Development and implementation of a real-time Pig Tracking System

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0. Abstract

During an in-line inspection, information on current speed and position of the inspection vehicle (the pig) is crucial. In the past, pigs were tracked manually by ‘tracking crews’ within Gasunie in the Netherlands. Despite large efforts, the information conveyed by the tracking crews was always delayed, subjective and incomplete. This motivated Gasunie to start the development of a system to provide relevant tracking information continuously and in real time to the operators.

The development process took a little over two years and included the design of the system lay-out including user interface and the mobile field units. The process resulted in a real-time pig tracking system, named DEXPTS. This system provides an information basis for decision-making and reduces manpower requirements. If a pig is stuck or “lost”, the recorded data can reduce time and costs for search operations.

Since the initial run in June 2013, the system is used during all in-line inspections. The system is gradually changing the way in-line inspections are monitored and controlled. In the meantime, several other infrastructure companies have shown interest in this development.

The purpose of this paper is to outline the development and implementation of this pig tracking system, and the influence it has on the way in-line inspections are executed.

1. Introduction

A common method for inspecting pipelines is in-line inspection with so-called ‘pigs’. A pig is a tool that runs through the pipeline, driven by the product flow. Pigs can have different functions: cleaning, product batching, and inspection of the pipeline condition. The latter is called an intelligent pig, or inspection pig. An inspection with a pig is called a pigrun. Because an inspection pig is an electronic measuring instrument, the speed of the pig has to be kept within certain limits, to allow for the optimum conditions to perform the measurements.

The actual speed and position of the pig is therefore vital information during a pigrun. Unfortunately this information usually only becomes available after the run, once the recorded data has been processed.
Every intelligent pig has a velocity range in which it operates best. Outside that range the data quality will be affected and the pig might run irregularly. Even with a utility pig one might want to control the speed.
The current position of a pig is important information although in a straight single-feed line with fixed flow this might be of less importance. In a wide, complex grid with many branches and alternating flow conditions however, this is vital information. The position of the pig is then used as input to direct gas flows, pressure settings and valve operation. In the worst case, if a pig should stop unexpectedly, information about the position of the pig is of crucial importance. This information can be used to decide which operational measures to take. In the end, this might even help to direct search operations, which can become very costly.

Figure 1: a 16” Inspection pig, photo courtesy of Baker Hughes PMG

2. Why pig tracking is important

Gasunie, operator of the high-pressure gas transmission network in the Netherlands and the northern part of Germany, operates some 15,500 km of pipeline. The transported medium is dry gas only.
Gasunie performs about 25 intelligent pigruns every year, varying from relatively straight forward runs in larger diameter pipelines to more complex runs in smaller diameter pipelines.

The operational complexity of a pigrun is determined by the following factors, including:

1. The diameter of the pipeline: the smaller the diameter, the smaller the margin for the inspection tool to pass any obstacle in the pipeline like weld penetration ("snotty welds"), high-low, wall thickness changes.
2. The diameter range: previously only single diameter lines where considered piggable. Nowadays dual- and even triple-diameter inspection tools are available. With a dual-diameter pipeline the pig obviously has to compress even further in the smallest diameter, thereby reducing the margin for the inspection tool to pass any obstacle in that particular section.
3. The density of the medium: the lower the density of the medium, the higher the compressibility. Running in (incompressible) liquids usually results in steady run conditions, whereas running in gas can produce irregular run conditions. This can be visualised by the various degrees of compressibility of a spring on both ends of the pig. This is referred to as the 'gas compression spring'.
4. The operational pressure: the lower the pressure of the medium (especially in gaseous media) the more pronounced the gas compression spring.
5. Year of build: in general the quality of materials, fitting and welding has increased over the years. With Gasunie, older pipelines see more out of spec features (especially weld penetration).

All the ingredients mentioned above will affect tool behaviour inside the pipeline. And this in turn will usually affect the running conditions, often resulting in stops and the associated high speeds thereafter.
Within Gasunie's portfolio of pipelines to be inspected, older, dual diameter 6"/ 8", low pressure gas pipelines rank as the most difficult to inspect. It is especially when pigging these lines that a lot of time and money is spent on tracking the pig during the inspection (pig tracking).

3. Pig tracking with Gasunie, past practice

Generally, the pigging contractor provides the inspection tool and the operator is responsible for creating and maintaining optimal run conditions during the inspection. Every intelligent pig has a velocity range in which it operates best. Outside that range the data quality will be affected and the pig might run irregular.
The current position of a pig is important information although in a straight single-feed line with fixed flow this might be of less importance. In a wide, complex grid with many branches and alternating flow conditions however, this is vital information. The position of the pig is then used as input to direct gas flows, pressure settings and valve operation. In the worst case, if a pig should stop unexpectedly, information about the position of the pig is of crucial importance. This information can be used to decide which operational measures to take. In the end, this might even help to direct search operations, which can become very costly.

Information from the pig, such as data on speed and position cannot be transmitted from the pig to the surface. That is because the pipeline is a "Farady Cage", which also lies beneath two metres of ground. That is why information on speed and position (and also about the condition of the pipeline) is only available after the run, once the data recorded has been downloaded.
This also means that tracking a pig during a run can only be done from the surface.[1]

In the past, pig tracking with Gasunie was carried out by tracking crews. The crews were positioned along the pipeline at regular intervals. Usually, they were positioned at valve stations at which they had a good physical connection with the pipeline. The crews used two tools to collect information about the speed and position of the pig: a geophone and a pressure sensor.

A geophone detects pig movement by amplification of the vibrations created by a pig moving through a pipeline. These vibrations are generated when the pigs traverse circumferential weld penetration at weld seams, along with the normal scraping of the cups and cleaning elements against the pipe wall.

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1 An exception to this is pig tracking by monitoring the flow inside the pipeline, to deduce the speed of the pig. If the pig has product by-pass this might not represent the actual situation.

These vibrations are converted into audible ‘noise’. By dividing the known pipe spool length by the interval between two audible weld seam passages, the speed of the pig can be estimated.

Secondly, the tracking crews used a pressure sensor. Pressure, especially when measured downstream of the pig, is a very helpful source of information. In a system (grid) where consumption of the gas is continuous regardless of the supply, pressure decreases as soon as supply is interrupted. So if the pig stops (for example when entering a section with a smaller internal diameter), the supply stops while consumption continues and the pressure downstream of the pig will decrease. Upstream of the stopped pig, depending on the operational settings, pressure may temporarily increase.
Pressure is also a good indication of the position of the pig, relative to the station where the pressure is measured. Every pig needs to create a seal inside the pipeline, to be carried with the medium (usually pigs are not self- propelled). This seal, together with the drag caused by the pig’s weight and possible scraping functions, will require a certain delta P to bring the pig to movement. This delta P varies between 0,1 bar for light pigs to several bars for longer pigs in smaller pipelines.
So when a pig passes a location where the pressure is monitored, the abrupt rise in pressure is a clear indication of the pig passage. The pressure sensor was connected to a power gas line or any part of the system with the same pressure as the pipeline to be inspected.

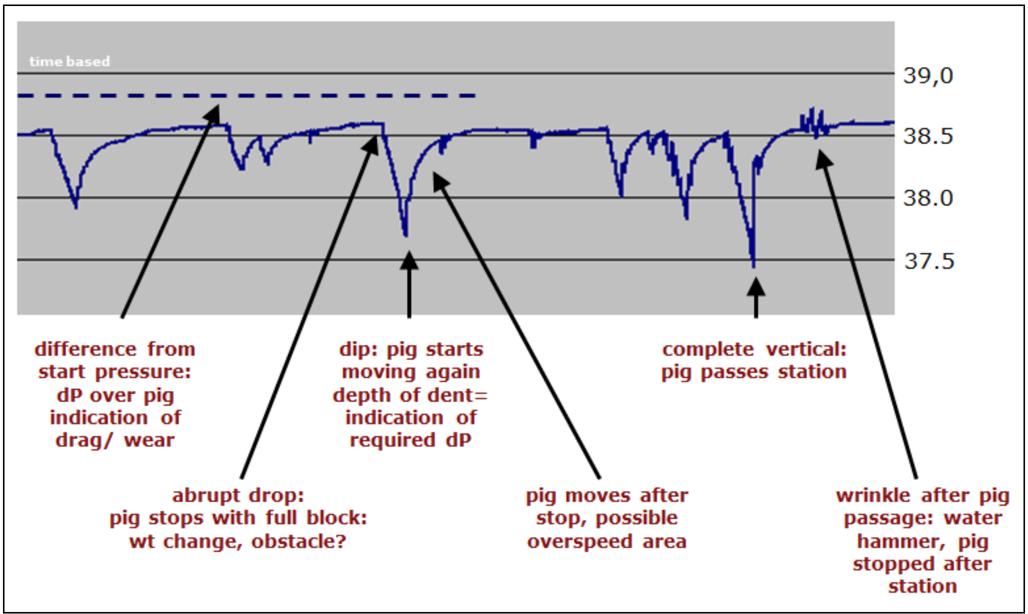

Figure 2: downstream pressure recording from Gasunie pigrun 8” 50 km, march 2011

The information collected by the tracking crews was passed on to the run leader by cell phone. It was up to the run leader to combine the information from various tracking crews into a workable basis for decision making. This was a laborious process. Despite large efforts, the information conveyed by the tracking crews was always delayed, subjective and incomplete.

Over the past few years, some inspection runs Gasunie performed failed (partially) due to the way pig tracking was organised. As an example, an inspection run in an 8” pipeline failed due to long periods when the pig was travelling at high speed. This only became clear after the run, when the so called speedgraph was generated.
On another run, the pig’s passage was not noticed by the tracking crews and the operational settings were changed too early, thereby increasing the flow and the speed of the pig to levels above the optimum speed range.
In an even more dramatic example, a pig got stuck somewhere between the launcher and the receiver, however the exact position could not be deducted from the verbal accounts the tracking crews provided.

These drawbacks prompted Gasunie to develop a new system to track pigs during an inline inspection.

4. Development phase

The development phase, from idea to realisation of a working prototype, took a little over two years. The technical development was awarded to Dexter System Solutions, an organisation specialised in high-end communication and signalling equipment for industrial and explosive hazardous environments.

The intended system design was clear from the start: multiple remotely controlled field units would transmit data to a central server. The field units had to be stand alone, battery operated, so that they could be positioned along the pipeline and left there for a series of subsequent pigruns. The server would then process the data and display it on an internet page. Anyone with a laptop or desktop with access to the internet would then be able to view the data from any of these field units.

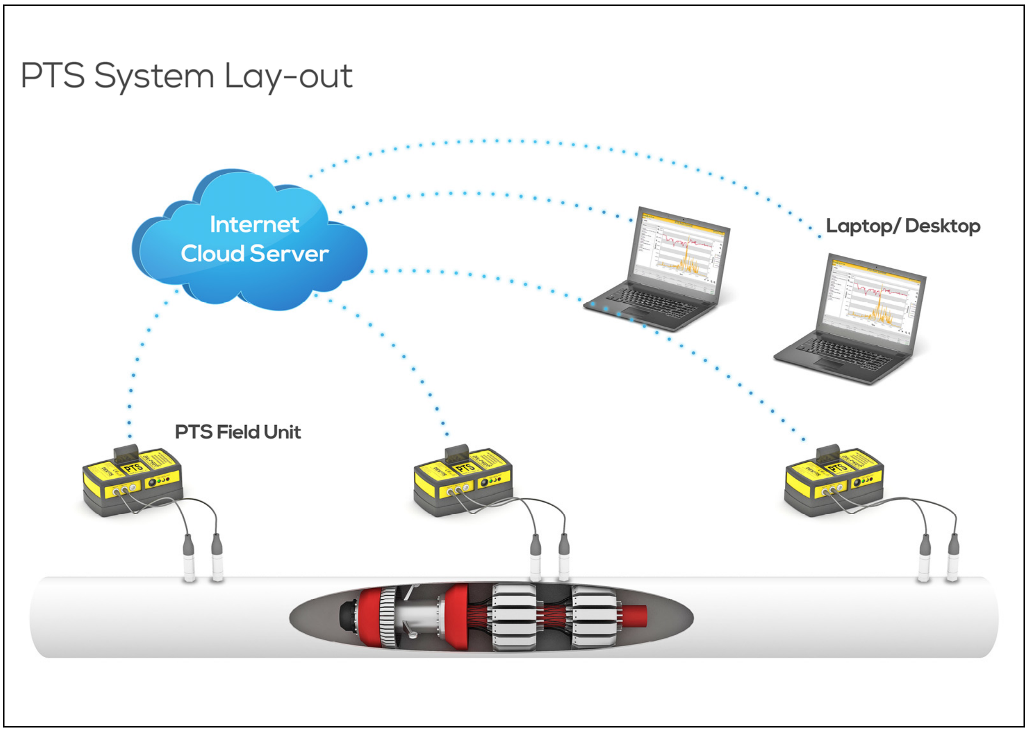

Figure 3: Pig tracking system lay out

The system layout was modelled on a rather similar system built by Mic-O-Data in the Netherlands that is used to gather and visualise information on the level of garbage in underground garbage bins. Although the volume of the GSM data collected by the DEXPTS is far greater and there is far more activity on the website, the basic principle is the same.

During the development process, the intended functionality of the system changed as time progressed. Initially the development project set out with the aim of developing field units which would transmit raw, unprocessed vibration and pressure data. The drawback of transmitting raw data, however, is that this is a lot of data to transmit and the operator still had to distinguish welds from noise.
At a crucial point during the development phase we decided to change the functionality from transmitting raw, unprocessed data to transmitting preprocessed data and reporting on anomalies only. As a consequence, the data now had to be processed inside the field units, which required the installation of on-board computing capacity.

The crucial part here was to "teach" the computer how to distinguish welds from noise. The better the system could do this, the more powerful the tool would be.
To do this, numerous pigruns were recorded and the vibration patterns were analysed. This was supplemented by the verbal accounts from the tracking crews and their account of what happened during that particular run. From this, a frequency range, as well as typical seam weld vibration profiles, were generated. This was then programmed into the on-board processor.
So now the field unit itself was capable of zooming in on significant vibration patterns only and reporting on them accordingly. This helped the operator to filter out relevant information only.

There were several other challenging aspects of developing the field units, some of which are illustrated below:

1. The units had to be as small as possible. The units might be deployed in urban areas not always secured by a fence. Besides that, the units may be deployed for days, sometimes weeks in a row so they are prone to theft. In between runs, the units have to be transported from one location to the other. By designing the units to be as compact as possible they are easier to hide and handle.
2. The units had to be robust and watertight. The units will operate outdoors, sometimes in remote locations. During transport, commissioning and service they may be subject to severe weather conditions and rough handling and transport conditions.
3. The units had to be ATEX zone 1 certified. The pressure sensor is directly connected to the medium inside the pipeline. Usually the unit is positioned on or near to the pipeline. This can be at remote locations or at compressor stations. Around any installation there is always the risk of an explosive mixture at any point in time. The project team decided to aim for the highest standard in the industry: ATEX zone 1. This was especially challenging because of the small number of units compared to the relatively high costs of designing and certification to the ATEX standard.
4. The operating time of the units needs to be as long as possible. There were two considerations here:
    a. At an early stage it was decided that the units would be battery powered. That is because most of the locations where the units will be placed have no connection to the electricity grid. The units need to be able to operate autonomously. Batteries with large storage capacity are generally big in size. Rechargeable batteries were preferred over disposable batteries but the power to size ratio of disposable batteries is better than that of rechargeable batteries.
    b. To save on power consumption, the units were designed with four power-consumption modes:
        i. Off: the unit is switched off completely and consumes no power.
        ii. Sleep: the unit is off, but will access the network every hour (handshake) to see if there are any new commands waiting to be processed.
        iii. Stand-by: the unit has a continuous connection with the server but the processor is not active. Power consumption in this mode is about one-third of the active mode.
        iv. Active; the unit has a continuous connection with the server and the processor is active. Vibration and pressure data are transmitted continuously. Power consumption in this mode is relatively high. With the current battery capacity the unit can run in this mode for a minimum of 30 hours continuously.

The development process involved continuously balancing these and other criteria. During this process Gasunie worked closely with the software design team, the system integrator and the ATEX compliance panel. By the end of 2013 this resulted in the production of the first batch of ten field units, a cloud-based server and a user platform.

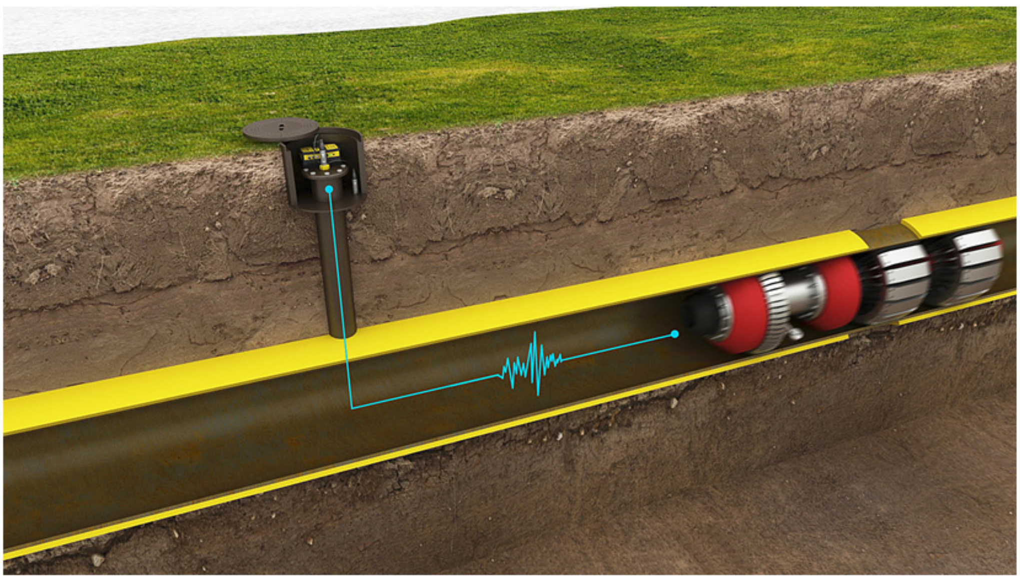

Figure 4: A pig approaching a field unit in a valve pit

5. The Pig Tracking System

The final product is called: “Pig Tracking System”, or DEXPTS as it has been branded by the developing company Dexter System Solutions in Almere, the Netherlands. Dexter has acquired the rights to produce and market the PTS system. For Gasunie, as a gas transport company, marketing this product is not a core business.

The complete system consists of several mobile field units, an internet platform and any computer or laptop with access to the internet. The installation of the system requires the brick-size field units to be placed along the line at variable intervals. The magnet-mounted vibration sensor has to be connected to the pipeline or any fixed structure on the pipe. A pressure sensor can be connected to the pipe, if so desired.
Once installed the field units will go into sleep mode, to be remotely woken up by the operator once the first pigrun starts. In active mode, the field units will start collecting and analysing vibration data. After processing the relevant vibration and pressure information, the data is sent to a server.
Vibration information reveals each weld seam or feature passed by the pig and from that the actual speed can be derived. Also pig stops, short pipe spools (bends) and valve stations can be identified. Pressure information indicates dP over the pig and is also a clear signal of pig stops. Once a pig passes a field unit the abrupt rise in pressure is a clear indicator of pig passage.
The data is displayed in real time on an internet page; the user interface. The user interface allows the operator to monitor vibration and pressure information from several field units (several locations) at the same time. All units can be switched to active, stand-by or sleep mode via the user interface. The user interface has an integrated logbook allowing the operator to document relevant operational notes. The web-based user interface also allows the central dispatch office to monitor the pigrun from Gasunie’s headquarters in Groningen.

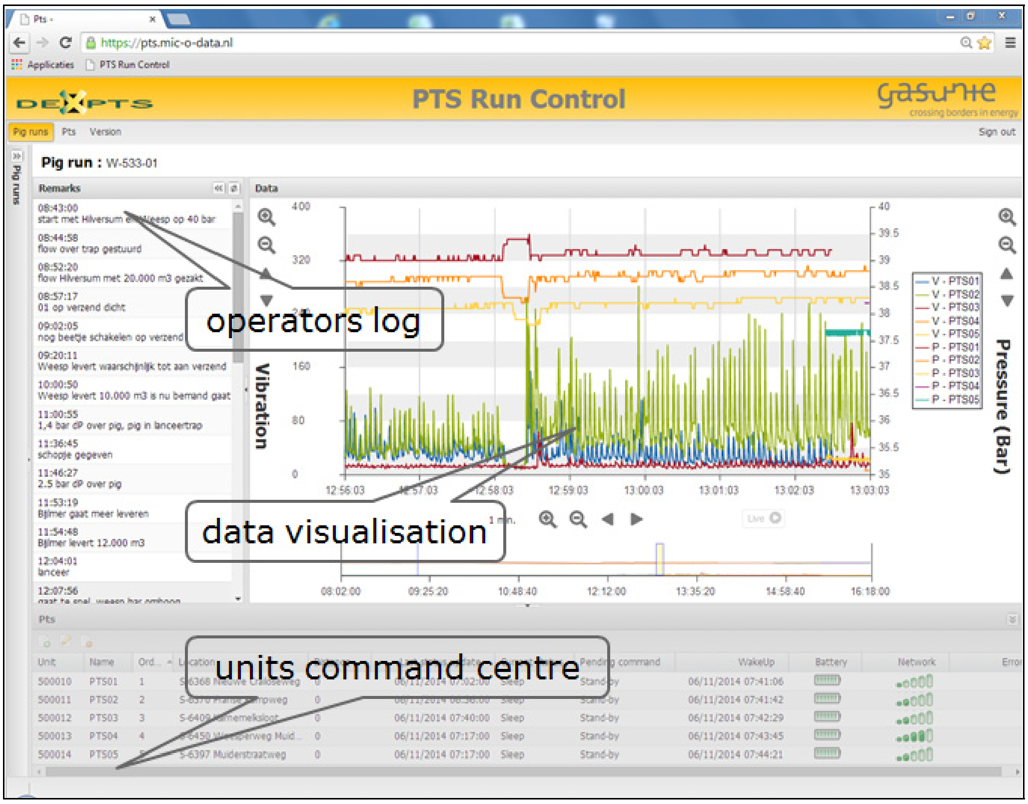

Figure 5: Screenshot of user interface

The field units have three interface connectors (pressure sensor, vibration sensor and serial RS232) and supports specific sensor devices.The system uses the already available GSM/ GPRS 2G network. Current network configuration allows for ten modules to be connected to the server at the same time.
Battery life time exceeds 150 hours in stand-by mode, plus an additional 30 hours of uninterrupted sending. A local data logging function was built in to store data in the event of a bad connection with the server. The most recent 10 hours of data is always stored inside the field unit. Both the modules and the attached components are ATEX certified for use in hazardous areas (Zone 1), because of an EX-i design.

Figure 6: Field unit with pressure and vibration sensor

6. Implementation phase

Gasunie started using DEXPTS on all pigruns from mid-2013. During a trial period, the system was deployed in parallel with the manual pig tracking by mobile tracking crews. This allowed for a learning period with the new system. It also allowed for a comparison between the two methods.

Some of the advantages of DEXPTS over manual tracking are:

- The information transmitted by the field units and displayed in the graphical user interface paints an on-going picture of the pigrun. The availability of continuous, real-time, objective information is an improvement over past practice, where fragmented information became available only gradually. This supports the run leader in decision-making during the run, thereby increasing the first run success rate.
- Because all data is stored, there is the potential for reviewing that data and learning from it so as to improve the operational conditions for each subsequent run, or any future inspection of the same line. During the trial period this was already frequently done resulting in a better understanding of the transmission system and pig behaviour and improved run conditions.
- As the system is web-based, tracking the pig during long hours or overnight can be assigned to the central dispatch department or any other party with internet access anywhere in the world.
- The use of DEXPTS reduces the manpower requirements significantly. In the past Gasunie spent about a thousand euros per run day on pig tracking. By mid-2014, some pigruns are already being performed without tracking crews, at the same time providing more accurate information. Operators need to become more confident about the system: seeing is believing.
- The prime advantage of automated pig tracking is that, if a pig gets stuck or lost, there is a database with time-based, objective data from various measuring stations along the pipeline. This allows the operator to zoom in on a particular line section, or even a pipe spool to determine the position of the pig. Over the past year three stuck pigs were located with information from the DEXPTS system, allowing the operator to take the appropriate corrective action. Previously this had to be done based on verbal information from the tracking crews.

The disadvantages of automated pig tracking over manual tracking are:

- The DEXPTS transmit data over the GSM network. As network strength varies and is not always optimal, transmitting data from some locations can be reduced/ not possible. In this case the unit has to be relocated to another location nearby.
- As all pig stops are visible (where previously they were not) the operator might become nervous which can cause the risk of acting (e.g. changing operating conditions) too frequently/early, thereby increasing the risk of high product flows and overspeed.
- The units are subject to theft. They have to be hidden, especially in urban areas. This requires some creativity. In some exceptional cases Gasunie has placed a DEXPTS unit under human surveillance.

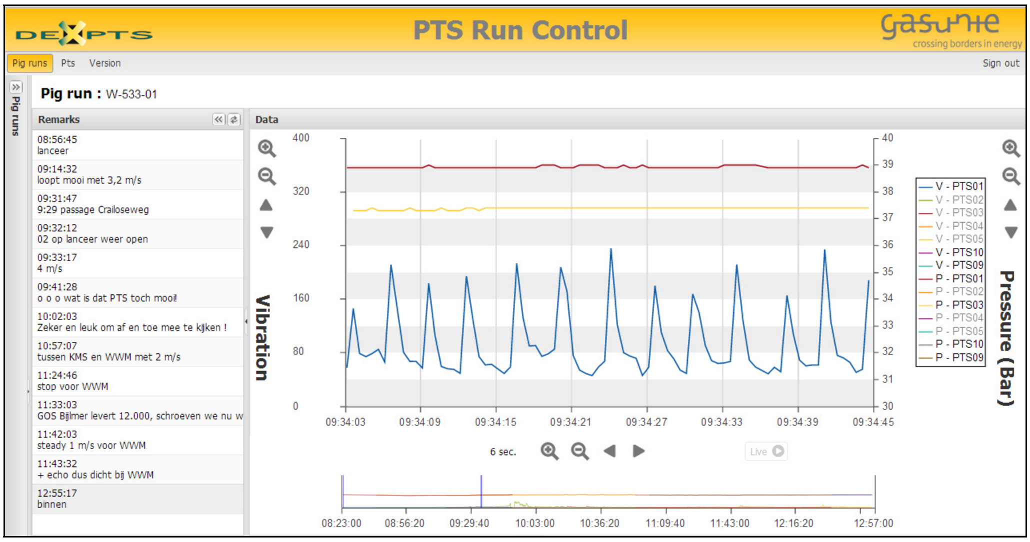

Figure 7: Typical screenshot of seam weld appearing in real time on screen

7. Conclusions/ lessons learnt.

- The development process forced Gasunie to think about pig tracking in a fundamental way. This resulted in a powerful yet user-friendly platform that allows the operator to monitor and control a pigrun in real time.
- Real time information on position (line section) and speed of the pig supports operational decision-making during the pigrun and facilitates learning/improving operations for each subsequent pigrun.
- Automation of the tracking process improves objectivity and reduces manpower requirements;
- The secure database with vibration and pressure data can direct search operations (which can become costly), it is an insurance premium.
- The system possibly requires improvement on data transmission capacity in area's with poor GSM network coverage.
- Automation is the next step in pig tracking. For Gasunie it is a logical successor to manual pig tracking. Gradually Gasunie will phase out manual pig tracking completely.