

DEVICE FOR MEASURING THE PAINTING THICKNESS AND CIRCUNFERENCIAL DEFORMATION ON 14" PIPELINES

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***Abstract.** This article presents the mechanical design aspects of a measuring device prototype (Tinta-P) designed to evaluate the internal operational condition on a 14" diameter pipeline for oil & derivatives transportation. The scenario of application is a 28 km length and 40 years old pipeline located in the State of Bahia, from Madre Deus marine terminal to the Petrochemical Complex of Camaçari. The pipeline operator, Petrobras, made a contract with a company to provide an extended life procedure against coating and corrosion, using a technology based on internal deposition of a chemical inhibitor along the pipe. The Tinta-P prototype was developed to verify the right distribution of internal painting in a given section of the pipeline and its circumference deformation. Tinta-P prototype has radial and angular positioning control ($R - \theta$ directions), waterproof facilities (two meters H_2O) and auto-compensation mechanisms. The design phases of the three constructed prototypes are the main topics related to this paper.*

***Keywords:** mechatronic design, measuring device, pipeline, robotics.*

1. INTRODUCTION

1.1. Operational site

Madre Deus marine terminal (Temadre) is located in the State of Bahia and since 1957 is controlled by Petrobras (SICM, 2007). In Temadre arrives at about 40 ships per month, mainly from offshore oil drilling platforms in the Sergipe-Alagoas Basin. Its installed facilities operate nearly 1,000,000 m³ of crude oil and derivatives per month. Most part of these products is transported by pipelines to Mataripe refinery (RLAM) and to the Petrochemical Complex of Camaçari. Both pipelines are under the soil and in many regions the nearby area is populated. This paper deals with the development of prototypes conceived to make internal inspections on the 28 km length pipeline from Temadre to Camaçari.

1.2. Pipeline maintenance

Inspection of the inside surface of the pipe is necessary to verify the existence of anomalies like corrosion and crack. Other important information regards pipe structural deformations such as bending and ovality as the result of external forces caused by soil motion or increase of pressure due to human constructions.

Pipeline cleaning is a usual procedure to increase the capacity of product transportation, since organic deposits as paraffin in crude oil and inner surface irregularities due to corrosion inside the pipe can cause turbulence and consequently increase friction loss, reduce pipe bore and decrease capacity in the product flow.

2. INTERNAL INSPECTION TOOLS

2.1. Pigs

Pig is a cylinder-shaped electromechanical device designed for cleaning or inspection of the internal wall of a pipe with non destructive testing techniques (Baldez1 et al, 2001). The term pig is associated to a device that travels with the propelling force of the fluid being pumped (liquid) or compressed (gas) through the pipeline. Rubber seals on the pig make it act like a piston in the pipeline. Instrumented Pig uses sensors, electronics, and recording or output

functions integral to the system. While traveling the onboard data acquisition system records the defect data, sensed by the sensors touching the internal surface of pipe wall. These data usually corresponds to defects sizing and location along the inspected pipe (Baldez1 et al, 2001).

Pig tools can be classified according to their operational tasks as metal loss tools: magnetic flux leakage and ultrasonic; crack detection tools: ultrasonic and transverse magnetic flux; elastic wave tools: ultrasound in two directions; geometrical tools: caliper (mechanical fingers or electromagnetic methods to detect dent or deformations); pipe deformation tool: caliper and gyroscopes provide pipe bend information; mapping tools: use of GPS (Da Silva et al, 2001).



Figure 1. Pig with geometrical tool. (Da Silva,2001).

2.2. Special tools

Pigs are very useful for pipeline cleaning and inspection, but are not able to make interventions or activities that require large consumption of electrical and mechanical power in specific positions, as occur in welding and ovality deformation repair in a circular pipe. Pigs cannot also be used in situations where the fluid has low velocity since the friction forces against the pipe wall can be higher than the propelling force of the fluid-pig interaction.

The development of special devices and tools for internal pipe intervention are necessary to execute those activities that a Pig is not able to do. In general they are teleoperated units formed by modules (locomotion or traction, data processing, instrumentation, power supply and so on) connected to an external operational base by an umbilical cable.

In Fig. 2 is presented the concept of a locomotion module denominated G.I.R.I.N.O. – Get Inside Robot to Impel and Normal Operation -. This teleoperated prototype was designed and constructed at CENPES/Petrobras (Reis,1999). It has an umbilical cable containing hydraulic and electrical lines, is hydraulically actuated and moves in a discrete mode.



Figure 2. Prototype of G.I.R.I.N.O. traction module.

3. PROTOTYPE DESIGN CONCEPTS

3.1. Project scenario

In 2002 Petrobras made a contract with a company to provide an extended life procedure against coating and corrosion, using a technology based on internal deposition of a chemical inhibitor along the pipe. The scenario of application was a 14" diameter pipeline with 28 km length and 40 years old located in the State of Bahia, from Madre Deus marine terminal to the Petrochemical Complex of Camaçari.

The first activity performed by the company was a "Pre-Inspection Preparation" of the internal surface using some cleaning Pigs. Then, an instrumented Pig with appropriate tool was used to paint the pipe inner surface with the chemical inhibitor.

In order to evaluate the contracted service, Petrobras asked for the development of a special instrumented device able to verify if the distribution of chemical inhibitor product in a given point of the pipe section was attending international standards and to quantify its circumference deformation. This device here denominated Tinta-P should be connected to the traction module G.I.R.I.N.O. and support an external pressure of two meters of water column. The measurements should be made with no flow at the pipeline.

Two prototypes were constructed and tested before the final conception of Tinta-P.

3.2. Design general aspects

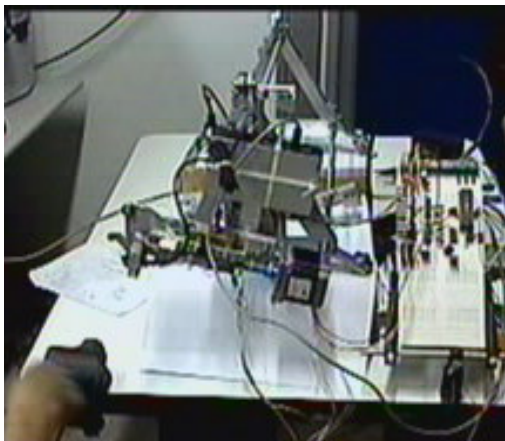
The general design aspects needed for the project are:

- Use of a commercial ultra-sound sensor to measure paint thickness.
- Capability of moving in curved pipes (curvature radius of 10 x diameter).
- Protection facilities to onboard camera and electronic hardware.
- Mechanism to guarantee the alignment of the prototype axis relative to the pipe axis.
- Weightless parts.
- Easy procedures for mounting and dismounting of parts.
- Commercial component for fast maintenance.
- Compact design.

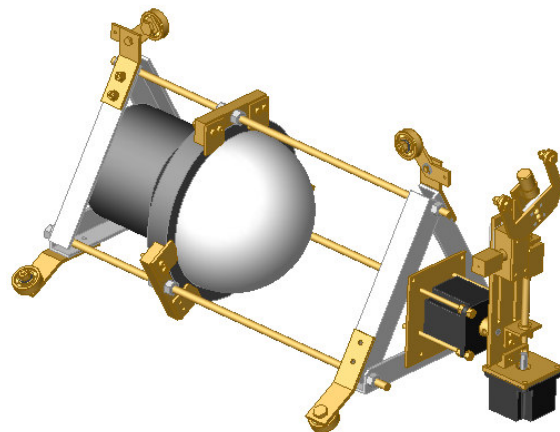
3.3. First prototype

The first prototype (Fig. 3) was developed to test a solution based on a two degrees-of-freedom (d.o.f.) mechanism and step motors (1.8° resolution). This device was characterized by:

- No pressure protection.
- No waterproof protection.
- Actuators:
 - ✓ 1 step motor for angular motion (sensor orientation).
 - ✓ 1 step motor for radial motion (sensor positioning).
- Radial motion: screw mechanism with a limit switch.
- Angular motion: direct drive.
- Safety return electro-mechanism actuated in case of energy fault (solenoid).
- Alignment mechanism.
- Programmed motion for data acquisition procedures.



(a)



(b)

Figure 3. First prototype. (a) Photo. (b) CAD model.

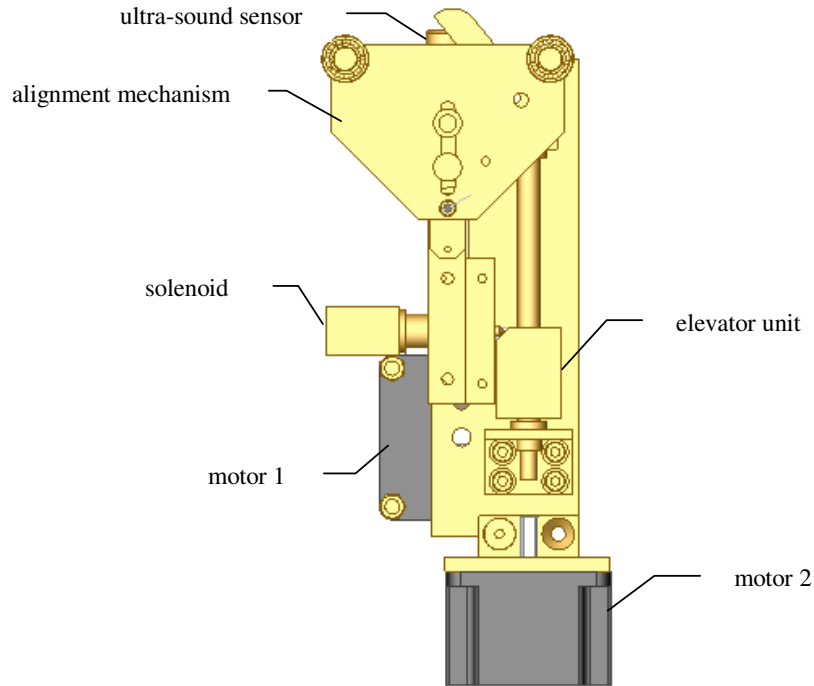


Figure 4. First prototype: mechanism main parts.

The first prototype mechanism worked properly but undesired vibrations occurred in the radial motion. Another critical part was the small amplitude of the alignment mechanism, reducing the system capability to move in curved pipes.

3.4. Second prototype

The main improvements made on the second prototype (Fig. 5) are related to the modified alignment system, ensuring more amplitude and rigidity to the system, and the adjustments on the motion mechanism to reduce vibration.



Figure 5. Second prototype.

The performance of this prototype was acceptable for the measuring of the specified parameters. After some tests the design team started the development of the final prototype.

4. TINTA-P PROTOTYPE

This final version prototype is characterized by the following improvements (Figs. 6 and 7):

- Radial and angular positioning control ($R - \theta$ directions).

- Teleoperated or robotic operation modes.
- Waterproof (2 meters H₂O) and explosion-proof container unit.
- Auto-compensated alignment system.
- Radial motion unit: pneumatic actuator and 2 d.o.f. mechanism.
- Angular motion: DC motor and planetary gear reduction.
- Pendulum sensor system to keep horizontal reference.

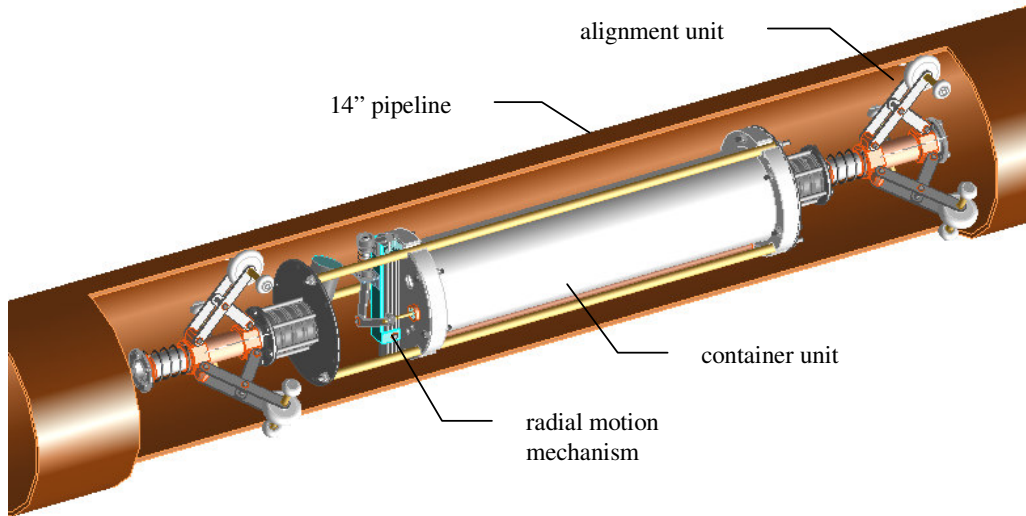


Figure 6. Tinta-P prototype and pipeline CAD model.

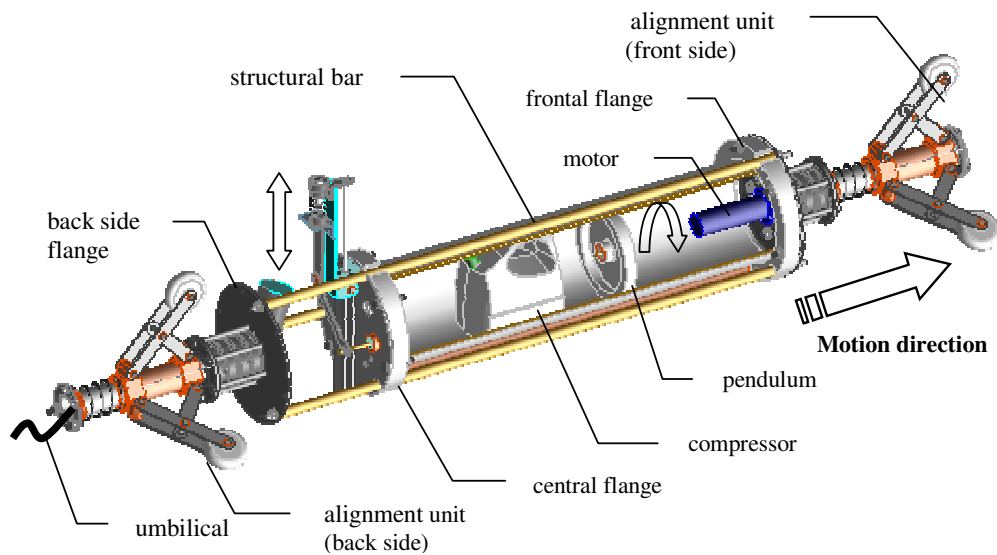


Figure 7. Details of Tinta-P components.

4.1. Structural unit

The structural unit provides the necessary rigidity, alignment and protection to all system units. It has stainless steel components and is formed by two circular shape flanges rigidly interconnected by three structural bars in pretension with screws.

The structure is also responsible for container unit protection against external forces/moments due to pipeline interaction.

4.2. Container unit

The container unit is located inside the structure and has cylinder components made in PVC. Its main functions are: isolation from external pressure and humidity (waterproof for 2 meters H₂O) of the onboard components, such as electronics – motor, encoders, data acquisition and control circuits, communication circuit - and pneumatic system – compressor, directional valves, air pressure reservoir -, and explosion-proof capability

The onboard components can be easily accessed due to container unit modular concept, as presented in Fig. 8.

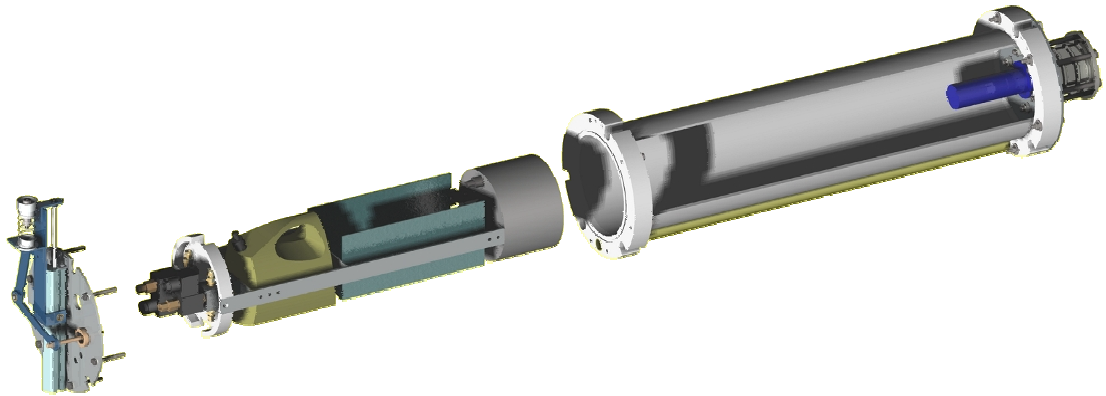


Figure 8. Details of the Tinta-P container unit and onboard components.

4.3. Sensor unit

Tinta-P was designed to measure in a given transverse section of the pipeline inner surface, the coordinates of selected points referenced to pipeline symmetry axis and their associated chemical inhibitor thickness. The database of sampled points represents the section mapping situation in terms of geometrical parameters: radial deformations due to external pressure from soil interaction and distribution of the internal painting.

A commercial ultra-sound calibrated transducer was used to evaluate the chemical inhibitor thickness. The sensor is located in a linear platform that moves in connection with a piston rod. When the piston rod moves upward and touches the pipe inner surface, the sensor achieves its proper position, orientation and contact force due to adjustment of a spring located in the extended extremity of a two d.o.f. arm.

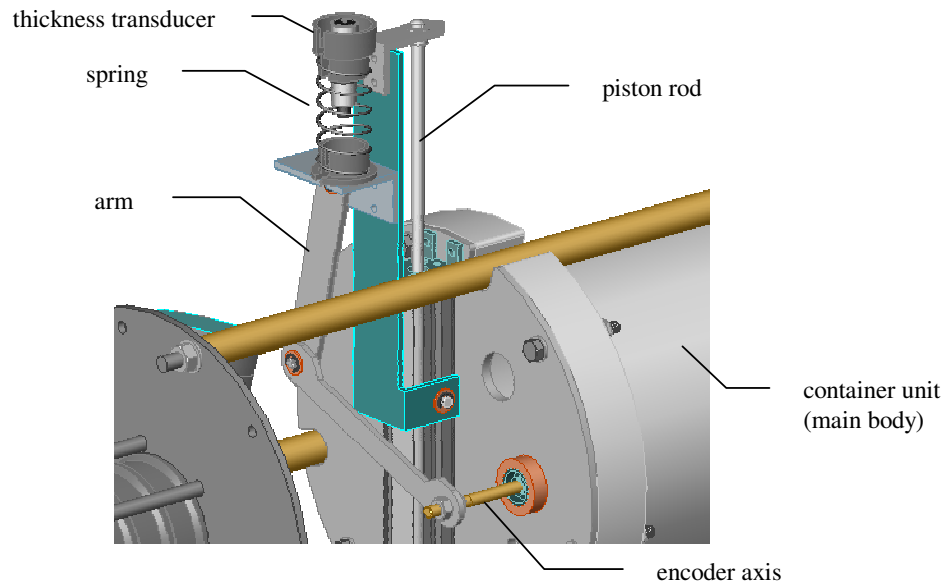


Figure 9. Details of the Tinta-P container unit and onboard components.

4.4. Alignment Unit

The auto-compensated alignment system is formed by back side and front side units (Fig. 7). Each one contains a tripod mechanism with wheels actuated by a rigid spring.

This system tends to keep the geometrical axis of the Tinta-P concentrically to the theoretical symmetry axis of the pipeline, in the vicinity of the region of analysis.

5. Motion Especification

In order to sample representative points located in the internal circumference of the pipeline wall, Tinta-P is able to move in the radial and angular directions.

5.1. Radial motion

The radial motion is obtained with the displacement of a piston rod associated to a pneumatic cylinder. This motion is necessary to move the ultra-sound transducer nearby the measurement point.

A planar two d.o.f. arm measuring system with revolute joints is used to quantify the radial displacements referred to the geometrical axis of the Tinta-P. One of its extremities is connected to the piston rod and the other to an encoder (Fig. 9). When the piston rod moves, induces the movement of the arm and consequently the angular displacement of the encoder.

A Denavit-Hartenberg parameterization (Sciavicco and Siciliano, 2001) was used to establish the analytical relation of the arm positioning and encoder angular displacement. The limit configurations of the radial motion are described in Fig. 10.

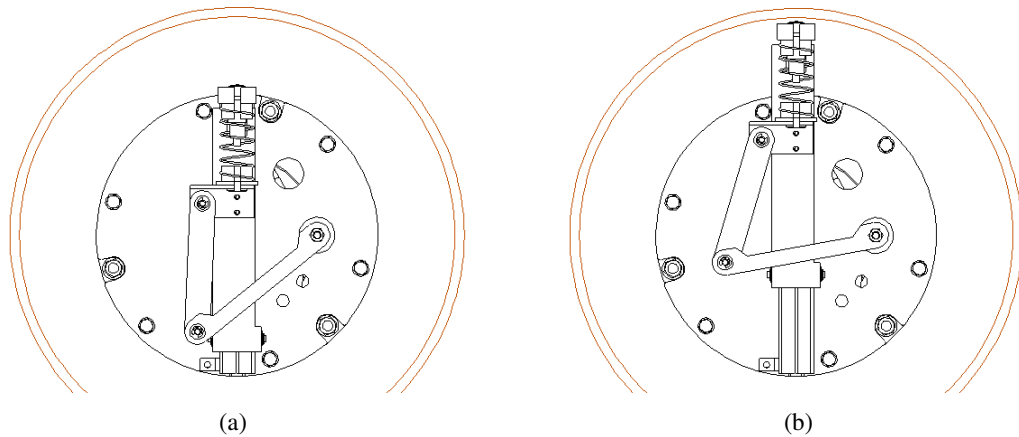


Figure 10. Arm measuring system. (a) retracted configuration. (b) extended configuration.

5.2. Angular motion

A DC motor and planetary gearhead module furnishes the torque to move the main body units, relative to the alignment units, that remain fixed to the pipeline. An encoder integrated to a pendulum gives the value of the relative angular motion (Fig. 7).

6. TESTS

6.1. Laboratory Set Up

The prototypes were mounted and calibrated at the Robotics Laboratory at Mechanical Eng. Department – UFRJ/COPPE (LabRob DEM-PEM).

To validate the performance of the equipments, test facilities such as 2 meters length linear and curved 14” pipes were installed at the Lab.

A “last minute” design modification on the alignment units of the 3rd prototype was necessary to permit the system to move along a visiting hole located at the upper part of the pipe. This consisted in the addition of wheels at the tripod mechanism. It should be noted that a visiting hole exists at each 200 m of pipeline length.

In Figs. 11 and 12 are presented the constructed prototype and a data mapping of a pipe section.

6.2. On Site Tests

While the 3rd prototype was under tests at the LabRob DEM-PEM, the 2nd prototype was sent to Bahia, in order to measure a pipeline sample submitted to the internal painting.

The 2nd prototype measured data proved that the distribution of chemical inhibitor product in a tested pipe section was not according to Petrobras standards.

Based on these results Petrobras was able to punish the company and redefine the service.

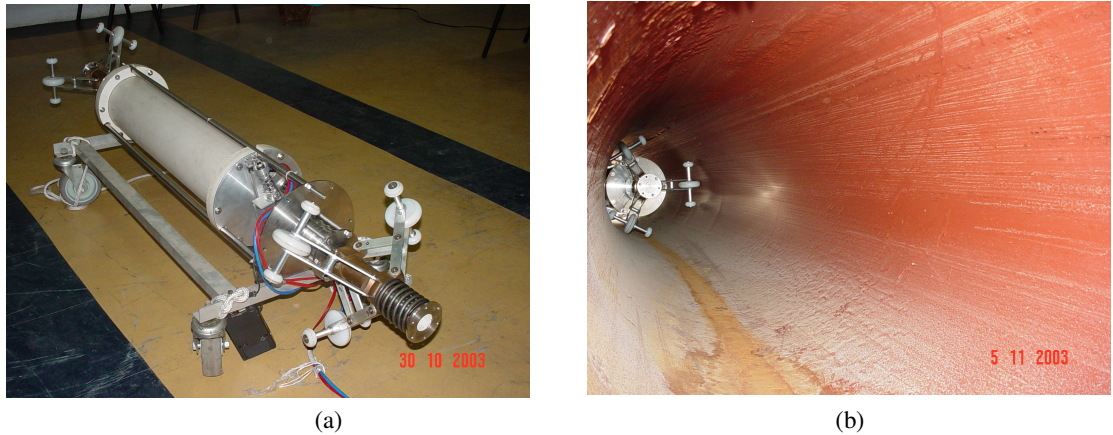


Figure 11. (a) Prototype at the Lab. (b) Testes in a curved 14'' pipe.

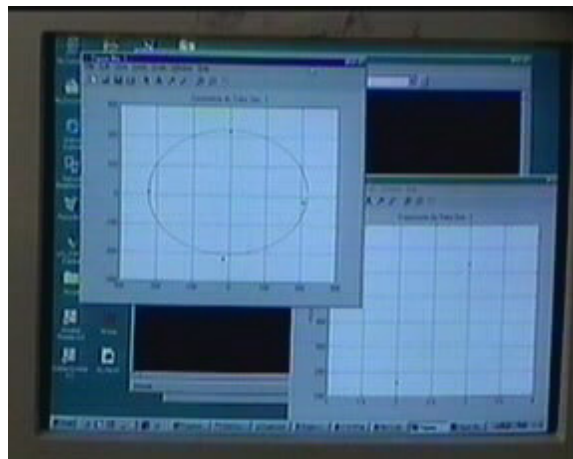


Figure 12. Mapping of a pipe section.

7. CONCLUSIONS

The mechanical characteristics of the second and third prototypes were able to measure the internal distribution of chemical inhibitor product in a 14'' pipeline section and its circumference deformation.

Although the concept of the 3rd prototype was more sophisticated than the 2nd one, the on site measuring tests with the 2nd prototype was enough to evaluate the pipeline conditions, according to Petrobras standards.

The successful performance of the equipment helped Petrobras to redefine the service and new conditions were established.

For future developments the authors suggest a new concept based on hydraulic actuators, so that a high pressure could be applied to the equipment and measurements be made with the presence of fluid flow at the pipeline.

8. ACKNOWLEDGEMENTS

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10. RESPONSIBILITY NOTICE

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