

A NOVEL "DEFLECTION-BUNCHING" SYSTEM AT THE KARLSRUHE ISOCHRONOUS
CYCLOTRON USED WITH A NEUTRON TIME-OF-FLIGHT-SPECTROMETER.

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Abstract

A system^{1, 2} consisting of two coupled electrostatic deflectors and the associated electronics is described. The principle of the system is shown in fig. 1: One deflector which is located near the center of the machine is used for a two-fold purpose a) to eliminate two out of three microstructure pulses by deflection to a beam stop and b) to form ion bunches of 4,5 μsec duration each consisting of fifty microstructure pulses. A second pair of deflector plates is located at a mean radius of 39 inches and serves to simultaneously deflect the set of microstructure pulses to a target positioned above the median plane of the cyclotron. At the time of deflection, the bunch is distributed over 4 inches in radius.

Using this method neutron pulses of $1 + 0,3$ nsec duration with a repetition rate of 20 kc/sec can be produced. A neutron time-of-flight spectrometer has been put in operation using this "deflection-bunching" system.

Introduction

Time-of-flight experiments are greatly facilitated by the high average beam current and the extremely small pulse width (< 1 nsec) of the microstructure pulses from the Karlsruhe isochronous cyclotron. The recurrence frequency of 33 mc/s, however, is far too high in view of the frame overlap problems in high resolution neutron time-of-flight spectroscopy. Reducing the repetition rate by the deflection of single microstructure pulses onto a neutron producing target would be an undesirable sacrifice in neutron intensity unless a very high internal beam is available.⁺ The Karlsruhe cyclotron was designed for an average maximum internal beam of 100 μa at continuous operation.

⁺A facility has been described by Howe et al.³ in which the NRDL- cyclotron is to operate in this fashion in connection with klystron-bunching.

The system described here avoids the frame-overlap problem⁺⁺ while largely preserving the high average neutron intensity available from the internal beam. This is accomplished by the bunching-deflection system, which reduces the pulse repetition frequency from 33 mc/s to 20 kc/s while the average beam intensity is only reduced by a factor of about 30. The gain in intensity per pulse is obtained at the expense of the homogeneity of the energy of the ions striking the target. Since the neutron target will be used as a "white" neutron source, the additional energy spread introduced by the ions is of no concern.

Deflector system I

The deflector consists of two tantalum plates with an azimuthal extension of about 35°, a radial extension of 4 cm and a gap of 1 cm. The deflector is set to the 4th orbit in a hill section of the pole tip which corresponds to a deuteron energy of about 0.8 MeV.

The minimum plate voltage for complete beam deflection is 4 kV. For the suppression of two out of three ion bunches a RF voltage of 11 mc/s and a negative bias voltage are applied to the lower plate of the deflector (fig. 2a). The upper plate stays at a constant potential whereby the beam is completely suppressed except for interruptions of a length of 4.5 μsec which follow at a repetition frequency of 20 kc/s. For this time the voltage is decreased to zero and the mentioned suppression of two out of three ion bunches occurs (fig. 2b). The voltage fall time is about 150 nsec, the rise time about 300 nsec.

⁺⁺Another possibility described by Brückmann and Haase⁴ was applied using the external beam of the Karlsruhe cyclotron and a recoil-proton telescope as a neutron detector. The proton energy is measured simultaneously with the neutron time-of-flight. Evaluating both, the pulse height and the neutron time-of-flight information allows one to determine the "gross" and "fine" neutron energy and this to unscramble frame overlap over a considerable range without any pulse reduction.

The axially deflected beam completes one further revolution before reaching the water-cooled beam stop. The beam stop and the holder for the deflector plates are mounted on the coaxial line which is adjustable from outside of the vacuum tank. Fig. 3 shows the inner deflector with mykroy insulators, leads and a part of the coaxial lines.

The coaxial lines and the RF power amplifier are one unit which can be easily removed. These lines are 2.50 m long and are situated below the median plane. The coaxial line for the RF voltage consists of a silver plated copper wire (1 mm in diameter) as the inner conductor and of a copper tube with an inner diameter of 50 mm which decreases to 8 mm within the pole gap of the cyclotron. The inner volume of the tube stays under normal air pressure. At the end of the coaxial line a quartz insulator is cemented vacuum tight into the tube with epoxy resin and cooled together with the beam stop. Small teflon spacers are holding the inner conductor. The line impedances are about 235Ω and 123Ω according to the different tube diameters. The useful pole gap of the cyclotron is only 3 cm at the deflectors location and about 4 cm for the larger radii.

The block diagram of the electronic is seen on fig. 1. The RF voltage of 33 mc/s taken from cyclotron generator is changed by a frequency divider into 11 mc/s. The phase bridge controls the phase of 11 mc/s RF. It receives the control signal from the phase comparator. This comparator (ratio detector principle) compares the time position of 33 mc/s and 11 mc/s RF waves. The reference voltage of 11 mc/s comes from the power amplifier resonant circuit via a manually adjustable phase shifter. The resonance circuit of the power amplifier is tunable by a motor driven capacitor.

Rectangular pulses of a width of 4.5 μ sec with a repetition rate of 20 kc/s produced by a pulse generator are fed into a H.V. pulse amplifier and into the phasing circuit of the electronic for the outer deflector. The H.V. pulse amplifier produces the necessary pulses for the inner deflector. When the deflection voltage at the side of the H.V. pulse amplifier fails the arc voltage of the ion source will be switched off by a relay to avoid a high deuteron current falling on the target at full radius. All voltages at the deflector plates are switched off when the cyclotron tank pressure increases above a critical value to avoid glow discharge.

Proper operation of the ion rate reduction is controlled by measuring the time-of-flight of prompt γ radiation from the target. A plastic scintillator mounted on a fast photo multiplier as detector and a time-to-pulse-height converter in connection with a multichannel analyzer are used. Fig. 4a and 4b show the time-of-flight spectra under normal operation and with 3:1 ion pulse rate reduction. The converter was started by the detector pulse and stopped by the 11 mc/s RF. Fig. 4c shows a set of about 50 microstructure ion bunches due to the complete ion pulse rate

reduction. In this measurement the converter was started by the correlated trigger pulse for the fast H.V. pulse generator.

Deflector System II

The outer deflection plates are made of 2mm thick aluminium and extend between radii of 37 and 41 inches. The ion bunch is deflected at a mean radius of 39 inches corresponding to a deuteron energy of 45 ± 5 MeV. The two plates are separated by a distance of 16 mm and subtend ~ 0.23 rad of arc as indicated in fig. 1. A photograph of the deflector plate assembly and the mounting flange of the vacuum chamber is shown in fig. 5. The bottom plate is grounded. Voltage is applied to the upper plate which is mounted on three mykroy insulators, 10 mm thick and 100 mm in length. Both plates are movable by swivel-mounted aluminium bars, so they can be adjusted from outside the vacuum chamber in height and angle to the pole tips. The deflection pulse is coupled to the top plate by a copper conductor which is insulated from the flange of the vacuum chamber using a kovar-glass seal.

A neutron producing target 10 cm wide and 1 cm in height, thick enough to stop 50 MeV deuterons, can be positioned by a pneumatically operated target support directly above the entrance to the deflector plates. This position represents the point of maximum deflection. Measurements of the voltage needed to deflect the entire beam onto the target showed that a value of 5 kV was sufficient.

For the deflector-plate pulser a type EGG 1802 hydrogen thyatron is used. The pulse generator operating as a hard tube pulser delivers a 5 - 8 kV pulse of about 400 A pulse current which is necessary to charge the 600 μ F capacitance of the deflector plates with a risetime of 25 nsec. The mean power required is 5 kw. The H.V. pulse-generator circuit is shown schematically in fig. 6. A power supply charges a 500 μ F condenser via a 1 Hy inductance and a 2 - 450 D diode. A suitable trigger pulse is applied to the grid. The H.V. pulse from the anode of the thyatron is fed directly into two cables, 50 m in length, connected to the deflector plates.

Difficulty was experienced in compensating the long term drift generally introduced by hydrogen thyatrons which is at maximum about 150 nsec. The drift was compensated by a regulated variable delay line. This compensation unit operates on the following principle: It is desired to hold the transit time through the pulser-delay unit to a constant. The compensation unit consists of a simple regulation system in which the variable delay line contains constant capacitances and variable inductances. The resulting time delay from the variable delay line and the hard tube pulser is measured by a time-to-pulse height converter. A conversion of the pulse height into a proportional d-c current which is compared with an equilibrium value permits the premagnetization of small magnetic cores. On each core there is a second winding which serves as one

inductance of a low-pass delay network. With this technique a time jitter less than 1 nsec is obtained over periods of days.

Phasing circuit

If the deflected beam is to produce only one single burst of neutrons, all the ions must hit the target during the same revolution cycle. That means that the deflection pulse should be applied at a time defined by the following conditions:

a) The ion bunch must have reached such a radius that all ions from the bunch pass between the plates of the deflector II during each revolution. b) The deflection pulse must rise from zero to its full amplitude during that time of the revolution cycle in which the bunch is completely outside the deflector plates.

The orbital period of the ions is 90 nsec, the azimuthal extent of the deflector is equivalent to 12 nsec, and the effective length of the bunch (~ 1 nsec) is negligible in comparison. Consequently the time available for applying the deflection pulse should be $\lesssim 75$ nsec.

A circuit used to meet both requirements is shown schematically in fig. 7. The principle is based mainly on a circuit developed at Harwell by Langsford et al.⁵. The output pulse from the 20- kc/s pulse-generator (see fig. 1) is delayed by 21 μ sec, the time required to accelerate the ion bunch from zero to 50 MeV. To obtain a suitable time correlation between a fixed RF-phase and the output pulse of this circuit, the RF from the cyclotron is gated by the delayed pulse from the 20 kc/s generator. The timing is arranged so that only a set of eight pulses can pass the gate after being shaped by an appropriate tunnel diode pulse shaper. The fourth pulse of the group is selected by 3 binaries. This enables the elimination of the time jitter introduced by the finite rise time of the gate pulse. The output pulse is used to trigger the high voltage pulse generator. Because of the finite rise time of the gate pulse additionally there is a nonzero probability that either 7 or 9 RF-pulses pass the gate. If the flip-flops of the binaries are not reset after a pulse group has been accepted, two output pulses can appear that give rise to incorrect timing. To avoid this problem an additional reset signal is produced from the delay unit of the phasing circuit. Using this pulse all the flip-flops are reset after one output signal has been delivered.

Neutron Time-of-Flight Spectrometer

The overall layout of the spectrometer is shown in fig. 8. A thick natural uranium target is used for production of a "white" neutron spectrum

(a typical time-of-flight spectrum is presented in fig. 9a). There are two collimators along the flight path defining a narrow neutron beam with an angle spread of $\sim 0,5^\circ$. The neutrons are detected with a liquid proton recoil detector at the end of an evacuated flight path, 50 m in length. For neutron time-of-flight measurements a digital time-sorter with a maximum of 32.000 channels and 1 nsec channel width was employed. The output signals were transferred to the MIDAS data-acquisition system at the Karlsruhe FR-2 reactor and accumulated on-line in a 16 k-memory block. The operation of the system was controlled simultaneously at the cyclotron building by means of a live display. The energy resolution of the spectrometer was determined by measuring the resonances of Fe^{56} near 512 keV and 530 keV respectively. For each energy there are two closely spaced resonances as Newson⁶ has demonstrated. The two resonances at ~ 512 keV were well resolved in our first transmission measurements. These two resonances are shown in fig. 9b. The data are not corrected for time dependent background. From a calculation of the maximum resonance cross section a resolution of about 200 eV for this energy was obtained assuming the higher energy resonance to be a s-wave resonance. The characteristic features of the spectrometer are summarized in table I. Time resolution of the spectrometer is expressed in nsec/m as usual for neutron time-of-flight facilities.

References

1. B. Duelli, G. Ries, European Colloquium on AVF cyclotrons, Eindhoven, April 1965
2. S. Cierjacks, K.H. Beckurts, Intern. Conf. on the Study of Nuclear Structure with Neutrons, Antwerp, July 1965
3. H.A. Howe, A. Svanheden, M. Reiser, IEEE Trans. on Nucl. Sci. 12 No. 3, 512 (1965)
4. H. Brückmann, E.L. Haase, Intern. Conf. on the Study of Nuclear Structure with Neutrons, Antwerp, July 1965
5. A. Langsford, D.E. Dolley, G.B. Huxtable, Nucl. Instr. Meth. 33, 57 (1965)
6. H. Newson, Rapport at the Intern. Conf. on the Study of Nuclear Structure with Neutrons, Antwerp, July 1965

TABLE I
TIME-OF-FLIGHT APPARATUS

Flight path	56 - 57 m
Deflection radius	0,930 m (40,5 MeV deuterons) to 1,030 m (50 MeV deuterons)
Time resolution	$(1 \pm 0,3)$ ns full width half maximum
Energy resolution	200 eV at 0.5 MeV
Resolution of Spectrometer	0,02 nsec/m
Integrated neutron flux at 3 μ A target current	$(5 \pm 2) \cdot 10^4$ neutrons $\text{cm}^{-2} \text{sec}^{-1}$ above 250 keV at 56 m

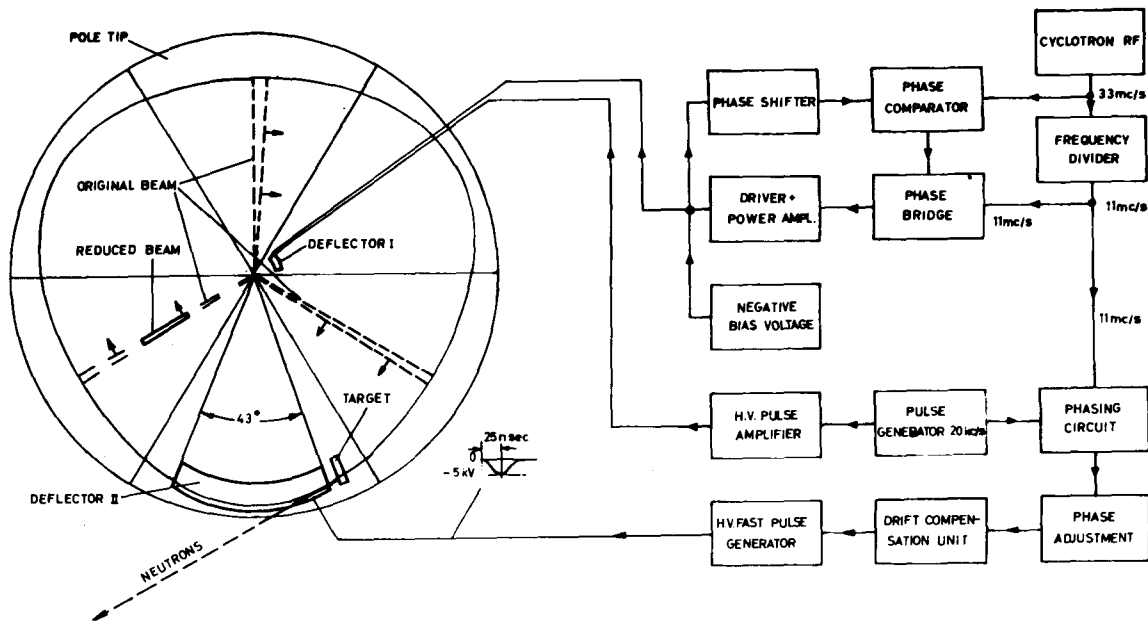


Fig. 1. Scheme of deflection-bunching system

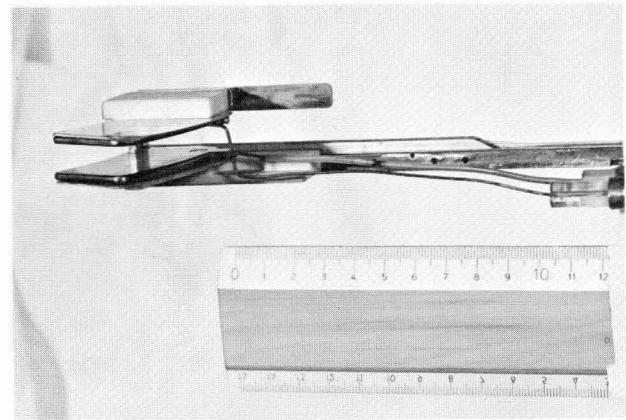
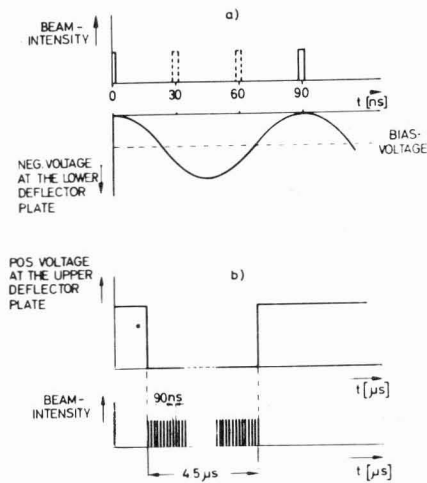


Fig. 2. Voltages at the deflector plates illustrating the principle of beam suppression
 a) elimination of two out of three ion bunches.
 b) production of 4.5 μ s pulses.

Fig. 3. View of the deflector-system I

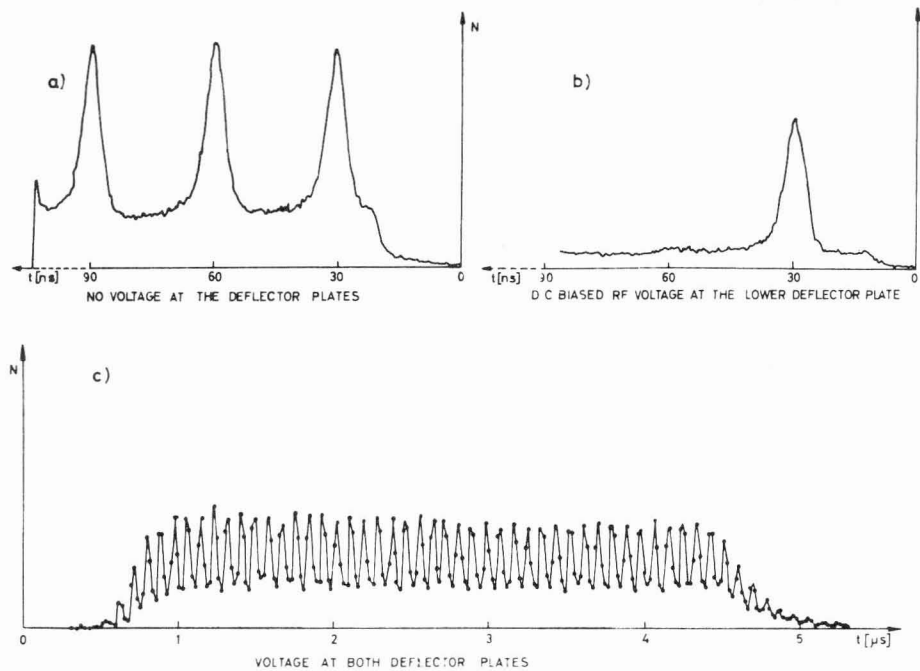


Fig. 4. Time-of-flight spectrum of prompt γ - rays representing particle bunches
 a) Under normal operation
 b) With 3:1 ion pulserate reduction
 c) Complete reduction to a bunch containing 50 microstructure ion pulses

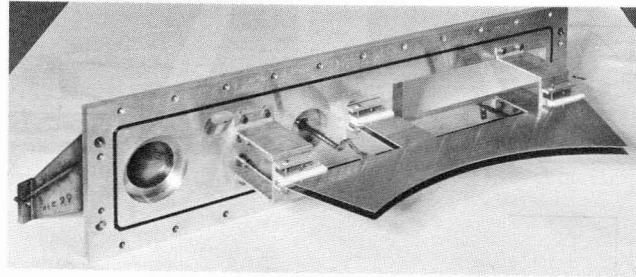


Fig. 5. View of the deflector-system II

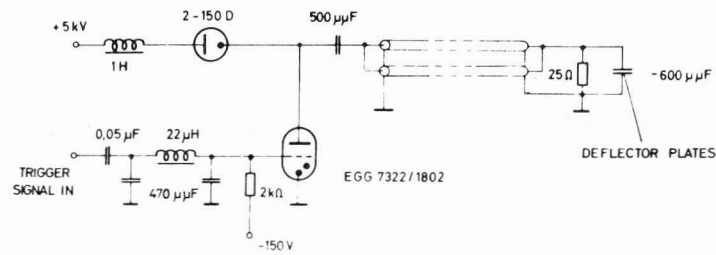


Fig. 6. H.V. fast pulse generator

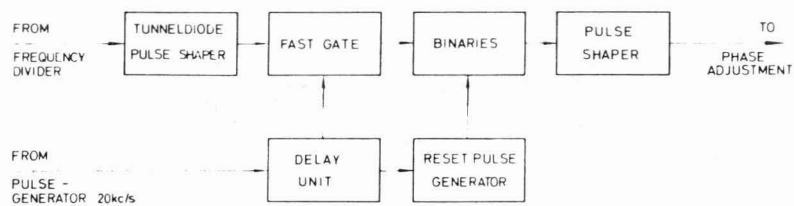


Fig. 7. Block diagram of phasing circuit

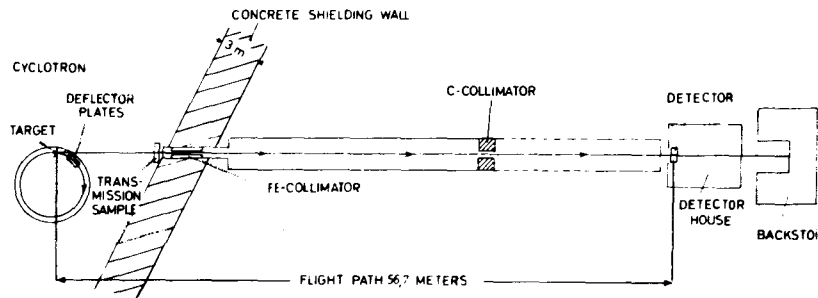


Fig. 8. Geometry of the Karlsruhe isochronous cyclotron neutron time-of-flight spectrometer (top view)

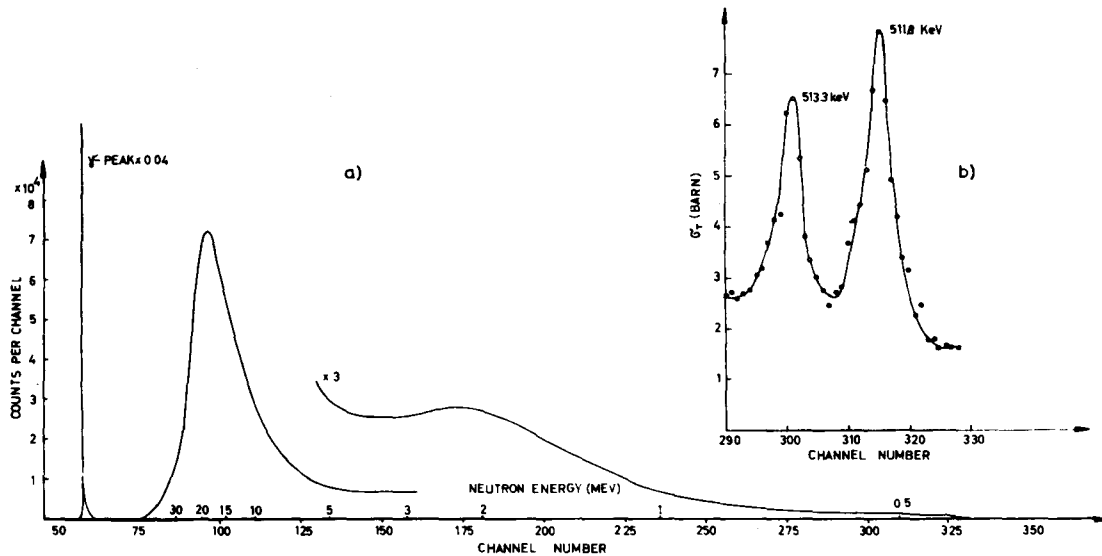


Fig. 9. a) Typical neutron time-of-flight spectrum
 b) σ_T for natural iron in the 510 keV region