New Apparatus and Methods of Measurement

# REVIEW OF THE PRINCIPLES OF REGISTRATION USED IN MULTICHANNEL PULSE-HEIGHT AND TIME ANALYZERS

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MULTICHANNEL pulse-height analyzers and multichannel time interval analyzers are widely used in experimental physics. A feature common to both instruments is a multichannel registering device, which must meet practically the same requirements in both cases. Many different multichannel registers are known today. As each one has its own advantages and shortcomings, it is difficult to select the right registering device for performing this or that actual task of multichannel analysis. A correct choice can be made only on the basis of a clear understanding of the differences both in the means employed in the multichannel register and in the methods, i. e. in the principles of accomplishing the registration. The present problem has practically not been touched in the literature.

The classification of registering devices, that is available in the reviews[1,2,3] about multichannel analyzers, has been developed unsystematically, often according to incidental features. It is important, therefore, to discuss multichannel registering devices apart from the analyzer in which they are used and to introduce a classification of these devices which will make possible a critical appraisal of the congruence between the task at hand, the principle chosen for registration, and the technical means used in its realization.

The classification proposed here satisfies these requirements to some extent. It is based on distinguishing the basic principles of the logical design of multichannel registering devices. By the logic of the design of any device is meant the nature of the operations to be performed by the device and the method of distributing the functions among the component parts of the device in order to effect these operations.

Our classification proceeds from the fact that in general a multichannel analyzer can be regarded as composed of two basic units: the sorter and the register. The sorter shapes the signals to be analyzed, blocks access to the analyzer during analysis and registration, discriminates the signal (i. e., determines the number of the channel into which a given event should be recorded), and sends the signal to the appropriate channel of the register.

Upon receiving these signals, the register performs the following operations: 1) it accumulates the numbers of the pulses in the channels, 2) stores the obtained results for the required time, 3) allows these results to be observed by one means or another, and 4) clears them before accepting new ones.

The early multichannel analyzers almost exclusively employed electromechanical counters as registering devices. At the present time there exist many means of registration: scaling circuits using cold-cathode thyratrons, incandescent lamps, dekatrons, or trochotrons; memory systems using delay lines, electron-beam devices, ferrites, a magnetic drum, and so forth. Regardless of such variety, any registering device must still perform the four functions enumerated above: accumulation, storage, display, and clearing. On the quantitative side, all these registers are characterized by 1) the capacity, i. e., the volume of data upon which the enumerated operations can be performed, 2) the speed of operation, i. e., the time required for these operations, especially for accumulation, and 3) the complexity, i. e., the volume of technical means expended on achieving the enumerated operations.

Reliability is the paramount requirement, without which a discussion of the other characteristics is absurd.

The enumerated operations and quantitative characteristics apply to a register with any number of channels. But the selection of the methods of registration becomes especially important for a considerable number of channels, amounting to several hundred in a few cases. With such a large number of elements, the quality of the register depends to a considerable extent on how the functions are distributed among these elements and on which elements are chosen for performing each one of the functions.

In spite of the variety of means of registration, it is possible to distinguish only four types of multichannel registers. Their main difference lies in the logic of the connection between the elements of the register, i. e., in the method of distributing the functions among them.

The first type, until recently the most prevalent one, is the multichannel register with independent registering devices in each channel.[4,5,6]. Such devices perform all four functions, have the required capacity, and the speed of accumulation decreases from the first element to the last. If a mechanical counter and a scaler are used, the change of speed is usually not achieved smoothly, but stepwise: the scaler has relatively high speed, and the mechanical counter is slow.

If dekatrons or cold-cathode thyratron circuits are used as registers, the first stages of the scalers have to be made of vacuum tubes to increase the speed.

The disadvantages of registers of the first type are well known: the large number of tubes, the bulkiness, the nongraphic and rather complicated display, and the frequent troubles with clearing. All these shortcomings are felt especially sharply with a large number of channels. Nevertheless the potentialities of the elements of the register are fully exploited. This type can be further improved by the creation of new universal counting devices.

The analyzer with a ferrite memory[7,8,9] illustrates the second type of multichannel register. Ferrites can be employed as memory elements because they are able to assume two different physical states and allow these states to be controlled. A chain of memory elements is inserted in each channel of the analyzer. An electronic scaling circuit performs the function of accumulation, during which it is the only one in the entire analyzer. The sorter determines the channel in which registration is to be performed. As a result of sorting and upon being found in a cleared state, the accumulating circuit is connected to the memory chain of the chosen channel. The number stored in the memory chain is transferred to the accumulating circuit. Then this number is increased by unity, and the new number is transferred back to the same memory chain.

Although the transfer of data from the memory chain to the accumulating circuit and back to the memory requires a complicated additional control circuit, the multichannel register of the second type is still more efficient than the first type, because the many accumulating circuits have been replaced by a single one, and because the very simple and small-sized ferrite cores perform the memory functions.

Are the capabilities of the elements in the analyzer of the second type utilized efficiently? Unfortunately, no. The accumulating trigger device is capable of serving as a long-term memory; this capability, however, does not find application. Not participating directly in accumulation, the elements of the long-term memory perform a dual passive role; but at the same time it is obvious that these elements could also perform the accumulation if they were appropriately connected among themselves. The trigger accumulating circuit would then be superfluous. This would lead to a marked simplification of the common system of commutation.

Obviously a register of type two does not have to be based on ferrites. Any system of long-term memory, whether it be a delay line, a magnetic drum, or an electron-beam tube, and so forth, can be used to construct a multichannel register of the second type. The register will be more or less complicated and faster or slower only to the extent to which the chosen memory devices are used efficiently. As to the ferrites in particular, it is noted that the display of data stored in them is rather awkward.

In addition to all the circuits listed above, an indicating cathode-ray tube and a system of sequential interrogation of all ferrites in the memory have to be provided. A further complication in the construction of ferrite registers is that mass production of high-quality ferrites has not yet been achieved.

The third type of multichannel analyzer appeared considerably earlier than the second and was built by Hutchinson and Scarrott.[10] In this apparatus there is none of the functional "underloading" of the register elements, which is characteristic for the second type. It is also strange that, compared with the analyzer of Hutchinson and Scarrott, the ferrite register, which appeared several years later, in its logical relationship represents a step back rather than progress.

Actually, if the analyzer of Hutchinson and Scarrott is considered, it is evident how efficiently all its elements are used: the delay line together with a relatively simple control circuit carries out the long-term storage and at the same time appears as an accumulating device in every channel. Moreover the relatively small number of memory elements possesses a large capacity. Although the display of results stored in the delay line requires an additional cathode-ray tube, no additional stages are needed in the control circuit for attaching the tube.

The only weak feature of the register of the third type is the purely sequential method of performing the operations. Hence it is sometimes necessary to read through all data in all channels in order to record only one analyzed pulse. On the average each entry of a new datum requires the processing of half the data in the register. If the memory device were ideal and did not require regeneration, it would not be necessary to process all the memory elements on the way to that element where it is desired to read out or write in information. Nevertheless this "ideal" would not yield a saving of time, since in the sequential mode of selecting the desired element time is wasted in waiting for this element to pass "by" the reading and writing device. In practice, therefore, it always proves to be advantageous to use the waiting time for regenerating the data in the memory elements being scanned. It is obvious that a purely sequential system cannot in principle be fast. A variant of the analyzer of the third type is that of Tsitovich.[11,12] It differs from the analyzer of Hutchinson and Scarrott mainly in its use of an ordinary cathode-ray tube instead of the mercury line. This simplified the circuit somewhat, but made the instrument even slower, reduced the reliability, and the replacement of the binary representation by the linear one decreased the capacity. One more difference of the analyzer of Tsitovich is that in it the memory elements do not pass by the reading and writing device, but the reading and writing beam runs through immobile memory elements. Such a change of roles, however, can hardly be called a principle of registration.

Instead of a mercury delay line, a quartz line is used in the analyzer of Schultz, Pieper, and Rosler,[13] whereas Ofengenden and Kotova[14] employ a magnetic drum. All the listed analyzers of the third type operate cyclically with a period equal to the time of scanning all memory elements. A register that would operate in the waiting regime, i.e., with a variable period, but would retain the purely sequential principle of introducing and withdrawing information, would also belong to the third type. The average dead time of such a register would be equal to half the maximum period of the cycle.

In order to retain the advantages of the register of the third type but to make it faster, it is necessary to replace the sequential selection of data by a parallel one, i.e., by one in which it is not necessary to process the data in other memory elements in order to process data in a desired element. If for the sake of circuit simplicity it is desirable to retain the sequential interrogation of the elements, then it is necessary to devise a program of interactions that minimizes the number of successive elements which have to be processed.

A principle for constructing analyzers satisfying these requirements was proposed[15] at the end of 1952. Multichannel analyzers based on this principle of registration are now widely distributed.[16,17,18]

In this, the fourth type of multichannel register a potentialoscope [ = electrostatic memory tube] is applied as the memory device. Like any other sufficiently capacious system of static storage, the potentialoscope begins to register a pulse in the proper channel immediately after sorting without wasting time on processing the data in other channels. The nondiscrete amplitude of the pulse being analyzed is converted by the sorter into a discrete one and gives a discrete horizontal deflection to the beam of the potentialoscope. After the deflecting voltage has been set, the beam is turned on.

From then on the control circuit processes sequentially the column of spots on the potentialoscope screen, which constitute the memory elements of the selected channel. The processing consists of the following. Falling onto a spot, the beam first reads out the existing entry, either a "0" or a "1." If a "0" is read out, then a "1" is written in immediately, the beam is turned off, and the deflecting voltage is cleared into its original state. If a "1" is read out, then a "0" is written into this spot, the beam is turned off and moves on to the next spot on the vertical. Thus the beam keeps moving until it "finds" a spot with a "0"; then it writes in a "1," whereupon both deflecting voltages are cleared.

It is easy to illustrate with examples that such a program of control of the potentialoscope beam causes the number of pulses in each channel to be written in a binary system of numbers, and that a large capacity is obtained in each channel. Upon entry of an analyzed pulse, only two spots, two memory elements have to be processed on the average, thanks to which it is possible to combine the simplicity of the sequential method of data processing with the speed of the parallel method.

Although ferrite registers of the fourth type are also feasible, the potentialoscope has advantages of its own. It is inexpensive and is manufactured in large quantities. Since development work on potentialoscopes is continuing, its characteristics improve from year to year, and the cost and size decrease. Moreover the potentialoscope is easily connected with an oscilloscope for observation; both tubes have the power supply and deflection circuits in common. The power consumed by the memory elements is negligible.

A recent analyzer with a register of the fourth type[18] contains about 60 electronic tubes in the register itself and has 1024 channels with a capacity of 65,535 in each. The processing time of a single memory element is about 3 microseconds.

In conclusion, mention should be made of continuously operating registers, for example recorders, photoregisters, and so forth. They are distinguished by a simple design and a graphical display of results, but like any analog arithmetic device they give rise to large errors of computation. Their use in the multichannel analyzer, a purely digital machine, is in general not expedient, and they find practical application only in the analyzer of the first type as an auxiliary means of displaying a spectrum.

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