Nuclear Instruments and Methods in Physics Research A 748 (2014) 39–45

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Neutron guide geometries for homogeneous phase space volume transformation

N. Stüßer*, M. Bartkowiak, T. Hofmann

Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Hahn-Meitner-Platz 1, 14109 Berlin, Germany

ARTICLE INFO

Article history:
Received 26 November 2013
Received in revised form
5 February 2014
Accepted 13 February 2014
Available online 19 February 2014

Keywords:
Neutron scattering
Neutron instrumentation
Guides
Beam profiles
Phase space

ABSTRACT

We extend geometries for recently developed optical guide systems that perform homogeneous phase space volume transformations on neutron beams. These modules allow rotating beam directions and can simultaneously compress or expand the beam cross-section. Guide systems combining these modules offer the possibility to optimize ballistic guides with and without direct view on the source and beam splitters. All systems are designed for monochromatic beams with a given divergence. The case of multispectral beams with wavelength-dependent divergence distributions is addressed as well.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Guide systems have played an essential role in the transport of neutrons for already more than half a century [1–9]. Straight guides allow neutrons to be transported over long distances, and offer the opportunity to provide homogeneous beam profiles. The latter is crucial to the performance of neutron instrumentation demanding high data quality.

Recently, we presented a novel focusing guide geometry that performs form-invariant phase space volume transformations [10]. This module was designed to transform a beam with a homogeneous profile of width w and divergence α to a homogeneous beam of smaller width and correspondingly larger divergence. Ballistic guide systems [11] were identified as a potential application of this module, besides its use as a beam compressor or expander.

Another important issue in neutron guide optics is the use of curved guide systems to avoid the direct view on the neutron source. This suppresses the background from the unwanted radiation significantly. Alternatives to the circularly bent guide [1] were proposed during recent years [2]. So far, however, only few designs were successful to achieve nearly homogeneous beam profiles [9]. Here we generalize our former considerations on guide geometries to achieve homogeneous phase space volume (HPSV) transformations, introducing beam compressions and expansions with beam rotations. Gravitational effects which become important for the design of long guide systems [4], are outside the scope of this work and will not be discussed.

Section 2 gives a short introduction to guides, phase space, and beam rotation.

Section 3 is at the heart of the paper. Here we derive guide modules with geometries performing HPSV transformations, including beam rotations. We first introduce our conceptual geometrical approach for the case of a special compressing beam rotator. The second example analyzes a pure beam rotator before we finally present a generalized beam compressing bender. The detailed analysis of phase space volume elements and their evolution in guide systems is an integral part of this chapter. It profits significantly from acceptance diagram techniques [12].

Since our considerations are based on an incoming beam of a homogeneous profile, and the geometry of the guide module is calculated for a fixed width in the divergence distribution, Section 4 addresses phase space volume transformations for a divergence width, which is different than the one that undergoes the homogeneous transformation. This becomes relevant for multispectral beams. Section 5 closes with some applications of guide systems composed of the presented modules. Combinations of HPSV-transforming guide modules allow the design of a ballistic guide system with or without a direct view to the source, as well as beam splitters.

2. Preliminaries

2.1. Neutron guides

Guides are intended to transport neutrons over long distances at a minimum loss of intensity. In most cases, guide surfaces are designed as multilayer structures. These so-called supermirror

* Corresponding author.
E-mail address: stuesser@helmholtz-berlin.de (N. Stüßer).

http://dx.doi.org/10.1016/j.nima.2014.02.028
0168-9002 © 2014 Elsevier B.V. All rights reserved.

coatings [13] allow neutron reflections up to a wave vector transfer of $q = m \times q_c$. The magnifying factor m characterizes the performance of the guide and defines the reflected angular range as multiple of the critical wave vector q_c of neutrons at a Ni–air interface ($q_c = 0.0217$ Å^{-1}). The critical wave vector transfer translates into a wavelength dependent critical angle θ_c via $q_c = 4\pi/\lambda \times \sin(\theta_c)$. For neutrons with wavelength $\lambda = 0.1$ nm the critical angle becomes $\theta_c = 1.7$ mrad. Reflections beyond the critical angle always cause beam attenuation in supermirror guides. This attenuation may be negligible for a single reflection, but severe issues arise if multiple reflections occur along the guide, as the total effect increases exponentially with the number of reflections. The concept of ballistic guides was introduced [11] to bypass this problem and to reduce the number of reflections by increasing the guide cross-section. Ballistic guides frequently employ an elliptical geometry. The necessary m-values for the coatings of the modules discussed below to assure the calculated performances will be specified.

2.2. Phase space

Spatial and momentum coordinates define the distribution of neutrons in phase space. A small-angle approximation for directed beams in neutron guides applies, as only neutrons with divergences of not more than a few degrees are efficiently transported. This allows a separation of the six-dimensional phase space into three subspaces for the x-, y-, and z-degree of freedom.

Neutrons of a collimated beam in a straight guide with rectangular cross-section travel by convention along the x-axis (guide axis) and are reflected at the walls in y and z direction. Each reflection reverses the momentum along y or z, whereas the x-component is always preserved. Consequently, we limit our discussion to a single degree of freedom y.

Our two canonical variables are the position along y and the associated momentum. The latter is proportional to the neutron velocity along y, and therefore to the divergence α. The reference system is centered on the guide axis with the velocity of the neutron along x. This moving reference frame was introduced in Ref. [10], where the other variables were parameterized with respect to the time variable. Here, we use the trace divergence α instead of the velocity along y. The quantity vt from Ref. [2] is replaced by αx. We perform the parameterization with respect to the position x along the beam direction.

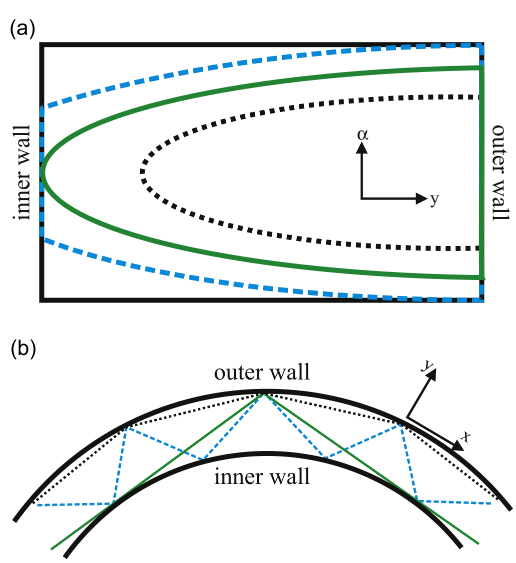

Fig. 1. Phase space diagram and geometry for a circularly bent guide system. All closed loops define the transported phase space volume which is determined by the wall coatings.

2.3. Beam rotation for circularly bent guides

Circularly bent guides were the first approach to avoid a direct view on the source [1]. They do not preserve a homogeneous beam profile in phase space. The qualitative profile in phase space at the exit of a long bent guide is sketched in Fig. 1. The phase space volume that can be transported has a “parabolic” shape with a flattened bottom. Neutrons travelling on closed trajectories can undergo reflections at the inner and outer wall. A removal of neutrons occurs if the neutrons are outside of the reflectivity range for either the inner or outer wall. Neutrons on closed trajectories in the phase space volume bounded by the green loop are so-called Garland neutrons [14] that reflect only at the outer wall, always at the same angle. No reflections occur at the inner wall. At the exit of a circularly bent guide, the divergence distribution depends on the position along the beam cross-section. The beam divergence increases continuously from the inner wall towards the outer wall. The beam profile is inhomogeneous.

3. Form-invariant phase space volume transformers

3.1. Compressing beam rotator

We present a compressing beam bender, which preserves the beam homogeneity. This chapter provides a geometrical analysis of the new module that is equivalent to the analytical approach in Ref. [10]. The resulting geometry resembles the device as presented in Ref. [10]. However, as a main difference the beam axis is not preserved in the device but rotated instead. Succeeding paragraphs generalize this geometry, applying similar concepts in the derivation as we introduce now.

In the previously discussed compression module a phase space volume $[0, w] \times [\alpha_m, -\alpha_m]$ with $\alpha_m = m\theta_c$ was transformed to $[\Delta w, w - \Delta w] \times [\alpha_m + \Delta\alpha_m, -(\alpha_m + \Delta\alpha_m)]$. The bending of both walls reduces the beam width and increases the beam divergence. Each individual wall causes a beam-width reduction on one side associated with a divergence expansion on one side as well. Therefore, bending only one wall and keeping the other wall straight will cause a transformation to $[\Delta w, w] \times [\alpha_m + \Delta\alpha_m, -\alpha_m]$. The center of the divergence distribution becomes $\Delta\alpha_m/2$, which corresponds to the beam rotation.

The phase space volume evolution is sketched in Fig. 2. Wall w_1 is bent in order to transfer neutrons to larger divergences. The opposite wall w_2 at position w is straight from the beginning to the end of the module. This becomes necessary in order to preserve the lower limit of the divergence distribution and to achieve the envisioned beam rotation by $\Delta\alpha_m/2$. A straight guide with an axis rotated by $\Delta\alpha_m/2$ can transport the outgoing phase space volume $[\Delta w, w] \times [\alpha_m + \Delta\alpha_m, -\alpha_m]$. The wall bending is dictated by the conditions for HPSV transformations. The front border-line FB of the newly populated phase space I′ “rotates” around the shearing center A and has to end at the wall position w_2. Liouville's theorem [15] implies the equality of the depopulated area I and the newly populated area I′, and therefore allows us to calculate the wall bending

$$1/2 \times (\alpha(x) - \alpha_m) \times (\alpha_m \times x - w_1(x)) = 2w_1(x) \times \alpha_m. \quad (1)$$

The second condition, as depicted in Fig. 2a, defines the wall position along the y-axis as function of x. With

$$\frac{w - \alpha_m x}{\alpha_m} = \frac{w - w_1(x)}{\alpha(x)}, \quad (2)$$

Download English Version:

https://daneshyari.com/en/article/1822662

Download Persian Version:

https://daneshyari.com/article/1822662

Daneshyari.com