A CONICALLY DIVERGENT GUIDE TUBE
AS A COLLIMATOR FOR NEUTRON RADIOGRAPHY

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ABSTRACT

Neutron guides are useful collimators for radiography, because they produce pure neutron beams of high intensity. For wavelengths beyond 5 Å, however, the divergency of neutrons from a nickel coated guide tube is too large for high resolution radiography. An essential improvement can be obtained with a conically divergent guide. Due to garland- and zig-zag-reflections in a curved guide differences in the neutron divergency of different wavelength can be equalized.

INTRODUCTION

Intensity and resolution in neutron radiography are basically determined by the collimation of the neutron beam. High resolution needs strong collimation and thus leads to low intensity. For high intensity work the collimation has to be relaxed and then the spatial resolution, especially with thick objects, is poor. An optimum choice of the collimation seems therefore appropriate.

The classical collimator for neutron radiography is a parallel or conically divergent tube with absorbing walls. The collimation is determined by the L/D ratio. L is the length of the collimator, D is its diameter near the neutron source. The far end cross section of the collimator determines the area, which can be radiographed by one setting. Typical L/D ratios are in the range of 50 to 500 (1). It is a main drawback of such a collimator that it cannot separate thermal neutrons from the background of γ-rays.
and filters of bismuth e.g. have to be used. These, however, reduce the neutron intensity by a factor 5 - 10. Such a loss of intensity is certainly a disadvantage, especially for time resolved radiography.

A more elegant way to filter out the $\gamma$-rays and fast neutron background is the use of a curved neutron guide tube (2). A neutron radiography station at the end of a guide tube is installed at the ORPHEE reactor in Saclay (3). The guide tube there has been originally designed for neutron scattering experiments and does not offer the optimum conditions for neutron radiography work. In the present paper we want to show how a neutron guide could be optimized for radiography applications.

THE NEUTRON GUIDE AS A COLLIMATOR

Guide tubes of 30 to 80 m length are nowadays standard components in neutron research work. Neutrons are transmitted by total reflection at the inner side of usually rectangular tubes (typical cross section 15 x 3 cm$^2$). The index of refraction is less than 1 for most materials and total reflection occurs, when the angle between the neutron's direction and the mirror surface is less than the critical angle $\gamma_c$, given by $\gamma_c = \lambda / N a / \pi$. $N$ is the particle density of the mirror, $a$ the coherent scattering length and $\lambda$ the wavelength of the neutrons. The critical glancing angle increases with wavelength and is $1 \times 10^{-3}$ radian/Å for a glass mirror and $1.7 \times 10^{-3}$ radian/Å for a nickel mirror of natural isotope composition. The beam divergency at any point of the exit of a straight guide is $2 \gamma_c$ in both horizontal and vertical direction independent of the dimensions of the guide. With a moderator of $T = 300$ K and an isotropic flux $\Phi$ at the entrance of a straight guide the current density $j$ at the exit is $j = 1.75 \times 10^6 \times \Phi / (n/cm^2 s)$. With a typical flux $\Phi = 10^{14} n/cm^2 s$ the usually needed $10^8 n/cm^2$ for high resolution neutron radiography (4) are obtained within 1 second and a picture of an object with cross section area $F$ needs about $F/f$ seconds exposure time, where $f$ is the beam area of the guide. For a straight guide looking to a thermal moderator the mean wavelength is about 2 Å and hence the beam divergency about $7 \times 10^{-3}$ radian. This estimate is, yet, slightly too optimistic, as it holds for a straight guide. In order to clean the neutron beam from $\gamma$-background the guide tube has to be curved. The guide is then a low-pass filter in the sense, that it cuts away the $\gamma$-rays and short wavelength (high energy) neutrons. If the curvature is matched to the maximum of the moderator spectrum, then the reduction of the total intensity due to the curvature is not more than a factor 2.

The neutrons of different wavelengths have different divergencies and these can be transformed into L/D ratios as shown in