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Band neutron chopper: a solution for large beams and limited space

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Abstract. With existing neutron choppers, the width of produced neutron pulses is coupled with the size of the rapidly rotating parts: the higher the linear speed at the chopper periphery, the shorter the produced neutron pulses. Indeed, choppers with a large diameter are in fact necessary. However, serious problems may occur when chopper disks are installed close to the neutron source (target) as this may result in a conflict with the shielding of neighbouring beams.

Here we describe a new type of chopper that is free from such limitations. It employs a circular band made of a flexible material transparent for neutrons and coated with a neutron absorber for exception of a few small parts serving as neutron windows. The band is driven by a motor with a controllable rotation frequency, allowing for the control of the linear speed of the band; indeed the neutron pulse width is decoupled from the source repetition rate. This kind of flexibility, which allows for the *in-situ* adjustment of the chopper parameters, cannot be provided by disk or Fermi choppers.

Moreover, an increase of the beam height does not influence the chopper construction, whereas for disk choppers, an increase in the diameter of the disk is necessary. Thanks to this flexibility and the arbitrary length of the band, the position of the motor and related electronic components also becomes arbitrary, so that they can be placed away from the neutron guide, in the "radiation-free" area. This prolongs their lifetime and offers an easy access to them during the source operation.

1. Introduction

Traditional neutron choppers are rotating disks coated with a neutron absorbing material fully absorbing neutrons. Neutron beam can only penetrate the disk through narrow stripes (neutron windows) that are either free from the absorbing coating or cuts in the disk body.

The frequency of the produced neutron pulses f_{pulse} is defined by the rotation frequency of the disk f_{disk} and the number of neutron windows on it:

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$$f_{pulse} = nf_{disk} \tag{1}$$

When used at pulsed neutron sources, disk choppers provide the time shaping of neutron pulses by moving a small chopper disk window of size S_w across the beam of the size S_{beam} with a high speed $v_{chopper}$. The width of the neutron pulse (FWHM) is given

$$\tau = \frac{\sqrt{S_{beam}^2 + S_w^2}}{v_{chopper}} \tag{2}$$

where $v_{chopper} = 2\pi f_{disk}R$ is the linear speed at the peripheree of the chopper disk of radius R, so that

$$\tau = \frac{\sqrt{S_{beam}^2 + S_w^2}}{2\pi f_{disk}R} \tag{3}$$

For the pulse shaping choppers, the rotation frequency of the chopper disk is equal to the repetition frequency of the pulsed source and the only free parameter to tune τ is the chopper radius R. Therefore, to achieve small τ at low repetition rates, e.g. for 10-15 Hz, R should be rather large. Indeed, the duration of the neutron pulses produced by a disk chopper is coupled with its size: the shorter should be the neutron pulse, the higher should be the linear speed at the chopper periphery and the larger should be the size of the disk. Moreover, the required size of choppers can be even larger in the case if they should be used to interrupt the beams propagating in the neutron guides of a large cross-section, particularly around the centre of elliptic focusing neutron guides, where the cross-section of those can approach 30cm.

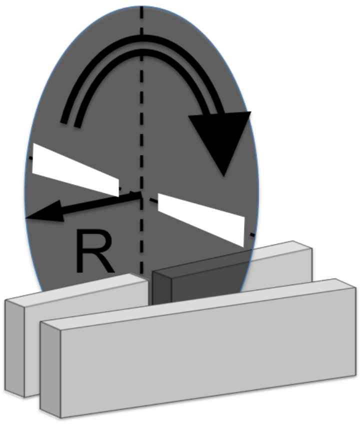

Fig. 1. Positioning of a large chopper disk in a neutron guide system and a possible place conflict

However, a possible size of chopper disks is limited. Beside mechanical constrains that may be imposed on large disks, serious problems may arise when chopper disks should be installed so close to the target, that they may conflict with neighbouring beams (Fig. 1). For example, for the 5.5^o beam separation thought for the ESS, the distance between neutron beams at the face of the biological shielding (6m from the target) is only 56cm. This does not only impose a limit on the chopper size, but also causes serious problems with an access to choppers during the operation of the source without interruptions of the operation of the neighboring instruments.

Therefore, there is a serious problem in the use of pulse shaping choppers to be placed close to the target. Another problem related to the use of the disk choppers is that the chopper motors and related electronics will be positioned rather close to the neutron beam at the beginning of neutron tract, where they can be heavily irradiated by high-energy gammas and fast neutrons, that may significantly reduce their lifetime.

Here we are suggesting principally a different kind of neutron chopper that doesn't employ the rotating disk and therefore is free from limitations discussed above.

2. Band neutron chopper

In the suggested neutron chopper a flexible band coated by a neutron absorbing material is used instead of the disk. The band forms the closed ring that is moved across the neutron beam (Fig. 2). A few places on the band are not coated with the absorbing layer and are functioning as neutron windows. This band is moving across the neutron beam (e.g. across the neutron guide) blocking the neuron beam all the time beside short time intervals when the neutron beam is crossed by a neutron window – this is how the chopping of the neutron beam is achieved.

In more details, the ring can be made for example of thin carbon fibre film (about 0.5mm), which is flexible in horizontal direction and transparent for neutrons (similar fibres, however even much thicker, are used in commercial disk choppers produced by ASTRIUM). The surface of the band is both side coated by a thin polymer film containing a strong neutron absorbing material (e.g. made of ^{10}B or Gd with the thickness of a few mm; alternatively, the neutron absorbing material can be embedded in the band), so that the band is completely opaque for the neutron beam. A few places on the band are not coated with absorbing layer and are functioning as neutron windows.

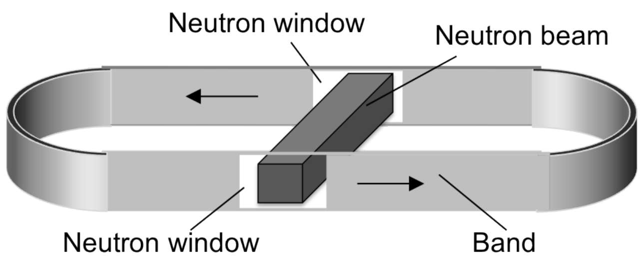

Fig. 2. Principle of band neutron chopper

To provide short neutron pulses with reduced speed of the band, two neutron windows on two bands moving in opposite directions are used, so that each of them is blocking a half of the width of the neutron beam (Fig.3).

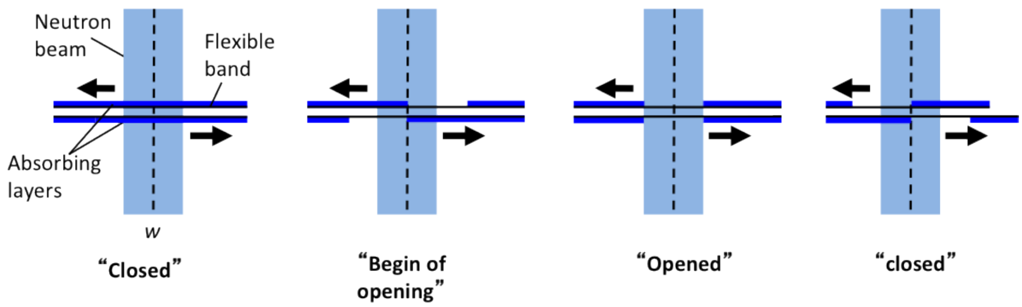

Fig. 3. The use of two oppositely moving bands for interruption of neutron beams

The opening time for the each half of the beam is given as w/v_{band}, where w is the width of the neutron beam and v_{band} is the speed of the band. If the width of neutron windows is equal to the beam width, then the closing time is equal to the opening time, so that the full width of the neutron pulse is $\Delta\tau = w/v_{band}$ (Fig. 4).

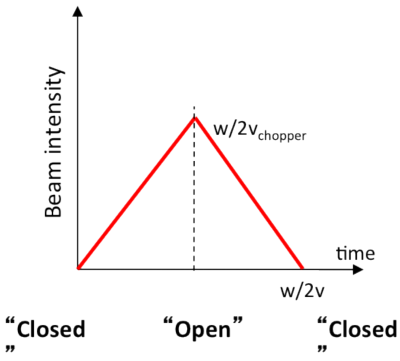

Fig. 4. Time diagram of neutron pulse

The band is driven by a motor (Fig. 5) and guided into the break in the neutron guide by a set of rollers. There are two different operation modes: (i) with a constant rotating speed; or (ii) with controlled and reversible rotating speed (e.g. DC-motor). In the mode (i) the distance l between neutron windows and speed of the band should be equal to the repetion time between neutron pulses

$$T = l / v_{band} \tag{4}$$

In the mode (ii), one can regulate the the band speed, e.g. to reduce the band speed to $v_{band}^{(1)}$ during the "closed" phase of the chopper, thus increasing T (see Eq.(3)), and then to increase the band speed (up to maximal) just before neutron windows enter the neutron beam to get a necessary pulse width

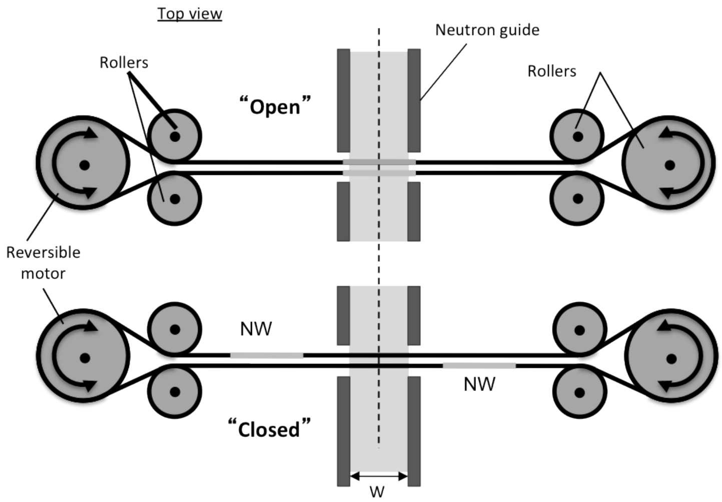

Fig. 5. The neutron band chopper: closed band is used for moving "sub-bands" with the same speed but in oppposite directions.

$\tau = w/v_{band}^{(2)}$ (Fig. 6). Thus, the neutron pulse width $\Delta\tau$ is decoupled from the period T of neutron pulses (or from the repetition rate of a pulsed source). Such a flexibility allowing for the "on-line" adjustment of chopper parameters can not principally be provided neither by disk nor Fermi choppers.

Another big advantage of the band chopper is that thanks to the flexibility and an arbitrary length of the band, the position of the motor and electronic components also becomes arbitrary, so that they can be placed at a practically arbitrary distance from the neutron beam in a "radiation-free" area (Fig. 6).

This has twofold positive consequences: first, the lifetime of motor and electronic components will be prolonged as they will not be heavily irradiated and, second, this will allow for the avoidance of the service or replacement of the failing parts of neutron choppers placed in areas with a very high

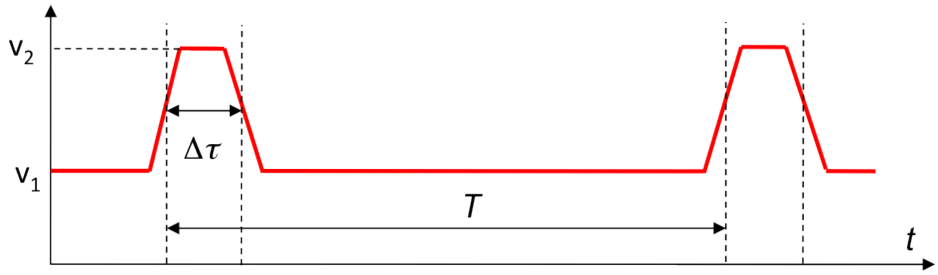

Fig. 6. Time diagram for band chopper with adjustable speed v_{band}.

radioactive level. The latter becomes especially critical for a neutron facility in the case of "a high density" of neutron beams (e.g. separated by 5^0, as planned at the ESS) and a large number of choppers simultaneously used at many instruments. Even a small failure rate, say 1% per cycle, will result in the failure of two choppers from all installed at 22 instruments means an average failure of one chopper each two cycles. If heavy shutters are used, access to a failed chopper will require the closing of shutters for at least two or even four instruments. However, in the case of the use of light shutters that only block thermal/cold neutrons, the forbidden for the access area around such a beam will be spread over much more instruments. Indeed, the access to the failed component will require the shut down of a large number of instruments or even the source as a whole – neither of these approaches is hardly an alternative to leave the failed instrument unusable for the whole operation cycle.

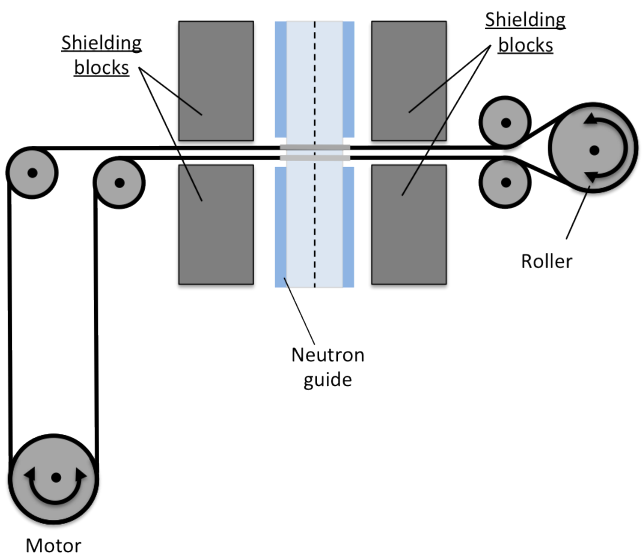

Fig. 7. Neutron band chopper with remotely positioned motor (and electronic components)

Possible operation modes of the band chopper are shown in Fig. 8. If the band is moving with a constant speed in one direction (Fig. 8a), then the operation is similar to one for standard disk choppers, however the discussed above flexibility of the positioning of the motor makes it attractive in the case of taught space conditions. If the band is moving in one direction, however with a variable speed (Fig. 8b), the pulse width and repetition rate are decoupled. The same can be achieved by the oscillatory motion of the band in opposite directions (Fig. 8c).

3. Conclusions

In this article we describe a new kind of neutron chopper – the band chopper. For the interruption of a neutron beam a flexible band coated with a sufficiently strong neutron absorber is used. In contrast to the currently used disk choppers, the linear speed of the band is not coupled with the chopper radius that should be rather large for slow rotation frequencies required for low repetition rate pulsed sources: the size of chopper disks may be limited because of the place conflict with neighbouring neutron guides.

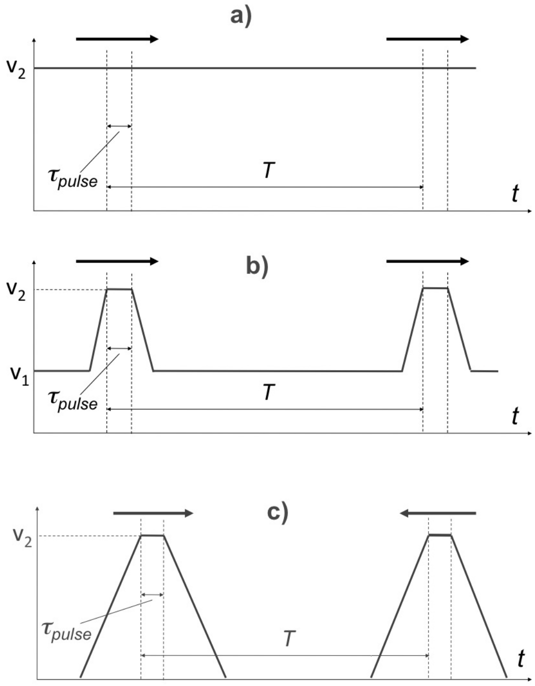

Fig. 8. Possible operation modes of the band chopper.

Moreover, because of the flexibility and an arbitrary length of the band, motor and related electronic components can be positioned in a "radiation-free" area outside of the biological shielding of the neutron beams. This will both prolong the lifetime of electronic components and allow for their service or exchange even during the operation of the source: the problem that becomes critical in the case of a dense neutron beams' arrangement, when access to failed components will require the shut down of a significant number of neighboring instruments.

From the engineering point of view, an advantage of the band chopper is that all mechanical components can be standardized, so that the choppers for different neutron beams will differ only by the band (height and size/position of neutron windows).

4. References

[1] Linander R, et al., "ESS target station-an overview of the monolith layout and design", *11th Int. Topical Meeting on Nuclear Applications of Accelerators, Bruges, 2013,* http://accapp13.org/sites/default/files/WEOTA03.pdf