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INTENSITY FLUCTUATIONS OF CYCLOTRON MICROSTRUCTURE BEAM PULSES

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Measurements of the intensity distribution of microstructure beam pulses from an isochronous cyclotron are described. Typical intensity distributions result in an increase of the chance coincidence rate of coincidence experiments by a factor of 2 over the ideal case of equally sized bursts. Among other factors stray frequencies in the rf may contribute to these intensity fluctuations.

1. Introduction

In all experiments involving the measurement of time coincident events a knowledge of the rate of accidental events is required. The inherent bunching of a cyclotron beam by the accelerating rf complicates coincidence measurements with resolving times in the range of the burst length. If the assumption is made that all single microstructure beam pulses have the same shape in time and comprise the same number of particles the rate of chance coincidences can be calculated[1]). In the Karlsruhe Isochronous Cyclotron, however, we observed an appreciable variation of intensity in the single beam pulses. The purpose of this paper is to describe measuring methods of the intensity spectrum and to estimate their influence on chance coincidences and the time required for an experiment.

2. Accidental coincidences in the case of intensity fluctuations of microstructure beam pulses

Let I_k be the intensity of the k^{th} pulse arriving at the target, and let the coincidence resolving time be larger than the pulse length and smaller than the pulse distance. The mean number of counts in each of two detectors due to a pulse of intensity I_k will be

$$N_{1k} = c_1 I_k,$$
$$N_{2k} = c_2 I_k, \tag{1}$$

where c_1 and c_2 are constants involving parameters of the detectors and of the nuclear experiment to be studied. Then the mean number of chance coincidences N_{ch} can be expressed in the form

$$N_{\text{ch}k} = c_1 c_2 I_k^2. \tag{2}$$

The total number of chance coincidence for n cyclotron pulses is

$$N_{\text{ch}} = c_1 \cdot c_2 \sum_{k=1}^{n} I_k^2. \tag{3}$$

For a normalized intensity distribution $h(I)$ the chance coincidences are given by

$$N_{\text{ch}} = c_1 c_2 \int_0^\infty h(I) I^2 \, \mathrm{d}I. \tag{4}$$

If all pulses have the same intensity I_0,

$$h(I) = \delta(I - I_0),$$
$$N_{\text{ch}0} = c_1 c_2 I_0^2. \tag{5}$$

This corresponds to the well known expression of chance coincidences for a beam without structure in which the particles are spaced randomly in time.

For a given mean current

$$\bar{I} = \int_0^\infty h(I) I \, \mathrm{d}I, \tag{6}$$

chance coincidences attain a minimum when all pulses have the same intensity, i.e. when $h(I) = \delta(I - \bar{I})$. This results in a minimum of machine time required for an experiment if the mean current is limited by the rate of accidental coincidences.

3. Measurement of the intensity distribution

3.1. Targets

For measuring the intensity of single microstructure bursts fast targets for current measurement are required (time constants of the order of a few nsec). Several such targets have been built. Two targets which may be used for measurements on the internal beam at different current levels have been described in detail in a previous publication[2]). The Faraday cups normally used for measurements on the external beam were not suited for this application as they have a capacity of a few nF with respect to ground. Therefore a special beam stop was developed which is shown in fig. 1. The capacity is about 20 pF, and with a 50 Ω terminator a time constant of 1 nsec is obtained. It should be mentioned, that there is no secondary electron shield around this probe. This results in an increase of 20% of the measured current as compared with the incident particle current.

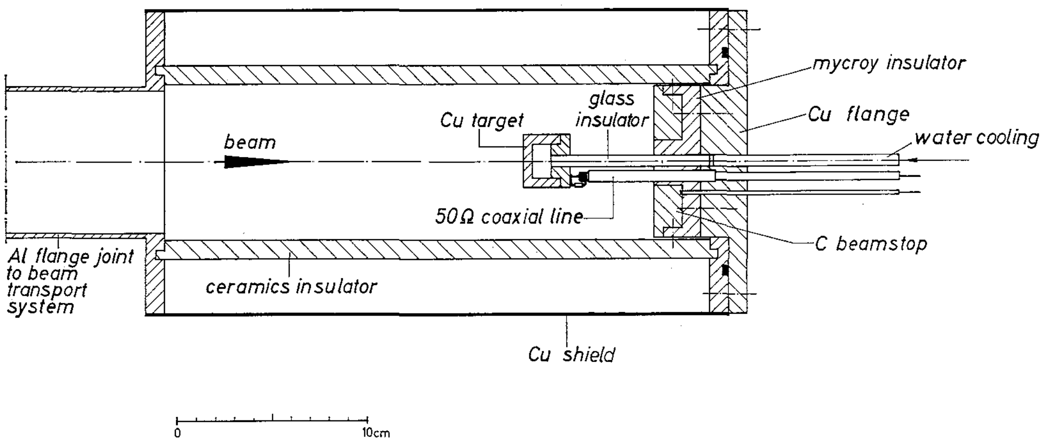

Fig. 1. A schematic drawing of the Faraday cup with a time constant of 1 nsec.

3.2. ELECTRONIC SYSTEMS AND RESULTS

The fast pulses from the targets occur at a rate of 33 MHz. Fig. 2 shows the electronic system used to process these pulses with a conventional pulse height analyser. First of all the repetition rate of the target pulses is decreased to 3.3 kHz using a frequency divider and a fast linear gate. The output of the linear gate is fed through a pulse stretcher to a multichannel pulse height analyser.

In some measurements the signal to noise ratio was improved without increasing the thermal load of the target by pulsing the ion source. It is then necessary to introduce an additional gating condition to avoid processing pulses during the rise and decay times of the current pulse. This is achieved by the circuit shown in the lower part of fig. 2. This part of the circuit is not used when the ion source is operated in steady state condition.

Measurements were performed at different current levels for deuterons and alpha particles on the internal and external beams. In all measurements the width of the intensity distribution was comparable to the mean

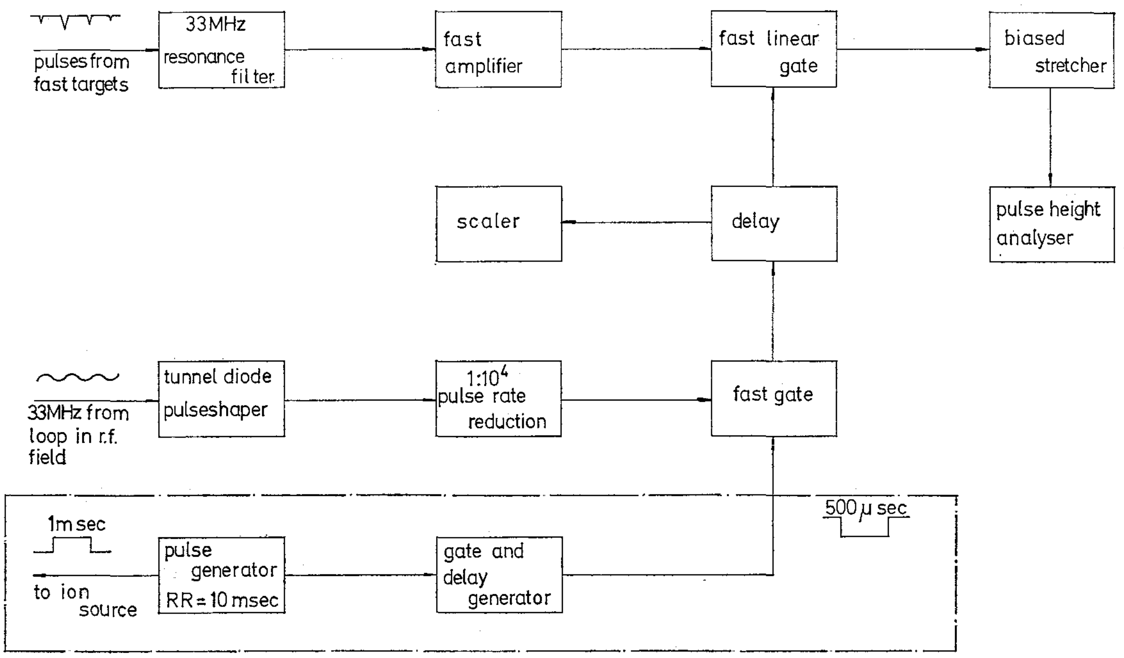

Fig. 2. Block diagram of electronics for analysing single beam pulses.

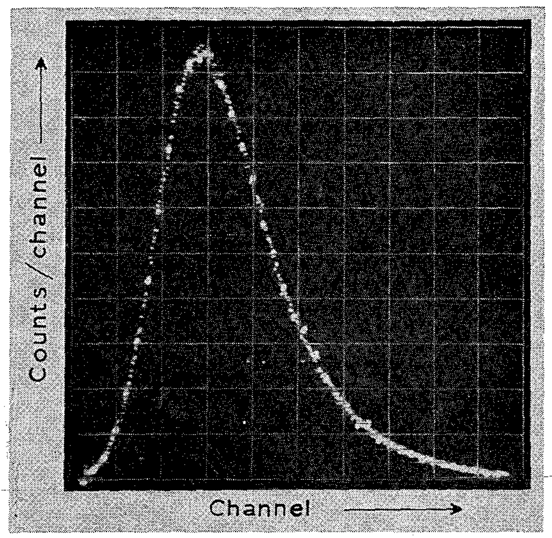

Fig. 3. Typical distribution of the single microstructure beam pulses obtained with the fast Faraday cup and α-particles at a pulse current of 30 μA.

value. A typical intensity distribution is shown in fig. 3. It was obtained with the external alpha particle beam with the ion source pulsed at a pulse current of 30 μA.

3.3. Increase of chance coincidence rate due to the observed intensity distribution

In order to calculate the rate of chance coincidences due to the observed intensity distribution by means of the formulae derived in section 2 the measured distribution was approximated by an analytical expression. The best fits were obtained by curves which represent a truncated exponential folded with a Gaussian distribution

$$h(I) = \{\sigma(2\pi)^{\frac{1}{2}}\}^{-1}\int_{-\infty}^{I_1} (N/|\varepsilon|)\exp\{(x-I_1)/\varepsilon\}\cdot \cdot\exp[-\tfrac{1}{2}(I-x)^2/\sigma^2]\mathrm{d}x, \qquad I \leqq I_1,$$

$$h(I) = \{\sigma(2\pi)^{\frac{1}{2}}\}^{-1}\int_{I_1}^{\infty} (N/|\varepsilon|)\exp\{(x-I_1)/\varepsilon\}\cdot \cdot\exp[-\tfrac{1}{2}(I-x)^2/\sigma^2]\mathrm{d}x, \qquad I \geqq I_1.$$

(This type of function was tried as a least-squares fitting program existed at this laboratory for the analysis of Ge(Li) γ ray spectra). In fig. 4 the measured and fitted distributions are shown. At the same mean intensity the chance coincidence rate is higher by a factor of 2.04 for the measured intensity distribution as compared with a δ-function distribution.

4. Measurements on the time correlation of the intensity

Time correlations of the intensity fluctuations are important if chance coincidences are measured by delaying one of the pulses by an integral number of rf periods. As will be shown they can also give information on the processes which cause the intensity fluctuations.

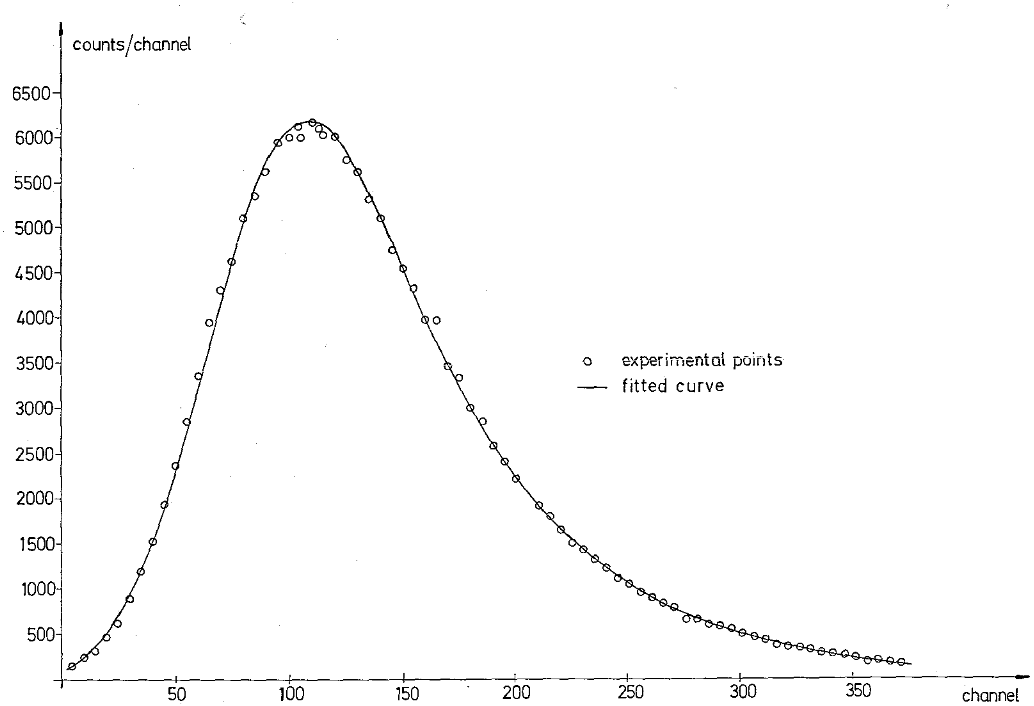

Fig. 4. Measured and fitted pulse height distributions.

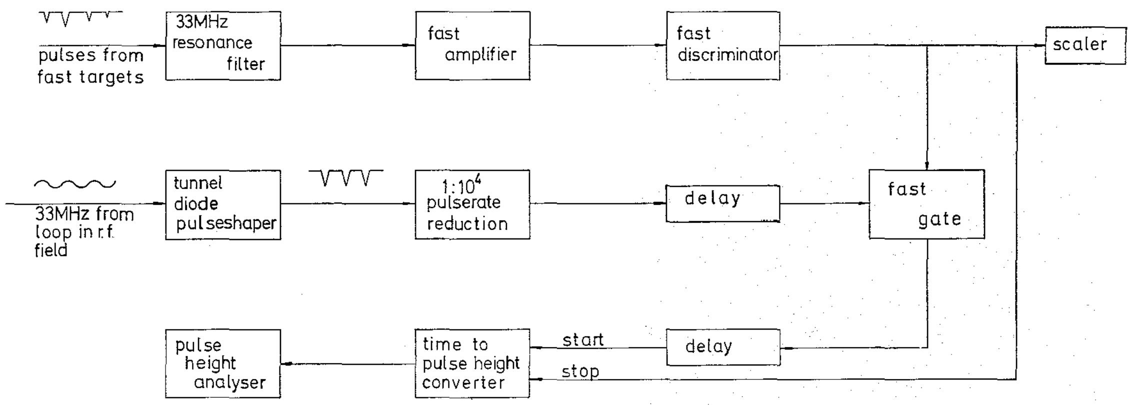

Fig. 5. Block diagram of electronics for time correlation measurements.

4.1. Time intervals between successive beam pulses above a given threshold

One method of investigating time correlations of the intensity of single pulses is to measure the distance in time of pulses which are large enough to overcome a certain threshold. This distance is, of course, always an integer multiple of the rf period τ. Let P be the fraction of all pulses which exceed the threshold. If the intensities of different rf bursts are uncorrelated the probability of measuring a distance of $n \cdot \tau$ is given by

$$W_n = P(1-P)^{n-1}, \qquad (n \geqq 1). \tag{7}$$

Any time correlation, as might be caused, e.g., by a periodic change of the intensity, would result in a deviation from this dependence.

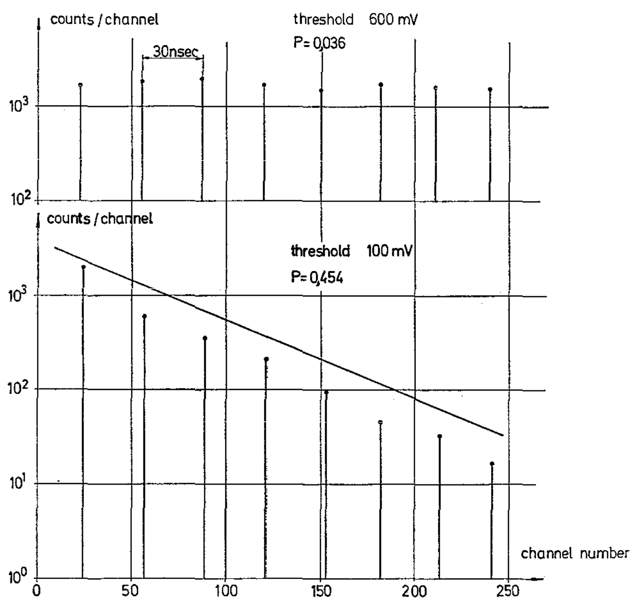

Fig. 6. Spectrum of time intervals between two successive pulses above a given threshold. The data were taken at a mean deuteron current of 1 nA.

Fig. 5 represents the block diagram of the electronics used to measure the distribution of time distances. The threshold is defined by a fast discriminator. The time to amplitude converter has the feature to be internally gated by the start input circuit to accept only stop pulses following a valid start signal. The start pulse is delayed by a fraction of a rf period such that one pulse can only trigger either the start or the stop input. In order to reduce the rate of start signals the start pulses are gated at a suitable pulse rate produced by a frequency divider from the cyclotron rf.

Some results of these measurements are shown in figs. 6 and 7. As expected the output spectrum of the time to amplitude converter consists of equally spaced lines with a distance corresponding to 30 nsec. The results of fig. 6 were obtained with the plastic target[2]) on the internal beam at a current of 1 nA. The straight line in the lower part of fig. 6 represents the decrease of the maxima expected from eq. (7) using the independently measured value of P. The excellent agreement of the slopes indicates that the intensities of different microstructure bursts are uncorrelated.

An entirely different situation is displayed by the measurements of fig. 7. Here the fast high current target[2]) was used at an internal deuteron current of 10 μA. The spectrum shows periodic intensity fluctuations at approximately 11 and 1.1 MHz. Similar time correlations habe been measured at quite different levels of current. It was unfortunately not possible to correlate the presence or absence of these correlations with the operating conditions of the ion source or other components of the machine.

4.2. Measurement of radiofrequency distribution in the central region

While the 1.1 MHz modulation of the beam intensity can be attributed to plasma oscillations in the ion

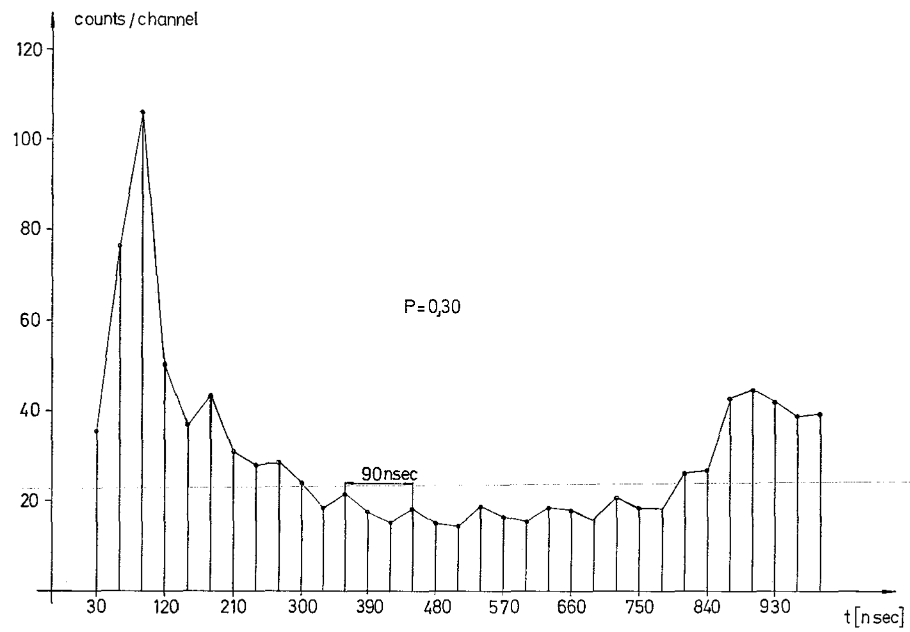

Fig. 7. Spectrum of time intervals between two successive pulses above a given threshold. The data were taken at a mean deuteron current of 10 μA.

source the observed frequency of 11 MHz appears to be too high for such oscillations. On the other hand, intensity modulations at this frequency were observed frequently. As a possible explanation it was proposed that this might be due to a 11 MHz component superimposed on the accelerating 33 MHz rf. As the first one and a half orbits of the Karlsruhe Isochronous Cyclotron are defined by a large number of slits[3]) the intensity of the beam depends very sensitively on the rf amplitude. This might result in an intensity modulation of the observed structure if a 11 MHz component were present in the rf field. To test this conjecture the radiofrequency distribution near machine center was measured. In order to avoid any change of the centre geometry a dummy ion source was built with a small pick up electrode at the position of the centre of the ion source extraction slit. Fig. 8 shows a photograph of this dummy source. The voltage from the pick up electrode was analysed using a selective microvoltmeter (Rhode und Schwarz type USVH-BN-1521) in the frequency range from 10 kHz to 10 MHz and a spectrum analyser (Tektronix type 1 L 20) in the frequency range from 10 MHz to 200 MHz. In order to avoid sparking it was necessary to reduce the rf amplitude by a factor of approximately 2.5 with respect to the value in normal machine operation. The results of these measurements are shown in fig. 9. Besides the basic frequency of 33 MHz and its harmonics at least 9 different frequencies can be detected, including a small contribution at 11 MHz. It should be pointed out, though, that the capacitive type of coupling employed tends to enhance the higher freqencies. It is known that the rf system of the cyclotron has a second characteristic frequency at 38 MHz which might also explain the presence of the 71 MHz oscillation. The origin of the other frequencies

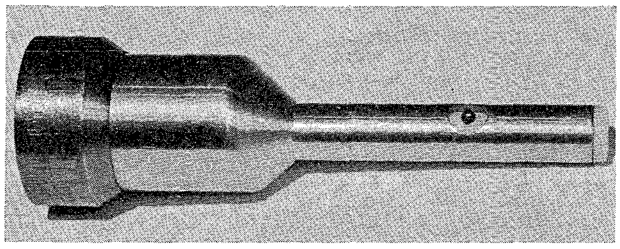

Fig. 8. Dummy ion source with pick up electrode.

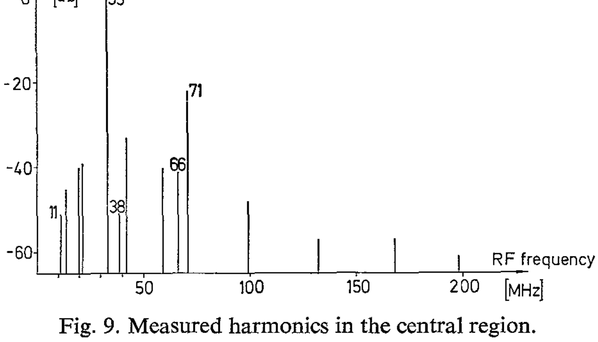

Fig. 9. Measured harmonics in the central region.

(excepting the harmonics) is unknown. In spite of the low level of the 11 MHz rf field present it is proposed as a tentative explanation of the intensity modulation observed at this frequency. Of course, the influence of these stray frequencies upon the acceleration process does not only depend on the amplitude, but also on the phase with respect to the main frequency which was not measured.

5. Discussion

The measurements reported in this paper have shown that the intensity of single microstructure bursts may fluctuate considerably more than the average current from a cyclotron. These fluctuations may have an appreciable influence on chance coincidences in coincidence experiments. Among the causes known to be present are instabilities of the ion source power supplies and oscillations in the ion source plasma. An additional factor is given by stray frequencies in the accelerating rf. The latter which may be a special feature of the Karlsruhe Isochronous Cyclotron due to its special centre design results in time correlations in the intensity fluctuations. These correlations become important if chance coincidences are measured simultaneously with real coincidences by delaying one of the signals by a fixed number of rf periods.

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References

[1] A. Z. Hrynkiewicz, S. Kopta, S. Szymczyk and P. Wolszak, Nucl. Instr. and Meth. **49** (1967) 229.

[2] D. Hartwig, W. Linder, M. E. Lösel, G. Schatz and H. Schweickert, KFK 754 (1968).

[3] M. Reiser, Nucl. Instr. and Meth. **13** (1961) 55.