Nuclear Instruments and Methods in Physics Research A246 (1986) 726–730
North-Holland, Amsterdam

FIRST RESULTS OF EXPERIMENTS WITH A MEDICAL ONE-COORDINATE X-RAY DETECTOR ON SYNCHROTRON RADIATION OF VEPP-4

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The first results of studying the performance of a fast X-ray one-coordinate detector on the SR beam from VEPP-4 are presented. The detector consists of 128 independent channels, each being a scintillation counter on the basis of NaI(Tl) crystals. The spatial resolution of the detector constitutes 1.5 mm and its speed of response is 128×1 MHz. The main purpose of the detector is to examine the human circulatory system by the method of difference angiography at an energy of quanta corresponding to the K-absorption edge of iodine (33.2 keV). The first results on radiation exposure of the blood vessels of a live dog with a spatial resolution of 0.75 mm are given.

1. Introduction

In recent years increasing interest has been shown in the utilization of synchrotron radiation (SR) for medical diagnostics of various diseases of the human being. The digital difference angiography (DDA) method is in a state of active development using the exposure of two radiographs at a quantum energy near the I K-absorption edge [1–4,6–11,13–14]. Development of this method has required the creation of an appropriate X-ray detector with the spatial resolution of the coordinates of the quanta being detected. As shown in ref. [7], such a detector must have a sensitive region of ~ 100 mm, a spatial resolution of ≤ 1 mm, a high detection efficiency up to 100 keV quanta (close to 100%), and an acceptable speed of response.

The one- and two-coordinate detectors available do not meet the basic requirements of the DDA method. They have a low detection efficiency (~ 1–10%) for 30–100 keV quanta, a low total (for the whole detector) counting rate ($\lesssim 1$ MHz) in the regime of quanta counting, and a low sensitivity to small fluxes of quanta in the regime of current.

A version of the one-coordinate semiconductor detector intended to be employed for the DDA method is described in refs. [4,5].

In the present paper we describe the design of a one-coordinate scintillation detector made at the Novosibirsk Institute of Nuclear Physics for DDA using synchrotron radiation and we give an analysis of its performance. The detector has a spatial resolution of 1.5 mm and comprises 128 independent scintillation counters with a counting rate of ~ 1 MHz for each channel. The mean efficiency of detection of 33.2 keV quanta is 70%. We also present the first results on radiation exposure of the blood vessels of a live dog with a 0.75 mm spatial resolution using the SR beam from the storage ring VEPP-4.

2. Arrangement of the detector

The detector is made up of 128 independent identical channels. Its sensitive region consists of NaI(Tl) crystals in which the energy of X-ray quanta converts to the bursts of light. The latter are registered by photoelectron multipliers FEU-60 connected to the NaI(Tl) crystals by ligth guides. The functional scheme of each channel of the detector is depicted in fig. 1.

A light guide is made from acrylic plastic and consists of two parts welded to each other: a flat and a cylindrical light guide. The scintillator washers of 4.5 mm diameter and 1 mm thickness are hermetically packed directly in the head part of the flat light guide. The construction of the light guide provides 15–20 electrons from the multiplier photocathode per quantum with an energy of 33 keV.

The detector is designed for work with synchrotron radiation incident on it after the passage through a monochromator as short pulses. Their duration is ~ 1

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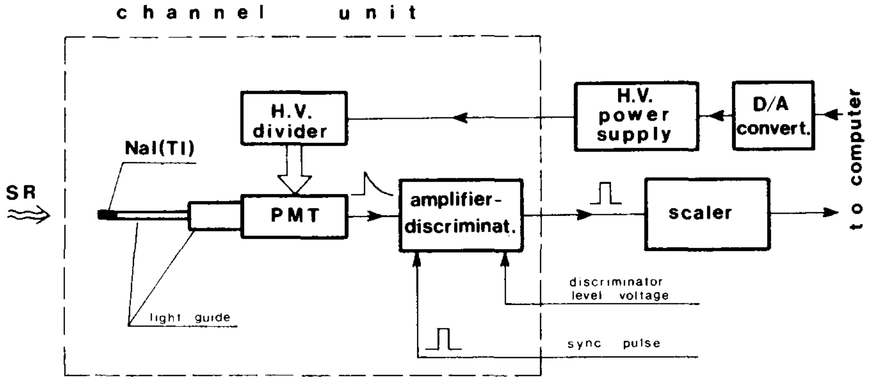

Fig. 1. Functional scheme of the detector channel.

ns. One or more X-ray quanta can occur in one pulse, and the pulse repetition frequency cannot exceed the revolution frequency of electrons in the storage ring in the one-bunch mode of operation of the storage ring.

A sequence of PM pulses, synchronized with the revolution frequency of an electron beam in the storage ring, comes to an amplifier–discriminator (AD). The determinated time structure of the signals to be analysed enables one to make an external forced synchronization of the operation of some AD nodes. This has led to an increase in the speed of response and in the noise immunity of the system and has made it possible to avoid the application of complex and inert schemes needed to restore the zero level of the discriminator usually employed in working with huge fluxes of statistically distributed quanta.

In addition, the AD allows a simple amplitude analysis of the signal. The scheme has two discrimination thresholds, for the lower and upper levels. The lower level discriminator offers the traditional service, it eliminates the noise PM pulses of low amplitude. The upper level discriminator is capable of detecting two or more simultaneously arriving quanta of monochromatic SR. When the amplitude of the PM signal is higher than the upper discrimination level, the AD generates an extra pulse to the counter. Two levels of discrimination make the detector faster by a factor greater than two in working with monochromatic synchrotron radiation.

The detector is manufactured in the block-module variant. Separate channel-modules of the detector constitute the sector-blocks placed in the detector body. A channel-module comprises the elements indicated by the dashed line in fig. 1. All parts of the module are attached to a special guide having an exact location in the sector.

The particular sector-block of the detector is designed for 16 channel-modules and is the segment of a circle with an angle of opening of ~ 140°.

For the guide of the channel-modules, the sector has the slots shaped as a swallow's tail. These slots are shifted to a transverse direction (in a spiral fashion) from channel to channel with a 1.5 mm step equal to the total thickness of the light guide. With such an arrangement of the sector, the flat light guides of the channel-modules, converging at the centre of the sector, form a fan of 24 mm thick. The detector is designed for 8 sectors (128 channels). Note that at the place of convergence of the flat light guides, a ruler-shaped region is formed which is sensitive to X-ray radiation.

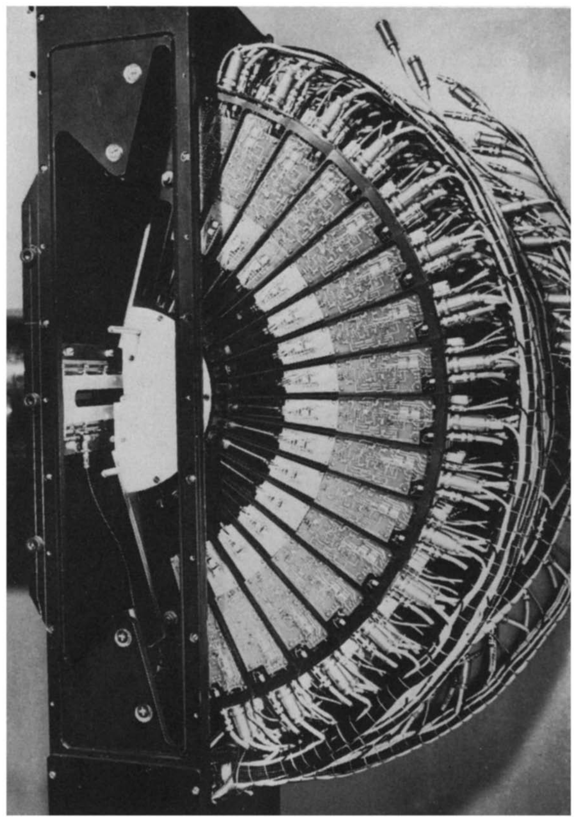

Fig. 2. General view of the detector.

Their sizes are 192 × 4.5 mm^2. The general view of the detector is shown in fig. 2. A more detailed arrangement of the detector is presented in ref. [12].

3. Experimental study of the performance of the detector on synchrotron radiation

The performance of the detector has been studied using synchrotron radiation from the VEPP-4 electron–positron storage ring [6]. The revolution frequency of electrons in the storage ring is $f_0 = 818$ kHz. The measurements were made when the VEPP-4 operated in the single-bunch regime. The beam of synchrotron radiation was monochromated by Ge(111) crystals. The monochromator is adjusted to the 33.2 keV energy of the quanta (K-absorption edge of iodine).

To verify the serviceability of the detector and tc study its parameters, the main characteristics of a single channel were analysed. For monitoring the flux of quanta arrived at the detector channel, we used the flight ionization chamber placed in front of the channel. The flux of X-ray quanta was controlled by a change of the collimator size. The ionization chamber signal was absolutely calibrated with the flux of quanta, using the quanta counting by a standard scintillation counter on the basis of FEU-130 coupled with an X-ray NaI(Tl) scintillator. At the indicated energy, such a scintillation counter ensured practically a complete separation of the photopeak of quanta absorption from the noise in the amplitude spectrum. The absolute efficiency of the scintillation counter was calculated with due regard for the thickness of the NaI(Tl) crystal and the emission of fluorescent and scattered quanta from the scintillator.

The load characteristics of the detector channel (dependence of the counting rate f in the channel on the flux of quanta F absorbed in the scintillator) were analysed for one- and two-threshold amplifiers–discriminators. The experimental dependences are illustrated in fig. 3. This figure also demonstrates the calculated curves obtained under the assumption of a complete separation of the single-quantum peak from a two-quantum one and from the noise, in the amplitude spectrum. It is seen that under larger loads the characteristics of the counting become close to their asymptotic values equal to f_0 for a one-threshold AD and $2f_0$ for a two-threshold one. Agreement between the experimental and calculated dependence for the two-threshold AD may be regarded as good, particularly under the $\lesssim 1$ MHz loads. A 30% decrease in the coefficient of the slope of the load curves occurs under $F = 340$ kHz for the one-threshold AD and under $F = 950$ kHz for a two-threshold one.

Employing the NaI(Tl) crystals as the scintillators leads to the appearance of definite peculiarities in the operation of the detector near the I K-absorption edge. The main reason for this is that at the quantum energy higher than the K-absorption edge of iodine, an intense radiation of fluorescent quanta of the K-series of iodine takes place in the scintillator. A fraction of these quanta

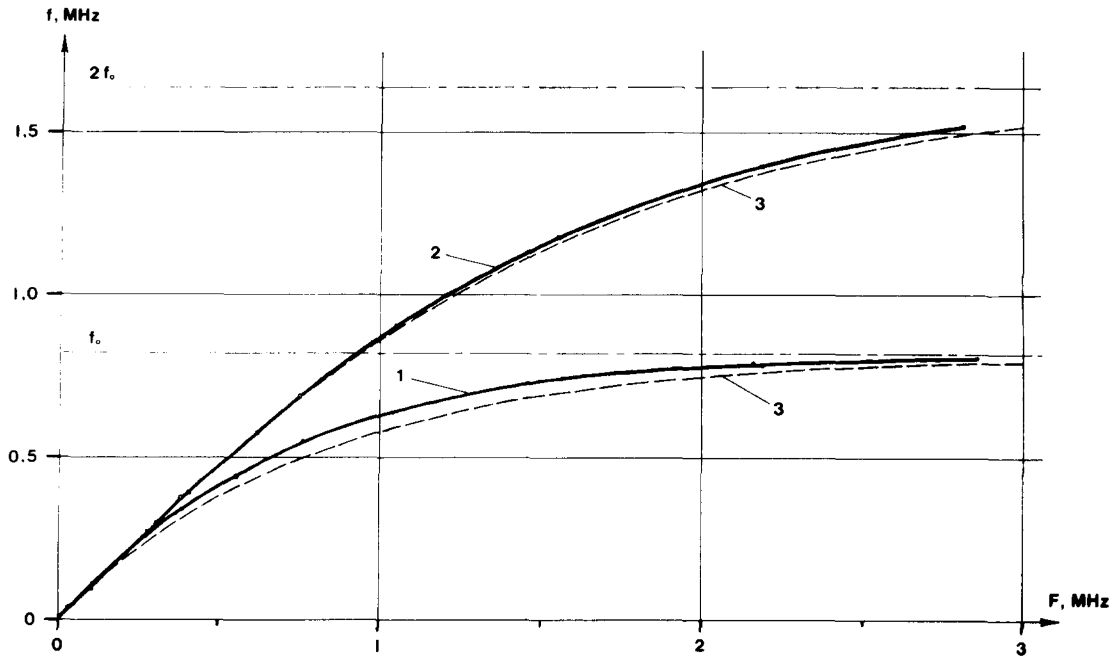

Fig. 3. Experimental dependences of the counting rate f in the channel on the load F: 1 – one-threshold discriminator, 2 two-threshold discriminator, 3 – calculational curves.

can reach the scintillators of the neighbouring detector channels. At a quantum energy lower than the iodine K-absorption edge, the fluorescence in the crystal takes place from the low-energetic L, M, etc. shells of the iodine atoms and, in practice, the fluorescent quanta are completely absorbed in the crystal. During the work at quantum energies, from the different sides from the I K-absorption edge, this gives rise to a change of the absolute detection efficiency and to a change of the influence of the neighbouring detector channels on each other.

Comparison of the counting rates in the detector channel and in the standard scintillation counter has shown that the detection efficiency of the channel constitutes 84% at a quantum energy lower than the I K-absorption edge and 57% at a quantum energy higher than the K-edge.

The influence of the detector channels on one another is analysed by scanning a set of flat light guides relative to a narrow X-ray beam and by measuring the counting rate in the working channel. The measurements have shown that the integral contribution of the neighbouring channels is 4% and 14% at quantum energies below and above the I K-absorption edge, respectively. Therefore, in the final construction of the detector 100 μm Ta washers were installed between the flat guides in the

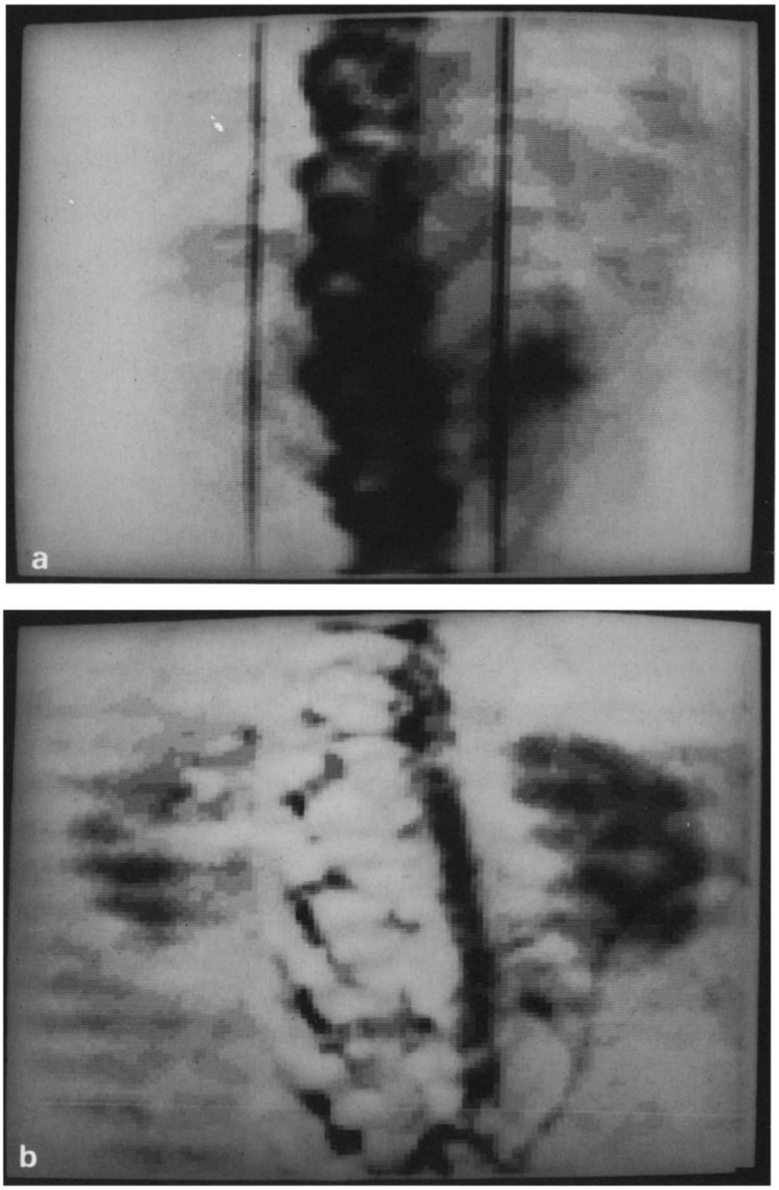

Fig. 4. Usual (a) and difference (b) radiographs of a part of region of the abdominal cavity of a live dog.

places where there are the scintillators. The washers should weaken the effect of the neighbouring detector channels to a level of 0.1%.

After the experiments on a single channel had confirmed the expected parameters of the detector, 64 channels (4 sectors) were assembled and put into operation. This made it possible to obtain the X-ray images. However, the SR beam available had a 30 mm horizontal size and, hence, only 20 channels of the detector could operate simultaneously. In order to obtain the images of larger horizontal size, we had to carry out a successive exposure of several 30 mm pictures with further "sewing together" of the images obtained. As an illustration, figs. 4a and 4b demonstrate the usual and difference radiographs of a part of the abdominal cavity of a live dog, which were obtained using the detector. The horizontal and vertical sizes of the images are 90 and 85 mm, respectively. In order to see clearly the details small in size, the radiographs were taken at a spatial resolution of 0.75 mm. This was achieved by an additional exposure with the detector horizontally shifted by 0.75 mm. On the difference radiograph one can clearly see the kidneys and the abdominal aorta branched in the lower part of the image. The aorta was contrasted through a catheter (seen in fig. 4b in the right lower corner) in the exposure process. The estimated mean concentration of iodine in the blood was about 1%. In this radiograph one can also see the artifacts because of insignificant shifts of the dog's body in the process of breathing and scanning in horizontal.

4. Conclusion

The study of the parameter of the detector and the work on obtaining X-ray images of live objects show that the detector under discussion has a high speed of response (~ 1 MHz/channel) and a high detection efficiency (60–80%). In addition, its channels have little influence on each other (~ 0.1%). By the end of 1985 we are planning to install and put into operation all 128 channels of the detector and to start the work with a wide (up to 150 mm) SR beam.

The main purpose of the detector is to be used for the DDA. However, the detector can be applied for other studies where there is no need for a high spatial resolution, for example, in the studies on the dynamics of diffraction pictures of various materials with high time resolution (~ 1 ms). The range of working energies of the detector is 15–150 keV. On the part of low energies, the range is limited by the light yield of the scintillator, while on the part high energies it is limited by a decrease in the detection efficiency of the quanta.

The authors express their deep gratitude to A.M. Pavlyonok and L.V. Ankudinov for the manufacturing of light guides and a thorough assistance in the work and also to G.M. Kolachev for useful discussions concerning the design of the detector.

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