Phase stability of double rotor facility at ET-RR-1 reactor

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A phased double rotor facility is used at ET-RR-1 to produce a pulsed thermal neutron polyenergetic beam. The rotors are suspended in magnetic fields and rotating at speeds up to 16000 rpm. A 16 Mc's quartz timer along with four signal generated by four optical devices, fixed around the rotors, were used to maintain the stability of both their rotating rates as well as the constancy of phase between them (jitter phase). The fluctuation of the rotor’s periods at any rotation rate was found not to exceed ±0.3 µs while the jitter phase between the ±1 µs. An improved method for precise time scale calibration of the double rotor facility is applied. The experimental check-up of its main parameters are given.

1 Introduction

The time-of-flight (TOF) method of structure analysis was proposed by several workers. For experiments of this type, a very high resolution is often required. In order to increase the neutron intensity in TOF spectrometers at a required resolution, curved slot rotors have been used, while the neutron beams usually formed using straight slot collimators.

It was shown that, for a required wavelength resolution and rotor radius, the obtained neutron intensity is higher at a high angular velocity Ω. However the strength function of the rotor material, together with the dynamic forces, present serious limitation to the maximum angular velocity obtained. To overcome such limitations Kalebin designed a phase multi-rotor system using magnetic suspension. Kalebin’s system produces a pulsed polyenergetic neutron beam with energies up to 1 KeV. As shown by Kalebin, the rotation of the two rotors with the same speed within high accuracy is not sufficient to maintain the constancy of the phase between them.

In order to achieve the synchronization of the two rotors, Kalebin applied a method based on the comparison between the rotors’ time periods with a preselected one generated by a high frequency quartz oscillator in a negative feed back loop. The rotor’s period was obtained as the time difference between two pulses generated using an optical device. The optical device consists of two mirrors fixed diametrically opposite on rotor body, parallel light source and photo-multiplier. The pulse was generated each time when the mirror intersects the light beam and reflects it to the photo-multiplier.

However due to the limited accuracy of the mechanical positioning of the two mirrors, it is difficult to achieve a high accuracy of the rotor rotation stability. To avoid such difficulty N, Habib et al. used two photo-multipliers and one mirror for rotation stability of high speed neutron TOF mechanical chopper.

Therefore, in the present work a unit for a high phase stability of the double rotor facility at ET-RR-1 was designed and put into operation. An improved method for precise time scale calibration of the double rotor facility was applied.

2 Phase Double Rotor Facility

A pulsed neutron polyenergetic thermal beam at ET-RR-1 is produced by a phased double rotor facility. The general layout of the facility is given in Fig 1. The first rotor is designed to operate as a rotating collimator, while the second one as a neutron chopper. The neutron chopper has two curved slots. The collimator’s dimensions were selected to match the curved slot chopper. Each of the rotors is mounted in a mobile platform and installed in a evacuated chamber. The rotors are suspended in magnetic fields spinning at a maximum speed of 16000 rpm. The rotor’s tail (2) made from duralu-
A mirror (7) made from a polished 2mm thick steel sheet with cross sectional area 0.5x1.0 cm² was fixed tangent to the rotor's body (1). Two optical devices (5) each of them was fixed on its mobile arc platform (6) around the rotor. The optical device consists of a parallel light source and a photo-multiplier. A logic pulse is generated each time when the mirror intersects the light beam and then reflects it to the photo-multiplier. As a result a logic pulse from each photo-multiplier is produced per revolution. The logic pulses are fed to the rotation stabilization and phase controlling system. The system consists of three main units two of them are the rotation stabilization units of rotors I and II respectively. Unit III is the phase control between them. The rotation stabilization units for both rotors are designed similar to that given by N. Habib et al.⁷

The logic pulses 1 and 2 were fed to the stabilization rotation unit I. The first pulse I-1 through a delay time \( \delta T_1 \) switches the gate of a quartz oscillator. The pulse train from the oscillator (with frequency 17 Mc/s) can then \( T_o \) can be selected from 20 cascaded IC flip-flops (F/F) by appropriate keys. The time periods can be varied from 65.6 ms to 1.5 ms through steps of 0.2µs which corresponds to rotation rates from 460 to 20000 rpm respectively. The output from the last (F/F) feeds the comparison unit. The second logic pulse I-2 through a delay time \( \delta T_2 \) controls the comparison unit. At the unit two modes of operation arise.

1) If the time elapsed \( T \) between pulse I and 2 is greater than \( T_o \), then the comparison unit feeds a preadjusted current to one of the controlling excitation coils of a three phase magnetic amplifier. Consequently the three phase current from a 600 Hz generator can pass to the rotor's coil (3). As a result the chopper will rotate with an acceleration until its angular velocity becomes higher than \( \omega_o \), i.e. \( T T_o \).

2) If the time \( T \) is shorter than \( T_o \), the comparison unit switches off the rotor's current and the chopper will rotate with decreasing its angular velocity until it becomes less than \( \omega_o \).

Such sequences are repeated each chopper cycle and the result of a cumulated processes is that the chopper period will fluctuate around \( T \). However, the rotation torque exerted on the rotor at the switching moments of
the on/off modes, of operation may cause a serious vibrations and the rotor may lose its dynamic stability. In order to damp these vibrations, the second controlling excitation coil of the magnetic amplifier was fed with a constant current. Its amplitude was selected sufficient to overcome the remaining rotor’s friction while it is not enough to maintain its rotation at a rate \( \omega_o \).

It was found that the fluctuation of the chopper’s period at any rotation rate did not exceed 0.3 \( \mu s \). Consequently the stability of the copper rotation at 460 and 16000 rpm were 0.0005% and 0.02% respectively. However, it was found that, the achieved high rotation stability of both rotors was not sufficient for their synchronization within high accuracy. Therefore, a phase unit was designed to maintain the synchronization of the two rotors at low jitter phase. At the phase unit the following sequences occur. The first logic pulse (I-I) opens the gate and the pulse train from 16 Mc/s generator passes to the phase timer. Using appropriate keys and delay lines the required time phase \( T_{ph} \) between the rotors can be selected within an accuracy of 0.1\( \mu s \). The last flip flop of the phase timber controls the gates of the time window \( \Delta T \). The value of \( \Delta T \) can be varied between 0.2-2.0 \( \mu s \) with steps of 0.2 \( \mu s \). The time period of the second rotor is selected at its Timber to satisfy the following conditions:

a) when the lower limit (LL) of the time window is in operation, the second rotor will rotate with angular velocity higher than that of the first one (more mode)

b) when the upper limit (UL) is switched, the second rotor will rotate in a less mode.

Therefore, the logic pulse II-1 through one of the window gates can pass to the stabilization rotation unit of the second rotor. Consequently the modes of operation at the timer phase unit are:

- If the pulse II-1 arrives before \( T_{ph} \), i.e. the phase difference between the rotors is less than the selected one. Then the last F/F of the phase timber opens, the phase gate and the II-1 pulse from (LL) time window passes to the stabilization rotation unit of the second rotor. The second rotor starts to rotate in a more mode and consequently the phase difference between the rotors start to increase until it reaches the value of \( T_{ph} \), at that moment the II-1 pulse passes to the stabilization rotation unit through (UL) gate (the less mode is now in operation). The phase difference between the rotor starts to decrease until it reaches again the value of \( T_{ph} \).

Such cumulated process make the II-1 pulse fluctuate around \( T_{ph} \). The fluctuations (jitter phase) are found to be vibrating with amplitudes of order of few tens of \( \mu s \). Moreover the vibrations are non-damping. This is mainly due to the slow response of the motor-rotor system to change its angular velocity from less to more mode and versa-vise. In order to damp these vibrations and decrease the jitter phase a damping unit was designed.

The function of the damping unit is to determine the elapsed time between \( T_{ph} \) and the II-1 pulse, in both case when the II-1 pulse arrives after or before \( T_{ph} \). This time interval is converted to a current amplitude, which is added to or subtracted from the constant one of the second excitation coil of the magnetic amplifier in more and less mode respectively. The amplitude of the current is vanished when the elapsed time reaches its maximum value in both cases. Since at these moments the angular velocities of both rotors are just the same. Therefore, the function of the damping unit is rapid the motor-rotor response and to make the II-1 pulse approaches to the \( T_{ph} \) very slowly. At optimum values of the motor currents and phase window \( \Delta T \), the jitter phase was found at any rotation rate not to exceed \( \pm 1 \mu s \).

### 3 Time Scale Calibration of TOF Spectrometer

Since the chopper has two diametrically opposite curved slots, thus two bursts of polyenergetic neutron are produced per revolution. Accordingly the precise coincidence of the zero TOF moments of both neutron bursts are essential for the time scale calibration.

However, due to the limited accuracy of positioning of the mirror w.r.t. the rotor axis, such coincidence within high accuracy can not be achieved. Moreover the two optical devices may be not aligned diematically opposite, consequently the angular velocity of the rotor will depend upon its rotation direction for the same preselected time period \( T_{ph} \).

Recently, Habib et al.\(^7\) reported a simple method for time scale calibration of TOF spectrometer having only one rotor. As shown above that for the synchronization of two rotors, the first one is considered as a leader, while the second as a follower. Moreover the logic pulse (I-I (0.5 \( \mu s \) duration) of the leader rotor is considered as the zero start moment of the time scale. While the zero TOF may be not coincidence the zero start moment of the time scale. While the zero TOF may be not coincidence with that moment. It may be advanced or delayed from that moment, depending upon the relative position of the optical devices w.r.t neutron beam direction.
Following Habib, let the angle between the optical devices 1-1 and 1-2 of the first rotor in clockwise direction is \( \pi + \delta \theta_1 \) and the angle which makes 1-1 with the perpendicular to the rotor's axis is \( \delta \theta_1 \). Fig. 2 presents the schematic diagram of the two rotors.

Thus, for a preselected time period \( T_{\text{rot}} \) at the stabilization rotation unit of the first rotor, its rotation rate in clockwise direction \( f_1 \) and anti-clockwise direction \( f_{-1} \) can be given as:

\[
2\pi f_1 (T_{\text{rot}} + \varepsilon_1) = \pi + \delta \theta_1 \\
2\pi f_{-1} (T_{\text{rot}} + \varepsilon_1) = \pi - \delta \theta_1
\]

where \( \varepsilon_1 \) is the uncompensated time due to the carry times through the flip-flops as well as the time required to stretch the control gates. Similar relation are hold for the second rotor.

The parameters \( f_1 \) and \( f_{-1} \) were measured as a number of start pulses per min at different value of \( T_{\text{rot}} \). The average value of \( \delta \theta_1 \) and \( \varepsilon_1 \) were determined at various \( T_{\text{rot}} \) and were found to be \( 1.18 \pm 0.04 \) degrees and \( 11.4 \pm 0.4 \) s respectively.

Since at synchronization the angular velocities of both rotors are the same, i.e. \( f_1 = f_{-2} \) and \( f_{-1} = f_{-2} \), the following relation is hold for the second rotor:

\[
2\pi f_{-1} (T_{\text{rot}} + \varepsilon_2) = \pi + \delta \theta_2 \\
2\pi f_{-2} (T_{\text{rot}} + \varepsilon_2) = \pi - \delta \theta_2
\]

Thus at any preselected rotation rate of the first rotor \( f_1 \) the following relation is hold for the second rotor:

\[
2\pi f_1 (T_{\text{rot}} + \varepsilon_2) = \pi + \delta \theta_2 \\
2\pi f_{-1} (T_{\text{rot}} + \varepsilon_2) = \pi - \delta \theta_2
\]

Therefore, at any two different rotation rates \( f_1 (i) \) and \( f_{-1} (j) (i \neq j) \) the values of \( \varepsilon_2 \):

\[
\varepsilon_2 = ((f_{-1} (i) T_{\text{rot}} - f_1 (i) T_{\text{rot}} (j)) / (f_1 (i) - f_{-1} (i))
\]

\[
\delta \theta_2 \approx \pi (\varepsilon_2 (f_1 (i) + f_{-1} (j)) + (f_1 (i) - f_{-1} (i) T_{\text{rot}} (i)) + f_{-1} (j) T_{\text{rot}} (i)) - 1
\]

Different values of \( T_{\text{rot}} (i) \) were selected and the corresponding values of \( f_1 \) were measured as a number of logic pulses per min. At each value of \( T_{\text{rot}} (i) \), the value of \( T_{\text{rot}} (i) \) was selected to meet the requirement of synchronization. The result of measurements as listed in Table I.

The average value of \( \varepsilon_2 \) and \( \delta \theta_2 \) were determined and found to be \( 11.5 \pm 0.3 \) s and \( 0.80 \pm 0.05 \) degree respectively.

In TOF spectrometer with multi-neutron bursts per revolution (two in our case) it is desired to achieve the coincidence between the start pulses w r t, their zero TOF moments, so the TOF spectra of the two neutron bursts could be stored in the same channel group of the
PCA (multichannel time analyzer). For such purpose a start unit was used, the specification of the unit is given in [Ref. 10].

However, as shown by Naguib, the transmitted neutron spectrum through the double rotor system depend upon the relative phase $\phi_{ph} + \delta \phi$ between them. Where $\delta \phi$ depends upon the value of $\phi_{1}$ and $\phi_{2}$. Therefore, in the present work $\delta \phi$ was determined from the peak of the distribution of the fast neutrons transmitted through the double rotor as a function of $\phi_{ph}$ [Ref. 12]. From the chopper parameters (the rotor, 32 cm in diameter having two curved slots with curvatures of 63.65 cm and $7 \times 10^{-3}$ mm$^2$ cross-sectional area) it was found that there are two straight paths at two angular ranges around the angles $\theta$ equal $5.827^\circ$ and $174.173^\circ$. The width of each range was $(0.51 \pm 0.003)$ cm, and lengths $6.675$ cm (see dashed lines Fig.2).

Following Adib the intensity of the fast neutrons $I_c(\phi)$ transmitted through the rotor can be given as:

$$I_c(\phi) = I_o \exp \left( - \mu L_c(\phi) \right)$$

where $I_o$ is the incident intensity of fast neutron per cm$^2$ sec., $\mu$ is the average fast neutron absorption coefficient, and $L_c(\phi)$ is material thickness of the rotating collimator facing the neutron beam at an angle $\phi$.

Similar equation holds for the intensity of the fast neutron $I_c(\phi)$ transmitted through the chopper rotor. Thus the intensity of the fast neutron $I_c(\phi)$ transmitted through the double rotor system can be given as:

$$I_c(\phi) = I_o \exp \left( - \mu L_c(\phi) L_r(\phi + \phi_{ph}) \right)$$

and the phase shift between the rotors $\phi_{ph}$ can be expressed as:

$$\phi_{ph} = 2 \pi f_0 (T_{ph} + \epsilon_{ph}) + \delta \phi$$

where $T_{ph}$ is the preselected time period at phase unit and $\epsilon_{ph}$ is a delay time.

The values of $L_c(\phi)$ and $L_r(\phi)$ were calculated from the rotor’s parameters is the angular range from $0$ to $2\pi$. The result of calculations $L_c(\phi)$ and $L_r(\phi)$ are displayed in Fig.3 as dashed and point dashed lines respectively. The total material thickness facing the beam at phase shift $4^\circ$ was also displayed in Fig.3 as solid line. From

- Total material thickness
- Rotating collimator
- Neutron chopper

![Fig. 3 — Total material thickness facing neutron beam](image)
Fig. 3 one can observe that at four angles the total material thickness facing the neutron beam is vanished, consequently the double rotor system becomes completely transparent to fast neutrons.

4 Result and Discussion

The fast neutron counting rate distribution was measured at the following operating condition:

\[ T_{oi} = 10854 \mu s \quad \text{i.e.} \quad f_{i1} = 2758 \text{ rpm} \quad T_{ph} = 24226 \mu s \]

Logic pulse L-1 through the start unit was delayed by 3000 \( \mu \)s, PCA operating in its MCS mode was used as multichannel time analyzer with channel time width 10 \( \mu \)s. Consequently each of its channel was equivalent to 5° of arc. Such low rotation was selected in order to improve the accuracy in determination of \( \phi_{ph} \). To remove the thermal neutron flux accompanying the fast one, a sheet of Cd of 1 mm in thickness was placed in the way of the neutron beam.

The observed experimental fast neutron distribution versus channel number is displayed in Fig. 4 as closed circles. It was found that the calculated distribution at \( \phi_{ph} = 4.57^\circ \) (solid line) fits the experimental one.

In order to determine \( \phi_{ph} \) and \( \epsilon_{ph} \), the fast neutron distribution was measured at different sitting of \( T_{ph} \). The observed position of the peaks \( P_1, P_2, P_3, P_4 \) were determined at each sitting of \( T_{ph} \) and then projected on the phase diagram. The phase diagram is the locus of the positions of the fast neutron peaks as a function of \( \phi \) and \( \phi_{ph} \). These positions were calculated as a function of \( \phi \) and \( L_r = 0 \). The deduced peak positions is displayed in Fig. 5 as solid lines. For each projected position the corresponding phase shift \( \phi_{ph} \) was deduced (dashed lines Fig. 5). It is easy to show that \( \phi_{ph} \) can be expressed as:

\[ \phi_{ph} = 2 \pi f_{ph} (T_{ph} + \epsilon_{ph}) + \delta \theta \]  

From which \( \epsilon_{ph} \) and \( \delta \theta \) can be deduced. The average values of \( \epsilon_{ph} \) and \( \delta \theta \) were determined and found to be (1.50 ± 0.02)\( \mu \)s and (2.10 ± 0.01) degree respectively.

Linearity of the time scale — The linearity of TOF time scale was checked at a rotation rate of 7272 rpm using the transmission of neutrons through polycrystalline Be. Since Be has well known Bragg cutoffs at the neutron wavelengths 3.94, 3.58 and 3.49\( \AA \) which correspond to reflections from the Be planes with Miller indices (100), (002) and (101) respectively.

Fig. 6 shows the transmission through 4cm thick Be as a function of the neutron wavelength. From the ob-

![Image](image-url)
design can be successfully applied for the proposed small angle neutron scattering spectrometer at ET-RR-2 [Ref.13].

References