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Inspection of an artificial heart by the neutron radiography technique

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Abstract

The neutron radiography technique was employed to inspect an artificial heart prototype which is being developed to provide blood circulation for patients expecting heart transplant surgery. The radiographs have been obtained by the direct method with a gadolinium converter screen along with the double coated Kodak-AA emulsion film. The artificial heart consists of a flexible plastic membrane located inside a welded metallic cavity, which is employed for blood pumping purposes. The main objective of the present inspection was to identify possible damages in this plastic membrane, produced during the welding process of the metallic cavity. The obtained radiographs were digitized as well as analysed in a PC and the improved images clearly identify several damages in the plastic membrane, suggesting changes in the welding process. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

The neutron radiography technique is largely employed to inspect several types of hydrogen-rich substances such as oil, water, plastics, adhesives, even wrapped by thick metal layers. This property has provided possibilities of application of the technique in a large number of areas, particularly in medical field [1,2].

The heart research institute-INCOR, in São Paulo, is developing an artificial heart prototype, to provide blood circulation assistance for cardiacal patients who are in urgent need for a heart transplant surgery. It was observed in the operational tests that some of such hearts presented internal blood leakage and additional inspections were necessary in order to clarify this circulation failure.

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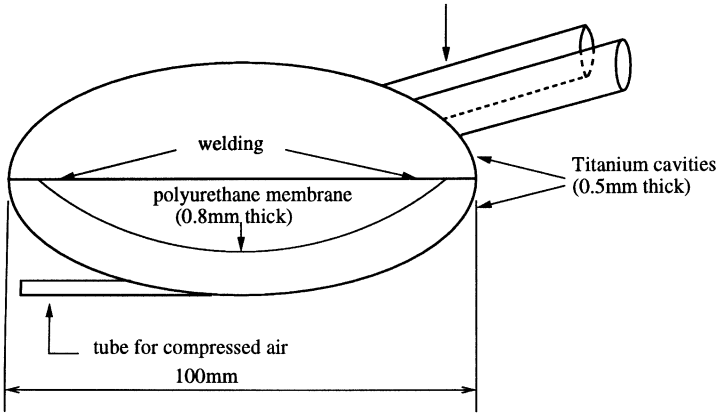

Fig. 1. Schematic diagram of the artificial heart.

The main objective of this work was to identify the possible damages in the plastic membrane which must have caused such blood leakage. For this purpose several artificial heart prototypes were neutron radiographed. The acquired radiographs have been digitized and processed in a PC. Improved images were then obtained and several damages in the plastic membrane employed for blood pumping, have been detected.

2. Experimental

The artificial heart is a device consisting of a cavity formed by two welded titanium hemispheres with a flexible polyurethane membrane fixed between them. Fig. 1 shows a sketch of this artificial heart. The membrane has also a semi-spherical shape and fits to the lower part of the cavity. The two titanium tubes shown in the upper side of the figure are used for blood circulation while the titanium tube in the lower part is attached to a compressed air pneumatic system. When the heart is filled with blood, the membrane stays in its lower position. The compressed air forces the membrane up, starting the blood pumping process [3].

The radiography facility shown in Fig. 2 is installed at the beam-tube 08 of the pool type IEA-R1 nuclear research reactor which operates at 2 MW with a thermal neutron flux $\sim 10^{13}$ n cm^{-2} s^{-1} in the core. The main characteristics of the neutron beam at the sample position are presented in Table 1 [4–6].

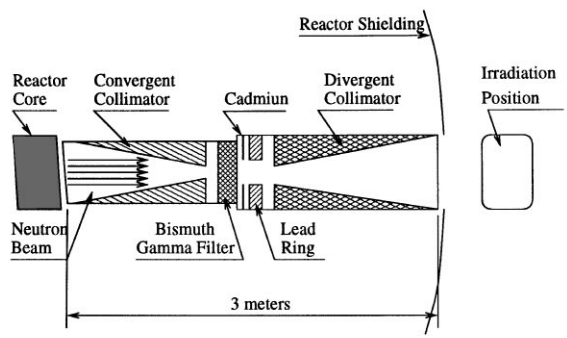

Fig. 2. Schematic diagram of the radiography facility.

The radiographs have been obtained by positioning the heart in front of an aluminum cassette fixed to an aluminum sample holder which is led to the irradiaton position by remote control. The direct method using a gadolinium metal foil (100 μm) as converter screen, together with the conventional double coated Kodak-AA emulsion film, was used. The films were developed according to the standard procedure [6]. The radiographs obtained in this work, have been digitized by using a transmission scanner (256 levels of gray, resolution 200 dpi) and a 500W negatoscope as light source, and the improved images, analysed in a PC. Three digital radiographs are shown in Figs. 3–5 where pre-processing operations for contrast and edge enhancement, noise reduction, etc., were employed. For obtaining such radiographs, the artificial heart has been kept empty, without any liquid inside it.

Table 1
Main characteristics of the neutron beam at the sample position

Neutron flux	3×10^6 n cm^{-2} s^{-1}
Collimation ratio	70
n/γ ratio	$> 10^5$ n cm^{-2} $mRem^{-1}$
Beam diameter	20 cm
Mean energy	5 meV[a]
Au/Cd ratio	> 150

[a] Theoretical value calculated considering a thermal neutron spectrum after 20 cm Bi-filter.

3. Results and discussion

Figs. 3 and 4 show radiographs obtained by positioning the artificial heart parallel to the blood movement plane, with respect to the neutron beam. These radiographs show the two titanium tubes employed for blood circulation (the third is visible in Fig. 5) and the polyurethane membrane in the position down and up respectively. In the former, the membrane is in its initial position and in the latter, it is air compressed.

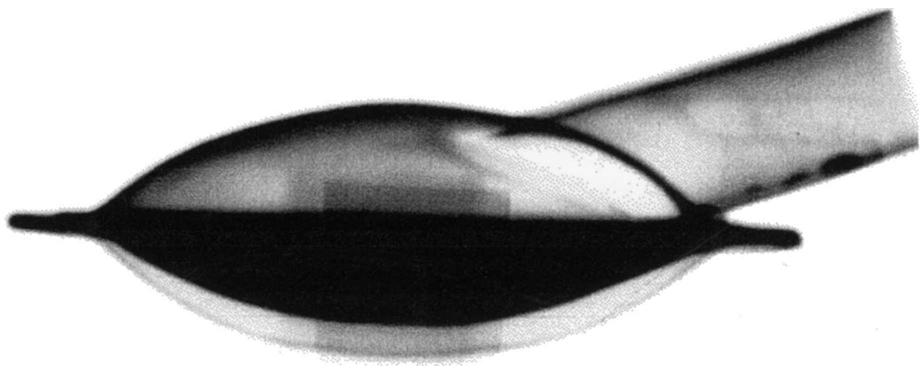

Fig. 3. Digital neutron radiography: heart membrane in its initial position.

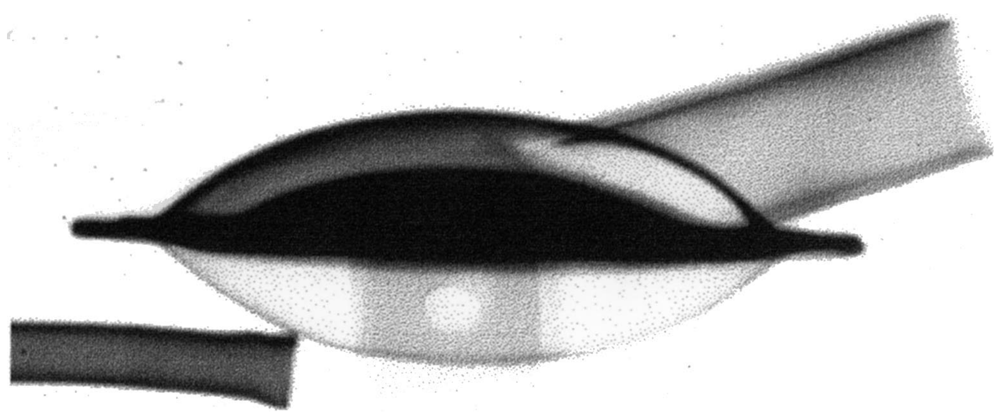

Fig. 4. Digital neutron radiography: heart membrane pressurized.

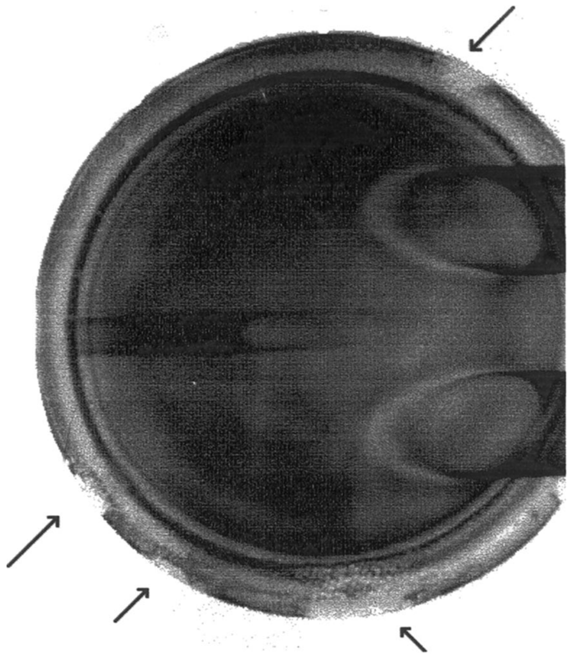

Fig. 5. Digital neutron radiography showing the damages in membrane, indicated by arrows.

Fig. 5 is the radiograph of the same original heart positioned perpendicularly to the blood movement plane. Several damages in the polyurethane membrane could be identified at the membrane extremity which acted like small holes that caused blood leakage, from the upper to the lower part of the cavity, when the membrane was air compressed. These membrane damages occured due to the high heating during the cavity welding process. Some welding experiments in lower heating conditions were also tried but all of them were not approved by the neutron radiography inspection. Presently a laser based welding system is being used and high quality prototypes are being obtained.

In order to complete the inspection and analysis of this artificial heart, the blood movement inside it should be monitored. In this case the employment of a real-time neutron radiography system, is very desirable. This improvement will allow, to observe some important aspects of the blood circulation, such as blood stagnation locations and blood leakage through membrane. For such purpose, a LIXI (light intensifier X-ray image) real-time based system is being installed at the IPEN radiography facility [7].

References

[1] A.A. Hawkesworth, Atomic Energy Rev. 15 (2) (1977) 169.

[2] H. Kobayashy, H. Wakao, Y. Ikeda, K. Okubo, A. Tsuruno, J. Nucl. Sci. and Technol. 29 (11) (1992) 1045.

[3] M.J.S. Maizato, MSc Thesis, University of Campinas-UNICAMP, Campinas-SP, Brazil, 1996.

[4] R. Pugliesi, M.L.G. Andrade, Int. J. Appl. Rad. Isotopes 48 (3) (1997) 339.

[5] M.P.M. Assunção, R. Pugliesi, M.O. de Menezes, Int. J. Appl. Rad. Instr. 45 (8) (1994) 851.

[6] M.O. de Menezes, Msc Thesis, IPEN-CNEN/SP, 1994.

[7] J.T. Lindsay, J.D. Jones, C.W. Kauffman, B.V. Pelt, Nucl. Instr. and Meth. A 242 (1896) 525.