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Dedicated x-ray scintillation detector for digital subtraction angiography using synchrotron radiation

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A one-coordinate x-ray detector for digital subtraction angiography using synchrotron radiation is described. It comprises two x-ray-sensitive lines, each having 128 independent channels of scintillation counters. The detector is designed to simultaneously measure the intensities of two linear monochromatic beams being 8–10 mm distant from each other. The spatial resolution of each line ranges from 0.2 to 2 mm. The maximum counting rate is 6 MHz for each channel, and the detection efficiency of the 33.2-keV quanta is close to 100%. Preliminary results of the testing of the detector channels on synchrotron radiation beam are given.

INTRODUCTION

At the Institute of Nuclear Physics (Novosibirsk), the current research program for digital subtraction angiography is founded on the scheme described in Ref. 1 and presented in Fig. 1. When using such a method of taking subtraction angiograms, an x-ray monochromator designed on the basis of two Laue diffraction Si crystals forms two wide monochromatic beams with quanta energy just above (E_1) and below (E_2) the *K*-absorption edge of iodine (33.2 keV). The monochromatic beams intersect at the location of an object to be examined, then diverge, and, spaced 8–10 mm apart, arrive at a detector where they are detected simultaneously, i.e., one line of the image is taken simultaneously at two energies of x-ray quanta. The complete subtraction angiogram is obtained via a vertical, line-by-line scanning of the object relative to the intersection line of monochromatic beams.

To realize this scheme using synchrotron radiation (SR) from the superconducting wiggler at the storage ring VEPP-3, a dedicated x-ray monochromator and a one-coordinate detector were designed and are being manufactured at the Institute. The present paper deals with the description of the detector design and electronics. Preliminary experimental results on the testing of the detector channels are reported.

I. DETECTOR DESIGN

The basic principles of the layout of the new detector are essentially similar to those underlying the previous model.[2–4] In contrast to it, the new one consists of two one-coordinate detectors, each having 128 independent channels. Sensitive to x-rays, the linear regions of the one-coordinate detectors are stacked up at as minimal distance as possible, thereby making it possible to simultaneously detect two isolated x-ray beams. Besides, the design of the detector allows the spatial resolution of the detector to be readily changed and offers the possibility of optimizing the conditions to obtain a subtraction angiogram for a particular object under examination.

As a construction, a one-coordinate detector comprises two units with 64 channel modules in each. A unit is shaped as a mechanical basket for 68 positions having a common bus. Sixty-four positions are intended for the channel modules, and four are used for a controller of the bus, each position being 20 mm wide. The total width of the basket is 1320 mm. The unit is mounted at a low angle to the middle axis of the incident beam (the magnitude of the angle depends on the given spatial resolution) and can be rotated in the horizontal plane about the vertical axis passing through the last (along the beam path) scintillator in the unit (Fig. 2). On the same axis there is the second unit placed in a mirrorlike position relative to the vertical plane passing through the rotation axis and the middle one of the SR beam. Rotation of the units about the axis makes it possible to obtain the spatial resolution ranging from 0.2 to 2.0 mm per channel.

Each channel module is an independent scintillation counter on the basis of a photoelectron multiplier FEU-60. The $YAlO_3$ (Ce) crystal with a decay time of 40 ns is employed as the scintillator. The crystal scintillator is stuck to the side face of a glass half-washer plate, which in turn is glued to the input window of the photomultipliers (Fig. 2). The remaining surfaces of the glass half-washer are covered by a thin Al coating to increase the efficiency of light collection. The crystal scintillator is 2 mm wide along the beam path, which provides in practice a 100% absorption of the 33.2 keV quanta of x rays. The photomultiplier and a high-voltage divider are placed in a light-tight plastic cylinder with a window for the glass half-washer and scintillator. For

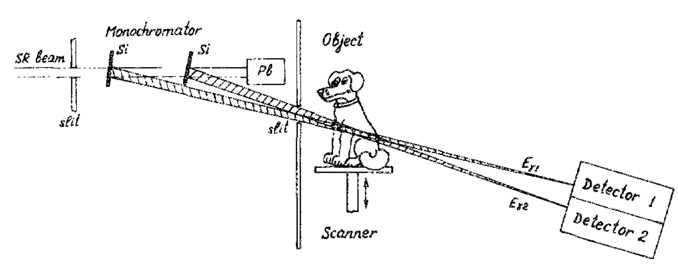

FIG. 1. Diagram of the subtraction angiograms taking.

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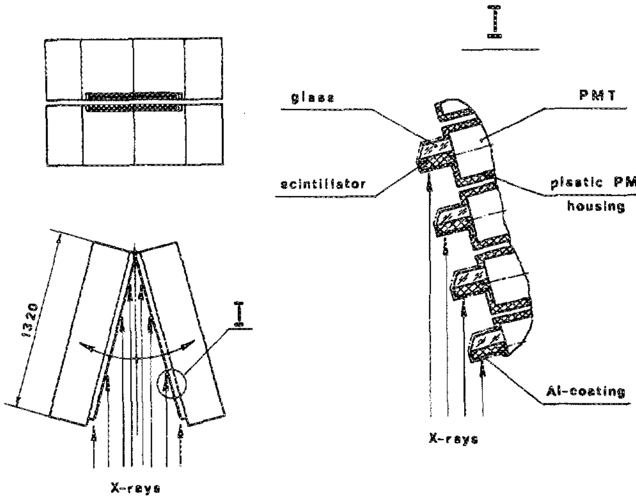

FIG. 2. The design of the detector.

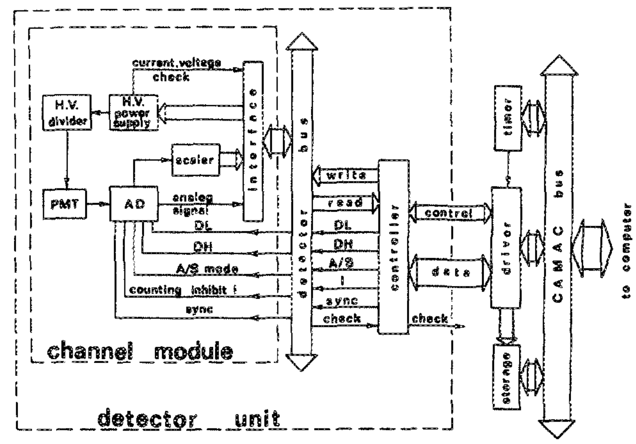

FIG. 3. Functional scheme of the detector unit.

better light-tightness, the protrusions from the window are black painted. This cylinder is mounted in such a way that it is capable of shifting along its axis relative to the module frame during the channel adjustment.

The modules in each unit form a rule consisting of crystal scintillators spaced apart along the detector (Fig. 2), and hence, there is a linear x-ray-sensitive region from the side where the x-ray beam enters the detector. The vertical size of the region is 10 mm (crystal size), while the horizontal one is determined by the given spatial resolution and can range between 25.6 and 256 mm (for the whole detector). When changing the spatial resolution, the scintillators of the two last (along the beam path) channels in the blocks do not shift horizontally because they are intersected by the geometrical axis of rotation of the units. Individual correction of the position of a photomultiplier tube (PMT) in each channel permits one to maximally decrease a possible geometrical difference in the widths of the detector channels.

The second one-coordinate detector is identical to the first and is placed in the mirror-symmetrical position relative to the x-ray beam, so that two independent x-ray-sensitive lines are formed as a result. The nonworking gap between the detector lines can be changed mechanically from 7 mm to several centimeters.

II. DETECTOR ELECTRONICS

The functional diagram of one of four detector units is shown in Fig. 3. Each channel module of the detector comprises a PMT with a high-voltage divider, a high-voltage supply source, an amplifier discriminater (AD), a scaler, and a bus interface. The PMT signal is applied, as a sequence of pulses, to the AD which enables a minimum amplitude analysis of the signals to be performed. The circuit has two discrimination thresholds, namely, the threshold of lower (DL) and upper (DH) levels. The lower-level discriminater offers the conventional function: it eliminates the noise PMT pulses of small amplitude, whereas the upper-level discriminater is tuned to detect two and more simultaneously arrived quanta of x-ray monochromatic radiation. If the signal amplitude exceeds the value of the lower threshold, one pulse is fed to a scaler, and if it exceeds the upper threshold, two pulses are applied to the scaler. As is shown in Refs. 2–4, such a way of pulse registration increases the counting rate capability of the detector channel. The values of the discrimination levels are equal for all channel modules. High voltage for PMT is controlled for each of the channel modules separately, and this provides a possibility to tune all the detector channels into a working mode of operation.

The AD can operate in two modes—self-synchronization (A) and external synchronization (S). In the first case, the PMT output signal triggers the AD and generates pulses supplied to a scaler. The first mode of operation is to tune the detector with statistical emission of x-ray quanta sources (for example, radioisotope sources) at a load of about 100 kHz. The second mode is used for detector operation using SR beams. In this case the deterministic time structure of the signals being analyzed makes it possible to forcely synchronize the operation of some AD circuits with the beam revolution frequency in the storage ring. The advantages and peculiarities of this mode are treated in Refs. 2–4. The integration time of the amplifier signal is taken equal to 120–150 ns and with garnets having a 40-ns decay time and, used as the scintillators, this offers the possibility to collect practically the complete PMT charge.

A scaler in any channel has a 20-bit memory (zero bit is the one of overflowing) and a 20-MHz fast response. The high-voltage supply source provides the output negative-polarity voltage from 0 to 1800 V with a 3.5225-V radiation discreteness and a load current not exceeding 1 mA. The exchange between the channel-module interface and the detector bus occurs similarly to that of the CAMAC standard. The controller and the driver connect the detector bus to the CAMAC one, and the detector is controlled in the same fashion as a module made according to the CAMAC standard. Computer control of the detector comprises high-voltage setting up in each channel, reading of the content of a scaler in each channel, simultaneous zero setting up over all scalers, setting up of permission/inhibition (I) for all scalers simultaneously, setting up the AD mode of operation, setting up of the discrimination levels, and switching on the checking one of the channels (the values of voltage and current of the high-voltage power supply, analog signal from the AD output).

Microprogramming operation of the tuned detector is also possible according to the next algorithms: the timer gives the time interval to count x-ray quanta; after this interval ends, the information from 64 scalers of the detector channels is sequentially introduced into the buffer memory. The information from one unit is read out for 64 μs; all four units are operating simultaneously. After that, zero is setting up to the scalers and the measurement cycle repeats. The information stored in the memory is then transferred to a computer.

As a construction, the electronic part of the detector channel module is a printed circuit board having a joint to connect to the common detector bus. On this board there are also a PMT with a high-voltage divider in the light-tight body and a mechanism to adjust the PMT. The detector bus is designed as the printed circuit board with the response joints on it.

III. PRELIMINARY STUDY OF DETECTOR CHANNELS

The detector components are being manufactured now, and therefore there was no possibility to perform a complete investigation of its real parameters. Nevertheless, we have obtained some of the characteristics, working with the prototypes of the channel modules. Our investigation was carried out using synchrotron radiation from the warm wiggler installed at the storage ring VEPP-3.

With the use of $YAlO_3$ (Ce) crystal as the scintillators, the amplitude differential spectra of the PMT signals, measured experimentally at a 33.2-keV energy of x-ray quanta, demonstrate good separation of the photoabsorption peak from noises (the peak/valley ratio is 10) and the amplitude resolution at a half-height is about 60%. One- and two-quantum photoabsorption peaks in the spectra are clearly separated. This assures us that the adjustment of the detector channels to the working mode presents no difficulties and guarantees a practical absence of the losses in efficiency of quanta detection.

It was interesting to study the load capability of the channel. The measurements of this kind were made through variation of the electron current in the storage ring. The counting rate f in the detector channel was measured for given values of the electron current I. The resulting load curve is depicted in Fig. 4. It is seen that rather acceptable

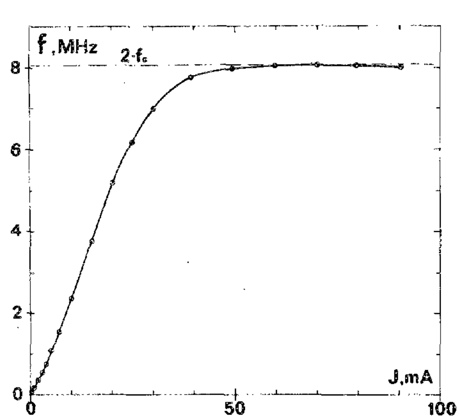

FIG. 4. Experimental dependence of the counting rate f in the detector channel on the electron current J in the storage ring.

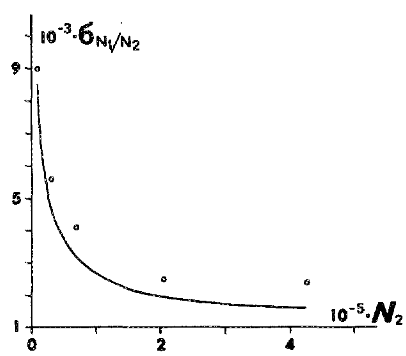

FIG. 5. Standard deviation of N_1/N_2 value as a function of detected quanta number N_2 (circles, experimental data; solid curve, calculated dependence).

linearity of the load curve maintains up to about 6–7 MHz (the ultimate counting rate detectable by the channel must be $2f_0 = 8.06$ MHz, where f_0 is the electron revolution frequency in VEPP-3).

Study has also been made of the stability of quanta counting by detector channels. For this purpose two channel modules were installed on the path of the horizontally wide monochromatic x-ray beam in a way that the left-hand part of the beam arrives at the scintillator of one channel, and the right-hand one comes to that of the other. Measurements have been made of the ratio between numbers N_1 and N_2 of detected quanta in these channels at a fixed time of measurement and for different fluxes of quanta in the incident beam (at different loads), i.e., depending upon the statistics of N_1 and N_2 obtained in the channels. This method of measurement nearly eliminates fluctuations in the magnitude of N_1/N_2 which can be caused by the instability of the electron orbit in the storage ring.

The experimental results obtained are given in Fig. 5. The standard deviation of the magnitude of the N_1/N_2 ratio is plotted on the Y axis and the statistical data acquired N_2 in one of the channels is laid off as abscissa. The time of data acquisition at the measurement point was 100 ms. The solid line on this figure illustrates the calculated dependence of the standard deviation, which determines the instability caused only by the statistics of x-ray quanta. It is seen that the experimental points are close to the calculated ones in values, but are shifted, and one can observe a regular shifting towards higher values by the quantity 0.0005–0.0009. This points to the availability of the instability in the counting, which is not connected with quanta statistics and needs further investigation.

IV. CONCLUSION

At present the detector is being manufactured and its basic elements are being adjusted. Though the results obtained on channel testing are of preliminary character, they show that the design parameters of the detector are quite real. The detector characteristics will be comprehensively studied after it is put into operation.

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