ICANS-VI

INTERNATIONAL COLLABORATION ON ADVANCED NEUTRON SOURCE

June 27 - July 2, 1982

A LINEAR POSITION SENSITIVE NEUTRON DETECTOR USING FIBRE OPTIC ENCODED SCINTILLATORS

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ABSTRACT

A linear position sensitive slow neutron detector with 3 mm resolution is described. It uses the fibre optic coding principle in which the resolution elements are separate pieces of lithium loaded glass scintillator each coupled by means of flexible polymer optical fibres to a unique combination of 3 photo multipliers (PM's) out of a bank of 12. A decoder circuit responds to a triple coincidence between PM outputs and generates a 12 bit word which identifies the scintillator element which stopped the incident neutron. Some details of the construction and decoding electronics are given together with test results obtained using a laboratory isotope neutron source and a monochomated, collimated neutron beam from a reactor. The count rate in the absence of neutron sources is 2-3 c min^{-1} per element; the element to element variation in response to a uniform flux is a few percent for 95% of the elements; the resolution as measured by a 1 mm wide prode neutron beam is 3 mm; the relative long term stability is about 0.1% over 3 days and the detection efficiency measured by comparison with an end windowed, high pressure gas counter is about 65% at a neutron wavelength of 0.9A^{o}.

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1. INTRODUCTION

The principle of fibre optic encoded neutron detectors has been described elsewhere[1][2]. This paper describes the properties of a linear detector module made to meet a specification for a 1600 element, high count rate detector for the proposed D20 powder diffractometer at ILL. The geometry and method of construction are briefly given together with measurements of uniformity of response, stability, intrinsic background, resolution and detection efficiency which were made using a laboratory neutron source and a collimated, monochromated neutron beam on the PANDA diffractometer at the Harwell PLUTO reactor.

2. GEOMETRY AND CONSTRUCTION

The basic geometry required for D20 is a linear array of 1600 resolution elements 3 mm wide by 150 mm high arranged as a "banana" detector on a radius of 1800 mm. A 100 element module with this geometry has been built, as shown in Fig.1, using the fibre optic encoding principle, in which each element is optically coupled to a unique combination of 3 photomultipliers (PM's) out of a bank of 12. The fibres are 1 mm diameter coated polymer type FP supplied in the UK by Optronic Fort Ltd of Cambridge. These have a numerical aperture of 0.5 (acceptance angle from air $\sim 30^{\circ}$) and a transmission of about 75% per metre at the wavelength of the light emitted by the scintillator which is lithium glass in this case (NE 905). Each resolution element is in the form of three pieces of scintillator 3 mm x 50 mm, with 3 fibres coupling to the end of each, as shown in Fig.1. Self absorption in the scintillator glass prevents the use of elements longer than about 50 mm. Each element is also a double layer giving a total thickness of 2 mm. These two layers are coded as separate elements, ie the module has really 200 elements. The reason for this is to afford a degree of γ discrimination because a Compton recoil electron from a γ absorption event is likely to penetrate more than one element and the electronic decoder rejects simultaneous counts from 2 elements. The dead space between elements is 0.1 mm.

In this arrangement a neutron event is identified by a triple coincidence in a bank of 12 PM's. These are EMI type 9843A, a low cost, 38 mm diameter end-windowed tube with a good single photoelectron pulse height distribution but moderate gain, and a typical operating voltage of 900 v. The PM's are optically coupled to the bundles of fibres at an angle of 25° to minimise the possibility of light being reflected from the PM back up the fibres, an effect which is believed to cause an undesirable form of cross-talk between elements. The number of elements coupled to each PM and to each combination of 3 PM's are 55 and 136 respectively.

The whole assembly is contained in an aluminium alloy light-tight box with the dimensions shown in Fig.1 which illustrates the compact nature of the design, allowing shielding to be placed close to the scintillator.

3. ELECTRONICS

The principle of the decoder is illustrated in Fig.2[3]. The number of the elements, A, can have a value between 1 and 200. X, Y and Z are the numbers of the particular PM's in the triple coincidence which codes for A. With the code used, for every pair of values of X and Y there is a number D such that D = A-Z as shown in Fig.2 for the first few values of A. This property is used in the circuit shown schematically in Fig.3. Each PM output is passed to a Le Croy MVL100 amplifier/discriminator chip where pulse height discrimination takes place at a level of about 1 mV. Logic pulses from these chips are passed to a circuit which produces an output, the validity signal, if 3 or more inputs are present within a time window of 200 ns. This output starts the sequence controller. For a "good" event 3 and only 3 input lines will have signals. These are presented simultaneously, by a special circuit, to a 16 bit pattern register. The sequence is stopped if the number of bits latched is more than 3. Next a priority encoder reads, in turn, the positions of the 3 set bits (X, Y and Z) and encodes them as 4 bit numbers in 3 registers, as shown. X and Y address a Read Only Memory which contains the values of D. This process is performed in parallel with the transfer of the third bit into the Z register. Finally, D is added to Z to produce a 12 bit position descriptor. The decoder is capable of handling 16 PM's (ie 560 elements) but only 12 are used for the D20 module. The time to decode is at present 400 ns but this time is being reduced to ∿ 100 ns using faster circuits.

4. PERFORMANCE MEASUREMENTS

4.1 Uniformity of Response

The detector was exposed to a 5 curie Pu/Be laboratory neutron source with a polyethylene moderator. The neutron flux at the detector position is roughly 5 n cm^{-2} s^{-1}. Fig.4 shows the result of a 6 h count. The general shape of the plot is due to the distribution of flux from the source which is not quite uniform. This is shown by the fact that if the detector is moved the same shape appears on a different set of elements. The element to element variation is a few per cent with one or two exceptions. The low count on the first element is because this one has only 5 pieces of scintillator rather than 6.

4.2 Intrinsic Background

The detector was placed about 10 m from the laboratory source and completely shielded by 30 cm of B_4C loaded plastic blocks. On an overnight run the average count recorded was 0.5 c min^{-1} cm^{-2}. The count per element varied between 2 and 3 c min^{-1}. This compares to about 10 c h^{-1} per element for an equivalent high pressure gas counter.

4.3 Stability

The relative long term stability from element to element was measured using the laboratory source over a period of 3 days 6 h. A million counts were accumulated in one particular element and the counts in all other elements recorded at that time. The average counts in 10 elements near the centre of the detector was found and used to normalise all subsequent counts which were taken every 2½ hours. This procedure does not reveal identical systematic changes in all the elements. The results are shown in Fig.5 and are about what would be expected from statistical variations. Subsequent absolute measurements (simply recording the counts in a given time) show small systematic changes in all elements which may be temperature effects. The room in which these measurements are made has large temperature variations. It may be that a simple temperature stabilising system is needed for the very best stability to be achieved.

4.4 Resolution

Measurements of the spatial resolution were carried out on the PANDA powder diffractometer at the Harwell PLUTO reactor using the normal specimen arm to move the D20 module behind a fixed vertical slit which defined the test neutron beam. The "slit" was made up from boron loaded resin shielding blocks, 30 cm high separated by thin spacers. To obtain a reasonable beam intensity, the full height of the PANDA beam was used, viz about 40 mm, though the vertical intensity distribution was highly non-uniform being sharply peaked. For scanning this slit beam across the elements the detector module was mounted in the normal orientation and to scan along the 150 mm dimension it was turned through 90°.

Fig.6 shows the results of a scan across a few elements in the centre of the detector. The full width at half height is 3 mm as expected. The level of the wings on either side of the response curves for each element was reduced in later mesurements by reducing the intensity in the beam with an extra lead collimator. (These measurements were all done in the direct beam from the PANDA monochromator where the radiation level measured by a β-γ monitor was 2r h^{-1}).

Fig.7 shows the results of a scan along the 150 mm dimension of an element. The small gaps between the three sections can be seen. The detection efficiency falls slightly near the end of the scintillator remote from the fibres due to attentuation of the light intensity in the scintillator itself. It also falls at the fibre end because for a small fraction of the neutron absorption events which occur very close to one fibre light cannot enter the other two fibres directly since the line of sight is outside the acceptance angle. These events may not be counted. The latter effect could be eliminated by interposing a short length of non-scintillating "stand-off" light guide between the fibres and the scintillator, at the cost of increased complexity during assembly.

4.5 Detection Efficiency

The detection efficiency was measured by comparing the response of the detector to a 10 mm diameter beam with that of an end-windowed ^{3}He detector to the same beam. The ^{3}He detector was an LMT type 43NH10/-5AX, 10 cm long with a 4 mm thick alumina window. Summing the counts on these elements exposed to the beam, the total was 67% of the count on the ^{3}He detector with neutrons of wavelength 0.9 Å. The stopping power of 10 cm of ^{3}He at 5 atmospheres is 97%. Losses in the ceramic window are approximately the same as those in the aluminium window of the PSD plus the losses due to dead space between the elements. An estimate of the absolute efficiency of the scintillator itself is thus 67 x .97 = 65%. The theoretical stopping power of 2 mm of NE905 scintillator for neutrons of wavelength 0.9 Å is 78%, so there may be some electronic losses. The efficiency scaled to a neutron wavelength of 1 Å is 69%.

5. CONCLUSIONS

The edge coupled fibre optic coded PSD using lithium glass sintillator has been demonstrated. It has good detection efficiency, stability and resolution. The module has proved reliable and has been moved many times to different neutron sources with no problems. The maximum countrate capability has not yet been measured due to lack of an intense neutron beam but is expected to meet the specificaion for the proposed D20 instrument at ILL, viz: maximum countrte for one element - 10^5 c s^{-1} with 10% dead time losses and 5 x 10^6 c s^{-1} for the whole 1600 element detector.

The countrate in the absence of neutrons is 2-3 c $\min^{-1}$ per element, considerably higher than the equivalent gas counter but adequately low for high countrate applications or for use on pulsed sources such as the SNS.

The constructional techniques are straightforward though tedious, the time consuming element being the fixing of the scintillator tiles not making the fibre optic encoder. The compact design allows large area detectors to be made by stacking modules without the containment problems associated with high pressure gas detectors.

ACKNOWLEDGEMENTS

The authors would like to thank Mr C Moreton-Smith, Mr E M Mott and Mr J C Sutherland for their work on various aspects of the fibre optic coded detector development.

REFERENCES

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2. Position Sensitive Slow Neutron Detectors Using Fibre Optic Encoding, P L Davidson and H Wroe, Proc ICANS IV, Oct 1980. (KENS Report II, March 1981, pp.642-649).
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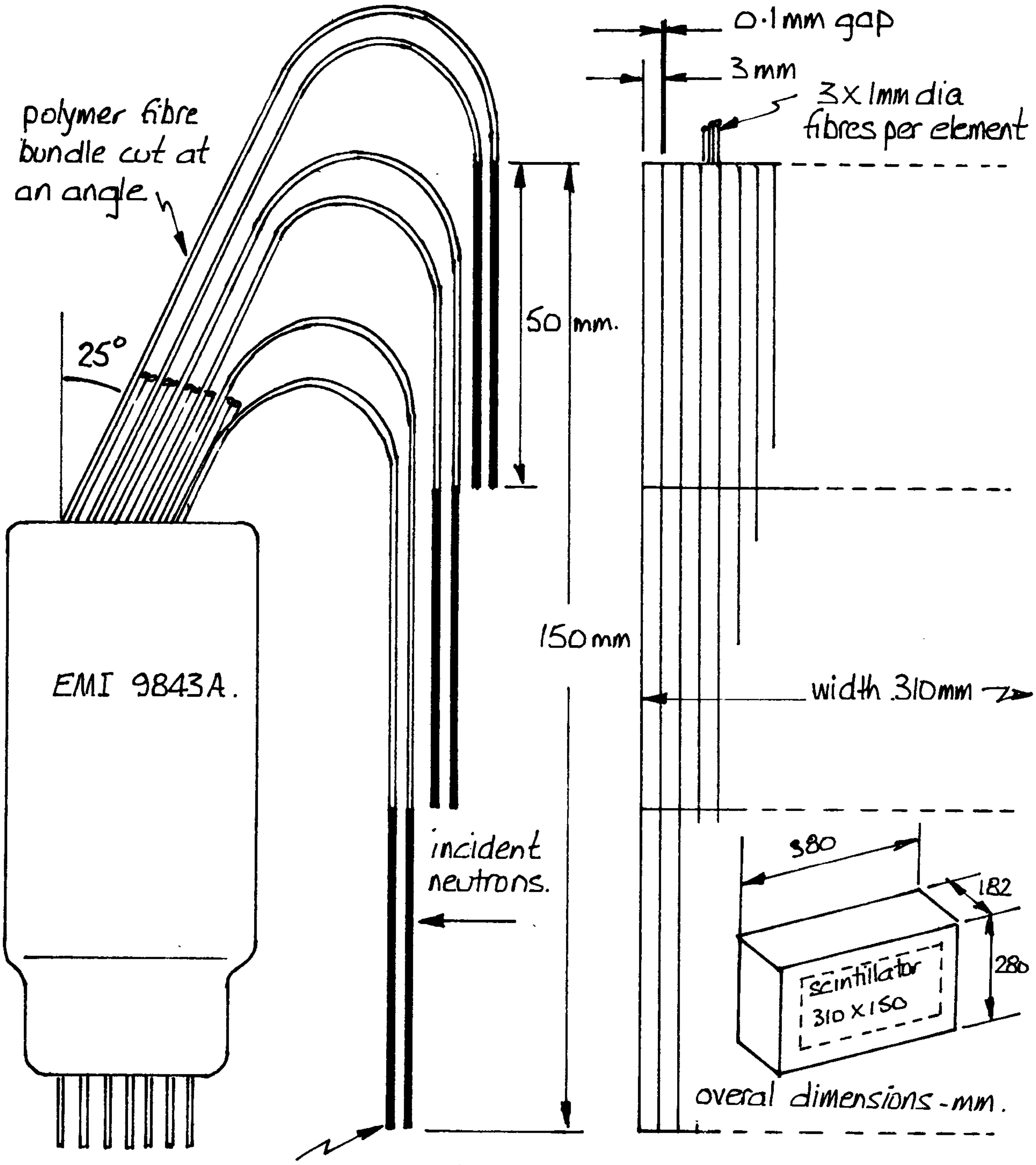

2 layers of 1mm thick scintillator coded as separate detectors ie 200 elements; 600 scintillator 'tiles' in all on a radius of 1800mm.

Fig. 1. Schematic arrangement of detector showing main dimensions.

Element No. A	Photomultiplier No.																X	Y	Z	D= A-Z
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16				
1	x	x	x														1	2	3	-2
2	x	x		x													1	2	4	-2
3	x	x			x												1	2	5	-2
4	x	x				x											1	2	6	-2
5	x	x					x										1	2	7	-2
6	x	x						x									1	2	8	-2
7	x	x							x								1	2	9	-2
8	x	x								x							1	2	10	-2
15		x	x	x													2	3	4	+11
16		x	x		x												2	3	5	+11
17		x	x			x											2	3	6	+11
18		x	x				x										2	3	7	+11

Fig. 2

Illustrating the code and parameters used in decoding

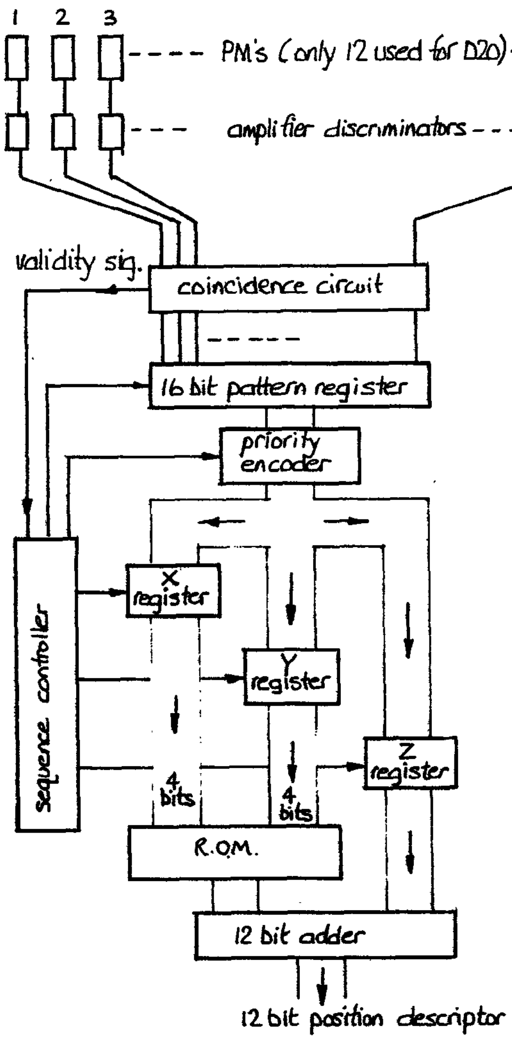

Fig. 3

Schematic of decoder

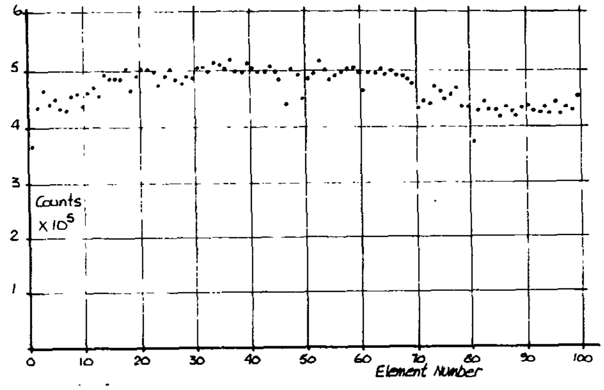

Fig. 4

Response to Laboratory Neutron Source.

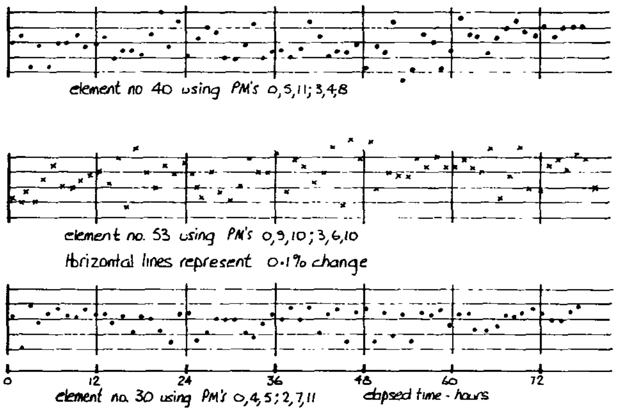

Fig. 5

Relative stability on laboratory source; April 30-May 3 1982.

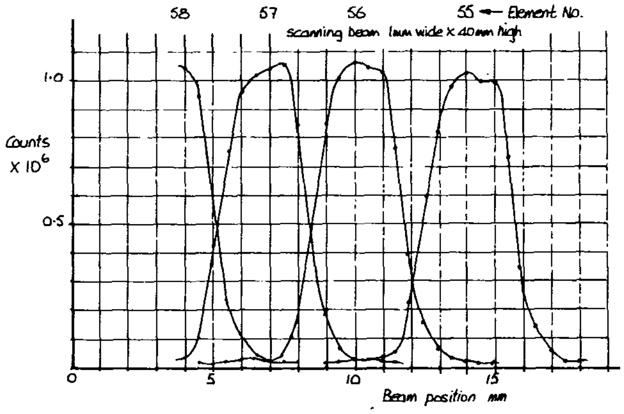

Fig. 6

Horizontal scan across centre of elements.

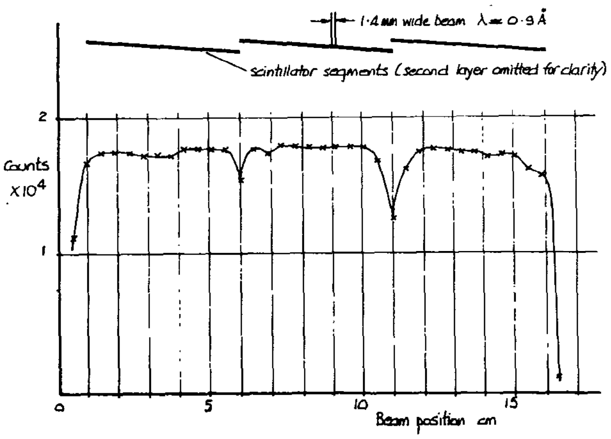

Fig. 7

Vertical scan along an element.