WIRE ARRAYS VS VIDICONS: A COMPARISON OF LARGE WIRE ARRAYS WITH OPTICAL SPARK CHAMBERS USING VIDICON READOUT

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ABSTRACT

Digitized spark-chamber systems using wire arrays are being used for increasingly complex types of events; their chief virtue is the provision of "on-line" information on the progress of the experiment, which we interpret as rapid enough to allow the results obtained to influence the future course of the experiment. Such on-line operation can also be obtained by several other methods for digitizing the data and introducing it into a computer, notably wire arrays. In particular, comparisons are made of the properties of wire arrays with a digitizing system in which visual spark chambers are viewed by vidicon television pickup tubes, whose output is immediately digitized for either tape storage or input to a computer. Such TV pickup systems have greater flexibility, require fewer special data storage provisions, automatically provide for indefinitely large numbers of tracks and track samplings and data redundancy, and fewer modifications for different experiments than wire arrays. In view of expected cost variations with size, it is likely that for sufficiently large systems, wire array readout will cost more than vidicon readout, in addition to being less flexible. Vidicon digitization is clearly preferable when many samplings are required, as in gamma-ray shower-detecting chambers.

I. ON-LINE OPERATION WITH WIRE ARRAY SPARK CHAMBERS

Experiments done with spark chambers in the last five years or so show a trend toward two principal systems of operation. On the one hand are wire-array systems, with the data recorded and stored in digital form, suitable for immediate (on-line) processing. On the other hand are the visual chamber systems, with film recording, frequently including large magnets, and successfully competing with bubble chambers in the recording and analysis of complex events.

While both types of systems have been highly successful in their respective spheres, it is clear from recent developments that the wire-array system is steadily expanding its sphere of operation. Current wire-array systems have two major

virtues: commercial availability of working components and data-handling systems, and on-line operation. The first of these is a direct consequence of the great appeal of the second. On-line data-recording systems allow the accumulation of large numbers of events (sufficiently large that statistics are no longer dominant in error determinations); in addition, they return some or all data in a time short enough, and a quantity great enough, to allow the conduct of the experiment to be determined by the results already obtained. Physicists who have run experiments this way will not willingly settle for anything less. The advantages--certainty of proper operation, improved operating efficiency, immediate knowledge of results--are well-known and unarguable.

As a consequence of their success, and resulting commercial availability, wire-chamber systems are becoming progressively more and more complex. The numbers of planes used, the size of the arrays, the complexity and redundancy of the system, and the sophistication of the experiments attempted have been steadily increasing. For some time now, experiments of designs in which either one or two particle trajectories must be determined have been assayed against wire-chamber technology as the standard. Experiments to study events as complex as associated production, and even the production of meson resonances decaying into three or more particles, are now being designed to be carried out by larger and larger arrays of wire chambers (in time). In brief, wire arrays are now being suggested for experiments which a decade ago were thought to be possible only to bubble chambers, and just a year or two ago only to spark chambers with film data storage and bubble-chamber type analysis.

The most recent example is the proposal of Leith et al., at SLAC for a system designed for a broad attack on all of boson spectroscopy. At present that system is envisioned to contain twelve wire-plane chambers (each of four planes), ranging up to 3×5 meters in size and with provision for storing 200 words per event.

II. ON-LINE SYSTEMS OTHER THAN WIRE ARRAYS

Since on-line operation is so desirable, and since wire-array experiments that achieve it for large systems appear to be in sight, it seems reasonable to ask whether in fact wire-array digitization is the only kind possible, and, if not, whether it is the best kind to use in all circumstances, considering cost, complexity, reliability, and similar factors. At least three alternatives appear to be possible:

1. Sonic chambers
2. Visual chambers with film recording, fast film development, and automatic scanning and measuring systems with fast turn-around
3. Visual chambers using TV pickup, electronic recording and digitization, and providing immediate computer access.

A. Sonic Chambers

The first digitized spark chambers were not wire arrays but sonic chambers in which the flight time of the shock wave from the spark to the microphone was recorded, in digitized form, by a fast clock started by the spark and stopped by the received sound pulse. The sonic chamber faded from favor only when it appeared that grave technical difficulties faced the recording of more than one spark per chamber and the wire-array alternative appeared. The sonic chamber is still capable of holding its own in a single-arm spectrometer experiment (and according to some sources may even surpass the wire array in precision).

The difficulties in handling multiple tracks must be considered a fatal drawback for use of sonic chambers for complex events.

B. Visual Chambers with Film Recording, Automatic Scanning and Measurement, and Fast Turnaround

In the earliest experiments with visual systems, it was natural to use conventional bubble-chamber scanning and measuring techniques. But it was recognized from the beginning that the simplicity of spark-chamber photographs, as compared to bubble-chamber photographs, implied that automatic scanning and measurement would be far easier than with the latter. Immediate attempts were made at automatic scanning and measurement, which promptly met with success. At present the automatic measurement of spark-chamber photographs is routine, and automatic, or nearly automatic, scanning is frequently achieved.

The existence of automatic scanning and measuring techniques for spark-chamber photographs means that it should be possible to reduce the difference between wire-chamber and optical-system feedback times to the hour or so required for film development and introduction into the automatic scanner. If we define on-line operation as the current availability of information on the results of the experiment, in time to influence its next stage, the extra hour is of little significance. To date, many on-line experiments have been done with wire-chamber systems, and to the best of my knowledge, none with optical systems.

Since such operation has been technically feasible for at least four years, and seems never to have been attempted, it is legitimate to ask why. The difficulties appear to be organizational rather than technical; it is easier to check out a wire-chamber system beforehand than the film analysis system. One may be the software problem. An on-line system demands the availability of well-debugged reliable general-purpose software systems. Such systems are available for wire-chamber and bubble-chamber operation, but the tendency in visual spark-chamber systems seems to have been to write ad hoc rather than all-purpose geometry and kinematics

programs. Exceptions exist (e.g. the CHLOE-Liberator system) but have not been used in this way. Another possible reason is the fact that spark-chamber teams are frequently marginal in size, and the manpower simply may not be available.

C. Visual Chambers with Electronic Readout and Digitization

We come now to another method of digitization, first proposed by Gelernter,[1] and used successfully in several high-energy physics experiments. In that method visual spark chambers are used; they were originally the conventional narrow-gap modules, but could nowadays more advantageously be wide-gap, or perhaps even streamer chambers. The camera images are initially stored not on film, but on the photosensitive surfaces of vidicon television pickup tubes. They are then read out by the scanning beam of the vidicon, operated not in the conventional television raster, but in a mode better adapted to the specialized use of the tube. The horizontal sweep, triggered by a control signal that starts a clock, traverses the storage surface until it strikes a track signal which, just as in the sonic chamber or the magnetostrictive wire-array readout, stops the clock at a reading proportional to the distance of the track from the starting point of the sweep. The orientation, density, speed, and number of sweeps are parameters readily variable which can even be under computer control. Systems that automatically control the sweep sequencing to extract all the interesting data are readily conceivable. The digitized clock readings can be recorded on magnetic tape or directly introduced into a computer. Unlike wire arrays, no special auxiliary data storage scalers are needed since the speed of readout can be adjusted to that compatible with the computer storage cycle time. Any number of vidicons can be used, and read out serially, with as much time devoted to each as its stored information warrants.

Since vidicons are relatively inexpensive, and their output signals can be readily combined, it is reasonable to use many vidicons in an experiment; it may even be cheaper to use separate vidicons for each view of a chamber, and it is possible to avoid the extensive multiple mirror systems, so tedious to install, which are frequently used to combine many spark-chamber views into one camera frame.

In a vidicon readout system, each vidicon looks at a given area of spark chamber, whose size is determined by the desired resolution. Experience indicates that given a good linear sweep, a track can be located in a single sweep to at least the width of the resolution element. The standard vidicon has about 1,000-line resolution, and current practice is to measure to 1/1,000 of a sweep. If the optical chamber used has an inherent setting error of 0.3 mm, the area imaged on the vidicon can be about 30 cm across without loss of accuracy.

Recently much progress has been made in producing vidicon tubes with improved

resolution and sensitivity. Vidicons with 4,000 and 5,000 lines are now available (RCA C23061A, C23063, C74137A). A 5,000-line tube will obtain 0.3 mm resolution over a 1.5 meter square field. The conventional vidicon light sensitivity is ample for wide-gap chambers; the new high-sensitivity silicon-diode vidicons are adequate for streamer chambers. With optical chambers, recovery times are normally 10 msec or more. Even if we use conventional 60 μsec horizontal sweeps, that allows time for 160 serial sweeps.

The vidicon also stores analogue intensity information, which is readily read out and is valuable both in track reconstruction and particle identification. Finally, the use of vidicons with optical chambers allows the use of the most accurate chambers now known (wide-gap spark chambers) with highly redundant information in a readout system which is inherently flexible enough to allow the recording and reconstruction of events of almost arbitrary complexity.

III. COMPARISON OF WIRE-ARRAY AND VIDICON DIGITIZATION

In a wire-array system, provision must be made for each plane intersecting and sampling the particle trajectories, for each point on a trajectory, for a maximum number of tracks to be sampled in each array, for solving ambiguities, and for a maximum number of storage locations and storage scalers in which the coordinates of these points will be stored. This storage is usually external to that of any computer that may be used and at present is explicitly provided. Thus in general, the hardware storage provisions for complex events increase at least linearly with the amount of data; other costs of wire arrays also increase linearly or faster with the number of wires. For a small system these costs are not excessive, and the convenience of the system, especially now that components are commercially available, is great. But for a large system, the costs mount rapidly. Thus, in the SLAC proposal referred to earlier, the twelve wire-chamber samplings (comprising 48 planes) are estimated to cost, including interfacing, about $850 K. In the vidicon system, by contrast, the costs will depend mainly upon the area of chamber to be observed and the vidicon resolution and precision required. The advantage of the vidicon system becomes most apparent the more complicated the event to be digitized.

Without detailed analysis, it is difficult to arrive at quantitative conclusions; however, it seems clear that while the wire chamber appears to have important advantages for simple events (one or two tracks), and very high event rates (about 1-2 μsec deadtime), vidicon readout becomes more and more attractive the more complex the event. In the extreme case of gamma-ray shower in a heavy-plate chamber, where very many tracks are observed and very many samplings are required, the superiority of vidicon digitization becomes obvious.

IV. SILICON PHOTODIODE DIGITIZATION

A comparatively recent development in camera "tubes" is the silicon photodiode array, in which the photosensitive elements are tiny diodes, as small as 0.001 in. in diameter, laid down by integrated-circuit techniques in large arrays. At least one vidicon is available (RCA C23136) with conventional television resolution, in which the signal is stored in what amounts to an array of perhaps 500×500 elements. Signals are read out by the conventional scanning beam. The silicon photodiode surface has very high quantum sensitivity, peaked in the infrared. It offers the ultimate possibility, already achieved in the laboratory, of a true solid-state digital camera, giving direct readout without electron beam scanning, provided the diodes are connected in a matrix allowing their intrinsic digital nature to be used.

REFERENCE

[1] H. Gelernter, Nuovo Cimento 22, 631 (1961).