EVALUATION OF SUPERFICIAL DAMAGE ON OIL PIPELINE BY FEELER PIG

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Abstract. *The modern technology of materials and structural integrity of pipelines requests the use of inspection tools named instrumented pigs to evaluate their thickness loss during their service life. It is the most efficient and usual way to detect, localize and measure the length, width and depth dimensions of the thickness losses of walls of buried and underwater pipelines. These tools run them internally, performing and recording measurements that allow measuring the thickness losses, with performance that varies according to the pig's technology. An instrumented pig technology, called feller pig, has recently been developed. This work aims to indicate factors that influence the feller pig technology performance in the detection and in the accuracy of measurement of the volumetric dimensions of the thickness losses on the internal surface of an oil pipeline wall under normal conditions of oil pipe inspection with pig. In this work is made a collection of factors and an analyses of the technology described in the literature, as well as an experiment to observe the technology and the factors operating. In the experiment, a feeler pig is used to inspect stretches of a pipeline that flows petroleum with no treatment, built in carbon steel and in operation and in witch are observed areas with internal thickness losses occurred naturally. These areas and their dimensions taken by automated ultra-sound are compared with the ones indicated by the feller pig. Based on the data collection, on the analysis and on the experiment, is discussed the influence of factors on the capacity of detection and on the accuracy of the measurements of the volumetric dimensions of thickness losses on the internal surface of the investigated pipeline with inspection by feeler pig.*

Keywords*: Pipeline inspection; instrumented pig; structural integrity evaluation; damage evaluation*

1. INTRODUCTION

Pipelines with wall thickness losses should have their restraint capabilities of fluid evaluated to avoid their failures. These assessments are based on the remaining wall thickness or in calculations of the pressure that can lead the pipeline to failure.

Most of the oil pipelines is buried or submarine, which makes the use of inspection tools called instrumented pigs of thickness loss, the usual and most efficient way to detect, locate and measure the volume dimensions of wall thickness losses of these pipelines. These tools run them internally performing and recording measurements that allow to measure the losses of thickness, with performance that varies according to pig technology. For the evaluations of structural integrity of pipelines based on information provided by instrumented pigs of thickness loss is necessary to consider, besides the area depth, length and width dimensions of thickness loss indicated by the pig, its performance in measuring these dimensions (Maes ; Dann, Salama, 2008).

The instrumented pigs commonly available can not detect, locate and measure dimensions of loss of thickness in many products due to difficulties related to the pig operational characteristics, their pipeline conditioning requirements and to the pipe geometry, or even related to the format of predominant thickness losses. Therefore, it has developed a technology of instrumented pig, called a feeler pig, which has overcome many of the major difficulties and has ability to detect, locate, measure and record the areas of thickness loss on the inner wall surface. This technology has been tested in pigs and pipes and the results of testing this technology were presented by Camerini et al. (2005, 2008).

1.1 Definition of the research objective

This research aims to indicate factors that influence the performance of the feeler pig technology in detecting and accurately measuring the dimensions depth, length and width of thickness losses on the internal pipeline wall surface under normal conditions of pig pipeline inspection.

It is a qualitative research and its results apply only to the feeler pig inspection in pipelines with the characteristics and conditions of inspection similar to the objective of the research.

2. LITERATURE REVIEW

2.1 Description of the feeler pig technology

The feeler pigs work based in sensors that perform a direct measurement by contact on the internal pipe surface. Each sensor has a rigid stick with an extremity that remains in contact with the inner pipe surface, under pressure from a spring, and the other extremity mounted on a set that contains magnets which allows the tilting movement around an axis that contains a Hall Effect transducer. Figure 1 illustrates the operation and format of the sensors.

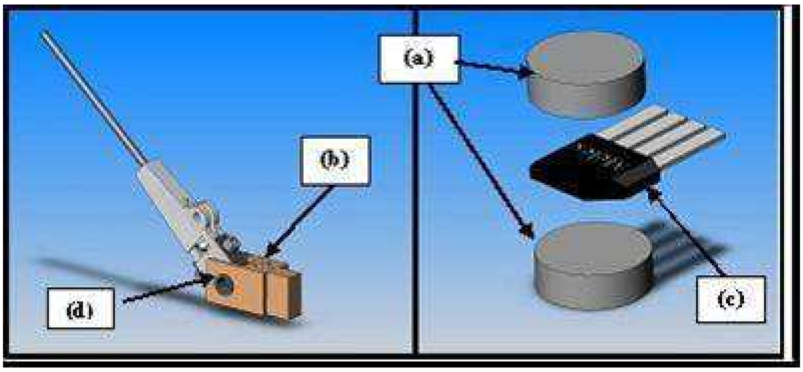

Figure 1 - Operation of the feeler pig sensors. Two magnets (a) are fixed at the base of the stick (b) in symmetrical positions with respect to the axis (d) around which they turn. A Hall transducer (c) is fixed within the shaft. Any inclination of the sitck around the axis is detected by the Hall transducer. Adapted from Camerini et al (2008)

The stick is tilted and has a tilting movement in the longitudinal pipe plan passing through its axis. By changing the inclination of the rod occurs a magnetic flux variation and the transducer generates an analogical signal proportional to the slope. The sensor is designed to be sensitive to any change in angular position of the stick.

Each sensor is calibrated individually in order to embed in the software of data acquisition the real response curve of each sensor, correlating the shaft angle with the transducer-generated tension.

The evenly distributed and radially mounted sensors form crowns. Some crowns alike and with the same number of sensors are mounted on each pig with angular gap between them so that the set of sensors is uniformly distributed on the circumference.

As in any other instrumented pig, its body structure serves as a support for fixing the sensors and housing of electronics and batteries. The pig body consists of modules axially connected by joints and electric cables.

Figure 2 shows the mounting of the sensors in pig forming crowns and the distribution of crowns of sensors in the pig.

Figure 2 – The feeler pig to the pipeline by 16-diameter inches. It has 6 crowns by 30 sensors, with a total of 180 sensors. The electronics and batteries are housed within the pig.

Polyurethane plates in the ends of the modules serve as guides in order to exert the centralization function of the pig in pipeline. The plates of polyurethane in the pig front module make the sealing of fluid passage through the pig in order to move it in the direction of pipe flow. Two odometers with wheels in contact with the inner surface of the pipe in the rear end of the pig, in diametrically opposed positions, measure the distance traveled. A pig turning sensor around its axis is installed internally to the electronics to provide a reference for registering the circular sensor position. The electronics loaded in pig also includes a clock.

With the pig being moved in the pipeline, the sticks of the sensors have their inclinations changed through the thickness losses in the internal wall of the pipe, generating signals that are correlated with the size of losses, as illustrated in Figure 3.

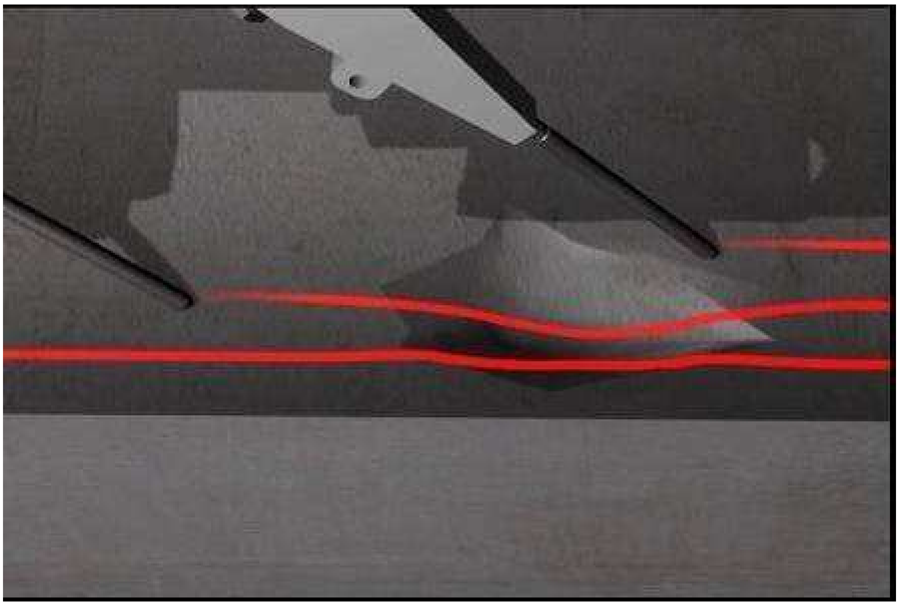

Figure 3 - Method of measurement of feeler pig. Loss of thickness on the internal surface of pipe wall is measured by the change in stick inclination of the sensors by going through them. Adapted from Camerini et al (2008)

2.1.1 Data Processing to measure the loss of thickness

The signals collected by feeler pig for the sloping changes of the sticks are recorded and processed so as to measure the depth of the loss of thickness. Janvrot (2008a, 2008b, 2008c) has developed software to process the data of these signals. One creates a reference surface that aim to compensate changes in signals resulting from the following factors:

- Calibration of sensors with a variation of error;
- Ovalizations and changes in diameter of the tube from its manufacture;
- Wear of the end of the stick in contact with the pipeline wall;
- Rotating of pig on its axis;
- Pig decentralization and inclination in relation to the pipe axis, for example, if the pig does not rotate on its axis and cause a preferential wear of the lower generatrix of pig plates, if the sensor crowns are in the center with different displacements in the pipe axis for occurrence of significant transversal movement of the pig, i.e. a front part moving radically in one direction while back in the opposite direction, as in curves or due to a greater wear on the front plates rather than the others;
- Occurrence of internal surface crusts within the pipe walls.

The loss thickness depths are indicated by the signals corresponding to variations in the stick inclinations having as reference this surface generated of the compensation of factors cited.

Janvrot (2008 d) has also developed software to separate the areas with loss of thickness indicating length and width of these areas from the sensor signal grouping. In it, a change in the stick inclination of each sensor indicated by signal is identified as the channel anomaly. Anomalies in the circumferentially contiguous sensor channel are grouped when they overlap to the length of the pipeline. The set of sensor channel anomalies together define the area of loss of thickness, which has given its size as criteria of European Pipeline Operators Forum (2005, p. 18 -19).

3. MATERIALS AND METHODS

The methodology consisted of a survey of factors object of research and analysis of the technology described in the literature available, in addition to an experiment to observe the technology and operating factors.

The feeler pig was used for the experiment in normal conditions of pig inspection to measure volumetric dimensions of areas of internal thickness losses occurred naturally in parts of a pipe in witch flows oil without treatment, built in carbon steel and in operation. The discontinuities and their size measured with ultrasound automated scanning was compared with the discontinuities and their sizes indicated by the feeler pig and, thus, it was evaluated the performance of technology in the detection capacity and in volumetric dimensions measuring. Having discrepancies ocurred, the present factors that may have caused them are observed.

A cleaning program with pigs preceded the passage of the feeler pig in pipeline in order to ensure the removal of all material that could be taken from them with conventional cleaning pigs, including pig and with brushes and with magnets. It was used a 16-inches-nominal diameter with 55 km long with losses in wall thickness occurred naturally over time of operation. The speed of pig varied between 1.2 and 1.8 m/s.The pipe material is carbon steel by API 5L X-60 with nominal wall thickness by 6.25 mm.

The feeler pig used, shown in Figure 2, was a 16-inches-diameter nominal pipe specific pig with circumferential and longitudinal 9 mm resolutions and has a 512 Hz sampling rate, which corresponded to a longitudinal resolution varying between 2.3 and 3.5 mm in proportion to the speed of the pig.

The automated ultrasound scannings were performed with equipment with circumferential and longitudinal resolutions by 1 mm and depth of 0.01 mm obtained with 10 MHz transducer, by serial number 8080343401 of the manufacturer Panametrics, with water as connecting, and equipment of the 4 LSI model of Physical Acoustics Corporation. The system was calibrated to measure the thickness of the pipeline manufacturing steel.

4. RESULTS AND DISCUSSION

4.1 Susceptibility of technology related to the performance

The processing softwares of the signals received by the feeler pig must compensate variations in the signals arising from factors that can be compensated, shown in previous chapter. Failures in this compensation may influence the performance in detecting and accurately measuring the volumetric dimensions of thickness losses.

One of these factors that makes the technology more susceptible to failure and can influence the performance in detecting and accurately measuring the volumetric dimensions of thickness losses is its extreme sensitivity to the calibration of sensors.

Ovalizations of pipelines may occur in the manufacture of pipes, in construction of the pipelines, or also by an accident after entry of the pipeline in operation. The manufacturing tolerance for pipes ovalization for a pipeline like the experiment one, for example, is up to 2% of nominal diameter, equivalent to 8.128 mm. Also in the manufacturing of pipes, there may be variations in diameter. The manufacturing tolerance for the diameter, for example, for a pipeline as the experiment one is ± 3.05 mm, equivalent to a total variation by 6.10 mm. Variations may also occur in the pipe wall thickness in manufacturing. The manufacturing tolerance for thickness, for example, for a pipeline like the experiment is ± 10% of the nominal thickness, which equates to a total variation by 1.25 mm. The manufacturing tolerances of pipelines are listed in according to the international standard is the pattern API Specification 5L/ISO 3183 (International Standard Organization, 2007).

As ovalization, diameter and thickness variations tolerated in the manufacturing can be of the same magnitude of wall thickness, as may occur randomly throughout the pipe and usually have the smooth start and end, can be very difficult to distinguish with the technology of feeler pig the increased internal diameter due to these factors and the whole loss of thickness on the internal surface.

If the pipeline is too long and the internal surface of the wall very rough, may occur wear at the extremity of the stick in contact with the wall of duct. It is necessary that the algorithms of the software for analysis of signals detect and measure this wear and compensate it when it is significant for the results of measuring the depth of the thickness loss. Ovalization, variation in diameter and wall thickness makes the compensation less effective. Thus, the performance of the technology on the accuracy of measuring the depth of the thickness loss in the final stretch of the pipeline can be damaged by wear on the extremity of the stick in contact with the pipeline wall.

Usually the internal thickness losses of pipelines are concentrated around some generatrix. It is more common around the lower generating, where is common that water and heavier sediments flow, which facilitates the corrosion and abrasion, and where most common form deposits are, which facilitates the corrosion under deposits. Furthermore, it occurs around the place where the oil/ water interface touches the wall or around the top generatrix. The vicinity of the generatrix where the thickness losses are concentrated in the internal surface is generally more rugged, causing greater wear on the sticks of feeler pig. The compensation of stick wear is easier and less critical if the pig rotates on its axis along the pipeline in order to wearing at extremities of sticks to be more distributed and uniform across the sticks. The wear of each plate is more uniform and distributed throughout the circumference of the pig and performance on the accuracy of measuring the depth of the thickness loss in the final stretch of the pipeline is higher if the pig rotates on its axis.

Inclination of the axis or decentralization of the pig in relation to the axis of the pipe can occur. The front plates of the pig tends to become more worn, due to its contact with abrasive material that causes abrasion on the plates and due to their surface in contact with the pipeline wall to be an area of sealing, putting more pressure on the wall of the pipe and, consequently, having greater wear by abrasion. This increased abrasion on the front plate can tilt the axis of the pig in relation to the axis of pipe. This tilt can also occur on curves. Decentralization of the pig also will occur in relation to the axis of the pipeline if the pig does not rotate on its axis and cause a preferential wear at lower generatrix of the plates. By occurring slope or decentralization of pig, the crowns of sensors are moved from the center on the axis of the pipe, implying the need for compensation in the signals recorded. Failures in this compensation may influence the accuracy of measuring the volumetric dimensions of thickness losses.

Losses of thickness on the internal surface of pipeline wall may be covered by crusts strongly linked to the surface in order to render the sticks penetrate to the bottom and thus hinder or preclude the detection and measurement of the sizes by the feeler pig. These crusts can be caused in the corrosive process of the pipe wall or in the process of material deposition from substances in the fluid being disposed, which may have other components besides the oil. The formation of deposits can, when present conditions for this, cause the occurrence of a process under deposit corrosion. Some products of corrosion in pipeline internal surface form crusts firmly attached to the pipeline wall when present conditions for this. Calcite, barite and anhydrite are crusts which occurr from substances present the fluid being disposed and are firmly connected to the pipeline wall when there are conditions for this.

Among the technology susceptibilities related to the performance of the sensors is the sensor overshoot in abrupt changes of thickness or sloping on the internal surface of the pipeline wall, as illustrated in the fig. 4.

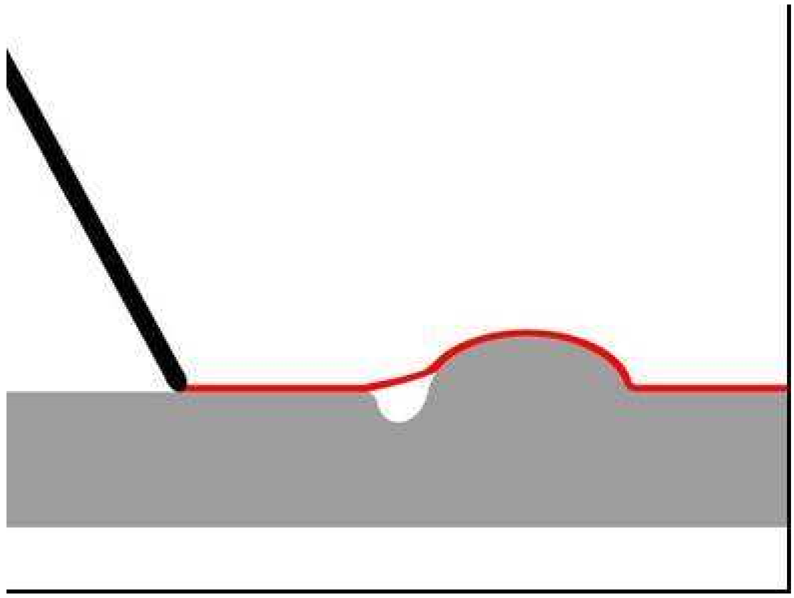

Figure 4 - Overshoot of feeler pig. The overshoot alters the received signal depending on speed of passage of the pig in the pipeline.

The possibility of overshoot of feeler pigs is related to the speed of the pig, being lower the lower the speed. The overshoot of feeler pigs influences their performance in detecting and accurately measuring the volumetric dimensions of thickness losses. The circumferential welds along the pipeline are places where is more usual to overshoot. They are also places where the presence of discontinuity is most critical to the pipeline integrity, so some discontinuities in the body of the tube that are not considered defects and they did not require repairs by standards or recommended practices. If they occur reaching the circumferential weld they may be considered defects, and require repairs by the same standards or recommended practices. However, not only the technology of the feeler pig, but also the conventional pig technologies of thickness loss have lower performance in the regions of circumferential weld rather than in the rest of pipeline.

Other susceptibility already known of same kind of "overshoot" is the undersize of discontinuity, which occurs when there is contact with the stick of the sensor with discontinuity surface more inclined than to the stick, at another point rather than its extremity, as illustrated in Fig. 5.

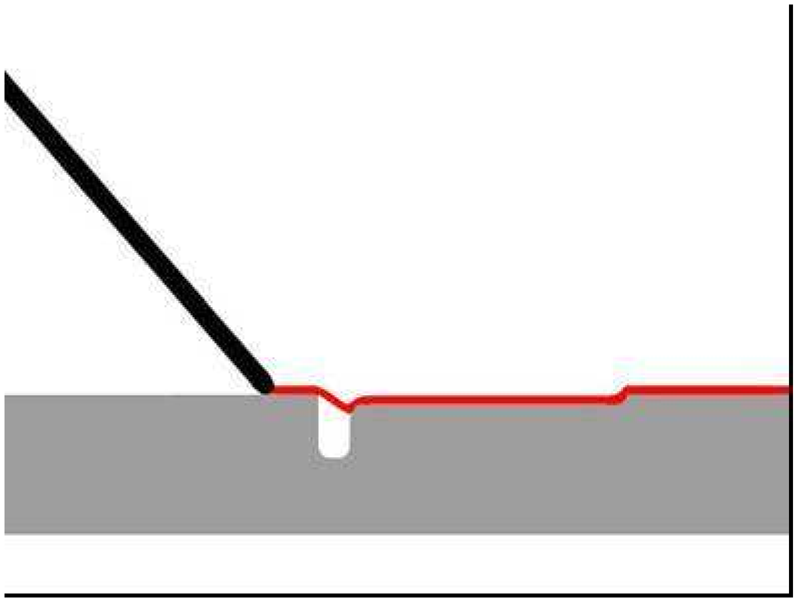

Figure 5 - Undersized due to the contact in other point of the stick rather than its extremity, because the stick tilting is smaller than the inclination of the wall surface.

Other susceptibility to factors related to the ability of detection and accuracy measurement of volumetric dimensions of thickness losses occurs when there is thickness loss on the internal surface of the duct wall in place where is present dent. The dent, moving into the internal surface of the pipe, causes the sensors generate signals that lead to errors in measuring the volumetric dimensions of thickness losses proportional to the size of the dent, leading to failure of detection. This failure of detection is critical because this is a case where the good practice has recommended repair of the pipe.

4.2 Results of the experiment

Of the 57 anomalies compared, only 35, equivalent to 61% were not reported. Of these 35, 32 (91%) had signs of crust in the region or neighborhood. The signs of crust are signals corresponding to gain of thickness. Of the 35 that were not reported, only 23 (65%) had records of signals in the vicinity which may be indicative of losses of thickness.

4.3 Discussion of results

A key factor for the performance of technology of feller pig is the effectiveness of software algorithms for processing the signals received by the pig in the compensation of variations in signals arising from the influence of factors that require compensations. The performance of the technology of feeler pig in detecting and accurately measuring the volumetric dimensions of thickness losses on the internal surface of the pipe wall is dependent on the software performance in the processing of signals.

This performance is enhanced by precise calibration, developed and systematized to reduce the variability of calibration between sensors.

The less is the ratio between the duct diameter and wall thickness, the more the performance of the technology; so the difficulty is less to the technology of feeler pig discriminate between the increase in internal diameter due to ovalization or the variation in diameter and generalized loss of thickness on the inner surface. As this ratio is generally higher for larger diameter pipelines, this problem tends to be higher for larger diameter pipelines. Here, the pipeline chosen for the experiment is one that does not favor the performance searched.

The occurrence of more than one of ovalization, change in diameter or thickness of the pipe, which is possible, has made it more difficult for the technology of feeler pig discriminate between generalized thickness loss and increase in internal diameter due to this occurrence.

The limitation of technology to detect and measure the dimensions of thickness loss on the inner surface with depths below the tolerance of the tubes for the manufacture of wall thickness is not significant. This is due to the nature of this limitation, so to the structural strength of the duct makes no difference if a thickness measured by the pig within the tolerance manufacturing of the tube is due to manufacture or the pipe wear in service.

The influence of the wear compensation in the extremity of the pig sticks in contact with the pipe wall in performance on the accuracy depth measuring of the thickness loss is related to the occurrence of ovalization, variation in diameter and the thickness of the pipe. The compensation of wear tends to be less effective in the occurrence of ovalization, variation in diameter and the thickness of the tube. The higher the ratio between the diameter of duct and thickness of wall, the greater is this tendency. In this sense, the pipeline chosen for the experiment is one that does not favor the performance searched.

The wear on the internal surface of the pipet generally makes it more rough and abrasive. The feeler pigs have a higher wear of sticks in pipelines with higher erosion on its inner surface. The pipeline chosen for the experiment is one with much internal corrosion, and does not favor the performance searched here too.

In experience, the feeler pig detect crusts on the wall along the pipeline and in areas of thickness loss used in measurements in the experiment. These crusts were connected to the duct wall to the point of not having been removed in the cleaning program of the duct prior to the passage of the pig inspection. They may have originated in the process of corrosion of the pipe wall or in the deposition process of material from substances in the fluid being disposed. Over 90% of the areas of thickness loss not detected by the feeler pig in the experiment have crusts indicated by the feeler pig in the region or proximity. The areas of thickness loss detected by the feeler pig have dimensions indicated by pig smaller than the actual size, which is consistent with the presence of crusts at the site.

Despite that the presence of crusts is a factor that affect the technology performance of the feeler pig in detecting and accurately measuring the volumetric dimensions of thickness losses on the internal surface of the pipe wall, the method of influence of this factor enables application of technology for solutions even demanded, such as the detection, measurement of size and location of crusts.

5. CONCLUSION

These are factors that influence the technology performance of the feeler pig in detecting and accurately measuring of the volumetric dimensions of thickness losses on the internal surface of the pipe wall under normal conditions of pig pipeline inspection:

• Calibration of sensors with a variation of error;
• Ovalization and variations in diameter and wall thickness of the pipelines resulted from the manufacture of pipes;
• Stick extremity wear in contact with the pipe wall;
• Rotating of the pig on its axis;
• Decentralization and inclination of the pig in relation to the axis of the pipeline, for example: if the pig does not rotate on its axis and cause a preferential erosion of the lower generatrix of pig plates; if the crowns of sensors get in the center with different displacements in the axis of the duct by occurrence of significant transversal movement of the pig, i.e., a front moving radially in one direction while back in the opposite direction, as in curves or due to a greater erosion on the front plates to the other;
• Occurrence of crusts on the inside surfaces in the pipe walls;
• Overshoot of sensors in abrupt changes of thickness or sloping on the inner surface of the duct wall;
• Contact of the sensor stick with surface of discontinuity more inclined to the stick;
• Presence of dent.

The experiment confirms that the occurrence of crusts on the inside surfaces in the pipe walls decreases the performance of technology in the detection and accuracy of measurement of dimensions and that leads to the indication of a smaller size than the real.

The technology of feeler pig can be applied in the detection, measurement and location of crusts.

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