Surface inspection of hot rolled seamless tubes

During hot rolling of laminated seamless tubes, surface marks and other defects may occur sporadically due to wear of the roll stands. This article describes a new automatic inspection technology for surface defects developed for a seamless tube manufacturer in Spain. The automated inspection system is installed at the exit of the push bench, just where the defects originate. Under harsh environmental conditions due to dirt, vapour and high temperatures, the system must be capable of inspecting the whole surface of the tubes in real time. An intelligent classification software tool based on a support vector machine is used to recognize the previously learned defects.

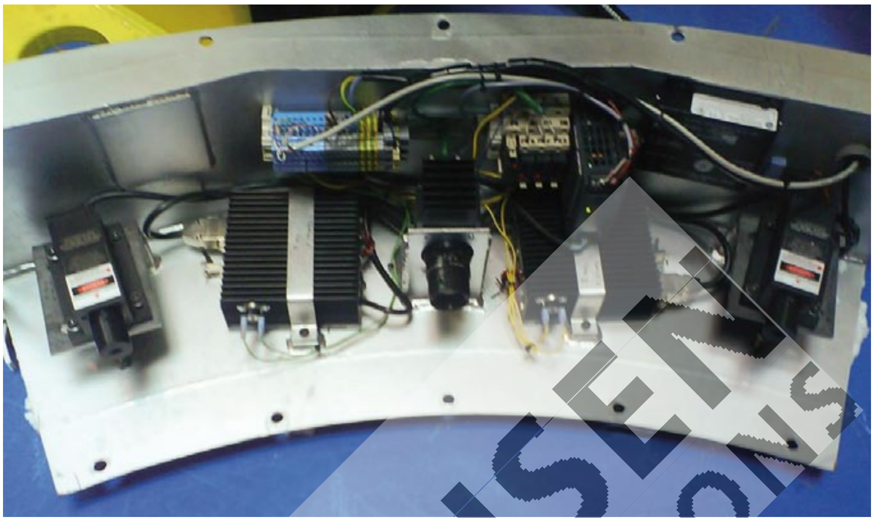

Figure 1. Inspection technology mounted in an enclosure

Introduction

Tubos Reunidos S.A. is at the head of a Spanish group made up of nine companies whose main area of activity is seamless pipe manufacturing. The companies Tubos Reunidos, S.A., Productos Tubulares, S.A and Aceros Calibrados, S.A. (ACECSA) make Tubos Reunidos Group the leading manufacturer in the Spanish seamless pipe market as well as a key supplier of seamless pipe on a worldwide scale.

Tubos Reunidos, S.A. offers hot rolled and cold drawn seamless pipes and tubes for many different applications: the oil and gas industry, both in its drilling activities and in petrochemical areas, the automotive industry, boiler manufacturing, mechanical engineering, the construction industry, etc. The three plants of Tubos Reunidos S.A. have a combined production capacity of more than 375,000 t/year of pipes. The company employs over 1,900 people.

Optical inspection of seamless tubes

The hot rolling process of seamless steel tubes occasionally produces marks and surface defects difficult to detect in the hot condition. These defects were detected only after various value-added production steps and after several tonnes of material had been processed. Consequently, in their quality improvement program Tubos Reunidos remarked that it was necessary to detect these defects as soon as possible and to include this point in the quality control system.

Robotiker-Tecnalia and Tubos Reunidos designed a new quality control system installed at the exit of the push bench, just where the defects originate. A frame supporting the equipment is placed immediately after the hot rolling stand area.

Challenging conditions. Due to the high temperatures, humidity and dirt the inspection conditions are critical. The data analysis is remotely performed. The diameter of the seamless pipe ranges from 140 to 220 mm and the length from 7 to 20.5 m.

During press-rolling of the tube the section is reduced and any the deterioration of these parts causes defects at the push bench, i.e.:

- bulged material, lack of material,
- semi-repetitive marks caused by rolling stands blocking,
- cracks, mainly on intersection areas of the rolling stands.

Usually the defects follow a repetitive pattern and they keep appearing until the rolling stands are changed. The conditions at the push-bench are extreme. The tube temperature is about 1,200 °C. The tube speed is 5.5 m/s. Due to the presence of water and oil steam, chips and dirt, inspection is a difficult task.

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Technical concept. For the surface inspection of the tubes an innovative method was proposed. The approach was to illuminate the tube using a wavelength far enough from the emitted spectrum of the incandescent steel. Then the image that reaches the camera is optically filtered with narrowband filters of the same wavelength, removing nearly all of the orange-infrared radiation of the tubes. Even when the visible emitted spectrum increases with the temperature (as the Plank law states), the tube images are acquired as if they were taken in the cold condition.

Viability study. Since the project team had not taken any samples of these defects under real conditions, prior to the project a viability study was carried out in order to minimize risks. The study was made in 2006 with the aim of verifying the planned approach. An induction heating device was installed to test the method. A viability platform (with provisional equipment) was installed at the Tubos Reunidos facilities for three months.

The technology was tested using intense white light (covering the majority of the visible spectrum), a matrix camera and different optical filters. During this viability study, the first image samples of the defects at the push bench were obtained.

Installed surface inspection technology

Hardware. For illumination of the tubes, laser technology was selected as light source due to its strength, focusing capabilities and monochromatic characteristics. Three high-speed linear cameras with medium resolution (1,024 pixels per line) are used. The line frequency of acquisition is about 14,000 lines per second.

The inspection equipment is mounted in three enclosures. Each enclosure includes (figure 1):

Figure 2. The bridge frame carries three enclosures

- camera, filters and optics,
- redundant system of lasers,
- security sensors,
- power sources, converters, additional electronics.

A bridge frame carries the three enclosures, located at approximately 120 degrees to one another (figure 2). The distance between the tube and the enclosures is about one meter.

A cooling system using clean pressurized air is used to keep the systems at an adequate temperature. Since external cleaning is a critical factor, the excess of cool air is used to generate an overpressure in the zone of thermal filters.

To ensure safe and reliable operation, three technologies are installed: air pressure, (redundant) temperature control for the enclosures and control of internal camera temperature.

An optical fibre Gigabit Ethernet system transfers data without interferences over 100 m to the processing unit located in the pulpit of the push bench. Both systems are electrically isolated.

With this equipment the complete surface of the tube is inspected. The field of vision of adjacent cameras overlap each other. Figures 3 and 4 show some real defects detected by the system: lack of material, hole, fold, crack, periodical marks.

Software. A custom-built application was developed by Robotiker-Tecnalia performing:

- image acquisition of the three cameras,
- image processing for automatic defect detection,
- database registration of defects and production information,
- control and communications.

The image data undergo on-line preprocessing to detect start and end of the tube and to calculate parameters that simplify post-processing. It should be remarked that performing this kind of data processing at high speed is difficult, but it is important to detect defects only on the tube (not the start of tube signal, only the push bench speed signal).

The captured images are post-processed in three seconds with a pattern recognition software capable of learning and clustering the patterns. It is based on the support vector machine algorithm.

Images, defect data, alarms (like pressure, temperature, speed signal and communications) and other production data are stored in an Oracle based database for quality control and traceability.

Network integration. The plant floor monitoring application (MOPLA) at Tubos Reunidos collects various tube production information. MOPLA is provided with the images of the defects to be stored in a database, together with data of the defects found and their locations on the tubes.

For remote inspection capabilities, the client application software can be installed on a computer connected to the Tubos Reunidos local area network LAN).

Evaluation phase and first results

The project was started in January 2007 and ended in September 2008. During that period the main risks of the inspection technology were evaluated and in most cases the technology past the tests.

Temperature protection enables reliable operation. The system controls the temperatures without problems.

Dirt is still a problem. External cleaning is required under some conditions of the production. The mechanical ad-

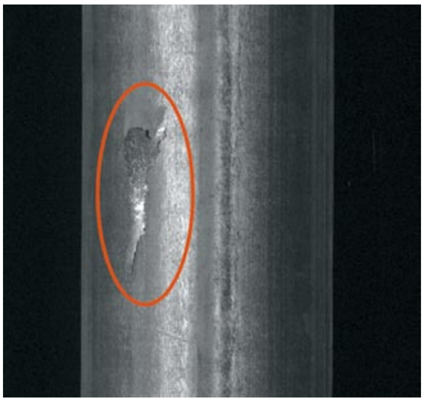

Figure 3. Surface defect: lack of material

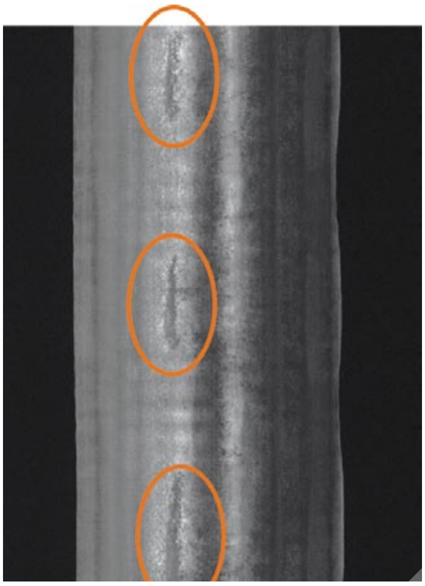

Figure 4. Surface marks due to broken rolling stands

justment system has been improved. The throughput of the system is sufficient. Data from three cameras (fourteen thousand lines per second) are processed at high speed. After defect generation and recognition, the system is now undergoing teaching.

There are still some difficulties to be solved. The quality of illumination is not homogeneous enough (non-uniformity of the lasers). Additional equipment and optics are still undergoing further testing to standardize laser characteristics. Laser and camera alignment are to be improved. These difficulties and non-uniformities emphasize the complexity of automatically detecting inner surface defects of tubes.

Conclusion

An innovative method of inspection was designed, tested and improved. After installation in August 2007 the system has been capturing and processing defect images of the whole tube production at Tubos Reunidos. The inspection system detects the defects automatically. The philosophy of the solution is adequate and it has proved functional.

However, the quality of illumination must still be improved in order to guarantee complete and homogeneous quality control. Additional filtering and cleaning systems are being tested to strengthen the solution. Further developments will be geared to improving stability and robustness.

This technology opens up promising potentials for other hot surface inspection applications (rolled wire, etc).