VESTA - A new Beamline for Cold Neutron Storage Experiments on ISIS

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In the past 3 years we have shown that long wavelength neutron pulses can be trapped between 2 perfect single crystal silicon plates 1 metre apart using magnetic switches to allow the neutrons entry to and exit from the storage device. Neutrons were stored for up to a quarter of a second undergoing 156 reflections in the process. A special set-up of the IRIS beamline was used for these measurements which meant that the spectrometer could not be used at the same time. We have now installed a graphite monochromator into the IRIS guide which will reflect out neutrons of 6.27Å into the storage device so that experiments can be carried out concurrently. The storage device itself has been upgraded so that its performance should be enhanced by a factor of at least 10. Amongst planned experiments are the storage of more than one ISIS pulse, an investigation into the question whether the motion is a coherent or an incoherent process and the possibility of observing electromagnetic interactions during this motion. The monochromatic beam could well find other uses in fundamental neutron physics and neutron scattering in the future.

1. Introduction

The method of storing cold neutrons by Bragg reflection from perfect crystal plates has been successfully tested at the ISIS pulsed neutron source [1,2]. A *1072 mm* long perfect single crystal of silicon, consisting of 2 rectangular endplates and a connecting crystal base was cut as one piece for the purpose of neutron storage. The surfaces of the crystal plates are parallel to the *(111)* lattice planes of the crystal. Neutrons of wavelengths about *6.27 Å* are Bragg reflected at a Bragg angle of exactly $90°$ between the two crystal plates. For a small region in the neutron's wave vector space ($\Delta k/k \sim 4 \cdot 10^{-5}$) the reflectivity of the crystal plates is almost unity (a lower limit for the reflectivity was determined to be *0.9978* by this method [2]). Pulsed electromagnets mounted on each of the end plates are used to shift the k-vector of these neutrons out of the total reflection region of the crystal, thus enabling a magnetic field dependent transmission probability through the crystal plates to be switched. The magnetic pulses have the shape of half a sine wave and their duration is long compared to the pulse width of the neutron beam ($\sim 150\ \mu s$) but shorter than the flight time of the neutrons between the crystal plates (*3.38 ms*). The magnetic field required to shift the k-vectors of the neutrons by the Darwin width of the total reflection region is *1.26 T*. The loss of neutrons due to the angular divergence of the incoming beam is minimized by inserting a neutron guide between the reflecting crystal plates. The guide is made of float glass with an angular acceptance range of about ± 7 *mrad*. The stored neutrons are therefore characterized by their position in k-space and their angle in respect to the axis of the neutron storage system.

The beamline for neutron storage at the pulsed neutron source ISIS is that used by the IRIS spectrometer. The main part of the IRIS neutron guide is hidden within a tunnel of shielding. Between this tunnel and the IRIS spectrometer there is a 3 m long freely accessible guide section surrounded by an interlocked area perfectly suited for the installation of the neutron storage system. A schematic survey is given in Fig. 1.

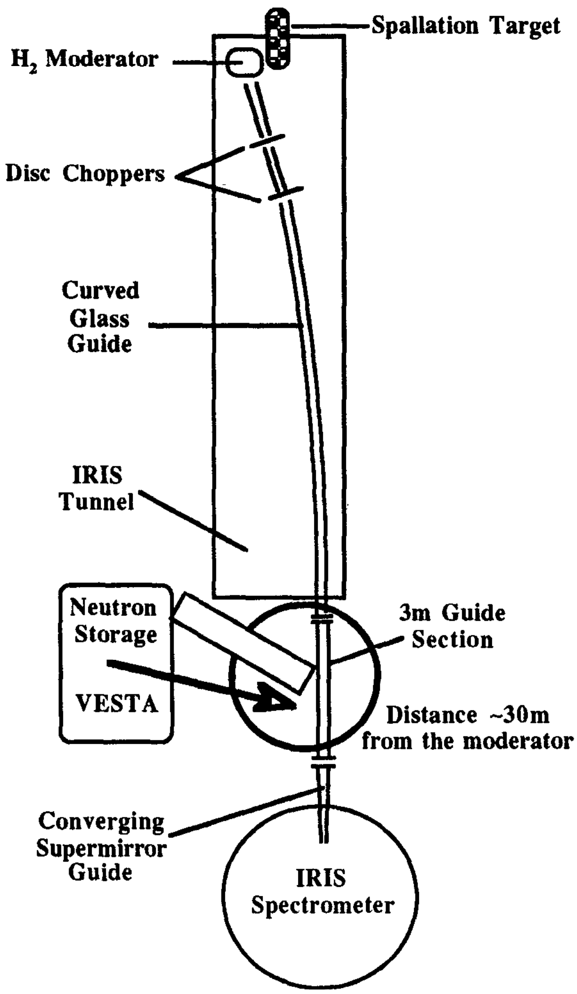

Fig.1 Area for Neutron Storage Devices on the IRIS beam line

2. The Prototype Storage Device

For our earlier feasibility studies the 3 m IRIS guide section was removed and replaced by the neutron storage device (Fig. 2). Its performance was characterized by the following quantities. The neutron guide had a length of *1000 mm* and a cross section of *26x40 mm.* The magnetic pulses reached a maximum field of *1.06 T.* A graphite crystal after the storage device was used to deflect the stored neutrons into the detector, therefore acting as an *analyzer* crystal. The detector consisted of 2 He-3 tubes of 1" diameter which were arranged side by side. (cf. Fig.2).

The main problem of this location was the fact that this mode of operation allowed *either* the use of the IRIS beamline for experiments on the standard inelastic neutron spectrometer *or* for experiments with the neutron storage apparatus. Considering the number of applications for the use of the IRIS spectrometer this situation needed a proper solution for future developments. It was decided that the neutron storage device should become an independent instrument which will be described in section 3 of this article. This also gave a timely opportunity to optimise the components of the neutron storage device itself [2-4].

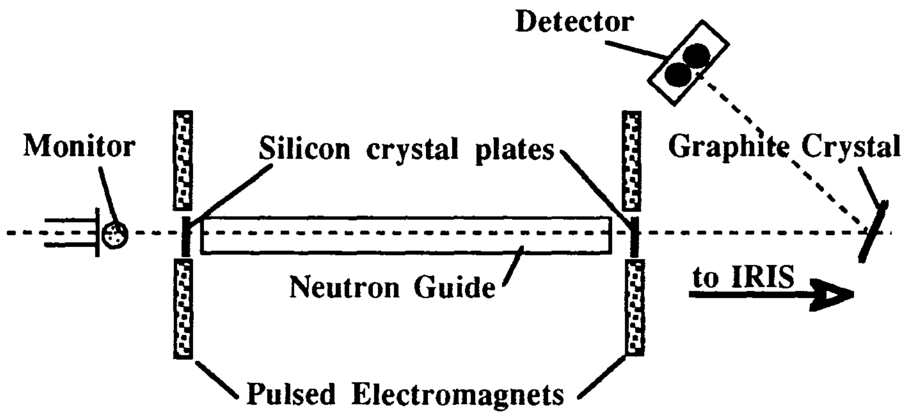

Fig. 2 The prototype neutron storage set-up

The loss in stored neutron intensity was found to be due to two different sets of factors. The first set contains factors external to the storage process such as the magnetic field, the graphite crystal and the detector. The second set deals with the storage process itself and has to take factors like the geometry of the neutron guide, vibrations of the system due to the pulse of the electromagnets or absorption and scattering by air molecules into account. The factors relating to the external storage process are independent of storage times, since they represent single loss events of the storage process. The factors relating to the internal storage process are time dependent with a varying influence in respect to increasing storage times, since they represent loss events associated with the travel of the neutrons through the storage device.

Due to electronic limitations the maximum magnetic field could not be greater than *1.06 T,* which was not sufficient to shift the wave vector of the neutrons by the full width of the total reflection region. The transmission probability for neutrons in the total reflection range is calculated to be *0.656* after applying a magnetic field of *1.06 T.* The height of the graphite analyzer crystal was *40 mm* corresponding to the height of the neutron guide in the storage device but was reduced by the clamps of the crystal holder. The loss of stored neutron intensity due to this fact was slightly more than 10%. The arrangement of the detector created an artificial loss in efficiency in the central region. Compared to a detector volume with rectangular cross section of 1" thickness the efficiency in the central region was reduced to *78%.* Monte Carlo simulations showed the gap between the crystal plates and the neutron guide to be one of the major loss factors. In the old set-up the width of the gap was *32 mm* on each side of the neutron guide representing a loss per traverse of 6%. The influence of vibrations on the storage process had not been taken into account by any damping system for the crystal supports.

3. VESTA - The Optimised Storage Device

The problems with the exclusive use of the IRIS beamline either for the standard instrument or for neutron storage experiments led to the concept of the neutron storage device as an independent instrument on ISIS. The instrument will be called **VESTA,** *the Viennese nEutron STorage Apparatus* (cf. VESTA, Roman Goddess of the hearth and household) and operated as a collaborative project between ATI (Atominstitut der Österreichischen Universitäten) and RAL (Rutherford Appleton

Laboratory). VESTA will be fed by a monochromatic beam of neutrons reflected from the IRIS beamline (cf. Fig. 3). A hole was cut into one of the neutron guides of the 3 m guide section, allowing a pyrolytic graphite crystal to be inserted into the IRIS guide, acting as a *monochromator* crystal which deflects neutrons of wavelengths around *6.27 Å* out of the IRIS guide into the neutron storage apparatus. The graphite crystal is mounted on an orientation unit allowing it to be aligned with respect to the IRIS beam as well as being able to insert and retract it according to the VESTA/IRIS operational modes. Fully inserted, the graphite crystal covers slightly less than half of the IRIS neutron guide cross section (*43x65 mm*).

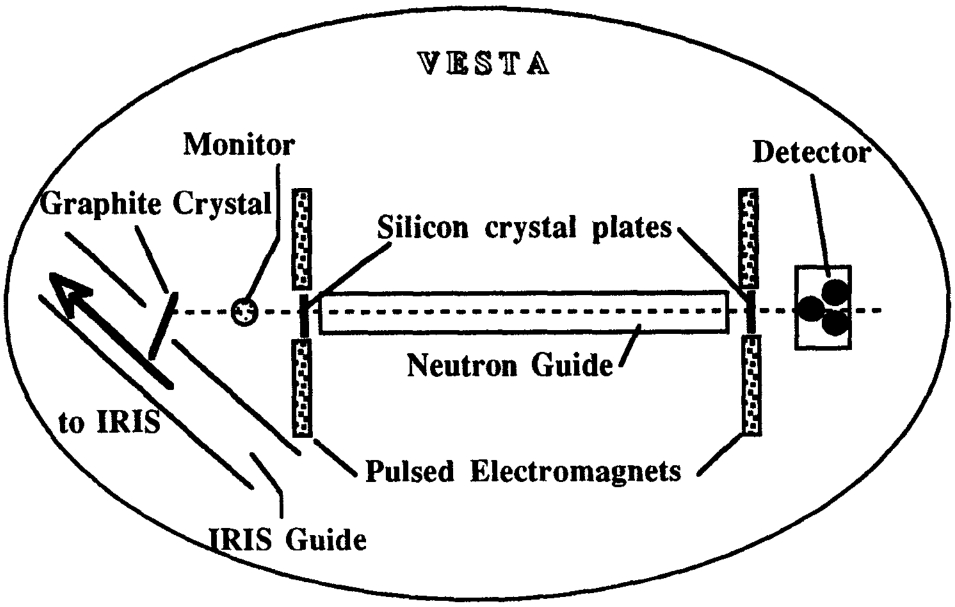

Fig. 3 The new neutron storage set-up

As a consequence of the loss factors of the old neutron guide, VESTA will be equipped with a new guide. The new guide is *1063 mm* long, reducing the gaps on each side between the neutron guide and the silicon storage crystal to *0.5 mm.* Assuming a linear dependence of neutron losses due to the gap width, this would reduce the influence of the gap by a factor *64* on each reflection. The cross section of the new guide is *26x43 mm,* while material and critical angle remain the same. The parallelism of opposite guide surfaces has slightly improved from $8 \cdot 10^{-5}$ *rad* to $7 \cdot 10^{-5}$ *rad.* The increase of the height of the guide cross section from *40* to *43 mm* now covers the total height of the silicon crystal plates (diminished only by the thickness of the neutron guide bottom plate and a vertical gap between the neutron guide and the storage crystal base which assures movability of the neutron guide and prevents the guide and the crystal from touching each other). A new graphite crystal, about *60 mm high* and *2 mm thick,* will ensure both good illumination of the storage device and acceptable transmission to the IRIS spectrometer. Furthermore an increase in the maximum magnetic field from *1.06 T* to *1.3 T* should raise the transmission probability from *0.656* to *0.826* at each plate. A third He-3 tube was added to the detector, thus increasing its geometrical efficiency by a factor *1.28* (cf. Fig. 3). To reduce the influence of vibrations a simple damping system was added to the support of the electromagnets. Putting together the gain in stored neutron intensity as a result of improving factors relating to the external storage process, i.e. height of graphite crystal and neutron guide, magnetic entrance and exit field and arrangement of the detector, a gain factor of *1.35* at the beginning and of *1.93* at the end of the storage process should be achieved. The influence of the improved conditions for the inner storage process have not been treated analytically but Monte Carlo simulations suggest an increase in efficiency of the inner storage process by a factor between 10 and 100 for longer storage periods. In addition the storage device will not be in the full IRIS beam. The wavelength band illuminating the storage device will be much narrower than previously, resulting in lower background effects.

4. Future plans

The initial commissioning runs of VESTA will show whether the improvements described in section 3 will have the expected influence with respect to loss factors and storage times. In 1989 neutrons were stored for *20.2 ms* [1] and in 1990 for up to *263.1 ms* [2]. The improved set-up should allow storage times well beyond 1 second to be achieved. The standard ISIS Data Acquisition Electronics (DAE) has been modified to create time frames up to *10 s*. Since, with increasing storage time, the neutron storage device will accept a correspondingly smaller number of ISIS pulses, e.g. 1% when ISIS operates at *50 Hz* and VESTA is storing with *0.5 Hz,* a special interaction scheme between the standard DAE and the Storage Control Electronics (SCE) was created to take the new mode of operation into account. The SCE was modified also to suit the advanced needs of the planned neutron storage experiments. The main goal will be the characterization of all the loss factors, again enabling a significant increase in storage time. It will also enable us to set an improved limit for the reflectivity of a perfect silicon crystal plate (presently *0.9978;* cf. Ref. 2). As the spatial length of a stored neutron pulse is about *10 cm*, compared with a flight path of 2 m between the crystal plates, the possibility of storing several neutron pulses at the same time has been considered [3,4]. With the present set-up a storage of 2 or 3 neutron pulses together seems feasible. Using neutrons of *2.09 Å* wavelength, which fulfils the backscattering condition for the silicon *(333)* reflection, neutrons of another wavelength band could be stored within the same neutron storage device. A demonstration of this capability is also amongst our future plans.

After a complete characterization of the instrument with its anticipated lower loss factors, two fields of application arise for a neutron storage device such as VESTA. *i)* The set-up offers the possibility of observing weak neutron interactions with other radiation in a defined area. If one considers for example the interaction of a neutron with an electro-magnetic field, one can observe this interaction for several seconds over a flight path which exceeds one kilometre while the characteristics of the electromagnetic field have to be controlled over a distance of only 1 m. As one could imagine observing the effect of such an interaction as an increase or decrease of stored neutron intensity, the knowledge of all loss factors of the neutron storage device has to be the first goal of its characterization. *ii)* The instrument could serve as a preparation stage for subsequent experiments. The advantages of this preparation are the flexible choice of measurement time, performing the subsequent experiment without disturbances and with excellent background conditions. It offers high monochromaticity *(0.15 μeV)* and low angular divergence of the beam. To obtain an effective preparation tool, the losses of the neutron storage apparatus have to be minimized. It is hoped to achieve this further step in perfect crystal storage techniques with the new VESTA set-up at the pulsed neutron spallation source ISIS.

5. Concluding remark

The intense monochromatic neutron beam out of the IRIS neutron guide can also be used for purposes different from neutron storage experiments. It is intended to be used as a test beam for new developments in fundamental physics experiments and advanced spectrometer set-ups for future pulsed sources such as AUSTRON and the European Spallation Source ESS.

Acknowledgement

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