THE FIRST TEST EXPERIMENTS OF THE POSITION SENSITIVE X-RAY DETECTOR OD-3*

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Abstract

Fast one coordinate X-ray detector of a new design aimedfor angular measurements in diffraction xperiments wasdeveloped in BINP. The detector is based on a multiwire proportional chamber with X-ray absorption drift volume. It allows to accept photons in the energy range from 6 keV to 20 keV with a maximum counting rate of 10MHz and coordinate resolution about 0.1mm (r.m.s.) in linear scale. First OD-3 chamber has 0.4mm thickness Be inlet window 200×10 mm^2, the photoabsorbtion length 50 mm and a parallax-free cathode structure for the angles up to ± 15 degrees at variable focal length (from 300 mm to 450 mm without any modification and to infinite at cathode plane replacement). The first test of the detector at synchrotron radiation beam line 5-b VEPP-3 and with X-ray tube shows a good performance. The detector construction specific and test results will be discussed in the report.

I. INTRODUCTION

A development of one coordinate detectors for X-ray experiments in Novosibirsk INP started since 1975. An old modification (1) was relatively simple device based on the proportional chamber with a delay line for the coordinate reconstruction. A project of a new detector was started since 1992 under the pressure of users' requests to improve frequency limitation, to increase efficiency, to delete parallax error.

A completely new one coordinate detector OD-3 (the main idea of which had been suggested in (2)) was designed to improve listed above deficiency. OD-3 has the following parameters:

- maximum counting rate increased up to 10 MHz;
- parallax-free at variable focal length (from 300 mm to 450 mm) without any modification and to infinite at cathode plane replacement;
- photoabsorbtion gap increased up to 50 mm;
- enlarged inlet window up to 200×10 mm^2.

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It has also several innovations in the fast coordinate reconstruction method (using two - dimensional tables in RAMs in pipe line), which can be used in any detectors of similar type.

This report contains a general device description, beam test and X-ray test results, and discussion the project present status.

II. DETECTOR DESIGN

OD-3 was designed to detect directions of the photons scattered by the target. It was assumed that the interaction point size of the photons with a target is small compare to the detector coordinate resolution ~100mm. The detector could be installed more than 30cm behind the target. Photons come into the detector through 0.4mm thick Be window and can be absorbed within 50 mm in the chamber gas mixture.

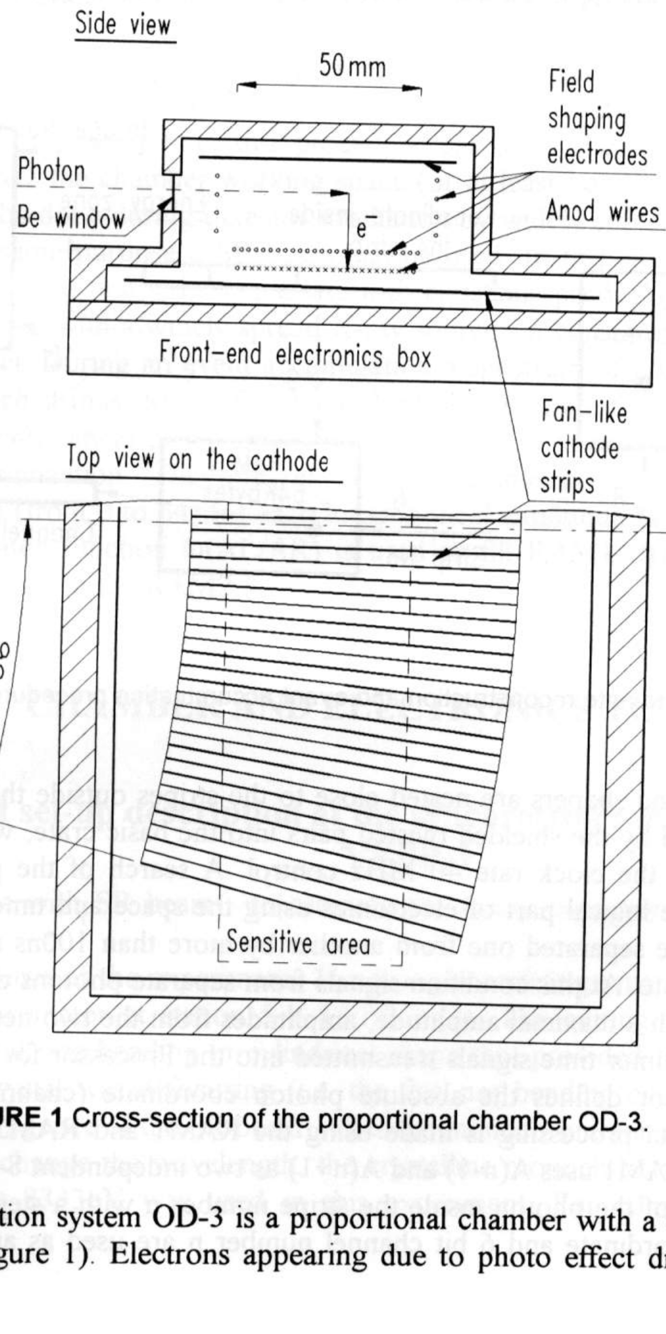

FIGURE 1 Cross-section of the proportional chamber OD-3.

A basic part of the detection system OD-3 is a proportional chamber with a drift gap overlapping the absorption volume (Figure 1). Electrons appearing due to photo effect drift through the field shaping wire grid cathode to the anode wires where the avalanche amplification occurs. A coordinate of an avalanche along the anode wires direction is measured using induced charge distribution over the cathode strips which serve as a second chamber cathode. The cathode has a fun-like shape of strips with the focus at the target plane in order to obtain the parallax-free images. To increase the focus distance about 1.4 times it is possible simply to incline the chamber as it was explained before (2). A strip cathode replacement is needed to get a large focus distance. To decrease a charge distribution dependence on the photon conversion point (due to the variable strip width) a cathode plane has a small angle to the plane of anode grid. In order to keep a gas gain uniformity within about 10% precision an anode wires are separated into the five groups with distributed potentials. A chamber placed into the leak-proof volume which allows to control a pressure from 0 to 3 atmosphere. Vacuum connectors are used to input high voltage and output signals. Construction materials were chosen carefully and a vacuum technology used in order to operate without gas flow. A frame was made of ceramics with metallic electrodes; field shaping and cathode wires - bronze with 150mm diameter; anode wires were made of 20mm diameter tungsten.

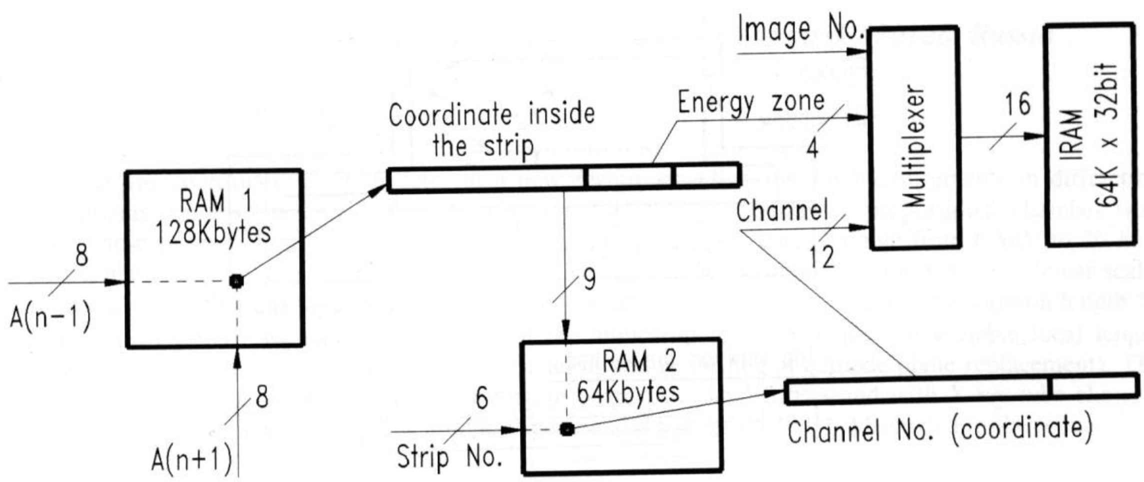

FIGURE 2 Fast coordinate reconstruction and event accumulation procedure in the processor OD-3.

The preamplifiers and shapers are nested close to the stripes outside the clean chamber box. The signals are transmitted by the shielded twisted pairs into the basic crate, where they are digitized by the flash ADC under the clock rate 40 MHz control. A search of the photons and event quality control is made in the logical part of electronics using the space and time criteria. A trigger selects the photons which are separated one from another by more than 100ns in the time and more than 12mm in the coordinate. At this condition signals from separate photons do not disturb one another. A number of strip with a maximal amplitude, amplitudes from the two neighbouring stripes A(n-1), A(n+1) and external timer time signals transmitted into the Processor for the selected events. Using this data the Processor defines the absolute photon coordinate (channel number) and a photon energy. The basic data processing is made using the RAM1 and RAM2 (Figure 2) loaded in the Processor memory. RAM1 uses A(n-1) and A(n+1) as two independent 8-bit addresses, and contains a relative coordinate of the photon inside the stripe number n with a step 1/512 of their angle size. This 9 bit relative coordinate and 6 bit channel number n are used as an addresses of the RAM2.

RAM2 contains the final 12 bits address (the final photon coordinate) which is stored through the Multiplexer in the Increment RAM (64K × 32 bit). According to the requested image number NI(1,2,4,...256), their sizes IS (256;512;1K;2K;4K), and a number of energy zone NZ(1,2,4,8,16) Multiplexer divides the Increment RAM and accumulates events. Listed above parameters are set by the program way. The window size may contain the total device scale, its part or any parts combination satisfying to the condition of memory size: NI × IS × NZ<64K. The image accumulation time is defined by the external timer. The minimal image exposition is about one microsecond. Electronics is placed in the two CAMAC crates. A special bus was added to one of them in order to manage the cross connection between neighbouring channels in the event selection logics. A crate with Processor operates under the control of any standard CAMAC controller. To the present time few computer codes on PC-486 have been developed for detector control.

III. CALIBRATION OF THE ELECTRONICS

In order to have got an equal reply from different electronics channels and correct coordinate reconstruction a special procedure named calibration should be done. It allows to obtain a data-set for RAM1 and RAM2. In present time this procedure based on the method required uniform distribution of photons over the chamber working space (or at least homogeneous distribution over the each strip). This can be done during detector irradiation by widely spread X-ray source (isotope or X-ray tube). For the same purpose a SR beam can be used. In this case a narrow SR beam is scanning the detector from the first strip to the last with constant speed. A result of the procedure with SR beam is the same as with a widely spread X-ray source - a constant number of the photons registrated in each channel. During an event accumulation a spectrum of possible ratios ln(AL/AR) normalized on 512 for each strip is stored. This logarithmical ratio has a raw of advantages compare with another functions: nearly linear dependence on coordinate, has asymmetry around a strip center that is significant for digitization. The integral of this distribution normalized on 64 gives a coordinate inside the strip (from 0 to 64) for each logarithmical amplitude ratio from interval 0-512. The values of the calculated function ln(AL/AR) is used to fill RAM1. An individual calibration curves for each strip is written in the RAM2.

IV. CHAMBER AND ELECTRONICS TEST

A. The test set-up description at the synchrotron radiation station 5-b VEPP-3

The aim of experiments with SR beam - to estimate the space resolution and parallax error in OD-3.

Figure 3 shows the scheme of the experiment. The triangle perfect germanium (111) crystal was used as focusing monochromator at station 5-b VEPP-3 (3). The cutting angle was equal to 7 degrees. Usually this crystal was bending in cylindrical shape that provided focus length equal 5m. For this experiment the crystal was defocusing (i.e. the flat, not bending crystal was used). It was made to overcome the divergence of the SR beam. After the monochromator the 0.1 mm vertical slit was installed. In order to change the wavelength, the crystalline monochromator can rotate around vertical axes. The energy 8333eV was used in this experiment. For compression of the third harmonic 24999eV which in the SR beam after monochromator, the Ag mirror was used. The vertical slit control the vertical size of the SR beam.

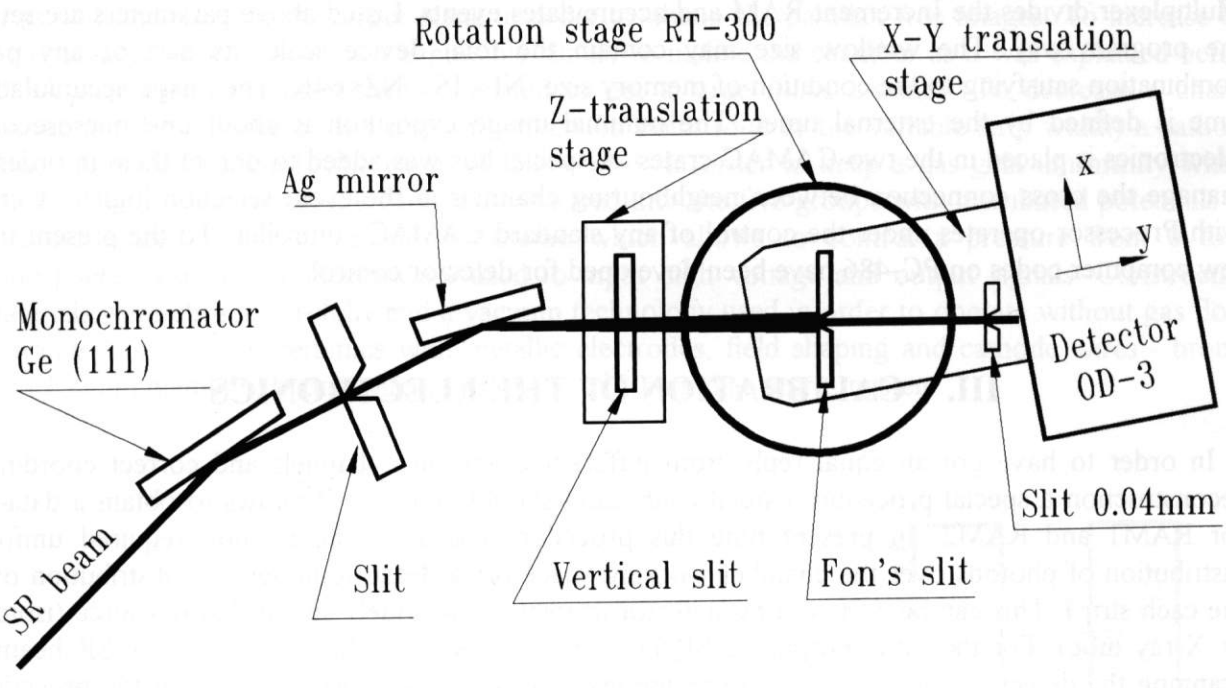

FIGURE 3 The scheme of the experiment for the test of the OD-3 at the SR beam line 5-b VEPP-3.

The detector OD-3 was installed on the rotation stage RT-300 (Microcontrole, step 0.001 degree) at the 350 mm from the center. The X-Y translation stage (NPZ, step 5 mm) was used for adjustment of the detector, because the rotation axis of the rotation stage RT-300 and focus of the OD-3 must be coincide with a precision 0.5 mm.

The background slit (0.1 mm) was installed at the independent support, separately from RT-300 above the center of the rotation stage RT-300.

The high precision 0.04 mm slit was installed in front of the OD-3 at the independent support, separately from RT-300.

To test the optical scheme, two Instant Sheet Film Polaroid PXW3018B (print resolution 18-22 line pairs/mm) was used for the registration of the SR beam. Films was installed at 350 mm (instead OD-3) and 1350 mm apart from the center of rotation stage RT-300. The width of the imaging at the first film equal 0.05 mm (equal to the print resolution of the film), and at the second 0.1 mm. After these experiment we was sure, that size of the SR beam at the entrance window is less then 0.1 mm and its divergence inside OD-3 equal 0.1 mrad.

B. OD-3 adjustment procedure

The adjustment of the detector was made in two steps: 1) adjustment of the central part, or central strip of the detector; 2) adjustment of the side part, or extremely left (right) strip of the detector.

At the first step detector was scanning by X-Y translation stage in X direction (perpendicular to the SR beam) and rotated by rotation stage RT-300 in such a way that SR beam heat at same position one of the central strips. A measured beam size was used as a monitoring parameter during adjustment. After few iteration the minimum of the measured beam size was found.

At the second step detector was rotated by rotation stage RT2-300 in such a way that SR beam heat at one of the side strips. After that the minimal measured beam size defined by scanning of X-Y translation stage in Y direction.

Initial measured beam size was more than 4 bins (r.m.s.) in the central part of the detector, after adjustment it decrease to 1.8 bins.

C. The parallax error measurement

As known, a big parallax errors of a flat position sensitive detectors are a big problem. OD-3 detector has a cathodes with an angular symmetry, but anode wires has not such improvement. Such a construction of the detector's chamber sufficiently decrease parallax error, but not absolutely solves this problem. So, there is necessary to estimate the parallax error. For that purpose the next test experiment was made: the detector rotated by rotation stage RT-300 at step equal 0.01 rad. This angle corresponds to the strip width. Every time SR beam hits close to the center of the next strip. Figure 4 shows an obtained coordinate distribution for chamber filled with gas mixture Ar-CO_2(10%). A similar distribution had been also obtained for Xe-CH_4(10%) gas mixture. A coordinate in the Figure 4 and in the further Figures is measured in terms of 1/64 from the angular strip size that roughly corresponds to 0.07 mm in linear scale. Figure 5 shows the measured R.M.S. beam width as a function of strip No from edge to the central part of the detector. Table 1 briefly summarized obtained results for two gas mixtures. The conclusion is following: parallax error is seen but does not exceed 50% from the best coordinate resolution.

Figure 6 shows the deviation of measured coordinate from calculated one as a function of strip No. It does not exceed 2.5 channel at the edge and 0.8 channel in the center and can be explained by the adjustment and calibration precision.

TABLE 1. Measured R.M.S. beam width in the central and the edge part of the detector and its difference for two different gas mixtures.

Gas mixture	Central part	Edge part	Difference edge-central
Ar-CO_2(10%)	3	3.5	0.5
Xe-CH_4(10%)	1.5	2.2	0.7

Figure 6 shows the deviation of measured coordinate from calculated one as a function of strip No. It does not exceed 2.5 channel at the edge and 0.8 channel in the center and can be explained by the adjustment and calibration precision.

D. A maximum rate capability test

Another problem, which can appear at using OD-3 is an influence of one event to another at high rate of photons flow.

The test experiment to estimate this phenomena can be done using two kind of signals: the first signals from a narrow photon beam or from a generator, which shows a good coordinate resolution while the second one from uniformly irradiated chamber with a maximum counting rate close to 10MHz which should influence on the first signals and leads to the degradation of coordinate resolution with a rate.

Unfortunately we had not done this experiment during SR beam test due to problem with X-tube. So late the generator was used in order to simulate first kind of signals on the three strip's preamplifiers.

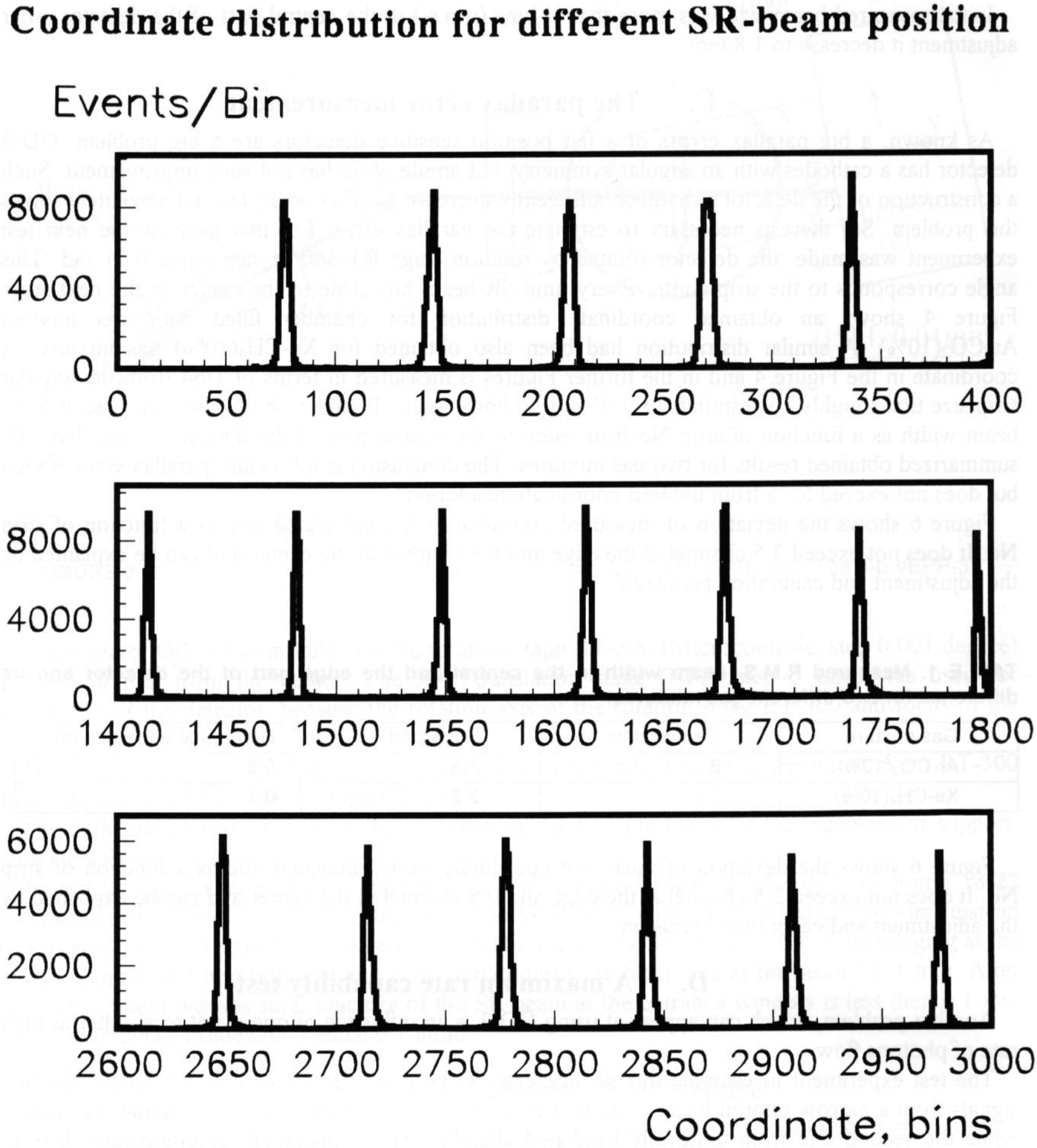

FIGURE 4 A set of experimentally measured coordinate distribution from the 0.04 mm wide SR beam, by OD-3 (gas-Ar).

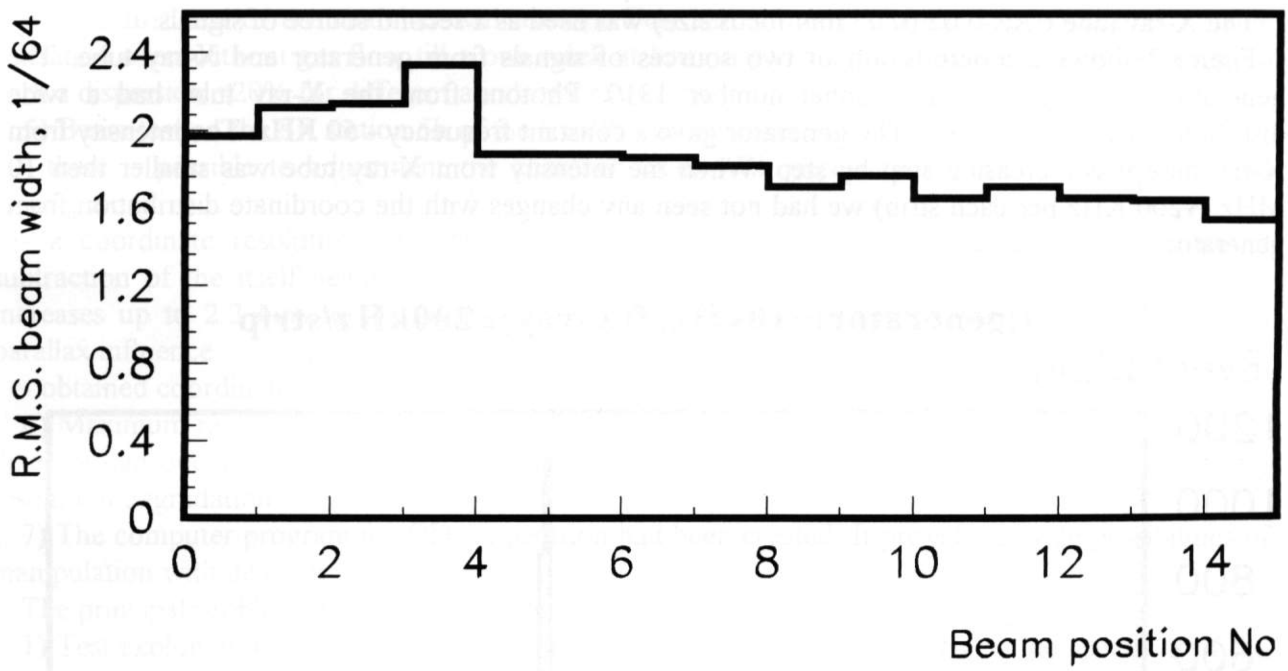

FIGURE 5 Measured R.M.S. beam width as a function of strip number. n=1 corresponds to the edge of the detector, n=14 - to the center.

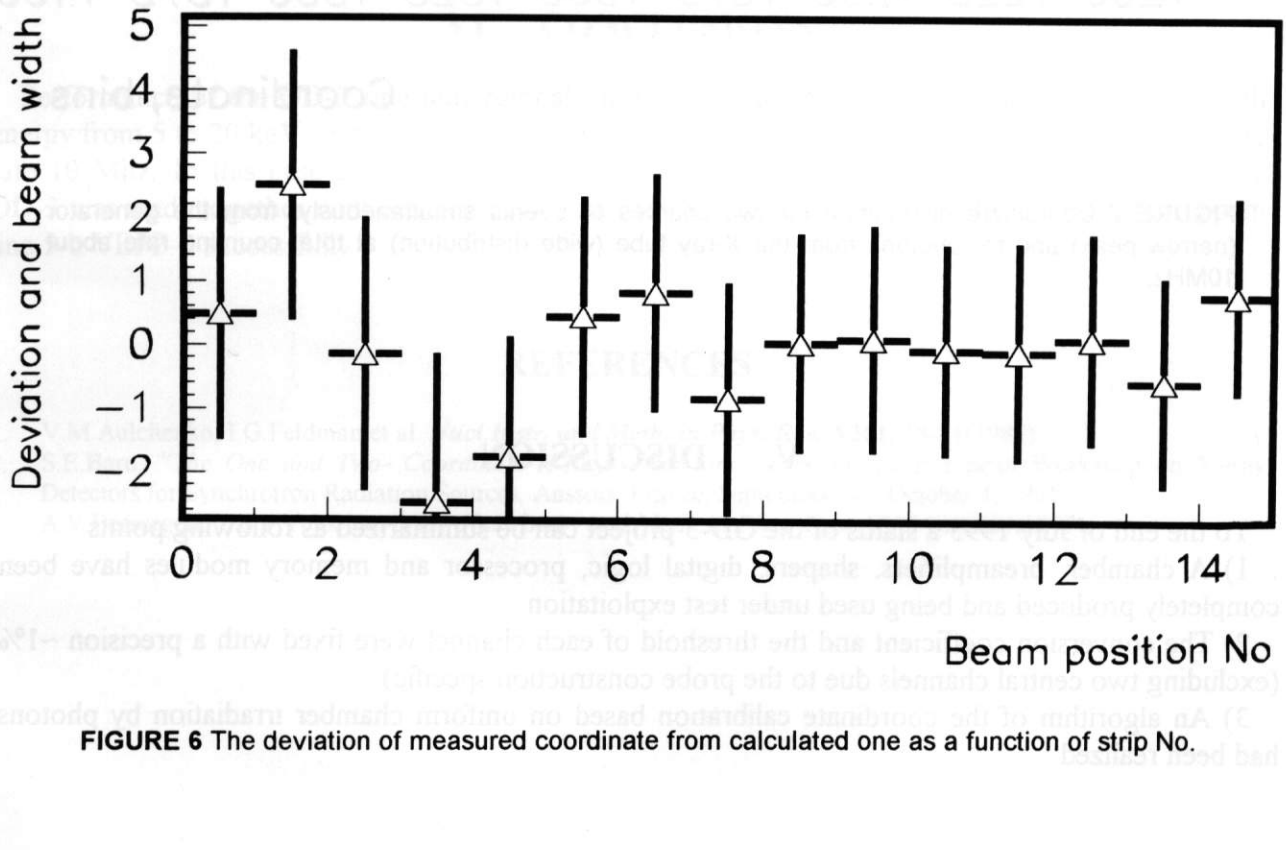

FIGURE 6 The deviation of measured coordinate from calculated one as a function of strip No.

The X-ray tube URS-0.02 (0.05 mm focus size) was used as a second source of signals.

Figure 7 shows a superposition of two sources of signals from generator and X-ray tube. The generator gave signals near channel number 1310. Photons from the X-ray tube had a wide distribution over all channels. The generator gave a constant frequency - 50 KHz. The intensity from X-ray tube was increasing step by step. When the intensity from X-ray tube was smaller then 10 MHz (~200 KHz per each strip) we had not seen any changes with the coordinate distribution from generator.

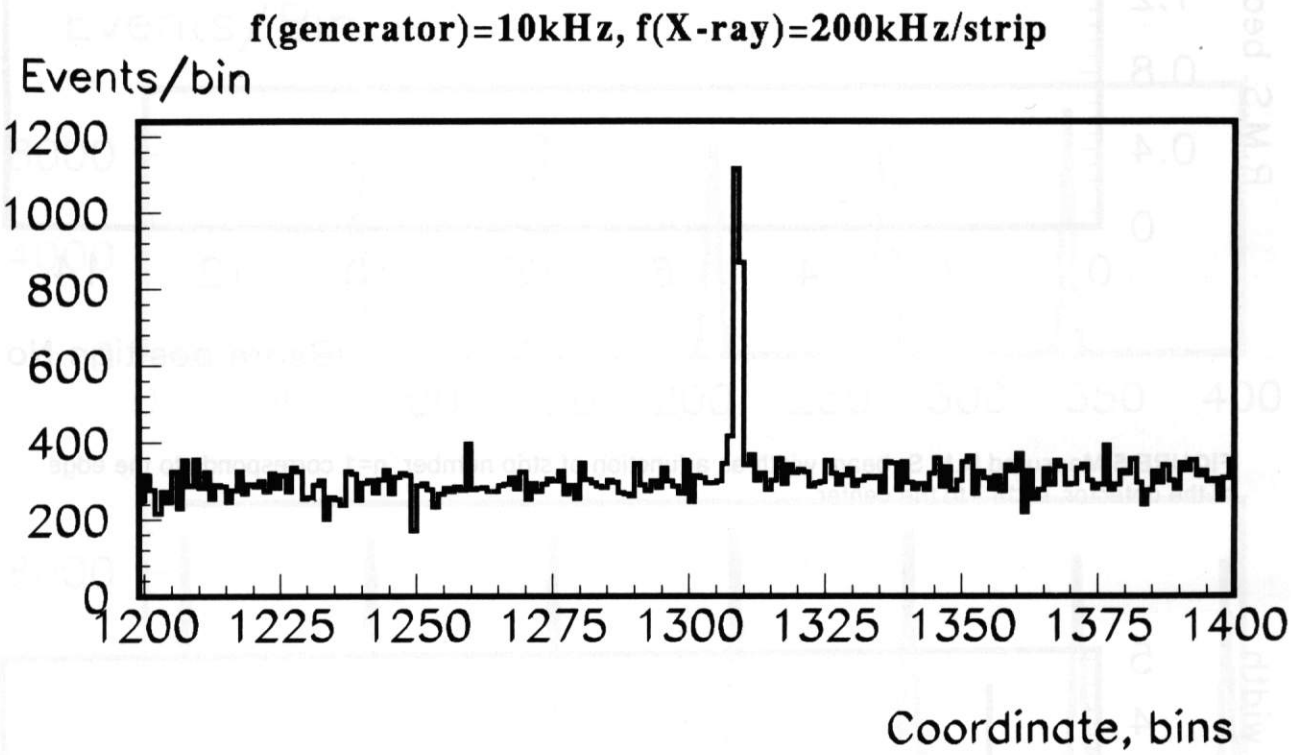

FIGURE 7 Coordinate distribution for two sources of events simultaneously: from the generator (narrow peak) and for photons from the X-ray tube (wide distribution) at total counting rate about 10MHz.

V. DISCUSSION

To the end of July 1995 a status of the OD-3 project can be summarized as following points.

1) A chamber, preamplifiers, shapers, digital logic, processor and memory modules have been completely produced and being used under test exploitation.

2) The conversion coefficient and the threshold of each channel were fixed with a precision ~1% (excluding two central channels due to the probe construction specific)

3) An algorithm of the coordinate calibration based on uniform chamber irradiation by photons had been realized.

4) The first test of the chamber with isotope Fe_{55} had showed: chamber demonstrated a stable operation even without gas flow till a one week at least; a gas amplification coefficient can be fixed with a dispersion <20% for different anode wires groups.

5) Beam test on the SR station 5b of the VEPP-3 complex had shown:

- there is possible to adjustment the chamber focus with necessary precision ~0.5 mm around turning axis;
- a coordinate resolution ~1.5 bins (r.m.s. in terms of 1/64 from the strip width) without subtraction of the itself beam size was measured in the central part of the chamber. This value increases up to 2.2 bins to the edge part of the chamber, that probably can be considered as a parallax influence.
- obtained coordinate resolution is close to the declared one.

6) Maximum rate capability test had been done with X-ray tube. Previous conclusion means that detector can operate at the maximum counting rate up to ~10 MHz without significant coordinate resolution degradation.

7) The computer program for OD-3 operation had been created. It provides a wide possibilities of manipulation with detector.

The principal problems which must be solved to the end of research exploitation.

1) Test exploitation shows that a quality of coordinate calibration depends on the spectrum of the signals. A simple solution of this problem is to make calibration in condition similar to the experimental one as close as possible. But still this question must be considered in detail.

2) An integer conversion of logarithmical amplitude ratio into the coordinate leads to the systematical bin width dispersion ~10% (it's clear to see the similar effect at Figure 4). This effect must be accounted at final image reconstruction that was not done still.

VI. CONCLUSIONS

Performance of the OD-3 one-dimensional photon detector has been studied. The photons with energy from 5 to 20 keV scattered inside the angle ± 15 can be detected with the maximum counting rate 10 Mhz. In this case a parallax-free coordinate resolution is ~100 mm. The chamber of the OD-3 was made together with electronics and first test has been done on synchrotron radiation beam line 5-b VEPP-3 successfully.

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