Implementation of Repetition Rate Multiplication in Cold, Thermal and Hot Neutron Spectroscopy

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Conventionally, in time-of-flight (TOF) neutron spectroscopy neutron pulses of one single monochromatic wavelength are used. Repetition Rate Multiplication implies the use of a set of several monochromatic wavelengths coming from each source pulse, instead of a single one [1]. This makes it possible to overcome a major efficiency drawback of pulsed neutrons sources, i.e. the fact that the pulse repetition rate is too low for TOF spectroscopy, and allows us to freely choose the pulse repetition rate at the sample. The Repetition Rate Multiplication method was first developed in the framework of the IN500 project at LANSCE (USA) [2] and has in the meantime been implemented at several projects at ISIS (UK) [3] and J-PARC [4]. Here we describe the application of the Repetition Rate Multiplication method to hot, thermal and cold neutron scattering by using fixed and wavelength dependent pulse suppression. Further we present the first experimental realization of this novel technique using the flexible disc chopper system of the TOF spectrometer NEAT at BENSC.

1. Principle of Repetition Rate Multiplications

The typical features of “ideal” neutron chopper spectrometers are variable pulse frequency with rates ranging between 60 and 1000 Hz; variable pulse duration to optimize intensity to experimental needs and sharp pulse shape function to explore small signals next to the large ones. All these features are best realized at spectrometers at continuous sources. Most of the TOF instruments at pulsed sources suffer from inefficient data collection, which - due to the low source frequency varying from 10 to 50 Hz - can be as bad as only taking data at 10% of the time. The advent of the next generation of much more powerful spallation sources (SNS; J-PARC) is an additional motivation to make best use of the increased flux of these sources by more efficient data collection rates at TOF spectrometers.

To overcome the efficiency drawback due to the low repetition rate of pulsed spallation sources, the Repetition Rate Multiplication (RRM) method was proposed [1]. Contrary to the conventional method, where one single wavelength is used of each source pulse, RRM suggests to use pulses of several wavelengths emitted by each source pulse (Fig.1). Thus the instrument repetition rate increases and becomes fundamentally independent of the repetition rate of the source.

In cold neutron spectroscopy Repetition Rate Multiplication can efficiently be implemented by using a disc chopper system which was originally developed for the IN500 project at LANSCE, USA [2]. The IN500 disc chopper system (Fig.1) combines features of advanced continuous source instruments with conventional wavelength band choppers at spallation sources. First a wavelength
band is defined by the slow choppers #1 and #2 rotating at the same frequency (20 Hz) as the source. This is later cut into a set of monochromatic pulses by the fast choppers #3 and #6, also defining the primary and secondary resolution of the instrument. While the slow choppers are designed to avoid overlap of neutrons coming from different source pulses, the fast chopper system removes the overlap of neutrons of different wavelengths coming from the same source pulse [2]. The frame overlap of scattered slow neutrons in the secondary spectrometer between the sample and the detectors can be further reduced, if necessary, in the similar way to continuous source TOF spectrometers by suppressing every second, third or fourth pulse by chopper #5 (not shown) of the basic 240 Hz pulse rate at the sample provided by chopper #6. Since the overlap of scattered spectra is defined by the time required for neutrons to cross the sample to detector distance the pulse repetition rate in an experiment is determined by the dimensions of the secondary spectrometer and not by the frequency of the source.

For the design of the IN500 chopper system we applied the new approach of "wavelength filtering" [5], the main principle of which is to divide the chopper system into sub-systems with fewer choppers and to study the mathematical set of wavelengths transmitted with any finite probability by such a single sub-system. The transmission wavelength spectrum of the total system is limited by the common part of these sets and can be then controlled by the shifting in time (phasing) the sub-units relative to each other. Such an analysis of adequately selected sub-systems offers a very efficient way to assure that no unwanted, spurious neutrons leak through the chopper system.

The Repetition Rate Multiplication can also successfully be realized in thermal and hot neutron spectroscopy with the help of Fermi choppers with broad wavelength transmission band, such as the one developed for the powder diffractometer EXED in Berlin [6]. However, additional aspects have to be considered. For instance, the spectrometer MAPS at ISIS [7] operates at a source frequency of 50 Hz with the source to sample distance of 12 m and the sample to detector distance of 6 m. For these distances RRM pulses from all wavelengths up to 4 Å can be accommodated within the 20 ms time between source pulses. Taking into account the sample - detector distance, the time between pulses at the sample should typically be about 1 ms for 0.5 Å incoming neutron wavelength and 8 ms for 4 Å. Thus, for neutrons with short wavelengths using a pulse rate of some 1000 Hz (i.e. about 0.33 Å wavelength step between adjacent pulses at the sample) the frame overlap in the secondary spectrometer sets in for incoming neutron wavelengths above 1 Å. In contrast, with 200 Hz pulse rate this only occurs above 3 Å, but the wavelength step increases up to 1.7 Å between adjacent pulses. Thus, any fixed pulse repetition rate at the sample, as produced by choppers #5 and 6, will typically allow for only 2-3 unperturbed RRM frames for an instrument like MAPS with relatively short primary and relatively large secondary flight paths. The pulse repetition in RRM mode on the sample can be improved further with the help of a wavelength dependent pulse suppression disc chopper, which runs synchronously to the source pulses (10 cm/ms peripheral speed at 50 Hz) and has a number of unevenly placed slits. In the example of MAPS, at 1000 Hz basic pulse rate at the sample (i.e. up to
13 RRM pulses within 20 ms arriving at the detector), typically this chopper has to suppress the 4th, 6th, 7th, 9th, 10th, 11th and 13th RRM pulses coming from the same source pulse in order to avoid overlapping of spectra at the detector. As a consequence one can usefully extract 6 RRM pulses from each ISIS source pulse by this extended RRM scheme with wavelength dependent, selective pulse suppression. The use of this scheme, which is first described here, is particularly suited for spectrometers that have a conventionally short source to sample distance, which is advantageous for the delivery of incoming hot neutron wavelengths below 0.9 Å.

Using RRM for cold, thermal and hot neutrons opens up the crucial opportunity to optimize the design of pulsed neutron sources for all types of scattering experiments. Without RRM, the large data collection dead times in TOF spectroscopy at low pulse frequencies, which in the past used to appear as a requirement for source parameters contradictory to other key applications, such as high resolution diffraction or small angle scattering.

2. First experimental implementation of Repetition Rate Multiplication

For the first experimental implementation of Repetition Rate Multiplication we used the time-of-flight spectrometer NEAT at BENSC [8]. NEAT runs 7 chopper discs with two slits each rotating at 40-333 Hz. The distances between the first and the last choppers (Ch1-2 and Ch6-7, which are pairs of counter-rotating discs), the first chopper and the sample and the sample and the detectors are 12, 13.3 and 2.5 meters, respectively. A He³ monitor is placed about 70 cm behind the last chopper.

In the two experimental runs studied the pulse of the source was emulated by the first chopper Ch1-2 operating at low speed and delivering the “source” pulses at 40 and 23.67 Hz, respectively. Choppers 3, 4 and 5 were stopped in open position so that the full cold neutron beam spectrum arrived to the last chopper. Sets of monochromatic neutron pulses were cut out from the pulsed white beam by the last chopper (Ch6-7) at frequencies that were equal to a multiple of the frequency of the first chopper pulses: \( v_{Ch6-7} = m v_{Ch1-2} \), where \( m \) is integer. In addition to polychromatic RRM scans we took series of monochromatic measurements by using the complete NEAT chopper system for wavelength identification and for a frame-overlap correction.

We collected two data sets, one at a pulse repetition rate of 160 Hz at the sample and a source frequency of 40 Hz (data set A) and one at a pulse repetition rate of 165.67 Hz at the sample and a

![Fig. 2 Signal in RRM mode delivered to the monitor (left) and the detector (right) at 165.67 Hz pulse repetition rate at the sample and 23.67 Hz source frequency. Temperature dependent inelastic spectra from water sample confined into porous silica are shown as directly measured in the RRM mode. Temperatures of 160, 200, 260 and 300 K are indicated in black, red, green, and blue lines in figure, respectively.](image)
source frequency of 23.67 Hz (data set B). In each case the length of the collected histograms was equal to the time between source pulses. The signal at the sample of the data set A consists of the wavelengths coming from the source pulse and providing the data collection trigger signal (“first frame” in pulsed source terminology) and neutrons with longer incoming wavelengths \( \lambda_{\text{inc}} > 9.2 \, \text{Å} \) emitted by the previous source pulse (“second frame”). To correct the data for this frame overlap we emulated the function of the frame overlap choppers by taking the spectra in the monochromatic mode at \( \lambda_{\text{inc}} = 11.33 \, \text{Å}, 13.37 \, \text{Å} \) and 15.34 Å and subtracting them from the polychromatic RRM spectra (longer wavelengths have negligible intensity). This approach enabled us to collect 3 useful RRM frames at the detector for each source pulse.

At lower source frequency the number of wavelengths which can be used from one source pulse increases. In the data set B taken at 165.67 Hz RRM pulse repetition rate and 23.67 Hz source frequency we were able to monitor 7 different wavelengths at the sample and to collect 6 wavelength frames at the detector. No frame overlap correction for the higher harmonics was required for the signal delivered to the sample, and the time T between pulses was long enough for neutrons up to 13.04 Å to arrive in the same data frame.

Both data sets demonstrate very well that there is enough time between pulses to record spectra for different wavelengths emanating from one source pulse. The shape of the scattered spectra reproduces those taken with monochromatic wavelength and no disturbing overlap is observed between the data sets for different wavelength RRM frames even at high temperatures and wavelengths except for very long ones, i.e. here 13.04 Å. Our RRM implementation study shows indeed that using low source pulse frequency enhances the efficiency of data collection also in TOF spectroscopy. The efficiency of the data collection can further be improved if the information collected is made more uniform, i.e. the difference between the individual RRM wavelengths extracted from one source pulse becomes smaller. This can be achieved by enhancing the distance between the source and the last choppers, which also improves the best available wavelength resolution.

2. Summary
Repetition Rate Multiplication can be successfully applied to hot, thermal and cold neutron scattering using fixed and wavelength dependent pulse suppression described here. The method offers a new way to operate TOF spectrometers at pulsed sources with efficiency similar to TOF spectrometers at continuous sources. The first experimental implementation of the Repetition Rate Multiplication technique was performed using the cold neutron TOF spectrometer NEAT at BENS. The characteristics of RRM data collection in real life experiments were examined using a sample with a complex inelastic behaviour. Our results provide full experimental proof of the principle of the method. The study shows the technical capability to collect useful spectroscopic data with about an order of magnitude higher pulse rate and efficiency than the conventional single wavelength approach offers. Furthermore, the polychromatic RRM data collection provides higher information contents than the monochromatic one.

References
[1] Mezei F., J. Neutron Res. 6 (1997) 3, and references therein.
[2] Russina M., Meze F., Trouw F, Proc. of ICANS-XV, editors J.Suzuki and S.Itoh, (JAERI-Conf:2001-002), 2001, p. 349
[3] Mezei F., Russina M., LET chopper system optimization, Reports #1 and #2, HMI (2005); and http://ts-2.isis.rl.ac.uk/instruments/let/
[4] http://j-parc.jp/MatLife/en/instrumentation/bl14/bl14.html
[5] Mezei F., Russina M., in: I.S. Anderson, B. Guerard (Eds.) Advances in Neutron Scattering Instrumentation, Proc. of SPIE 4785 (2002) 24
[6] Peters J, Bleif H.-J., Kali G., Rosta L. and Mezei F., Physica B 385-386 (2006) p1019
[7] http://www.isis.rl.ac.uk/archive/excitations/maps
[8] Russina M., Mezei F., J. Nucl. Instr. and Meth., A604 (2009) pp. 624-631