MODERNIZATION OF NEUTRON FOURIER CHOPPER FOR HIGH-RESOLUTION FOURIER DIFFRACTOMETER (HRFD) ON THE IBR-2 PULSED REACTOR

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The High-Resolution Fourier Diffractometer (HRFD) is operated at the pulsed reactor IBR-2 (FLNP JINR, Dubna) allow to carrying out precision research of the crystal structure and microstructure of crystalline materials. The use of the fast Fourier chopper for intensity modulation of the primary neutron beam and the correlation method of diffraction data accumulation is a principal feature of the HRFD design. This allows one to obtain extremely high resolution ($\Delta d/d \approx 0.001$) at HRFD in a wide range of interplanar distances at a relatively short flight path from the chopper to the sample position (L = 20 m). In 2016 the old Fourier chopper (the operation period ~15 years) was replaced with a new one manufactured by the Mirrotron Ltd company (Hungary). The basic mechanical characteristics of the previous version of the Fourier chopper have been maintained, but a series of innovations were introduced in particular in the chopper control and monitoring system, which are discussed in this paper.

Keywords: neutron diffraction, Fourier diffractometer, high resolution, pulsed neutron source

1. Introduction

The High resolution diffractometer is one of the indispensable types of spectrometers in every advanced neutron research center. At pulsed neutron sources with short pulses ($\Delta t_0 \leq 30$ μs) based on proton accelerators with a heavy metal target, the high resolution ($\Delta d/d \leq 0.003$) of the time-of-flight (TOF) diffractometer is reached if the flight path, L, is 50 m or longer. At the IBR-2 reactor (JINR) the pulse width of thermal neutrons is about 350 μs; thus, to reach high resolution the flight path would need to be prohibitively long ($L > 500$ m). It was decided that effective shortening of the neutron pulse should employ a particular type of fast disk chopper [1].

The Fourier method is based on modulation of the neutron beam intensity using the chopper with a periodic transmission close in form to a sine function. The chopper consists of the rotating disk (rotor) and the stationary part (stator) with the same modulation pattern of radial sectors transparent and non-transparent for thermal neutrons. To the first approximation, at the chopper's fixed rotation frequency the intensity of scattered neutrons, $I(\omega)$, would be a Fourier transform of the sample scattering cross-section. Accordingly, by measuring (the intensity of scattered neutrons) $I(\omega)$ over a wide frequency range, it is possible to reconstruct the scattering cross-section $\sigma(t)$, where t is the time of flight, related to the momentum transfer or d-spacing.

The first version of the Fourier chopper was manufactured at the Technical Research Center of Finland (VTT, Espoo). The chopper consisted of a rotor disk (Ø540 mm), a stator plate (both constructed from Ti–Zr zero matrix alloy), a motor (W = 7.5 kW) and an optical encoder measuring the rotor speed and forming pick-up signals. The optical encoder has subsequently been replaced by a magnet encoder with an extended service lifetime under conditions of high radiation background. The rotor and stator had a modulation pattern of 1024 radial slits with 0.7 mm width in the middle of its 60 mm height the covered by Gd_2O_3 in an epoxy resin.

The motor was controlled by a VECTOR V750 drive capable of controlling the motor within the rotating speed range of ± 9000 rpm, which allowed modulation of the neutron beam intensity with a frequency of up to 150 kHz [2].

However, there were some serious methodical problems, directly affecting the diffraction data quality: low quality of the pick-up signal due to incremental magnetic speed sensor with an interpolation factor 8, vibration of the disk at high speed due to its rotation in air, complicate and low precisely manual procedure of stator position calibration. As a result, we had a complex peak shape, with small negative dips on one or both sides of the diffraction peaks and cannot be described analytically. Largely, this problem was solved by developing a special-purpose MRIA software package for the data processing by the Rietveld method. In the MRIA package, there is a possibility of introducing a two-sign model that can be specified numerically [3]. Meanwhile, the necessity for further efforts on enhancement of the situation with the shape of diffraction peaks was obvious.

2. A new HRFD concept

The main mechanical features of the previous version, particularly, the rotor diameter, the number of slits, the length and width of the slits, the absorbing material and the thickness of the Gd_2O_3 layer (0.8 mm), were kept unchanged in the new Fourier chopper, constructed by Mirrotron Ltd. Hungary. The new rotor is made of the strengthened Al alloy (Al 7075T6) and provides for the maximum rotational speed of 6000 rpm. Unlike the previous version, the rotor and the stator are installed in a hermetic casing. The mechanical design of the stator allows one to have exact configuration and fixation of the pick-up signal phase. A new type of incremental magnetic pickup sensor of the chopper disk rotation speed with an interpolation factor of 2 instead of 8 is applied, the rotor vacuum and vibration monitoring sensors are installed, a new control system for stator position is used. The new pick-up signal sensor and control systems have allowed one to decrease the differential nonlinearity of the rotor instant speed to ~2.5%. The chopper control and monitoring system based on the software logic controller Omron provides the predefined law of change in the Fourier chopper rotation speed and monitors the readings of the vacuum, vibration and temperature control sensors.

Figure 1. The new Fourier chopper on the HRFD spectrometer

The quality of modulation of the neutron flux by the Fourier chopper is high, the measured transmission function has a triangle-like shape with contrast about 98%.

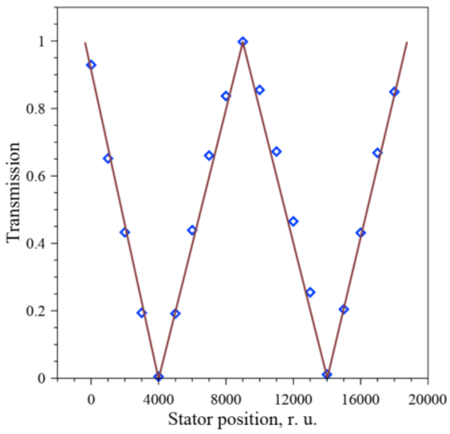

Figure 2. Transmission of the chopper for the stator step-by-step movement.
The solid line is provided as a guide for the viewer [1]

The use of a vacuum ($5 \cdot 10^{-2}$ Torr) in a hermetic casing reduces the vibration of the disk rotation. The casing also is made of aluminum alloy (AlMgSi). As to the total width of the casing at the point of transmission of the neutron beam is 92 mm the casing has a compact size.

For the stator position control, new mechanical and electronic system are used. The design of the stator allows precise adjustment and fixation of the phase of pick-up signals. For the stator movement, a built-in step motor "Haydon-Kerk" and a step block are used, which convert the rotational motion from the motor into linear movement of the screw with a small pitch. Absolute accuracy of movement can reach 0.0025 mm at the command of a full step. As a feedback, a two-pole resolver is used, which has high radiation resistance. The position of the drive is stable even in the non-powered state, due to the high pitch of the screw, as well as the stator locking system. The user can move the stator with an accuracy of ±0.01mm. The rotation of the stepper motor is controlled by the Copley Motion DeviceNet stepper drive.

The sensors for monitoring the vacuum and vibration of the rotor were installed on the Fourier chopper disc. The first sensor was designed to measure the proportional component of the vibration velocity and provides readings in mm/sec. The vibration speed-reader provides information on mechanical errors in the design of the chopper, as well as in balancing errors. The frequency range for this component is from 10 to 1000 Hz. Another vibration sensor monitors the acceleration value of the vibration and provides a signal in grams/sec. This sensor provides status information on bearings. The range of frequencies measured by this sensor is from 10 to 10000 Hz. Each sensor has an analog current output 4-20 mA.

For the design of the new Fourier chopper, the experience of using the old one on the HRFD spectrometer as well as the operation of the Fourier chopper on the FSD (Fourier Stress Diffractometer) spectrometer were taken into account. Many technical points are closely intertwined in them [4]. For example, the Tekel TK2 561-F-1024 optical incremental (position) sensor (the interpolation coefficient is 1) was installed on the old Fourier chopper. Unfortunately, this type of incremental encoder had a short life-time. The reason for exiting from exploitation is the degradation of the photodiode of the sensor due to exposure to high levels of radiation.

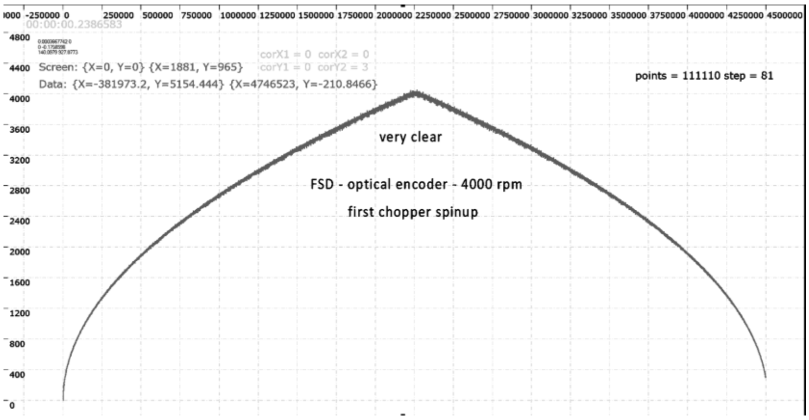

Figure 3.The new condition Tekel TK2 561-F-1024 optical incremental sensor

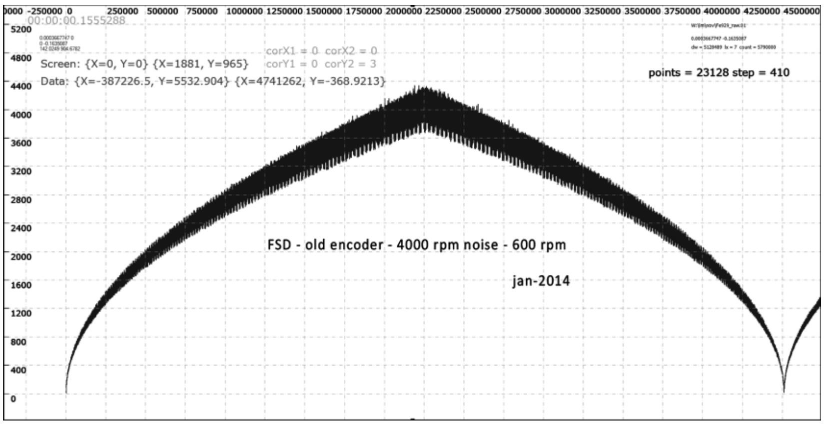

Figure 4. Degradation of the photo diode of the old Tekel TK2 561-F-1024 sensor

Instead of optical sensors, magnetic incremental encoders were used on the HRFD and FSD spectrometers. They had a significantly longer life-time at high radiation. Nevertheless, they also failed over time. Figure 3 shows the pick-up signal value from the magnetic sensor in dependence on rotation speed and time on the FSD spectrometer before long operation of the sensor at a high level of radiation. Due to the only 128 physical poles ("teeth") in the sensor, the signal was interpolated (the interpolation coefficient is 8) to 1024-like poles to improve the resolution of the data by a function implemented in the magnetic sensor. After about 1 year of exploitation at high levels of radiation (average dose ~0.5 Sv/h) the sensor showed significant degradation of the signal (Fig.4).

Therefore, due to the high radiation in the place of the chopper operation the Lenord and Bauer MiniCoder GEL 2444T-Z2G3K-030E magnetic sensor, as well as the ferromagnetic disk Lenord and Bauer ZAZ 0512 with 512 teeth were installed on the rotor shaft. The entire system was placed in a vacuum casing. The new incremental encoder also provides rectangular pulses called A, B, Z and their inverted copies.

In the new type of incremental magnetic encoder, the interpolation coefficient is 2 instead of 8. This made it possible to increase the discreteness of determining the rotation speed of the Fourier disk in acceleration and deceleration modes. Thereby, the computation speed and signal sampling are increased.

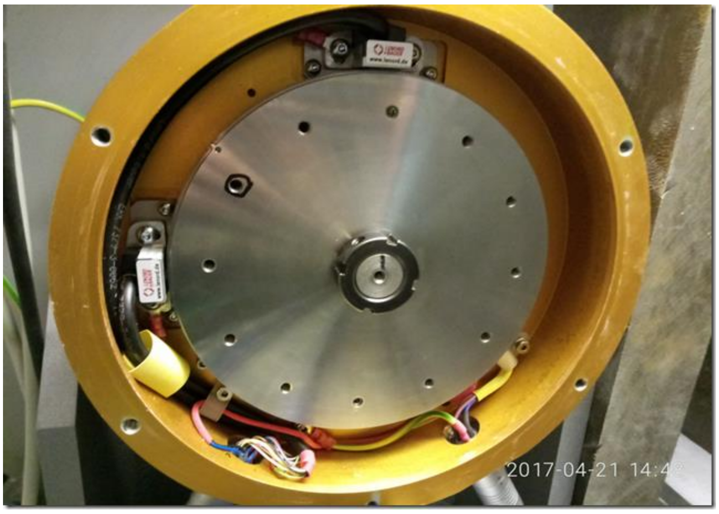

Figure 5 . The new incremental encoders GEL 2444T-Z2G3K-030E on the rotor shaft of the chopper and the ferromagnetic disk Lenord and Bauer ZAZ 0512 with 512 teeth

The new Fourier chopper has a rigid connection between the encoder gear wheel and motor shaft, in contrast to the previous system, where a flexible coupling (a plastic clutch) connected the encoder and motor shaft. The coupling rigidity could degrade due to long operation and radiation exposure and, as a result, could affect the quality of the pick-up signal (kinematic-transmission error).

In order to create a convenient control system for the Fourier chopper, the Programmable Logic Controller (PLC) "PLC Omron CJ2M CPU31" was used. It handles the communication between the control computer and the motor servo drive, processes and converts the analog input signals, receives and sends the discrete signals. It is able to intervene in processes if necessary. For example, if the vibration level is over the limit, PLC stops the rotation of the chopper and generates an error signal for the User.

3. Conclusion

The successful upgrade of the Fourier chopper has opened a new level of quality of diffraction data obtained at HRFD and allowed to maintain some important parameters of HRFD at the level of several of the world's best neutron high-resolution diffractometers. Placing of the rotor and the stator in a sealed casing, operation under vacuum, the design of the stator, a new incremental magnetic speed sensor allowed one to provide fine-tuning and characteristics of the pick-up signals. The results of this work will be used in the further upgrade of choppers in other Fourier diffractometers (FSS, FSD) at the IBR-2 pulsed neutron source.

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