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Cold-Neutron Multi-Chopper Spectrometer for MLF, J-PARC

Kenji Nakajima[1], Ryoich Kajimoto[1], Mistutaka Nakamura[1], Taku J. Sato[2], Toyotaka Osakabe[3], Masaaki Matsuda[3], Naoto Metoki[3], Kazuhisa Kakurai[3], Shinichi Itoh[4] and Masatoshi Arai[1,4]

[1]Neutron Science Research Center, Japan Atomic Energy Research Institute
2-4 Shirakata Shirane, Tokai, Naka, Ibaraki 319-1195, Japan
nakajima@neutrons.tokai.jaeri.go.jp

[2]Institute for Solid State Physics, University of Tokyo
106-1 Shirakata, Tokai, Naka, Ibaraki 316-1106, Japan

[3]Advanced Science Research Center, Japan Atomic Energy Research Institute
2-4 Shirakata Shirane, Tokai, Naka, Ibaraki 319-1195, Japan

[4]High Energy Accelerator Research Organization (KEK)
1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Abstract

We are planning to construct a cold-neutron multi-chopper spectrometer for a new spallation neutron source at Materials and Life Science Facility (MLF) at J-PARC, which is dedicated to investigation of low energy excitations and quasi-elastic excitations in the field of solid state physics, chemistry, materials science, soft matter science and biomaterial science. The planned spectrometer will be installed at a H_2-coupled moderator and will be equipped with a pulse-shaping disk-chopper in addition to a monochromating disk-chopper, and realizes both high-energy resolution (DE/E_i=1%) and high-intensity (one order of magnitude higher than the present state-of-the-art chopper spectrometers).

Keywords: Chopper Spectrometer, J-PARC, Cold Neutron

1. Introduction

The JAERI (Japan Atomic Research Institute)-KEK (High Energy Accelerator Research Organization) joint project, Japan Proton Accelerator Research Complex (J-PARC) is now under construction in JAERI Tokai saite [1]. At J-PARC, a proton linac, 3 GeV and 50 GeV proton synchrotrons will provide MW-class proton beam. This high intensity proton beam will produces various secondary and successive decay particle beams, with which we will atain 3 major scientific goals i) materials and life sciences, ii) nuclear-particle physics and

iii) R&D for nuclear transformation. In this research complex, 4 experimental facilities are planned, Nuclear and Particle Physics Experimental Hall, Neutrino Facility, Accelerator-Driven Transmutation Experimental Facility and Materials and Life Science Experimental Facility (MLF). MLF is the facility dedicated to the neutron science and the new spallation neutron source will be placed at the heart. A pulse neutron source at MLF is a 1-MW class next generation spallation neutron source employing a liquid mercury target, and provides a high intensity (10~100 times of that of ISIS facility in the peak intensity) and high quality neutron beam to 23 beam ports. The construction of MLF will be finished in the end of 2007, and then we will have the first neutron beam at J-PARC.

For MLF, J-PARC, KEK-JAERI joint project team is proposing 10 'day-1' instruments [2]. 3 of 10 project-team instruments are inelastic spectrometers. HRC (High Resolution Chopper spectrometer) is a direct-geometry spectrometer for investigation of excitations in wide dynamic range, 1-1000 meV, with fine energy resolution (DE/Ei~1%). DIANA spectrometer is an indirect-geometry crystal-analyzer instrument, which can cover low-energy region (>2? µeV) with high intensity. The third one, that is a cold-neutron multi-chopper spectrometer (CNMCS), is the spectrometer dedicated to study of inelastic and quasi-elastic scattering from cold to thermal neutron region ($1 < E_i < 80$ meV) with fine resolution and high intensity.

CNMCS is a new type of a direct-geometry chopper spectrometer at a pulsed source. The spectrometer equips with a second main chopper at upstream position in addition to the other one at downstream, just before the sample position, while a conventional chopper spectrometer has only a later one. Being installed at the coupled moderator, the spectrometer realizes high intensity, high resolution and high flexibility. CNMCS is expected to cover the scientific research areas of solid state physics (collective excitations in single-crystal samples, diffuse scattering from structural and magnetic fluctuations...), chemistry (diffusion of ions and molecules in liquids...), materials science (diffusion of atom in batteries and catalysts...), and soft matter science (dynamics in biological materials and polymers).

2. Cold-Neutron Multi-Chopper Spectrometer

In Fig, 1 and Fig.2, provisional image and drawing of CNMCS are shown. Characteristic parameters are listed in Table I.

Before starting our plane, we have found following requests from scientific fields in the scope of our spectrometer. i) The spectrometer is expected to cover the dynamic range of 1~20meV mainly, and it should be at the best (in intensity and resolution) in this region. Also, the spectrometer should work more higher with appropriate performance to complete most of the experiments within this spectrometer. ii) The favorable energy resolution is DE/Ei=2~3%, and DE/Ei~1% at the finest. It is important that the resolution can be tunable to meet each experimental condition. iii) Large-$\boldsymbol{Q}$ coverage is desired by investigations of non-crystalline and liquid systems, and fine $\boldsymbol{Q}$ resolution is required by studies on collective motion in single crystal samples or other subjects. Request to the iv) high intensity (delivering high flux to the sample position and detecting scattered neutrons with high sensitivity) is beyond question. v) Accepting small samples, vi) fully adapting to polarizing analysis, and vii) permitting to install various specialized sample environments should be taken into account.

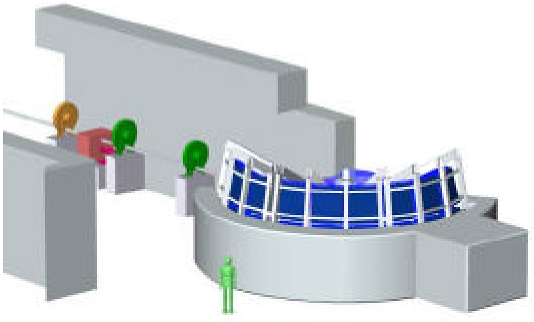

Fig. 1 An Image of Cold-Neutron Multi-Chopper Spectrometer for MLF, J-PARC.

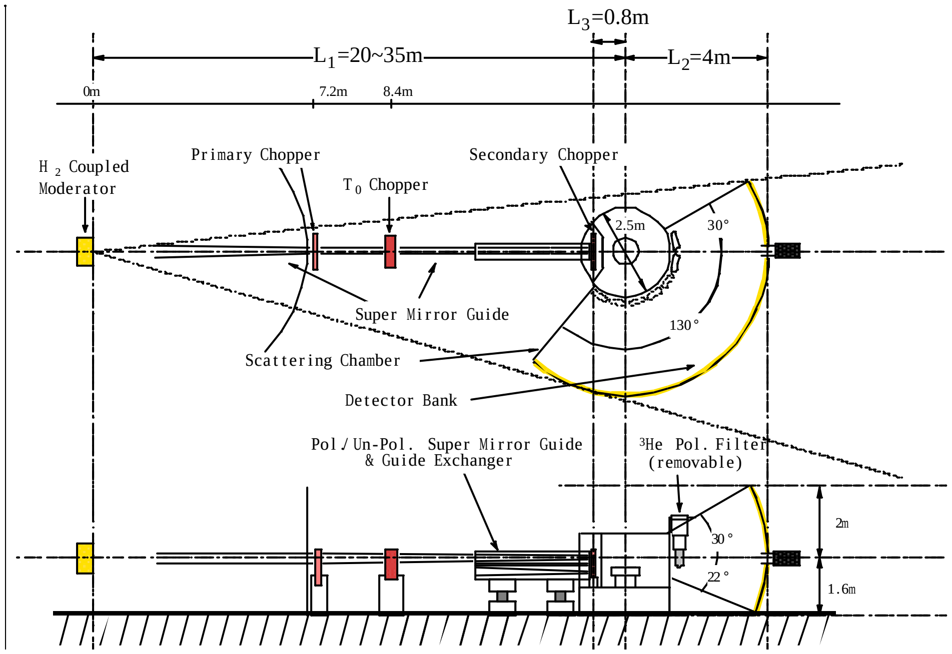

Fig. 2 A Provisional Drawing of Cold-Neutron Multi-Chopper Spectrometer for MLF, J-PARC.

In high resolution inelastic experiments in wide energy and ***Q*** range, a direct-geometry chopper spectrometer shows its outstanding performance, as one can see in the success of chopper spectrometers at ISIS. To realize both high intensity and fine resolution, we have decided to construct a double-chopper type direct-geometry spectrometer viewing a coupled H_2 moderator. Peak intensity of a pulse from a coupled moderator is much higher than that from a decoupled moderator. The disadvantage of a coupled moderator is a broader width and a long tail in time structure of pulse, especially in the long wave-length region. Such a 'bad' shape of pulse degrades the performance of a chopper spectrometer, especially in the energy resolution. Therefore, a conventional chopper spectrometer at a pulsed sourse, which has only 1 main chopper, normally views a decoupled moderator. The concept of a double-chopper type spectrometer is utilizing high peak intensity of a coupled pulse source without degrading the essential performance of the spectrometer by 'shaping' a broad pulse from the moderator using double main choppers. This type of spectrometer is also planned for 2nd target station at ISIS (LET) and SNS (CNCS).

Main choppers of CNMCS are counter-

Table 1 Characteristic Parameters of Cold-Neutron Multi-Chopper Spectrometer for MLF, J-PARC.

Moderator	Coupled H_2
Flight Path	L_1=20~35 m, L_2=4 m, L_3=0.8 m
Incident Energy	1-80 meV
Energy Resolution	$DE/E_i > 1\%$ (variable)
Scattering Angle	Horizontal: -30° ~ +130° Vertical: -22° ~ 30°
Q Range	$0.04<Q<1.3$ Å^{-1} (E_i=1 meV) $0.16<Q<7$ Å^{-1} (E_i=20 meV)
Q Resolution	$DQ/k_i > 0.5$ %
Sample Size	20 mm × 10 mm *f*
Main Choppers	Counter-Rotating Disk Chopper Radius: R=350 mm Slit Width: 10, 20, 30mm Max. Revolution: f=350 Hz
Auxiliary Choppers	T_0 Chopper: f=25 Hz at 8.4 m Flame-overlap Suppression Choppers: f=25 Hz at 9.5 m and 13.7 m
Detectors	1/2inch ^{3}He PSD (20atm) × 3000
Polarizer & Analyzer	Polarizer: Magnetic Supermirror Analyzer: ^{3}He filter

rotating disk-choppers. The primary chopper is placed at the exit of the biological shielding, 7.7 m form the moderator, and the secondary chopper is placed just before the sample. Disks of radius R=350 mm (300 mm from the center to the center of slits) with a 10 mm slit revolving in counter-rotating style at f=350 Hz at the maximum give DE/E_i=1% energy resolution up to E_i=20meV. For experiments with coarser resolution, we can reduce the revolution of choppers or can chose other size of slits, 20 and 30mm, which provide the flexibility in experiment in the conditions.

40 m^2 detector bank surrounds an evacuated scattering chamber covering the scattering angle of -30° ~ +130° in horizontal and -22° ~ 30° in vertical. The final flight path (sample-detector) is L_2=4 m. CNMCS will use 1/2 inch 1 dimensional position sensitive ^{3}He detectors. The diameter of the detector tube meets the $\boldsymbol{Q}$ resolution. The $\boldsymbol{Q}$ resolution of the spectrometer is DQ/k_i< 0.5% at the finest and DQ/k_i= 1~2 % over all. The resolution is mostly governed by the angular beam divergence caused by the beam transport section, which we will use a 3Q_C super mirror guide.

Primary flight path, L_1 (moderator-sample) is one of issues which we have been discussing. We are considering L_1=20~35 m. Analytic calculations and Mote Carlo simulations tell us that we can get the intensity maximum at about 25 m. To reduce the background, we are considering introducing a curved guide to the beam transport section. Then, longer L_1 is preferable. Also, the utilities in the MLF building are limiting our choice. We still continue detail discussion.

Expected neutron flux from CNMCS is calculated by using Monte Carlo simulation code, McStas [3]. Figure 4 shows calculated flux at the sample position at several energy resolution cases. In this calculation, primary flight path is assumed L_1 =20 m. At the DE/E_i=1% condition, we expect 10^4~10^5 neutrons/cm^2/sec., which becomes up to 10^6 neutrons/cm^2/sec. in the case of DE/E_i=2.5%. When we operate the primary chopper in low speed not to shape the original pulse from the moderator, we can get much intensity, although the energy resolution becomes boarder. Setting the Dt_m (pulse width at the moderator) = Dt_{ch2} (burst time of the secondary chopper), we can expect 10^7 neutrons/cm^2/sec. at the best. The energy resolution in the Dt_m=Dt_{ch2} mode is DE/E_i<7%.

Another version of intensity expectation is presented in Fig. 4, in which intensity at the detector position of 3 inelastic machines planned for MLF, J-PARC are shown. In these calculations, Vanadium powder is assumed at

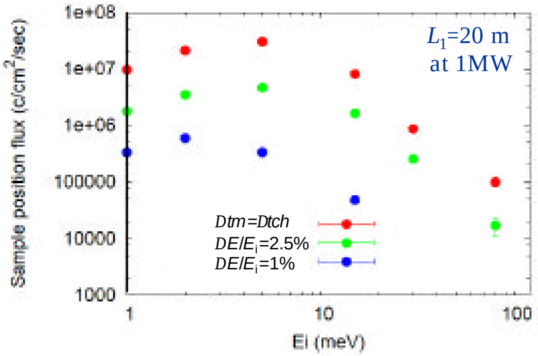

Fig. 3 Expected Neutron Flux of CNMCS at the Sample Position Calculated by Mote Carlo Simulation.

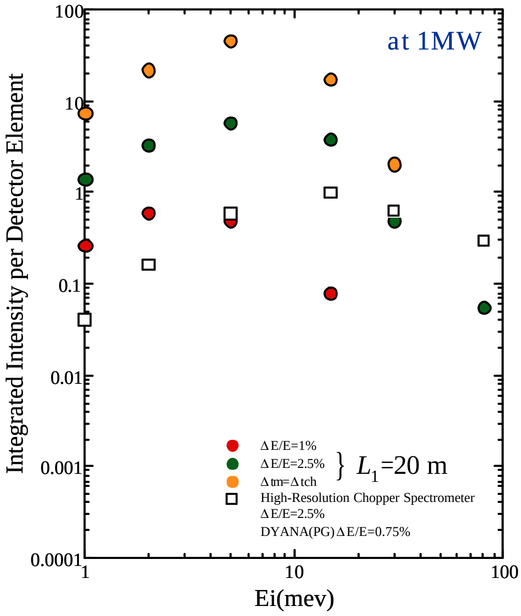

Fig. 4 Comparison of Expected Intensity at Detector Position of 3 Inelastic Instruments at MLF, J-PARC. (see text)

the sample position. L_1 =20 m is again assumed for CNMCS. The expected intensity from HRC crosses over that from CNMCS at E_i=20 meV. Below E_i<20 meV, CNMCS is superior to HRC. DIANA shows high intensity and fine energy resolution in the low energy region, although the ***Q*** resolution is rather moderate because of its large crystal-analyzers. CNMCS bridges HRC and DIANA. With the enough overlap region, these 3 spectrometers cover the experimental subjects at MLF, J-PARC in wide dynamic range in high performance.

3. Development Issues

Numbers of developmental works are under progress for CNMCS. Some of important issues are listed here.

i) High-Speed Disk-Chopper

Main disk-chopper is one of the most important components of CNMCS. We are developing a high-speed disk-chopper for CNMCS. Our final goal is achieving the counter-rotating 2 disks of R=350 mm running at the maximum revolution of 350 Hz with the phase control precision of < 0.1°. In the first stage of the development, we are aiming to achieve the maximum revolution and the necessary phase control precision. Finite-element-method analyses of a disk and design of controller electronics have been done. We have prepared several almost-real disks as prototypes (Fig. 5). Disks are made of carbon fiber reinforced plastics (CFRP) and $^{10}B_4C$ is coated as neutron absorber. The prototype chopper is under test now.

ii) Neutron Polarizer

Performing polarization analysis is indispensable feature of CNMCS. For selecting incident neutron polarization, a guide section (1.5 m) just before the secondary main chopper will be replaced by a magnetic super mirror guide. For an analyzer, we are considering to employ a ^{3}He filter, since it can accept large solid angle and large energy band, both of which are necessary for a chopper spectrometer.

Fig. 5 A CFRP-Disk (upper panel) and a Housing (lower panel) of a Prototype High-Speed Disk-Chopper of CNMCS.

Fig. 6 A Prototype Quartz Cell of ^{3}He Polarizing Filter.

Producing a large filter cell which can cover wide solid angle and can last higher gas pressure is one of development issues. We have started to prepare prototype cells (Fig. 6). A quartz cell stands up to 5 atm is already available. Investigating and accumulating necessary techniques to realize polarization analysis on CNMCS (guide field magnets, flippers, reducing background from filter cells, minimizing field gradient around ^{3}He filters, etc.) are other tasks, which we are also working on.

iii) Detectors

CNMCS will use 1/2 inch diameter tube ^{3}He PSD detectors rather than those of 1 inch, since the dimension meets the fine $\boldsymbol{Q}$ resolution of this spectrometer. However, the counting efficiency becomes lower in a thinner tube detector. To overcome this problem, we prefer 20 atm gas pressure, which is much higher than normally used pressure 10 atm. Then, severe problems are expected. For example, increasing gas pressure may cause increase of electric noise. Higher pressure gas detectors need thicker wall, which may cause spurious scattering. In cooperation with HRC team, we are purchasing several prototype 20 atm PSDs and testing them at KEK.

iv) Software

Software plays an increasingly important and indispensable role in a chopper spectrometer as a number of detector pixels increases and as objective systems become more complex. CNMCS detector system has more than 2 hundred thousand pixels and many experiments with single crystals investigating not only low-dimensional but also 3-dimensional correlations in these systems will be carried out on this spectrometer. Therefore the software development is quite serious issue.

KEK-JAERI joint project instrument team is sharing the problems concerning software development. We are taking part in the development of new date reduction and analysis software module, *Manyo-library* [4] in the flame work of MLF computing environment design group. However, chopper dedicated part of software based on *Manyo-library* is still left and is a future task of CNMCS development.

4. Schedule

After the plane of CNMCS was launched as one of 10 project-team instruments, we have submitted a letter of intent to Neutron Instruments Planning Committee of J-PARC, which was accepted in 2004. Then, we proceed to full proposal, which is under the review now.

Now the status of the construction is almost at the end of the conceptual design stage. We are proceeding to the detail design which will be finished in 2006 Japanese Financial year (ended in March 2007). Most parts of developments will be finished also in 2006 JFY. The main part of the construction will be finished in the end of 2007, when we will have the first neutron beam at MLF. After 1 year commissioning, we hope that we will start user program in the end of 2008.

Acknowledgements

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References

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