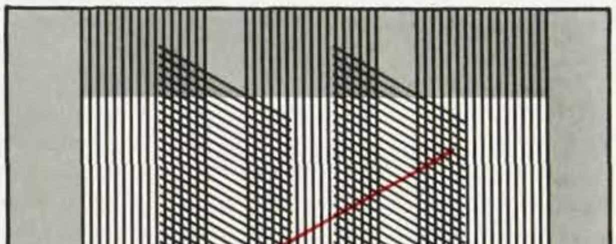
Wire Spark Chambers

As small, fast computers have become available for on-line analysis, wire spark chambers have become more and more important in high-energy physics. These devices provide rapid data recording, readout, analysis and display.

by Winslow Baker



THE WIRE SPARK CHAMBER is emerging as one of the dominant instruments for high-energy research. Usually a part of a larger system involving other particle detectors and computers, it is relatively inexpensive and can be easily replaced or exchanged in an experiment. The high rate at which it collects data permits the simultaneous study of several different reactions of similar topology. It is also being introduced into other fields where it is necessary to measure the trajectory of a charged particle quickly and accurately.

Part of the credit for the popularity of the wire chamber must go to the availability today of small, fast, multiple-access computers. The high rate at which data flow from wire chambers requires fast storage or buffering equipment. A computer provides this speed and can also analyze data while the experiment is in progress.

Several decades ago, particle physics was often done with a comparatively small number of scintillation or Geiger-Müller counters connected to coincidence circuits, and the resultant counts were displayed on scaling circuits. Through a few manipulations of a slide rule the experimenter could then evaluate a cross section, lifetime or whatever while his experiment was in progress. Besides the obvious esthetic appeal of this procedure to the physicist, it meant that decisions governing the running of the experiment were based on a knowledge of the final answer.

With cloud chambers and since the introduction of bubble chambers and photographic spark chambers, it is possible to study more complex events and to locate particles with greater precision. But because one must photograph the event the analysis must be postponed.

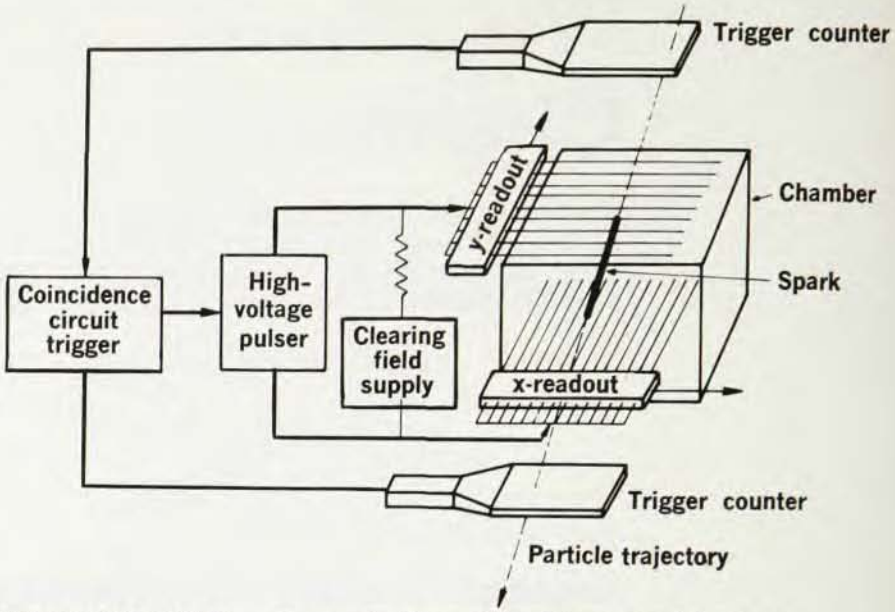
With wire spark chambers one has a bit of the best of both worlds: the possibility of immediate data analysis and the large amount of information and spatial resolution associated with other types of chambers. There are also a few bonuses as will be seen.

The chamber

The wire spark chamber is the natural descendant of the usual parallel-plate spark chamber. Its detection properties are essentially the same; the major difference is the method for extracting information.

The use of gaseous breakdown to determine the trajectory of an ionizing particle first began about ten years ago. The most common type of spark chamber consists of two parallel conducting plates across which a high-voltage pulse is applied just after a charged particle has crossed them. An avalanche develops in the gas along the path of ions created by the particle, and a spark discharge occurs from one plate to the other. The original procedure was to record the sparks photographically.

Unlike other trajectory-measuring devices the spark discharge is an elec-



SPARK CHAMBER fires when a coincidence in the trigger circuit turns on the high voltage, inducing a spark along the trajectory. —FIG. 1

trical phenomenon of considerable magnitude. Consequently it can be made immediately available for processing. This goal is accomplished by replacing the uniform plates of a chamber by a layer of parallel wires typically 0.1 mm in diameter and spaced 1 to 1.5 mm apart (figures 1 and 2). The spark coördinate is then given by the particular wire through which the discharge current flows. The problem remaining is to detect this current with a reliable and inexpensive readout system and transfer the information to a data-storage or processing device.

Several different types of spark chambers have been developed, but the most commonly used is the narrow-gap chamber. In this the electrode planes are separated by about 1 cm with several such gaps often included in one chamber. In a particle-physics experiment, arrays of such chambers are placed around some source of particles such as a liquid-hydrogen target in a beam of particles from an accelerator. The chambers are filled with a noble gas at atmospheric pressure, usually commercial-grade neon containing 10–30% helium. To this is added a few per cent of a polyatomic quenching agent like alcohol or propane.

Little scattering. As the gas is at atmospheric pressure, the windows of the chamber through which the particles pass can be very thin; therefore spark chambers have the important property that they contain little scattering material. This property permits accurate measurement of the particle trajectories when chambers are used in a series as in the spectrometer shown in figure 3. In a wire chamber of two planes the total amount of material is typically 15 mg/cm^2, which is an order of magnitude less than in the thinnest scintillation counter.

Memory. Perhaps the most significant characteristic of the spark chamber is its memory. Because of it, after a particle has passed through the chamber, external logical circuitry can decide whether or not to trigger the chamber and complete the detection process. The memory time is controlled partly by an electric clearing field that sweeps away the primary ions. It is usually adjusted so that the memory is just long enough to permit the high-voltage pulse to turn on and produce a spark with good efficiency. Memory times of about 1 microsec are obtained with a clearing field of the order of 100 volts, depending on the chamber geometry and gas used. The memory time is kept short because it is also the resolving time.

High-voltage pulse. Application of the high-voltage pulse is one of the more difficult engineering aspects of spark-chamber operation. A narrow-gap chamber requires a pulse of as much as 1000 amp at several kilovolts, and its rise-time must be about 10 nanosec. The time delay that the logical triggering circuit introduces between the passage of the particles and application of the high-voltage pulse is kept short, a few tenths of a microsecond, because the primary ions are being swept away during this period. A fast rise-time is needed to prevent the pulse from acting as a clearing field and sweeping away the primary ions before the gaseous discharge can develop. The high-voltage pulser usually consists of a capacitor that is kept charged to a high voltage and is discharged into the chamber with a hydrogen thyratron or spark-gap switch. The duration of the spark is adjusted according to the amount of energy needed to operate the readout system with good chamber operation.

Recovery time. Once the discharge is completed, a large number of ions remain that must be cleared away before the chamber can be triggered again without "remembering" the previous event. This recovery time is dependent on the energy in the discharge and for wire chambers is a few milliseconds. In an experiment using a number of chambers recovery time corresponds approximately to the time necessary to transfer the coördinate data to the storage device. The minimum repetition period of a wire-spark-chamber system then is inherently of the order of a millisecond.

Resolution. The spatial accuracy of a wire chamber is, of course, related to the wire spacing. Because more than one wire in a plane is involved in a discharge, a resolution smaller than the wire spacing is expected. Resolutions smaller than half the spacing between wires have been observed.

Efficiency and redundancy. Two problems to be taken into account in

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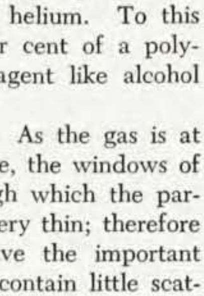


wire-chamber application are spurious sparking and chamber inefficiency. Although the former can be held to a few per cent of the good sparks and efficiencies of more than 95% can be expected, redundancy must be built into a large system. To determine a straight line trajectory, for example, three points must be measured to identify and reject spurious sparks. In a large system requiring good overall efficiency a fourth point should also be measured on the line to allow for chamber inefficiency. Thus there are four chambers preceding and following the magnet in the spectrometer of figure 3.

The readout system

For a system of wire chambers involving tens of thousands of wires, one must have a readout method that is reliable and inexpensive. Attached to each plane is a device that detects those wires that carry spark current. Such a device can be mounted on both the grounded plane and the plane that is pulsed to a high voltage as in figure 1 or on the ground plane only. In the latter case, of course, the number of planes must be doubled to obtain both the x and y coördinates. Two types of readout systems are in use; one uses ferrite cores and the other a magnetostrictive wire.

Ferrite core. Frank Krienen[1] showed that the spark current traveling down a chamber wire could be used to flip a ferrite core; the core could later be interrograted by normal computer techniques. This method has many attractive features. It requires a minimal spark current, about 1 amp, to set the core; therefore the energy of the discharge is small with a consequent reduction in chamber recovery time. With this system it also is possible to let the noise associated with the high-voltage pulse dissipate before actuating any electronic sensing circuitry. The cores are the memory where the information stays until the computer asks to receive it.

Each core is traversed by three wires instead of four as in a computer memory. The first is the *chamber* wire, which sets the core; the second is the *read* wire, which resets the core, and the third is the *sense* wire, which detects the transition when it occurs (figure 4). The read-address amplifiers reset each group of cores sequentially, and an encoder establishes the address of the flipped core and transmits it through suitable interfacing to the data storage.

One of the first systems of this type to be used in a full-scale high-energy physics experiment was developed by Joachim Fischer at Brookhaven and used at the AGS by George B. Collins and collaborators to measure inelastic proton-proton scattering.

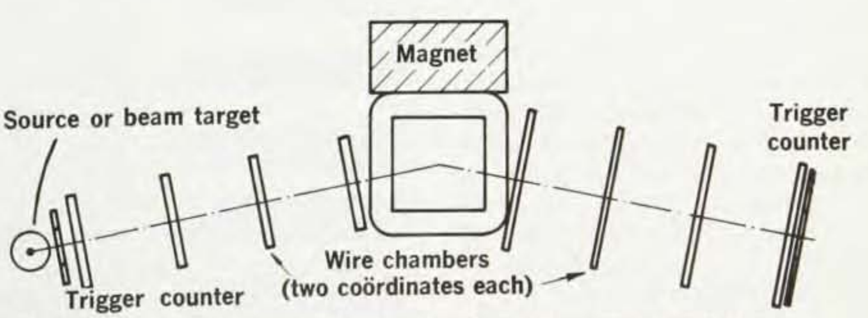
Magnetostriction. Guglielmo Gianelli[2] demonstrated that the location of a spark on a chamber wire could be determined by measuring the transit time of an acoustical wave produced in the wire by the spark. By making the chamber wires of an iron alloy, the wave could be produced and detected by the magnetostrictive effect. The electrical current flowing in the wire was ignored. With an acoustical wave velocity of 5 mm/microsec, he was able to locate the spark to within 1 mm.

For large systems this method was impractical as it required a detector on each wire of a chamber. Victor Perez-Mendez and James Pfab[3] avoided this difficulty by placing the magnetrostrictive wire perpendicularly across the wires at the edge of the chamber. This wire is close but not in electrical contact with the chamber wires. The chamber wire carrying the spark current then acts as a single-turn coil to induce the acoustical pulse in the readout wire. Unlike Gianelli's method this arrangement does not give the position of the spark along the chamber wire but instead indicates which wire or wires of the chamber the spark has struck just as the core readout system does.

In figure 5 is shown the corner of a wire plane with a simple magnetostrictive readout system. A coil is wrapped about a portion of the readout wire that contains some of the return flux of a magnet. When the acoustical pulse arrives, deformation of the wire alters the flux through the coil inducing a current in it. The wave continues along the wire until it is absorbed by the termination. The signal from the sense coil, after amplification and shaping, stops a clock that was started when the chamber was triggered. The clock, or scaler, thus gives the transit time of the acoustical wave and thereby identifies the wire or wires hit by the spark. In the case of one spark striking several wires, the peak of the resultant wave from several wires can be taken as the spark position with good accuracy.

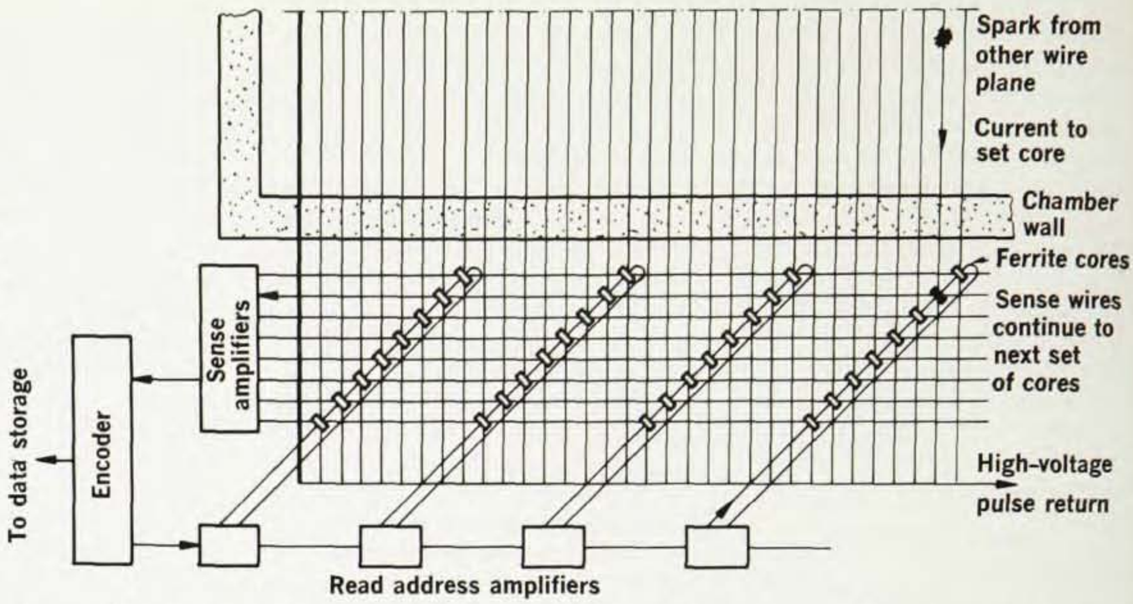
The beauty of this method is the relative simplicity of its construction. When, however, there are several sparks in a chamber, an additional scaler should be added for each one. Ways of circumventing this are possible, but in any case it is necessary to have some immediately available memory device for each spark coördinate signal as it arrives. In general this cannot be the computer or final storage device in a large experimental system where many chambers must be interrogated. However, when only one or two particles are expected to pass through a chamber and few or no spurious sparks are likely, this is an attractive system to use. Wide-gap chambers have essentially no spurious sparking, and such a chamber with magnetostrictive readout is shown in figure 2.

Many ingenious variations and improvements have been made in these two basic types of readout systems, but the fundamental attributes of the wire spark chamber remain the same,



SERIES OF CHAMBERS permits one to identify and reject spurious sparks and allow for chamber inefficiency. —FIG. 2

MAGNETIC CORE readout senses which core has been set by the spark, resets it and stores the address, which specifies the wire in which the spark occurred.
—FIG. 3



namely, that points on particle trajectories can be measured with an accuracy of a few tenths of a millimeter and that all the information from an event in an elaborate experimental arrangement can be in the memory of a computer ready for processing 1 or 2 millisec after the event has taken place. Furthermore, in the process of observation the particles have been disturbed by a minimal amount of material.

Other detectors. Other spark-chamber systems with immediate electronic readout have been developed. They do not, however, seem to be as useful as wire chambers because of lack of accuracy or inability to resolve several sparks. Among these is the sonic chamber in which the transit time of the sound of the spark in the gas is measured with microphones. Vidicon television cameras have also been used to replace film cameras in viewing optical spark chambers. In another system, the position at which a spark hits a spark-chamber plate is determined by measuring the relative currents arriving at opposite edges of the plate.

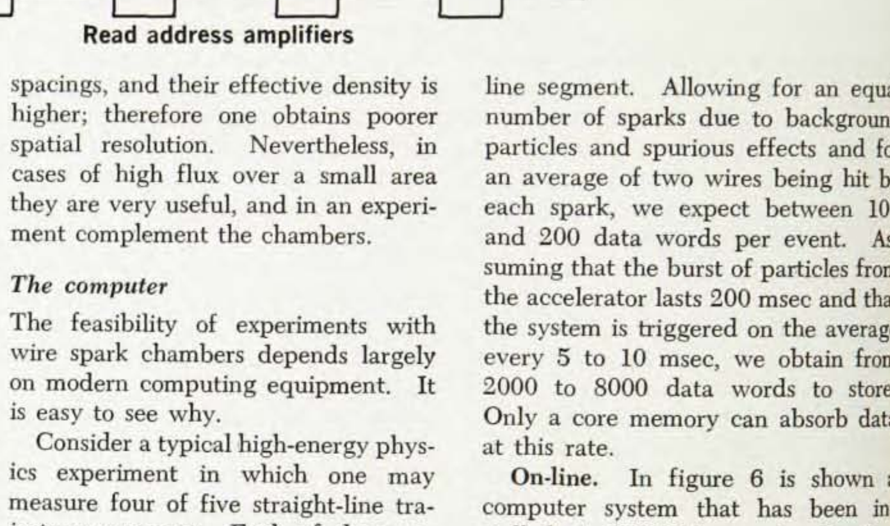
A different type of detector for the on-line measurement of particle trajectories is the scintillation counter hodoscope. This is a plane made up of strips of plastic scintillator viewed by photomultiplier tubes. Hodoscopes have resolving times of less than 10 nanosec, but with a phototube for each digitizing element, they are far more expensive than wire chambers. The elements are larger than wire spacings, and their effective density is higher; therefore one obtains poorer spatial resolution. Nevertheless, in cases of high flux over a small area they are very useful, and in an experiment complement the chambers.

The computer

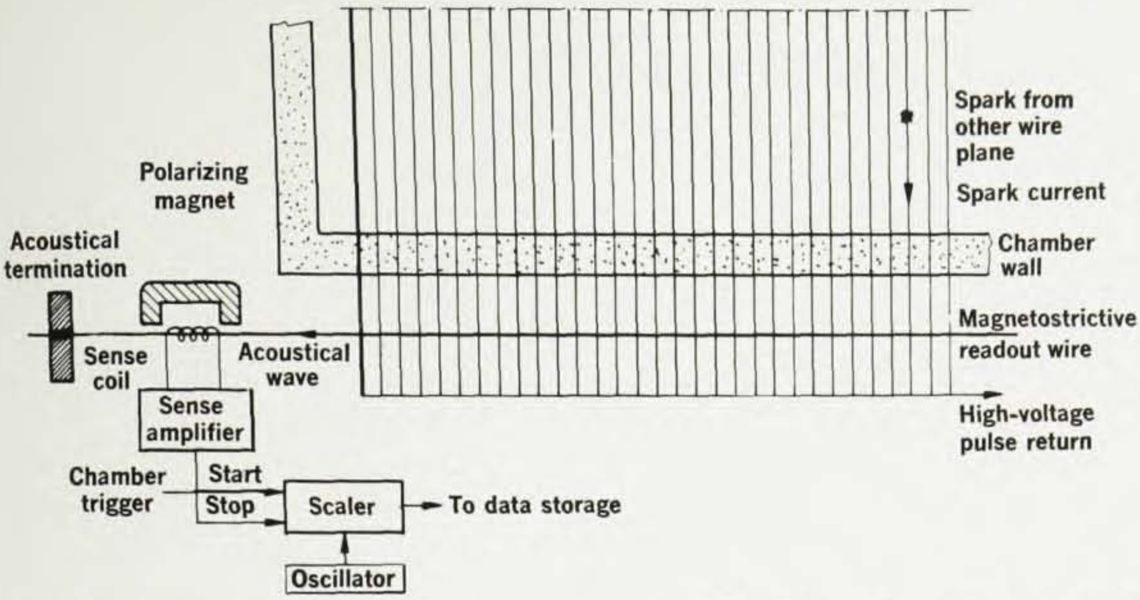
The feasibility of experiments with wire spark chambers depends largely on modern computing equipment. It is easy to see why.

Consider a typical high-energy physics experiment in which one may measure four of five straight-line trajectory segments. Each of these requires four points in two projections or a total of eight digitizing planes per line segment. Allowing for an equal number of sparks due to background particles and spurious effects and for an average of two wires being hit by each spark, we expect between 100 and 200 data words per event. Assuming that the burst of particles from the accelerator lasts 200 msec and that the system is triggered on the average every 5 to 10 msec, we obtain from 2000 to 8000 data words to store. Only a core memory can absorb data at this rate.

On-line. In figure 6 is shown a computer system that has been installed at CERN for a wire-chamber experiment. The local computer, an IBM 1800, is located near the experi-



DATA PROCESSING sequence combining on-line and time-shared use. —FIG. 5



ACOUSTIC readout uses time interval between trigger pulse and arrival of the acoustic pulse at the end of the magnetostrictive wire to locate the plane in which the spark occurred. —FIG. 4

ment at the accelerator. It is connected through a kilometer-long cable to a powerful backup computer, a CDC 6600, at the CERN computing center. The experiment is under the control of the local computer, which is the type normally intended for process-control functions in industry. It is equipped with the multiple-level interrupt facilities necessary for it to communicate with a number of external devices interchangeably. Its primary function is to absorb data from the spark chambers and other equipment during the accelerator burst and to record it on magnetic tape in the time remaining between bursts. This tape becomes the permanent record of the experiment. The second function of the local computer is to monitor the chambers for proper operation. Some rudimentary calculations can be made locally, but the bulk of the data analysis is left to the backup computer. Results of the analysis can be transmitted back to the local computer and printed out for the experimenter to study.

Before the data links were available, the tapes from the local computers were rushed by hand to the computing center in what became known colloquially as "bicycle-on-line" experiments.

The processing of data from wire chambers in a particle-physics experiment depends heavily on experience gained with bubble-chamber and optical-spark-chamber film analysis. In particular, it often makes use of computer programs written for the automatic measurement of these films with flying-spot digitizers.

Program for speed. In contrast to most fields, the application of automated data reduction in high-energy physics is extending from more complex to less complex problems. Flying-spot digitizers were originally built for the measurement of bubble-chamber film, but fully automatic measurement and analysis of a bubble-chamber photograph with 10 to 20 incident tracks is still considered a formidable task. With photographic spark chambers the problem is considerably reduced as the only tracks on the film are those of the event of interest. The amount of data to be handled is still large, being of the order of several thousand digitizations per frame; but fully automatic data reduction has become quite common especially in experiments involving over 100 000 photographs. With wire spark chambers the data per event decreases again—by an order of magnitude. In addition the pattern-recognition problem is reduced, and the random noise introduced by the interface of photographic film is removed. On the other hand, wire chambers can recycle 10 to 100 times faster than photographic chambers. Thus the data processing needs are, if anything, increased—and drastically so if one expects the analysis in an on-line computer to keep up with the chambers in a complex experiment.

With such computing demands the use of generalized Fortran programs is a luxury. Two approaches have been taken to reduce analysis time; one is to write programs in the more difficult but faster language particular to a computer. The other is the use of highly specialized programs valid for only one configuration of the experiment. Both approaches require a considerable increase in programing effort, but the gain in speed is often astonishing.

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APOLOGIA: *It is impossible in an article of this scope to cite many of the contributions in this field. Below are listed, in addition to papers of historical interest,[1-3] review articles[4,5] and conference proceedings[6-9] where a wealth of information can be found.*

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