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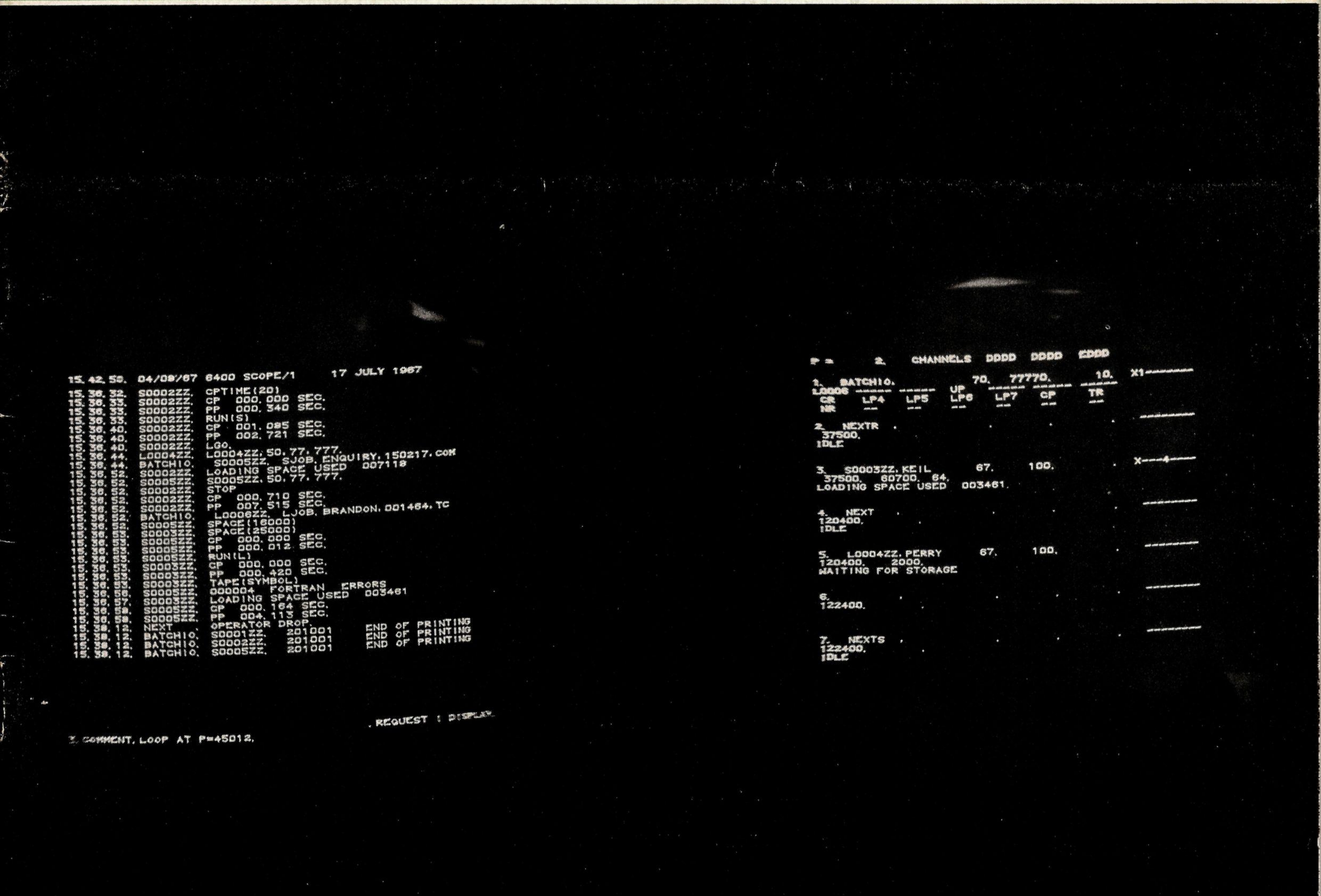

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15.42.59. 04/08/67 6400 SCOPE/1      17 JULY 1967
15.36.32. S0002ZZ.  CPTIME(20)
15.36.33. S0002ZZ.  CP   000.000 SEC.
15.36.33. S0002ZZ.  PP   000.340 SEC.
15.36.33. S0002ZZ.  RUN(S)
15.36.40. S0002ZZ.  CP   001.095 SEC.
15.36.40. S0002ZZ.  PP   002.721 SEC.
15.36.40. S0002ZZ.  LGO.
15.36.44. L0004ZZ.  L0004ZZ.50.77.777.
15.36.44. BATCHIO.   S0005ZZ.  SJOB.ENQUIRY.150217.COM
15.36.52. S0002ZZ.  LOADING SPACE USED  007118
15.36.52. S0005ZZ.  S0005ZZ.50.77.777.
15.36.52. S0002ZZ.  STOP
15.36.52. S0002ZZ.  CP   000.710 SEC.
15.36.52. S0002ZZ.  PP   007.515 SEC.
15.36.52. BATCHIO.   L0006ZZ.  LJOB.BRANDON.001464.TC
15.36.53. S0005ZZ.  SPACE(16000)
15.36.53. S0003ZZ.  SPACE(25000)
15.36.53. S0005ZZ.  CP   000.000 SEC.
15.36.53. S0005ZZ.  PP   000.012 SEC.
15.36.53. S0005ZZ.  RUN(L)
15.36.53. S0003ZZ.  CP   000.000 SEC.
15.36.53. S0003ZZ.  PP   000.420 SEC.
15.36.53. S0003ZZ.  TAPE(SYMBOL)
15.36.56. S0005ZZ.  000004  FORTRAN  ERRORS
15.36.57. S0003ZZ.  LOADING SPACE USED  003461
15.36.58. S0005ZZ.  CP   000.164 SEC.
15.36.58. S0005ZZ.  PP   004.113 SEC.
15.38.12. NEXT      OPERATOR DROP.
15.38.12. BATCHIO.  S0001ZZ.   201001     END OF PRINTING
15.38.12. BATCHIO.  S0002ZZ.   201001     END OF PRINTING
15.38.12. BATCHIO.  S0005ZZ.   201001     END OF PRINTING

                                    .REQUEST : DISPLAY.
3.COMMENT.LOOP AT P=45012.
```

```
P =    2.   CHANNELS DDDD  DDDD  EDDD

1.  BATCHIO.             70.  77770.      10.  X1
L0006                    UP
 CR     LP4     LP5    LP6    LP7    CP     TR
 NR

2.  NEXTR   .                .      .      .
 37500.
IDLE

3.  S0003ZZ.KEIL      67.      100.        .   X---4---
 37500.  60700.  64.
LOADING SPACE USED  003461.

4.  NEXT    .                .      .      .
120400.
IDLE

5.  L0004ZZ.PERRY     67.      100.        .
120400.    2000.
WAITING FOR STORAGE

6.          .                .      .      .
122400.

7.  NEXTS   .                .      .      .
122400.
IDLE
```

Cover photograph: The two oscilloscopes on the control console of the main computer, CDC 6600. On the right is indicated the programs which the computer is handling at that point in time; on the left, the various stages of computation that the programs are undergoing.
(CERN/PI 69.8.67)

Contents

Comment

One of the biggest single influences on contemporary life is the growing use of the electronic computer. We are now learning to hand over to these machines enormous problems of analysis and control, the solutions of which are transforming our capabilities. And, for all the sophistication that has already been brought to the construction and use of computers, we are still in the early days of learning what we can do with them.

The work of CERN is a very small and specialized part of contemporary life but sub-nuclear physics research is one example of a field which could not have sustained its rate of progress had it not been for the parallel development of computers. CERN has a wide variety of problems to which computers can be applied and the intricacy and volume of these problems have led to CERN becoming the most powerful computer centre in Europe.

Unfortunately, the increasing demands of our work are even outpacing the capabilities of existing computers and CERN has had to accept the problems which come from working at the frontier of what is technically feasible. Despite the impressive systems that are now on site, CERN has already to consider how its requirements of the 1970's can be met by foreseeable advances in computer technology.

This issue of CERN COURIER is devoted to the electronic computer and its use at CERN.

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CERN, the European Organization for Nuclear Research, was established in 1954 to '... provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto'. It acts as a European centre and co-ordinator of research, theoretical and experimental, in the field of sub-nuclear physics. This branch of science is concerned with the fundamental questions of the basic laws governing the structure of matter. CERN is one of the world's leading Laboratories in this field.

The experimental programme is based mainly on the use of two proton accelerators — a 600 MeV synchro-cyclotron (SC) and a 28 GeV synchrotron (PS). At the latter machine, large intersecting storage rings (ISR), which will allow experiments with colliding proton beams to be carried out, are under construction. Scientists from many European Universities and national Laboratories as well as from CERN itself take part in the experiments and it is estimated that some 700 physicists outside CERN are provided with their research material in this way.

The Laboratory is situated at Meyrin, Canton of Geneva, Switzerland. The site covers approximately 80 ha about equally divided on either side of the frontier between France and Switzerland. The staff totals about 2300 people and, in addition, there are over 400 Fellows and Visiting Scientists.

There are thirteen member States participating in the work of CERN. The contributions to the cost of the basic programme, 172.4 million Swiss francs in 1967, are in proportion to their net national income. Supplementary programmes cover the construction of the intersecting storage rings and preliminary studies on a proposed 300 GeV proton synchrotron for Europe.

The Electronic Computer
A Machine with a Past

G. A. Erskine

It is about 130 years since the wealthy mathematician and amateur engineer, Charles Babbage, conceived the idea of a completely automatic calculating machine.

Babbage realized that if his machine was to operate without human intervention, it would have to print its results and would require an internal store or 'memory' in which intermediate results of the calculation could be placed for subsequent use by the machine. This store was to consist of a thousand columns of digit wheels, each column containing 50 decimal digits. The automatic control of the sequence of arithmetic operations was to be provided by perforated cards of the kind used for controlling the lifting of the warp threads in a Jaquard loom.

With remarkable insight, Babbage realized that a truly universal calculating machine would need to vary its sequence of operations depending on the unforeseeable result of intermediate calculations. He therefore provided for a mechanism that would cause the machine to skip forwards or backwards over a specified number of control cards when the number contained on some specified storage column changed its sign. He also provided for the automatic detection of the overflow which would occur if any result exceeded 50 digits in length, and he foresaw the use of what would now be called programmed multilength arithmetic to deal with such cases. Thus Babbage anticipated many of the essential features of the modern computer.

Babbage prepared detailed drawings of many parts of his Analytical Engine and spent much of the remainder of his life experimenting with pieces of the mechanism. During a visit to Italy, he described the proposed machine to a small group of people which included L.F. Menabrea, an army engineer and mathematician. Menabrea was so much interested by Babbage's machine that he published a general description of it in the Bibliothèque Universelle de Genève in 1842.

In the same year, Lady Augusta Lovelace, daughter of the poet Byron, published an English translation of Menabrea's article, to which she added explanatory appendices which were three times the length of the original article. Lady Lovelace, mathematician and a friend of Babbage, understood clearly what was involving in 'programming' the Analytical Engine, possibly more clearly than Babbage himself. One of her appendices gives a complete — and completely modern — program for calculating the successive Bernoulli numbers by means of a recurrence relation (see page 165). The program shows how the repetitive nature of the calculation was to be exploited by the machine.

Since even Babbage's substantial fortune was not sufficient to pay for the cost of constructing the Analytical Engine, Babbage and Lady Lovelace devised, and put into practice, an infallible system for backing horses. The results were disastrous.

The Twentieth Century

From the time of Babbage's death in 1871 until the late 1930s, there seems to have been no attempt to construct a completely automatic general-purpose calculator. Manually operated calculators underwent a steady improvement and electromechanical punched card machinery was invented and developed. Such machines could sort, add, subtract, and print, but there was no means of specifying that an arbitrary sequence of arithmetic operations should be carried out without manual intervention.

In 1939, Howard Aiken of the University of Harvard entered into collaboration with the International Business Machines Corporation to construct an automatic electro-mechanical calculator in which the sequence of operations was to be controlled by a perforated paper tape, in rather the same way as Babbage's machine (of which Aiken knew nothing at the time) was to be controlled by Jaquard cards. This machine, the Harvard Mark 1 calculator, was completed in 1944.

In the meantime, work had begun at the University of Pennsylvania on the first completely electronic computer, the ENIAC. This computer, designed by J. W. Mauchly and J. P. Eckert under a contract with the United States Army, was completed in 1946. Vacuum tube circuits were used to provide arithmetic capabilities together with internal storage for twenty 10-digit numbers. Each 10-digit storage location required 550 tubes, and the whole computer used approximately twenty thousand tubes. Programming was by means of switches and plug-in wires, and the time required to set up a new calculation might be anything from a few hours to several days. The ENIAC was certainly fast: addition took 200 mircoseconds (200 μs) and multiplication 3 milliseconds (3 ms).

Some time in the summer of 1944, while the ENIAC was still under construction, the mathematician John von Neumann learnt of the ENIAC in an accidental meeting with a colleague, H.H. Goldstine. It is tempting to think of von Neumann as being horrified by the thought of those twenty thousand vacuum tubes being used to provide such inflexible computing facilities. In any case, von Neumann and Goldstine, in collaboration with members of the ENIAC team, set to work on the logical principles of an electronic computer which would be far more versatile than the ENIAC while using much less hardware. These principles were presented to an international audience at a summer school held at the University of Pennsylvania in 1946, and were subsequently published in a series of reports.

The von Neumann Computer

The computer proposed by von Neumann and Goldstine in 1946 is essentially the modern computer. The fundamental proposal was that the 'instructions', which specify the sequence of operations to be performed, should be coded into numerical form and held in the same high-speed storage device as the numbers on which the computer was to operate. The computer could then extract successive instructions from the store at the same speed as it could extract numbers, and could, when necessary, be made to jump easily from one place to another in the instruction sequence according to the result of some simple test (for example, a test on the sign of the number in a specified storage location). Using an input medium such as paper tape, it would be possible to load in a few seconds a program containing hundreds of instructions, thus preparing the computer for a new calculation.

The von Neumann and Goldstine reports also describe the use of a library of programs (already foreseen by Babbage) and the means by which sub-routines (sequences of instructions for performing

The first programmer, Ada Augusta, the Countess of Lovelace, and (opposite) the first programm, prepared by Lady Lovelace in 1842 for calculating the Bernoulli numbers on Babbage's Analytical Engine. (Reproduced from Lord Bowden's book 'Faster Than Thought' with acknowledgement to Lady Wentworth).

frequently occurring operations), prepared in a form which was independent of their final position in the store, could be 'relocated' before the beginning of a calculation.

One effect of the 1946 summer school was to start a computer-building race. This race was won by a team headed by M.V. Wilkes of the University of Cambridge, whose EDSAC computer came into operation in May 1949. Only shortly behind came the University of Manchester with its computer incorporating the first index registers.

The Vanishing Programmer

The designers of the early computers assumed that programming would be in the hands of a small group of specialists, probably mathematicians, and that it would be undesirable to make the task too easy. For example, von Neumann and Goldstine presented the following argument against providing built-in floating-point arithmetic: 'The floating binary point represents an effort to render a thorough mathematical understanding of at least part of the problem unnecessary, and we feel that this is a step in a doubtful direction'. Thinking along the same lines, the University of Manchester adopted for their first computer a programming code in which all instructions were constructed from a group of 32 teleprinter characters. Thus the sequence of instructions for calculating a sum of the form $a_1 b_1 + a_2 b_2 \ldots + a_{16} b_{16}$ became

```
@ / T :
V E Q O
/ I U K
/ U U F
£ E Q G
E / / T
```

This programming code was retained when engineered versions of the Manchester University computer were offered for sale commercially ! Gradually, however, the manufacturers of computers began to wonder whether perhaps difficulties of programming might not be discouraging prospective customers. This led to the development of simplified programming languages, of which Fortran (introduced in 1957) has been one of the most successful. The sequence of instructions given above can be written in Fortran as follows:

```
   SUM = 0.0
   DO 10 J = 1,16
10 SUM = SUM + A(J)*B(J)
```

where the asterisk denotes multiplication. In this way, programming became a 'do-it-yourself' activity, and the only full-time programmers to remain in business were those whose job it was (and is) to write the complicated compilers and supervisory programs which constitute the vital'behind-the-scenes 'software' of the modern computer.

The Communication Gap

It was soon realized that the electronic computer, invented to do arithmetic quickly, could also perform non-numerical tasks. Computers can be programmed to play a good game of draughts, but only an indifferent game of chess. They can make poor translations from one language into another. If connected to suitable equipment, they can read printed text or control machine tools. The only limit to their capabilities, apart from their finite — but ever-increasing — speed and storage capacity, seems to lie in the intellectual limitations of those who programme them.

Since a computer cannot execute everyone's program at once, programs and data (in the form of punched cards or perforated paper tape) are usually placed in a queue in which they wait until they can be processed. The results generated by programs may also queue on some large-capacity 'backing-store' until they can be printed. The delay introduced by these queues constitutes the 'turn-around-time', often amounting to several hours.

For many computer applications, this delay is not acceptable. For example, computers have been successfully programmed to do algebra and simple calculus. But who wants to do algebra by computer if he must wait several hours between making a minor change to a formula and receiving a printed result ?

In principle, the answer to this objection lies in the introduction of a time-sharing console system similar to the MAC project of the Massachusetts Institute of Technology. The user of such a system sits at an electric typewriter which is connected to a large computer and types in programs or data and receives back results, ignoring the fact that the computer is simultaneously providing a similar service to other typewriters. In fact, the computer is rapidly servicing the users in sequence, sharing its time equitably between them. Unfortunately, if there are too many users, the delay between typing a request and receiving a reply becomes intolerably long ; and no computer at present in existence could provide an adequate service to all of the 250 or so people who use the main CERN computer each day.

Perhaps there never will be computers big enough and fast enough to provide this kind of on-line service to all who want to use them. If small computers continue to become simultaneously faster and cheaper, the use of a big computer may become the exception rather than the rule. But whatever the direction of the future development, we shall presumably see a continuing increase in Babbage's hoped-for 'substitution of machinery, not merely for the skill of the human hand, but for the relief of the human intellect'. What will happen when the human hand and the human intellect have been sufficiently relieved remains to be seen.

Number of Operation	Nature of Operation	Variables Acted Upon	Variables Receiving Results	Indication of change in the Value on any Variable	Statement of Results	Data			Working Variables										Result Variables			
						$^1V_1$ ○ 0 0 0 1 . $\boxed{1}$	$^1V_2$ ○ 0 0 0 2 $\boxed{2}$	$^1V_3$ ○ 0 0 0 4 $\boxed{n}$	$^0V_4$ ○ 0 0 0 $\boxed{}$	$^0V_5$ ○ 0 0 0 $\boxed{}$	$^0V_6$ ○ 0 0 0 $\boxed{}$	$^0V_7$ ○ 0 0 0 $\boxed{}$	$^0V_8$ ○ 0 0 0 $\boxed{}$	$^0V_9$ ○ 0 0 0 $\boxed{}$	$^0V_{10}$ ○ 0 0 0 $\boxed{}$	$^0V_{11}$ ○ 0 0 0 $\boxed{}$	$^0V_{12}$ ○ 0 0 0 $\boxed{}$	$^0V_{13}$ ○ 0 0 0 $\boxed{}$	$^1V_{21}$ ○ B_1 in a decimal fraction $\boxed{B_1}$	$^1V_{22}$ ○ B_3 in a decimal fraction $\boxed{B_3}$	$^1V_{23}$ ○ B_5 in a decimal fraction $\boxed{B_5}$	$^0V_{24\cdots}$ ○ 0 0 0 $\boxed{B_7}$
1	×	$^1V_2 \times {}^1V_3$	$^1V_4, {}^1V_5, {}^1V_6$	$\begin{Bmatrix} {}^1V_2 = {}^1V_2 \\ {}^1V_3 = {}^1V_3 \end{Bmatrix}$	$= 2n$	—	2	n	$2n$	$2n$	$2n$											
2	−	$^1V_4 - {}^1V_1$	$^2V_4$	$\begin{Bmatrix} {}^1V_4 = {}^2V_4 \\ {}^1V_1 = {}^1V_1 \end{Bmatrix}$	$= 2n - 1$	1	—	—	$2n - 1$													
3	+	$^1V_5 + {}^1V_1$	$^2V_5$	$\begin{Bmatrix} {}^1V_5 = {}^2V_5 \\ {}^1V_1 = {}^1V_1 \end{Bmatrix}$	$= 2n + 1$	1	—	—	—	$2n + 1$												
4	÷	$^2V_5 \div {}^2V_4$	$^1V_{11}$	$\begin{Bmatrix} {}^2V_5 = {}^0V_5 \\ {}^2V_4 = {}^0V_4 \end{Bmatrix}$	$= \frac{2n-1}{2n+1}$	—	—	—	0	0	—	—	—	—	—	$\frac{2n-1}{2n+1}$						
5	÷	$^1V_{11} \div {}^1V_2$	$^2V_{11}$	$\begin{Bmatrix} {}^1V_{11} = {}^2V_{11} \\ {}^1V_2 = {}^1V_2 \end{Bmatrix}$	$= \frac{1}{2} \cdot \frac{2n-1}{2n+1}$	—	2	—	—	—	—	—	—	—	—	$\frac{1}{2} \cdot \frac{2n-1}{2n+1}$						
6	−	$^0V_{13} - {}^2V_{11}$	$^1V_{13}$	$\begin{Bmatrix} {}^2V_{11} = {}^0V_{11} \\ {}^0V_{13} = {}^1V_{13} \end{Bmatrix}$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} = A_0$	—	—	—	—	—	—	—	—	—	—	0	—	$-\frac{1}{2} \cdot \frac{2n-1}{2n+1} = A_0$				
7	−	$^1V_3 - {}^1V_1$	$^1V_{10}$	$\begin{Bmatrix} {}^1V_3 = {}^1V_3 \\ {}^1V_1 = {}^1V_1 \end{Bmatrix}$	$= n - 1 (= 3)$	1	—	n	—	—	—	—	—	—	$n -$							
8	+	$^1V_2 + {}^0V_7$	$^1V_7$	$\begin{Bmatrix} {}^1V_2 = {}^1V_2 \\ {}^0V_7 = {}^1V_7 \end{Bmatrix}$	$= 2 + 0 = 2$	—	2	—	—	—	—	2										
9	÷	$^1V_6 \div {}^1V_7$	$^3V_{11}$	$\begin{Bmatrix} {}^1V_6 = {}^1V_6 \\ {}^0V_{11} = {}^3V_{11} \end{Bmatrix}$	$= \frac{2n}{2} = A_1$	—	—	—	—	—	$2n$	2	—	—	—	$\frac{2n}{2} = A_1$						
10	×	$^1V_{21} \times {}^3V_{11}$	$^1V_{12}$	$\begin{Bmatrix} {}^1V_{21} = {}^1V_{21} \\ {}^3V_{11} = {}^3V_{11} \end{Bmatrix}$	$= B_1 \cdot \frac{2n}{2} = B_1 A_1$	—	—	—	—	—	—	—	—	—	—	$\frac{2n}{2} = A_1$	$B_1 \cdot \frac{2n}{2} = B_1 A_1$	—	B_1			
11	+	$^1V_{12} + {}^1V_{13}$	$^2V_{13}$	$\begin{Bmatrix} {}^1V_{12} = {}^0V_{12} \\ {}^1V_{13} = {}^2V_{13} \end{Bmatrix}$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} + B_1 \cdot \frac{2n}{2}$	—	—	—	—	—	—	—	—	—	—	—	0	$\left\{-\frac{1}{2} \cdot \frac{2n-1}{2n+1} + B_1 \cdot \frac{2n}{2}\right\}$				
12	−	$^1V_{10} - {}^1V_1$	$^2V_{10}$	$\begin{Bmatrix} {}^1V_{10} = {}^2V_{10} \\ {}^1V_1 = {}^1V_1 \end{Bmatrix}$	$= n - 2 (= 2)$	1	—	—	—	—	—	—	—	—	$n - 2$							
13	−	$^1V_6 - {}^1V_1$	$^2V_6$	$\begin{Bmatrix} {}^1V_6 = {}^2V_6 \\ {}^1V_1 = {}^1V_1 \end{Bmatrix}$	$= 2n - 1$	1	—	—	—	—	$2n - 1$											
14	+	$^1V_1 + {}^1V_7$	$^2V_7$	$\begin{Bmatrix} {}^1V_1 = {}^1V_1 \\ {}^1V_7 = {}^2V_7 \end{Bmatrix}$	$= 2 + 1 = 3$	1	—	—	—	—	—	3										
15	÷	$^2V_6 \div {}^2V_7$	$^1V_8$	$\begin{Bmatrix} {}^2V_6 = {}^2V_6 \\ {}^2V_7 = {}^2V_7 \end{Bmatrix}$	$= \frac{2n-1}{3}$	—	—	—	—	—	$2n - 1$	3	$\frac{2n-1}{3}$									
16	×	$^1V_8 \times {}^3V_{11}$	$^4V_{11}$	$\begin{Bmatrix} {}^1V_8 = {}^0V_8 \\ {}^3V_{11} = {}^4V_{11} \end{Bmatrix}$	$= \frac{2n}{2} \cdot \frac{2n-1}{3}$	—	—	—	—	—	—	—	0	—	—	$\frac{2n}{2} \cdot \frac{2n-1}{3}$						
17	−	$^2V_6 - {}^1V_1$	$^3V_6$	$\begin{Bmatrix} {}^2V_6 = {}^3V_6 \\ {}^1V_1 = {}^1V_1 \end{Bmatrix}$	$= 2n - 2$	1	—	—	—	—	$2n - 2$											
18	+	$^1V_1 + {}^2V_7$	$^3V_7$	$\begin{Bmatrix} {}^2V_7 = {}^3V_7 \\ {}^1V_1 = {}^1V_1 \end{Bmatrix}$	$= 3 + 1 = 4$	1	—	—	—	—	—	4										
19	÷	$^3V_6 \div {}^3V_7$	$^1V_9$	$\begin{Bmatrix} {}^3V_6 = {}^3V_6 \\ {}^3V_7 = {}^3V_7 \end{Bmatrix}$	$= \frac{2n-2}{4}$	—	—	—	—	—	$2n - 2$	4	—	$\frac{2n-2}{4}$	—							
20	×	$^1V_9 \times {}^4V_{11}$	$^5V_{11}$	$\begin{Bmatrix} {}^1V_9 = {}^0V_9 \\ {}^4V_{11} = {}^5V_{11} \end{Bmatrix}$	$= \frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{4} = A_3$	—	—	—	—	—	—	—	—	0		$\left\{\frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{4} = A_3\right\}$						
21	×	$^1V_{22} \times {}^5V_{11}$	$^2V_{12}$	$\begin{Bmatrix} {}^1V_{22} = {}^1V_{22} \\ {}^0V_{12} = {}^2V_{12} \end{Bmatrix}$	$= B_3 \cdot \frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{4} = B_3 A_3$	—	—	—	—	—	—	—	—	—	—	0	$B_3 A_3$	—	—	B_3		
22	+	$^2V_{12} + {}^2V_{13}$	$^3V_{13}$	$\begin{Bmatrix} {}^2V_{12} = {}^0V_{12} \\ {}^2V_{13} = {}^3V_{13} \end{Bmatrix}$	$= A_0 + B_1 A_1 + B_3 A_3$	—	—	—	—	—	—	—	—	—	—	—	0	$\{A_0 + B_1 A_1 + B_3 A_3\}$				
23	−	$^2V_{10} - {}^1V_1$	$^3V_{10}$	$\begin{Bmatrix} {}^2V_{10} = {}^3V_{10} \\ {}^1V_1 = {}^1V_1 \end{Bmatrix}$	$= n - 3 (= 1)$	1	—	—	—	—	—	—	—	—	$n - 3$							
Here follows a repetition of Operations thirteen to twenty-three																						
24	+	$^4V_{13} + {}^0V_{24}$	$^1V_{24}$	$\begin{Bmatrix} {}^4V_{13} = {}^0V_{13} \\ {}^0V_{24} = {}^1V_{24} \end{Bmatrix}$	$= B_7$	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	B_7
25	+	$^1V_1 + {}^1V_3$	$^1V_3$	$\begin{Bmatrix} {}^1V_1 = {}^1V_1 \\ {}^1V_3 = {}^1V_3 \end{Bmatrix}$ $^5V_6 = {}^0V_6$ $^5V_7 = {}^0V_7$	$= n + 1 = 4 + 1 = 5$ by a Variable-card by a Variable-card	1	—	$n + 1$	—	—	0	0										

Computers and Computing at CERN

G.R. Macleod

Past

The first successful use of electronic computing techniques in a particle physics experiment was made in 1956 by a group at Berkeley, doing experiments using a cloud chamber to record nuclear events produced in a beam from the Bevatron. They programmed a computer to do a series of dull, repetitive calculations (of space coordinates from measurements made on stereoscopic photographs) much faster and more reliably than they had been doing up to then by hand. This group was the first to exploit the two principal characteristics of computers which, to-day, make them indispensable tools in the analysis of experimental data in high-energy physics — to do arithmetic fast and, once programmed, to repeat the same calculation as often as required.

In high-energy physics, one is attempting to understand the nature of sub-nuclear particles by studying their collisions one with another. These so-called events can be recorded, somewhat imperfectly, and their properties measured using various detectors such as bubble chambers, spark chambers, and counters. By calculations based on the measurement of the energy, angles, etc... of the particles produced in an event, it is possible to determine some numbers which describe the physical process which occurred. A typical experiment will require the analysis of many thousands of examples of the event. To repeat the same calculations, which are generally very complex, for each event is the main use of computers in high-energy physics and something approaching two thirds of the computing capacity at CERN is used for this kind of calculation.

This use of computers has been strongly stimulated by improvements in experimental techniques ; in the early 1950s a cloud chamber experiment might record a few events per day ; by the late 1950s, the development of the bubble chamber increased the possible rates of data collection to many events per hour. The ability to absorb this increase in data-taking rates has been made possible only by the use of computers to assist in the various analysis procedures.

Initially, computers were used in arithmetic roles simply to carry out the required computations at a rate commensurate with the operation of the bubble chamber. Special hand-operated measuring projectors were built to speed up the measurement process and to present the measurements in a digital form suitable for input to a computer. Increased rates of data collection, measurement and computation, however, produced more information to be processed at the various stages of the analysis. (More measurements, more intermediate output between successive computer programs, more computed data to be studied, more punched cards, paper tapes and magnetic tapes and, worst of all, more paper.)

A second kind of use, in data-handling roles, therefore evolved to meet these problems. Special measuring equipment is now often operated 'on-line', that is directly connected to the computer, which controls the operation of the equipment, makes checks on the measured data, keeps records of the measurements and so forth.

A similar evolution can be seen in electronics experiments. Developments in spark chamber techniques have increased data-taking rates, thus increasing the use of computers firstly for arithmetic, and subsequently for data-handling on-line.

The Ferranti Mercury

About the time of the emergence of the bubble chamber technique, and under the influence of Dr. Lew Kowarski's keen awareness of the future need for adequate data-handling facilities when CERN's experimental physics programme would begin, CERN's first electronic computer began operation in the Autumn of 1958. This was a Ferranti Mercury, at that time one of the most recent and most powerful European-built computers.

Its installation and first year of use taught CERN two lessons which were hard to accept, but are apparently still valid today. Firstly, installing new large computers brings serious unforeseen difficulties ; the Mercury was delivered some eighteen months late and gave recurring hardware and software problems over its first year of use. Secondly, the ready availability of a computer stimulates computer use at an alarming rate ; Mercury had barely completed its first year of operation when CERN had to order its second computer.

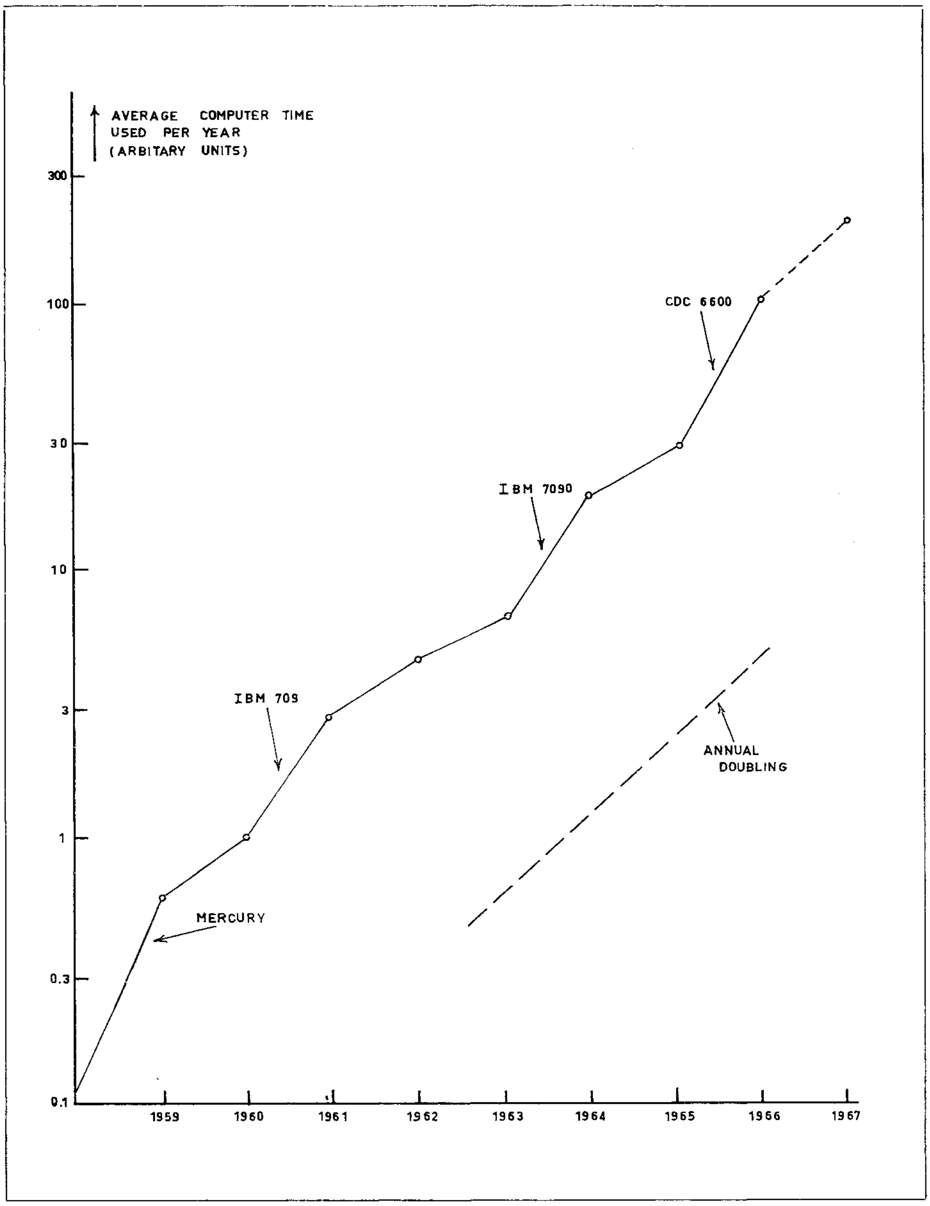
Before the arrival of Mercury, some computing, largely concerned with design problems for the synchrotron and evaluation of kinematic tables for two-body interactions, had been done on computers in London and Paris. By the end of its first year, the Mercury was being used for about 30 % of its time on program development and event processing for the first bubble chamber experiments. Large amounts of time had also been used for accelerator research calculations and for theoretical physics work, evaluating phase-space integrals for particle production spectra as part of the preparation for the experimental programme.

Most of the programming was done in the basic instructions of the computer, but advantages in the use of Autocode (a so-called higher-level language in which the user writes his program in text and algebra-like equations which the computer translates into its own basic instructions) were becoming appreciated, amidst protests from the computer purists who believed that widespread use of such languages would lead to inefficient use of the computer. So it did, in a way, but it also allowed many more scientists to use the computer, which is perhaps a better criterion for efficiency. Essentially, all research laboratories to-day use Fortran, Algol, Autocode or similar language for scientific work.

The IBM 709

The mounting pressure of work from the first bubble chamber and electronics experiments at the synchrotron early in 1960, meant that Mercury was overloaded well before the second computer came into operation in December 1960. The installation of this machine, an IBM 709, put CERN amongst the most powerful European computer centres, and provided, roughly, a four-fold increase in capacity over Mercury. This type of computer was already well established in the USA with several years operational experience, so we were spared the uncomfortable difficulties associated with new large computers.

This was the first occasion where we had to face the situation, which has



Average annual computer use at CERN since 1958. The more rapid increases correspond to the introduction of new computers as indicated. The general trend seems close to an annual doubling.

The first computer, a Ferranti Mercury, being used in the first on-line electronics experiment at CERN in 1963.

CERN/PI 2.10.63

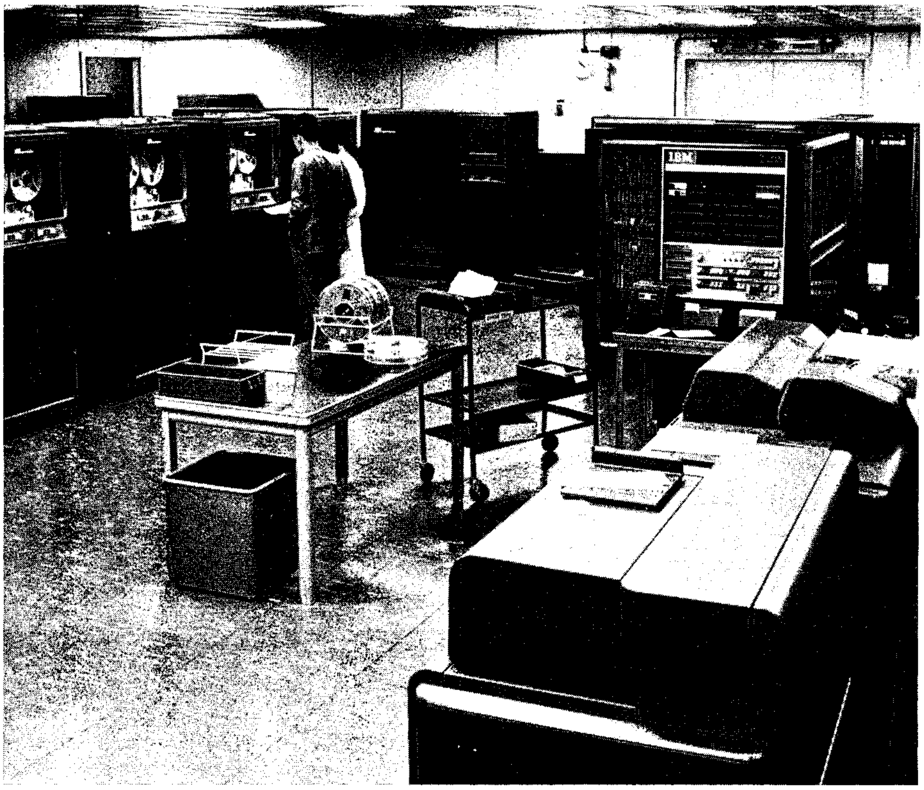
continued to exist ever since, of CERN's needs significantly exceeding the capacity of the largest available European-built computer. Although creating some disappointment in European computer circles, the ordering of an American computer provided the computing capacity needed, and greatly eased exchange of information, programs, and experience with laboratories in the USA which, in computing and data analysis techniques, still had some advance over CERN.

With Mercury and the 709 operating together, CERN had its first experience of the problems of ensuring compatibility between different computers. Magnetic tape units were attached to Mercury to allow data to be exchanged between the computers on tapes, whilst programming compatibility was achieved (one way only) by writing an Autocode translator for the 709. Compatibility problems are still a continuing source of difficulty as more and more different computers are coming into operation in the laboratory, and as many of CERN's programs are used on different computers in Member States. Fortran made its debut at CERN with the IBM 709, and the use of this language was encouraged so that to-day it is essentially the only language in general use, available on all the central computers and used for programs which are exchanged with other laboratories.

Mercury continued in full time use for general computing and the growth of work on the 709 proceeded quickly. By 1962, the limitations of input and output operations became very apparent as the work load, particularly bubble chamber data-analysis, increased. The 709 could do the calculation for an event faster than it could read in the measurements and print the results. To relieve this situation a small 'satellite' computer, an IBM 1401, was installed to carry out many of these input/output operations, including printing, for the 709. By the end of 1962, the 709 was operating 16 hours/day (of which about two thirds was on bubble chamber work) representing an increase in the total computing done at CERN of a factor approaching four over two years.

In 1960, the first ideas for flying spot digitizers to measure bubble chamber film began to take shape. The prototype device

The two IBM machines - the 709 (top) and the 7090 (bottom).



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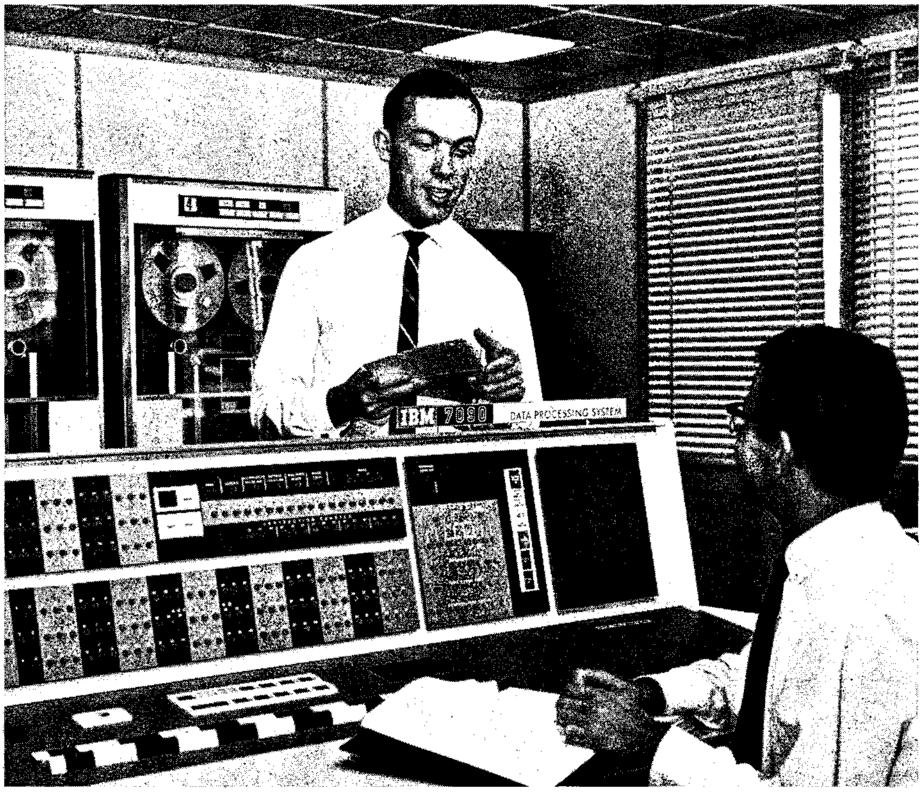


CERN/PI 86.10.63

was operating on-line to the IBM 709 computer in 1962, beginning the trend towards on-line use of computers for processing experimental data. It also had the less enviable distinction of being our first experience of another hard fact of life (whose effect is not by any means limited to CERN), namely, that adequate software is as essential as hardware and much more difficult to achieve. It was not until 1964 that the device was sucessfully measuring film for a spark chamber experiment, and 1965 before it was measuring the bubble chamber film for which it had been conceived.

The IBM 7090

By mid-1963, two and a half years after installation, the 709 was overloaded and CERN was having to send work to other machines in Europe. An IBM 7090 was installed in September 1963 to replace the 709, providing an increase by roughly a further factor of four in overall computing capacity together with a considerable improvement in reliability, as this was CERN's first computer using transistors.

During 1963-64, the amount of bubble chamber film to be analysed increased considerably as chambers from France and the United Kingdom came into operation at CERN. Groups carrying out electronics experiments began to catch up on the lag they had vis-à-vis the bubble chamber groups on the use of computing techniques. Extensive use of Fortran made the computer more readily accessible to the scientific staff. All these factors contributed to the very rapid rise in computer use. A second 1401 had to be added to meet the increased speed of the 7090, which was in use round-the-clock seven days per week by the end of 1964, and we again had to start sending work outside. CERN had thus increased its computing by another factor four over about eighteen months.

General computing on the Mercury began to decrease during 1963 and the computing service on this machine was ended early in 1964, by which time Mercury was contributing only a few percent to the overall capacity. Nevertheless, Mercury still had a second pioneering role to play before being finally closed down and given to the Institute of Mining and Metallurgy at Krakow University in 1966. It was connected, via a one kilometer data-link leading to the synchrotron experimental hall, to counter and spark chamber equipment and was used in the first physics experiment at CERN using a computer on-line to analyse the experimental data in 'real-time', that is as soon as it was obtained during the course of the run on the accelerator.

Present

For the computers in use at CERN to-day, the present really begins in the middle of 1963. At that time it was becoming increasingly clear that the computing facilities available to the laboratory would play a fundamental role in the full exploitation of the accelerators. This realization prompted physicists from CERN and its Member States to set up a European Committee on CERN's Future Computer Needs. The Committee worked through the Summer and Autumn of 1963 recommending to the Director General a considerable enlargement of the computing capacity. At the time, the only computer tendered which could give this increase was the Control Data Corporation 6600, and, in March 1964, CERN placed an order to purchase this computer.

In recommending the CDC 6600, the European Committee tried to ensure that the laboratory would have sufficient computing capacity to meet its need for several years. The excess capacity in the first two years was to be used to develop various specialized computing techniques relevant to the experimental physics programme. Such things as providing flying spot digitizer operation for 15-20 hours per day, on-line use of small computers in electronics experiments with direct connection to the central computer, as well as remote console operation by many users were clearly the desirable lines of development.

In the light of the information and experience available at that time, it seemed a natural step to use the multiprogramming features of a large computer to achieve these aims. Some limitations in the ability of the 6600 design to meet all these requirements were, of course, foreseen, and provision was made in the budget forecasts included in the European Committee's report, for additional equipment to give more storage and input/output facilities.

The CDC 6600

CERN's 6600, serial number 3, was delivered at the beginning of 1965 and, although the expected multiprogramming operating system had not materialized, a Fortran computing service was begun in May. By August, all the computing on the 7090, with the exception of the flying spot digitizer work, had been transferred. The performance of the 6600 seemed satisfactory and improving over this period, and on the basis of this experience, the 7090 was taken out of operation and returned to IBM. (Although by no means an overriding consideration, the economic pressure to return a rented machine played a part in the discussion leading to this decision). The software was still unsatisfactory and, following repeated delays in delivery, CERN undertook to complete the multiprogramming operating system. After a crash programme of work, this system was successfully introduced in April 1966.

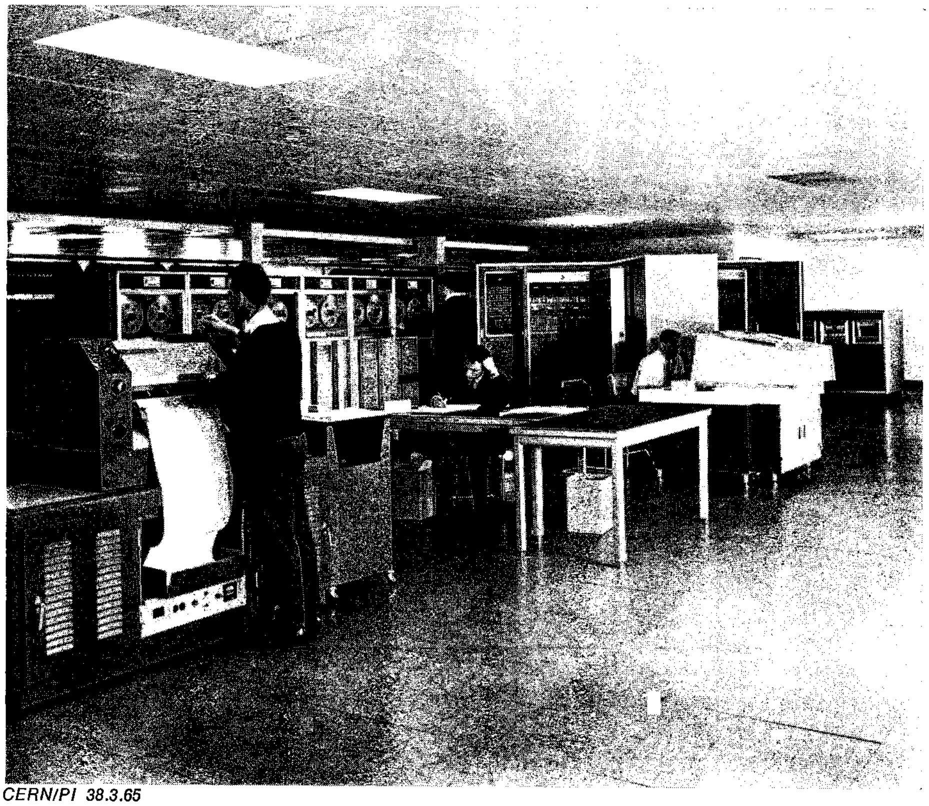
This period would have been acceptable had the 6600 performance continued at the same level. In fact, soon after the 7090 had been returned, the reliability of the 6600 dropped alarmingly. Arrangements were rapidly made for the more urgent work to be sent outside and CDC installed a 3400 computer as on-site back-up. Recurring problems with 6600 reliability continued for over a year, periods of fair performance alternating with periods of intensive engineering work as reliability dropped again. This caused very serious difficulties for all those trying to use the 6600, whether developing computer and data handling systems, or providing or using the computing service.

Since the end of 1966, all of these initial problems have been overcome, the software ones largely by our own efforts, the hardware ones largely by those of CDC. The 6600 now operates regularly with only one or two percent time lost because of machine faults. A large volume of work is processed under the multiprogramming system, which handles concurrently a general computing service, flying spot digitizers, and data-link applications. With the exception of the remote console operation, which will only come into use in a limited way by the end of 1968, the plans outlined by the European Committee in 1963 have been realized, but later and with much more difficulty — and therefore at more cost — than foreseen.

It is clear that neither users nor manufacturers had, in 1963-64, any realistic appreciation of the difficulties which would be encountered in bringing the new generation of large scientific computers into operation. Technical difficulties of a kind very similar to those CDC had on the 6600 computers have affected all other manufacturers introducing new large machines in the last few years. Laboratories and companies installing early versions of such computers have undergone, and in some cases are still undergoing, similar experiences to CERN's.

Nevertheless, it is the context of CERN's work that the difficulties and costs must be seen, and now that the storm has passed these can be more clearly understood. The effects of the technical problems on the 6600 were very widespread, affecting, through an unreliable computing service, almost every aspect of the laboratory's work. Direct costs have been comparatively small, since favourable agreements on the costs of outside computing and of staff re-directed to crash programmes, were negotiated with CDC. More serious is the loss of time. Although in some ways it must be accepted as an occupational hazard of development work, the loss of time will be seen to have had the most pernicious effect, since fire-fighting essentially brings development to a standstill. In the more general computing work, the effect though still serious is more temporary and can to some extent be recouped with an improved service. That the effect has been so widespread would suggest that installing an early model of a new line of large scientific computers, perhaps came too early in our history.

The computing needs of high-energy physics laboratories will, for the foreseeable future, be more than can be met singly by the largest machines the manufacturers can provide, and so to some



The CDC 6600 photographed in the computer room soon after its arrival at CERN in 1965.

CERN/PI 38.3.65

extent laboratories will have to continue to face the problem of installing the largest available machines with their attendant risks. On the other hand, it is becoming more generally accepted that laboratories like CERN should operate their central computing services with two or more large machines for reasons of capacity, flexibility and continuous service. This, together with the fact that we own rather than rent our 6600, will ensure an uninterrupted service, for an indefinite period if necessary (rather than the six months overlap foreseen for the 6600 installation), when the next generation of large computers is installed.

At first sight, it may seem paradoxical that this two-year period of very unpleasant computing conditions saw a marked increase in the amount and diversity of computing at CERN. This is due not so much to physicists liking the hard life, as to the growing need for specialized applications of computing. These are being met by acquiring a number of small computers having access to the central computer for supplementary capacity. Human nature being what it is, the natural reaction of users to an unreliable central computer service also played a part, but this was expressed not so much in terms of 'Let's get one of our own', as 'Let's get two for the laboratory'. This retained the original concept of a number of small special-purpose computers backed up by a large central installation, a concept essentially imposed by economic considerations alone.

The present central service

The central computing service is now based on two large scientific computers, the CDC 6600 and (temporarily) a CDC 3800, together with an IBM 1401 which is used for various input/output operations. They operate round the clock, seven days per week. The 3400, installed initially as back-up for the 6600, was upgraded to a 3800 a year ago.

In order to provide a more flexible arrangement, as well as some increase in capacity, a CDC 6400 was installed last April. This computer will come into general use during the Autumn and will eventually take over the work on the 3800, which will probably leave CERN in 1968. The 6400 is entirely compatible with the 6600 and will therefore allow much more flexible scheduling of work between the two main machines, as well as more effective use of our systems development effort by having only one system to worry about.

On closer acquaintance, the 6600 seems capable, with further software improvements, of giving a capacity equivalent to about ten times an IBM 7090 with CERN's work load, rather than the fifteen which was estimated in 1963. To-day, it is giving about seven times which, together with the work processed on the 3800 means that the computing work is at present using a capacity of about nine IBM 7090's. The two machines are comfortably full, though not yet overloaded. The laboratory has therefore increased its computing work by a factor of about nine over the last three years.

The 6600 provides a general batch-processing service, computing over 3000 jobs per week, as well as concurrently serving two on-line applications. The 3800 is used mainly for production jobs. Broadly speaking, one third of the overall computing capacity is used for bubble chamber experiments, one third for electronics experiments and one third for general computing (theoretical physics, accelerator studies, and the development of data-handling and computer systems).

The smaller computers

A number of small computers are now in operation to provide for more specific or local needs. About ten small computers are being used or set up for data-acquisition in electronics experiments. These are situated in the synchrotron experimental halls close to the detection equipment. They record data and make simple checks to ensure the correct functioning of the experiment. Some machines (SDS 920, two IBM 1800s and an IBM/360-44) are owned by CERN experimental groups, some (for example, two IBM 1800s, an IBM 1130 and two PDP-8s) by visiting teams. The 920 and one 1800 are connected by high-speed data-links to the 6600.

Three other small computers (two CDC 3100s and an IBM 1130) are used to service on-line hand-operated measuring machines for bubble chamber film. These computers 'lead' the operators through an ordered sequence of measurements, and make calculations to check the validity of the data as it is accumulated. Two machines (PDP-9s) are being built into the control electronics for automatic film measuring devices, which represents another kind of use of small computers — that is as variable logic elements in the construction of electronic equipment. Many sequences of logical operation which earlier would have been provided by special circuits can now be achieved by a program in the small computer, with all the advantages of flexibility to change or add features which this provides, as well as advantages in check-out, maintenance and fault finding procedures.

Use of computers in data-logging applications, which may evolve later into process-control, has begun with an IBM 1800 for the proton synchrotron and a PDP-9 for the 2 metre hydrogen bubble chamber. Two machines, NCR 390 and IBM/360-30, are being used for administrative data processing.

Total score — over twenty here and more to come in 1967 ; thirteen different kinds, and all but two expected to exchange data with the central computers. Herein lies yet another of the major problems for the next stage of development.

Future

A second flying spot digitizer is just coming into operation on the 6600 ; in 1968-69, a remote access facility to connect several small computers to the 6600 and provide program editing and execution facilities for groups setting up electronics experiments will be in use ; during the same period, several electronics experiments will be running with small computers accumulating large amounts of data for processing on the 6600 or 6400 ; and, in 1969, a new film measuring device is planned to begin operation. All of these developments will cause a significant increase in the required capacity.

A change of operating system is under way which, by making the 6600 and 6400 appear identical from the programming point of view, will open the possibility of increasing the overall throughput of the two machines by better partition of the work-load between them. Improvements in the compilers, as well as some new features being considered for the operating system, may increase the throughput and flexibility of operation. Nevertheless, it seems clear that these systems developments can at best provide something like a 30 % increase and the machines will certainly be seriously overloaded in 1969.

Since the early 1960s, there has been a steady increase in the computing capacity used at Berkeley, Brookhaven and CERN, which in each case has shown a similar rate close to a factor of two per year. Extrapolation over a three or four year period gives a fairly reliable estimate of what future requirements will be. How essential this rate of growth is, or how long it can continue are questions open to debate, just as whether computer technology is advancing fast enough for manufacturers to be able to supply machines to meet this growth rate. But the question of brute computing capacity, expressed as how much arithmetic one can do per hour, is only one of the considerations which are going to affect seriously the future policy. Problems of access, data-transfer and storage are also becoming limitations on what can be achieved, particularly when higher standards of reliability are also required.

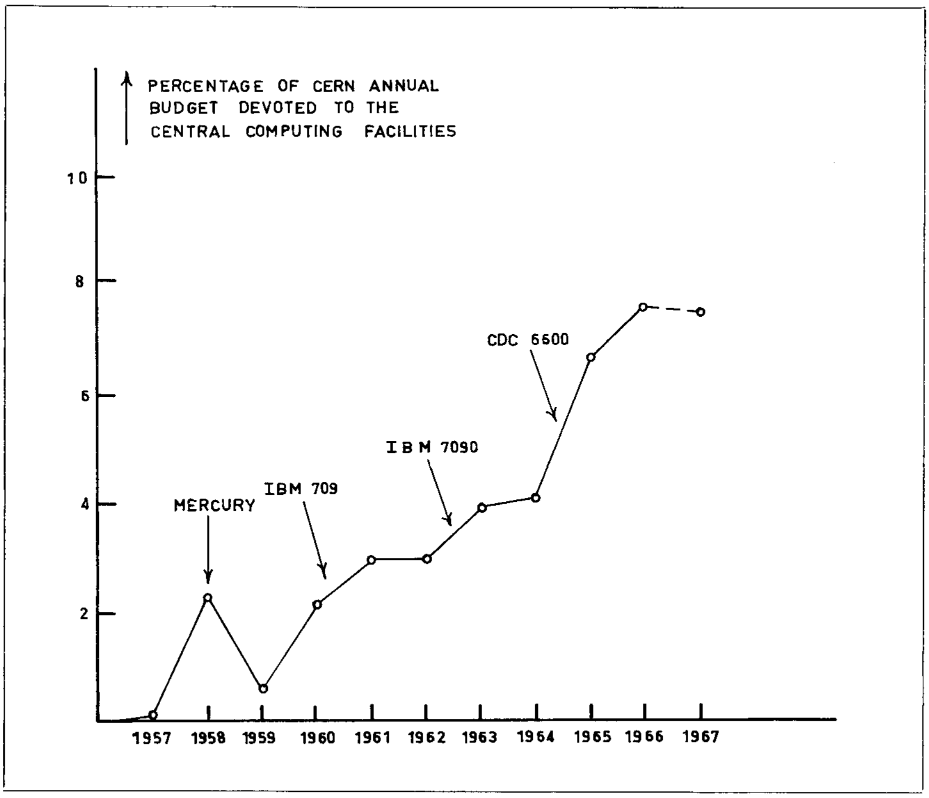
At other Laboratories

None of these problems is unique to CERN ; they represent areas where present-day computer technology, in the broadest sense, is at the limit of what is feasible, but still below what computer users would like. In particular, laboratories such as Berkeley, Brookhaven, Rutherford, Saclay, etc... all face similar problems. Their solutions have many features in common and there is a frequent exchange of views.

Berkeley has a 6600 as its main general purpose computer and a second 6600 is being installed to provide more capacity. An extensive display system is under development on their 6600 to provide a graphical input/output facility. With some 25 000 magnetic tapes on site, a large photo-optic store has been ordered to provide more random access storage. An IBM 7094 and 7044 are used for on-line applications, and several smaller computers are used in data-acquisition roles at the accelerator.

Brookhaven has already installed a second 6600 this year, and plans to connect the two via a large shared store. Their 7094/7044 installation is being devoted entirely to flying spot digitizer work. Plans are discussed for data-link connection of the 6600s to other computers in experimental areas, whilst a medium sized computer with display facilities is also planned to be connected into the 6600 complex.

In Europe, the Rutherford Laboratory has an IBM/360-75 for a general computing service as well as real-time uses such as flying spot digitizers and electronics experiments at Nimrod. A similar machine will be used at DESY, whilst at Saclay a 360-75 and a 6600 have been installed.



Annual expenditure on the central computing facilities since 1957 expressed as a fraction of the total CERN annual expenditure. The peak in 1958 corresponds to the purchase of Mercury. Periods when the other computers were brought into operation are indicated. The 709 and 7090 were rented so the increase in expenditure when the machines arrived was maintained as long as they were at CERN. Capital cost of the 6600, which has been purchased, is being spread over several years, so from the budget point of view it appears similar to a rented machine.

Access, data-transfer and storage

Solving these interrelated problems of capacity, access, data-transfer and storage is hampered by an almost monumental ignorance of the detailed characteristics of the work-load we ask our computers to handle, of what is really happening on a fraction-of-a-second time scale everywhere inside a large multiprogramming system, and also by the absence of any established and reliable method for expressing or resolving these problems quantitatively. The idea of time-sharing on large computers, which seemed three or four years ago to be a fairly clear line of development, has foundered on just these problems, with one or two spectacular shipwrecks in the last year.

Very considerable attention is now being given to performance analysis by computer manufacturers as well as users. A better understanding of CERN's work from this point of view is a vital element in the studies for the laboratory's computing requirements in the 1970s ; it is equally important to make the best use of the equipment already installed.

In any one week, about 400 scientists and engineers use the central computers. In the next five years, this figure may increase by 50 % or more as the new synchrotron experimental hall (West Hall) and the storage rings come into operation and new computer applications arise. With the development of the French part of the site, the users will be spread over larger distances but will continue to want to pose questions to the computers and get answers back at a rhythm dictated by their own working habits rather than by those of the computers. Typically, when writing and testing a program or making short calculations, a user would like to obtain results within a few minutes; when carrying out long calculations with a working program it is usually adequate if results are obtained after a few hours or even days.

The crux of the access problem is to give back results to many users, spread out over several kilometers, within minutes rather than hours if they wish, at a realistic cost ; behind the scenes, this time includes not only access to computing power but also access to stored programs and data. A further aspect of the question of access is the means of communication between the user and the computer. Printed paper, keyboards, punched cards, etc... are not well suited to many current uses. Various kinds of visual displays, graph plotters, etc... are coming into more general use to facilitate communication in ways better suited to human assimilation of information.

With many different computers requiring some communication and transfer of data, the speed with which these transfers can be made is often a determining factor in the success of the overall operation. Flying spot digitizers or on-line experiments are typical sources of large amounts of data which have to be processed rapidly, possibly involving several different programs on several computers ; on-line measuring tables work at the speed of their operators and therefore produce data slowly which can be processed on a central computer more leisurely. At present, nearly all such transfer operations are done via magnetic tape and a bicycle ; in five years time, there will be many applications which cannot operate without direct high-speed data transfers.

About 10 000 magnetic tapes are in use at CERN, largely for storing data ; some are used only infrequently, most a few times a month, some every day. The number of tapes will increase rapidly as the various small computers come into regular operation. Since information is stored on magnetic tape item after item down the length of the tape, this kind of storage is well suited for information which is produced, or required, in a serial order. As soon as one wishes to be able to pick items out of their serial sequence ('random access') the process of getting the information off tape becomes very cumbersome. New programming techniques, whereby data from complete experiments are summarized on a few tapes and subjected to extensive and repeated analysis, will increase the frequency of random access required.

The time spent in tape handling will reach alarming proportions over the next few years unless some alternative means of bulk storage can be used for data requiring frequent or random access. A single tape may store something like 10^7 bits of information, whilst disk files have capacities around 10^8 to 10^9 bits. Larger disk files, data cells or magnetic card stores of 10^9-10^{10} bits capacity and photo-optic stores of 10^{11}-10^{12} bits capacity are either just becoming available or being developed by manufacturers. With the data volumes in question at CERN and the diversity of machines around the site, we have to consider the requirements for data storage for users of the central facilities, for users of the small machines and also the data-transfers. To decide how much storage, where, and for whom, will be more difficult than chosing the equipment to do it.

The computing facilities in the 1970s will most probably be based on a network of several computers and stores, with different degrees of connection between them. The computing capacity will have to be accessible from different parts of the site, with direct connection between remote input/output terminals and computers of various sizes providing general or special purpose computing. There will have to be enough redundancy in the overall system that computing continues when some machines or storage elements are out of action. The facilities will have to be built up in stages, both to ensure a sound basis for development and to provide extensions for growing needs.

The internal studies and contacts with manufacturers to provide necessary information before we can define more clearly our needs and realistic ways of meeting them, have been started this year. What is feasible depends, in the first instance, on what hardware manufacturers can offer and subsequently on what software can be prepared by CERN and the manufacturers to meet the specific needs of a high-energy physics laboratory.

A human computer

As a little light relief from the welter of information on machines in this issue of CERN COURIER, and to restore man's ego in the face of electronics, it is a pleasure to tell the story of a human computer. He is Mr. William Klein who has been a member of the Theory Division at CERN since November 1958.

William Klein has been recognized as a calculating prodigy since his early schooldays and has entertained audiences for many years with his exhibitions of lightning speed in the manipulation of numbers. Multiplication of any five figure numbers takes a few seconds ; even the calculation

$$1388978361 \times 5645418496 = 7841364129733165056$$

he did completely in his head in sixty four seconds. (This involves twenty five multiplications each of two two-digit numbers and twenty four additions of four-digit numbers — forty nine operations in all.) Division, addition, subtraction, powers, roots, logarithms and factors come with equal facility.

Behind this extraordinary ability lies a phenomenal memory for numbers and phenomenal speed in mental arithmetic. If he is called upon to analyse the route by which he arrived at his almost immediate result, he has rarely in fact followed the standard sequence of calculations which a computer would follow, but has taken a series of short cuts. His basic armory includes, for example, knowing by heart the multiplication tables up to 100 × 100, all squares up to 1000 × 1000, logarithms of all numbers less than 150 (to five decimal places) and all prime numbers less than 10 000, in addition to an enormous number of odd facts about numbers which can slice a difficult problem in half.

A little story will illustrate this. While at the British Business Exhibition in 1953, he visited the Friden stand and asked for a demonstration of their new 'root' machine. The operator offered 'Lets try all the fives' and fed in 555555555555. Before he could press the button for the result, Klein said '745356 should be about right'. The operator nearly collapsed when 745355.9924 came out. William Klein had obviously not been through the laborious process of working out the square root conventionally but had remembered that 0.5555.. is the decimal fraction for $^5/_9$ for which the square root is $^1/_3$ root 5. Knowing root 5 and dividing by 3 gives the answer very simply.

He can also give the day of the week corresponding to any date in history, and knows the date of birth and death of some hundred composers. One of his favourite feats of memory is to call on an audience for a number going up to say 24 digits and to recite them half an hour later, forwards or backwards, having done some dozens of intricate calculations in the meantime.

Up to the present time, no machine has been programmed to exhibit the sort of intellectual skill that William Klein brings to computation.

CERN/PI 177.8.67

William Klein in action at a special 'lecture' arranged for vacation students at CERN on 22 August.

The Computing Service

N. Spoonley

The CERN Computing Service has the responsibility of providing a general facility which satisfies the varied requirements of the users throughout the laboratory. To enable this to be done, CERN is equipped with large general-purpose computers which provide a 24 hour service, seven days per week.

The principal computer is the CDC 6600 which was delivered to CERN at the beginning of 1963. The machine comprises a very fast central processor (CPU) and ten smaller peripheral processors (PPU). The actions of the central processor as it works on a program are monitored by one of the peripheral processors. The CPU cannot itself read from or write information to any of the peripheral equipment and this is done via the PPUs. Thus the CPU is seen as a calculator, with the PPUs as the link with the outside world, receiving the data from the peripheral equipment controlling and monitoring its movements in the computer and feeding out the results.

The peripheral equipment comprises 16 magnetic tape units, 2 large disk files, 3 line printers, a card reader, punch, plotter and console. The CPU is capable of handling more than one job at a time as the monitoring PPU can direct its attention to any one of the programs in the central memory. In this 'multiprogramming mode' more than one job can be in simultaneous operation, and the total resources of the computer are shared amongst the programs contained in the memory. Thus, it is possible to attach real-time devices and allow them to run continuously while the computer is also processing other work. At present, there are attached three flying-spot-digitizers (see page 179) and two data links to smaller computers and, generally, at least one of these real-time devices is in operation while several normal programs are going through the computer at the same time.

The second large general purpose computer is a less powerful version of the 6600, the CDC 6400 computer. It is equipped with a smaller but similar set of peripheral equipment. It is a more recent arrival (March 1967) and is at present being used principally for 'systems development' work (see page 176) prior to being introduced as a general-purpose facility.

These two computers are similar in their operation and the same basic operating system will be available on each one. Thus, in theory, a CERN user may have his job, within certain limits, placed and run on either machine without changing the program. Over 3000 programs are run on the 6600 per week and one of the major organizational problems is not merely to process this work, but to ensure that the time between the programmer presenting his program and receiving his results is close to that which the programmer wishes.

A third large computer, a CDC 3800, is also providing a general service and, until it leaves CERN, it will continue to process general CERN work. This machine does not multi-program and thus each program in the machine is considered as occupying the whole computer. There are eight magnetic tape units, a card reader, punch and printer, and all of these units are connected directly on-line to the 3800. Thus, whereas in the 6600 the peripheral equipment is operated independently of the central processor by the peripheral processors, in the 3800 the central processor is held up while such equipment is in operation.

In addition to these three large computers, there is also an extensive array of conventional card punches, reproducers, interpreters, etc. and an IBM 1401 computer. These machines are used by programmers to prepare their programs and data and then to change the medium on which this information is stored if they so wish. Thus, information on cards may be placed on magnetic tape or printing obtained from information on a tape etc... A small pool of punch operators exists to punch cards on demand but in general the programmers prepare their own work.

The running of such a computer service necessitates a large group of computer operators who run the round-the-clock service, and in addition the computer manufacturers retain on-site a team of engineers for the maintenance of the computers. The programming at CERN is done on an open-shop basis i.e. the user writes his own program and the Data Handling Division provides the service to receive his program, put it on to the computer, and return it with the results.

To enable the user to keep informed of the available facilities and to receive advice when he requires it, there is an extensive documentation service providing manuals etc., a Programming Enquiry Office and a regular issue of a newsletter. The Programming Enquiry Office not only answers enquiries but also gives advice on how to write and correct programs and how to use the equipment more effectively and efficiently. As a result of the continual changes in the research staff of CERN, a large number of the high energy physicists and engineers in Europe have been taught how to program at CERN. This on-the-job training is further enhanced by the organization of lectures and seminars on a whole range of computing topics.

Supporting all these services which maintain a direct contact with the users there is a systems programming group which provides the operating systems and compilers (see page 176).

The decision with regard to the priorities associated with the work to be processed is taken as far as possible by the users themselves. Various Divisions or Groups of Divisions can allocate priorities to the jobs within their total load. The proportion of resources allocated to each Division is, as far as possible, decided at a higher policy planning level.

1. *A view of the console of the CDC 3800 with the magnetic tape units in the background.*

2. *One of the eleven 'pages' of the main frame on the CDC 6600 showing both logic and memory modules.*

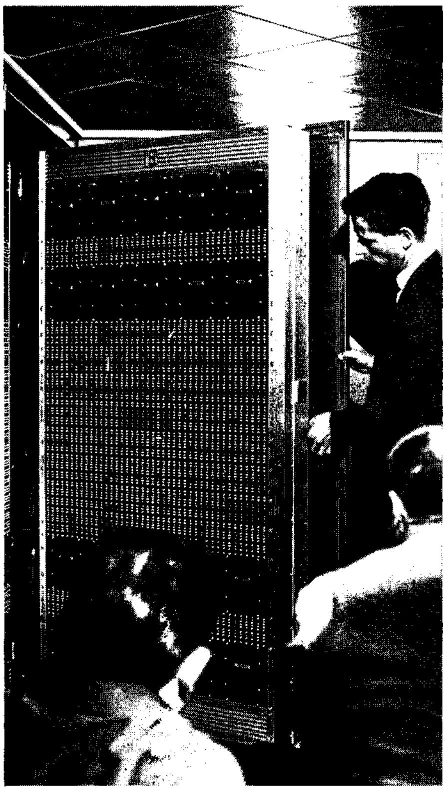
3. *A familiar look of puzzlement greeting the results chattering from a line-printer. At present, the CERN central computers consume about 60 000 sheets of paper per day.*

4. *The 'pigeon holes' where results from the programs fed to the central computers are placed for collection by the users. The racks back directly onto the computer room with access from there and from the side shown.*

5. *Examining a magnetic tape. Some 10 000 tapes are now in use at CERN. A machine has recently been installed for the microscopic examination of tapes.*

6. *The cubicles next to the computer room each with a card punch for programmers to punch their own cards to build up their computer programs. About 20 of these cubicles have been set up next to the computer room.*

CERN/PI 281.2.67 1.



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CERN/PI 153.2.67 5.

CERN/PI 64.9.67 6.

Software Development

D. Ball

As computers have become larger, faster and more complex, so have the programming systems necessary to exploit their capabilities. The development of these systems ('software') is estimated to cost the manufacturer as much as the construction of the machine ('hardware'). This increase in complexity and magnitude of the software for the latest machines has arisen because of :

a) the increase in the speed of the central processor (the time to add two floating point numbers on CERN's first computer — the Ferranti Mercury — was 180 μs ; the time on the CDC 6600 is 0.4 μs) has not been matched by corresponding increases in the speed of peripheral devices. In an attempt to keep the central processor busy, designers have resorted to more and more complex stratagems, as, for example, in the CDC 6600 where 10 smaller machines feed the main processor which operates in a multiprogrammed mode. The co-ordination of these eleven machines in one must be performed by software.

b) the variety of input and output devices on current machines (contrast the range of devices on the CDC 6600 with the paper-tape reader and punch which were used on the Mercury). The software must drive these as efficiently as possible, often with several of them sharing an input/output channel.

c) the wide range of applications for which the computer is used ; for example, on-line flying-spot-digitizers (see page 179), real-time programs, and batch processing.

Although, in general, the manufacturer supplies software, it will rarely fit the needs of a large specialized organization such as CERN exactly. Thus it is necessary to adapt and modify the systems locally. With the CDC 6600, the situation was aggravated because the machine acquired for CERN was one of the first to be produced, and it was delivered without its software. This made it necessary to accept an incomplete system and develop, in a crash programme, together with a local CDC support group, the present operating system which is called SIPROS. Specific additions made were : the facilities needed to drive real-time devices in parallel with batch processing, a sophisticated error recovery procedure, a program to drive a multiplexor with teletypes (this synchronizes the slow input and output equipment with the computer), a plotter and a tape reel number display system (this informs the computer operator which magnetic tape requires loading on the machine), and flexible magnetic tape routines for checking special tape labels and processing various tape formats.

Since the programs for the analysis of bubble chamber experiments are used in laboratories throughout Europe on a number of different computers, it was decided to standardize on a restricted version of the computer language Fortran (called CERN Fortran) which was generally available on these computers. It was therefore necessary to modify the CERN computer accordingly.

About the time that SIPROS began to be used at CERN, CDC decided to concentrate their effort on the development of a different operating system called SCOPE. Since this would be used by other computers of the CDC 6000 series and since all future compilers, etc. would be written to work with SCOPE, the decision was taken to change over as soon as a suitable local version was available. The work on this conversion from one operating system to another has been carried out mainly on the CDC 6400 in recent months and it is planned to phase out SIPROS by the end of the year.

It is also the responsibility of the systems section to advise on trends in software and hardware and to help evaluate possible equipment for CERN.

To gain experience in some of the new fields, experimental work is in progress, both on the 6000 series machines and on a CDC 3100. On the former, a symbolic debugging package for checking Fortran programs (it allows the user to print out selected data while the computer is working on his program without modifying his program) has been developed, and studies of a file manager carried out (which makes it possible to store programs and data in 'files' in the computer from which they can be retrieved and modified). A group of programmers are developing a system on the 3100 to give an improved computing service on the 6000 series machines for remote on-line users. Facilities will be available for transmitting program and data files to these machines from the 3100, and for output files to be returned. Users will be able to store files and edit them from remote typewriters.

An oscilloscope display is also fitted to the 3100 so that experience can be gained on possible uses for graphical displays at CERN.

The use of computers
a. In electronics experiments

The electronics experiment in which this particular complex of counters (72 of them in this matrix alone) collected between one hundred and two hundred pieces of information to help in the analysis of each of the particle events, which were observed at a rate of three to ten per second.

W. F. Baker

Although various methods are used to detect and record data in electronics experiments (those using electronic counters and spark chambers), the questions asked of the computers in all of them are similar. Events of the type A + B → C + D + ... are usually studied in which some particle A produced by an accelerator strikes a target particle B producing particles C, D, and sometimes more. It is the particles emerging from the interaction and the relations between them, that are the phenomena of interest.

Before any experimental apparatus is installed at the CERN proton synchrotron or synchro-cyclotron, calculations must be done to determine whether the experiment is feasible and to work out the best way to set up the equipment. In some of these tests an imaginary experiment is performed in the computer under certain assumptions. The computer is told that the equipment is set up in a particular way ; it is then made to generate a large number of artificial events of the type to be studied with randomly different properties and it calculates how many would actually be detected by that arrangement of the apparatus. This random generation of events is known as the Monte Carlo method, and it gives the efficiency of a particular layout of the experiment.

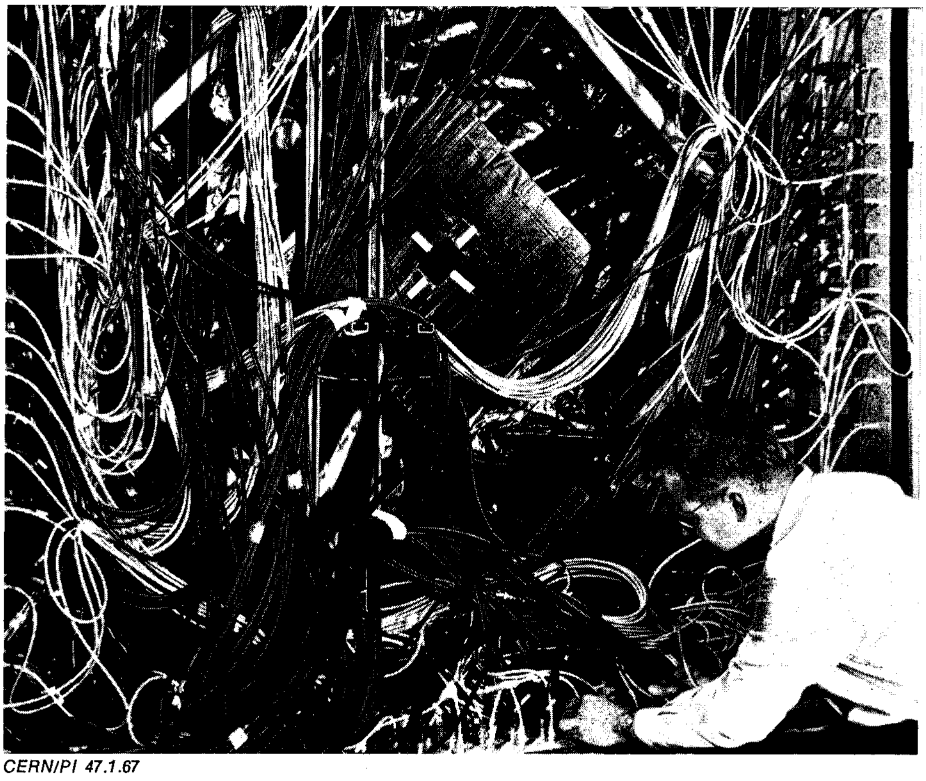
Calculations of another type are done while the experiment is in progress. These check that the equipment is operating properly and they are particularly necessary for the more complex experiments. They monitor, for example, the efficiency of the counters and spark chambers, the direction and focus of the incident beam, and, in particular, check that the desired events are occurring and are being recorded. These checks can take from a few seconds, in the case of computer-on-line experiments (see page 184), to several hours, when the experiment involves developing and measuring film (from optical spark chambers).

By far the largest amount of computer time is consumed in analysing the data after the experiment at the machine itself is completed. The initial stages of this analysis depend upon the detection technique used. In the case of counter hodoscopes, sonic spark chambers and wire spark chambers the data is recorded on magnet tape and is ready for feeding directly to the computer. With optical spark chambers, the photographs must be either scanned and measured by hand and the data transferred to punched cards or magnetic tape, or they must be measured by one of the flying spot digitizers (see page 179). In the case of hand measurements, the scanner measures the tracks of the particles directly ; in the other cases the tracks must first be reconstructed by the computer.

Once the tracks in an individual event are found, the computer continues to test the event to determine if it is a good 'fit' to the type desired. For example, in an elastic scattering experiment, in which the two final particles are the incident and target particles (A and B), the computer program first checks that the tracks of the two outgoing particles and of the incident particle meet in a common point or vertex. It then tests for coplanarity, that is that these three tracks lie in a common plane.

Certain checks for self-consistency are also made, for example, that the incident particle comes from the proper direction, that the vertex lies in the scattering target and that the final state particles have not scattered off some second object. The event is then fitted by comparing the angles and momenta of the outgoing particles with the values required from the kinematics for an elastic scattering process. Whether or not the event is accepted and included in the final results is decided by the 'goodness' of the fit, which is the overall error in the fit as compared with the error which is expected from the resolution of the detectors used in the experiment. When an event is accepted as 'good', the parameters are recorded on a 'Data Summary Tape'.

This tape which contains the events in sequence is then processed by a program called SUMX, which combines those events which have similar parameters. In the case of elastic scattering, events with the same angle of scattering are summed to give a distribution of the number of events as a function of the scattering angle. When this distribution is combined with the efficiency, as calculated in the Monte Carlo program, the angular distribution of the differential cross section is obtained ; this is the final result of the experiment.



CERN/PI 47.1.67

b. In bubble chamber experiments

R.K. Böck, J. Zoll

The photographs of the traces left in a bubble chamber by interacting high energy particles are man's most direct and striking access to the sub-nuclear world. Stereoscopic pictures are taken of the particle events and it is these photographic records which allow quantitative analysis of the phenomena occurring. The phenomena are quantum mechanical in essence, (that is to say statistical) hence the precision of the experimental results increases with the number of events which are analysed. This number is typically tens of thousands at present and will soon be hundreds of thousands.

This article outlines the use made of computers in handling this large volume of bubble chamber data. It leaves aside those techniques which bubble chamber physicists have in common with other people, particularly those carrying out electronics experiments.

The first task is the measurement of the pictures. Hand-operated measuring machines have been built to deliver coordinates of particle tracks onto a recording medium which can be fed to the computer. But, with the growing number of pictures, this task has become too painful and new solutions in the direction of automatic scanning and measurement have been looked for. The scanning, the recognition of interesting particle tracks and interactions, which comes naturally to the human eye, does not lend itself at all easily to digital techniques. Despite many laborious attempts, it is impossible with present day computers and ideas to separate the wanted events from the background with an interesting degree of reliability, generality and economy. Thus the burden of scanning is still carried by people. However, various attempts to get more or less automatic measurement under computer control have been successful. They are described in the articles on the use of computers in automated film measurement (page 179) and on computers on-line to measuring equipment (page 185).

The second task is the analysis of the ever growing volume of raw measurements and this would be unthinkable without computers. It is carried out by a chain of programs. The first program stage converts the film measurements into a 3-dimensional description of the events, yielding the direction and momentum of each track. The second stage uses the conservation laws to test the various possible interpretations of each event. The third stage picks the correct interpretation, either automatically or under control from the physicist, and prepares the event for statistical analysis.

The computer spends most of its time processing unproblematic events. The programmer on the other hand, spends most of his time foreseeing possible difficulties and programming the computers to deal with them. Such difficulties can come from the experimental conditions : particularly short or long tracks, faint or thick bubbles, unusable views etc... Or, problems arise from mistakes made by operators or machines.

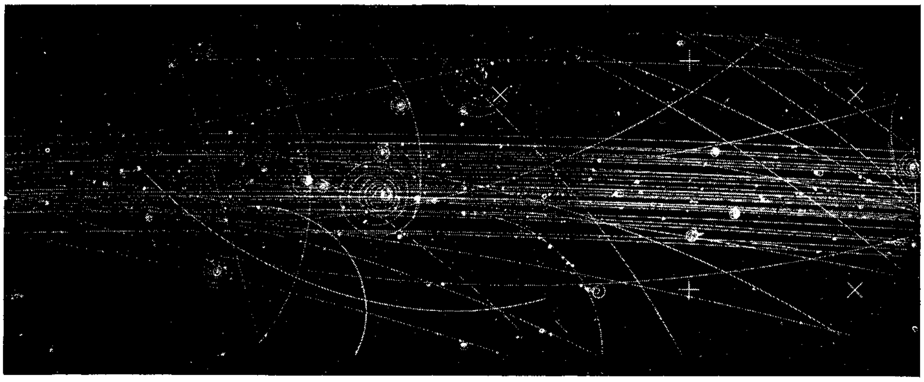
All these abnormalities must be handled correctly. Automatic or manual recovery at any stage has to be foreseen. In this way, one avoids biassing the final results and enables the program to by-pass faulty conditions.

This 'data processing' aspect of analysis programs as opposed to the purely mathematical routines represents a substantial fraction of the effort in the development of the programs.

Much of this stream-lining work also goes in a different direction. It is possible and necessary for many bubble chamber experiments to share the same basic set of analysis programs. It is possible because the many different types of experiment all build up from rather fewer 'topologies', combinations of 'vertices', and at any vertex (the interaction point) one deals with tracks measured in the same way which obey the same laws of motion and interaction. It is necessary because the effort needed to get a set of programs operational far exceeds what may reasonably be invested in an individual experiment.

In fact, only a few program chains have been developed in various laboratories for use in the analysis of bubble chamber experiments ; the CERN chain is called THRESH, GRIND, SLICE. They are communicated between some hundred high-energy physics institutes all over the world, equipped with nearly as many different computers. Such large scale use of basic programs has been made possible by the use of FORTRAN, the programming language accepted on nearly all general-purpose computers.

The price one pays for this generality is a certain loss in memory space and computer time. Programs written in the machine's own language can be substantially shorter and executed faster, so that certain simple but frequently used



A bubble chamber photograph, taken on the CERN 2 metre hydrogen chamber, which gives some indication of the problems of extracting information of particle behaviour from these experiments. The photographs must be 'scanned' to identify interesting events, these events must then be accurately measured, and these measurements, in combination with thousands of others, must be analysed by the computer.

sub-programs are often recoded for a specific computer.

Naturally in a field under continual development, these programs have to incorporate many new ideas as they arise. So there exist two conflicting requirements : the user needs a stable program so that he can become familiar with it, and the authors of the program need a stable program to keep the task of documentation within bounds. But the program has to keep up with the development of bubble chambers, of measuring equipment and of analysis methods. Until now, the practice has been to include everything into 'standard programs', so that from time to time the programs change. Sometimes the release of new versions of a program goes at the unhealthy rate of periodicals.

The idea of the 'standard program' has three very undesirable effects : the programmer has to go to great lengths to minimize the trouble caused to the user by the incorporation of new pieces ; the user has to put up with program changes, even if he is not immediately interested in the improvements which have led to them (indeed he must sometimes go to extra trouble to continue running with the old version), and finally, the programs grow in size because they contain everything, resulting in serious overheads in memory space and, sometimes, computer time.

To overcome this problem, one is presently experimenting with an editing program, which will put together selected pieces of the multi-purpose standard program and produce input for the compiler, ready to be executed. This automatic program composition may be a major step towards having more efficient and flexible programs.

c. In automated film measurement

B. Powell

The use of computers in high-energy physics experiments can be considered in two parts — a) acquisition of the data and its conversion into a form convenient for processing and b) processing of the data. The processing stage, though often quite complex, is a straightforward application of what computers were originally designed for. But the data acquisition stage is less obviously a field where the computer has an important role to play. Their growing use in this field for electronics experiments is described in the article on page 184. For bubble chamber (and optical spark chamber) experiments, almost all the systems for automatic film measurement rely on being directly coupled to a computer (i.e. being 'on-line') and an ever increasing proportion of semi-automatic devices are being put on-line as the advantages become more apparent.

This article, rather than describing *how* computers are used in automated film measurement tries to explain, *why* they are used. The advantages can be considered in five categories :

i) Feedback during operation

Automated measuring systems, whether on-line or not, are intended to run at higher rates than previous systems. To do this, the operator has to have less direct contact with the measurements which are being made, with the resultant risk that if a fault occurs, it may go unnoticed for some time. For example, measuring track radii by hand with a projector and a set of curves may lead to errors from time to time, but a properly trained operator will not systematically measure every track wrongly. A semi-automatic machine, such as the IEP with paper tape output, could however develop a fault leading to incorrect results which would not be detected by the operator at the time of measurement, but would be found when the paper tape was fed into the computer. In the past, this has usually been up to 24 hours later and, in the worst case, all data taken during that period would be useless. These are the risks that automation, even at this level, can bring unless adequate precautions are taken to get sufficiently rapid feedback of information.

It is even more essential with a rapid measuring device such as Luciole, where in one day of intensive operation one could measure 50 000 pictures and one would consume a correspondingly large amount of computer time. As the gain in speed over hand-measurement increases, the need for the safety provided by feedback also increases. The solution preferred for all types of measuring device has been to attach them to a computer to provide at least some checking of the data within seconds of the measurement.

The ideal arrangement would be for the whole processing of the picture or the event to be done at once, so that if any rejection at the level of single events is to occur, one would know it straight away. Not only would this provide the most exhaustive checking, it would also avoid the considerable labour which results from breaking the processing of the data into a succession of steps (as in the programs THRESH, GRIND, etc.). In practice, no-one does the whole processing immediately because it involves the use of big computers which would be difficult to run efficiently under such circumstances. Also, for some applications such as the on-line IEPs, the freedom which results from using a small computer, independent of breakdowns or system changes on the main computer, seems to compensate more than adequately for the loss in computing power.

Which are the different levels of checking that occur ? At the lowest level, it amounts to checking the incoming data directly for hardware failures — for example, 'Are the characters being read in legitimate ones ?' At a similar but slightly higher level, 'Are the parts of the data consistent? Have sufficient fiducial marks been found ? Have enough points been taken on a track ? Has the correct picture been measured ?' All these checks help to ensure that the system has operated correctly.

At the next level, instead of merely checking the data against previously established criteria, the data is examined as a specific pattern in two dimensions. 'Does it represent an event of the specified type ? Do the points belong to smooth curves ? Do the curves intersect at the requisite points ?' Then, in three dimensions, 'Do the measurements of the different views agree with one another and are the overall internal errors consistent with what we would expect ?'

Finally, some statistical property of a group of measurements can usually be examined to provide an overall check on the correctness of all the steps combined — for example, the shape of a distribution or the shape of a missing-mass plot where certain well known features are expected to occur. Even though only a portion of these different checks may actually occur immediately after the measurement, they all have to be done at some time and the fact that at any level, an undesirable feature may appear, underlines the advantages of obtaining feedback of information at the earliest possible moment.

ii) Ease of Construction

The first benefit of an on-line computer shows even before construction of the equipment has started. By assigning a small computer entirely to a given device, it becomes feasible to think of the computer as a part of the electronics. Thus some logical operations may be done by the computer which, in the past, required special hardware. For example, in HPD, the instruction to advance a certain number of pictures, to reach the next one to be measured, comes from the computer. The counting of these pictures is then done externally. On a big computer, where one may wish to be able to test the HPD independently, this is reasonable, but with a small computer permanently available, the counting could perfectly well be done inside the computer by providing as input the counts which would normally have driven the external counter. Similarly, considerable logic which is necessary in the present HPDs to provide the computer with information in the correct sequence, could be replaced by a suitable program inside the small computer.

This is not an argument for the small computer against the big one, but for incorporating a small computer into one's equipment through which one may be connected to the big one.

iii) Reduction of Manual Intervention

Systems which operate off-line not only have to rely on extra electro-mechanical equipment (card punches, paper tape punches, magnetic tape units) which require more maintenance than a direct on-line connection, but also involve a greater amount of handling and organization of output. For example, the output from one 'Milady', (the pre-measurement table for the HPD) is currently some 1500 to 2000 punched cards per day. Even the task of moving these from the Milady room to the computer room and back to their storage area becomes an embarrassment when there are several machines operating simultaneously every day. (To date, rather more than two million cards have been punched on the Miladies.)

Similarly, some automatic devices have been built to write their data onto magnetic tape directly without any preliminary processing. In this case, the number of tapes rapidly becomes an expensive embarrassment. (When Luciole operated in this way for a time, tapes were filled at the rate of three per hour. Operating in an on-line mode, a tape is now filled with partially processed data about once every 5-10 hours). Operating on-line saves, therefore, on both storage of data and on the amount of book-keeping required to keep it under control.

iv) Feedback during Testing

One can also use a computer on-line to help in routine work which does not form a part of the actual operation. For example, HPD programs exist for exhaustively testing the device itself and for determining the constants of the optical system. Without the almost immediate results which these programs provide, operation would be much more cumbersome and unreliable. As it is, it has been a routine procedure to run both programs each day to check the state of the machine before attempting any production.

Programs of this sort not only help to detect faults, but also to locate them and to help adjust the machine. For example, a fault may be traced to one particular card by systematically interchanging cards in the suspected area and testing with the program after each change, until the defective one is found.

To emphasize the extent to which on-line computers are already with us, the various devices (in operation or planned at CERN), for the measurement of the film from bubble chambers and optical spark chambers, are listed below. (The flying spot digitizers — HPD and Luciole — were described in CERN COURIER, vol. 6, page 7; on-line use for the IEPs is described in the article on page 184.)

Device	Computer
HPD 1	*CDC 6600*
HPD 2	*CDC 6600*
Luciole '66	*CDC 6600*
Luciole 2	*PDP-9*
Spiral Reader	*PDP-9*
Miladies	*IBM 1130*
IEPs	*CDC 3100*
NPA measuring tables	*CDC 3100*
CERN/Orsay CRT scanner	*SDS 920*

v) Additional Flexibility

On-line operation often allows additional benefits over and above the immediate ones used to justify the system. For example, the Miladies are being attached to a small computer mainly to avoid the use of punched cards for output and to provide almost immediate checking of the data. Additional gains will be the possibility of collecting, with no additional effort, statistics on the operation of the devices — number of pictures scanned, number of events found, number of hours lost due to breakdown etc...

The advantage of feeding back information has already been discussed, but a further benefit which comes more-or-less 'for free' is that immediately an error is detected, is the ideal time to put it right. An error which in previous systems might necessitate remeasurement at a later date (losing time loading the film, finding the right picture etc...) can usually be rectified at once with an on-line system. Not only is time saved in the sense of having less manipulation to do, but also in the sense that an experiment will usually be completed in less time. Though hard to evaluate in terms of cost, the ability to obtain reliable results in a shorter time is particularly valuable in the competitive field of high-energy physics.

Other Features

One of the desirable objectives is to automate the organization which surrounds each experiment and each device. At present, it is a person, not a machine, who keeps track of the stage reached in the analysis of an experiment — the records of which films have been measured, which tapes carry what information etc... Since experiments using automatic devices involve very large quantities of data, this is a major problem. It should not be too difficult for all this to be handled automatically.

Computers also lend themselves to use as an expensive variety of teaching machine and one can dream of a system whereby a totally inexperienced operator could be presented with the equipment, told how to indicate his presence to 'the system' and from then on to obey the instructions and to answer the questions put to him by the system. So far, we seem very remote from this kind of operation, all the effort having gone into knowing what is happening rather than defining what people should do about it. For the present HPD system, perhaps the most encouraging message the beginner can extract from the computer is, 'Following message incorrect, try again'.

Conclusion

Though relatively expensive initially, the attachment of measuring apparatus on-line to a computer allows a great improvement in convenience, reliability and speed. In the case of the automatic measuring machines, these gains almost make the difference between whether a device can be usefully used for measurements or not. The benefits can only be obtained if the computer system itself is extremely reliable. Fortunately, the standards of reliability reached by the smaller computers are extremely high and everything suggests that, in the future, more and more reliance will be placed upon the on-line computer for an ever increasing variety of applications.

Specific computer applications

a. Process control at the 2 m bubble chamber

T. Ball

The CERN 2 metre hydrogen bubble chamber is a particularly striking example of a laboratory instrument which, of necessity, has required development on an industrial scale. A few figures will illustrate this.

The main structure weighs some 700 tons, including an electromagnet of 450 tons which consumes 6 MW of electrical power to produce a magnetic field of 17 400 gauss. To dissipate the heat generated, about 150 tons of demineralized water are circulated each hour through the hollow conductors of the magnet coils. Before leaving the coils this water has been raised 30° C in temperature. (A normal week's running provides enough hot water to fill a bath tub for each inhabitant of the city of Geneva !) The liquid hydrogen is contained in a strong stainless steel vessel maintained at a temperature of —247° C, and the hydrogen is illuminated and photographed through optically corrected glass windows and condenser lenses (weighing 2¼ tons). The refrigeration and production of liquid hydrogen is assured by a liquefaction plant, which circulates 5600 m^3 of purified hydrogen gas each hour.

When the chamber is put into service, it requires about three days to be cooled down from ambiant temperature, and filled with liquid hydrogen. Once cooled and filled, it is maintained in this state for periods of six to nine months. This requires continuous attention by the operating crews on a 24 hours, seven days a week basis, because loss of control of the refrigeration process for only a few minutes could prevent operation of the chamber, and involve rewarming to ambient temperature. Quite apart from the interruption to the experimental programme, such incidents would be extremely costly.

Manipulation of liquid hydrogen poses severe technical problems and demands most rigorous safety precautions. The first requirement of any automatic control system is to ensure the safety of the plant. This is done by a sophisticated arrangement of alarms and interlocks, which operate at three different levels :

Alarm 1 : indicates a fault which is not dangerous, but requires intervention to restore correct operating conditions.

Alarm 2 : indicates a fault which is serious enough to prevent operation, or which could lead to a potentially dangerous situation. It automatically interlocks appropriate sections of the plant until the fault has been repaired.

Alarm 3 : indicates the existence of a potentially dangerous situation. Appropriate sections of the plant are automatically interlocked and the whole plant switched to the safest possible condition. Operation can only be resumed after the normal safe conditions have been re-established.

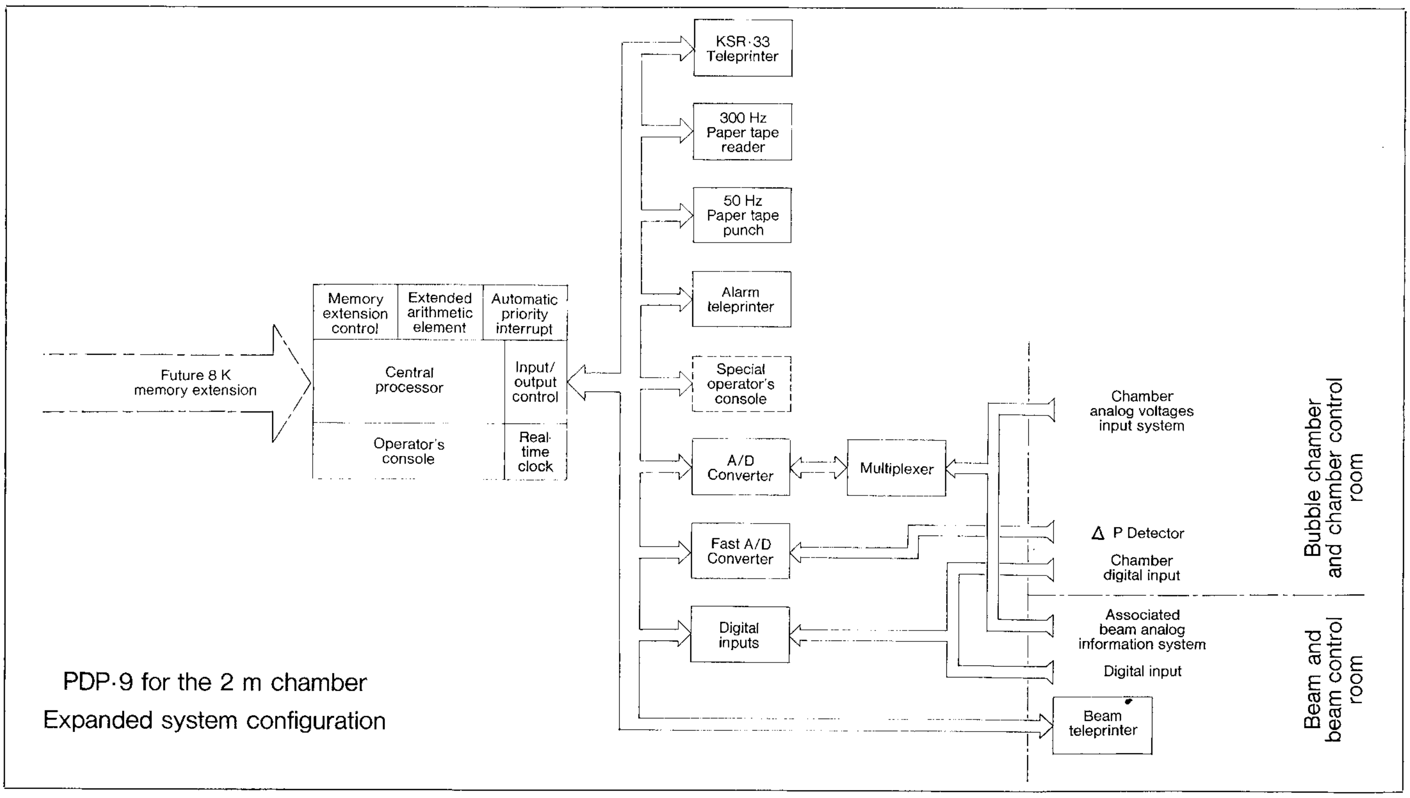
This system has operated with complete reliability since the chamber came into service in December 1964. It will be retained as the over-riding 'All or nothing' safety control.

Obviously, a safety alarm system should only come into action when there has been a failure of a component or a process, or a failure by the operating crew to react to a deteriorating situation. But these are extreme operating situations; there are many modes of chamber operation, and, from week to week, different, extremely sophisticated requirements may need to be satisfied to produce the appropriate experimental conditions.

For these reasons, it has been decided to improve the control system by the addition of a small, fast, real-time computer whose first use will be systematically to assimilate data on-line from the bubble chamber and the associated particle beam, and from this to provide information about deviations from desired performance. In this way, warnings will be received of developing faults whilst they are still incipient. The computer will also log statistics required for the physics experiment.

A second phase will be to feed the computer with data on specific aspects of operation, and to extract a programmed response which should indicate the parameters to be changed to achieve optimum performance. A third and much later phase will be to control certain aspects of the operation directly from the computer.

The chosen system will use a PDP-9 computer as the central processor. It has a cycle time of 1 μs and is controlled by a real-time clock. Initially, the computer will have an 8 K memory core; this can



PDP-9 for the 2 m chamber
Expanded system configuration

be extended in the future, if necessary. The configuration is shown in the Figure.

The central processor will be located in the bubble chamber control room, and provision has been made to receive both analog and digital inputs directly from the chamber or the control room, and also from the beam control room. Print-out of information will be on separate teleprinters: one will signal 'Alarm' values which are outside operating limits, and can log the values of parameters which are associated with the alarm condition; another, in the beam control room, will supply the information of direct concern to the physicists who are carrying out the experiments.

In the bubble chamber control room there will also be a special console at which selected values (e.g. Alarm or operating limits) can be modified by the chamber crew without altering the computer programme from the control console of the central processor.

One real-time application of the computer which is particularly interesting, concerns the control of the quality of the photographs which are taken in the bubble chamber. (A typical experiment takes about 125 000 photos, in four views, during a week's run, requiring about 100 kilometres of 50 millimetre film.)

To be sensitive to the formation of tracks, the liquid hydrogen must be quickly brought to a metastable superheated state. This can be done by holding the liquid at an initial pressure which is sufficiently above the saturation vapour pressure to have quenched any previous boiling, then suddenly reducing the pressure to a final value which is just sufficiently below the saturation vapour pressure to sustain the growth of bubbles. This superheated state, usually lasts for a few milliseconds. The vapour bubbles must be photographed as near as possible to their points of origin, so that the tracks will be as precise as possible.

The ionization power of a given charged particle in the superheated hydrogen, is highly dependent upon the *pressure drop below the saturation vapour pressure* of the liquid. And the saturation vapour pressure depends upon the *temperature* of the liquid.

The bubbles must be allowed to grow to about 350 microns diameter in order to be photographed. Their rate of growth is strongly dependent on the temperature of the liquid (usually about 1 millisecond is necessary). About 15-20 particles from the beam are admitted to the chamber at each pulse and if the time interval between arrival of the first and last particles is a large fraction of a millisecond, then significant differences of bubble diameter will exist. Similarly, particles arriving at different pressures below the critical pressure will leave tracks showing correspondingly different ionization. Consequently, the parameters governing the pulse of the chamber liquid, temperature, pressure and real-time relationship to the passage of the charged particle beam are of vital importance. The computer is fast enough to sample the pressure-time pulse of the chamber whilst it is actually happening, and to provide a wealth of detailed statistical information.

At the moment, the chamber pulses about once every two seconds. Plans are now well advanced for pulsing four times in about 350 milliseconds to take advantage of the longer 'flat top' in the PS beam. The new controls for the chamber expansion system are being specially designed for 'conversation' with the computer, and it is more than probable that at some future date they will be directly digitally controlled.

b. Process control at the proton synchrotron

H. van der Beken

In 1965, the Proton Synchrotron Division decided to purchase a digital computer in order to facilitate the operation of the synchrotron and to investigate the possibilities for further developments. An IBM 1800 computer was ordered in April 1966 and was installed in May 1967.

One of the characteristics of this machine is that it can work on a time-sharing basis in a rather flexible manner, if it is provided with an auxiliary memory (magnetic disk). There is a wide choice of possible configurations, and the following was chosen:

Memory capacity : 8 K
Number of bits per word : 16
Memory cycle : 2 μs
Input : 16 digital-words
: 48 analog points
48 interrupt bits
Output : 8 digital-words
10 analog
Auxiliary memory : magnetic disks
(512 000 words)

Card reader and punch

2 typewriters with keyboard.

The reasons why it is considered desirable to incorporate a process control computer in synchrotron operation are as follows:

i. The number of parameters involved in the operation of the accelerator is very large (3-4 000). A fast digital computer can take care of the collection, processing and monitoring of these parameters and thus make operation easier.

ii. For the same requirements, using a computer is a flexible way of centralizing the control of parameters and the collection of relevant data.

iii. One of the main characteristics of synchrotron operation at present is an increasing complexity in the use of the accelerated beam. The problems of sharing between internal targets and the various ejection systems absorb a lot of effort. The computer can take over some of the tedious tasks involved in the operation and thus relieve the operating team, giving them more time to set up and supervise new processes.

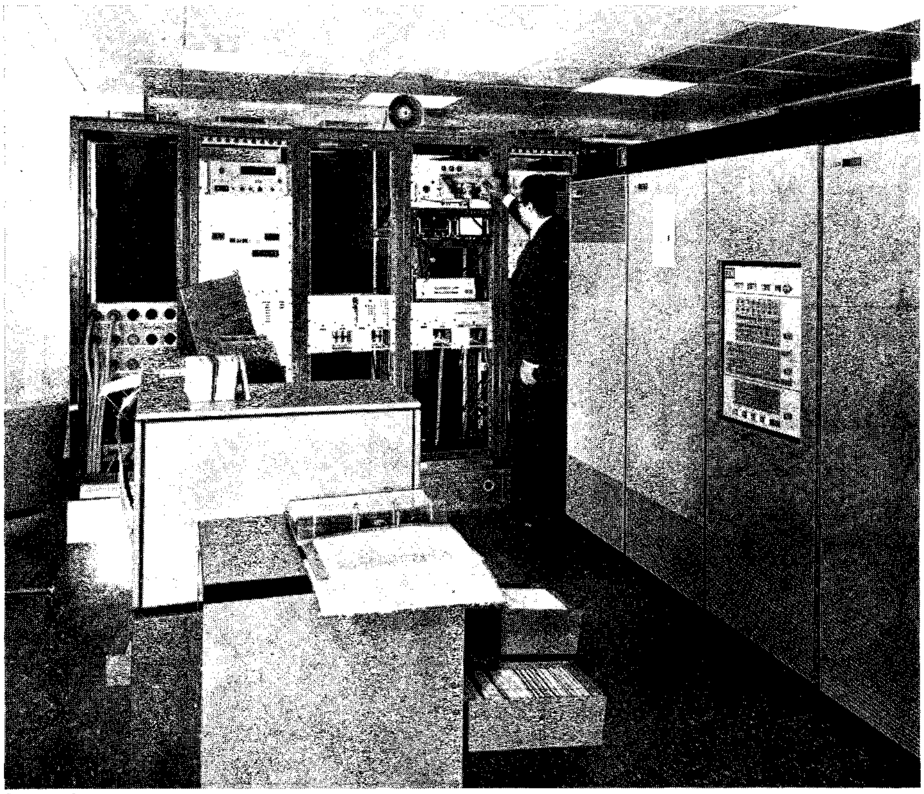
iv. The computer will also be of considerable use for certain machine studies and research work to learn more about the physics of accelerator operation. It should speed up the analysis of certain investigations which previously took a long time.

The incorporation of a computer in a complex which already exists poses some problems, especially regarding the links between the complex and the computer. Two acquisition and transmission systems have been developed and installed for this purpose. One is a high speed multiplexed digital acquisition system (S.T.A.R.), driven by the computer, able to transmit 16 bits in parallel at a rate of 50 000 words per second. The other system, using 'Carryplex' modules, can be used for multiplexed acquisition of the analogue parameters. These two systems are able to cover all the PS, i.e. they can collect and transmit to the computer, data from any point in the machine. In addition, prototype control units are being constructed to enable the computer to adjust the values of the parameters directly.

It is planned to bring the computer gradually into full operation performing the following sequence of tasks. Its first job will be the acquisition of the parameters; the computer can then compare them to reference values and inform the operating crew of any variation observed. Later on, when the control units have been installed, the computer will be capable itself of adjusting the values to correspond to predetermined ones, and even of adapting them to a new situation.

The practical applications envisaged include: monitoring an ejected beam; analysing accelerator performance; processing data on the trajectory of the particles in the magnet ring and correcting the trajectory; and also gathering data from the linear accelerator, which will make it possible, for example, to analyse the quality of the Linac beam.

The first tests, which will be carried out before the end of the year, should make it possible to estimate the potential of this computer and should indicate the best course for future development.



The process control computer, IBM 1800, installed adjacent to the Main Control Room of the proton synchrotron.

CERN/PI 33.9.67

c. On-line to experiments

H. Overas

The article on page 177 discussed in general the questions which counter and spark chamber experiments (often called 'electronics experiments') ask of the computer. This article is concerned with a specific application — the use of computers on-line to such experiments, to perform a variety of tasks, in particular those of storing data and providing information to guide the course of the experiments as they proceed.

This use of computers began at CERN about three or four years ago, but it has expanded rapidly, and by the end of this year the Nuclear Physics Division and its visiting teams will have some ten computers of various kinds, including PDP-8, SDS 920 and IBM computers 1130, 1800 and 360-44. The usefulness for many experiments of a small data acquisition computer on-line has in the meantime been clearly demonstrated, but there is still some discussion on *how much* on-line feedback is needed, in other words to what extent on-line access is needed also to a large computer, directly or indirectly via the small one.

A typical on-line computer, also known as a data-acquisition computer, has fast and flexible input/output (e.g. one word per memory access cycle), a good instruction set for handling binary integers, short word length (12-24 bits), small memory (4-16 K), magnetic tape units, typewriter, and a paper tape or card read/punch device. Some of the computers also have a disk and even a line-printer. The IBM 360/44 exceeds these basic requirements somewhat, as it is intended to be capable also of quite ambitious calculations. The other computers are usually backed up by larger ones, either on-line via a data link or off-line via magnetic tapes. All the computers can be put next to the control electronics of the experiments they serve, most of them installed in a mobile hut.

One would not, however, get much into such computers if fast particle detectors with good spatial resolution and digital output were not available, as an alternative to the film-producing ones. Counter hodoscopes and sonic spark chambers are well established by now, and wire spark chambers of various kinds are being made and tested, and are on the point of a major break-through in many experiments. Since these devices in most cases need a fast buffer (a facility that holds the information until it can be treated), the step to using a small computer on-line is short, giving at the same time running control of the experiment.

A typical electronics experiment, as discussed in the earlier article, consists of particles directed onto a target, particles coming out from it, with magnets and detectors to control and observe their presence. The detectors, which pass information to the computer, are normally triggered by coincidence signals from scintillation counters, so as to eliminate a large amount of uninteresting information which could otherwise enter the computer. Each 'trigger' constitutes an 'event', recorded as a set of binary words from the digitized detectors. This set is read into the computer memory in a block transfer of information from the detector electronics. This transfer is initiated by an 'interrupt' signal to the computer, which tells it to leave the computation it is doing and prepare itself to receive new input. The average number of words per event may be in the range 10 to 100, depending on the complexity of the experiment.

The events can, of course, normally occur only when there is a beam, i.e. during the bursts of accelerated particles from the proton synchrotron, say 0.2 s every 2 s or so. The average number of events taken during these 0.2 s depends on the beam intensity and the dead time of the detectors (the time for which they are not sensitive to particles just after recording an event), and also on the speed of the readout system and computer input. Up to now, this has been rather below 20, but it may reach several hundreds. When the number of events per burst is low (say up to three), the advantage of fast buffering is not so great; and for complex events the upper limit may be well below 100, even when the IBM 360/44 is used, if checks and data reduction, which are very desirable when data is being taken at high rates, are called for between bursts.

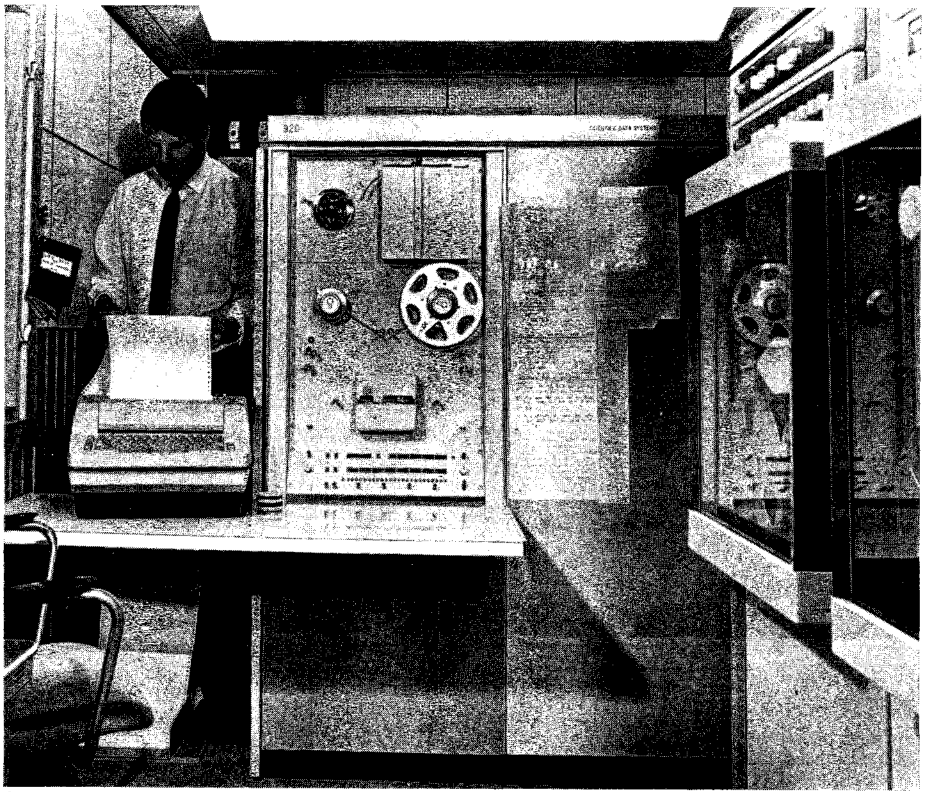
The computer on-line performs a number of tasks. The list below gives those most frequently carried out at present on the computers in the Nuclear Physics Division, though not all these possibilities are called for in all experiments. (i., ii., and iv. are practically always used; the link mentioned in vi. is working for two computers, but improvements at the large computer end are needed before this service reaches its expected flexibility; viii. has not yet been used at CERN, but will certainly come).

i. *Buffering* permitting fast data acquisition, for example during bursts of particles from the synchrotron.
ii. *Checks* and logging to give a running control of the detectors and the readout system, and possibly the immediate rejection of events which do not fulfil basic format criteria.
iii. *Sorting* performed according to some (physics) criteria on all events, with or without a certain degree of rejection of unwanted events and some simple computing operation on the retained ones.
iv. *Storing* of the data to be retained (for example on local magnetic tape) often involving some conversion of the format the information is in.
v. *Sampling* involving calculation to some degree of sophistication on a certain fraction of the retained data.
vi. *Communication* on-line with a larger computer (for example the CDC 6600) via a data link.
vii. *Output* of large amounts of numerical or graphical data, via a typewriter, line printer, oscilloscope or plotter.
viii. *Control parameter output* using the computer for the setting of magnets, detectors, etc.

A final remark on the capacity of the data acquisition computer: Besides its important task of providing fast feedback to the experimenters, it may play an increasing role in data rejection. This will serve to reduce both the data transmission rates required at various later stages and the amount of storage (magnetic tapes) needed, and also will avoid powerful computers wasting much of their time on rather trivial operations. It may not be the best overall economy to keep the capacity of all the data acquisition computers down to the barest minimum.

d. On-line to measuring equipment

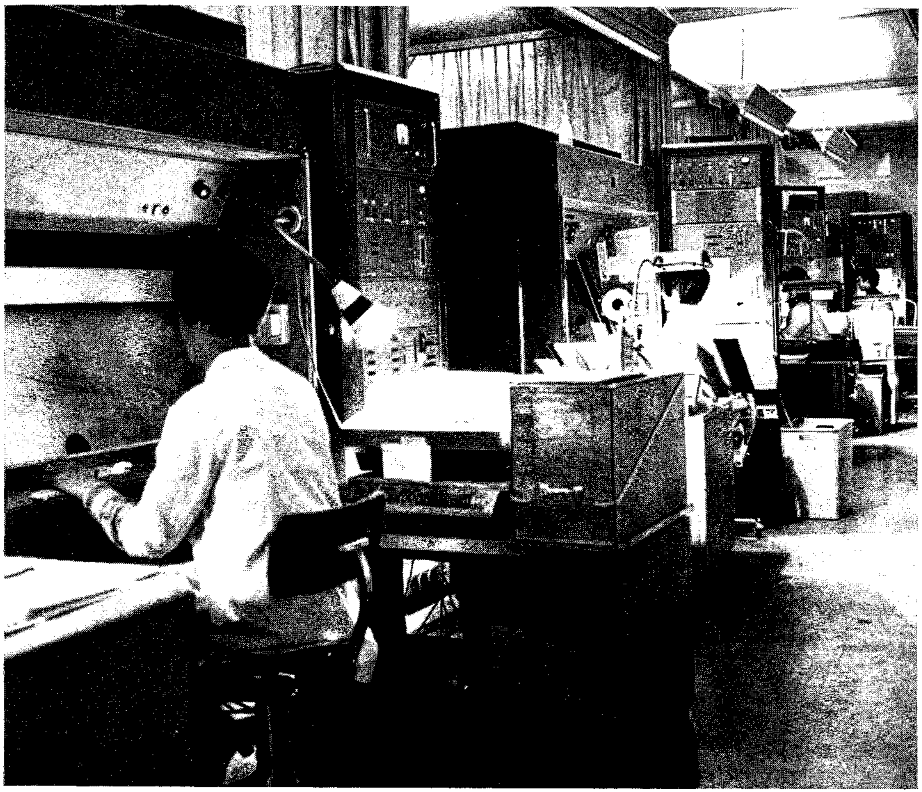
C. Verkerk



CERN/PI 18.2.65

1

1. *The SDS 920 computer installed in a mobile hut for use in on-line electronics experiments.*



CERN/PI 93.4.67

2

2. *The IEP measuring machines in the Track Chamber Division now connected on line to a CDC 3100 computer.*

A large fraction of bubble chamber photographs, recording interesting particle events, is measured on digitized projectors such as the IEPs (Instruments for the Evaluation of Photographs). Normally the measurements are recorded on paper tape or cards in a coded form. The paper tape produced during, for instance, one day of operation is then taken to the large central computers for analysis.

The form in which the measurements are made is not easy for the operator to interpret and it is only when the big computer begins its computations that any errors are detected. Mistakes may originate with the operator or with the measuring machine and in either case the events in question have to be remeasured. (These problems are discussed in detail in the article on page 179).

It would obviously be a great advantage to check whether the measurements are good as the measurement proceeds. Due to the coded form of the paper tape and the large amount of calculation involved, only a computer on-line can do this job fast enough to be useful. For this purpose, both the Track Chamber Division (who are concerned with the analysis of part of the photographs from the hydrogen bubble chambers in operation at CERN) and the Nuclear Physics Apparatus Division (for photographs from the CERN heavy liquid bubble chamber) have each installed a medium sized computer, a CDC 3100. Some of their measuring projectors are connected electrically to these computers so that the measurements are fed straight to the computer instead of being punched on paper tape.

The program in the 3100 immediately checks if the measurements are good or if there are errors. When an error is detected, the computer instructs the operator within a second, via the typewriter which is part of the measuring equipment, to do something which will correct the error. Thus the operator can receive messages meaning such things as 're-measure this track' or 'remeasure this event', or 'add more views', etc.

When the measurements of a particular event are satisfactorily completed, for all stereo-views, the computer passes the message 'Measure the next event'. One can then be reasonably sure that the completed measurements will not have to be done again.

The tasks of the computer are not limited to error checking. It also guides the operator as to the next item to be measured, warns the operator when special attention is needed and so on. The measured events emerge from the computer on magnetic tape ready for the full analysis in the central computers (see the article on page 178). The on-line computer also does a large part of the book-keeping for the experiment. Further projects are to make the computer control directly some functions of the IEPs such as the film advance; then the operator will not have to search for the photograph to be measured — the computer will find it automatically.

In the Track Chamber Division, the 3100 was installed in August 1966, and eventually nine IEPs will be brought on-line (this complex of measuring projectors has become known as the IEP factory). The 3100 has not been equipped with floating point hardware (a multiplication takes about 350 μs) and only a limited amount of slow peripheral equipment. It has a memory of 16 K, 24 bit words. It does not therefore run other programs in addition to its real-time work with the IEPs. With the memory available there is not sufficient space for a complete spatial reconstruction and the geometrical tests on the measurements it receives are limited to checks on the fiducial marks and the quality of the measurements. Nevertheless they are sufficiently elaborate to ensure a high probability of success when the full spatial reconstruction is done by the program THRESH in the central computer.

In the Nuclear Physics Apparatus Division, six measuring tables will be connected to the computer which was installed about six months ago. Spatial reconstruction will be possible in the computer — which is equipped with a magnetic disc, making it possible to change parts of the program rapidly — and will further decrease the number of events which need to be remeasured.

e. ADP Project

M. Wenner

Towards the end of 1965, a study group was formed at CERN to examine the desirability and feasibility of developing an administrative data processing system, taking into account the extension of the Laboratory and the projected increase in its activities over the next five years. This study group reviewed the existing administrative operations for purchasing, accounting, salaries, manpower statistics, stores, workshops, and budget forecasting and planning. In all these operations, certain common features were seen to be contributing to the difficulties of the various services — the sharp increase in the volume of transactions of all kinds, the inability of existing staff to cope with the increasing volume, and the growing demand for more up-to-date and detailed information.

Several possible solutions were considered: the extension of the existing clerical systems, but the hiring of greater numbers of staff eventually presents more problems than it solves; individual mechanization applied independently by each unit involved, but this carried the grave risk of unco-ordinated action with duplication and conflict of effort; a combined data processing system for administration based on a medium-sized computer designed for commercial applications.

This last alternative seemed to be the only solution capable of absorbing the increasing volume of input data and arresting the serious increase of clerical staff. It would also make it possible to obtain up-to-date statistics rapidly, to maintain control of stocks and do accurate stores accounting to satisfy the multiple planning and costing operations of the central workshops, to deal with the complicated requirements of manpower statistics, and eventually to offer computer support in such additional areas as the insurance and medical services, the Library, the Public Information Office, transport, building and construction, site and plant maintenance, etc. It could meet the long-term aim of a fully integrated management information system.

In March 1966, the study group reported that the introduction of a computerized data processing system was not only justified but essential if CERN's administrative services were to keep pace with the ever-developing activities on the site. It emphasized the importance of going beyond mere short-term relief, and of considering immediately a long-term solution likely to cover the requirements of the 1970s.

ADP Specifications

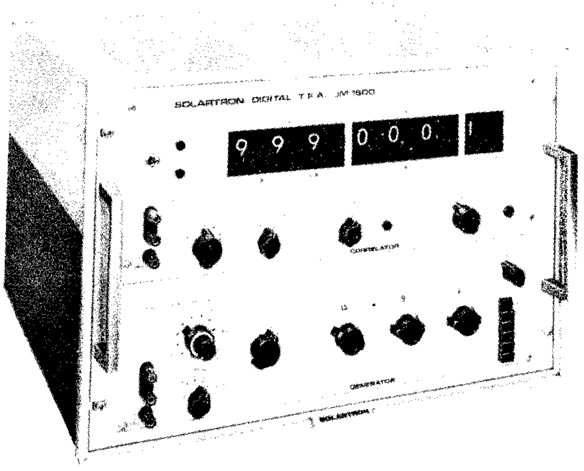
A document was drawn up specifying the basic requirements for an ADP system and this was sent to sixteen computer manufacturers in Europe, inviting them to make a survey of CERN's ADP requirements and to present detailed proposals. The firms were also invited to send representatives to an information seminar which covered all the necessary details on which to base their proposals.

In order to have a facility capable of fulfilling the short-term requirement of mechanizing the existing clerical accounting applications, as well as the longer-term aim towards full administrative integration, the following criteria were adopted: it must be a machine firmly established in the European market, with thoroughly proven hardware and sufficient random access storage capacity to process the CERN work-load with a margin in reserve; it must permit development towards an integrated system; the hardware must be available in mid-1967 supported by proven software and capable of using the computer language 'COBOL'.

In accordance with these criteria, proposals received from four firms were subjected to a detailed comparative evaluation. In February 1967, the Finance Committee approved the award of a contract to IBM for a model 360-30 computer, comprising a 32 K central processor with external random access storage provided by four disk drives allowing a total on-line capacity of 29 000 000 characters; peripheral units including a 1 000 card per minute reader, 300 card per minute punch and a 600 line per minute printer with a maximum of 132 characters per line.

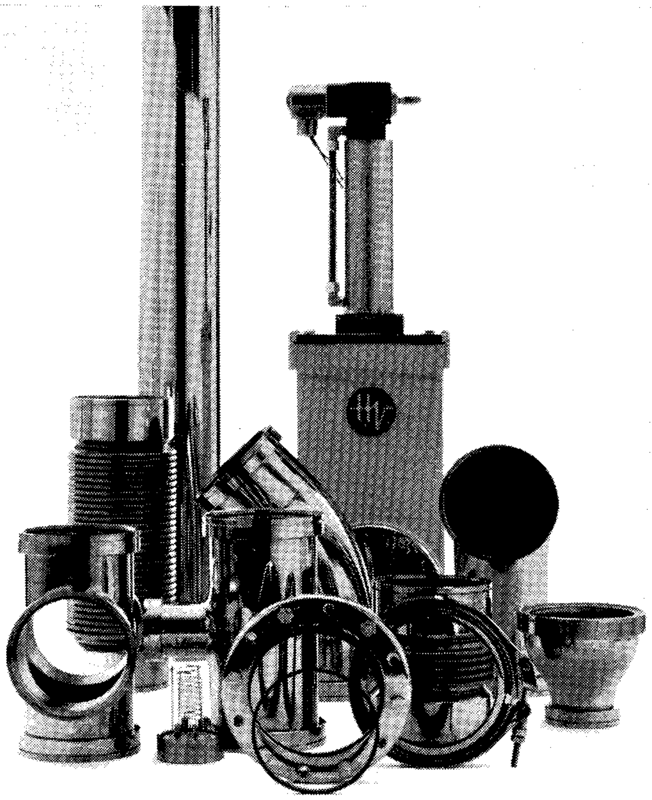
Implementation and Organization

The 360-30 was delivered and installed to schedule in July 1967. Its first application is to be in connection with the stores to replace the existing Kardex system, gradually developing a more scientific



system of stock control and stores accounting. Preliminary processing is planned for October, with effective take-over from January 1968. From then on, other applications due for system review and processing on the computer include general accounts, personnel statistics, budgetary accounting, workshop job costing, payroll and insurance work.

The aim of the ADP project is to build up a computer facility eventually integrating and serving all data processing needs. During the first few years this will consist of progressively applying the computer to much of the work done up to now by conventional accounting methods within Finance Division. The ADP section entrusted with the new system's design, programming and operation has, therefore, been established as a unit directly under the leader of Finance Division. Since the project will, however, affect other Divisions, particularly Personnel, in their day to day work, and since almost all the Divisions will see changes, for example in the format and presentation of information, a Co-ordination Group has been set up consisting of representatives from Finance, Personnel and Data Handling Divisions and from the Budget Planning Group. The task of this Group is to follow and co-ordinate use of computer. The policy to be adopted as the ADP project develops is the responsibility of the Director of Administration and of the leaders of Finance and Personnel Divisions forming an overall Policy Committee.



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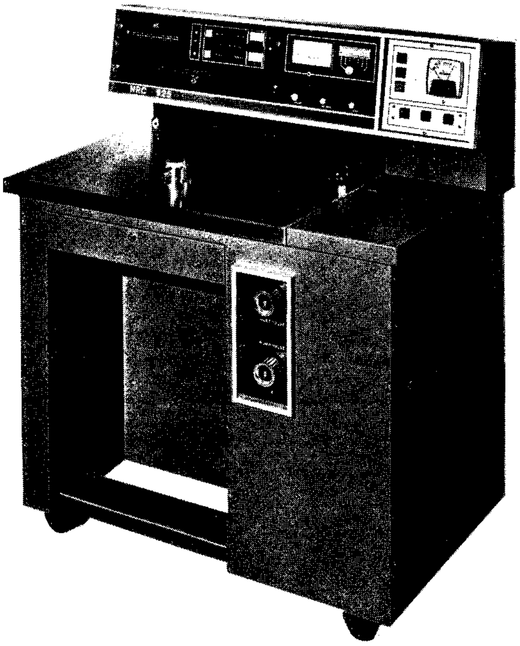

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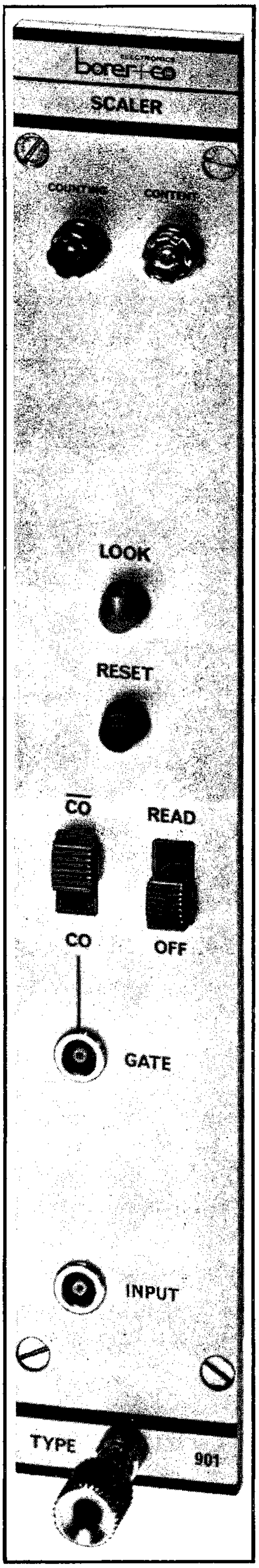

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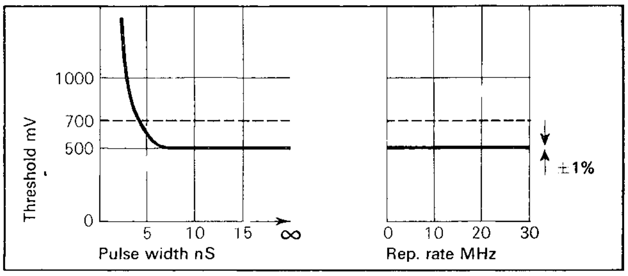

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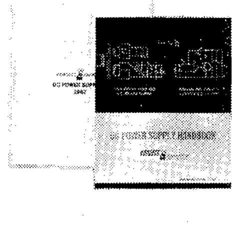

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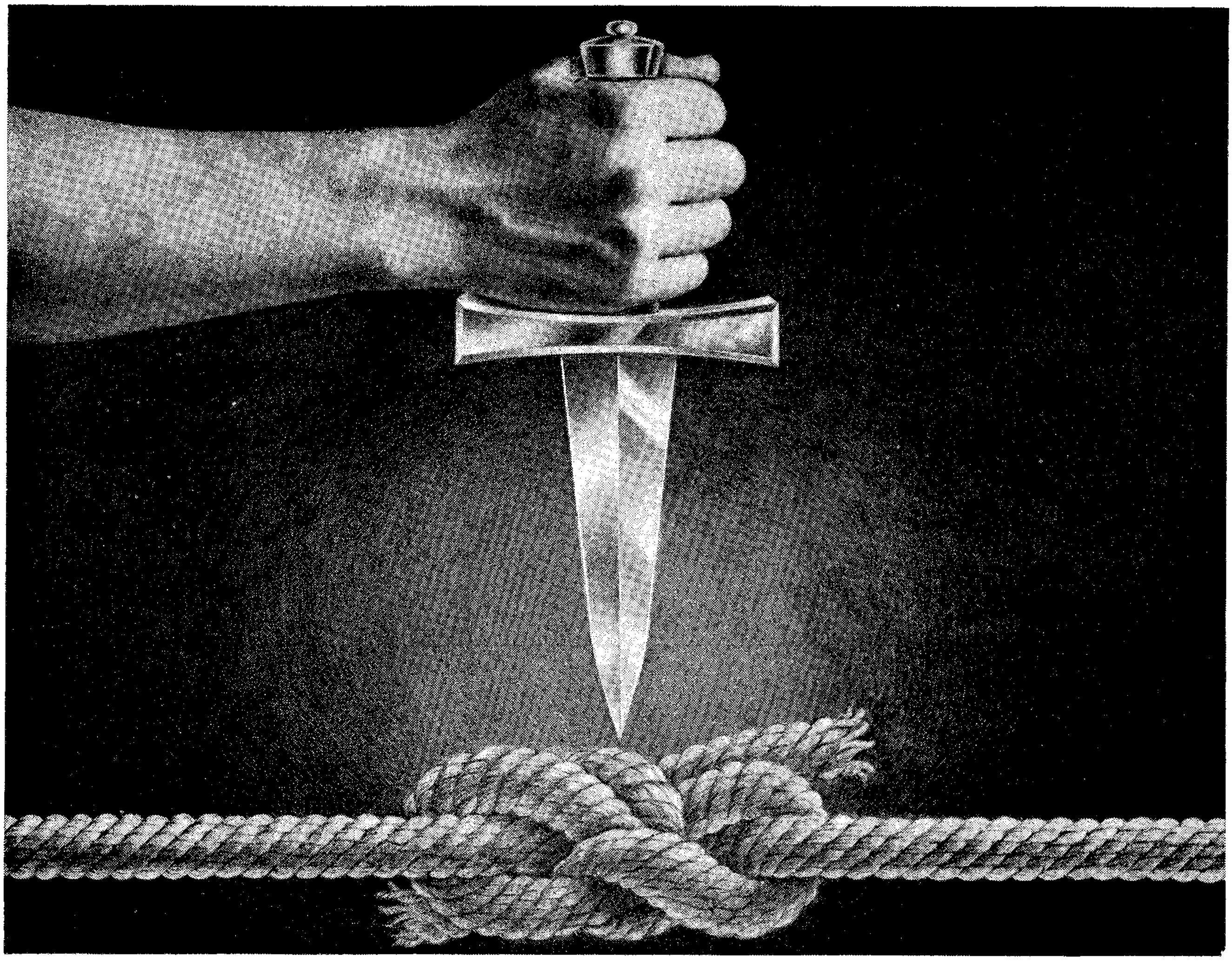

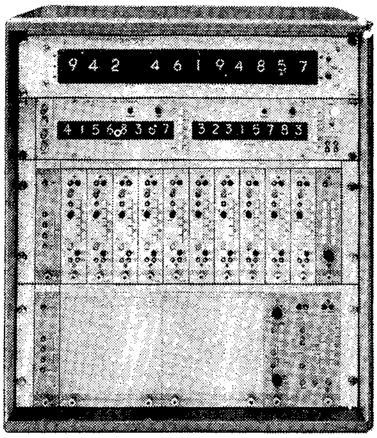

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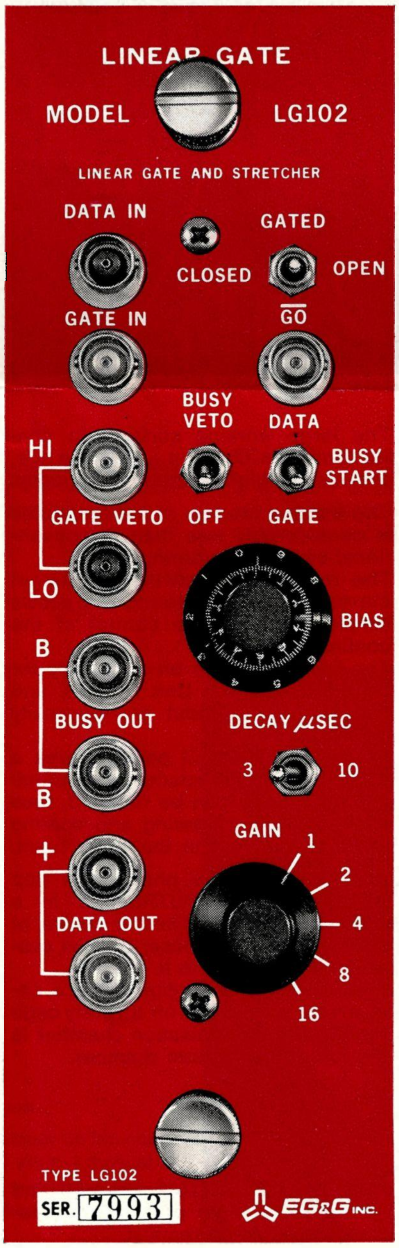

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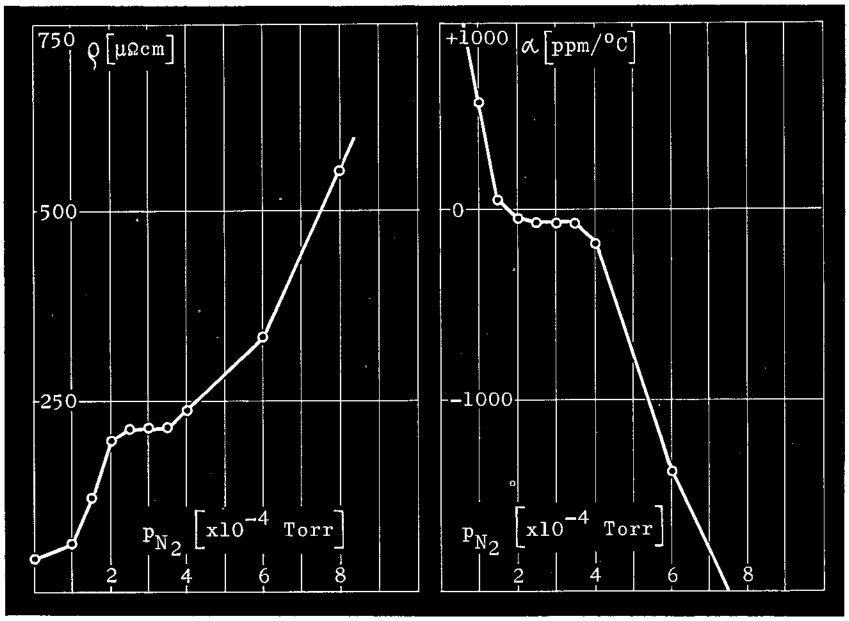


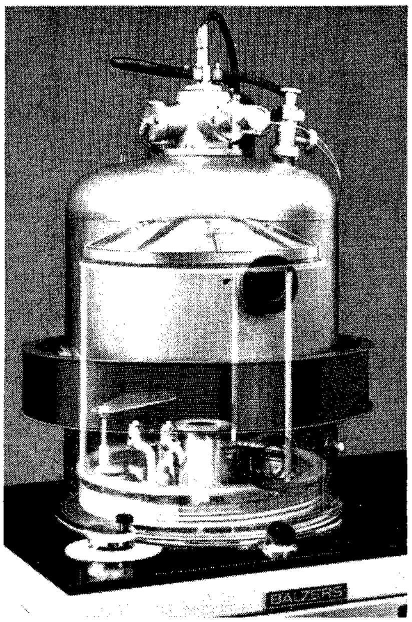
Tantalum films with a specific resistance which, at 30–40 μΩ · cm is only three times higher than of the solid metal, can be readily produced by the Cathode Sputtering method in BALZERS apparatus SPUTRON II.
This modern equipment for triode sputtering in a low pressure gas discharge also provides facilities for reactive sputtering, as an example of which the specific electrical resistance ρ and the temperature coefficient α of tantalum nitride films, sputtered at varying partial pressures of N_2 are given.

Special Features of the SPUTRON II

- Low working pressures in the 10^{-4} Torr range ensure the very clean conditions necessary for the deposition of the above-mentioned Ta-films.
- The extremely high ion current density of > 50 mA/cm², in conjunction with the low working pressures allows deposition of pure aluminium films at a sputtering rate of > 200 Å/min.
- The modern design of the SPUTRON II provides an extremely large working surface: a minimum of 24 5 x 5 cm substrates can be sputtered at the same time.
- Films produced in the SPUTRON II are of uniform thickness: with 5 x 5 cm substrates the uniformity is < ± 2 %; with 10 x 10 cm substrates < ± 4 %.
- The large working surface, in conjunction with the high sputtering rate, provides a high sputtering capacity.
- The thermal loading of the substrates is considerably less than in conventional cathode sputtering.
- The relationship between the target current and the sputtering rate allows simple and accurate control of the coating cycle.
- The SPUTRON II is an accessory for BALZERS Coating Unit BA 510, and can be fitted without any necessity for modifications.
- As the SPUTRON II only requires a small amount of space, the normal thermal source can be retained, thus allowing both sputtering and coating to be carried out in the same plant.

The double exposure photograph (top right) shows the SPUTRON II in a BA 510. The target is in the centre of the vacuum chamber base, with an evaporation source next to it.
The substrates are supported on a calotte which is mounted on a rotary cage assembly and the ionisation chamber is at the top of the vacuum chamber.

Leaflets DN 806, DN 1087, DN 1091 and DN 1134 giving more detailed information are available on request.



BALZERS®

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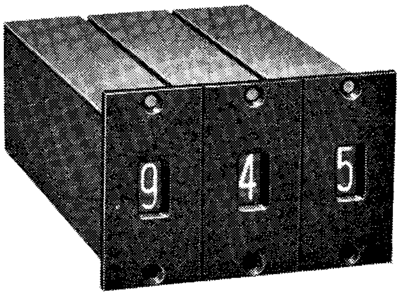
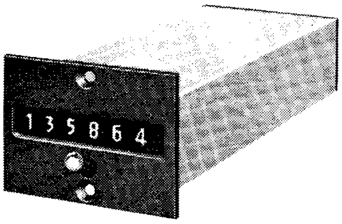
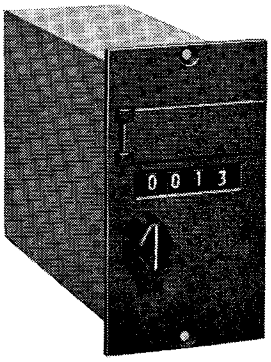
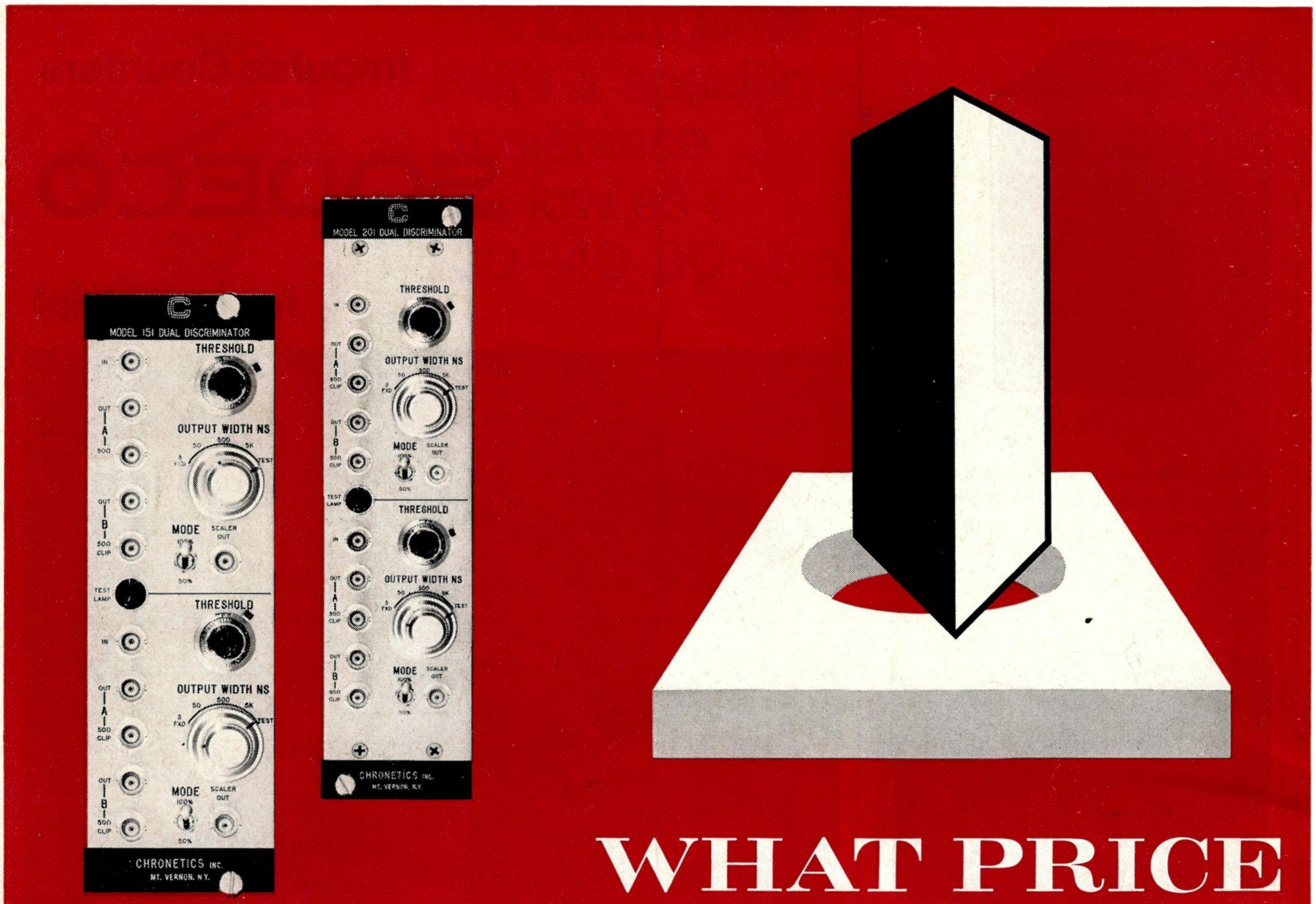
Telephone : Berkhamsted 2181





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