DEVELOPMENT OF A SEMI-AUTOMATIC ULTRASOUND SYSTEM FOR PIPE WELDING INSPECTION

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Abstract. *The use of welding mechanisms and robots are increasing the productivity in pipeline manufacturing. However, every welded joint has to be inspected before final approval, and if this procedure cannot be made in the same speed as the welding, it creates a new bottleneck in the production. To solve this problem, it was developed a system that is capable of holding up to 4 ultrasound sensors while moving at a controlled speed around the joint to be inspected. The system was also developed to be waterproof and field resistant, coupled with an easily transportable control box.*

Keywords*: Robot, Orbital welding, Ultrasound, NDT, Orbital inspection.*

1.INTRODUCTION

The ultrasound is a non destructive testing is used to detect flaws inside the material, inserting a sound beam with characteristics appropriate for the tested material. If this beam crosses any discontinuity, it will be reflected, and the echo will be shown at the interface as a peak response. This test requires a highly trained operator, with very high remuneration, and the equipment also has a high cost. The complete automation or mechanization would increase the productivity and reduce cost.

The chosen equipment, the X-32 by Harfang, is a “phased array” ultrasound inspection system. This equipment was designed to be manually operated, but is also suitable to be semi-automatic, and the system should be adapted to do field inspection of welded joints in gas and oil pipes. The reason for developing this system is because in Brazil there is no industry that dominates this technology, and the foreign equipment is too expensive to compete with man inspectors. The other reason is that the available systems are not designed specifically for field use, being resistant to weather damage.

The needs for the mechanism, like orbital movement and control, weather-proofing and ultrasound sensor movement are the subjects of this paper. This mechanism has an architecture similar to a orbital welding robot developed by our laboratory, and further information is presented in Bracarense et al. (2004) and in Lima II et al. (2005).

2. ULTRASOUND NON-DESTRUCTIVE TESTING (NDT)

This type of testing is capable of detecting very small flaw inside the material. The propagation of the sound waves are blocked, and the echo, or reflection is detected by the equipment. The sound pulse is emitted by a transducer coupled to the inspected material, and the reflected waves are captured by the same or a second transducer (pitch and catch mode), and the amplitude of the signal is shown in the equipment display. The ultrasound is an acoustic wave with frequencies over the human hearing threshold, with frequencies between 0,5 and 25MHz.

The peak response is when the defect is at the transducer center, and with that is possible to determinate the actual size of the flaw. This is important to determinate, according to the accepted parameters, if the piece should be accepted or rejected. Ultrasound can also be used to measure thickness and determinate corrosion damage.

The ultrasound test is the NDT most used to determinate flaws inside the material (ABENDE, 2009).

2.1. “Phased Array” technology

The phased array ultrasound system inspects with multiple ultra-sound beams at different angles and focal laws, but with only one transducer configuration. The control is done through carefully controlled delays in the emission and reception of the pulse of each element of the transducer set.

The data can be processed to show top, side, front or section view of the inspected area. The phased array system naturally produces sector views of the materials, an unique feature of this technology. A controlled movement with constant velocity or distance encoded allows a 3 dimensional data of the inspected area.

The detection and sizing capabilities are determinate by the beam width, which theoretically can be smaller than 1mm, being dependant on the sound frequency and beam focalization capability. This resolution is enough to detect lack of fusion at the groove, lack of penetration in the root pass, lack of fusion in the root pass, porosity and slag inclusion.

The automation of the ultrasound inspection is more suitable for the phased array technology mainly because of the ability of inspecting with only one passage in S-scan, and store the image in a friendly user method (B-Scan). The travel velocity of the phased array transducer can be as fast the conventional transducer, but the amount of data generated limits the actual speed due to hard drive constraint.

2.2. HARFANG X-32 System

The HARFANG X-32 system, shown in Fig. 1, is a “phased array” ultrasound NDT system. Is capable of doing data acquisition with four inspection head, with 32 channel each, for a total of 128 multiplexed channels. It is capable of storing section and 3 dimensional views of the part, in a portable, light weight and battery operated package. It is a PC-LINUX based system capable of receiving standards add-ons.

Figure 1. X-32 system (left); MP-2 control system (right)

2.3. The automation of the ultrasound NDT system

Among the products available in the market to automate the inspection, Harfang offers the MP-2 portable motor & pump unit, shown in Fig. 1 right. This package has a closed loop motor control system, to enable constant velocity, and manual or Ethernet movement control. Also has a coupling liquid pump and a wireless router for distribution of the reports.

The devices used to carry the transducer, show in Fig. 2, substitute the hand of the operator during the inspection and travels all around the tube. This system attaches to the tube by means of permanent magnets in the wheels, being safely secure even in case of electrical failure. It is important to notice that the ultrasound, the MP-2 case, the power system, the water storage and the cable harness are each one individual package. Since each weld inspection is made in only a few minutes, reducing the transportation time between inspections (6 to 12m, depending on the pipeline) is a key issue. The equipment available in the market is not suitable for field work mainly because it is not tightly integrated in a fully functional weatherproof package.

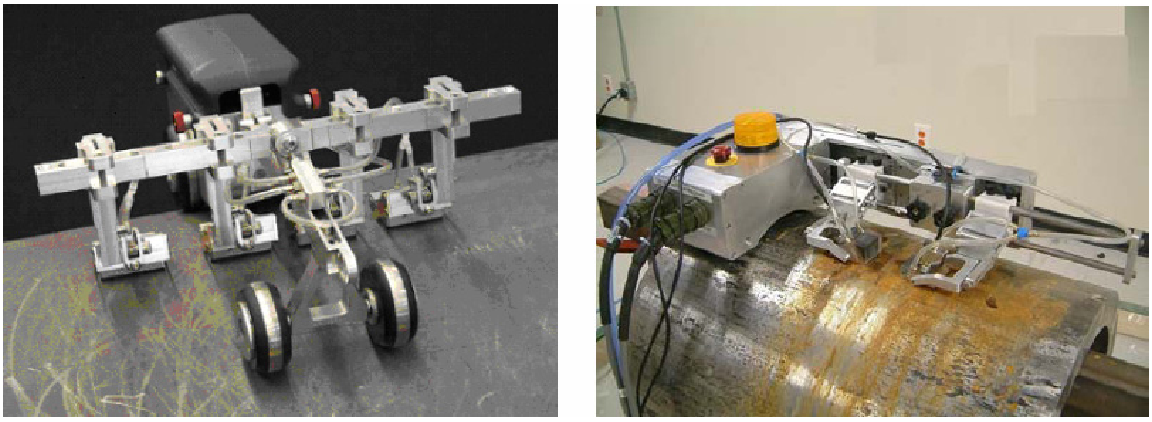

Figure 2. Two different models of scanners.

3. DEVELOPMENT AND REQUIREMENTS

3.1. Manual Vs. Semi-automatic system

When manually operated the weld inspector have to go all around the tested joint with the transducer in one hand, and carry the X-32 system on the other. Sometimes, both hands are needed to operate the ultrasound computer. This means that he has to inspect one side, jump to the other side of the pipeline, inspect the other side, crawl under a 60cm clearance to do the underside and sometimes go up a ladder to do the top part if the pipe is too big. It is easily noticed that the quality of the results get highly dependent on the ability of the operator to keep the same position, angle and pressure relative to the weld.

In the semi-automatic system, the operator is positioned in front of the display all the time, and controls the position of the transducer with a joystick. When any peak is found, the operator can stop the movement and investigate throughout the flaw, to determine size and type. It can also go all way around the tube and mark the exact position where suspicious sound peaks where detected, with the ability to return to these points at any time.

The ultrasound inspection have four degrees of freedom (4DOF), the translational movement around the tube, movement of the transducer perpendicular to the weld and the yaw angle relative to the perpendicular of the weld, all shown in Fig. 3. The pressure, or the vertical movement, wouldn't exist if the tube were perfectly round, which is not the case. The pressure has to be maintained above a certain threshold all the time, and for that the car might have to move up to 5mm.

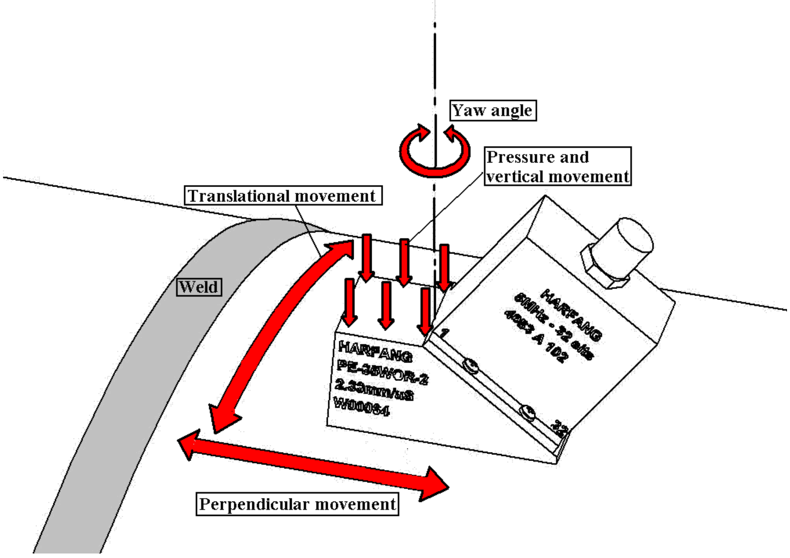

Figure 3. Degrees of freedom of the ultrasound pipe inspection

To be a fully automated system, the computer that decodes the ultrasound should also be able to auto-diagnose the flaw, and although this already exists, it lacks the confidence necessary to put in field work with pipeline inspection, where security is the major priority.

3.2. Requirements

For this design, the company that gave financial support, demanded a device that not only incorporated all the characteristics of the available projects, but also went beyond with further capabilities and weather proof packaging. Some of the incorporated features are described below.

3.2.1. Constant speed

Since the bottleneck of the ultrasound process is writing the huge amount of data in the hard drive, the speed should be maintained at maximum possible all the time, so the inspection time could be minimized. The load in the motor varies greatly, because of the plane, up and down movement. So a closed loop control system was used with a CC driver.

3.2.2. Measuring absolute position

The Harfang X-32 system needs some kind of feedback on the translational movement so it can stitch each section view side by side and maintain the correct dimensions in the 3D view. The problem was solved in 2 different manners. The first with the same encoder used for constant speed control, giving differential position, and with an inclinometer, for absolute position. Each one has its own advantages and drawbacks, and it should be chosen case by case. Roughly, the first should be used for greater diameters, and the second for all the other cases. With the constant velocity feature, the operator can also make acquisition on a time-based system, but this is less reliable, but more flexible.

3.2.3. Semi-automatic system

The joystick and all the controls stay close to the operator, so he can maintain his eyes fixed at the monitor at all times. The computer has no means to alarm the operator for a small flaw, and if the operator doesn't keep focused all the times, he might miss some critical information. All the movements necessary to fully inspect the pipe are available, and after the assembly, even the calibration can be done through the joystick. All the movements can also be uploaded in the internal PLC, and the operator have only to watch the screen. If some signal is detected, he can go back with the joystick.

3.2.4. Reconfigurable system

The system should be on automatic function most of the time, to guarantee minimal inspection time, but it has to be easily changed to manual operation to investigate something suspicious promptly. A resume function is also enabled. For doing this, a set of keys are used to alternate between the modes. It is also possible to connect the computer through an ethernet cable or wireless router for PLC reprogramming, computer based control, full automation and future improvements.

3.2.5. Ultrasound transducers

The image quality is as good as the coupling system used. Without the coupling, there is no way to transfer the sound waves from the transducer to the material. For that, two things were necessary, to keep the pressure over the transducer over a certain threshold, but not too high to avoid excessive friction. It is also necessary sufficient coupling liquid in the interface to guarantee sound transmission. The coupling liquid should have it's own reservoir integrated inside the package with pumps, with enough capacity to avoid constant refilling, but without adding to much weight.

4. DESIGN

4.1. The structure

The structure was designed to be light weight and easily constructed. Special design tools, as "Design For Manufacturing and Assembly" (DFMA) and "Laminated Object Modeling" (LOM) were used to achieve a simple, low cost, easily manufactured and assembled structure. Further details can be found in Ramalho Filho and Bracarense (2006).

Everything was designed to be build with one process, the LASER cut, and in only two different plate thickness. In Fig. 4, the designed structure and the main parts.

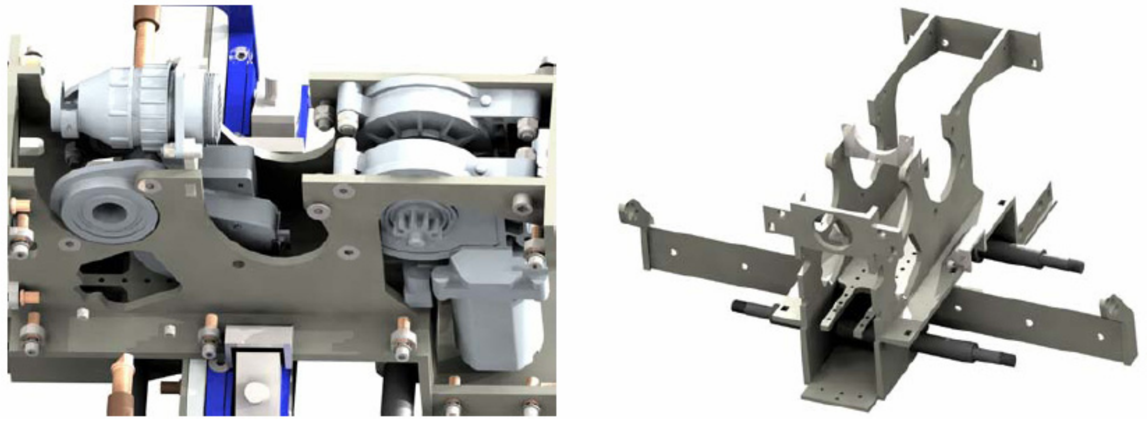

Figure 4. Bare structure and attached to the main components

Due to the acquired experience with the orbital welding system, it was decided to keep using the chain system to attach the device to the tube, but optimized to be smaller, reliable and with one axis less, as seen on Fig. 5. The chain serves both to keep the device tangent to the tube and to move it around. This new chain architecture needed to be fully tested with a prototype. See Lima II et al (2005) for more details.

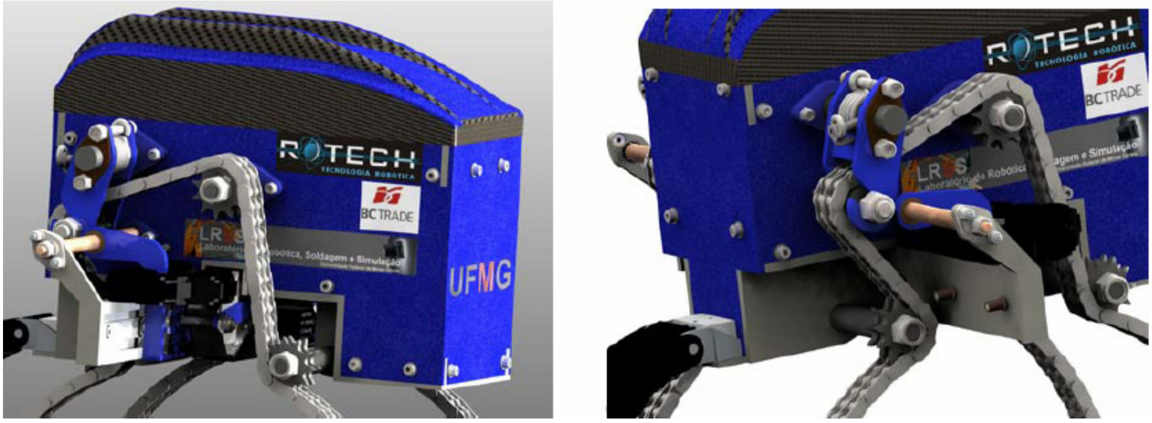

Figure 5. Chain system for positioning and movement

Each motor on the sides of the structure acts in the chain. The first motor moves the middle axis that is responsible for the movement, and the other motor is used by the chain tightener axis in the back, as seen in Fig. 6.

The structure was designed to keep all sensors and electrical components inside, so there was no risk of short circuit due to the couplant liquid leakage. Some room was spared for future improvements. All the structure was covered with liquid tight panels that can be easily disassembled for maintenance. Every axis have seals, all the screws and rivets are blind and all the external components were made of corrosion resistant materials, including the linear guides and the carriages. All the data and power cables were protected, to avoid entanglement with the power train.

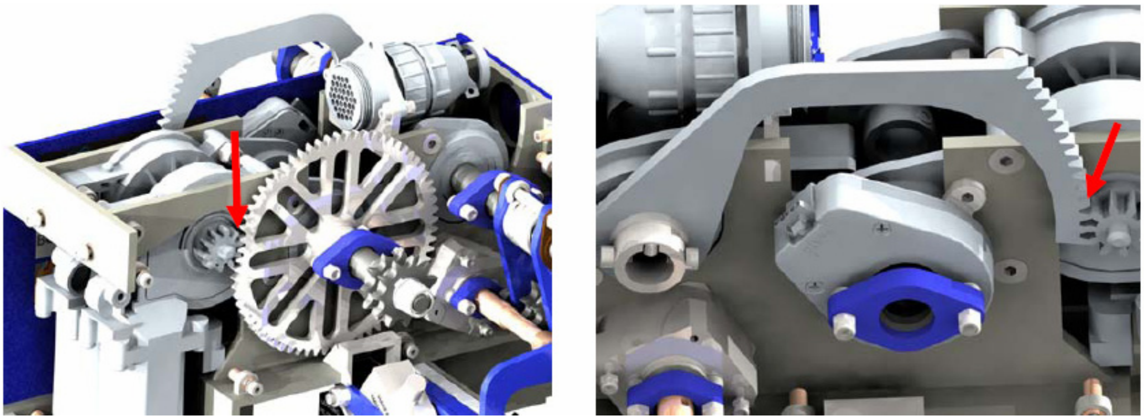

Figure 6. Power train and chain tightener.

The structure allows the position of the transducers along a linear guide for freedom of axial movement. It is important that the transducer stays in the middle plane of the system, to keep the transducer tangent to the tube even with problems in roundness. Each transducer can be moved independently, by means of a screw, for calibration, adjustment or investigation of a flaw. Fig. 7 shows this feature.

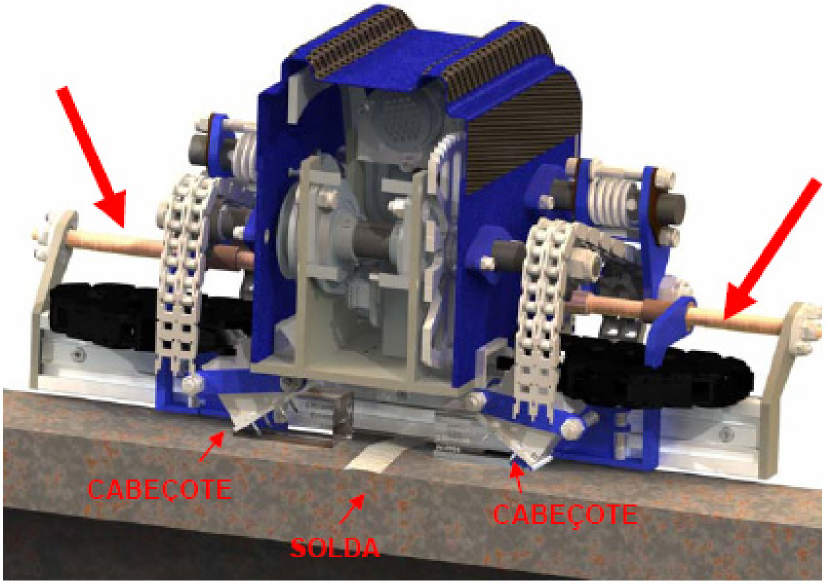

Figure 7. Axial movement of the transducers.

When equipped with the maximum of four transducers, will be supplied with thirteen cables, making necessary a special cable carrying system to keep everything organized and to avoid excessive friction against the tube. Also, it is very important to keep all the cables away from the teeth of the pinion or gears. The cable carrying system can be seen on Fig. 8.

The system, beyond all that, had to be light, so it could be easily carried to be mounted on the tube by the same person dozens of times a day, and had to be slim, so it could fit in the small gaps between the suspended pipe and the ground. It also should have a tool-less assembly to speed up inspection and external buttons, for small adjustments that are easier to make looking to the robot, like aligning the transducers to the right distance.

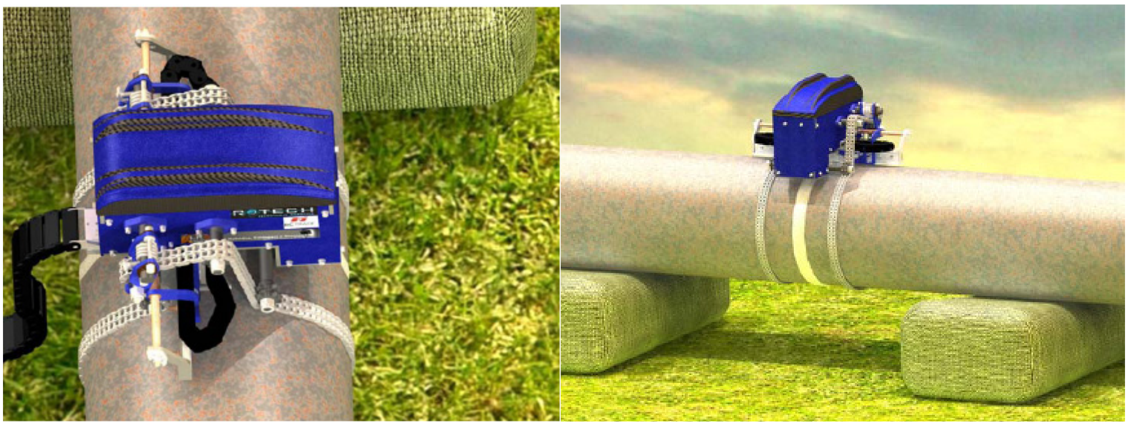

Figure 8. Cable carrying system and system clearance from the ground.

4.2. Control system and packaging

To fully integrate the system in a package, even when traveling or storage, a multipurpose package was designed, as shown in Fig. 9. With steel structure and aluminum cover, the upper half has a multipurpose storage room, and can be disassembled during operation. The whole package can be assembled over a vehicle or a push-car. During operation, without the upper half, the operator have only to pick the system from the small rack over the lid, assemble in the tube and open the lid to access the computer and the interface, shown in Fig. 10.

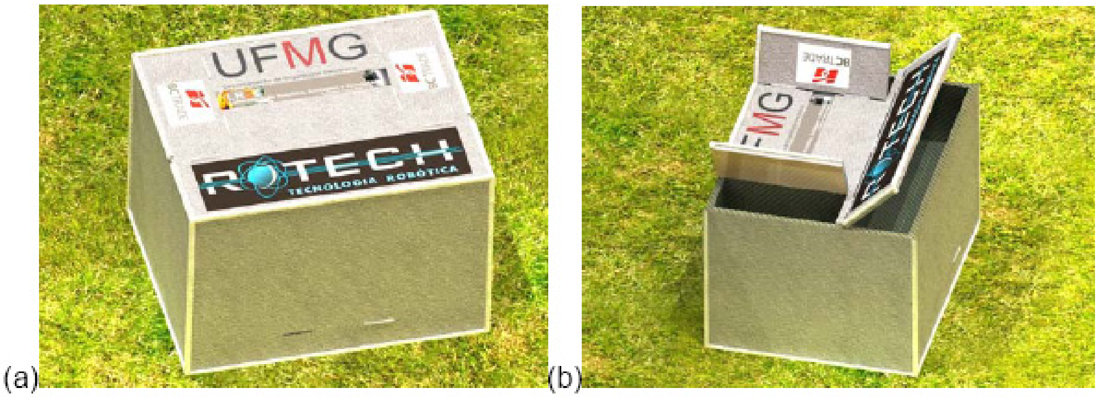

Figure 9. (a) Package; (b) extra room for accessories

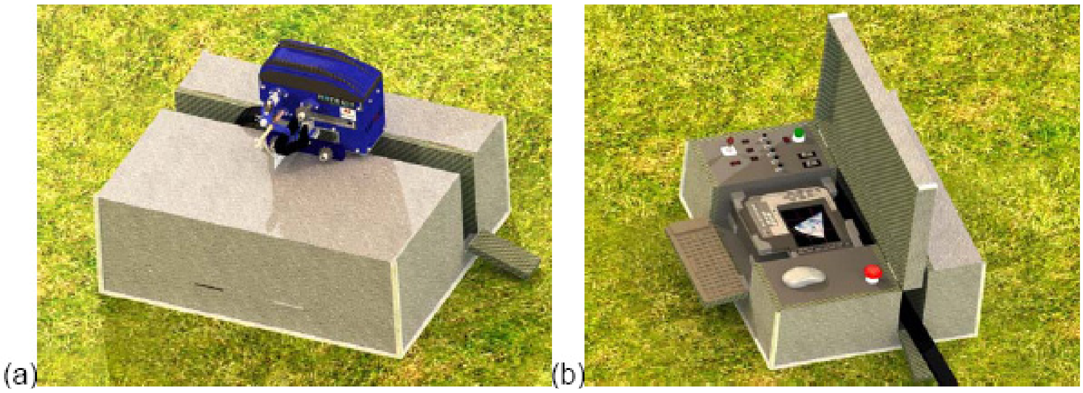

Figure 10. (a) Scanner rack (b) Interface lid

On the bottom of the package are the batteries, motor drives, fuses, PLC and other electronics components. In a separate chamber, on the other side of the cable carrier system, is the water reservoir and pumps. If by any chance happens a leakage, all the liquid is directed to the cable storage space, that is lower and completely isolated from the electronics.

The complete system, ready for inspection is shown in Fig. 11, where it wasn't necessary to attach a single cable, only to install the chain and mount the system.

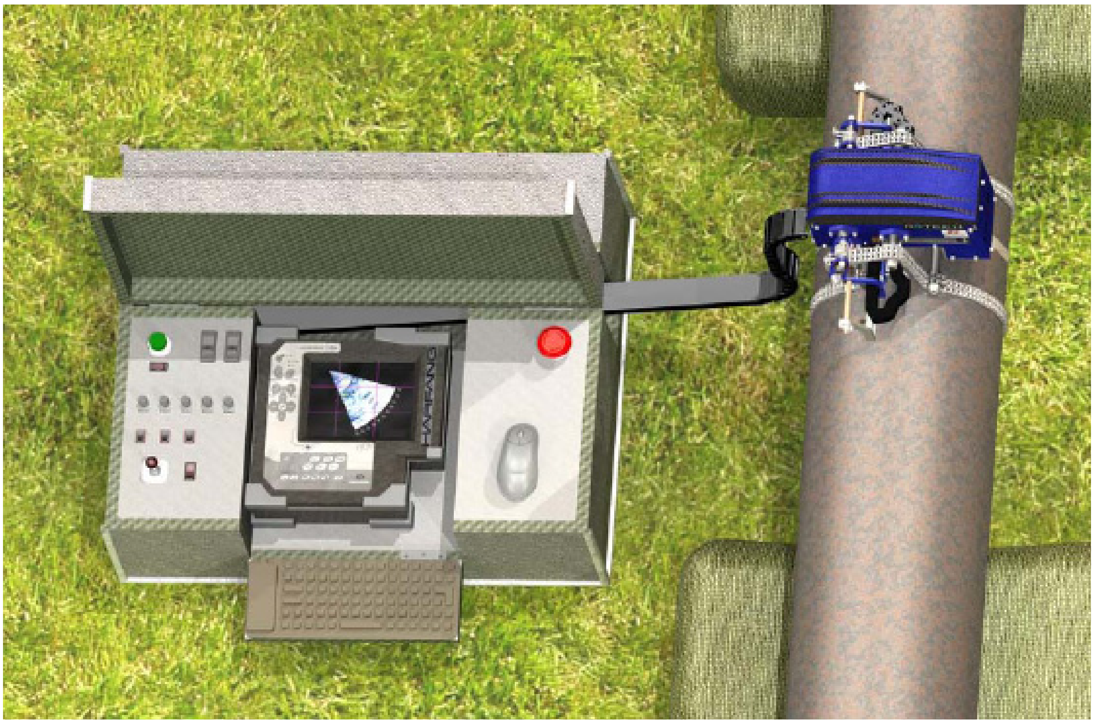

Figure 11. Complete system for NDT

4.3. Proof of concept

To prove the feasibility of the project, a prototype was built using the techniques described previously, with LASER cut and assembly with welding. No extra process was necessary, which keeps the cost low. Figure 12 shows the prototyped parts and the assembled structure.

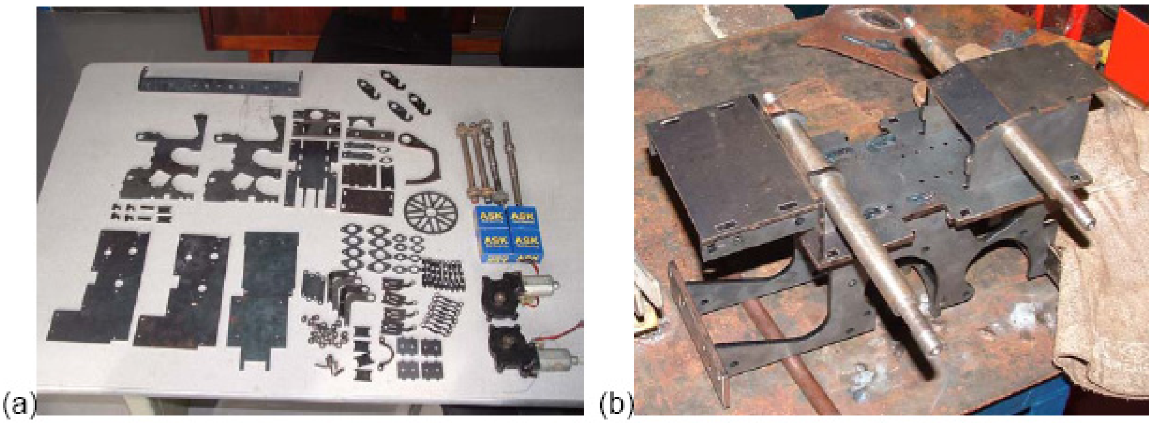

Figure 12. (a) LASER cut parts (b) Assemble of the structure

The prototype was submitted to the initial tests to prove the feasibility of the new chain architecture. The techniques used in the conception and design of the system allowed the prototyping, assemble and test to be made all within 5 days, at a total cost of less than U$500 plus 16 man hours. Figure 13 shows the first assemble and motion tests.

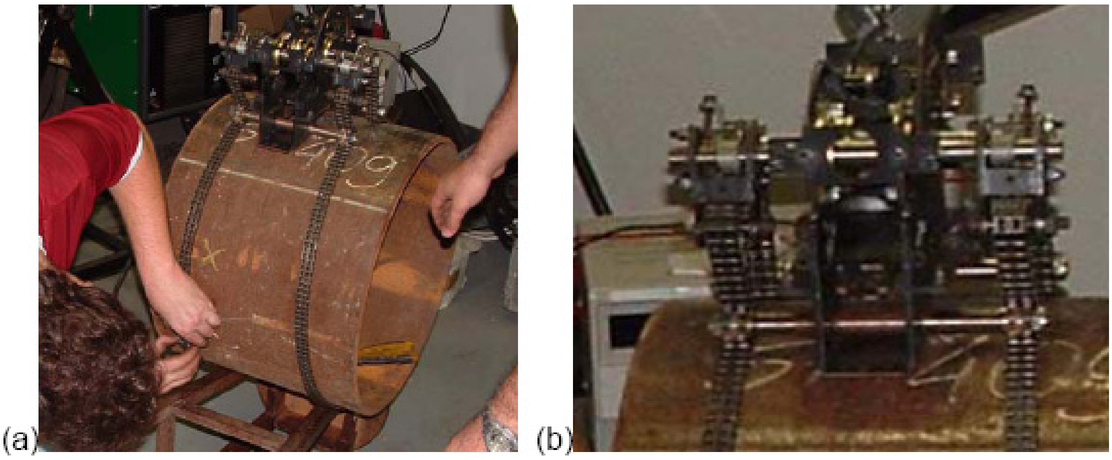

Figure 13. (a) Installation and chain adjustment (b) motion tests

5. CONCLUSION

Conventional industrial robots have become increasingly attractive by increasing the efficiency of production. But, for industrial applications in fields such as welding of pipelines, the conventional robots are unable to operate effectively enough to justify the high cost of implementation. It is therefore necessary to create new systems that can fill the gap in conventional applications where the robots are not effective.

The development of a semi automated system of ultrasound inspection of welded joints, have great benefits compared to the manual process. There is a better control in the positioning and smaller deviations in the samples due to movement variation. It is also important to notice the versatility in controlling the system, using a joystick and not needing to take the eyes from the monitor, diminishing the chances of human failure during inspection. Expressive gains in productivity, quality and lower cost can be expected.

One of the great advantages of this system is the cost, being far simpler to build and costs only a fraction of its international competitors.

6. AKNOWLEDGEMENTS

The authors wish to thanks BCTRADE the technical and financial support for the project.

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