THE SCINTILLATION PSD JULIOS AND ITS USE IN TOF-DIFFRACTOMETRY AT ISIS

W. Schäfer, E. Jansen, A. Szepesvary, R. Skowronek, G. Will
Mineralogisches Institut, Universität Bonn, Poppelsdorfer Schloß,
D-53115 Bonn, Germany

and

R. Reinartz, K.D. Müller
Zentrallabor für Elektronik, Forschungszentrum (KFA), Postfach 1913,
D-52425 Jülich, Germany

Abstract

JULIOS is a plane linear position-sensitive neutron detector based on a modified Anger technology and aimed at applications in time-of-flight experiments at pulsed spallation sources. Three versions differing by the type of photomultipliers used are developed: (1) standard version of 680 x 25 mm^2 sensitive area and 2.3 mm spatial resolution, (2) small version of 200 x 20 mm^2 size and 1.0 mm resolution, and (3) large version of 940 x 75 mm^2 size and 3.5 mm resolution; resolution values are based on the light output of 1 mm ^{6}Li glass scintillator. The use of other neutron scintillators like ^{6}LiI(Eu) and ^{6}LiF/ZnS;Ag is discussed.

Concept and design of the JULIOS electronics including provisions for long-term stability of the detector, and high resolution timing modules to synchronize detector activities with the time structure of the neutron source, are described. Events are registered in 32 bit data words containing 12 bit position and 16 bit time information each. The detector can be operated as a standalone system controlled by an EISA-bus PC with the memory under the control of a 28 bit increment module; alternatively, it can be connected to the ISIS DAE.

The detector was tested under ISIS conditons in white beam angular dispersive time-of-flight diffractometry. A permanent installation of a JULIOS diffractometer at ISIS aimed at crystallographic and magnetic structure and texture research is envisaged.

Introduction

JULIOS stands for 'JUelicher LInear Ortsauflösender Szintillationsdetektor'; it is a linear position-sensitive scintillation detector and it operates on the basis of a modified Anger technology [1]. In standard configuration, Li-6 scintillator glass is used as neutron absorber. The solid state absorber implies a rather thin detection zone of only 1 mm depth and simultaneously high sensitivity over the thermal wavelength spectrum. The scintillation detector is specially suited for applications in time-of-flight (TOF) technology at pulsed spallation sources. The JULIOS development had been started in Jülich originally in connection with the SNQ spallation source project. Design and construction were performed in collaboration between KFA Jülich and Bonn University.

In the meantime, eight JULIOS detector units have been built or are under construction for installation at conventional powder and texture diffractometers at steady state neutron sources. Besides the standard detector configuration we have developed two more types devoted for high resolution or high intensity application, respectively; the corresponding physical characteristics will be given in the next chapter. There is now a ten years experience with JULIOS in routine operation at the University Bonn service instruments at the FRJ-2 in Jülich (see [2] to [5]).

In 1990, an additional timer unit has been added to the JULIOS electronics, in order to run the position-sensitive detector also in a time resolved mode as a standalone system. We have performed test measurements in TOF technique under spallation source conditions at ISIS [6]. First results from d-spacing patterns obtained with JULIOS in a short term experimental setup at the testbeam facility at ISIS have been reported in [7]. Those results encouraged us to do further experiments at ISIS with JULIOS positioned in forward-, 90°- and backscattering diffraction geometry. These measurements were done in 1992 at TEST and ROTAX instrument positions. The ROTAX spectrometer at ISIS [8] being currently under commissioning, is equipped with one unit of the JULIOS PSD; test results of ROTAX are reported in a separate paper during this conference by H. Tietze-Jaensch et al. [9].

JULIOS installations at both a steady state reactor and a pulsed spallation source were used for a direct comparison of the efficiency of conventional diffractometry with monochromatic neutrons and of TOF diffractometry with the sample positioned in the primary white beam, respectively [10]. Angle dispersive TOF-diffraction in a pulsed beam is an efficient technology to exploit the thermal neutron spectrum. In constant wavelength diffraction at a continuous source, monochromatization reduces the utilization rate of the thermal neutron beam to about one percent. The PSD can only serve for an optimum detection of this small fraction. In pulsed white beam TOF-diffractometry, however, principally the total thermal spectrum can be used simultaneously; and the crucial element for the potential of the diffractometer is the PSD-system and its electronic ability for high resolution time encoding and count rate capability.

JULIOS construction

Neutrons are absorbed via the ^{6}Li(n;α)-reaction in a transparent ^{6}Li containing solid state scintillator of about 1 mm thickness. Photons emitted by each capture event are transmitted and confined into a cone inside a plane rectangular light disperser, which is arranged behind the scintillator and in front of the photocathodes of a linear row of 24 photomultipliers (PM) (Fig. 1).

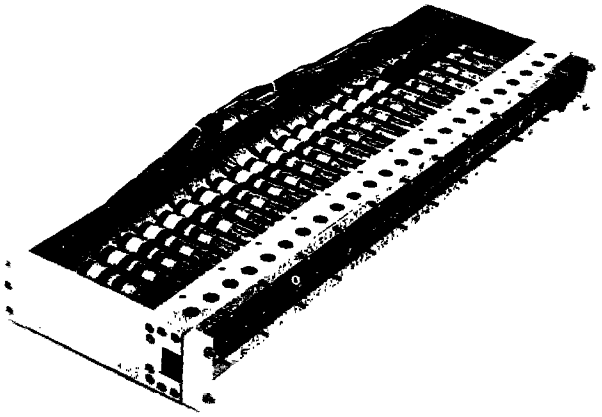

Fig. 1: JULIOS detector head (without light-proof box) in its standard version

The position analysis of an absorbed neutron is based on the determination of the light distribution on three adjacent PMs; for physical and constructive details see [1] and [2]. The digitized PM signals are processed in a dedicated hardwired computer to calculate the final position by means of special lookup tables; for electronical details see [3] and [11]. The spatial resolution of the detector is limited due to the statistics in distributing light on the PMs and in the light-to-photoelectron conversion. While the conversion rate is an intrinsic property of the PMs, the statistics of light distribution can be influenced by the total light output of the neutron scintillator and by the size of PM cathodes and suitable dimensions of the disperser. Model calculations were performed by Schelten and Kurz [12] to optmize the resolution function of the detector. The shape of the resolution function can be described by a gaussian function. The spatial resolution is given by the full width at half maximum (FWHM) according to the empirical formula

$$\mathrm{FWHM} = c \frac{a}{\sqrt{N}} \qquad (1)$$

where N is the total number of photoelectrons per capture event and a is the linear size, i.e. the separation of the adjacent PMs; c is a constant (see also [13]).

Neutron scintillators

The total number of photoelectrons depends strongly on the light output of the scintillator. By default, the JULIOS detector is equipped with ^{6}Li scintillator glass manufactured by Levy Hill Ltd. For details of ^{6}Li scintillating glasses we refer to papers of A.R. Spowart [14,15]. The glass thickness used in the JULIOS detector is 1.0 mm with absorption efficiencies of about 65% and 85% for 1 Å and 2 Å neutrons respectively. The Ce doped ^{6}Li glass creates about 4000 photons of 400 nm wavelength per neutron capture event and at least 200 photoelectrons are finally generated in the photocathode of the PM. Based on these values the linear spatial resolution of the JULIOS detector can be roughly estimated to about one tenth of the diameter of the PM tubes. This is in fair agreement with experimental results of 2.3 mm spatial resolution for the standard JULIOS unit, which is equipped with cylindrical PMs of 28 mm cathode diameter.

In the pulse height spectrum of ^{6}Li-glass, there is a certain overlap of neutron pulses with gamma pulses. A gamma quantum, which is absorbed by photoeffect in the interior of the scintillator, produces the same amount of light, provided it has an energy of more than 1 MeV. Although the JULIOS electronics (see next chapter) provides for pulse height discrimination, a rest gamma sensitivity of about 2×10^{-4} has been measured for the ^{6}Li glass. It should be mentioned, however, that the gamma sensitivity depends strongly on the purity of the scintillator glass as was experimentally shown on the example of the KG- and GS-type glasses [3]. Other neutron scintillator materials are desirable with respect to higher light output and improved gamma discrimination. By comparison, the light output of the neutron glass scintillator ammounts to only 2% of the light output of a NaI(Tl) crystal for gamma rays. There are two other neutron scintillators, which have been and are being tested with the JULIOS detector.

One is ^{6}LiI(Eu). The light output for neutrons was found to be twelve times larger with single crystalline ^{6}LiI than with ^{6}Li-glass; therefore a $\sqrt{12}$ better resolution is achieved. Another advantage of ^{6}LiI is that this detector is practically insensitive to gamma rays of energy below 3.5 MeV due to more favourable conditions in the pulse height spectrum [16]. However, ^{6}LiI is highly hygroscopic and therefore encapsulation is required. We have built a JULIOS prototype detector with an encapsulated ^{6}LiI single crystal scintillator produced by Harshaw. Technical details are described in [11]. A spatial resolution of 0.5 mm was measured. Due to its difficult technical handling the use of ^{6}LiI is restricted to detector dimensions of about 100 mm.

^{6}LiF/ZnS;Ag is another neutron scintillator of rather simple technical handling and without any size restrictions for the detector. ^{6}LiF-ZnS;Ag is known for a much higher light production during the scintillation process compared to ^{6}Li glass. The problem here is the reduced transparency of the material in getting the light out. In the very beginning of the JULIOS development we did comparative tests with both the ^{6}LiF/ZnS;Ag and ^{6}Li glass scintillators with the result of a poorer photoelectron production by a factor of 10 in the case of ^{6}LiF/ZnS;Ag. Encouraged by different experiences in the scintillation detector development at RAL more recently [17], we are about to do new tests with the JULIOS detector using ^{6}LiF/ZnS;Ag sheets of 0.1, 0.4 and 0.6 mm thickness. It is an essential advantage of the JULIOS construction that the scintillator material can be exchanged very easily.

Different types of photomultipliers

Besides the neutron scintillator the characteristic properties of the JULIOS detector are determined by the photomultipliers. Three different types of JULIOS have been constructed (Table 1). They differ by the PM tubes installed in the detector head (Fig. 2). Position resolution and size of sensitive detector window depend on the size of PM photocathodes. Development started with PMs of circular photocathodes of 28 mm diameter (standard-type A in Table 1 and Fig. 2). When using PMs of circular shape there is a conflict between two aims of the detector: spatial resolution and effective detector height. In normal powder diffractometry spatial resolution should be as small as possible for optimum peak separation and the detector should be rather high in order to profit from the vertical divergence of the neutron beam for intensity reasons. According to equ. (1) spatial resolution depends linearily on the PM diamter a, thus limiting the detector height. Type A PMs are a compromise between good resolution and reasonable detector height (see Table 1).

Table 1: Technical and physical specifications of three JULIOS types constructed with different photomultipliers.

Specifications	type A	type B	type C
scintillator-material (Levy Hill)	6-Li-Glas	6Li-Glas	6-Li-Glas
thickness of scintillator (mm)	1.0	1.0	1.0
detector form	plane	plane	plane
number of photomultipliers	24	24	24
type of photomultiplier (Hamamatsu)	R268	R2937	R1612
form of photocathodes	circular	rectang.	rectang.
effective detector length (mm)	682	200	940
effective detector height (mm)	25	20	75
max. 2Θ-coverage in 1.0 m distance (°)	38	11	50
max. 2Θ-coverage in 1.5 m distance (°)	26	7	34
linear spatial resolution (mm)	2.3	1.0	3.5
gamma sensitivity	$< 10^{-4}$	$< 10^{-4}$	$< 10^{-4}$

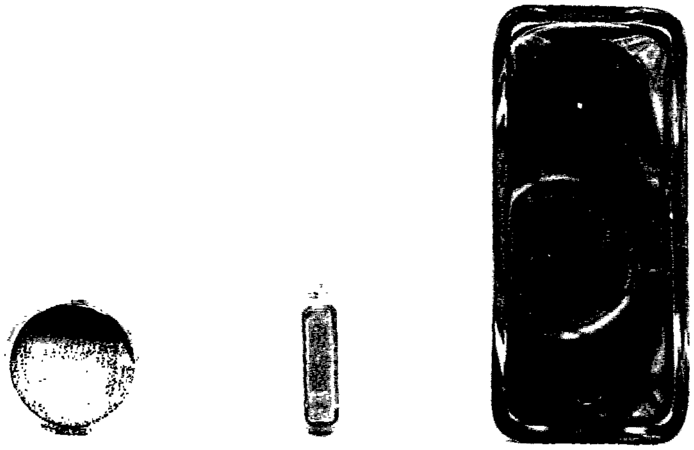

Fig. 2: View on the photocathodes of three PMs used for JULIOS type A (left), type B (middle) and type C (right); compare Table 1.

Advanced PM developments resulted in a large variety of PMs with also rectangular shaped photocathodes matching special detector requirements. Two different rectangular types are used (Table 1 and Fig. 2). PM type B enabled the construction of a higher resolution version of JULIOS; 1.0 mm is obtained with the light output of the normal ^{6}Li glass scintillator. Type C being composed of PMs with photocathodes of 40 x 80 mm cross section is a wide window version with still reasonable resolution; the effective detector height is enlarged by a factor 3 in comparison with type A.

Electronic signal processing and stabilisation

The signal processing of the JULIOS detector with respect to position computation can be followed by the blockdiagram depicted in Fig. 3. PM output signals, fed into voltage preamplifiers followed by a shaping amplifier, are preselected according to highest signals and multiplexed into four ADCs. The ADC signals are processed in a dedicated hardwired computer (Q-calc in Fig. 3) to perform the position analysis. Position computation of an event is performed stepwise by (1) selection of those three PMs yielding the largest output signals, (2) calculating the center of gravity Q with the digitized output signals by using a fast look-up table scheme, and (3) correcting Q according to nonlinearities and inhomogenity of either scintillator or photocathode by means of a special look-up table. Position computation is performed within 70 ns. Look-up tables are generated once by a calibration measurement. For further details we refer to [11].

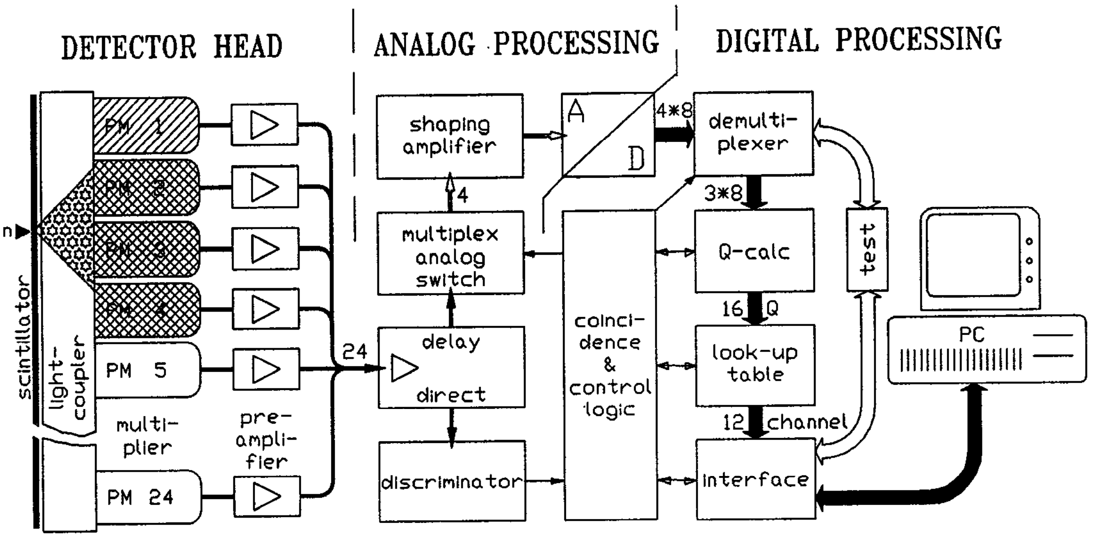

Fig. 3: Blockdiagram of the signal processing of the JULIOS electronics.

Long-term stability of the JULIOS detector is achieved by stabilising the gains of the PMs, knowing that drift rates of about 10% within several days are possible. Gain stabilisation is achieved by adjusting the PM high voltage according to reference light pulses, which are distributed via light guides from a LED to the PMs. The cathodes of the PMs are connected to high voltage DACs for changing the gain. The stabilisation runs completely automatic and takes about half a minute for the whole detector unit. For details of the gain stabilizing circuitry we refer to [18]

Timing module and interface

For operating the detector in a time resolved mode, the JULIOS electronics is supplemented by a new timing module to synchronize the detector activities with the time structure of the neutron source. High flexibility in timing is achieved by using XILINX devices, which are programmable to assume various desired functions. XILINX devices in combination with a programmable timing generator allow those timer specifications listed in the central box of Fig. 4 with respect to channel width, delay and window. Detector events can electronically resolved up to 12 bit position and 16 bit time information each; the configuration of position and time addresses on the MUX-module (Fig. 4) can be chosen arbitraryly.

The electronic concept provides for two alternatives. One is the operation of JULIOS as a standalone system without any mainframe computer, the other is the provision of a well defined interface to central data acquisition systems like DAE at ISIS. The realisation of this concept can be seen in Fig. 4.

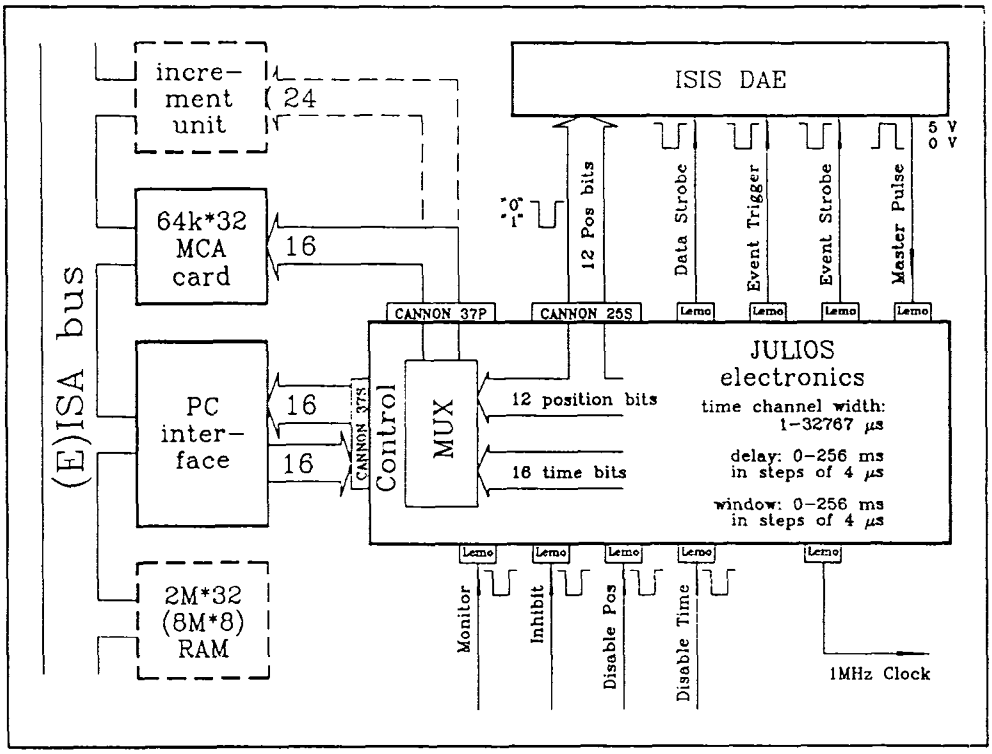

Fig. 4: Interface to JULIOS electronics

As a standalone system the JULIOS electronics is connected to a 32 bit PC with EISA-bus architecture. The PC is equipped with specially developed interface and data storage devices. Events are registered via a 24 bit increment module and stored in 2M*32 PC-RAM. Additonally, there is a 16 bit multichannel analyser card of 64K*32 capacity to be used as on-line monitor during the experiment. The 16 bit may be variably configurated for position and time information.

When connecting the JULIOS electronics to DAE at ISIS, only the 12 bit positon information has to be transferred and to be synchronized to the DAE timing. The corresponding interface provides three outputs: (1) event trigger to define the arrival time of an event at the detector, (2) event strobe to define the time of an event being in a pipeline for position analysis, and (3) data strobe to transfer the positon synchronized to the external DAE time information.

TOF-diffractometry with JULIOS at ISIS

A detector like JULIOS performing simultaneous position and time encoding of detected events can be used favourably for angular dispersive TOF diffractometry at a pulsed neutron source. The pulsed beam diffractometer consists of only sample and detector device; the sample is positioned directly in the primary beam and no further mechanical components like monochromator or chopper are needed. Test measurements have been performed on standard materials like mica, quartz, corundum and nickel (Fig. 5); we refer to [6,7,10]. A JULIOS type diffractometer is designed to consist of three detector units, which are positioned under fixed scattering angles in forward-, 90°- and backscattering geometry, respectively. A total flight path of about 20 m is envisaged; the intensity spectrum of every ISIS neutron frame can be utilized. d-spacings to be analysed lie between about 0.3 and 30 Å and d-spacing resolution is within 1 x 10^{-3}

and 5 x 10^{-2}, respectively. The instrument can be accomodated by opening up the downstream end of an existing ISIS beam line. The diffractometer is aimed at crystallographic and magnetic structure and at texture research.

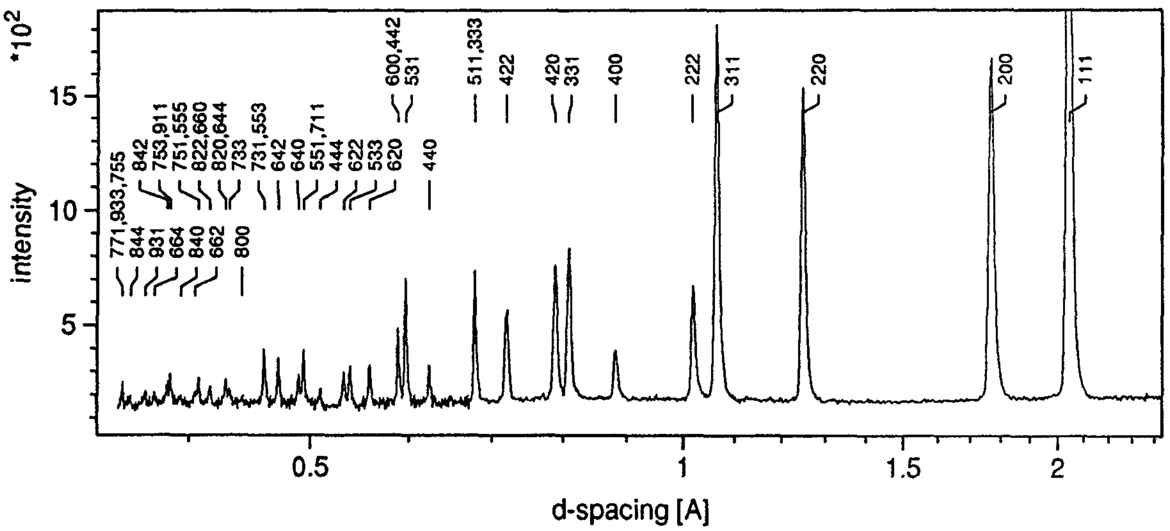

Fig. 5: d-spacing pattern of Ni, which was contained in a V-can of 11 mm diameter. The total neutron flight path up to the JULIOS detector was about 16 m. Detector window: Δ2Θ from 136.1° to 152.9°, Δλ from 0.675 to 1.344 Å. The detector was operated in a 8 bit mode for time and position information each.

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