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"PIG" Detection with Pressure Transducers

Victor C. G. Freitas[1], Gustavo F. Lima[2], Andrés O. Salazar[3], André L. Maitelli[3]

Master Student, Engineering Department of Petroleum, UFRN, Natal/RN, Brasil[1]

PhD Student, Engineering Department of Petroleum, UFRN, Natal/RN, Brasil[2]

PhD Professor, Engineering Department of Computer and Automation, UFRN, Natal/RN, Brasil[3]

ABSTRACT: Pipelines are a key component of an oil and gas supply system, so their maintenance is essential. Among the maintenance techniques, the use of PIGs has been successfully applied in many situations, such as cleaning, product separation and integrity inspection. Generally, the velocity a PIG travels inside the pipeline must be constant for higher efficiency, so we propose a system that aims to simulate the conditions of a gas pipeline in order to develop speed controllers. The system consists of a 6-inch pipeline with pressure sensors to detect PIG's motion in order to provide information about its dynamics.

KEYWORDS: pipeline maintenance; pigging; pressure transducer; speed excursion; PLC.

I.INTRODUCTION

Among the techniques developed to perform maintenance of oil and gas pipelines, we can highlight the use of PIGs [1].A PIG (Pipeline Inspection Gauge) is a device that is inserted into a pipeline and travels along its length to perform from simple cleaning to detailed inspection.

We can classify PIGs in several groups according to the ir purpose. For example, a Cleaning PIG is used to remove paraffin depositsor other debris originated from the transported product; a Sealing PIG can be used to isolate pipe sections in certainoperations; a Smart PIG is able to detect signs of corrosion by means of sensors installed on its body, providing data on thepipeline integrity. The Figure 1(a) shows a picture of a commercial cleaning PIG, made from polyurethane, and the Figure 1(b) shows a carbon steel prototype PIG mounted for this project.

(a) Foam PIG

(b) Prototype PIG

Fig. 1.PIGs used in this work.
Source: By author.

From cleaning to inspection, the PIG velocity generally must be kept constant to achieve better results. The importance of controlling speed is even more evident in gas pipelines due to its characteristics, such as compressibility, lack of lubrication and occurrence of speed excursions [2]. The speed excursion is an undesired speed peak the PIG reaches uncertain pressure conditions. It is caused by the high-pressure difference that often arises when an obstruction in the pipe shortly limits PIG movement.

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Given the importance of regulating the speed and the high costs involved in the inspection operations, the development of speed control techniques that seek to increase the efficiency of these operations is required. We therefore propose a system to simulate the conditions of a gas pipeline, in order to assist the development and validation of these techniques, especially in the speed excursion situation. We use pressure sensors to estimatePIG speed, considering that, as it travels along the pipeline, the device itself affects the pipeline pressure.

II.RELATED WORK

Various types of PIGs, their importance and the operations they are able to perform in pipeline maintenance are described in [3]. It also presents relevant aspects to be considered in pipeline design in order to allow the passage of PIGs.

Some geometric aspects and equations for determining the size of the PIG depending on the tubing geometry are addressed by [4].

A history of PIG speed control is presented by [5]. It describes a control system that operates by means of a by-pass valve. In addition, it states that Smart PIGs must move at constant speed to avoid distortions in the data collected, since the sampling period of the acquisition system is constant.

The speed control is important in several types of PIGs according to [2] and it describes speed control methods. In [6], the authors present a mathematical model and propose a non-linear technique to control speed, while in [7] the controller is based on fuzzy-logic.

A low-cost test bench to simulate speed excursion and a control strategy based on PWM (Pulse-Width Modulation) are proposed by [8].In [3], a system designed to test various types of PIGs under varying flow condition is described. It includes pressure and flow transducers that are useful in the study of PIGs' behaviour. The results indicate that the average speed of the device can be calculated by means of pressure transducers. A test bench to evaluate models for the removal of paraffin by cleaning PIGs is presented by[9].

However, it is important to note other devices can be more efficient than PIGs depending on the situation. In [10], the author present a tool called "GIRINO" (tadpole, in Portuguese) whose movement is based on amphibians and it is able to move inside the pipeline irrespective to flow direction. Several tools and the most appropriate choice to perform a certain operation are addressed by [11].

III. THEORETICAL FOUNDATION

This section will provide a simple theoretical background for understanding the work, as well as present a simplified model of the PIG's motion and explain pressure sensor's measurement principle.

A. PIG movement

Once the PIG is inserted into the pipeline, transported fluid drives the device thanks to pressure difference, as illustrated in Fig. 2.

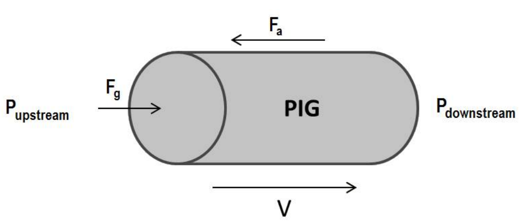

Fig. 2. Forces exercised on the PIG.
Source: By author.

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This movement can be explained in terms of Newton's Second Law of Motion, according to Eqs. (1) to (3):

$$M \cdot a = F_g + F_a \quad (1)$$

$$F_g = \Delta P \cdot A \quad (2)$$

$$F_a = B \cdot v + F_s \quad (3)$$

where: M is the PIG's mass; a is the PIG's acceleration; ΔP isthe pressure differential applied on PIG; A is the PIG's area; B isthe coefficient viscous friction; v is the PIG's speed; $F_g$is the force due to pressure differential over PIG's body, pushing the PIG;Fa is the friction force between the PIG and pipeline's wall; F_s is the dry friction.

Disregarding the dry friction (F_s = 0) and replacing $a = \frac{dv}{dt}$,we have:

$$M \cdot \frac{dv}{dt} = \Delta P \cdot A + B \cdot v + 0 \quad (4)$$

$$M \cdot \frac{dv}{dt} = \Delta P \cdot A + B \cdot v \quad (5)$$

Therefore, from Eq. (5) we can state that the PIG's motion mainly depends on pressure.

B. Pressure measurement

The most common types of pressure sensors are the bridge based or piezo resistive because of their simple construction and durability. Piezoelectric pressure transducers are generally more expensive, but they have superior dynamic response [12].

Piezoelectric pressure sensors, e.g., measure dynamic pressure. They are based on piezoelectric effect, which is the result of straining a piezo element to generate a voltage, as illustrated in Fig. 3.

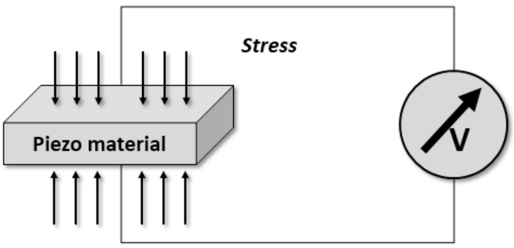

Fig. 3. Piezo electric effect.
Source: By author.

IV.PROPOSED SYSTEM

The system we have constructed consists mainly of a testing pipeline, pressure transducers, a PLC (Programmable Logic Controller) and a desktop computer.

A. THE PIPELINE

The pipeline was constructed with carbon steel and it has a length of approximately 55 meters, with diameter between6" and 8" and thickness of 5 mm. It is filled with compressed air up to 800 kPa.The structure has a simplified launcher and a receiver. They are used, respectively, to insert the device into the pipeline and to remove it. The Fig. 4 illustrates the constructed pipeline.

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B. THE PRESSURE TRANSDUCERS

The pressure transducer we have chosen is the Novus NP-300, suitable for low-pressure applications and with relative low-cost. It uses piezoelectric principle to measure relative pressure inside the pipeline, so it provides a good dynamic response. Its measuring range is 0-1 MPa; the supply voltage is 11-33 V_{DC};accuracy <0.25% of upper range limit; dynamic response <30 ms.It has an integrated 2-wire transmitter (4-20 mA).

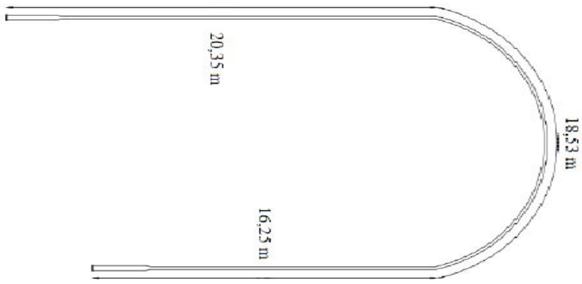
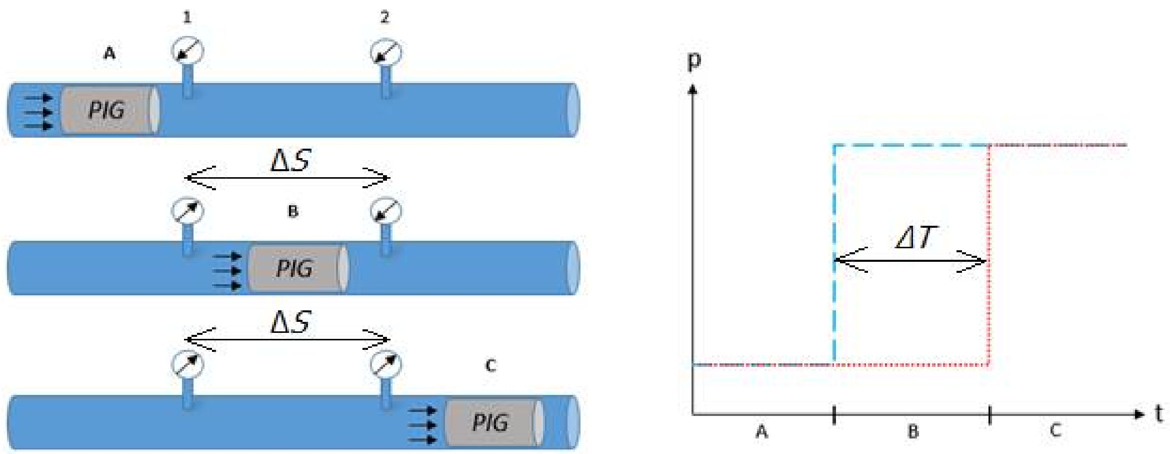


Fig. 4. Representation of pipeline schematic (upper view).
Source: By author.

The Figure 5 showsthe expectedbehaviour of pressure in the pipeline based in two sensors (see Fig. 5(a)) and their pressure response versus time (see Fig. 5 (b)). At first, the measurement pressure by two sensors would be equal,so the curves would be overlapping(Region A). Later, when the PIG passes by first sensor, pressure increases(Region B). Lastly, when the PIG passes by second sensor, the pressure measurement by two sensors should be the same (Region C).



(a) Pipeline's stretch with two sensors. (b)Pressure response versus time of the two sensors
Fig. 5. Behaviour expected for pressures sensors.
Source: By author.

Therefore, knowing the time range between two pressure measurements (ΔT) and the distance between two sensors(ΔS), it's possible to calculate average speed for PIG by equation$V_{avg} = \frac{\Delta S}{\Delta T}$.

C. THE PLC

The PLC - in this case, WEG TPW-03 60HT-A –provides the interface between the transducers and the computer. It converts the transducers analog signals to digital signals by means of a 10-bit ADC. The digital information is then available to the desktop computer via Modbus protocol.

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D. THE SUPERVISORY

We have used Elipse SCADA demo version v2.29, running on Microsoft Windows XP, to retrieve data from the PLC. The application displays time-series of pressures and allow us to store data on the computer hard disk.

V. METHODOLOGY

In order to validate the proposed system, we must use a PIG to travel along the pipeline. For this work, we have used a cleaning PIG known as foam PIG, made of polyester foam (see Fig. 1 (a)).
A PIG's passage starts at the launcher and ends at the receiver. The launching procedure consists of inserting the PIG into the launcher and establishing a pressure difference that is able to move the PIG towards the receiver.

We manually control the pressure in the pipeline by meansof valves installed at the launcher and at the receiver. The pipeline counts on manometers for local indication of pressure.

During the PIG's passage, the supervisory stores data of the pressure transducer on computer's hard disk, so it is possible to analyse them later.

VI. RESULTS

The Figure 7 show data from two pressure transducers during the foam PIG's passage.We have used Microsoft Excel^{TM}to produce the plots.The pressure tends to decrease as the PIG passes along the pipeline due to system pressure losses, except when speed excursion occurs, which explains the pressure behaviour at 11:30:57.371, 11:31:19.377 and 11:32:40.765.

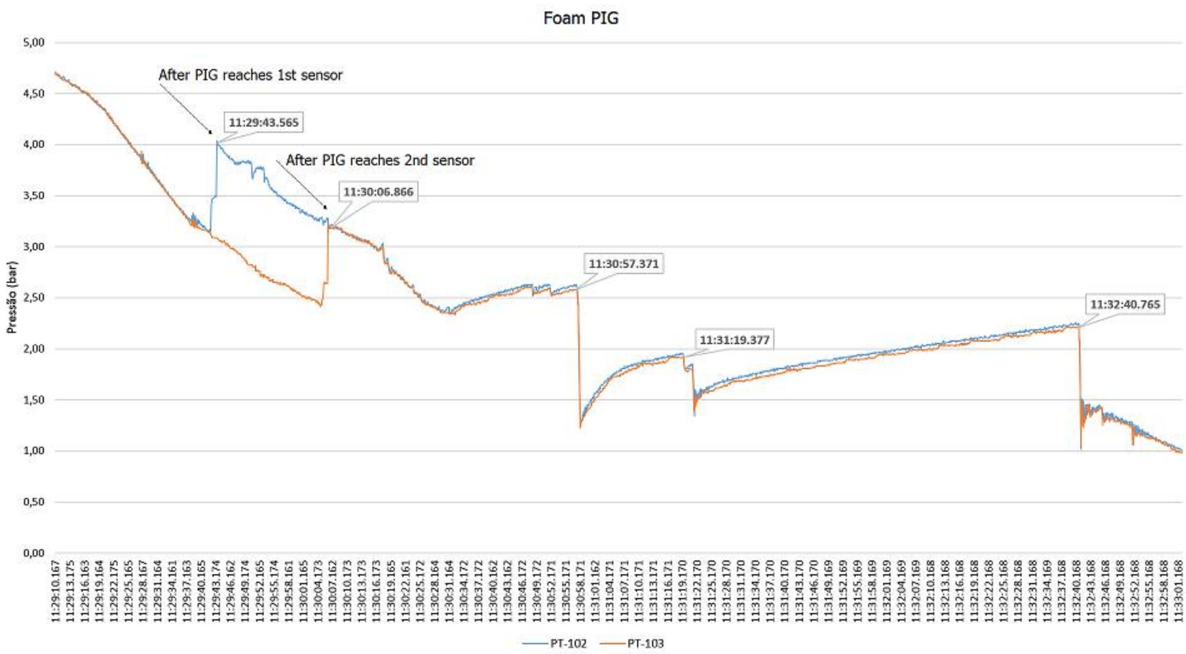

Fig. 7. Results of the foam PIG's passage with two sensors.
Source: By author

Figure8presents data from six pressure transducers during the foam PIG's passage. As illustrated on Figure 8, at 16:59:36.418 the PIG reaches first transducer; at 16:59:52.419, reaches the second sensor and so on.

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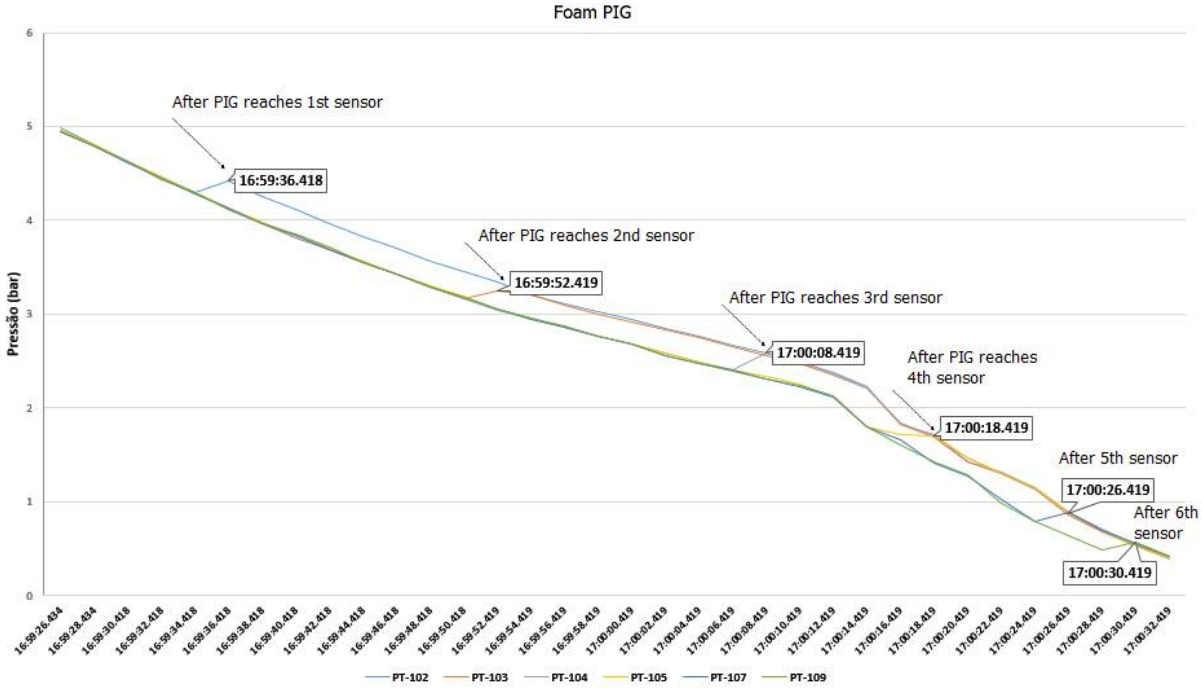

Fig. 8. Results of the prototype PIG's passage with six sensors.
Source: By author

In both cases, the pressure rises significantly after the PIGreaches sensor. Since we know the time PIG spends betweentwo sensors and the distance between them - in this case,6 m - we can estimate the average speed using $V_{avg} = \frac{distance}{time}$. For the foam PIG, the estimated speed was0.28 m/s with two sensors and 0.698 m/s with six sensors.

VII. CONCLUSION

The test results show that the proposed system is able to simulate the speed excursion. In this case, welding imperfections - which affect internal geometry of the pipeline - were the cause of PIG's obstruction. With low-cost pressure transducers, we were able to detect PIG's passage and estimate the average speed between known positions. Further, the time series of pressure provides information about PIG's motion that may be useful for studying its dynamics. For future work, we intend to increase the number of pressure sensors in order to improve the estimated speed's accuracy and collect more data along the PIG's passage.

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BIOGRAPHY

Victor Carvalho Galvão de Freitas Computer Engineer with license in Industrial Automation from Federal Universityof Rio Grande do Norte (2013). Master Student of Engineering Department of Petroleum (UFRN).

Gustavo Fernandes de Lima ElectrialEngineerfromFederal Univertyof Rio Grande do Norte (2003). Master degree in Electricaland ComputerEngineeringfromFederal Univertyof Rio Grande do Norte(2014). PhD StudentofEngineeringDepartmentofPetroleum (UFRN).

Andrés Ortiz Salazar Electronic Engineer by National University of Engineering (1981). Master degree in Electrical Engineering from Federal Universityof Rio de Janeiro (1989). PhD in Electrical Engineering from Federal Universityof Rio de Janeiro (1994). Professor in Engineering Department of Computer and Automation from Federal Universityof Rio Grande do Norte (UFRN).

André Laurindo Maitelli Electrical Engineer from Federal Univerty of Mato Grosso(1986). Master degree in Electrical Engineering from Univerty of Brasilia(1988) and PhD in Electronic Engineering and Computer from Technological Institute of Aeronautics(1994).Professor in Engineering Department of Computer and Automation from Federal Universityof Rio Grande do Norte (UFRN).