ACTA IMEKO
ISSN: 2221-870X
June 2026, Volume 15, Number 2, 1 – 8

A compact and high productive shearography system for inspection of composite coatings applied on metal pipes

Gabriel Vieira de Oliveira[1], **Daniel Pedro Willemann**[2], **Armando Albertazzi G. Jr.**[1]

[1] *Universidade Federal de Santa Catarina, Brasil*
[2] *Universidade do Estado de Santa Catarina, Brasil*

ABSTRACT
This paper presents a novel system for non-destructive testing (NDT) aimed at improving the inspection of composite-coated metallic pipelines in the oil and gas industry. The proposed system utilizes shearography combined with induction thermal loading to enhance defect detection efficiency, achieving significant improvements in inspection speed and adaptability for field applications. The developed system features a compact, lightweight structure, produced using 3D printing, with an effective clamping mechanism that allows operation by a single person. An integrated induction coil applies controlled thermal loading, enabling active shearography inspection without interrupting plant operations. The methodology involves a dynamic inspection process where adjacent regions are sequentially analyzed: while one region undergoes shearography inspection during its cooling phase, the next region is heated by induction, optimizing the workflow. Initial results demonstrate a significant increase in inspection productivity, reducing the average inspection time by approximately 60 % compared to conventional shearography techniques, while maintaining the defect detection quality. This innovative solution is particularly suited for restricted spaces and remote locations, addressing key challenges in field inspections. The system can be adapted for various industrial applications requiring efficient defect detection in composite materials.

Section: RESEARCH PAPER

Keywords: shearography; composite materials; non-destructive testing; product design

Citation: G.V. de Oliveira, D. P. Willemann, A. Albertazzi G. Jr., A compact and high productive shearography system for inspection of composite coatings applied on metal pipes, Acta IMEKO, vol. 15 (2026) no. 2, pp. 1–8. DOI: 10.21014/actaimeko.v15i2.2251

Section Editor: Maik Rosenberger, Ilmenau University of Technology, Germany

Received: November 26, 2025; **In Final Form:** June 19, 2026; **Published:** June, 2026.

Funding: No funding specified.

Corresponding Author: Armando Albertazzi G. Jr., e-mail: albertazzi@labmetro.ufsc.br

1. INTRODUCTION AND LITERATURE REVIEW

Ensuring the safety and reliability of facilities has become a top priority in the oil and gas (O&G) industry, driven by both economic and environmental concerns. Despite continuous efforts to preserve structural integrity, many components inevitably deteriorate over time, particularly those exposed to aggressive environments and corrosive agents, which leads to substantial investments in maintenance operations [1], [2].

Among the most persistent challenges faced by the O&G industry is corrosion, especially in metallic structures located near coastal regions or in offshore facilities, where saline water exposure is a critical factor. If not adequately addressed, corrosion tends to spread across the metal surface, causing structural degradation such as cracking and wall thickness reduction, which can escalate to operational failures, leakage, or even total structural collapse [1], [2].

Several strategies have been developed to mitigate corrosion, including the use of high-alloy steels or stainless steels with increased chromium content. However, due to their high cost, these solutions are not feasible for large-scale application. In this context, the use of composite materials coating has grown significantly. These materials have become especially valuable for mitigating corrosion-related damage in harsh operating environments where metallic components are frequently exposed to aggressive chemical agents [3], [4].

In particular, composite coatings, often made of glass fiber-reinforced polymers (GFRP) or carbon fiber-reinforced polymers (CFRP), are applied to metallic pipelines as a means of mechanical reinforcement and barrier protection. Their high impermeability helps slow the corrosion process while simultaneously restoring the structural integrity of the damaged pipeline. These repairs are cost-effective and can be performed without interrupting production, as the application process does not involve high-temperature techniques such as welding [3].

Additional advantages include ease of maintenance and a superior strength-to-weight ratio compared to bulk materials like steel. These characteristics, combined with the high specific stiffness of fiber-reinforced composites, explain their growing adoption in structural applications, particularly where downtime must be minimized [4].

However, composite repairs are not without challenges. Defects such as voids, delamination, and disbonding may arise during application or in-service operation. These flaws can compromise the mechanical performance of the coating and allow the ingress of corrosive agents through paths not visible during visual inspection, potentially leading to catastrophic structural failure. Defects are generally categorized as either manufacturing-related or service-induced [5].

To ensure long-term performance, periodic inspection using non-destructive testing (NDT) is essential. These methods allow for the identification of defect location and severity, guiding decisions regarding maintenance or replacement of the affected sections [6], [7].

Shearography is a laser-based optical non-destructive testing (NDT) technique that relies on speckle interferometry to detect surface and subsurface defects in materials. By analyzing the phase difference between two states of an object subjected to slight deformation, shearography enables full-field measurement of displacement gradients, making it especially suitable for identifying delaminations, disbonds, and voids in composite structures [8], [9].

The fundamental principle of shearography is based on the laser speckle phenomenon, which occurs when coherent light is diffusely reflected by a rough surface, forming a granular interference pattern. These patterns are highly sensitive to deformation and can be analyzed using interferometric techniques to extract mechanical information from the surface [8].

Unlike traditional interferometry that measures absolute displacement, shearography introduces lateral shearing of the optical wavefront, allowing interference between adjacent points on the surface. This leads to measurement of displacement gradients ($\partial w / \partial x$ and $\partial w / \partial y$), which inherently eliminates rigid body motion from the analysis and improves robustness under industrial conditions [8], [10].

Fringe patterns are produced by the interference of sheared images before and after a load is applied to the test object. These fringes localize strain concentrations associated with structural anomalies. Shearography systems can extract phase information using temporal phase-shifting (multiple frames) or spatial methods based on carrier fringes and Fourier transform techniques [8], [11].

Temporal phase-shifting, such as the four-step algorithm, is sensitive to environmental vibrations, limiting its use in field inspections. To overcome this, digital shearography using spatial phase shifting enables phase recovery from a single pair of images using Fourier analysis, greatly increasing inspection speed and robustness against vibration [8], [11].

Recent advances have enabled multi-directional one-shot systems, which capture deformation gradients in multiple axes simultaneously, using specially designed multi-aperture masks and optical configurations [12].

The success of shearography depends on the method used to induce measurable deformation. Common loading techniques include mechanical stress, such as vacuum suction, pressure, or tension, and thermal excitation, which can be applied through hot air, infrared radiation, or electromagnetic induction [11].

The application of shearography offers several distinctive advantages: full-field imaging, contactless operation, high sensitivity to shallow and subsurface defects, and resilience to environmental noise, especially when spatial phase-shifting is employed [10].

Applications in the oil and gas industry include inspection of pipelines and pressure vessels repaired with GFRP or CFRP composites, where access may be limited and the use of portable, vibration-insensitive systems is critical [9], [10]. Recent studies have compared different system configurations, including those based on consumer-grade cameras, showing that even medium-resolution setups can achieve adequate defect detectability when combined with robust algorithms [13], [14].

Continued research in compact and portable shearography systems, including lightweight structures and embedded loading modules, is addressing the demand for efficient field inspection solutions. These efforts reflect the growing maturity of shearography as a practical NDT tool for composite material evaluation [8], [11]. Motivated by the need for greater portability and productivity in field inspections, this research aimed to develop a compact and efficient shearography system optimized for in-situ applications.

2. METHODOLOGY

The development of the compact and high-productivity shearography system followed a structured product development model which encompasses different stages of design. The objective was to create a lightweight, ergonomic, and operable-by-one-person inspection device suitable for use in restricted or difficult-to-access industrial environments.

2.1. Informational design

The informational design phase included a market analysis and the definition of functional and operational requirements. Benchmarking of existing compact shearography systems, such as those from Steinbichler [15] and Dantec [16], guided the identification of key features to be incorporated. Based on this analysis and discussions with industry professionals and research collaborators, a set of design requirements was established: Compact dimensions, portability, affordability, transparency to production processes, high productivity, robustness, innovation, and operation by one person. Also, from this analysis, the following operational requirements were established:

- Inspection area between $50 \times 50\,\mathrm{mm}^2$ and $100 \times 100\,\mathrm{mm}^2$;
- Compatibility with composite-coated metallic pipes up to 152.4 mm (6 inches) in diameter;
- Suitability for both laboratory and field use.

2.2. Conceptual design

The conceptual design stage focused on breaking down the system's global function, shearographic inspection, into elementary functions: (i) load application, (ii) illumination, (iii) image acquisition, and (iv) system fixation. A morphological matrix was used to generate different solution principles for each of these functions, resulting in three conceptual designs. A decision matrix evaluated these conceptions against functional requirements and determined the best configuration:

- Electromagnetic induction for thermal loading;
- Low-power diode laser (532 nm, 40 mW) for illumination;
- One-shot shearography system, based on Barrera [12] for image acquisition;
- Manual fixation structure for equipment stability.

The resulting concept was transformed into an initial model that served as a basis for the system's mechanical and functional development. This initial model is presented on Figure 1.

Also in this stage, the system's operating workflow was defined to streamline usage in both laboratory and field conditions. The

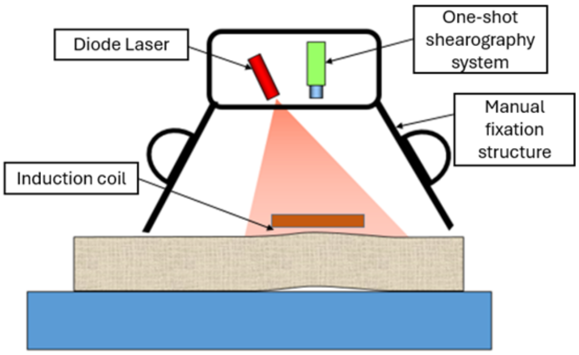

Figure 1. Model layout.

procedure begins by positioning the system over the composite-coated surface and securing it in place. The laser-based illumination is then activated to generate a coherent speckle pattern over the region of interest. Subsequently, thermal loading is applied via the induction coil to induce local deformation in the composite material. A reference image is captured immediately after heating. Then, while the surface cools naturally through air convection, a second image is recorded. This sequence avoids the need to reposition the system mid-inspection, contributing to greater repeatability and robustness. Finally, the two images are processed using spatial Fourier techniques to retrieve the phase map, from which fringe patterns indicating potential defects are extracted and analyzed.

2.3. Preliminary design

The preliminary design phase consisted of defining the physical layout and assembling the functional modules of the shearography system selected in the conceptual design stage. This step aimed to integrate all components, thermal loading, illumination, image acquisition, and fixation, into a unified and operable prototype, manufactured primarily using additive manufacturing techniques to ensure reduced weight and cost. Each subsystem was designed individually and then adapted for mechanical and functional compatibility within the overall device. Special attention was given to portability, modularity, and ergonomics to enable easy operation by a single user in confined field environments.

2.3.1. Thermal Loading Module

The thermal loading module is responsible for generating localized deformation in the composite coating to enable phase variation detection during the shearographic inspection. In this system, electromagnetic induction was selected as the excitation mechanism due to its non-contact nature, rapid heating capacity, and suitability for composite repairs over metallic substrates. The system's current source was based on a repurposed commercial induction cooktop. This unit was chosen for its affordability and availability. Internally, the cooktop includes a 30-turn copper coil with 2.5 mm diameter wire. After rectification, it operates at approximately 50 A current and 25 kHz frequency, which are adequate for inducing rapid localized heating in metal structures. To validate thermal performance, the coil was activated over a metallic pipe segment (152.4 mm diameter) coated with a 5 mm thick composite repair layer. A thermal camera was used to monitor the temperature distribution after short heating pulses (5 s to 10 s). The results confirmed the system's ability to quickly raise the temperature of the inspection area sufficiently (less than 5°C) to generate detectable deformation, without damaging the composite surface. This confirmed the effectiveness of the induction module for loading during shearographic measurements.

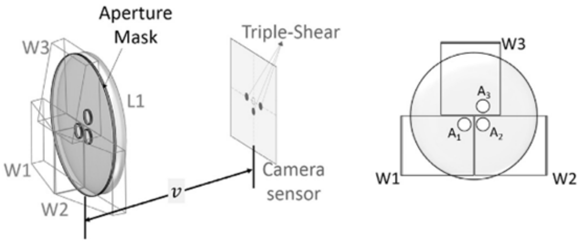

Figure 2. Triple-aperture configuration for simultaneous measurement in three shearing directions [12].

2.3.2. Illumination Module

The illumination system in a shearography setup is responsible for delivering coherent light to the surface under inspection, enabling the formation of speckle patterns necessary for interferometric analysis. Based on the conceptual design results, a low-power diode laser was selected due to its cost-effectiveness, compact form factor, and sufficient optical output for shearographic imaging. For that, a 532 nm (green) diode laser with 40 mW was chosen [17]. The selected laser is supplied in a compact metallic housing, which facilitates integration and mechanical mounting. Some of the limitations of diode lasers are their beam ellipticity and relatively low beam divergence, typically around 12 mrad in this model, which results in a narrow illumination cone. To expand the beam and ensure uniform coverage of the entire inspection area, a pair of aspheric lenses with 2 mm focal length was employed.

2.3.3. Image Acquisition Module

The image acquisition module of the shearography system is composed of a digital camera, an interferometric optical head, a fringe carrier generation device, and a set of lenses for image formation. This module is responsible for capturing the speckle interferograms used to extract phase information related to surface deformation. A 5-megapixel camera was selected for this purpose [18]. Following the conceptual design, the optical head was based on the multi-directional one-shot shearography system developed by Barrera et al. [12]. This system enables phase retrieval using spatial phase-shifting techniques, eliminating the need for temporal phase stepping and reducing sensitivity to vibration or object movement during inspection. The optical configuration consists of a mask with three apertures that introduce carrier fringes, and three optical wedges (W1, W2, W3) responsible for introducing controlled lateral shifts between the captured images. This setup, presented in Figure 2 enables simultaneous acquisition of multiple sheared views, enhancing the robustness of the phase calculation and allowing multidirectional deformation analysis.

To determine the appropriate field of view (FOV), the distance between the camera head and the specimen was set at 120 mm. Two different front lenses were tested: a lens with focal length $f = 8.0$ mm, which provided an FOV of approximately 60×60 mm^2, and a lens with $f = 3.5$ mm, which produced an FOV of approximately 110×110 mm^2. Due to the small size of the test specimens used in laboratory evaluations, the 8.0 mm lens was selected for all experimental procedures described in the following section.

2.3.4. Fixation Module

After defining and assembling the thermal loading, illumination, and image acquisition modules, preliminary laboratory tests were conducted to validate their individual performance and integration. These tests were carried out on an optical table under controlled conditions using different specimens to assess the system's ability to detect defects in composite-coated metallic surfaces. All inspections followed the operational workflow defined earlier, and the system successfully identified the intended defects in each case. Encouraged by these results, the project advanced to the development of the fixation module, responsible for integrating all components into a compact and portable structure. The fixation module was designed to ensure proper positioning and mechanical stability of the system during inspections, particularly in confined spaces and on cylindrical surfaces such as pipelines. While the initial tests were conducted with the components positioned on an optical table, this configuration was not practical for real-world field applications. As a result, a dedicated structural frame and fixation mechanism were developed to support the complete shearography system in portable and on-site inspection scenarios. As defined in the operational requirements, the fixation module is designed to couple to pipes up to 152.4 mm (6 inches) in diameter lined with composite material. The system is based on a support with three non-collinear points to ensure stable contact with the surface of the test object. The optical modules are attached to a structural frame that maintains the relative alignment between components and allows for compact integration of all subsystems. To simplify the assembly process and minimize weight, the entire structure was designed to be manufactured using additive manufacturing with polymeric material. At this stage, it was defined that the illumination and image acquisition modules would be positioned in the central region of the structure, while the thermal loading module would be placed in an adjacent area. This configuration proved advantageous for simplifying the overall system design, as it eliminated the need for a mechanical mechanism to reposition the induction coil—i.e., to move it in and out of the inspection field during operation. An additional benefit of this configuration is the increase in inspection productivity. While image acquisition is being performed over the current inspection zone, the induction coil can simultaneously heat the next area to be inspected. This sequential workflow reduces idle time between measurements and allows the operator to conduct inspections more efficiently and continuously. Figure 3 presents the final version of fixation module structure, and Figure 4 presents a model of the complete system, containing all its modules and the composite coated piping under inspection. The illumination and image acquisition modules are positioned in the central region of the structure, delimiting the inspection area, and the thermal loading module is located in an adjacent region. Furthermore, a cover made of opaque fabric can be attached to the outside of the structure to minimize the influence of external lighting in very bright environments, such as outdoor measurements on sunny days.

With the definition of all system modules, completion of the mechanical design, and the selection of appropriate manufacturing and assembly processes, the preliminary design phase was concluded. The project then proceeded to system validation and performance testing, as detailed in the following section.

3. RESULTS AND DISCUSSION

3.1. Prototype manufacturing and testing

The first step of the detailed design stage was the fabrication of the fixation module, as previously described. After 3D printing the structural frame, the complete system was assembled by attaching the thermal loading, image acquisition, and illumination modules using screws. Additionally, three metal inserts and screws were installed at the support points to enable stable positioning of the device on cylindrical surfaces such as pipes. Figure 5 shows the fully assembled prototype positioned over a test pipe during inspection.

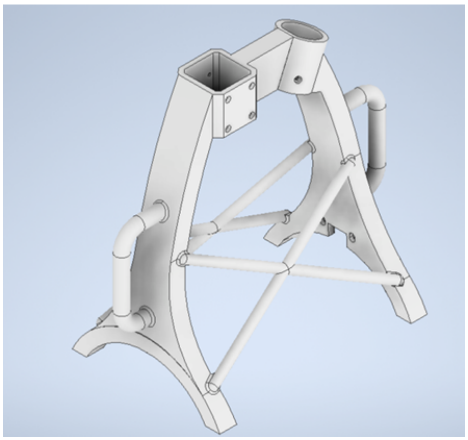

Figure 3. 3D model of the fixation module structure.

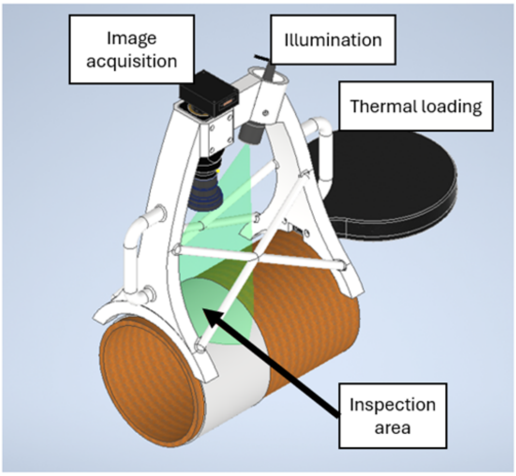

Figure 4. Model of the complete system.

Thanks to the use of polymeric 3D printing, the resulting structure is lightweight, with a total mass of approximately 1500 g, which facilitates portability and single-operator handling.

To validate the prototype's performance, an inspection was carried out on a metallic pipe coated with composite material containing an artificial wall defect (test specimen (i)). The shearography image acquired during this test is shown in Figure 6. The resulting fringe pattern clearly highlights the presence of the defect, which is observable at the center of the image. This confirms the system's ability to successfully detect anomalies through deformation mapping, validating the functionality of the integrated modules and the chosen design approach.

To further validate the capabilities of the developed system, additional tests were conducted on another specimen, different from the previously tested straight pipe section. In this case, a curved 4-inch diameter metallic pipe, also coated with composite material, was selected to simulate a more complex inspection scenario (test specimen (ii)). Due to the curved geometry in this configuration, a different fixation strategy was adopted. Commercial elastic straps with plastic hooks were used to secure the prototype onto the pipe surface. This solution proved effective in maintaining system stability during inspection, while also demonstrating the adaptability of the fixation module to non-standard geometries. Figure 7 shows an image of the prototype being inspected in this new test specimen. This image already shows the fixing system with elastic straps.

The test confirmed the system's functionality even under non-ideal mounting conditions, reinforcing the potential of the pro-

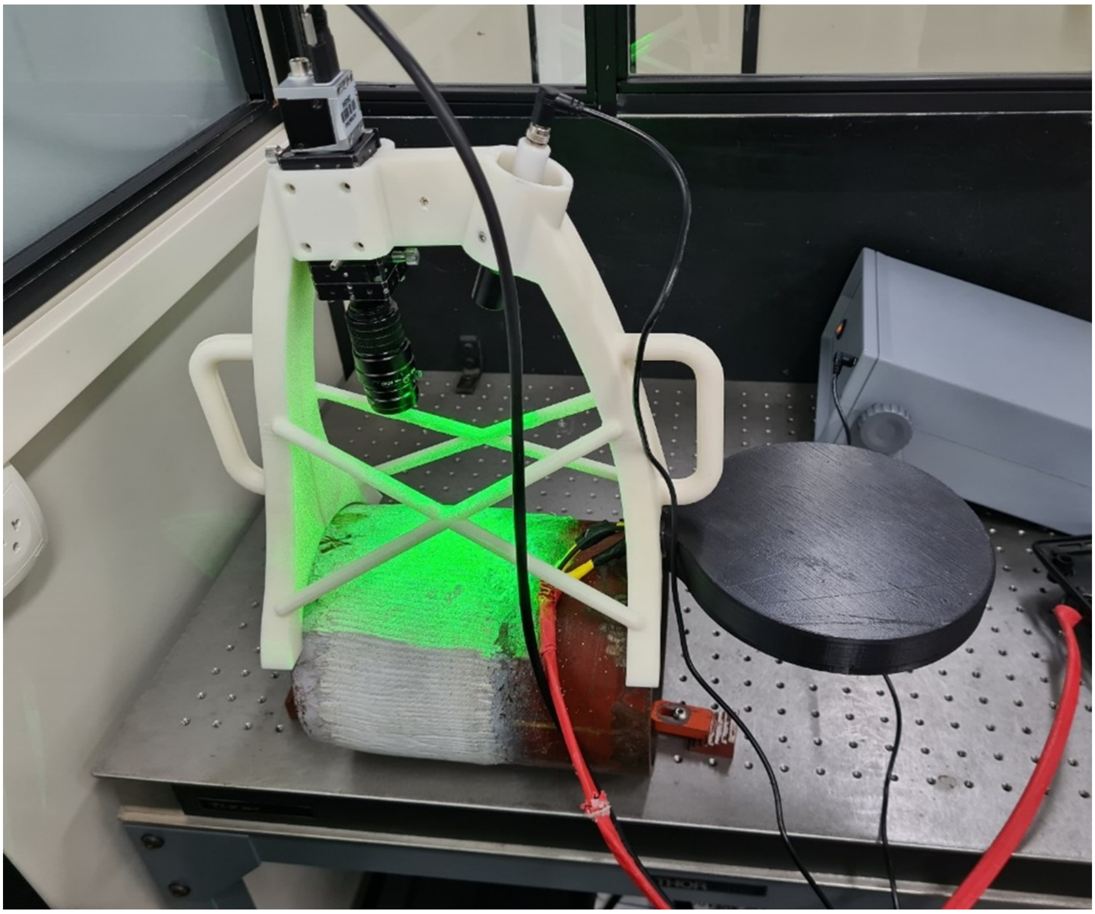

Figure 5. Experimental assembly of the prototype.

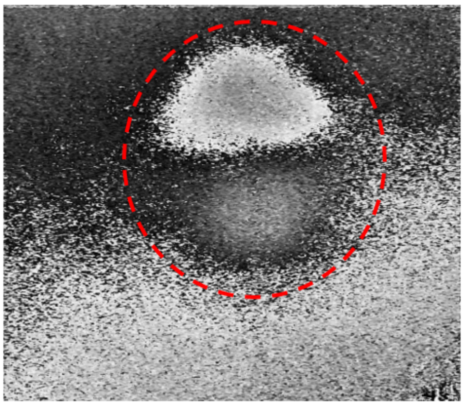

Figure 6. Result of shearography inspection of the prototype on test specimen (i).

posed solution for field applications in diverse real-world scenarios. Figure 8 shows the result of this inspection, in which it is possible to see that the system was able to identify a region of the pipeline with the presence of defects, evidenced by the fringe pattern highlighted in the image.

These results demonstrate that the system as designed, built, and tested successfully meets the objectives defined in this study. The developed prototype enables practical shearography inspections of pipelines coated with composite materials. Thanks to its compact dimensions and simple fixation mechanism, the system can be operated by a single user. Once the structure is fixed onto the inspection region and the thermal excitation is applied, the operator can independently perform image acquisition and processing. After completing an inspection cycle, the operator simply moves the system to the next inspection area and repeats the same procedure. This workflow supports sequential inspection with minimal repositioning effort, making the prototype well-suited for field applications that demand mobility, efficiency, and operational simplicity.

3.2. Analysis of system productivity gains

Based on the experimental results presented in the previous section, it can be inferred that the developed system demonstrates higher productivity for pipeline inspections when compared to traditional shearography systems that rely on more complex positioning mechanisms. Such systems typically involve time-consuming procedures for alignment and fixation, resulting in slower and more labor-intensive inspections. To quantitatively assess this productivity gain, it would be ideal to construct a standardized test pipe with embedded defects distributed in multiple directions across the surface. This setup would allow a controlled, repeatable comparison between different shearography configurations. However, due to the lack of such a specimen during the development of this work, the productivity comparison presented here is based on an estimated analysis between the developed prototype and a previously built shearography system. The reference system selected for comparison features direct fixation to the pipe using a ratchet strap collar, as shown in Figure 9. It includes an image acquisition module and an illumination module but lacks an integrated thermal loading unit. For the purpose of this analysis, it was assumed that an external electromagnetic induction heater would be used to provide thermal excitation for both systems.

The shearography inspection procedure was broken down into the following sequential steps: Initial positioning and fixation of

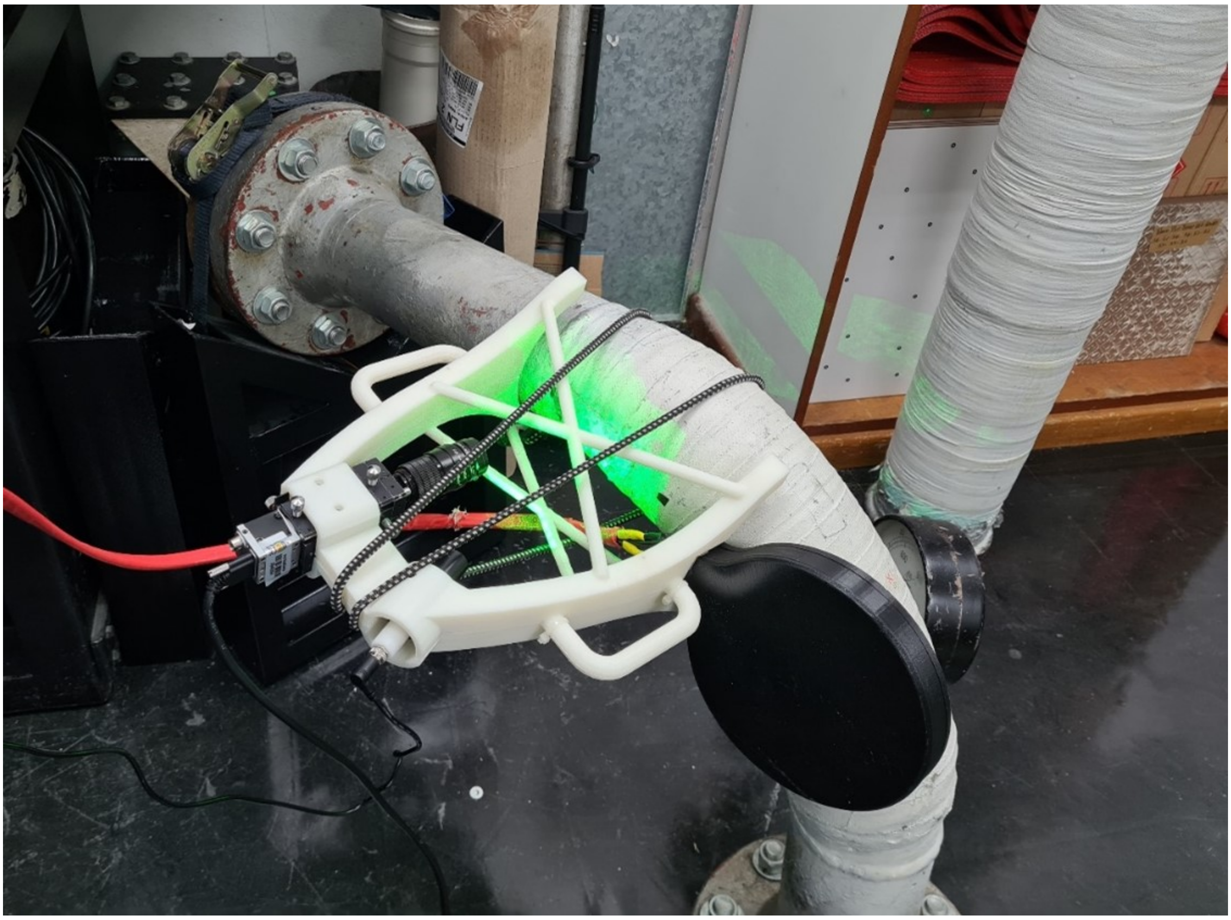

Figure 7. Prototype under inspection with elastic fixation on test specimen (ii).

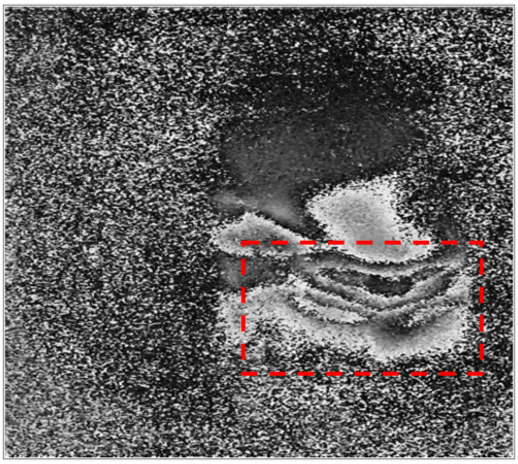

Figure 8. Result of shearography inspection of the prototype on test specimen (ii).

the system; Thermal loading of the test surface; Image acquisition from the first inspection area; Repositioning of the system; Heating the next area; Image acquisition from the subsequent region. Table 1 presents the estimated time required to perform each step for both systems. It is important to note that time intervals were estimated, as the actual execution time may vary depending on the operator's experience and on-site working conditions. To simplify the comparison, it was assumed that both systems inspect a similar area of approximately 60 mm × 60 mm. Pre-test procedures, such as locating and preparing the test object, were excluded from the analysis since they are common to both systems.

According to the estimated data, the average time to perform an inspection using the proposed system was approximately 40 % of the time required by the reference system under similar conditions. The main productivity advantages of the developed prototype come from two key factors: faster repositioning, enabled by the use of elastic straps for fixation rather than mechanical ratcheting collars; and the ability to initiate thermal loading of the next inspection area while image acquisition is being performed on the current region, minimizing idle time between inspections. It is worth noting that this productivity analysis was based on two consecutive inspections, but the efficiency gains become more pronounced as more tests are performed in sequence. With each repositioning and loading cycle, the time-saving benefits of the proposed system compound, resulting in significantly greater cumulative productivity when inspecting larger surface areas or multiple regions.

4. CONCLUSION

This work aimed to develop and evaluate a compact and high-productivity shearography system to facilitate the non-destructive inspection of composite-coated steel pipelines, especially in hard-to-access or restricted environments. The proposed system was successfully designed, built, and tested under laboratory conditions, demonstrating its capability to detect defects effectively and with higher operational efficiency compared to existing systems. Therefore, the main objective of the study was fully achieved. The system development followed a structured engineering methodology, including the definition of design and operational requirements, functional decomposition, and generation and evaluation of solution principles. Each selected principle—diode laser il-

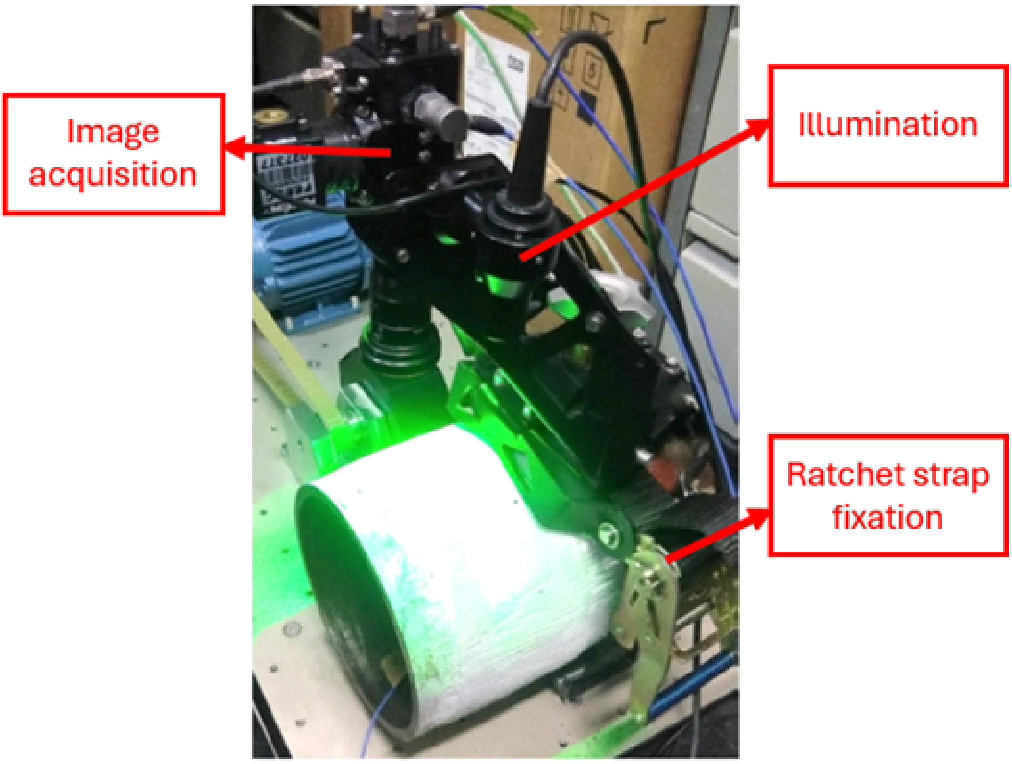

Figure 9. Shearography system used as a reference for comparative analysis.

Table 1. Comparative estimate of system productivity.

Steps	Proposed system (s)	Reference system (s)
1- Initial positioning and fixation of the system;	$60 < t < 90$	$240 < t < 360$
2 - Thermal loading of the test surface;	$15 < t < 30$	$15 < t < 30$
3 - Image acquisition from the first inspection area;	$30 < t < 60$	$30 < t < 60$
4 - Repositioning of the system;	$15 < t < 30$	$60 < t < 120$
5- Heating the next area;	0 (during step 3)	$15 < t < 30$
6- Image acquisition from the subsequent region.	$30 < t < 60$	$30 < t < 60$
Total (inspection of two regions)	**150 < t < 270**	**390 < t < 660**

lumination, electromagnetic induction heating, and one-shot shearography for image acquisition—was experimentally validated and integrated into the final prototype. The 3D-printed structure of the prototype proved lightweight, solid, and ergonomic. Its inspection area was suitable for detecting defects in all tested specimens and could be easily adjusted by changing the camera lenses. The complete inspection process using the developed system was found to be simple and agile. Unlike conventional tripod-mounted systems, this prototype can be directly fixed to the surface of the pipe, greatly improving ease of positioning and allowing rapid progression along different inspection regions. A comparative productivity analysis with a reference system—fixed by a ratchet strap—revealed that the proposed system required only about 40 % of the inspection time, clearly demonstrating its operational advantage. The prototype built also has the advantage of compact dimensions and low mass, which are especially important characteristics for offshore applications, which require air transport and inspections in difficult-to-access locations and restricted environments. The experiments confirmed the system's effectiveness in identifying and localizing defects in composite-coated pipelines. These results were achieved under testing conditions designed to simulate the challenges encountered during field inspections. Overall, the system demonstrated high potential for industrial implementation, with promising results under simulated field conditions. Finally, a patent application for the invention presented in this work has been filed and is underway.

4.1. Future work

Future research should focus on enhancing the system's automation and field adaptability. Key developments include designing a dedicated control module for the induction heating system and incorporating an elastic tensioning mechanism to improve ergonomic fastening on various pipe diameters. Additionally, evaluating the feasibility of battery-powered operation would assess potential improvements in portability. Finally, further experimental validation using standardized test specimens and testing under vibration-prone environments will focus on assessing the system's robustness in operational environments.

AUTHORS' CONTRIBUTION

Gabriel Vieira de Oliveira: Conceptualization, Investigation, Validation, Writing – original draft. **Daniel Pedro Willemann:** Conceptualization, Supervision, Writing – review & editing. **Armando Albertazzi Gonçalves Junior:** Conceptualization, Resources, Supervision, Writing – review & editing.

ACKNOWLEDGMENT

The authors acknowledge the support from the Universidade Federal de Santa Catarina (UFSC) and the financial support from CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) and CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior).

REFERENCES

[1] B. Guo, S. Song, A. Ghalambor, T. R. Lin, Offshore Pipelines: Design, Installation, and Maintenance, 2a ed. Waltham: Elsevier, 2014.

[2] J. G. Speight, Handbook of Offshore Oil and Gas Operations, 1. ed. Kidlington: Elsevier, 2015.

[3] V. M. Karbhari, Rehabilitation of Pipelines Using Fiber-reinforced Polymer (FRP) Composites, Cambridge: Woodhead publishing, 2015.

[4] P. K. Mallick, Composites Engineering handbook (Materials Engineering), Taylor I& Francis Inc., 1997, 1264 p, ISBN 0824793048.

[5] R. A. Smith, Composite defects and their detection, Materials Science and Engineering, Vol. III – Composite Defects and Their Detection, Article 6.36.5.3, 2002, p. 41.

[6] G. L. Workman, P. O. Moore, Non-destructive testing handbook: Non-destructive testing overview, 3rd ed. v. 10, American Society for Nondestructive Testing, 2012.

[7] S. Gholizadeh, A review of non-destructive testing methods of composite materials, Procedia Structural Integrity, Volume 1, 2016, pp. 50-57.

[8] L. Yang, X. Xie, Digital shearography - New Developments and Applications, 1. ed. Bellingham: SPIE, 2016.

[9] M. E. Benedet, A. Vieira Fantin, D. P. Willemann, A. Albertazzi Gonçalves Júnior, C. Ramos Schmitz, A. L. Fampa Seabra d'Almeida, S. Damasceno Soares, L. D. Montenegro Lana, V. Azevedo Perrut, The use of Shearography technique to evaluate polymeric composite repairs – case study, Matéria (Rio J.) 22 (02), 2017, 8 p.
DOI: 10.1590/s1517-707620170002.0241

[10] M. Viotti, A. Albertazzi, Robust speckle metrology techniques for stress analysis and NDT, Bellingham: Society of Photo-Optical Instrumentation Engineers (SPIE), 2014.

[11] R. Sirohi, Shearography and its applications – a chronological review, Light: Advanced Manufacturing, 3, 1. 2022.
DOI: 10.37188/lam.2022.001

[12] E. S. Barrera, A. Vieira Fantin, D. P. Willemann, M. E. Benedet, A. Albertazzi Gonçalves Jr., Multiple-aperture one-shot shearography for simultaneous measurements in three shearing directions, Optics and Lasers in Engineering, 111, 2018, pp. 86–92.
DOI: 10.1016/j.optlaseng.2018.07.018

[13] K. M. Abedin, N. Tao, A. G. Anisimov, R. M. Groves, Comparative performance of high and medium resolution cameras for defect detection in CFRP by digital shearography, Proc. SPIE 12618, Optical Measurement Systems for Industrial Inspection XIII, 2023.
DOI: 10.1117/12.2669718

[14] T. Lima, F. Broetto, A. Pinto, L. Sales, I. Andrade, A. Albertazzi, Performance evaluation of a compact and flexible shearography device formed by an adapted commercial still camera, Measurement: Sensors, Volume 38, Supplement, May 2025, 101781.
DOI: 10.1016/j.measen.2024.101781

[15] directindustry.com, ISIS-Shearography NDT, Online [Accessed 16 June 2025]
https://pdf.directindustry.com/pdf/steinbichler-optotechnik/isis-shearography-ndt/24625-167939.html

[16] Dantec Dynamics, Laser Shearography NDT. Online [Accessed 02 June 2025]
https://www.dantecdynamics.com/solutions/laser-shearography-ndt

[17] Thorlabs, Diode Laser 532 nm DPSS. Online [Accessed 16 June 2025]
https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=5597&pn=DJ532

[18] Basler, Basler ace acA2440-75um. Online [Accessed 16 June 2025]
https://www.baslerweb.com/en-us/shop/aca2440-75um