II. Automatic Calculating Machines. By P. E. Ludgate.

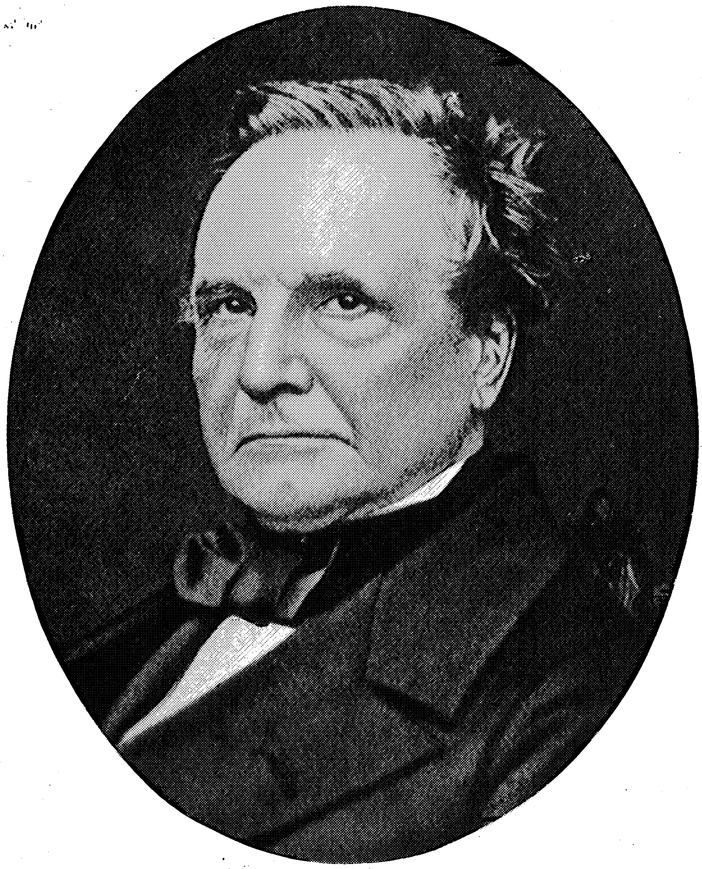
Automatic calculating machines on being actuated, if necessary, by uniform motive power, and supplied with numbers on which to operate, will compute correct results without requiring any further attention. Of course many adding machines, and possibly a few multiplying machines, belong to this category; but it is not to them, but to machines of far greater power, that this article refers. On the other hand, tide-predicting machines and other instruments that work on geometrical principles will not be considered here, because they do not operate arithmetically. It must be admitted, however, that the true automatic calculating machine belongs to a possible rather than an actual class; for, though several were designed and a few constructed, the writer is not aware of any machine in use at the present time that can determine numerical values of complicated formulæ without the assistance of an operator.

The first great automatic calculating machine was invented by Charles Babbage. He called it a "difference-engine," and commenced to construct it about the year 1822. The work was continued during the following twenty years, the Government contributing about £17,000 to defray its cost, and Babbage himself a further sum of about £6000. At the end of that time the construction of the engine, though nearly finished, was unfortunately abandoned owing to some misunderstanding with the Government. A portion of this engine is exhibited in South Kensington Museum, along with other examples of Babbage's work. If the engine had been finished, it would have contained seven columns of wheels, with twenty wheels in each column (for computing with six orders of differences), and also a contrivance for stereotyping the tables calculated by it. A machine of this kind will calculate a sequence of tabular numbers automatically when its figure-wheels are first set to correct initial values.

Inspired by Babbage's work, Scheutz of Stockholm made a difference-engine, which was exhibited in England in 1854, and subsequently acquired for Dudley Observatory, Albany, U.S.A. Scheutz's engine had mechanism for calculating with four orders of differences of sixteen figures each, and for stereotyping its results; but as it was only suitable for calculating tables having small tabular intervals, its utility was limited. A duplicate of this engine was constructed for the Registrar General's Office, London.

In 1848 Babbage commenced the drawings of an improved difference-engine, and though he subsequently completed the drawings, the improved engine was not made.

Babbage began to design his "analytical engine" in 1833, and he put together a small portion of it shortly before his death in 1871. This engine was to be capable of evaluating any algebraic formula, of which a numerical solution is possible, for any given values of the variables. The formula it is desired to evaluate would be communicated to the engine by two sets of perforated cards similar to those used in the Jacquard loom. These cards would cause the engine automatically to operate on the numerical data placed in it, in such a way as to produce the correct result. The mechanism of this



PORTRAIT OF CHARLES BABBAGE.

[*To face p.* 124.

engine may be divided into three main sections, designated the " Jacquard apparatus," the " mill," and the " store." Of these the Jacquard apparatus would control the action of both mill and store, and indeed of the whole engine.

The store was to consist of a large number of vertical columns of wheels, every wheel having the nine digits and zero marked on its periphery. These columns of wheels Babbage termed " variables," because the number registered on any column could be varied by rotating the wheels on that column. It is important to notice that the variables could not perform any arithmetical operation, but were merely passive registering contrivances, corresponding to the pen and paper of the human computer. Babbage originally intended the store to have a thousand variables, each consisting of fifty wheels, which would give it capacity for a thousand fifty-figure numbers. He numbered the variables consecutively, and represented them by the symbols V_1, V_2, V_3, V_4 . . . . . V_{1000}. Now, if a number, say 3·14159, were placed on the 10th variable, by turning the wheels until the number appeared in front, reading from top to bottom, we may express the fact by the equation $V_{10}=3{\cdot}14159$ or $V_{10}=\pi$. We may equate the symbol of the variable either to the actual number the variable contains, or to the algebraic equivalent of that number. Moreover, in theoretical work it is often convenient to use literal instead of numerical indices for the letters V, and therefore $V_n=ab$ means that the nth variable registers the numerical value of the product of a and b.

The mill was designed for the purpose of executing all four arithmetical operations. If V_n and V_m were any two variables, whose sum, difference, product, or quotient was required, the numbers they represent would first be automatically transferred to the mill, and then submitted to the requisite operation. Finally, the result of the operation would be transferred from mill to store, being there placed on the variable (which we will represent by V_z) destined to receive it. Consequently the four fundamental operations of the machine may be written as follows :—

(1) $V_n+V_m=V_z$.
(2) $V_n-V_m=V_z$.
(3) $V_n\times V_m=V_z$.
(4) $V_n\div V_m=V_z$.

Where n, m, and z may be any positive integers, not exceeding the total number of variables, n and m being unequal.

One set of Jacquard cards, called " directive cards," (also called " variable cards ") would control the store, and the other set, called " operation cards," would control the mill. The directive cards were to be numbered like the variables, and every variable was to have a supply of cards corresponding to it. These cards were so designed that when one of them entered the engine it would cause the Jacquard apparatus to put the corresponding variable into gear. In like manner every operation card (of which only four kinds were required) would be marked with the sign of the particular operation it could cause the mill to perform. Therefore, if a directive card bearing the number 16 (say) were to enter the engine, it would cause the number on V_{16} to be transferred to the mill or *vice versa*; and an operation card marked with the sign ÷ would, on entering the engine, cause the mill to divide one of the numbers transferred to it by the other. It will be observed that the choice of a directive card would be represented in the notation by the substitution of a numerical for a literal index of a V; or, in other words, the substitution of an integer for one of the indices *n*, *m*, and *z* in the foregoing four examples. Therefore three directive cards strung together would give definite values to *n*, *m*, and *z*, and one operation card would determine the nature of the arithmetical operation, so that four cards in all would suffice to guide the machine to select the two proper variables to be operated on, to subject the numbers they register to the desired operation, and to place the result on a third variable. If the directive cards were numbered 5, 7, and 3, and the operation card marked +, the result would be $V_5+V_7=V_3$.

As a further illustration, suppose the directive cards are strung together so as to give the following successive values to *n*, *m*, and *z* :—

Sequence of values for		*n* . . .	2, 6, 4, 7.
,,	,,	*m* . . .	3, 1, 5, 8.
,,	,,	*z* . . .	6, 7, 8, 9.

Let the sequence of operation cards be

$$+ \times - \div$$

When the cards are placed in the engine, the following results are obtained in succession :—

1st	operation,	$V_2+V_3=V_6$.
2nd	,,	$V_6\times V_1=V_7$.
3rd	,,	$V_4-V_5=V_8$.
4th	,,	$V_7\div V_8=V_9$.

From an inspection of the foregoing it appears that V_1, V_2, V_3, V_4, and V_5 are independent variables, while V_6, V_7, V_8, and V_9 have their values calculated by the engine, and therefore the former set must contain the data of the calculation.

Let $V_1=a$, $V_2=b$, $V_3=c$, $V_4=d$, and $V_5=e$, then we have

1st	operation,	$V_2+V_3=b+c=V_6$.
2nd	,,	$V_6\times V_1=(b+c)a=V_7$.
3rd	,,	$V_4-V_5=d-e=V_8$.
4th	,,	$V_7\div V_8=\dfrac{(b+c)a}{d-e}=V_9$.

Consequently, whatever numerical values of *a*, *b*, *c*, *d*, and *e* are placed on variables V_1 to V_5 respectively, the corresponding value of $\frac{a(b+c)}{d-e}$ will be found on V_9, when all the cards have passed through the machine. Moreover, the same set of cards may be used any number of times for different calculations by the same formula.

In the foregoing very simple example the algebraic formula is deduced from a given sequence of cards. It illustrates the converse of the practical procedure, which is to arrange the cards to interpret a given formula, and it also shows that the cards constitute a mathematical notation in themselves.

Seven years after Babbage died a Committee of the British Association appointed to consider the advisability and to estimate the expense of constructing the analytical engine reported that: " We have come to the conclusion that in the present state of the design it is not possible for us to form any reasonable estimate of its cost or its strength and durability." In 1906 Charles Babbage's son, Major-General H. P. Babbage, completed the part of the engine known as the " mill," and a table of twenty-five multiples of π, to twenty-nine figures, was published as a specimen of its work, in the *Monthly Notices of the Royal Astronomical Society*, April 1910.

I have myself designed an analytical machine, on different lines from Babbage's, to work with 192 variables of 20 figures each. A short account of it appeared in the *Scientific Proceedings, Royal Dublin Society*, April 1909. Complete descriptive drawings of the machine exist, as well as a description in manuscript, but I have not been able to take any steps to have the machine constructed.

The most pleasing characteristic of a difference-engine made on Babbage's principle is the simplicity of its action, the differences being added together in unvarying sequence; but notwithstanding its simple action, its structure is complicated by a large amount of adding mechanism—a complete set of adding wheels with carrying gear being required for the tabular number, and every order of difference except the highest order. On the other hand, while the best feature of the analytical engine or machine is the Jacquard apparatus (which, without being itself complicated, may be made a powerful instrument for interpreting mathematical formulæ), its weakness lies in the diversity of movements the Jacquard apparatus must control. Impressed by these facts, and with the desirability of reducing the expense of construction, I designed a second machine in which are combined the best principles of both the analytical and difference types, and from which are excluded their more expensive characteristics. By using a Jacquard I found it possible to eliminate the redundancy of parts hitherto found in difference-engines, while retaining the native symmetry of structure and harmony of action of machines of that class. My second machine, of which the design is on the point of completion, will contain but *one* set of adding wheels, and its movements will have a rhythm resembling that of the Jacquard loom itself. It is primarily intended to be used as a difference-machine, the number of orders of differences being sixteen. Moreover, the machine will also have the power of automatically evaluating a wide range of miscellaneous formulæ.

(1) H.M. Nautical Almanac Office Anti-Differencing Machine.

By T. C. Hudson.

This machine embodies successive developments (suitable for mathematical purposes) from the original Burroughs Adding-Machine of the years 1882–1891. It will work either in decimals, or in hours (or in degrees), minutes,