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ULTRASONIC PIG FOR OIL PIPELINE INSPECTION

Celso Massatoshi Furukawa
Julio Cezar Adamowski
Escola Politécnica da Universidade de São Paulo, Departamento de Engenharia Mecânica
Av. Prof. Mello de Moraes 2231, 05508-900, São Paulo, SP. Email: cmfuruka@usp.br

Claudio S. Camerini
CENPES/PETROBRÁS

Abstract *– A pig is a kind of equipment used by the petroleum industry for carrying sensors and other instruments through pipelines. This work describes the pig that is being developed for locating defects like points of pronounced corrosion in pipelines, using ultrasound. It is used the pulse-echo technique to measure the distance from a collection of ultrasound transducers to the internal wall of the pipeline, providing in this way an indirect measure of the wall thickness. A prototype was constructed and tested in an immersion tank. The results show that the ultrasonic measuring system can clearly identify points of alveolar corrosion, which are often present inside pipelines.*

Keywords: *pipeline inspection, ultrasound, non-destructive testing*

1 INTRODUCTION

An oil pipeline is a long tubular structure for transporting petroleum and other fluids. It is composed by welded carbon steel pipes with 200 to 500 mm of diameter. It is common to find continuous pipelines connecting terminals or pumping stations hundreds of kilometers apart.

Such steel structures are exposed to corrosion, which may cause the reduction of the thickness of the wall of the pipe. Without preventive action, an eroded wall may fail and produce fluid leakage. If a leakage happens in the middle of a very long pipeline, it would take time to be detected, with the risk of becoming an ecological disaster or killing and injuring people. Therefore, oil pipelines must be periodically inspected to find points of corrosion that must be repaired before a leakage occurs.

Usually, corrosion is more intense inside an oil pipeline than outside, and is more frequent in the lower section, due to water, sand and other impurities that cumulates in this region when it is not in use. For this reason, the internal wall must be inspected along all the extension of a pipeline. However, in most cases *in situ* inspection is not possible since the diameter is too small to allow a person to move inside the pipes. So, it is necessary to use special equipment that can be inserted in the pipeline, called *pig*.

A pig is a device that is used to carry sensors and instruments through the interior of pipelines. Its main function is to collect information about the real condition of the wall of the pipe while it moves along it. The data is processed to locate excessively eroded point or cracks in the wall [1, 2].

Since oil pipelines are usually very long, it would be too expensive to use cables to connect the pig to the launching station. So, the pig must autonomously move by its own means, acquiring and storing data for off-line analysis. Consumption of energy must be low to allow the pig operate longer. Usually, a pig does not move by itself, but the flowing fluid pushes the pig through the pipeline. Another advantage of this approach is that it permits inspections to be conducted during the normal operation of the pipeline.

This work describes the pig that is being developed to assess corrosion inside pipelines. The assessment is performed using ultrasonic waves [3]. This method is bases on the measurement of the time of propagation of an acoustic wave through the liquid inside the pipeline, from the emitter to the internal wall.

There are presented preliminary experimental results of a prototype of the pig in an immersion tank.

2 DESCRIPTION OF THE PIG

Figure 1 shows a schema of the pig inside a pipe. The mechanical structure of the pig includes two rubber disks that support a cylindrical capsule, keeping it centered in the pipe. The capsule houses the electronic circuits and the batteries. The fluid pressure acts on the rear disk and makes the pig to move through the pipeline. The capsule is free to rotate around its horizontal axis. The position of the center of mass is lowered in order to keep the ultrasonic transducer facing down, i.e. facing the region where there is higher incidence of defects.

The pig has an odometer to measure the displacement inside the pipeline. Spring action keeps the odometer wheel in contact with the pipe wall. Turning while the pig moves, the odometer provides electric pulses approximately every 100 mm of displacement.

The ultrasonic transducers measure the distance to the inner wall using the pulse-echo technique. A transducer emits one ultrasonic pulse that propagates straight through the fluid in the pipe until reaching the wall, generating an echo that propagates back to the transducer where it is converted to an electronic signal. The electronic control processes this signal to

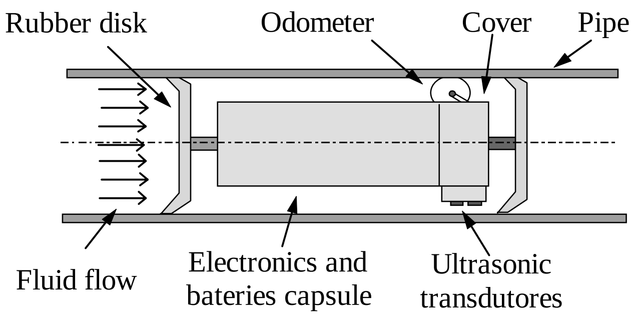

Fig. 1. Pig inside the pipeline

determine the *time of flight* of the ultrasonic wave, i.e., the delay time between firing the transducer and the arrival of the first echo. The time of flight t_f is related to the distance d between the transducer and the reflection point by

$$d = \frac{c\, t_f}{2}, \qquad (1)$$

where c is the propagation speed of sound in the fluid.

The pig can be configured to carry from one to four sensing heads, each one composed of sixteen ultrasonic transducers. The sensing heads are mounted on the capsule cover. The rubber disks are designed to keep the head 30-mm distant from the wall of the pipe, but that distance is not precise. When the pig passes a curve, for instance, the whole transducer set can move away from the wall.

In this way, the system can not analyze individually the information given by each transducer and it has to properly compensate for the movement of the pig. However, corrosion points typically found inside oil pipelines have the aspect of small semi-spherical excavations known as *alveolar corrosion*. In other words, usually there are not extensive depressed areas uniformly eroded. These characteristics simplify the motion compensation, given that the geometry of the sensing heads is known.

Figure 2 shows a photo of the pig, in the moment it was being prepared for a test run n a pipeline loop at CENPES – the research laboratory of Petrobrás, Rio de Janeiro.

3 CONTROL ELECTRONICS

Low energy consumption and high storage capacity are two important constraints that must be observed, since the pig has to operate autonomously for long periods of time and gather data of long runs. Besides, the voltage decays while the batteries discharge, thus the electronic system must be properly designed to operate powered by a voltage that can vary within a large interval.

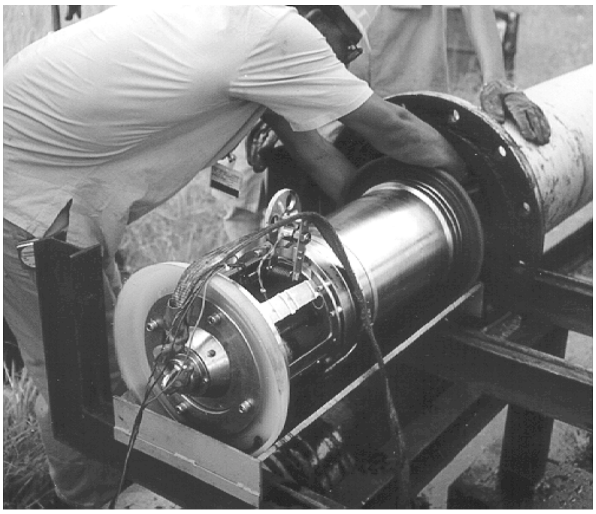

Fig. 2. Photo of the pig being inserted in a pipeline loop

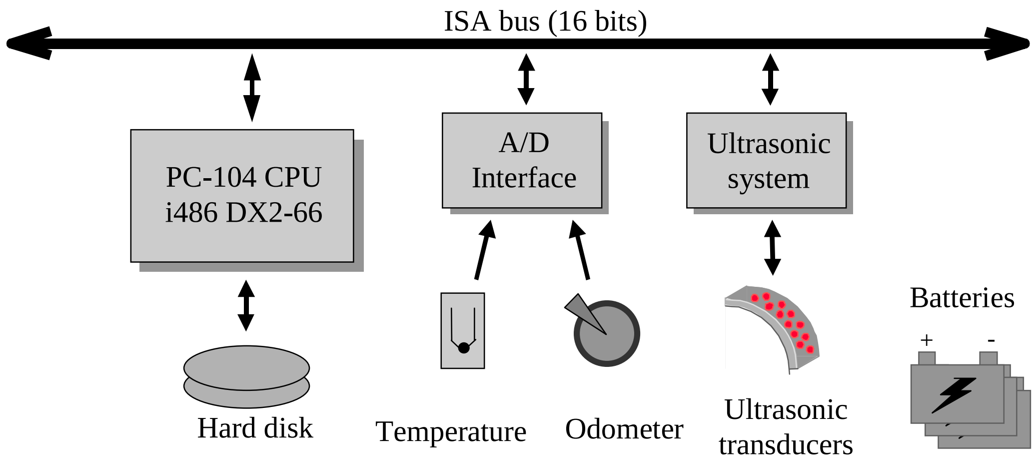

Fig. 3. Block diagram of the control system.

Figure 3 shows the structure of the electronic control system of the pig. An on-board computer controls the pig and performs data acquisition. It is implemented with an embedded controller board PC-104 compatible, a low power AT ISA computer highly integrated in a small printed circuit board.

The CPU is an Intel 486 DX2, 66 MHz, with 4 megabytes of main memory. The main board also comprises the following devises: IDE hard disk and floppy disk controllers and parallel, serial and keyboard interfaces (tough the pig does not use a keyboard in normal operation). The pig has a 2.5-gigabyte IDE hard disk for mass storage. The disk is very small (2.5 inch form factor) and is only 10-g heavy.

Parameters and configuration of an inspection run is downloaded from a mobile computer to the controller of the pig via the serial interface. After job completion, the serial interface is also used to transfer the acquired data to another computer, for off-line processing.

A custom interface card was designed to drive the ultrasonic transducers. A MOSFET driver sends pulses of 250 V, 50 ns long, to fire the transducers. The echoes received by the transducers are amplified and sent to a fast comparer for threshold detection, that generates a pulse that stops the time-of-flight counter. The counter has 12-bit resolution and it is clocked at a frequency of 10 MHz. This configuration provides a resolution of about 0.08 mm in measuring the depth, considering a propagation velocity of 1,500 m/s.

The acoustic attenuation coefficient of petroleum is very high, so the receiver circuit must have a high amplification gain of 60 dB, that imposes additional difficulties related to stability and noise immunity in the implementation of the receiver electronics.

The control system has also an A/D acquisition card to read other sensors used in the pig to monitor variables like temperature and battery voltage. The A/D card is PC-104 compatible and plugs directly to the CPU bus.

4 ULTRASONIC TRANSDUCER

The nominal frequency of the ultrasonic transducer is 5 MHz, presenting a good compromise between axial resolution and acoustic attenuation. The higher the frequency, the shorter is the wavelength, providing better axial resolution. On the other hand, attenuation raises exponentially with frequency.

The transducer has 6 mm of diameter. Since radial resolution is related to beam aperture, a polimetil metacrilate acoustic lens is attached to each transducer to focus the ultrasonic beam. The lens has 30 mm of focal length and gives 2 mm of focus aperture.

Figure 4 shows a photo of one of the transducer heads of the pig. It is a stainless steel block that houses 16 transducers. The acoustic lenses can be seen closing the holes, with the transducers inserted behind them.

5 DATA ACQUISITION

The on board computer controls the firing of the ultrasonic transducers. If enabled, the transducers fire sequentially, and the time of flight of each pulse is transferred to the main memory using DMA cycles, and is stored in a temporary circular buffer. A cyclic timer periodically activates an interruption handler to transfer one block of data from the DMA buffer to the hard disk or to a definitive memory location.

Typically the pig moves at 0.5 m/s. The acquisition rate of ultrasonic data is one complete readout every 1.6 ms. Using this configuration, the transducers provide a set of measurements every 0.8 mm of displacement of the pig inside the pipeline. This resolution is appropriate for detecting alveolar defects as small as 10 mm wide. Alveolar defects that can compromise the safety of a pipe are usually bigger than 10 mm, considering the widest extension [4].

6 EXPERIMENTS

A prototype was constructed and the ultrasonic measuring system was tested in an immersion tank. The pig had run in a pipe segment with pronounced alveolar corrosion. The pipe nominal diameter is 40.6-mm (16”) and the wall is 6.7-mm thick. The pig moved at a low velocity of 0.1 m/s, and the transducers where fired every 0.25 mm of displacement (400 Hz of measuring rate).

The scan map shown in Figure 4 has 16 tracks, each track corresponding to one ultra-

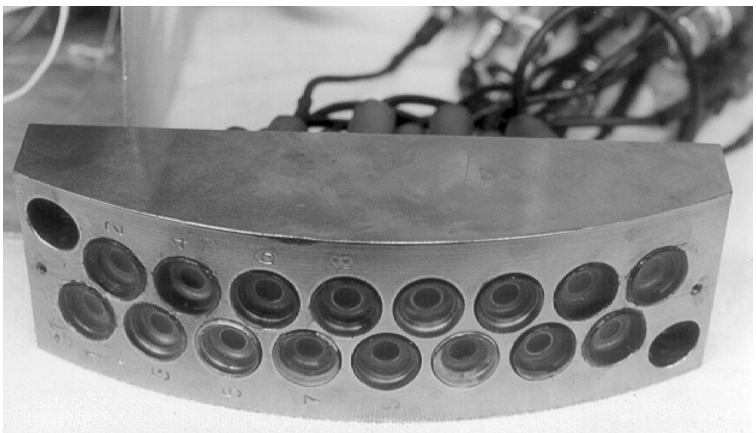

Fig. 4. Ultrasonic head with 16 transducers (in the holes, behind the acoustic lenses).

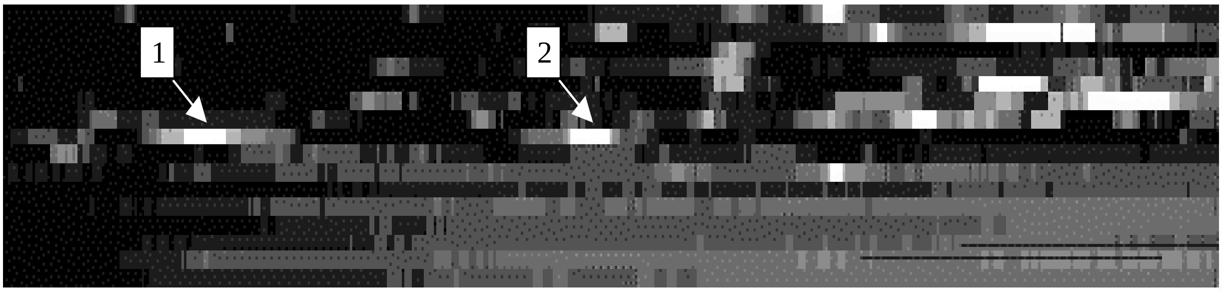

Fig. 4. Image representation of an ultrasonic scan with 16 transducers.

sonic transducer (the figure is not in scale). The transducers uniformly cover a range of 130 mm of linear extension, measured on the inner perimeter of the wall. The gray level represents the corrosion depth: the brighter, the deeper the corrosion. One can observe that all defects show the typical shape of alveolar corrosion, i.e., crescent depth until reaching the deeper point, following a gradual return to the normal thickness.

As an example, the following discussion describes the two defects indicated by arrows 1 and 2 in figure 4. Defect 1 is approximately 38-mm long and 18-mm wide, with the length measured along the direction of the pig movement. In the center, there is a hole about 10-mm long and 7-mm wide. Just ahead, following the same track, defect 2 corresponds to an intense corrosion with approximately 5.5 mm of depth.

The upper half of the image shows that the corresponding region of the wall of the pipe has severe defects, while the lower half shows a region with more superficial corrosion. This condition is observed in the actual pipe that was used for the test.

It was observed that when an ultrasonic pulse reaches the edge of a hole, there is dispersion of the wave front and no echo is detected. This information can be stored too, to give an extra indication of the presence of severe defects when the data are processed.

7 CONCLUSIONS

This work describes the pig that is being developed to inspect the interior of pipelines using ultrasonic transducers to assess damage caused by corrosion. A prototype was constructed and tested in an immersion tank. The ultrasonic measuring system was tested making the prototype run inside segments of pipe.

Experimental results show that the system can clearly map small corrosion points, like hollows with 10 mm of diameter and 1 mm depth. This performance conforms to the minimum requirements foreseen for the operation of the pig in a real situation. The measuring system has also good repeatability, providing measurements with only one bit of dispersion, what corresponds to 0.08 mm in depth.

The continuity of this work will include field tests, using a pipeline loop that is available at the research center of Petrobrás (CENPES, Rio de Janeiro).

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