PRE-TRIGGERED FLASH TUBES FOR PARTICLE DETECTION*

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A new form of flash tube has been investigated as a particle detector, with special interest in its performance at liquid nitrogen temperature. The results indicate that the tubes count efficiently and with sufficiently good time resolution to be able to assist in resolving independent events in bubble-chamber neutrino pictures.

1. Introduction

It is difficult to find a particle detector which gives good time resolution, covers a large area with some spatial resolution and which will work reliably when mounted inside a bubble chamber. Scintillation counters require too large an area of light-guide to be brought through the walls of the chamber. Multiwire proportional chambers cannot operate at cryogenic temperatures. Solid argon ionisation chambers¹⁾ give such a weak signal that their pre-amplifiers would need to be mounted close to the detector in a harsh and inaccessible environment. In a search for some suitable Internal Fast Detector (I.F.D.) to be placed inside the large CERN bubble chamber BEBC, a new mode of operation of flash tubes has been investigated^{2,3)}. The results, reported here, suggest that a simple and robust flash-tube system can be developed which will provide important extra information in the analysis of neutrino pictures from BEBC.

The novelty in these investigations was to operate flash tubes with a square high-tension pulse of a few milliseconds duration. Each tube was sensitive to the first charged particle which passed through it after the start of the pulse. This is in contrast to normal flash tubes which are pulsed af-

ter the particles have already passed through and been detected by a scintillator trigger³⁾.

2. Apparatus

The square ht pulse was generated using a hydrogen-thyratron pulser connected to a high voltage generator. Pulses of between 3 and 17 kV were delivered to the flash-tube electrodes, with a duration that could be varied from a few hundred microseconds to a few milliseconds. The rise time was about 10 μ s and the fall-off time, after the flat-top of the pulse, about 1 ms.

Two sets of flash tubes were used for these studies. The first set of eight tubes were of sandwich construction, each bank of tubes being made by sticking transparent Lexan⁴⁾ sheet, 1 mm thick, over the two faces of a 10 mm thick transparent Lexan spacer into which four parallel slots had been milled, each 15 mm wide by 313 mm long. Gas was supplied to the tubes in series and a brass probe 1 mm in diameter projected 8 mm into the end of each tube. Aluminium electrodes were clamped around the two banks of tubes, with the ht electrode in the middle and the two ground electrodes on the outside (see fig. 1). The ht electrode stopped about 20 mm short of the ends of the tubes, so that the tips of the probes lay outside the high field region. The probes were connected to NIM discriminators by 30 m of 50 Ω signal cables, with the sheaths connected to the ground electrodes. Holes in the electrodes allowed β -rays from a ¹⁰⁶Ru source to penetrate into any one of the tubes.

* Work done at CERN. A fuller account of this work is available as a CERN report.

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Fig. 1. The layout of the two sets of flash tubes in the beam from the CERN P.S. S_1 and S_2 are scintillation counters. T_A and T_B are the pair of tubes from the transparent set which were counted in coincidence.

After some experience with these "transparent tubes" a second set of three "wrapped tubes" was made. These were separate single tubes, each with 8 mm inside diameter by 300 mm long, made by boring through a transparent Lexan rod which was milled down to a rectangular external section 11 mm $\times$ 16 mm. Lexan plugs were stuck into the ends and gas channels were provided so that the tubes could be connected in parallel. A brass probe in each tube reached to the edge of the high-field region. Copper foil electrodes were placed on both 16 mm faces of two of the tubes and stuck down by folding a piece of black PVC tape over the tube and the foil (see fig. 1). The tubes were bound together so that no light could get into them from outside or pass from one tube to another. The four foil electrodes were connected alternately to the ht supply and to ground and the probes were connected, as before, to 50 Ω signal cables. Since the tube walls were thin, tests with the β -source could be made very simply by placing it in contact with the wrapping of one of the three tubes.

The gas in the tubes was Henogal (75% Ne–25% He mixture) at slightly above atmospheric pressure. For certain tests, as mentioned below, small amounts of nitrogen or hydrogen were added.

3. Tests with the transparent tubes

At room temperature, with the β source, an investigation was made of the factors which caused variations in the performance of the tubes. Three aspects of performance were looked for; noise counts without source, crosstalk between adjacent tubes and genuine counts due to β -rays. The noise counts were found to increase with the rate of gas flow, with the ht pulse voltage and with the am-

bient lighting intensity. Noise counts were also more probable if the tube had just flashed on a previous pulse. Crosstalk was caused by visible light from one tube triggering a flash in adjacent tubes. The crosstalk was worst in the same conditions which gave rise to high noise rates; i.e. with a high gas flow (~ 1 l/min) and a high voltage ≥ 7 kV. With a lower gas flow (~ 0.1 l/min) it was possible to reduce noise and crosstalk to a low level, and to see clear β -ray pulses coming from the probe in the tube over which the source had been placed. In these conditions there was a clear counting plateau over the range of ht voltages from 4 to 7 kV. The height of the pulses from the probes was proportional to the termination resistance of the signal cables. With 6.5 kV on the ht supply the pulse heights were 100–200 mV into 50 Ω , 2–3 V into 1000 Ω and well over 40 V into the high impedance oscilloscope input. All counting with the transparent tubes was done using a discriminator with a 50 Ω input impedance and a bias of between 40 and 70 mV. The rise-time of the pulses was ~ 200 ns as observed at the end of ~ 30 m of cable.

A special test was made with the probes from two adjacent tubes connected to one coaxial signal cable. When one tube flashed the other one did not break down, though a normal pulse was observed on the cable. Occasionally a second pulse would be seen on the signal cable due to the two tubes flashing separately at different times. Only in this situation with two tubes connected in parallel, did two signal pulses appear on the same cable during one ht pulse. Otherwise the tubes always were dead once they had fired, until the high voltage was removed. But within a few hundred microseconds of the removal of the high

voltage, tubes which had flashed were observed to flash for a second time, and also to give a simultaneous signal pulse of the opposite sense to the primary signal pulse. These "return pulses" were interpreted as the discharge of ionisation from the walls of the tubes which had been held there after the plasma of the primary discharge had quenched.

With a particle beam from the CERN proton synchrotron passing through the tubes, as shown in fig. 1, a number of coincidence combinations were set up between the tubes and the scintillators S_1 and S_2 . At low gas flow, with an ht voltage of 8.5 kV, tubes T_A and T_B counted in coincidence with better than 90% efficiency. Due to crosstalk between tubes in the same bank, more detailed studies of efficiency were delayed until the wrapped tubes were available (see below).

The advantage of Lexan over plexiglass is that it can be cooled to cryogenic temperatures without becoming brittle. As a first test of the low temperature performance of flash tubes, avoiding the complications of working at liquid hydrogen temperature, the transparent tubes and their electrodes were immersed in liquid nitrogen in a glass Dewar. When the ht pulse was first applied to the tubes, after cooling down, they gave signals from the beam in the same way as when warm, but after a few hundred pulses they began to flash as soon as the ht was applied, without waiting for a particle to arrive. A number of unsuccessful techniques were used to try and suppress this early-pulsing; a reverse cleaning field, a rest of a few minutes from ht pulses, variations in the rate of gas flow, the addition of nitrogen to the gas. Finally it was suggested⁵⁾ that a small amount of hydrogen should be added to the Henogal flow. This immediately cured the early pulses and the tubes began to behave when cold in the same way as they had done warm. Further cold studies were carried out with the wrapped tubes.

4. Tests with the wrapped tubes

Because the probes in the wrapped tubes penetrated right to the edge of the glowing plasma the pulse-height into 50 Ω was larger than before; 3 or 4 V with an applied ht of 6 kV. At higher ht voltages this gave rise to electronic crosstalk between the signal cables at first, but this was eliminated by careful screening and by adding a 9.1 Ω resistor directly between each probe and the grounded sheath of its signal cable. The rise time of the sig-

nal pulses was less than 100 ns and the falling edge had a decay time of about 200 ns.

After successful tests with the β -ray source, the tubes were placed in the beam (see fig. 1). Singles counts from scintillator S_1 and the tubes T_1 , T_2 and T_3 were recorded, and coincidences were set up for $S_1 \cdot S_2$, $T_1 \cdot T_3$, $t_1 \cdot T_2 \cdot T_3$ and $S_1 \cdot T_1$. To simulate the dead-time of a flash tube, only the first $S_1 \cdot S_2$ count was recorded within the counting gate which covered the flat-top of the ht pulse. The area of scintillator S_2 was approximately the same as that of a flash tube so this combination provided a good normalisation for variations in beam intensity. The $S_1 \cdot T_1$ coincidence was used to trigger a pulse-height analyser on which the distribution of delay times was recorded between the scintillator pulse and the flash tube pulse. The ratio of the $T_1 \cdot T_2 \cdot T_3 / T_1 \cdot T_3$ coincidences gave an estimate of the efficiency of tube T_2 .

Fig. 2a shows the variation of some of these counts with ht voltage. The counting statistics are low because only one count could be accepted per cycle of the proton synchrotron. Nevertheless, very clear plateaux can be seen. The reduction of $S_1 \cdot T_1$ coincidences, compared with T_2 singles, at the highest voltages is due to noise on tube T_1 . The ratios $T_1 \cdot T_2 \cdot T_3 / T_1 \cdot T_3$ and $S_1 \cdot T_1 / T_2$ are slightly less than 1.0 due to the high rate of singles counts, coming from neutral and uncollimated particles in the test beam. These ratios varied according to the thickness of the equipment which upstream users were testing. When these background effects were allowed for, the efficiency of tube T_2 was consistent with 100%, with no sign of any noise or crosstalk from 6 to 16 kV.

For the cold tests it was necessary to put more material very close to the flash tubes: a copper gas-cooling coil, the glass Dewar and the liquid nitrogen. Preliminary checks with the warm tubes showed that such material increased the background singles rates even more, compared with the good beam. Thus it is not surprising that, in fig. 2b, the $S_1 \cdot T_1$ counts rise to a smaller fraction of the T_2 singles rate than in fig. 2a. Nevertheless, when background singles are unfolded from the points in fig. 2b, especially the high statistics points at 9 kV and 10 kV, the efficiency of T_2 was again consistent with 100%. Because of the crude gas system used, it was necessary to keep the Henogal flow at about 1 l/min in order to dilute the smallest controllable hydrogen flow, and the tubes were connected in a way which led T_1 to re-

Fig. 2. Plateau curves for the wrapped tubes, (a) at room temperature, (b) in liquid nitrogen. The lower plots are normalised to 25 counts of the $S_1 \cdot S_2$ coincidence with simulated dead-time (see text). The straight lines are merely to guide the eye.

ceive a disproportionate share at high rates of flow. This accounts for the increase of noise on tube T_1 which can be seen in the drop of $S_1 \cdot T_1$ coincidences at higher voltages. Tubes T_2 and T_3 were a great deal less noisy than T_1 , as judged by their counting rates without beam, and fig. 2b shows no sign of noise effects on T_2 even at 16 kV.

The time delay between pulses from scintillator S_1 and from tube T_1 was converted to a pulse-height and histogrammed on a pulse-height analyser. The time-jitter of the flash-tube signals was taken to be the range of delay times containing 90% of $S_1 \cdot T_1$ coincidences. With the wrapped tubes warm the time-jitter was 80 ns at 10 kV and 110 ns at 6 kV. With the wrapped tubes in liquid nitrogen the time-jitter was 420 ns at 10 kV and 585 ns at 9 kV.

5. Conclusions

Flash tubes made from Lexan can be operated

in a pre-triggered mode at a repetition rate compatible with bubble-chamber neutrino experiments. Their efficiency is high over a finite range of applied voltages, both at room temperature and at liquid nitrogen temperature. Pulses can be extracted on conducting probes which reach into the gas of the tubes. The pulses are large enough to drive a NIM discriminator without pre-amplification. They have a rise time of ~ 100 ns and a time jitter of a few hundred ns.

Further tests are continuing to investigate the performance of pre-triggered flash tubes at liquid hydrogen temperature, to understand the quenching of early pulses by hydrogen, to look for other quenching techniques and to develop suitable large area modules which could be mounted on the inner wall of the BEBC bubble chamber at CERN.

I. Mannelli first suggested this form of flash tube and took part in the earlier tests at CERN²⁾. We are grateful for advice and encouragement from M. Conversi and C. Peyrou; also for help from G. Trouillier, A. Rudge, T. Broome, M. Firth, J. Tischauser, M. Thevenon, H. Leutz, W. Willis and C. Fabian.

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- 4) Lexan is the tradename for polycarbonate plastic, manufactured by the General Electric Company, U.S.A.
- 5) Use of H_2 was suggested independently by M. Conversi and C. Peyrou.