ICANS XIX,
19th meeting of International Collaboration on Advanced Neutron Sources
March 8 – 12, 2010
Grindelwald, Switzerland

Development of T0 chopper at KEK

S. Itoh, K. Ueno, R. Ohkubo, Y. Funahashi, H. Sagehashi, T. Yokoo, T. J. Sato*, T. Otomo and S. Satoh
High Energy Accelerator Research Organization, Tsukuba, 305-0801, Japan,
**The University of Tokyo, Tokai, 319-1106, Japan*

ABSTRACT
We developed the T0 chopper rotating at 100 Hz and confirmed that the phase control accuracy and the lifetime were satisfied with the specifications. Based on the result of the development, we have started to produce actual machines to be installed at the beam lines at J-PARC.

1. Introduction

In 2002, we started the development T0 choppers to be installed at J-PARC, as a collaboration project of Neutron Science Division (KENS) and Mechanical Engineering Center (MEC) at KEK. In those days, T0 choppers rotating at 50 Hz were in practical use at ISIS [1]. Previously, we reported the design and the assembly of the prototype [2-4]. At present, further developments as well as the production of the actual machines at J-PARC are described.

To utilize eV neutrons with the beam cross section of 80 mm × 80 mm, we designed and assembled a T0 chopper rotating at 100 Hz of the rotational frequency. The dimension of the chopper blade (shielding part) on the rotor was determined to be 82 mm × 82 mm × 300 mm (300 mm is the length along the beam) with a margin of ± 1 mm. This margin corresponds to the phase control accuracy of ± 5 μs. The rotational radius of the rotor is 300 mm, this is the distance between the centers of the rotational axis and of the chopper blade. If this T0 chopper rotating at 100 Hz installed at 8.5 m from the neutron source, high energy neutrons up to 2 eV can be utilized. In our T0 chopper [2], the rotor made of Inconel X 750 was mounted inside the vacuum, the shaft is supported by ball bearings, and the rotation is transferred through a magnetic seal from the motor located outside the vacuum chamber. A continuous running time of 1000 hours and a total running time of 4000 hours are required without changing components.

2. Basic developments

The rotation of the T0 chopper must be synchronized to the timing of the neutron generation with the rotational fluctuations (the deviation of the rotational period) less than ± 5 μs at 100 Hz. To realize this requirement, the following items should be examined at development and design stages [2-4]: a toughness of the machine body, an accuracy of the machining and the assembly, a stable rotation, an extension of the life time of the components, a choice of the most suitable bearing type, a lubricant of the bearings (a grease for vacuum), magnetic seals suitable for this system and so on. Also we suppressed the rotational fluctuations using a dynamic damper. To minimize the rotational fluctuations, a phase control system was developed. Furthermore, we have to take care of a user interface such as a control panel, a remote access at maintenance, and irradiation properties of components of the T0 chopper. We here summarize some important points and describe what we have obtained later.

2.1. Mechanical reduction of rotational fluctuations

The T0 chopper has a simple structure where the rotor (mass: 120 kg) is supported by ball bearings at the ends of the shaft. But, for a stable rotation, a very precise machining for the rotor is required: the coaxiality of components on the shaft should be within 10 μm and the balance level of the rotor should be G1. In addition, at the end of the shaft of the rotor, we mounted a dynamic damper as a device absorbing the change of the rotational frequency. We named this device a stabilizer, developed and installed this device to improve rotational properties. The stabilizer was found to be indispensable to reduce the rotational fluctuations at 100 Hz.

2.2. Phase control system

We took measures to reduce the rotational fluctuations mechanically as much as possible as described above [3], but the rotational fluctuations are influenced by such reasons as a heat transformation and a change of the grease viscosity with changing temperatures. It is not easy to maintain the rotational frequency at 100 Hz within the fluctuations of ± 5 μs. Therefore, the control system of the T0 chopper was developed, and the rotational frequency and the phase were automatically controlled by a pulse of the stepping motor in case of the frequency out of a designated range of the expected frequency (one pulse corresponds to 0.044°). By mounting this phase control circuit, we successfully reduced the rotational fluctuations to 1 μs (full width at half maximum) [4].

2.3. Semi-auto installation mechanism

The location of the T0 chopper on the neutron beam lines at J-PARC is at the bottom of the shielding of which height is 4 m. At the maintenance, we should stand on a part of the shieldings, and mount and remove the T0 chopper by a small number of procedure using a crane after removing the shieldings above the T0 chopper. The main body sits on the base, and cooling water, electricity and vacuum are connected through the base. In our design, these are connected / disconnected just by sitting on / removing from the base by a crane [4]. Figure 1 shows the design of the model of the semi-auto installation mechanism for cooling water. We performed a repeating test of connection / disconnection for the mechanism. Based on such developments, we designed the actual machine shown in Fig. 2.

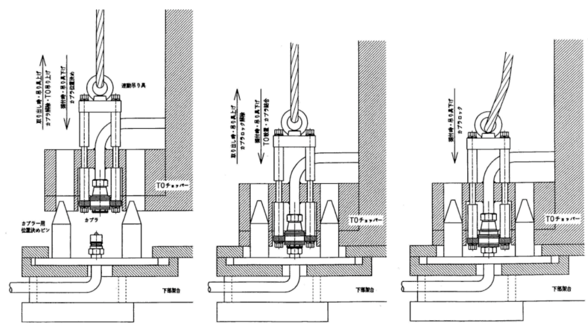

Fig. 1 A model of semi-auto installation mechanism for cooling water.

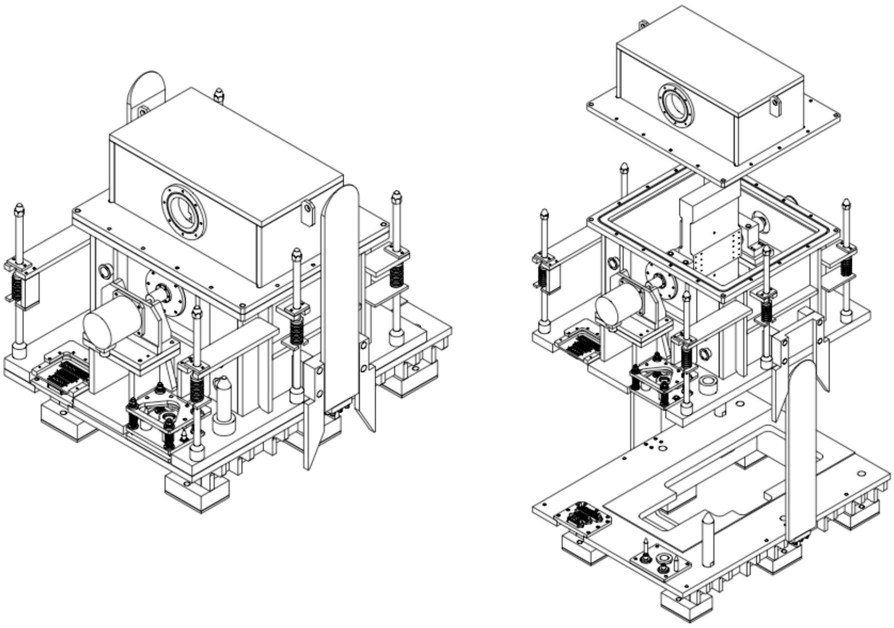

Fig. 2 The T0 chopper mounting the semi-auto installation mechanism. In the right figure, the upper part of the vacuum chamber is removed to show the rotor. Normally, the upper part is fixed at the body.

2.4. Lifetime

The T0 chopper consists of consumptive components having the lifetime such as bearings, magnetic seals and so on. We previously reported that the lifetime of this system was more than 4600 hours except for magnetic seals and without irradiation [4]. The lifetime of the whole system of the T0 chopper was limited by that of magnetic seals. The lifetime of conventional products of magnetic seals used in the T0 chopper was approximate 2500 hours [4], because of evaporation of solvents in magnetic fluids. By changing the magnetic fluid to that having higher vapor pressure, optimizing the filling quantity of magnetic fluid and changing the magnetic circuit, the performance of the magnetic seals was greatly improved, in collaboration with the vender and us. As the result, we confirmed that the lifetime of the magnetic seals was extended to 4400 hours. We mounted new magnetic seals on the actual model of the T0 chopper.

2.5. Irradiation properties

The radiation damage of main components such as bearings, magnetic seals, belts and rotation sensors is one of the factors to limit the lifetime of the T0 chopper. The important components are located on the rotational axis at 300 mm from the neutron beam line. At this position, γ-rays are dominant and the absorption dose can be calculated in the order of 1 kGy/yr at 1 MW of the accelerator beam power [5]. We investigated radiation properties of some components of the T0 chopper by irradiating high energy γ-rays emitted from Co-60 [4,6]. The dose irradiated to the samples was controlled to be 1 kGy, 10 kGy and 100 kGy, and the properties of the materials were investigated after the irradiation. The irradiation was performed at the Cobalt 60 Irradiation Facility, Takasaki Advanced Radiation Research Institute, Japan Atomic Energy Agency.

Grease in rotor bearings was investigated [4,6]. Grease consists of a puffing agent and a base oil. The scanning electron microscopy shows that the particle size of the puffing agent was almost unchanged up to 100 kGy. The molecular weight of the base oil was was found to be unchanged up to 10 kGy and slightly decreased at 100 kGy by NMR.

Decreases of the load wear index and the friction coefficient of the grease were detected at 100 kGy by four-ball tests. As for magnetic seals [6], the evaporation rate and the viscosity were unchanged up to 10 kGy. The hardness and the material strength of the timing belt were unchanged up to 10 kGy. These components were unchanged or slightly changed, and therefore the irradiation to these components does not seem to have much influence on the lifetime of the T0 chopper. However, the photo-interrupter used for the detection of the rotation of the rotor and the encoder of the motor, which are made of semiconductors, were remarkably damaged by the irradiation. The photo-interrupter worked at 1 kGy, but did not work at 10 kGy. The encoder did not work even at 1 kGy.

It is necessary to take measures for irradiation to semiconductor components. We performed the following geometrical change in design. Since the rotation of the rotor is necessary to be detected on the rotational axis directly, a signal from a marker on the axis was transferred by an optical fiber, instead of the detection by the photo-interrupter. The optical fiber was connected to the amplifier located 200 mm below the rotational axis, and a steel plate of 50 mm thickness was inserted between the axis and the amplifier, because the amplifier is more damaged by irradiation than the optical fiber. The motor encoder is on the motor axis located 500 mm below the rotational axis of the rotor. There exists a steel plate of 40 mm thickness (a part of the vacuum chamber) between the encoder and the rotational axis. As the result, the absorption dose for the rotation sensor and the motor encoder can be expected to be reduced to approximate 20 % of that on the rotor axis. It is required to investigate the validity of the measures for irradiation.

3. Actual machine production at J-PARC

We transferred these results of our development to a company and started the production of the actual machines of the T0 chopper to be used on the beam lines, BL04, BL12, BL16, and BL21, at J-PARC.

The first high frequency model (100Hz) shown in Fig. 2 was successfully produced for Neutron-Nucleolus Reaction Instrument (BL04), and installed by the first neutron beam production at J-PARC in May 2008. The cross sections of nuclear reactions are measured on BL04 and eV neutrons are required. By installing the T0 chopper at the 13 m position from the neutron source, neutrons up to 18 eV are utilized at 100 Hz. The reduction of the background noise by the T0 chopper was observed on BL04, for the first time.

High Resolution Chopper Spectroscope (BL12) is an inelastic neutron scattering instrument by using neutrons monochromatized by a Fermi chopper, and the dynamics in matter can be investigated with high resolutions by utilizing neutrons up to eV region. By installing the T0 chopper at the 8.5 m position from the neutron source, neutrons up to 2 eV are utilized at 100 Hz. The high frequency model of the T0 chopper was installed in March 2010. In this high frequency model, the rotor, which has a symmetric shape against the rotational axis, was originally made of Inconel X 750 in one body including the rotational axis, to reduce the maximum stress to the material strength. Recently, since the material price was drastically increased, the structure was changed. The rotor body including the rotational axis was made of cobalt free stainless steel and a cylindrical Inconel part was inserted to the beam hitting position. These two materials were bonded by the hot isostatic press method, and then, the stress was successfully reduced. The rotors for BL04 and BL12 were produced by this method.

High Intensity Total Diffractometer (BL21) utilizes neutrons with a wide wavelength band. To increase the wavelength band, the rotor of the T0 chopper has an asymmetric shape and then the beam line is shut once for one rotation, also a counter rotating set-up of two T0 choppers are planned. For this purpose, the length along the neutron beam should be minimized. The short model can be realized for a lower rotational frequency of 50 Hz by using a short base and removing the stabilizer. Also the connecting part of the water and electricity at the base was re-designed. The total length of the high frequency model is 1.3 m and that of the short model is 1 m as shown in Fig. 3 (left). One of the two T0 choppers was produced in March 2010.

On High-Performance Neutron Reflectometer with a Horizontal Sample Geometry (BL16), surface structure of materials can be investigated by the momentum dependence of the neutron reflection on the sample surface mounted horizontally. BL16 has two beam lines, and the angle between the horizontal line and the beam line can be chosen to be 2.2° or 5.7°. Therefore the T0 chopper for BL16 should have two beam holes. The rotational axis is located between the two beam lines and the rotor shape is asymmetric as shown in Fig. 3 (right). It will be installed in the summer 2010.

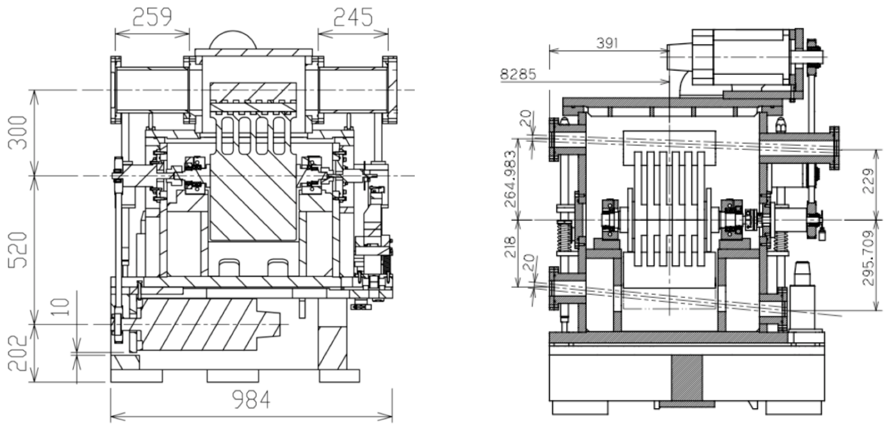

Fig. 3 Variations of models of the T0 chopper. A short model rotating at 50 Hz for the total scattering instrument (left) and a two-hole model rotating at 25 Hz for the reflectometer (right).

4. Summary

We performed the basic development of the T0 chopper rotating at 100 Hz, and confirmed that the phase control accuracy and the lifetime were satisfied with the specifications. Based on the results of the development, we have started the production of the actual machines to be installed at J-PARC. Although it is necessary to take measures for irradiation to some parts, the effects of the measures done for the actual machines will be investigated.

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