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WIDE GAP SPARK CHAMBERS : ON THE STATE OF THE ART WITH PARTICULAR REFERENCE TO THE WORK IN PROGRESS WITHIN THE PS/FES GROUP, CERN

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SUMMARY

The available data on the performance of wide gap spark chambers, both in the spark and streamer modes of operation, are assessed. Particular attention is given to the work completed in the course of the present experimental and theoretical investigations of the operation of a wide gap spark chamber in the spark mode. The aim of this work has been to understand the mechanism of formation of inclined sparks, and so comprehend precisely the influence of experimental parameters on properties such as chamber efficiency and accuracy. This aspect of the operation of a wide gap spark chamber has, in general, received very little attention, despite the numerous publications which deal with wide gap spark chambers. Further lines of enquiry in the present work are discussed and outlined.

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1. INTRODUCTION

Over the last few years, the spark chamber has emerged as one of the principal diagnostic tools in high energy physics experiments. This trend shows no sign of stagnation [1], and current developments in the field are along two general directions. On the one hand, spark chambers are being equipped with systems for the automatic readout and treatment of data, and, on the other hand, the versatility and accuracy of spark chambers are being improved. In this latter context, the most significant contribution was the discovery around 1960 of the track following property of a spark in a wide gap spark chamber [2),3),4)] : the spark follows along the trajectory of the particle even though the direction of the track does not coincide with the direction of the applied electric field. An examination of this phenomena has been the subject of considerable interest, and from this work there emerged a second mode of operation of a wide gap spark chamber [5]. This is the, so called, streamer mode in which the track of an ionizing particle is seen, at a pre-spark stage, as a result of the light emitted from electron avalanches of high number density which develop at intervals ~ 4 mm along the track.

Wide gap spark chambers have already found application in high energy physics experiments [6),7)], and preparations are currently underway at Stanford [7], Argonne [8], Princeton [9], Frascati [10], Harvard [11], Dubna and Serpukhov [12] to extend their use. This trend towards the use of wide gap rather than the conventional narrow gap spark chamber has arisen because of the improvement in precision brought about by a track delineating instrument, because of the high multitrack efficiency obtainable with the system, and also in view of the inherent simplicity of the apparatus. At the same time, however, the full potentialities of a wide gap spark chamber are not fully realized, and the precise manner in which experimental parameters influence qualities of precision and efficiency is not very well understood.

The present communication is concerned principally with the motivation for the continuation of work in an investigation of the properties of a wide gap spark chamber operated in the spark mode which is in progress within the PS/FES Group, CERN. This work has been in progress since some time and has involved both experimental and theoretical studies. Before proceeding to discuss this work and its further direction, it is first of interest to review briefly the work conducted elsewhere with wide gap spark chambers, both in the spark and streamer modes of operation.

2. WORK WITH WIDE GAP SPARK CHAMBERS CONDUCTED ELSEWHERE

2.1 Spark mode of operation

The earlier investigators of track following sparks established that track following takes place only up to a limiting angle of the track with respect to the direction of the applied field. There remained some disagreement as to the actual value of the maximum angle, and quoted values were of the order 30 - 40^{o} [3)4)]. More recently Bolotov et al [13)] have shown that the maximum angle is a function of experimental conditions, and can be extended up to 55^{o} by a suitable choice of operating parameters. At the same time as the angle of the track with respect to the direction of the field is increased, it has been shown that the tracks become dimmer. From measurements of the density of sparks on photographic film, Keller et al [8)] have obtained a quantitative measure of this dependence, and over the angular range 0 - 40^{o} they found a diminution in intensity by a factor of about one order of magnitude.

The property of a wide gap spark chamber to display many tracks simultaneously is a factor which has been noted in many investigations. From a study of the performance of three wide gap spark chambers arranged in series, Bolotov and Devishev [14] concluded that the registration efficiency of a wide gap spark chamber is unaltered even with 50 particles traversing the chamber. In further contrast to a narrow gap spark chamber, the sensitive time may be as large as a few tens of micro seconds (and cannot readily be reduced by the application of clearing fields). Values of this order have been measured by studying the efficiency of detection as a function of the delay in applying the high voltage pulse. A more realistic figure is obtained by investigating the response of a wide gap spark chamber in the presence of two particles, with a defined interval in their appearance and with the chamber triggered by the second particle. This has been done by Eisenstein et al [15] who found a figure of around 3μs for the sensitive time measured in this manner.

Experiments have shown that spark tracks in a wide gap spark chamber are of width about 1 mm [8],[11], and that the displacement, or so called coherent drift, of the spark from the particle trajectory is typically of the order 3.5 mm [10],[11],[16]. From the work of Manno and Visentin [10], it would appear that the coherent drift, as measured in the field direction, is independent of particle inclination, and furthermore that the coherent drift is only a slowly varying function of field strength. This latter fact is in keeping with the observations of Garron et al [11] who found a change of value of the coherent drift, measured in the field direction, from 5 to 3 mm for a change in field strength from 4.5 to 22 kV cm^{-1}. The individual deviations of spark centres, or so called incoherent distortions, have been investigated by Keller et al [8] and by Garron et al [11] who found r.m.s. values of around 0.1 mm for the range of particle inclinations investigated (0-40, 0-25^{o} respectively). This result may be compared with the values of the r.m.s. deviation of individual sparks in an array of narrow gap spark chambers of 0.25,0.5 and 0.8 mm measured by Rutherglen and Pattison [17] for the ranges of inclination 0-15, 15-30 and 30-45^{o}. In principle, therefore, a wide gap spark chamber is capable of higher angular resolution than that attainable with an array of narrow gap spark chambers, provided, of course, that the direction of the spark actually represents the direction of the particle. The work of Bolotov et al [16] and of Keller et al [8] lends no evidence in favour of any systematic error, within a resolution of about 1 mrad. But Garron et al [11], using a system of higher resolution, found evidence of small systematic errors, of the same order of magnitude as the incoherent distortions, at inclinations greater than about 20^{o}. These errors were found to be functions of the chamber geometry and of the spark position, and were attributed to the finite propagation time of the spark along the ionized channel resulting in variations of the "coherent" drift along the trajectory. The observed dependence of the magnitude of the errors on chamber geometry and spark position would, however, suggest an alternative explanation in terms of some residual field non-uniformity. As demonstrated by Garron et al and by others [16], the accuracy of the response of a wide gap spark chamber can be significantly altered by a non-uniformity of the electric field.

From a series of measurements of the curvature of tracks in two chambers arranged in series in a magnetic field of 13.3 k Gauss, Garron et al proceed to show that the overall accuracy of a wide gap spark chamber of length 40 cm is such that the momentum of a 1 GeV particle may be determined with a standard deviation of $\pm$ 1.4 o/o. The authors demonstrate that this error is greater than that to be expected on the basis of errors introduced by the measuring system, errors due to multiple Coulomb scattering, and errors in defining the position of spark centres, and conclude that the performance of a wide gap spark chamber in a magnetic field is also influenced by variations of the "coherent" drift and/or other unknown sources. The accuracy found by Garron et al compares with the uncertainty of $\pm$ 2.5 o/o which would be expected using a typical 40 cm array of narrow gap spark chambers under comparable conditions [18], and the limit of $\pm$ 2.4 o/o imposed solely by multiple scattering on a 40 cm length of track in liquid hydrogen.

The momentum resolution of a wide gap spark chamber of length 40 cm has also been investigated by Aronson et al [9], who found that for particles of energy 395 MeV in a magnetic field of 5.2 k Gauss the accuracy of momentum determination of $\pm$ 1.1 o/o was set by the method of measurement and not by the performance of the spark chamber

2.2. Streamer mode of operation

With the streamer mode of operation of a wide gap spark chamber, the formation of a highly conducting and continuous path between the electrodes of the spark gap is no longer a pre-requisite for track visualization. For this reason, a response is obtained over all orientations of the track with respect to the electrodes of the chamber; indeed, any isolated electron is a potential "streamer". Experiments have shown that the sensitive time may be as great as a few hundred micro seconds [5], [19], and, as with the spark mode, it has been established that the intensity of a track is a function of inclination [20]. Moreover, with the streamer mode the quality of the track depends on the direction of viewing. In a direction parallel to the electric field the track is seen as a series of circles of diameter about 1 mm, whereas in a direction perpendicular to the field the track appears as a series of dashes of length about 5 mm and of no well defined profile. Chikovani et al [5] and Bulos et al [4] have measured the scatter of streamer centres in the two views and quote respectively r.m.s. values of 0.3 and 0.2 mm for the view parallel to the field, and 2 and 0.5 mm for the view perpendicular to the field.

The main difficulty with the streamer mode of operation of a wide gap spark chamber rests with the rather low level of the emitted light which presents difficulties with respect to photography in any chamber of large dimensions. The light level is such that a minimum lens stop of f 2 is required for photography with the most sensitive of available films. To arrive at a reasonable resolution over a range of object space, therefore, a large demagnification is necessary, but a limit to this procedure is set by the resolution of the lens and of the film. To cover a depth of field of 60 cm in their chamber of volume 2 m^3, Bulos et al [7] show that a demagnification of around 70 represents the optimum value. (At this demagnification, the size of image projected back into object space is a minimum, and also the circle of confusion due to depth of field, projected back to object space, is equal to the projected size of streamer circles in focus.) Under these optimum conditions, there is a variation in intensity across the chamber by a factor of 2, and the projected size of an object of real size 1 mm may be as large as 3 mm. This degree of resolution clearly limits the accuracy with which tracks may be defined in the 2 m^3 chamber, and Bulos et al estimate an uncertainty of $\pm$ 5mm in locating streamer centres in the view parallel to the electric field. In the view perpendicular to the electric field, the uncertainty is likely to be considerably greater.

Experiments have been conducted with a view to relating a property of wide gap spark chambers to the energy loss of the incident particle [19][20][21]. In this respect, the streamer mode of operation has received the greater attention, and parameters such as streamer brightness and streamer density have been investigated as a function of the energy of the incident particle. A relation involving the former quantity is, however, complicated by the dependence of track brightness on the inclination of the track. A more promising approach seems to be along the lines of streamer density, and recent unconfirmed reports from the U.S.S.R.[12] indicate that Dolgoshein, working with helium gas, has reproduced the energy loss curve in terms of streamer density.

2.3. Conclusions

This brief review of experimental work clearly shows that wide gap spark chambers hold considerable promise as track detectors in high energy physics experiments. Properties of angular resolution and of multitrack efficiency are superior to those of a narrow gap spark chamber, and the device is capable of providing data on the momentum of particles of high energy with an accuracy exceeding that of any other track detector.

A choice between the spark or streamer mode of operation of a wide gap spark chamber rests with the demands of the particular experiment. With the streamer mode, a response is obtained over all particle orientations, but the light level is rather low and the definition is good only in a view parallel to the direction of the electric field. With the spark mode, the light output is sufficient for direct photography with a good depth of field. The angular range is limited, but in high energy collisions there is a preponderance of forward motion so that a response over an angular range of $\pm 45^{\circ}$ is clearly adequate for most experimental purposes.

At this stage it is perhaps interesting to reflect that although the principles of the wide gap spark chamber have been known for a number of years, it is only at this time that plans for their application are underway at anything approaching a large scale. The reason for this is not immediately clear, but a possible explanation may lie with the readiness of the experimental physicist to employ the well tried narrow gap spark chamber with correspondingly lower voltage sources. In reality, the construction of a wide gap spark chamber does not present any great technological problem, and, as Gygi and Schneider [22] and others have shown, voltage generators of up to a few hundred kilo-volts may be readily prepared. A second reason may lie with the fact that despite the numerous publications concerning the wide gap spark chamber, the basic characteristics of the instrument remain ill defined. The response does clearly depend on experimental conditions, but the precise way in which factors such as accuracy and efficiency are influenced by changing experimental parameters is not understood. In an attempt to offset this rather unsatisfactory situation, the present work was directed towards obtaining the basic characteristics of the response of a wide gap spark chamber operated in the spark mode, and, at the same time, to clarify the factors involved in the spark formation process.

3. WORK COMPLETED IN THE PRESENT INVESTIGATION

3.1 Experimental studies

The stage reached in the programme of experimental work has been outlined in a recent publication [23]. Systematic measurements have been made of :

a) Spark formation time

b) The dependence of the spark intensity on field strength

c) The temporal dependence of spark intensity.

In all cases, the influence of the direction of the incident particle with respect to the external field was investigated, and the spark chamber was excited by a rectangular high voltage pulse. This latter condition was arranged only so as to simplify the interpretation of experimental data. The studies b) and c) were undertaken using a photomultiplier to measure the light emitted from the spark chamber. In this manner, phenomena of pre-breakdown and of spark evolution could be evaluated on a quantitative basis.

The measurements of spark formation time t_s for track following sparks showed the values of t_s to increase with increasing inclination of the particle and to decrease with increasing field strength. This dependence of t_s on inclination provides a possible cause for the angular dependence of spark intensity found in photographs of track following sparks. This follows since the brightness of a spark will depend on the excess pulse length i.e. the amount by which the pulse length exceeds the spark formation time.

A study of the light emitted from the spark chamber as a function of field strength, at a fixed pulse length and over a range of inclinations, provided a comprehensive set of data on the dependence of spark intensity on angle with the spark at different stages of formation. With a fully developed spark, the measurements showed the intensity to decrease by a factor of 7 in changing the angle from 0 to 40°. This result is of the same order as that deduced by Keller et al [8] from measurements of the intensity of spark tracks on photographic film. In addition, the present measurements revealed the interesting fact that the intensity of the emitted light was dependent on track inclination even a level $\sim 10^{7}$ below that corresponding to a spark discharge.

A possible explanation for this observation has been discussed in terms of the interaction of the early generation of avalanches with metastable atoms produced by the particle along its track. It is interesting to note that a similar process could account for the dependence of streamer brightness on angle observed experimentally (see paragraph 2.2).

Studies of the temporal growth of light emitted from the spark chamber provided the first direct measurements of the growth of electron number in a wide gap spark chamber. The results showed the electron number to grow initially at an exponential rate dependent only on field strength. This behaviour is consistent with the growth of electron number according to the avalanche or Townsend multiplication process. After this avalanche stage of growth, the electron number was found to increase at a higher rate which is a function of the inclination of the particle track. This second stage culminated in the formation of a spark discharge, and the intensity of the formed spark was found to increase very slowly in time. It is interesting to note the consistency of the data, in that the angular dependence of the higher rate of electron growth, as observed in the second stage of growth, is in keeping with the independently observed increase of spark formation time with increasing angle.

An explanation for the higher rate of electron growth was given in terms of local space charge fields which augment the applied field. Moreover, the action of these local space charge fields was identified with the process which brings about the track following characteristic of the spark discharge. Two extreme schemes for the establishment of local space charge fields were considered. According to the first, the discharge develops as a series of distinct avalanches, and the space charge influence arises from the interaction between these avalanches.

The interaction involves the forces exerted by both electron and positive ion clouds on the motion of electrons, but the net effect is considered as an enhancement of the rate of growth - in keeping with the experimental observations. According to the second scheme, the inter-merger of avalanches at an early stage in the development of the discharge gives rise to an uniform charge front between the electrodes of the spark chamber. The space charge influence is then manifested as a result of the removal of electrons to the anode of the discharge. This brings about a region of net positive charge at the anode, which accelerates the growth of electrons and directs their motion to a specific point at the anode. The process of the net gain of positive charge rapidly extends along each finite volume of the track, until finally a space charge controlled discharge extends from anode to cathode.

3.2. Theoretical Studies

One of the earliest published papers on theoretical aspects of spark formation in a wide gap spark chamber is due to Lyubimov et al [24] who, following the proposal of Fukui and Miyamoto [4], considered the field between the electrons of one avalanche and the ions of the foregoing and neighbouring avalanche to be the active mechanism for the formation of inclined sparks. These authors dealt first with the temporal development of a single avalanche, and later extended the results to the case of a discharge initiated from a line source of electrons. The formulation does, however, contain certain oversimplifications and is essentially based on the qualitative streamer theory of Raether [25] and of Meek and Craggs [26]. No account is made for the spacial distribution of charge, and the influence of electron space charge on the motion of electrons is completely neglected.

A more correct theoretical analysis of the role of an inter-avalanche space charge field is due to Evans [27], a visitor to this group. He employed second order iterative methods to solve numerically the equations for the electron growth in a three dimensional field distorted by space charge. On the basis of primary ionization processes with a line source of electrons, he showed that a rotation of the resultant current vector takes place away from the direction of the applied field towards the direction of the initial line source of electrons i.e. the track direction. This occurs to some extent for all track angles, but the rate of rotation depends strongly on the track angle and is greatest for small angles. With an increase of gas pressure the rate of rotation is increased, but at the same time the dependence on angle is also greater.

Data on the temporal growth of electron number were also evaluated for one of the conditions of field strength and of gas pressure at which experimental data on the temporal growth were obtained. The results of the calculation exhibit a strong angular dependence at the later stages of development, in agreement with the experimental observations. However, the slopes of the experimental curves at the later stages are greater than with the calculated curves, and Evans discusses the possibility of an increase in the effective ionization coefficient brought about by an increase in current density. With the addition of a non-linear ionization term, he shows how the calculated curves may be brought into agreement with experiment. To summarize, therefore, this work provides a verification of the role of an inter-avalanche space charge field on the development of a track following spark, although the precise nature of secondary processes active in the discharge is not clear. It is of considerable interest to extend the calculations and to examine in more detail the influence of experimental parameters on the rotation of current vectors. A further refinement to this theoretical work could be made by the inclusion of statistical treatments, both with regard to ionization processes and also the distribution of the initial seed electrons.

With a view to obtaining possibly a more immediate indication of the factors governing the role of an inter-avalanche space charge field, a second and somewhat simpler line of enquiry was initiated. This work involved the calculation in time of the field configuration due to a series of electron avalanches, with each avalanche represented by a dipole of length $1/\alpha$ (α , the primary ionization coefficient, is the average distance traversed by an electron in the field direction between making ionizing collisions). The radii of electron and ion clouds are given according to $r = (6Dt)^{1/2}$, where D is the coefficient of diffusion of electrons and t the time. No allowance is made of ionization in a field distorted by space charge, rather the computation is arrested when the total field E_T at any point exceeds the applied field E by a small but fixed amount, i.e. when $E_T = kE$, where k is a constant. This point is then regarded as the critical point at which our measurements have shown the growth to proceed at a very much faster rate. Indeed, if the supposition is made that the post-critical evolution hardly contributes to the breakdown time, the time at which $E_T = kE$ may be regarded approximately as the spark formation time. At this point when $E_T = kE$, an inspection of the spacial distribution of fields permits the influence of adjacent avalanches on the development of a particular avalanche to be ascertained. The tendancy of the spark to follow along the track is clearly related to the coupling between avalanches, and a measure of this coupling may be found from the magnitude of the angular rotation away from the applied field direction and towards the track direction of the total field vector at the head of electron avalanches. The magnitude and direction of the total field vectors around each avalanche are determined by the primary ionization coefficient of electrons, the electron drift velocity and diffusion coefficient, and the inter-avalanche separation - all of which are functions of the electric field strength and/or gas pressure. In this manner, therefore, the influence of changing parameters on the time of onset of space charge influence and on the angular efficiency for track following may be investigated [28].

Preliminary results obtained in this way have shown that the time observed experimentally for the onset of the higher rate of electron growth, at a field strength of 6.73 $kVcm^{-1}$ and for zero inclination, can be identified with the instant at which the calculations, with an inter-avalanche spacing of 0.20 cm, indicate that a 10 o/o distortion of the applied field is attained. Selecting $k = 1.1$ to signify breakdown, the difference in the calculated breakdown times for 0 and 30° is in agreement with the value deduced from the measurements of spark formation time. With an increase in electric field strength, the calculations show a decrease in spark formation time, but more significantly a marked decrease in the coupling between avalanches. On general grounds, it is unlikely that the track following tendancy actually changes as rapidly as the results of the calculations imply. This situation could be offset if the values of inter-avalanche spacing employed in the calculations were allowed to decrease with increasing field strength, and the experimental work of Fukui and Miyamato [4] lends support to this decrease in avalanche separation. The underlying reason for a decrease in inter-avalanche spacing with increasing field strength is not clear, but may be associated with the fact that in a certain region around each avalanche the space charge field acts so as to oppose the external field. The growth of an avalanche located in the reduced field region of a neighbouring avalanche would be suppressed. Calculations have shown that the lateral size of the region is inversely proportional to the primary ionization coefficient of electrons, α , and so the effectiveness of the mechanism of suppression would be reduced with the decrease in $1/\alpha$ accompanying an increase in field strength. This would allow the number density of avalanches along the track to increase with increasing field strength, and so permit the track following tendancy to be restored to a higher level. In the absence of precise experimental data on the angular efficiency of a wide gap spark chamber as a function of field strength, no definite conclusions may at present be drawn.

4. CONCLUSIONS CONCERNING THE PRESENT WORK AND ITS FURTHER DIRECTION

The programme of work completed in the course of the present investigation has provided data on the fundamental characteristics of the operation of a wide gap spark chamber in the spark mode, as well as some insight into the mechanism of spark formation. Information of this nature is essential if the full potentialities and limitations of a wide gap spark chamber are to be realized.

A comparison of the measurements of the temporal growth of electron number with the results of rigorous theoretical calculations, obtained for one of the conditions of field strength and of gas pressure investigated experimentally, lends support to the view that the track following characteristic is brought about by the action of inter-avalanche space charge fields. At the same time, however, agreement between theory and experiment is complete only if a non-linear ionization term is included in the calculations. Possibly, the final stages of spark formation are accelerated by a build up of positive ion space charge, as discussed in paragraph 3.1, but the precise effect of this and other processes remain to be investigated.

On the basis of the dipole model proposed to represent the mechanism of an inter-avalanche space charge field, calculations have been made of the influence of experimental parameters on the rotation and magnitude of total field vectors (see paragraph 3.2). This work has mainly centred around the role of electric field strength, but, as pointed out earlier, a comparison of the results of the calculations with experiment is limited because of the lack of precise data on the angular efficiency of a wide gap spark chamber as a function of field strength. A close liaison between the calculations and experiment would provide a clarification of the factors which influence the role of an inter-avalanche space charge field. With the apparatus developed in the course of the present investigation, electric field strength and pulse length may be specified with a high degree of accuracy, with the additional features that the electric field strength and/or pulse length may be varied over wide limits. In the form employed for the measurements described in paragraph 3.1, however, no means was available for obtaining information as to the physical condition of the discharge. In anticipation of the next stage in the experimental programme, a photographic facility has by this time been incorporated into the system. In this form, an investigation may be made of the influence of electric field strength and of pulse length on the efficiency for track formation as a function of angle, which would provide direct experimental evidence for comparison with the results of calculations. Of additional interest is the fact that it is now possible to correlate measurements of the temporal growth of electron number in the spark discharge with photographic evidence as to its physical development. The temporal growth measurements already completed have shown the form of the growth at the later stages of development to be a function of the angle of the particle path with respect to the direction of the applied electric field. The elucidation of this behavious in terms of the physical condition of the discharge should permit a further clarification of the processes involved in the formation of track following sparks. Apart from the intrinsic interest in these latter observations, they are in fact a prerequisite of a detailed study of the physical form of the spark, since they serve to define the range of pulse lengths of interest at each fixed value of the electric field. In fact, a collection of simultaneous and correlated data on electron number and the physical form of the discharge over a large series of inclinations would contain all the information required as to tracking efficiency, but such a procedure would be rather laborious and uneconomical. Rather, a more practical approach is proposed in which at a fixed field strength simultaneous data on electron number and the physical form of the discharge would be obtained for only about three values of the inclination of the particle. The inclinations will be chosen so as to include the maximum angle (45°) available with the apparatus, and so possibly arrive at the contrasting situation of a discharge leading to a track following and a non track following spark. In this study attention will be given, in addition, to the form of the voltage pulse across the spark chamber in order to determine precisely the moment of voltage collapse. With all this information in hand, a series of pulse lengths will then be selected for which to pursue a photographic study of the form of the spark as a detailed function of angle. The experiments will cover the range of field strengths from around 4 to 12 $kVcm^{-1}$, with the gas pressure at the value of 1 atmosphere.

The extension of the work to include the influence of gas pressure will necessitate the construction of a new gas pressure and flow regulator, and a decision to build such a system should be considered in the near future. It is anticipated that the complete study of the influence of electric field strength on the response of a wide gap spark chamber will involve around two months work, once a suitable parasiting beam is obtained at the proton synchrotron. Should a pressure regulator be available at the end of this time, the work could continue in a similar fashion for a range of field strengths at new settings of gas pressure.

The general philososophy in this work, as stated earlier in the text, is that of continual interchange between theory and experiment. The aim of the dipole calculations will be to reproduce as closely as possible the observed efficiency and time sequence for the formation of track following sparks as a function of the experimental parameters investigated. In this work, if necessary, the inter-avalanche separation will be treated as a variable parameter, in which case it will be of interest to link the derived variation of avalanche density with that to be expected within the framework of the mechanism of inter-avalanche suppression outlined in paragraph 3.2. On this theoretical side of the work, it would be of advantage to invite Dr. C.J. Evans, University College of Swansea, to continue with his more complete calculations of the development of track following sparks. The aim should be to investigate the influence of various secondary processes on the final rate of build up of charge in a wide gap spark chamber, and to extend the work to an investigation of the influence of experimental parameters on the efficiency of track following,analogous to the work with the dipole model. A comparison of the results with the corresponding data obtained with the dipole model will be of significant interest. It is to be hoped that this programme of experimental and theoretical work will permit a further clarification of the processes involved in the formation of track following sparks, besides providing accurate data on the registration efficiency as a function of experimental parameters which will be of direct value in experimental applications of wide gap spark chambers.

The rate of progress to be expected in this work with the wide gap spark chamber must, however, be considered in the light of the responsibility we bear as to the testing and development of the pulse shaping networks of the new fast ejection facility to be installed at the proton synchrotron, CERN [29]. This work is likely to occupy our attention fully for at least the next four months.

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