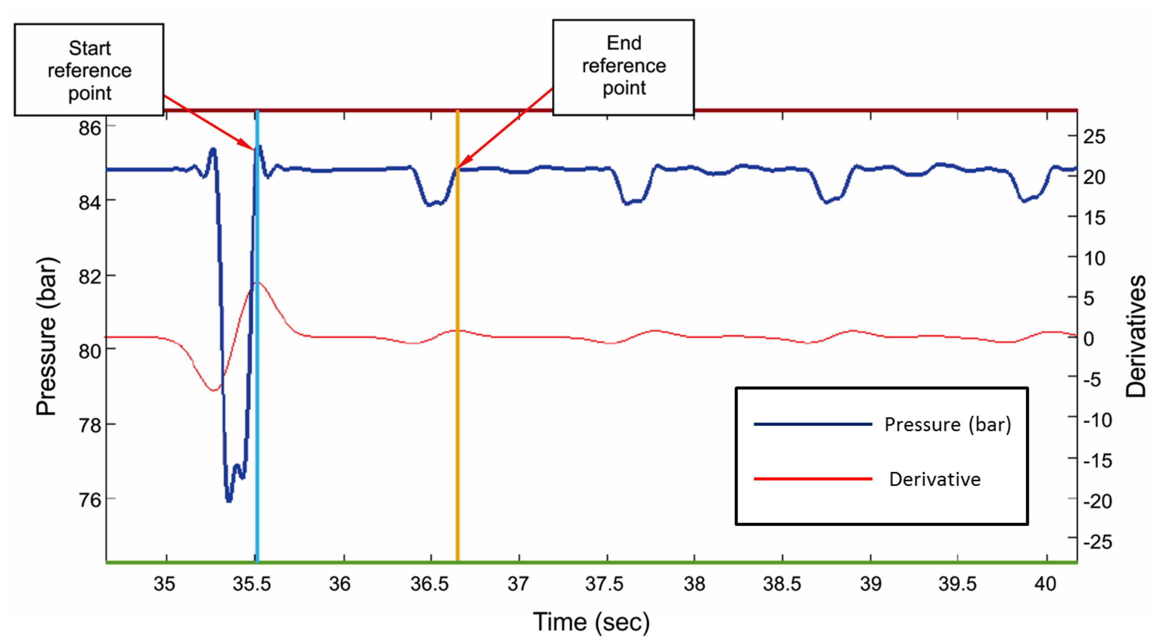

Figure 3. Blockage location pressure wave analysis.

A number of reflexes are often seen when tracking objects. Only the first reflex is used in object tracking calculations. Reflexes after the initial end reference point are caused by the pressure waves bouncing back and forth along the pipeline between the object and pulse generation points.

For object tracking, the time difference between the start reference point and end reference point in Figure **3** can then be used along with the acoustic velocity calculated in equation 2 to determine the distance to the blockage using Equation 4.

Object Tracking Case Study

There was an urgent need to locate a stuck commissioning pig in a new build pipeline in the Mediterranean Sea. An ROV survey to locate the pig was not practical. A non-intrusive survey was suggested as this would quickly and effectively locate the pig with minimal effort and no intervention required within the main pipeline. A non-intrusive pressure wave survey offered the lowest risk and quickest option to locate the blockage and track recovery of the pig.

The precommissioning pig was being propelled by Nitrogen gas. From equation 1 the acoustic velocity of Nitrogen at the operating conditions was found to be 349m/s. Understanding the acoustic velocity would allow locating and tracking of the pig though pressure wave analysis.

After setup of the temporary InnerVue™ equipment to record and induce pressure waves, a number of pressure waves were introduced into the pipeline behind the stuck commissioning pig. Average pressure wave response from the surveys can be seen in the figure below.

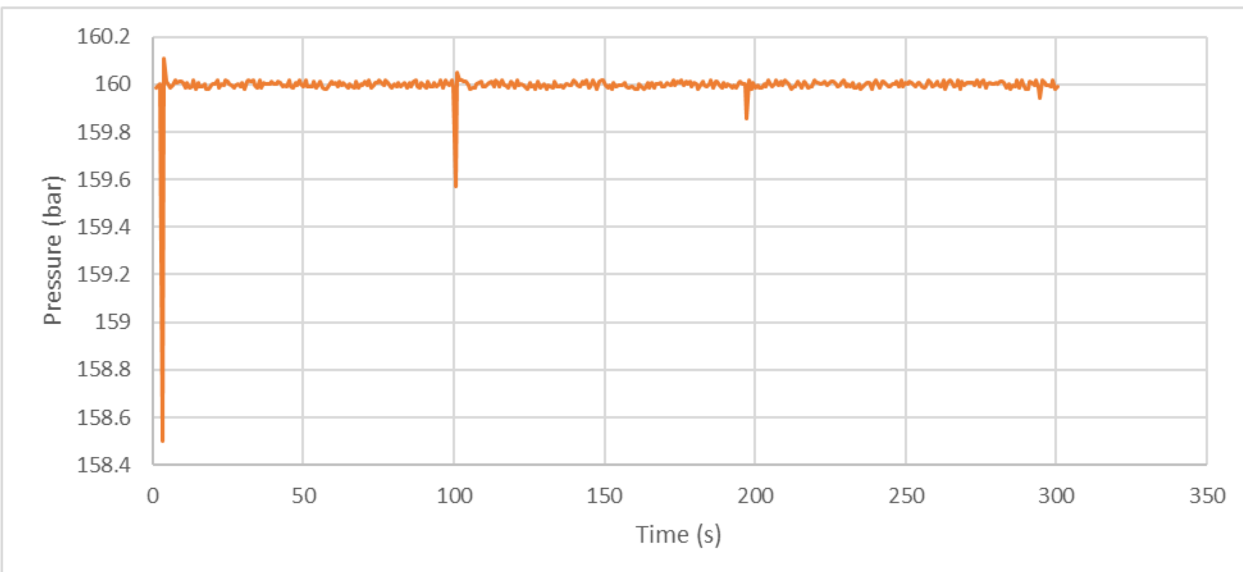

Figure 4 – Initial pressure wave analysis to identify pig location

The initial pressure wave recording shows the pressure wave being created at time 3s and then a large reflex at 100.1s followed by a much smaller reflex at 197.2s. The time between the first and second reflexes is consistent at 97.1s. This shows a strong initial pulse wave and response followed by a further response as the pressure wave travels back out to the pig and returns to the data recorder.

The pressure wave response time and acoustic velocity can be used to determine the location of the object in the pipeline, in this case the stuck commissioning pig. Equation 4 is used, and this confirms the location of the pig to be at 16,500m.

In this instance, now the blockage location was known, a remediation plan was put together. It was decided to drive the pig back to the pig launcher using a foam pig. During reverse pigging, pressure wave analysis was performed at short intervals to confirm pig average velocity, pig location and estimate pig arrival time back at the pig launcher. A sample data set taken 2 hours into reverse pigging operation can be seen in the chart below.

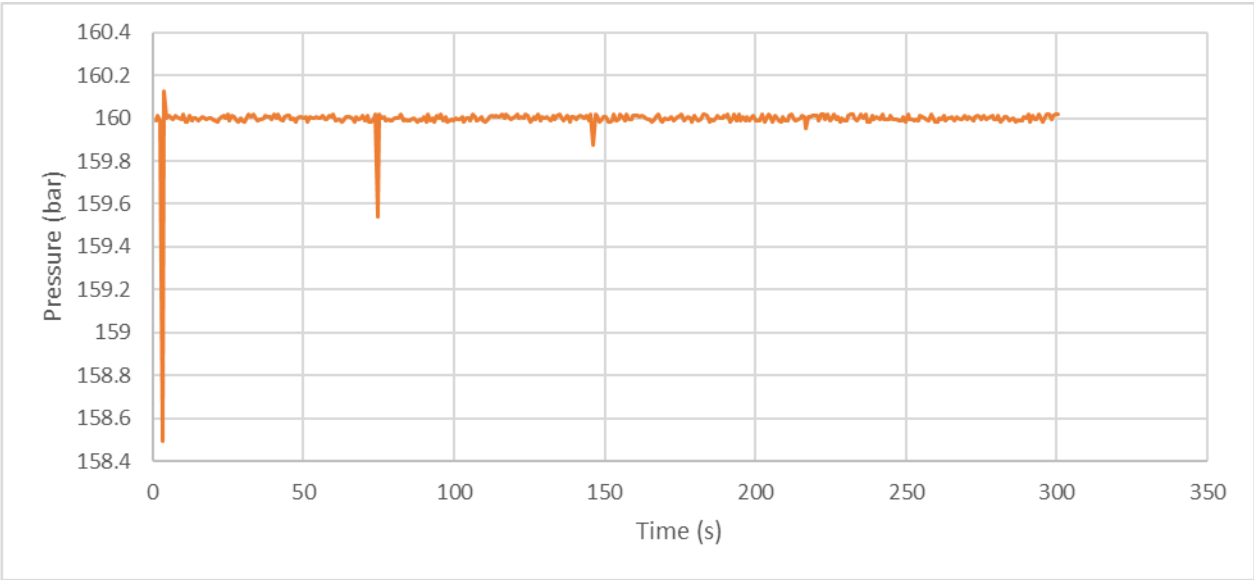

Figure 5 – Pressure wave analysis after 2 hours reverse pigging

The pressure wave analysis shows a response time at 74.2s. The pressure wave was created at 3s, this gives a pressure wave transit time of 71.2s. The new pig location from equation 4 is 12,100m from the survey point. The pig had transited approx. 4,400m with a pig velocity of 0.6m/s. The estimated time of arrival was calculated at 5.6 hours.

Further pressure wave analysis was performed at regular intervals until the pig was received back at the pig launcher. The acoustic velocity was updated as the surveys progressed, and the operating parameters of the pipeline changed. The pressure wave analysis allowed continuous tracking through the recovery operations.

Conclusion

The theoretical models behind the methodology are validated by proven results in actual pipelines, showing an acute level of accuracy when locating pipeline blockages and tracking moving objects. In addition, the pressure wave analysis removes the risk of inserting tools into the pipeline or investing in costly onshore excavations or offshore vessel based ROV surveys.

Pressure wave analysis has been shown to be an effective method for locating, tracking, and monitoring movement of pigs and potentially any object within a pipeline. The method offers reduced cost and reduced risk when compared to traditional methods with pig signalers or otherwise. Locating and tracking can be performed using pressure wave analysis at any point in a pipeline with very little intervention required. The technology offers a cost-effective low risk option for tracking of objects.

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