ART. XV.—*On a New Difference Engine;* by GEO. B. GRANT.

THE great labor and expense involved in the construction of reliable astronomical and nautical tables by mental computation, as well as the impossibility of getting them entirely correct, suggested to Charles Babbage the idea that this work might be done almost entirely by machinery, and the machine he invented for that purpose has become famous, as one of the most complicated and costly pieces of mechanism ever contrived. The English government appropriated eighty-five thousand dollars for its construction, on the strong recommendation of a committee of the Royal Society, containing some of the most eminent men of the time, but after years of study and labor had been spent on it, the appropriations were stopped on account of the indefinite expense. Though never completed as a working machine, it proved the feasibility of the scheme.

Babbage's idea was carried out more successfully by Edward Scheutz, and the two machines constructed on his plan are the only ones ever built for this purpose. One of these was bought for the Dudley Observatory at Albany, but has been but little used. The other was built by the British government in 1862, and has since been extensively used in the calculation of life insurance tables.*

The idea of contriving a machine for calculating tables first occurred to myself while laboriously computing a table for excavation and embankment. Having never heard of either Babbage's or Scheutz's engines, I imagined it an easy matter, but gave it up in disgust after some study. Last year I heard of Babbage's engine, became interested again, and designed a machine that might possibly have worked, but I could convince nobody that it would do so, and gave it up again. About four months ago, my teacher in the Mining School, Prof. Wolcott Gibbs, asked after the design, encouraged me in my work, and the result is the design for the difference engine, which it is the purpose of this article to describe.

Though I have built no large machine, the efficiency of the design for its purpose may be considered as having been proved, as through the liberality of the superintendent of the Coast Survey, Prof. Benjamin Peirce, I have been able to build a model of small capacity, which has worked to satisfaction.

I am indebted to Mr. John N. Bachelder of Cambridge, as well as to Professors Eustis, Winlock and Whitney, of Harvard College, for encouragement and help given. Mr. Bachelder had charge of the Scheutz engine when it first came to this country, and is one of the few who have had practical experience with any machine of this class.

A short explanation of the method of differences may not be wasted on many of my readers.

If the first term of any table be subtracted from the second, the second from the third, and so on, a new table will be formed, called the first order of differences. In the same way

* Accounts of Babbage's engine may be found in the Edinburg Review, July, 1834, in Taylor's Scientific Memoirs, v. 3, and in the inventor's work, "Passages from the Life of a Philosopher;" short articles on the same in Tomlinson's Cyc. of the Arts and Sciences; Harper's Mag., 1865; Manufacturer and Builder, 1870; Timb's Stories of Inventors, &c. Scheutz's engine is described in "The Swedish Calculating Machine," by Charles Babbage, in "The Manufacturer and Builder," Aug., 1870, and in detail in the British patent specifications, Oct. 17, 1854, No. 2216.

a second order can be formed from the first, a third from the second, and ultimately an order of differences will be reached, which is constant or nearly so. For example, take a table of the cubes of the natural numbers, and forming the several orders of difference, it is found that the third order is invariably six.

Table.	1st order.	2nd order.	3rd order.
1	7	12	6
8	19	18	6
27	37	24	
64	61		
125			

It is plain that with nothing but the first terms 1, 7, 12 and 6, the table might be constructed to any extent by simple addition. A difference engine is nothing but a machine to operate this method, using several orders of differences, and a large number of decimal places.

In logarithmic, trigonometrical, and in fact in the greater number of tables, there is no constant order, but one can be found that is so nearly so, that the error of considering it exactly so will not creep into a given number of decimal places, till any required number of terms have been calculated. A fresh start must then be taken, and the table completed by a number of such operations.

This engine, like both the others, consists of a calculating and a printing part. In the printing part, the calculated results are stamped into a sheet of lead, wax or other plastic substance, from which a stereotype plate is taken for printing the table, thus avoiding constant error in copying the numbers and setting them up in type from manuscript. No description of this part is given, as it contains nothing new of importance.

The calculating part consists of the main wheels, A, on which the first terms are set up, the additions made, and from which the calculated results are taken by the printing part; the drivers B, which make the additions, and the carrying apparatus C.

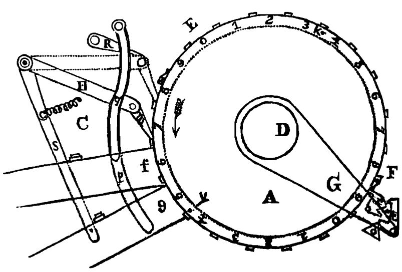
The main wheels are about one-third of an inch thick, and five inches in diameter, all turning on the same axis D, in the same direction independently of each other, the axis being stationary.

They are arranged in sets of two, three or more, according as the first, second or higher order is designed to be constant. There are as many of these sets as there are decimal places in the largest number to be used. Each wheel is furnished on one edge with twenty teeth, and on the other with two cams, a and a', which project a little farther from the wheel than the teeth. The spaces between the teeth are stamped with the ten numerals, zero to nine, twice in succession.

The first set represents the units or lowest decimal place, the next set represents the next higher decimal place, and so on. The first wheel in each set represents the corresponding decimal place of the tabular number, the second wheel, that of the first order, and the last wheel is the constant order, and is furnished only with a cam, the teeth being omitted. It can be fastened at any figure, as it never requires to be changed after once being set. By this arrangement each wheel is separated by but the sixteenth of an inch from the wheels of the same place in the next higher and next lower orders.

The point E is chosen as the point at which to read all numbers, and it is evident that any number may be shown on any order by turning the wheels till the right numbers appear at E. The cams are so arranged with regard to the numbers, that one of them shall be at the point F when the wheel reads zero. Now as the wheel is turned, as every number passes E, the cam will be moved one space further from F, so that at any time the wheel could be read as well by observing the number of spaces the cam is distant from F, as by reading the figure at E.

The drivers B are attached to the carriage G, one driver opposite each wheel except the constant ones. They consist of a catch *b* and hook *c*. The catch is pressed toward the wheel, and the hook pressed on the catch by the same spring *d*. The carriage is driven by a crank over ten spaces on the wheels, and back again, making one oscillation to every turn of the crank. As the carriage leaves the rod *e*, the catch drops between the teeth of the wheel and carries it along. The catch projects over its wheel far enough to strike the cam on the next wheel when it gets to it, and be lifted out of the teeth by it, having added to its wheel the number of spaces that the cam is distant from F. As it is raised up, the hook catches in the nick *h*, and prevents it falling back on the wheel, so that it moves the rest of the stroke and back without moving the wheel. As the carriage comes back, the projection on the hook strikes the rod *e* and the hook is lifted out of the catch, letting it onto the wheel again.



It is necessary that while one wheel is being added to, the next wheel should not move. For this purpose the first stroke adds the first, third and odd orders to the numbers on the table, second, fourth and even orders, the odd orders being held firm by a clamp not shown. Meanwhile the rod *e* has been moved, so that the drivers belonging to the even orders are not released as the carriage comes back, but those belonging to the odd orders, so that at the next stroke the even orders are added to the odd ones, and the number on the table-wheels printed; every two strokes of the carriage giving a new term of the table.

On each wheel between the teeth and cams are two grooves. The two slips *f* and *g* rest in these grooves, being held there by light springs. The pin *k* is so arranged that, when the wheel reads nine, it will be under the first slip *f*, holding it up; and as it passes from nine to zero it drops the slip *f*, raises and drops the slip *g*. To each wheel there is an arm H, to which the catch *m* is attached, the catch resting on the teeth of the wheel. This arm would be drawn back by a spring, but is held by two catches *p* and *q*. If the catch *p* is drawn, the arm will be held by *q* only, and if *q* is then drawn it will spring back, the catch falling over the next tooth. The slip *f* of each wheel is connected with the catch *p* of the wheel of the same order in the next decimal place higher, and the slip *g* with *q*. Each arm is connected by the lever *s* with its own slip *g*, so that it will draw it out when it springs back. As each nine on the wheel A comes to the point E, the slip *f* is pushed out, and the catch *p* to the next place B drawn; and as the zero comes to E, the slip *g* is pushed out, the catch *q* drawn, and the arm over B is sprung, drawing with it the catch *q* of the next place higher, C, but not releasing the arm at C, as it is still held by *p*. *p* will, however, be drawn, if B stands on nine, and both arms sprung, as it should be, for if the arm over B is released it indicates that one is to be added to it, and if it is already nine the addition of that one will make it necessary to carry one to C also. If C is nine, one must be carried to D, and so on; one must be carried to the first wheel which is not nine.

This is all done during the addition, after which and during the return of the carriage, the cam K brings all the arms back that are up, adding one to each wheel whose arm is up.

The entire printing part, as well as some details of framing, gearing, etc., are omitted from the accompanying sketch, which is meant merely as an outline drawing showing the principal parts only.

The size of a completed machine would vary with the capacity. An engine of the same capacity as that of Scheutz, would be three feet long, twelve inches high, and eight inches wide. The cost is estimated at from two to three thousand dollars.

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