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Application of Digital Radiographic Imaging Technology in Metal Wall Thickness Measurement

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Abstract: Digital radiographic imaging technology applied in metal wall thickness measurement mainly addresses the non-contact thickness measurement for online inspection of high-temperature operating equipment and devices. This technology utilizes the penetrating and attenuation principles of rays, combined with the precise capture of digital detectors and image software analysis and processing, to achieve estimation and measurement of changes in metal wall thickness. The study reveals the unique advantages of digital radiographic imaging in metal wall thickness measurement, facilitating the detection of thickness changes caused by corrosion and thinning, thus providing reliable data support for the safety assessment and maintenance decisions of metal structures.

Keywords: Digital radiographic testing; metal wall thickness measurement; nondestructive testing

Introduction

Metal structures play a crucial role in industrial applications, and their wall thickness, as a key safety parameter, is of great importance for ensuring the stability and durability of these structures. The exploration of digital radiographic imaging technology in metal wall thickness measurement aims to provide valuable reference and guidance for research and practice in this field.

1. Principle of Digital Radiographic Imaging Technology

Digital radiographic imaging technology is an imaging technique that uses rays (such as X-rays) to irradiate the object being inspected, then converts the transmitted rays into digital signals through detectors, and processes and analyzes them on a computer. The basic principle involves the rays passing through the workpiece, where the attenuated ray photons are received by digital detectors and converted into digital signals after a series of transformations. These digital signals are amplified and converted via A/D (analog-to-digital) conversion before being processed by a computer, which outputs the final result as a digital image displayed on a monitor. Specifically, when rays penetrate materials such as metals or other inspected objects, the rays interact with the material, including processes such as transmission, absorption, and scattering, which lead to the attenuation of ray intensity. The attenuated ray photons are captured by the radiographic detector and converted into electrical signals. These electrical signals are further transformed and processed, converting them into digital signals that are received by the computer. The computer then processes and analyzes these digital signals, forming a digital image, which is displayed on the screen[1]. By observing these digital images, defects, structures, and other internal characteristics of the inspected object can be detected and analyzed. These digital images can also be stored on the computer or digital storage media, making it convenient for subsequent viewing and processing. Compared to traditional radiographic film detection methods, digital radiographic imaging technology offers higher detection efficiency and sensitivity, while avoiding the chemical pollution and waste issues associated with film processing. It is thus more environmentally friendly and sustainable.

2. Digital Radiographic Detection Method for Metal Wall Thickness Measurement

2.1 Measurement Principle and Method

The core principle of the digital radiographic imaging technology for metal wall thickness measurement lies in utilizing the penetrating ability of rays through metal materials and the attenuation differences in ray intensity caused by varying material thickness. As rays pass through metal, their intensity gradually decreases with the increase in thickness. By measuring the intensity of the rays after penetration and comparing it with the initial intensity, the variation in metal thickness can be measured through changes in grayscale. In practice, digital radiographic imaging technology is commonly used, as it can automatically capture multiple images and gather all necessary data for accurate measurement.

The measurement methods include experimental comparison and calculation-based measurement.

(1) Experimental Comparison Method: This method involves designing and manufacturing test blocks with identical materials and thicknesses, as shown in **Figure 1**. On these test blocks, flat-bottom holes with the same diameter but different depths are created. The same radiographic procedure and detection method used for the inspected workpiece are applied to the test block. The radiographic images of the test block are collected, and the depth of the flat-bottom holes is assessed. The same radiographic process is then used to inspect the workpiece. The grayscale information from the workpiece's radiographic image is compared with that of the test block. In this process, image processing software identifies and calculates the grayscale value of each pixel in the image. Based on the change in grayscale, the actual wall thickness value is estimated.

(2) Calculation Measurement Method: Through calculation and analysis, mathematical and graphical relationships are derived, which account for changes in the thickness of the workpiece, the inclination of the radiographic angle, and other factors under the same radiographic conditions. The image data from the inspected workpiece is then analyzed to compute or graphically estimate its wall thickness.

The detection methods include tangential radiography and dual-arm radiography. The selection of the appropriate detection method is determined based on the conditions of the workpiece, ensuring a reasonable and effective detection approach.

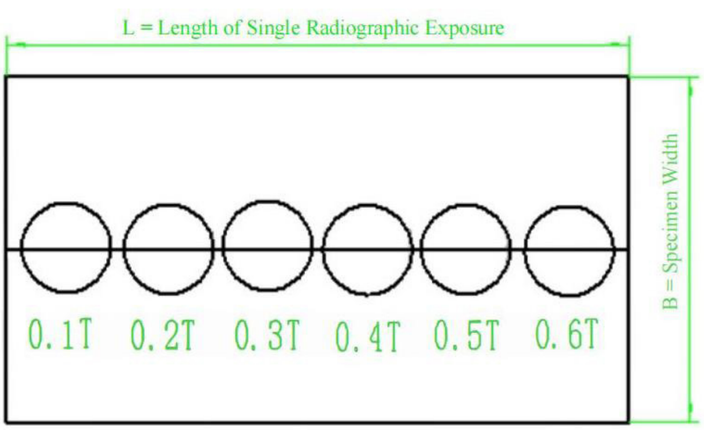

Figure 1. Schematic of the Comparison Test Block

2.2 Measurement Example and Data Analysis

As an example, the wall thickness measurement of a metal pipeline is carried out using digital radiographic imaging technology. First, the pipeline is pre-processed to remove surface dirt and coatings to ensure measurement accuracy. The pipeline is then placed between the radiation source and the detector for radiographic exposure. By adjusting the exposure and focal length, a clear X-ray image is obtained. During the image processing stage, specialized software is used to enhance and filter the image to improve clarity and contrast. Tangential techniques and double-wall measurement methods are employed to measure the pipeline wall thickness. The measurement results show that the wall thickness of the pipeline is uniformly distributed and meets design requirements[2]. To verify the accuracy of the measurement, the obtained data is compared with standard values. Specifically, the deviation between the measured values and the standard values is within ±0.1 millimeters, which is well within the acceptable range, strongly demonstrating the high accuracy and reliability of digital radiographic imaging technology in metal wall thickness measurement.

3. Application of Digital Radiographic Imaging Technology in Metal Wall Thickness Measurement

3.1 Application in Industrial Pipeline Wall Thickness Measurement

In the online measurement of industrial pipeline wall thickness, pressure pipelines are widely used in industrial applications. Over time, the inner and outer walls of these pipelines are prone to corrosion damage, which can lead to failure. When corrosion damage occurs on the inner and outer walls of the pipeline, thinning of the actual wall thickness can be observed at the damaged areas. There is a thickness difference between the corroded and non-corroded areas. Since the pipeline is in operation, and due to factors such as temperature, surface conditions, and the inability to remove protective coatings, the use of digital radiographic imaging technology for inspection is more sensitive and intuitive compared to other techniques. At a large chemical park, digital radiographic imaging technology is employed to conduct wall thickness inspection to ensure the safe operation of pipelines transporting corrosive chemical materials over long distances. Traditional detection methods require manual measurement by workers at multiple points along the pipeline, which is inefficient and difficult for pipelines that are deeply buried underground or elevated in high locations. With the aid of digital radiographic imaging technology, a small mobile crawler device is used on the pipeline's outer wall to secure the radiation source and detector. The crawler moves forward under motor drive according to process requirements. The digital detector quickly captures the penetrating radiation and converts it into digital signals, which are transmitted in real-time to the data terminal via high-speed data transmission lines. The analysis software uses advanced algorithms to process the data quickly and generate a pipeline wall thickness variation curve In a detection of a 10-kilometer-long pipeline, some areas were difficult to access, resulting in missed potential thinning points. Using digital radiographic imaging technology, 15 thinning areas were accurately located, with the most severe thinning measured at 0.5 millimeters. This provided precise data support for subsequent maintenance and reinforcement, greatly improving the efficiency and accuracy of pipeline inspections and significantly reducing the risk of chemical material leaks.

3.2 Application in Pressure Vessel Wall Thickness Measurement

Pressure vessels are commonly used equipment in industrial production, and their wall thickness directly impacts the vessel's load-bearing capacity and safety performance. The application of digital radiographic imaging technology in pressure vessel wall thickness measurement also offers significant advantages. Pressure vessels may experience corrosion damage, which can affect their safety performance. Ultrasonic thickness measurement, known for its high accuracy and speed, is a commonly used method for detecting wall thickness changes. Ultrasonic testing measures the propagation time of sound waves in the vessel wall, allowing for precise calculation of the wall thickness. However, ultrasonic testing is a contact-based method, and it cannot be used for high-temperature equipment, coated equipment, unremovable insulation-layered equipment, or devices with irregular shapes and nonparallel surfaces. In contrast, digital radiographic imaging technology has unique value in these complex scenarios. By optimizing the layout of the radiation source and detector, the digital radiographic imaging system can achieve wall thickness measurement at various locations on the vessel, meeting the needs of different complex operating conditions. This technology also provides a wealth of inspection information, such as wall thickness distribution maps, defect locations, and dimensions. This information is crucial for the safety assessment and maintenance decisions of the vessel. For instance, after identifying areas of wall thinning, corresponding maintenance plans can be formulated based on the degree and location of thinning, helping to avoid potential safety risks.

3.3 Application in Wall Thickness Measurement of Other Metal Components

In the field of bridge engineering, digital radiographic imaging technology provides a powerful tool for the safety assessment of metal structures in bridges. For example, in a large-scale sea-crossing bridge, the steel box girder structure is subjected to long-term corrosion from sea winds, impact from ocean waves, and vehicle loads, which may cause wall thickness variations and internal defects in certain areas. Traditional non-destructive testing methods struggle to comprehensively detect the internal conditions of the complex structure of the steel box girder. By utilizing digital radiographic imaging technology, a portable device specifically designed for inspecting bridge steel box girders has been developed. Inspectors fix a small radiation source and detector at the inspection location of the steel box girder using custom-made fixtures. The emitted rays penetrate the multi-layered metal structure, and the detector captures the transmitted radiation images. After image processing and analysis, the wall thickness conditions of the internal welds, partitions, and other parts of the steel box girder are clearly displayed. In the shipbuilding industry, for the complex metal components of large ships, digital radiographic imaging technology can precisely measure the wall thickness and detect defects in key areas such as the hull keel and bulkheads, ensuring the structural strength and safety of the ship in harsh marine environments.

4. Development Outlook of Digital Radiographic Imaging Technology in Metal Wall Thickness Measurement

4.1 Technological Optimization and Innovation Directions

To further enhance the performance of digital radiographic imaging technology in metal wall thickness measurement, it is essential to focus on several key technological aspects. In terms of radiation sources, the development of radiation sources with higher energy, greater stability, and precise control over the direction and intensity of the radiation beam is crucial. This would improve the ability of radiation to penetrate thick-walled metal components and complex structures, reduce image interference caused by scattered rays, and enhance measurement accuracy. For instance, using new nanomaterials to manufacture key components of radiation sources is expected to enable the miniaturization and high performance of radiation sources. In the detector field, the development of digital detectors with higher resolution and faster response times is becoming a trend[4]. By optimizing the pixel layout and signal conversion mechanism of detectors, they can more sensitively capture subtle changes in radiation intensity, providing richer data for accurate wall thickness measurement. In the area of image processing algorithms, the introduction of deep learning technology to upgrade existing algorithms is highly promising. Deep learning algorithms can automatically identify and analyze complex radiographic images, accurately extract wall thickness information and defect features, significantly improving detection accuracy and efficiency while reducing the influence of human factors on the results.

4.2 Expansion of Potential Application Areas

With industrial development and technological advancements, the potential application areas of digital radiographic imaging technology in metal wall thickness measurement will continue to expand. In the manufacturing of new energy vehicles, the uniformity of the wall thickness and the internal quality of metal components such as battery casings and motor stators are critical to the performance and safety of the products. Digital radiographic imaging technology can be used for online inspection during production, monitoring the wall thickness of components in real-time, detecting manufacturing defects, and ensuring product quality. In the field of cultural heritage preservation, many metal relics, due to their age, suffer from surface corrosion, and their internal structural conditions are unknown. Digital radiographic imaging technology can be used to measure the wall thickness of the metal material of these relics precisely, without causing damage, and analyze internal structural changes, providing a scientific basis for restoration and conservation efforts. In the manufacturing of aerospace engines, the wall thickness measurement of key components such as high-temperature alloy blades has a significant impact on engine performance. Digital radiographic imaging technology can meet the demand for high-precision, highly reliable wall thickness measurements, supporting the improvement of aerospace engine manufacturing technology.

Conclusion

In summary, digital radiographic imaging technology demonstrates exceptional performance and a broad range of application prospects in metal wall thickness measurement. It not only improves the accuracy and efficiency of measurements but also provides strong support for the safety assessment of metal structures. In the future, with continuous technological advancements, digital radiographic imaging technology will play an increasingly important role in the field of metal wall thickness measurement, contributing to industrial safety and sustainable development.

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