A SONIC SPARK CHAMBER SYSTEM USING LONG MICROPHONES

B.D. JONES and J. MALOS

H.H. Wills Physics Laboratory, University of Bristol, Bristol.

W. GALBRAITH and G. MANNING

Rutherford High Energy Laboratory, Chilton.

(presented by G. Manning)

1. INTRODUCTION

This paper reports on the development of long microphones for use in sonic spark chambers. Details are given of tests carried out with these microphones in chambers designed for use in an experiment on elastic charge exchange scattering of neutrons by protons. The experimental arrangement will be described together with the computational procedures that are used in the data analysis.

2. EVALUATION OF SPARK COORDINATES USING FOUR LONG MICROPHONES

Four long microphones are arranged in a rectangle to completely surround the sensitive area of the spark chamber, see Fig. 1. The time interval between the occurrence of the spark and the first sound wave reaching the microphones are recorded by suitably gating scalers counting on 8 Mc/s oscillator, resulting in four numbers N_1, N_2, N_3 and N_4.

The spark coordinates can then be written as:

$$\left.\begin{aligned} x &= N_3\,\nu + \Delta - X = X - N_4\,\nu - \Delta \\ y &= N_1\,\nu + \Delta - Y = Y - N_2\,\nu - \Delta \end{aligned}\right\} \qquad (1)$$

where ν is the velocity of sound in the gas and Δ is a constant determined by the timing delay used before opening the gates of the timing scalers and the effective size of the spark.

Solving equation 1:

$$\left.\begin{aligned} x &= \frac{(N_3 - N_4)\,(X - Y)}{N_3 + N_4 - N_1 - N_2} \qquad & y &= \frac{(N_1 - N_2)\,(X - Y)}{N_3 + N_4 - N_1 - N_2} \\ \nu &= \frac{2(X - Y)}{N_3 + N_4 - N_1 - N_2} \qquad & \Delta &= X - \frac{(N_3 + N_4)\,(X - Y)}{N_3 + N_4 - N_1 - N_2} \end{aligned}\right\} \qquad (2)$$

Figure 2 shows the sensitivity of the determination of the spark coordinates to errors in the distances recorded by individual microphones. The curves have been evaluated assuming that these errors are equal for all probes (δ) and they have been combined to give a root mean square error ($\langle dx \rangle$ or $\langle dy \rangle$).

$$\frac{\langle dx \rangle}{\delta} = \left[\frac{1}{2} + \frac{x^2}{(X - Y)^2}\right]^{\frac{1}{2}}$$

$$\frac{\langle dy \rangle}{\delta} = \left[\frac{1}{2} + \frac{y^2}{(X - Y)^2}\right]^{\frac{1}{2}}$$

It can be seen that if one is to use this type of analysis, square or nearly square chambers should be avoided.

2.1 Advantages of long microphones over conventional point microphones

The use of long microphones offers several advantages over conventional point detectors:

i) The calculation of spark coordinates is made very simple (see equation 2). (The corresponding calculation for four point detectors involves the solution of four simultaneous quadratic equations.) This makes the production of an analogue display of the spark coordinates very simple.

ii) The sum of the times recorded by opposite microphones is independent of spark position and is constant within limits set by variations of velocity and effective spark size. This forms a useful control during the testing and setting-up of the spark chambers and is also a check against multiple sparks. The equivalent check for point detectors can in general only be made after determining the spark coordinates.

iii) The variation in amplitude of the signal given by the long detector is less for sparks at different positions in the chamber than is the case for point detectors. This results because the earliest output always corresponds to the shortest, i.e., perpendicular, distance and also because the length of the microphone reached by the sound wave in a given short length of time increases as the square root of the distance between spark and detector. This latter effect gives a partial compensation for the reduction in amplitude of the sound wave.

2.2 Construction of microphones

Two types of microphones were constructed, electrostatic and piezoelectric. Fig. 3 shows the construction of both types. The piezoelectric microphones proved to be the best and they have been adopted for this experiment. Detectors of lengths from 25 to 110 cm have been made. The piezoelectric crystals used are lead zirconate titanate. The individual strips of 0.4 cm width, 0,1 cm thick and 7.5 cm long are cemented with conducting araldite to a brass backing bar which has been milled flat to within 0.005 cm. The silvered front faces of the crystals are soldered together.

2.3 Tests of microphones with test sparks

Figure 4 shows typical pulses from both types of detectors. The pulses from the piezoelectric microphones have rise times of the order of 1 μsec, and amplitude of a few millivolts. The output of the microphones is amplified (gain 200) and fed through 20 m of 50 Ω cable to the counting room. The pulses are detected there by tunnel diode discriminators set to trigger at 0.05 - 0.1 volts.

Figure 5 shows the amplitude observed for test sparks at different positions with respect to the microphone for typical detectors of both types. Fig. 6 shows times recorded for test sparks at fixed distances from different parts of the microphones. The error bars represent standard deviations for individual determinations of the times. It can be seen that a timing accuracy of better than 1 μsec can be achieved over the full length of the microphone.

2.4 Tests of microphones in single gap chambers

Four piezoelectric microphones were mounted in a single gap, thin plate, spark chamber and tests were made using β particles from a Sr^{90} source detected by two thin scintillators in coincidence to trigger the spark chamber. The chamber was accurately moved with respect to the source and scintillators and the average coordinates determined from about 100 sparks are compared with the coordinates set in Table 1. The deviations between set and evaluated coordinates have a root mean square value of 0.03 cm.

A further check was made by plotting histograms of the sums of times recorded by opposite probes, see Fig. 7. This also indicates that a standard deviation of 0.03 cm is expected for the determination of coordinates.

2.5 Tests of microphones in multiple gap systems

Groups of 3 or more gaps placed in a straight line have been triggered both by cosmic rays and an 8 GeV/c proton beam. A straight line was fitted to the recorded coordinates by a least squares method and the standard deviation errors determined for a large number of sparks. Fig 8 is a histogram for 3 gaps triggered by cosmic rays. The standard deviation is again seen to be about 0.03 cm.

These measurements also gave an efficiency for single gaps of greater than 99.5%.

3. EXPERIMENTAL ARRANGEMENT FOR CHARGE EXCHANGE SCATTERING EXPERIMENT

A neutral beam is taken at 0° from an internal target in NIMROD, γ-rays are absorbed by 7.5 cm of lead, the beam is collimated and passed through sweeping magnets resulting in a neutron beam of width about 5 cm and height about 8 cm. The beam is passed through a 60 cm long, 15 cm diameter hydrogen target and a trigger is formed by a coincidence between a threshold Cherenkov counter and momentum defining scintillation counters on either side of the spectrometer magnet. Anticoincidence counters before and around hydrogen target reject charged particles entering the system and bias against inelastic events. The scattering angle is determined by two spark chambers, 350 cm apart, before the magnet and the momentum by these and two further chambers also 350 cm apart after the magnet. The momentum resolution of the system is expected to be $\leq \frac{1}{2}\%$. The angular range covered is 0 - 45 mrad and the angular resolution will be ≤ 0.5 mrad.

The experiment will look for protons produced in the target of the full energy of the circulating beam in the proton synchrotron resulting from elastic charge exchange scattering both in the internal and external targets. The resolution required is that to distinguish an energy change of a pion mass in 8 GeV, i.e., $\leq 2\%$.

Three gaps are used for all spark chambers, each gap being fed by a separate condenser (1000 pF). The chambers are made with 0.003 cm aluminium plates mechanically stretched onto aluminium frames and stuck with araldite. The live plates have a window frame of mylar as insulation. The gap between the plates is 1 cm and is made gas tight by an inflated hollow gasket. Ne He (80% 20%) gas is used.

The microphones are shock mounted on small rubber rings from the aluminium channel frame forming the earth plate and are held in contact with positioning bolts which are accurately located (accuracy of ~ 0.005 cm) in jig-bored holes. The separation of the microphones is known to 0.01 cm.

4. ANALOGUE DISPLAY

The position of the sparks in all 12 gaps is reconstructed on a storage oscilloscope as an analogue display. This display shows as 12 dots the vertical trajectory of the particle and a further 12 show the horizontal trajectory. The demagnification for the vertical display is 2.5:1 permitting a resolution in real space of one or two millimetres. The horizontal demagnification is 25:1. This analogue display is extremely useful and allows any event to be immediately approximately analysed for scattering angle and momentum. It provides a constant monitor of the functioning of all 48 microphones.

5. COMPUTATIONAL DETAILS

The numbers registered by the scalers are recorded on punched paper tape which is later fed into a computer.

x, y, ν and Δ are evaluated for each gap using equations 2. The velocity for each gap is compared with an average velocity for that gap determined from the previous events and the solution is permitted providing the velocities do not differ by more than some predetermined amount (typically 1%). If the velocity test is passed a similar check is made using Δ. Here a typical limit of 0.05 cm is used. These two simple tests are found in practise to remove cases of two sparks and yet do not reduce the efficiency by rejecting good events.

Straight lines are then fitted to the evaluated coordinates in the horizontal and vertical plane before and after the magnet. There are a maximum of six possible sparks for each fit but events are accepted if some gaps have failed providing that at least two gaps give solutions for each chamber position. This requirement of only two gaps out of three is of considerable benefit as it results in a high efficiency even though the individual gaps have a few per cent inefficiency. In addition the experiment can continue even if a gap ceases to function completely.

The individual spark coordinates are compared with the straight lines fitted and gaps having deviations of greater than 0.05 cm are rejected and a new fit made. The final vertical plane trajectories are compared before and after the magnet to reject events in which the particle has been scattered in the vertical plane between the second and third spark chambers.

The scattering angle, bending angle in the magnet, and other relevant information can then be printed out or recorded on magnetic tape for further analysis and grouping.

The whole system is now operational and is at present undergoing tests in its final form.

ACKNOWLEDGEMENTS

We wish to acknowledge the help of Mr. B.T. Payne in the design and construction of the electronic equipment, and Messrs. A.G. Parham, J. Burrows and P.D. Day for valuable assistance.

The experiment on charge exchange scattering is being undertaken by the following physicists in addition to those concerned with the development of the microphones and chambers (who are listed as authors for this report); Drs. N.H. Lipman, D. Reading and R. Van der Raay, and Messrs. J. Jafar and D. Ryan.

TABLE I

Values read from calibrated screws		Mean Values computed by acoustic method				Differences between read and computed coordinates	
x cm	y cm	x cm	y cm	νcm/1/8 μsec	Δ cm	$\bar{\delta}x$	$\bar{\delta}y$
25.00	32.00	24.99	32.00	0.005871	0.61	0.01	0.00
25.00	39.00	25.01	38.96	0.005879	0.59	-0.01	0.04
3.00	39.00	3.02	38.97	0.005872	0.61	-0.02	0.03
3.00	32.00	3.05	32.03	0.005870	0.64	-0.05	-0.03
25.00	25.50	25.05	25.52	0.005882	0.58	-0.05	-0.02
47.00	39.00	47.06	38.94	0.005873	0.62	-0.05	0.06
47.00	32.00	47.00	31.99	0.005867	0.64	0.00	0.01
47.00	25.50	47.02	25.56	0.005866	0.62	-0.02	-0.05
25.00	32.00	24.99	32.01	0.005866	0.61	0.01	-0.01

Results of measurements in a spark chamber.

Comparison is made of mean spark coordinates as measured directly and as calculated by the acoustic method. Values of ν and Δ also given. Eight source positions are listed in chronological order. At each position sparks were produced in the chamber in a region 0.4 x 0.4 cm^2. About 100 readings were taken for each source position and an average was taken of the computed coordinates. The estimated standard deviation of the mean coordinates due to the source size is 0.013 cm. The values of Δ have been corrected for the delay introduced before starting the timing scalers and so represent effective spark sizes.

Figure captions

Fig. 1 Microphone geometry and labelling system. The microphones are numbered 1, 2, 3, 4. The origin of coordinates 0 is at the centre of the outer rectangle defined by the sensitive faces of the four microphones ($70.282 \times 34.722\ \text{cm}^2$). The inner rectangle represents the sensitive area ($50 \times 15\ \text{cm}^2$) of the chamber.

Fig. 2 Average accuracy of coordinate determination calculated for different spark positions and shapes of chamber.

Fig. 3 i) Section through electrostatic microphone

a) Aluminium alloy bar of $0.6 \times 3\ \text{cm}^2$, cross-section with a slot of $0.4 \times 0.6\ \text{cm}^2$ cross-section milled into it.

b) Alloy strip $0.2 \times 0.5\ \text{cm}^2$.

c) Araldite (MY 753 + HY 951) to support and insulate b).

d) Air gap of thickness 0.01 cm.

e) Aluminised mylar diaphragm. The mylar was 6μ m thick; the aluminized layer $\sim 1\ \text{m}\mu\text{m}$.

ii) Section through piezoelectric microphone

a) Brass bar $0.6 \times 2.5\ \text{cm}^2$.

b) Conducting araldite.

c) Crystal of lead zirconate titanate $0.4 \times 0.1\ \text{cm}^2$ silvered on upper and lower faces.

Fig. 4 Output wave form of piezoelectric (shown on left) and electrostatic microphones taken with a test spark at 20 cm. The vertical scales are 2 mV/cm (left) and 5 mV/cm, while the horizontal scales are 2 μsec/cm (upper left), 5 μsec/cm (upper right), 10 μsec/cm (lower left) and 20 μsec/cm (lower right).

Fig. 5 Amplitude of first pulse for piezoelectric (upper) and electrostatic microphones as a function of position of test spark. The discriminator levels used are shown. The arrows indicate the limits of the sensitive regions of the microphones.

Fig. 6 Intervals of time between the occurrence of sparks in air and the detection of sound at the piezoelectric (upper) and electrostatic microphones. The timing is seen to be constant within ~ 1 μsec corresponding to a spatial accuracy of ~ 0.3 mm. Each point represents the mean of ten readings and standard deviations for individual sparks are shown.

Fig. 7 Sums of times recorded by opposite pairs of microphones uncorrected for changes in $\sim$ or Δ . $1\,\mu$sec corresponds to 0.5 mm for the gas used in the chamber.

Fig. 8 Histogram of deviations of calculated spark coordinates from least squares fitted line. Results were obtained with 3 gaps. The abscissa is the square root of the sum of the squares of the deviations for the three sparks.

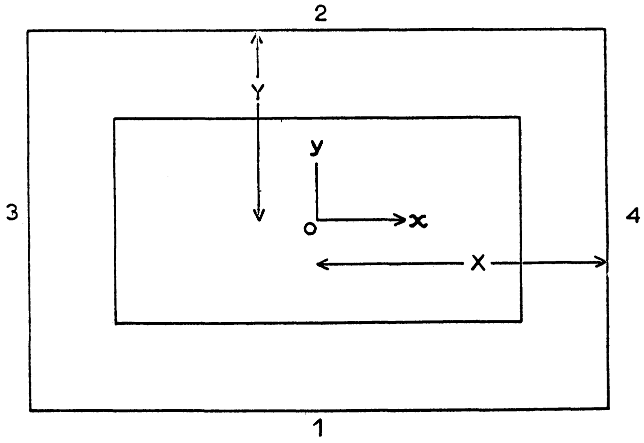


Fig. 1

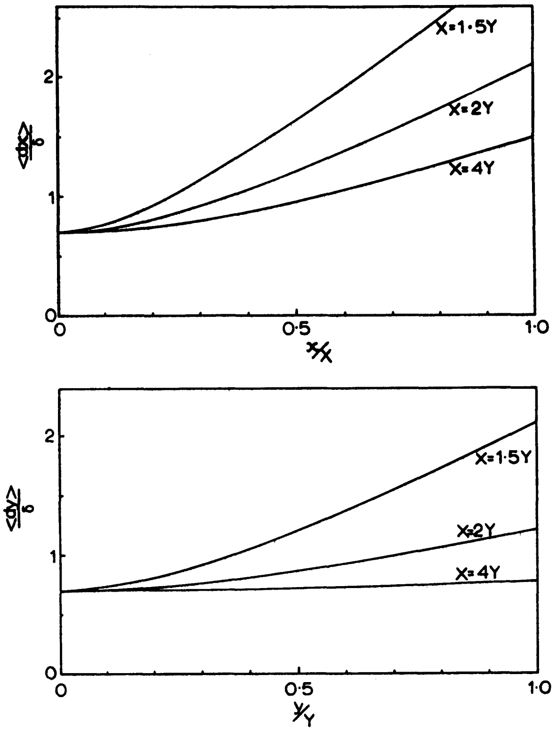


Fig. 2

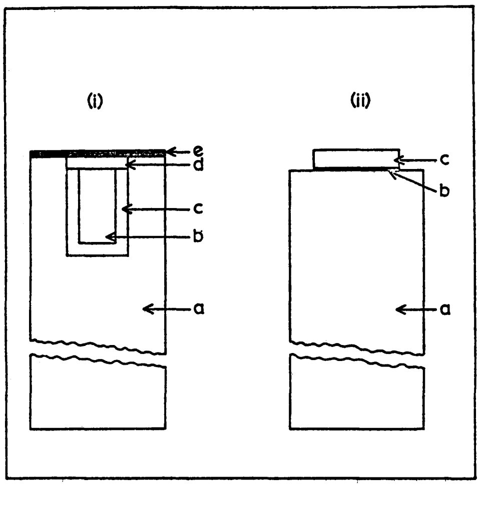


Fig. 3

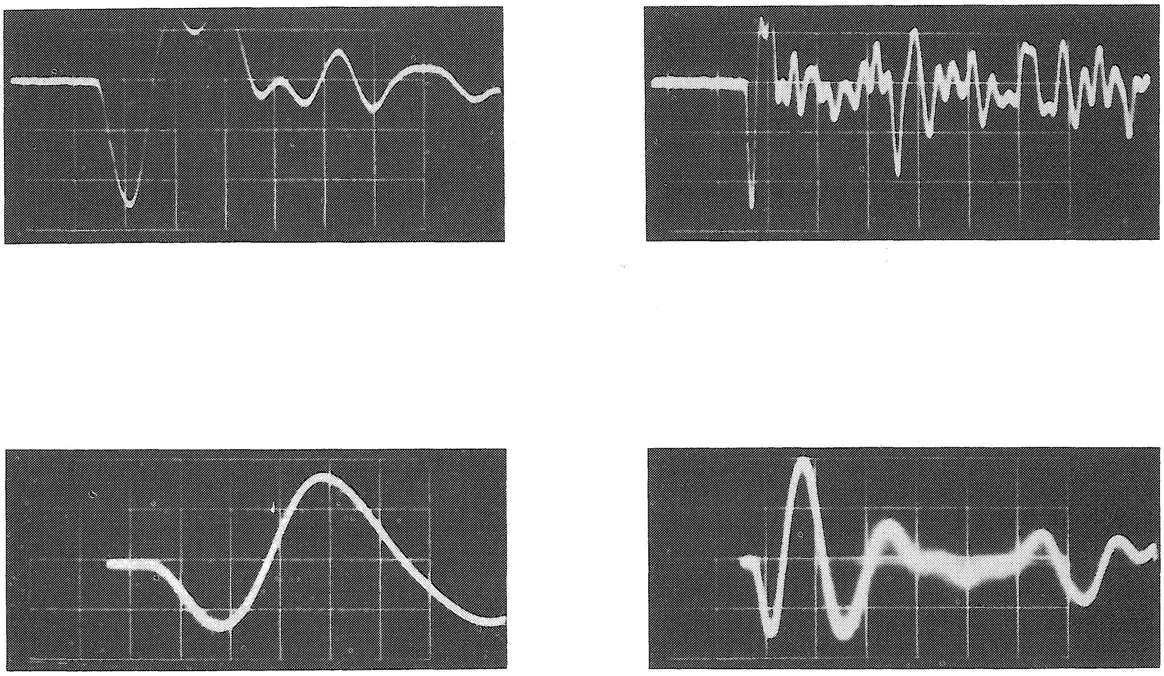
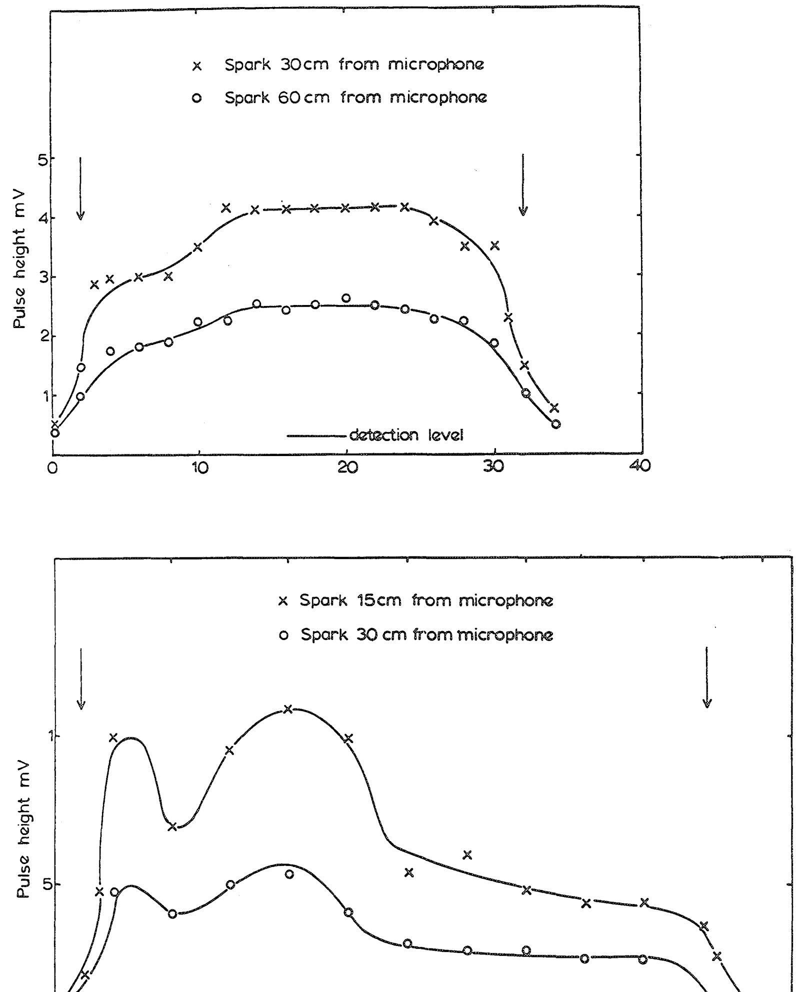


Fig. 4



× Spark 30cm from microphone
o Spark 60cm from microphone
Pulse height mV
1
2
3
4
5
detection level
0
10
20
30
40
× Spark 15cm from microphone
o Spark 30 cm from microphone
Pulse height mV
0
5
1
detection level
60
40
20
0
20
40
60
DISTANCE CM.

Fig. 5

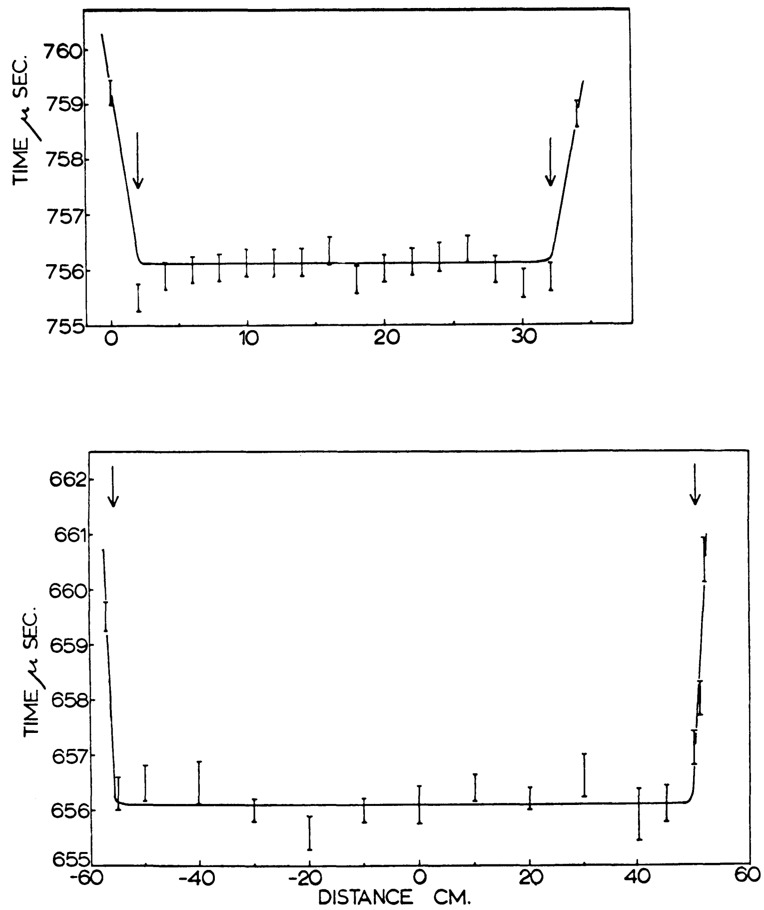

TIME μ SEC.
760
759
758
757
756
755
0
10
20
30
662
661
660
659
658
657
656
655
-60
-40
-20
0
20
40
60
DISTANCE CM.

Fig. 6

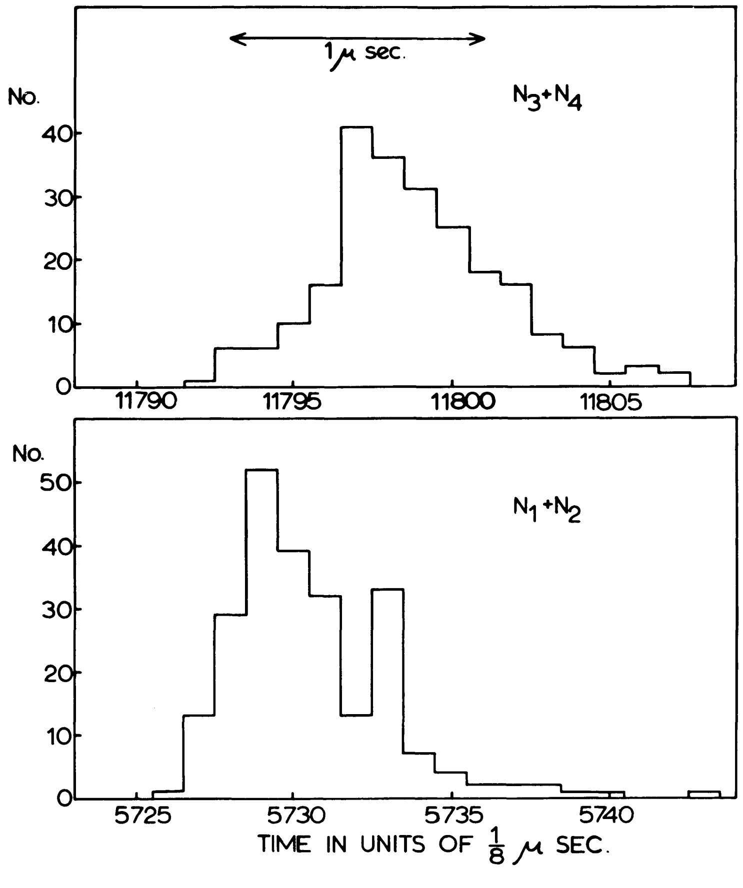

1 μ sec.
No.
N_3+N_4
40
30
20
10
0
11790
11795
11800
11805
No.
50
40
30
20
10
0
N_1+N_2
5725
5730
5735
5740
TIME IN UNITS OF $\frac{1}{8}$ μ SEC.

Fig. 7

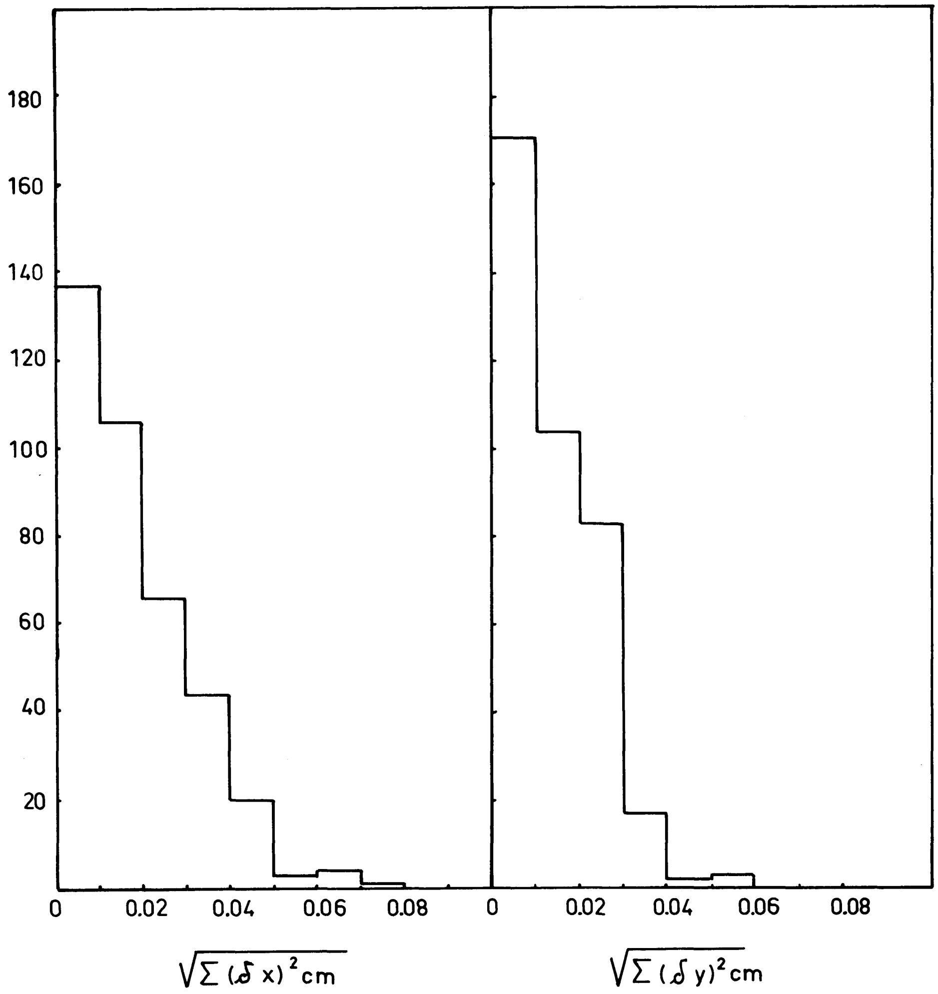

180
160
140
120
100
80
60
40
20
0
0.02
0.04
0.06
0.08
0
0.02
0.04
0.06
0.08
$\sqrt{\Sigma (\delta x)^2}$ cm
$\sqrt{\Sigma (\delta y)^2}$ cm

Fig. 8

DISCUSSION

PEREZ-MENDEZ: What is the dead time of your system ?

MANNING: The dead time of this particular system is determined completely be the readout, which I did not mention. The readout at the moment is on punched paper tape only. The reason for this is that the experiment is expected to have a trigger rate of the order of 0.1 per machine burst and therefore taking 4 seconds to print out is no real limitation. I think in practice we would prefer to speed it up, and equipment is being built which eventually will make it faster.

PEREZ-MENDEZ: I also wanted to know what the recovery time of the microphones is ?

MANNING: Of the order of 5 msec, depending on their length. Obviously the sound hits them for a long time and therefore they continue to ring for a long time. It depends on their overall length.

LILLETHUN: What is the overall length between the first and last chamber, and what is the delay between particle passage and the application of the high voltage ?

MANNING: The path is of the order of 15 metres. The distance between chambers A and B is 350 cm and also between C and D. The overall delay we have between the particle going through the first chamber and putting the voltage on that chamber is of the order of 300 nsec. This is predominantly flight time and cable length.

VERNON: Is it true that in these microphones this long ringing time is associated with the fact that the crystal is a very high 'Q' resonant circuit ?

MANNING: We find that you can excite the microphones very easily by tapping them for example and they have a characteristic frequency of the order of 20 kc. Although we have no real proof of it, we think this is due to oscillations going along the microphone. In other words the first pulse you get is characteristic of the transient pressure, but the ringing after that is characteristic of the ringing of the whole probe assembly.

VERNON: There was something pointed out to me by Professor Dicky's group in Princeton. They have had this sort of problem in using this type of transducer and in order to reduce the dead time it is possible to redrive with 20 kc frequency out of phase to damp out the oscillations. You essentially reduce the 'Q' of the crystal then and it might be of some use to people who might want to look for second sparks.

MANNING: I think if people want short probe dead times it is probably better to use capacity probes. They are much less susceptible to excitation from the backing; quite clearly the thing which you have to disturb is the front membrane, and this is rather difficult to excite from the back. We found, in practice, that the cross talk we got through excitation through the backing in capacitor microphones was very small, and also the signal dies out much more rapidly and it doesn't have this characteristic 20 kc frequency.

ANDERSON: Do you make any attempt to match the impedance of the long condenser strip microphones with your cable ?

MANNING: No. We use a 50 Ω cable of the order of 2 metres to 3 metres long. This cable goes into an amplifier which has a gain of the order of 200 and is the only amplifier in the system. We then transmit through a 20 metre cable length. Now the input circuitry to this amplifier is just that we feed through a 1K resistor and have 2 diodes back to back. The reason for this is that any large voltage pulses you get from the electrical pick-up are limited and are then clipped by the diode. This circuit does nothing to small pulses which feed into the input of the amplifier which has an input impedance of 20K.