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Author for correspondence:
Carlos Diez Gonzalez
e-mail: carlos@muon.systems

Non-destructive testing of industrial equipment using muon radiography

Pablo Martinez Ruiz-del Arbol[1], Pablo Gomez Garcia[2], Carlos Diez Gonzalez[2] and Aitor OrioAlonso[2]

[1]Physics Institute of Cantabria (IFCA), University of Cantabria, Santander, Spain
[2]Muon Tomography Systems S. L. Vasque country, Spain

PMRA, 0000-0002-7737-5121

A new application of muon radiography (MR) is presented in the context of non-destructive testing of industrial equipment. The long-term operation of industrial facilities frequently involves the deterioration of critical components such as pipes and cauldrons due to corrosion and other processes. The precise determination of the inner state of this equipment is needed to ensure the integrity of the facility. MR can be used to infer the thickness of these components through the comparison and further classification of muon observables with respect to well-known templates. A simulation example is presented where the thickness of a pipe made of steel is studied using the Point of Closest Approach method and simple Kolmogorov–Smirnov statistical tests. A precision of about 2–4 mm is obtained using a simple detector with a spatial resolution of 4 mm and exposure times of about 2 h.

This article is part of the Theo Murphy meeting issue 'Cosmic-ray muography'.

1. Introduction

In 1912, Victor Hess initiated a series of balloon-flights over the roofs of Vienna to measure the intensity of the radiation in the atmosphere at different heights. He found that radiation was more intense at greater altitudes and concluded that the Earth was being bombarded by a flux of particles. These particles are nowadays known as cosmic rays and they are known to be composed mainly of protons which often interact with the atoms of the atmosphere producing large cascades

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Kolmogorov–Smirnov test can be performed to classify the target sample. It should be noted that more sophisticated classifiers based on machine learning techniques can be applied directly to the muon observables. This work is currently under investigation.

Table 1 shows the score obtained in the KS test when each of the test samples is compared with every template sample. These numbers show how in most of the cases the best compatibility between a test and a template sample occurs when the thickness of the pipes are coincident. This is strictly true for variations of the order of 2 cm. The cases in which a variation of 0.2 cm was performed are not so clear and some confusion can be observed with the neighbouring templates. A good discrimination at the level of 0.2–0.4 cm can be claimed.

5. Conclusion

This simulation study shows, using a simple mathematical apparatus, how statistical compatibility between muon observables can be used to classify the amount of wear suffered by a steel-made pipe. A simple set-up composed of four hybrid multiwire–multistrip chambers have been considered with a spatial resolution of 4 mm. Pipes with a different thickness have been modelled and MR simulations of 6900 s each have been produced. The distribution of the radius of the POCA scattering centres have been studied and compared to template simulations with different thicknesses. The results show how this procedure is able to discriminate between templates differing by 0.2–0.4 cm. New studies will be carried out to understand what resolution can be obtained with this technique, reducing the symmetry assumptions and using more sophisticated algorithms based on machine learning classifiers.

Authors' contributions. P.M.R.-d.A. conceived the study and performed most of the simulations, figures and mathematical analysis. P.G.G. and P.M.R.-d.A. drafted the manuscript, while C.D.G. and A.O.A. contributed to the preparation and maintenance of the computational infrastructure and have read the analysis and provided useful comments.

Competing interests. The authors declare that they have no competing interests.

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