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X-ray Computed Microtomography for the Inspection of Flexible Risers

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Abstract: The integrity of flexible risers, essential for transporting oil from wells to platforms, is often compromised by residual gases such as CO_2 and H_2S, which cause fatigue through corrosion. The marine environment, with its bending loads, radial forces, and internal and external pressures, intensifies this process, requiring continuous monitoring and maintenance to prevent the degradation of the metallic layers. Flexible risers are composed of polymeric and metallic barriers, each with specific functions to ensure flexibility and pressure resistance. However, the rupture of wires in the tensile armor layers, often initiated by manufacturing defects, represents a significant failure mechanism. A gap has been identified in current inspection methods, which are intrusive or have limited sensitivity in some regions of the risers. To address this issue, the use of X-ray Computed Microtomography (microCT) is proposed as a non-invasive technique to detect microcracks in the layers of flexible risers. In this study, a section of flexible riser 440 mm in length and 155 mm in diameter was scanned by the Phoenix V|tome|x M/Waygate Technologies microtomograph, which has a 500 W range microfocus tube and a GE PXR250RT detector with a pixel size of 200 µm. Subsequently, the projections were reconstructed, and the images were analyzed in specialized software. The results showed defects along all layers of the riser. The application of microCT to enhance defect detection is suggested, which could contribute to safer and more reliable offshore oil and gas operations.

Keywords: computed microtomography, flexible riser inspection, X-ray image, offshore structure monitoring.

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Microtomografia Computadorizada de Raios X para a Inspeção de Risers Flexíveis

Resumo: A integridade dos risers flexíveis, essenciais para o transporte de óleo dos poços para as plataformas, é frequentemente comprometida por gases residuais como CO_2 e H_2S, que causam fadiga por meio da corrosão. O ambiente marinho, com suas cargas de flexão, forças radiais e pressões interna e externa, intensifica esse processo, exigindo monitoramento e manutenção contínuos para prevenir a degradação das camadas metálicas. Os risers flexíveis são compostos por barreiras poliméricas e metálicas, cada uma com funções específicas para garantir flexibilidade e resistência à pressão. No entanto, a ruptura dos arames nas camadas de armadura de tração, muitas vezes iniciada por defeitos de fabricação, representa um mecanismo de falha significativo. Identificou-se uma lacuna nos métodos de inspeção atuais, que são intrusivos ou possuem sensibilidade limitada em algumas regiões dos risers. Para abordar essa questão, propõe-se o uso da Microtomografia Computadorizada de Raios X (microCT) como técnica não invasiva para detectar microfissuras nas camadas de risers flexíveis. Nesse estudo, uma seção de riser flexível de 440 mm de comprimento e 155 mm de diâmetro foi escaneada pelo microtomógrafo Phoenix V|tome|x M/Waygate Technologies, que possui um tubo microfoco com alcance de 500 W e um detector GE PXR250RT com 200 μm de tamanho de pixel. Posteriormente, as projeções foram reconstruídas e as imagens analisadas em softwares especializados. Os resultados evidenciaram defeitos ao longo de todas as camadas do riser. A aplicação da microCT para o aprimoramento da detecção de defeitos é sugerida, podendo contribuir para operações offshore de petróleo e gás mais seguras e confiáveis.

Palavras-chave: microtomografia computadorizada, inspeção de riser flexível, imagem de raios X, monitoramento de estrutura offshore.

1. INTRODUCTION

In the context of oil production, there is a close correlation with advances in pipeline inspection technology, highlighting the importance of flexible risers. These play a fundamental role in oil transport, connecting wells to platforms through a system of pumps and injections [1,2]. However, the presence of residual gases such as CO_2 and H_2S causes degradation and fatigue of the risers, accelerating the corrosion process, and reducing their useful life. The loss of material in metallic layers results in damage that leads to the appearance of microcracks [3]. Furthermore, risers are subject to internal and external pressures, as well as intense mechanics during operations, highlighting the need for continuous monitoring and maintenance [4,5].

Flexible risers are made up of overlapping multilayers that consist of two fundamental elements: polymeric barriers, which protect against failures and corrosion, and prevent friction between the metal layers; and metallic barriers, which provide the mechanical properties of the risers, providing flexibility and ensuring support for internal and external pressure [6]. The metallic parts that make up these structures are the internal layer – the interlocked carcass, that transports the internal product; the pressure armor layer; and the tensile armor layers, which ensure resistance to existing loads [4,5]. Despite the functional independence of each layer, the project is designed to promote interaction between them. The purpose is to ensure that each layer is fit for purpose to meet requirements in the field [1].

Analysis indicates that the main origin of failures in flexible risers is related to the rupture of wires in the tensile armor layers. Marks and elevations resulting from the manufacturing process have the potential to initiate the formation of cracks in the tensile armor wires, causing serious fracture mechanics problems. The breakage of these wires triggers the rebalancing of loads, causing friction between the intact wires and generating structural fragility, resulting in progressive failure due to fatigue [6]. Therefore, constant monitoring of the layers throughout the useful life of the riser is essential to ensure safety and identify failures as early as possible to avoid irreparable damage [1].

Non-destructive testing (NDT) techniques such as fiber optics, acoustic transmission, electromagnetism, radiography, and others, are applied to the inspection and monitoring of risers, in addition to a combination of techniques that can increase the representativeness of the methods. Most techniques are intrusive or are not considered sensitive methods in different regions of the riser structures, or some limitations prevent development for field application [7]. The X-ray Computed Microtomography (microCT) is a non-invasive technique, based on the X-ray attenuation process, which promotes the formation of high-resolution 3D images, allowing the visualization and analysis of the internal structures of the studied sample [8,9]. This work aims to evaluate the effectiveness of the microCT technique in detecting defects such as microcracks in flexible risers, focusing on the structural integrity and reliability of the offshore oil and gas system.

2. MATERIALS AND METHODS

In this study, a section of the flexible riser, 440 mm in length and 155 mm in external diameter, taken from the production area, was scanned in a microtomography system. The microtomography system, Phoenix V|tome|x M/Waygate Technologies in Figure 1, has integrated control between X-rays, detector, and sample manipulation, allowing high quality configurations when scanning images. The system has a high power microfocus tube, with a voltage of up to 300 kV at a maximum power of 500 W, and a stable digital detector, GE PXR250RT, with a pixel size of 200 μm and 2024 x 2024-pixel matrix.

Figure 1: Phoenix V|tome|x M – microCT system: X-ray tube, sample, and detector

The riser section was rotated in the system by 360 degrees, in analogous angular steps, and image acquisitions were optimized as shown in Table 1.

Table 1 : Acquisition Settings

ACQUISITION SETTINGS	FLEXIBLE RISER
Voltage (kV)	260
Current (μA)	340
Acquisition Time (ms)	500
Projections	1200
Effective Pixel Size (μm)	113.8
System Rotation	360º

After acquisition, the projections were reconstructed using Phoenix Datos|x Reconstruction software, a high-performance tool that rapidly and efficiently generated volumetric data. The process included file size optimization, automatic reduction of ring artifacts and noise, correction of beam hardening, and background subtraction, thereby mitigating potential interferences that might have arisen during projection acquisition.

Subsequently, the images were imported into VGStudio Max software, enabling the visualization of 2D sections in three planes (axial, sagittal, and coronal) as well as the riser volume, allowing for detailed analysis across the sections. Additionally, the images were processed using CTan and Avizo software [10].

The segmentation process was carried out in CTan, which involved the identification of regions of interest (ROIs), facilitating the precise segmentation of the riser layers. Image segmentation involves discretizing the digital image with the goal of highlighting elements relevant to the analysis [11].

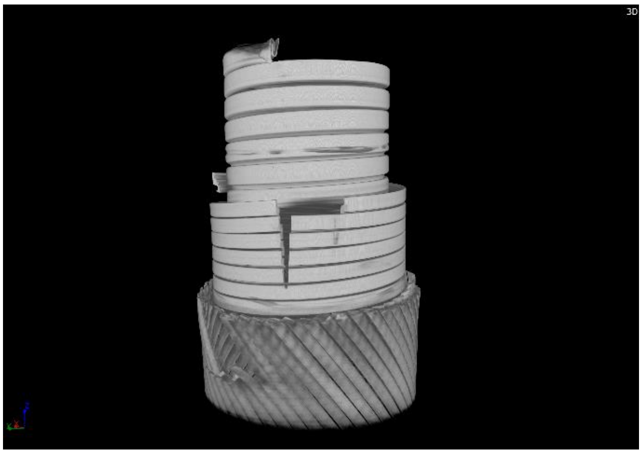
The axial view was chosen as it provided the best visualization of the riser layers, allowing for a clearer and more detailed analysis. For each riser layer, the segmentation process was performed individually. 2D slices were defined with initial and final points, delimiting the interval for each layer. The ROIs were traced along these 2D slices and, through an interpolation process, were extended along the riser layer, ensuring precise segmentation while accounting for the variation and continuity of characteristics along the riser.

The segmentation process was based on the global thresholding method, in which a single threshold value was applied to separate the pixels of the image into two groups: those belonging to the riser layer and those representing defects. The segmented images were then binarized, resulting in images composed only of black and white pixels, which facilitated defect identification. From the ROIs, the volume of interest (VOI) was generated, corresponding to the sum of the areas analyzed along the different 2D slices, representing the 3D volume of the riser layer. The segmentation process ensures precision in analyzing the layers and quantifying defects, enabling a detailed evaluation of the structural integrity of the riser layers.

3. RESULTS AND DISCUSSIONS

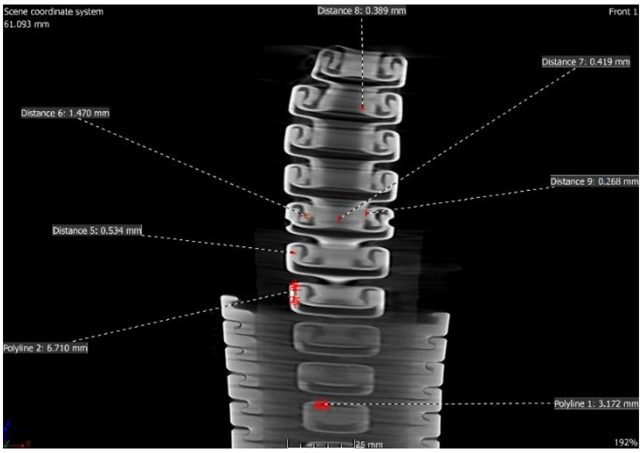
The 3D image in Figure 2 displays all the structural layers of riser, from the internal to the external, revealing the presence of the interlocked carcass, the pressure armor layer, and the internal and external tensile armor layers.

Figure 2: 3D Image of the riser layers – VGStudio Max software



During the analysis of the 2D images, defects were observed in the innermost layer of the riser, the interlocked carcass, among which the smallest one measured was of 0.268 mm. Figure 3 shows the interlocked carcass with the detected and measured defects and shows the pressure armor layer.

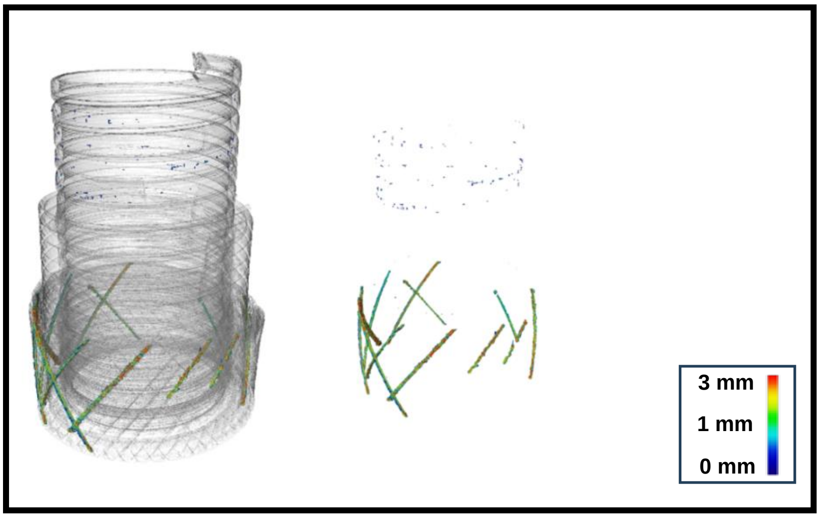
Figure 3: 2D image of the riser – detection of defects along the interlocked carcass and the pressure armor layer – VGStudio Max



The image segmentation process was used to identify each riser layer individually. During the analysis, defects were detected in all layers. However, the defects in the internal and external tensile armor layers, as well as in the interlocked carcass, were highlighted due to their greater size relevance for the study. The defects in the pressure layer were not presented due to their very small size and limited effect on the overall performance of the image.

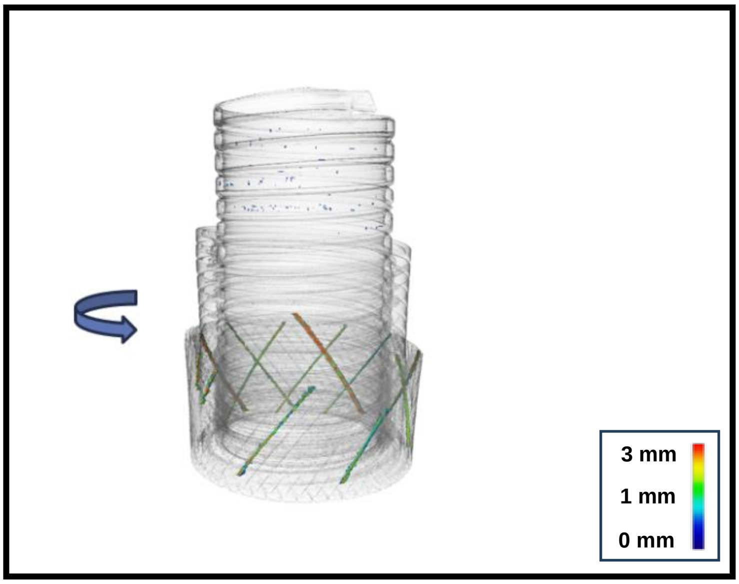
In Figure 4, the defects found in the internal and external tensile armor layers, as well as in the interlocked carcass, are visualized and measured on a scale ranging from dark blue, representing 0 mm, to red, indicating 3 mm. The defects were extracted to enhance their visibility, highlighting their relevance in the analysis.

Figure 4: MicroCT image of the riser - defect sizing represented by the color scale and defect extraction



In Figure 5, the riser image was rotated 90 degrees, which allowed for a different region of the riser to be highlighted. This rotation emphasized the defects found in the internal and external layers of the tensile armor wires and the interlocked carcass. The defects were quantified and displayed on a scale ranging from 0 mm (dark blue) to 3 mm (red).

Figure 5: MicroCT image of riser – defects sizing in the internal and external tensile armor wires and in the interlocked carcass represented by the color scale.



4. CONCLUSIONS

The application of microCT proves to be a promising approach for inspecting the metallic layers of flexible risers. Through the image segmentation process, different layers of the riser were identified and highlighted separately. The results revealed defects in all layers of the riser, with the smallest defects found in the interlocked carcass, measuring approximately 0.268 mm. Considering that the interlocked carcass is the innermost layer, the microCT images provided substantial results, demonstrating the technique's effectiveness in non-destructive inspection and defect detection, potentially contributing to the structural integrity and safety of marine environments.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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