Section D

CALCULATING MACHINES

Calculating Machines. By F. J. W. Whipple, M.A.

The following notes on calculating machines are on the lines of the *Catalogue raisonnée* which I prepared for the Exhibition in connection with the Fifth International Congress of Mathematicians held at Cambridge in 1912. The blocks are lent by the Cambridge University Press. I wish to make it clear that my point of view is that of the user of a machine who wishes to have a general idea of how it works rather than that of the expert who has to master every detail. I propose to confine my remarks to purely arithmetical machines, and say nothing of other apparatus, such as slide-rules or mechanical integrators.

It is convenient, in discussing arithmetical calculating machines, to take the fundamental operations of arithmetic in the following order:—numeration, addition, multiplication, subtraction, and division. For mere numeration or counting, there are two systems in general use. The simpler to construct is the one in which the wheels, whose position indicates the values of various digits, are always in gear with one another, as in an ordinary clock, and the figures of each denomination change gradually. When we look at a clock which shows twenty-eight seconds after eighteen minutes past three, we really see the hands indicating 3 hours + about $\frac{1}{3}$, 18 minutes + about $\frac{1}{2}$, and 28 seconds, respectively. For time, this is the most satisfactory system, but for most purposes it is easier to read figures presented to the eye as they would be written down. It is important to notice, however, that in a counter which shows figures in this way, the wheels cannot be continually in gear with one another. An example which shows the advantage of the displayed digit system is furnished by the cup anemometer.

Addition.—The process of addition involves two distinct operations, the addition of digits and the carrying of figures from one denomination to the next.

As far as I am aware, there is no machine which can be said to know the addition table. If 5 is shown on a counter and 3 has to be added to it, then the operation of adding 1 is gone through three times in rapid succession; there is not a sudden jump from 5 to 8.

Methods of Adding a Digit

The devices used for ensuring the addition of a particular digit determined by the operator may be classified as follows :—1, rocking segments ; 2, stepped reckoners ; 3, alternative racks ; 4, variable cog wheels.

1. *The rocking segment* is shown in fig. 1. Whilst the segment is turning in the direction shown by the arrow it is in gear with the counter C. When turning back again it is thrown out of gear. The angle through which the rocking segment can turn is settled by the key which has been pressed down (7 in the diagram).

The rocking segment will be found in the Cash Register and in Burrough's Adding Machine. In these machines the segment is turned by means of a

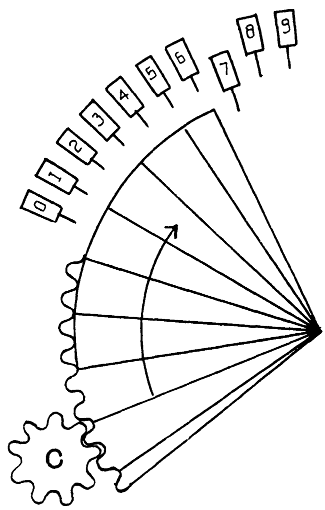


Fig. 1.

handle or by electric power. In the Comptometer the pressing of the key not only decides the range of the rocking segment, but causes it to rock.

2. *The Stepped Reckoner*.—The wheel R in fig. 2 is stepped, *i.e.* the cogs do not cover its entire length, but some are longer than others. When the wheel J is in the position shown in the diagram, only one of the cogs on R can engage with one on J. If, however, J were moved to the right until the pointer was under the 3, then three of the cogs on R would engage. Thus one turn of R will be recorded by a 1 or 3 on the counter, as the case may be. The stepped reckoner is used for addition in machines of the Thomas type, examples of which are the Arithmometer,[1] the Saxonia, and the T.I.M. The drawback of the system is the slow method of adjusting the sliding piece J. In a machine used especially for adding, the slide would have to be set by pressing a key.[2]

3. In the Mercedes machines the cog wheel J is adjusted in the same way,

[1] The Arithmometer is of British manufacture, and is notable for the smoothness of its action.

[2] This is done in the XxX machine (*Zeitschrift für Vermessungswissen*, 1913, S. 716).

but instead of stepped reckoners there are *racks* which move through different amplitudes. A single set of racks suffices to turn all the counters.

4. *Wheel with a Variable Number of Cogs.*—By means of the handle H the ring R is pushed through slots in the sliding knobs K. The wheel in the diagram has five knobs ; by moving the handle H clockwise the number of knobs can

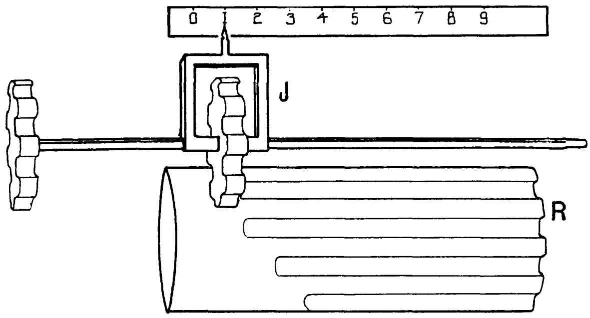


FIG. 2.

be increased to six. When the handle H has been adjusted the wheel is turned as a whole, and the knobs K knock the counter as they pass it.

This neat device is found in the popular Brunsviga machine.

Carrying.—The mechanism in an adding machine undertakes a task which is beyond the human brain. If a man has to add together two numbers such as 526314 and 131524, he has to think of the additions of separate

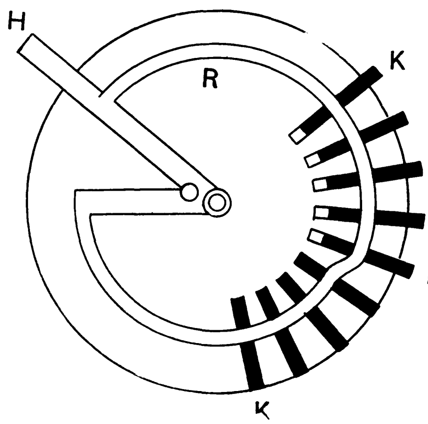


FIG. 3.

orders of magnitude *seriatim* : as a general rule the machine can attend to all the additions simultaneously. If the counter of the machine is watched while the handle is turned slowly, the digits are seen to change gradually but independently. On the other hand, when carrying has to be dealt with, the operation on the units column must be timed to precede the operation in the tens column, and so on. When unity is added to 995999, the transformation must begin on the right and stop short at the fourth figure. It cannot begin everywhere simultaneously.

It will be seen that carried figures may arise in two ways, which the designer of a calculating machine must regard as distinct. If to 57447 the number 21586 is added, then, apart from the carried figures, the sum is 78923. Carried *ones* are now waiting to be added to the 2 and to the 9. It is not until after these *ones* have been added that the *one* which is to be added to the 8 appears.

The mechanism which is used for controlling the carrying of figures is the most delicate part of a calculating machine. The details, which vary in the different types, are not easy to explain without models.

Multiplication.—Multiplication is essentially repeated addition, and therefore any adding machine can be used for multiplication, at any rate when small multipliers are concerned. For such work the comptometer will be found most useful. For dealing with large multipliers, some method of changing the place value of figures by sliding the part of the apparatus carrying the multiplicand relative to the part carrying the partial product is essential.

It should be noted that it is practically impossible to deal with English coinage, weights and measures, without expressing them in the decimal system, thus it is customary to express shillings and pence as decimals of a pound. This can be done with a calculating machine with less risk of error than in ordinary arithmetic, as there is less temptation to round off the figures and retain too few decimal places.

As we have already remarked, multiplication is repeated addition, and the ordinary multiplying machine goes through the process of addition: to multiply by 7, the adding process must be repeated seven times, as seven times the multiplicand has to be added to zero. The Millionaire calculating machine differs from the others in that it contains an automatic multiplication table. A marker is set, say to 4, and a pointer to 7, and the product 28 is recorded after a single turn of the handle. During this turn there are two distinct operations: at the end of the first half-turn the 2 appears in the right place in the product and the product-carriage moves one place to the left: in the second half-turn the 8 appears to the right of the 2. This effect is secured by controlling the amplitude of the motion of racks which move under pinions similar to those used with the stepped reckoner (fig. 2). Corresponding to each multiplier there is a tongue-plate which forms a multiplication table. For example, the "7" tongue-plate has nine pairs of tongues, the lengths of which correspond in length to so many cogs on the racks, 0, 7; 1, 4; 2, 1; 2, 8; 3, 5; etc. When 4 is multiplied by 7 the fourth rack is pushed by a short tongue on the seventh tongue-piece through two teeth, then the tongue-piece is itself displaced laterally, whilst the rack returns to its original position, and finally a longer tongue pushes the same rack through eight teeth.

Subtraction.—The process of subtraction being the reverse of addition, it might be expected that any adding machine might be used for subtraction by reversing the motion of the handle. This would lead to difficulties, however, as the process of carrying tens must run from right to left in subtraction as well as in addition. Accordingly, it is usual to have a switch which reverses the motion of the main shaft whilst keeping the same direction of rotation of the handle.

In some machines there is no separate mechanism for subtraction, but the computer adds 999356 when he wishes to subtract 000644.

Division.—The process of division with a calculating machine is closely analogous with ordinary long division. The computer has to be very alert, or he makes his quotient too big and has to retrace his steps. For many calculations it is advisable to use a table of reciprocals, and substitute multiplication for division.

There is one machine, however, the Mercedes-Euklid,[1] which is especially designed for division. The method adopted may be described as successive approximation to the quotient from above and below.

As a simple illustration let us consider the division of 10 by 7. The first process is subtraction, which is effected in machines of this type by the addition of the complementary number; to subtract 7, the machine adds 3, 93, or 993, as the case may be, according to the place value. Now if 93 is added to 10 twice, the sum is 196. So after two additions 2 appears as the first approximation to the quotient and 96 is the corresponding "remainder." The mechanism prevents the handle from being turned further. The operator is warned thereby that this stage of the process is complete: he moves a pair of keys; the carriage shifts to change the place value of the divisor, and the handle is set free for the next step in the division.

	10
	93
1	(1)03
	93
2	96
	7
19	967
	7
18	974
	7
17	981
	7
16	988
	7
15	995
	7
14	(1)002

During this stage the quotient 2·0, which is too great, is reduced. At each turn of the handle the quotient is reduced by a unit in the second place, and at the same time the remainder is increased by 7 in the corresponding place. As long as the 7's can be added without any 10 being carried on the left of the sum, the handle turns freely.

Now, starting from 960, and adding successive 7's, we arrive after six additions at 1002; the figures 002 appear as the remainder, and as the 1 cannot be "carried," the handle locks again. The quotient is now 20−6 or 14, and the remainder 2, *i.e.* at this stage we have the same approximation as in ordinary arithmetic and a quotient which is too small. The next step gives too big a quotient, and so on.

[1] *Zeitschrift für Instrumentenkunde*, 1910.

Successive remainders and quotients are (ignoring the decimal point) :

96	002	9999	00004	999998
2	14	143	1428	14286

These correspond to the equations

$$\frac{10}{7}=2+\frac{96-100}{7}$$

$$\frac{100}{7}=14+\frac{2}{7}$$

$$\frac{1000}{7}=143+\frac{9999-10000}{7}$$

$$\frac{10000}{7}=1428+\frac{4}{7}$$

and

$$\frac{100000}{7}=14286+\frac{999998-1000000}{7}.$$

Two features of this machine may be mentioned as displaying remarkable ingenuity—the way of determining the complement of a number and the system according to which the handle is stopped at the right place during division.

If we want to write down the complement of any number such as 374093, we write down the difference between each figure and 9 with one exception, viz., we must take the difference between the last figure and 10. How can this exception be allowed for without depriving the machine of all symmetry ? The answer to this question has been found in the provision of a hidden extra digit on the right. This digit is always zero for addition and 10 for subtraction. Thus if we write t for the digit 10, we may say that the machine takes $625906{\cdot}t$ as the complement of $374093{\cdot}0$.

It will be remembered that in the course of a division operation the locking of the crank is the end of each step. The locking in addition is a simple enough process. If 041 is added to 095, the first half-turn brings 036 on to the counter, and in the next half-turn the carried 1 appears, making 136. If, however, 41 is added to 95, the first half-turn brings 36 on to the counter, and in the next half-turn the locking catch slips into position. When the machine is adjusted for subtraction, the actual process is the addition of the complementary number. Thus, in the case discussed above as an example of division, 93 is being added to 10 : the first sum is (1)03, but the carrying of the 1 does not lock the crank : the second sum is only 96, and it is necessary for the process to stop at this stage. Accordingly, we have the contrast : in addition the occurrence of the 1 to carry locks the crank ; in subtraction the lack of the 1 to carry locks it.

The Scope for Improvement of Calculating Machines

There are certain developments in calculating machines which would be of considerable value, and which could be made if there were sufficient demand. In the first place, it is remarkable that no multiplying machine which does long multiplication automatically is on the market at present. With such a machine it would be possible to set up the multiplier and multiplicand and then turn the handle without giving it any conscious attention until the locking of the motion showed that the operation was complete and the product was ready to be read off. I fancy that it would not be difficult to modify the Thomas machine to enable it to act in this way.

A more valuable invention would be a multiplying machine which could do continued multiplication. If three or more numbers have to be multiplied together, the first product has to be used as one of the factors for obtaining the second product. The transfer of the figures from one set of indicators to another is likely to lead to mistakes, and in any case wastes time. In such problems as the formation of a compound interest table or the calculation term by term of a hypergeometric series, the additional labour is so irksome that the computer would probably prefer to use logarithms.

Two ways of making a machine which would overcome the difficulty occur to one. There might be two indicators related in such a way that either could stand for multiplicand or for product; or, again, there might be three indicators, A, B, C, mounted on a cylinder, so that when A was used for the multiplicand the product appeared on B; when B was the multiplicand, the product was on C; and finally when C was multiplicand, the product was on A.

The mechanical difficulties in making continued product machines would be considerable, but by no means insuperable.

Finally, I should like to raise the question whether there is sufficient scope for a machine for calculating tables to justify its construction. Large sums of public money were voted in the early nineteenth century for the construction of Babbage's Difference Engine, which was to be used for this purpose. In these days of automatic tools, Babbage's Engine could be constructed at a moderate cost, but it would probably be better to start afresh and re-design it throughout. The story of Babbage's efforts end at present in a confession of national failure, and it would be gratifying to British mathematicians if a happier sequel could be written in our annals. Will the potential importance of the Difference Engine as a tool in the computer's workshop be recognised again, or shall we have to admit that Babbage's invention was never brought to perfection because the need for it was imaginary?

Exhibit of machines from the Mathematical Laboratory, University of Edinburgh:—

Archimedes.
Brunsviga (ordinary and miniature).
Burroughs Adding (printing).
Comptometer (two).
Mercedes-Euklid.
Millionaire.
Tate's Arithmometer.

All the machines described in Section D are exhibited and demonstrated.

I. Calculating Machines Described and Exhibited

(1) The "Archimedes" Calculating Machine

The Glashütter calculating machine "Archimedes" brings a new model into the market. The endeavour of every manufacturer of calculating machines is to reduce their size and weight without detriment to their stability

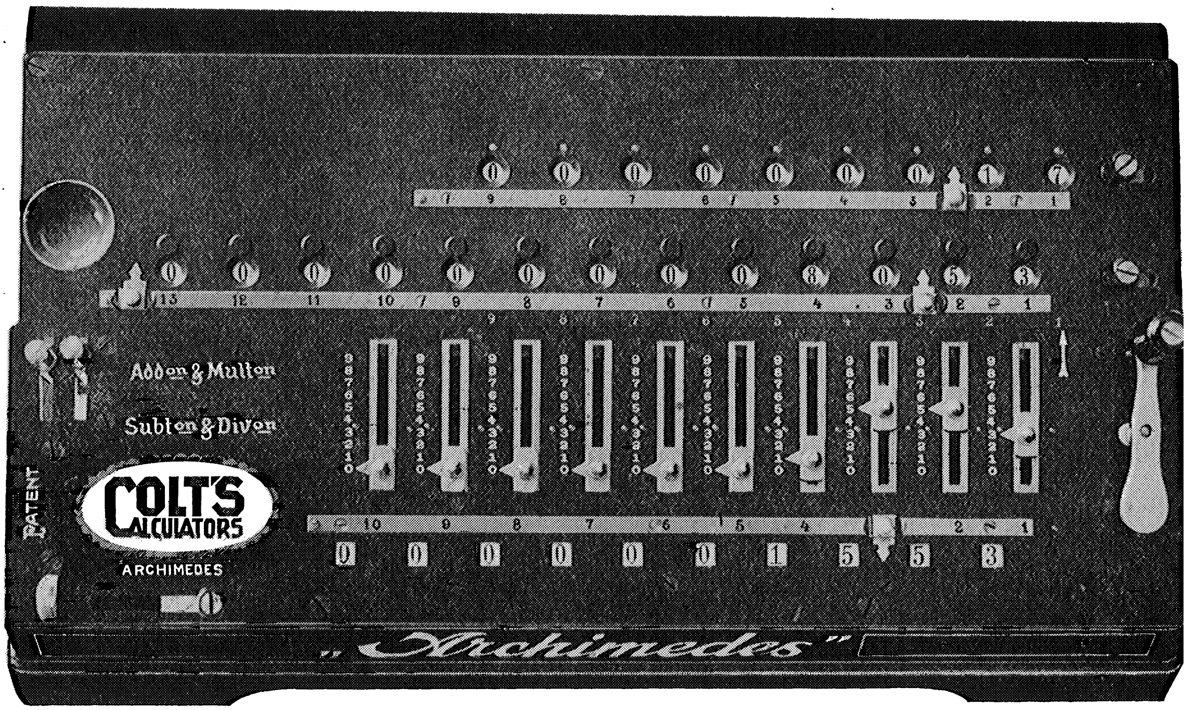


FIG. 1.

and efficiency. The new Glashütter calculating machine "Archimedes" weighs only 7 kg., and works extremely smoothly and silently.

In the accompanying diagram (fig. 2) the essential parts of the setting and the counting mechanism of the "Archimedes" are shown. First of all, in the right-hand bottom corner is the stepped reckoner, invented originally by Leibnitz. It is a cylinder, on the outer surface of which nine teeth of increasing length are so arranged that they occupy about one-fourth of the circumference. For each place in the setting mechanism a similar cylinder (1) is provided and set on a square axle. All the axles are driven from the shaft (3) by a crank-handle, by means of pairs of bevel wheels (2). Corresponding to the turning of the crank in a positive direction, the stepped cylinders turn so that the tooth corresponding to the digit *one* is the last to come into gear. Above these cylinders, and close to the covering plate, there is a square axle, on which is a sliding pinion (4) with ten teeth, which engages with the teeth in the cylinder. Each pinion is gripped by a fork-shaped continuation of the sliding indicator on the setting plate above, and moves simultaneously with it. It is thus obvious that the pinion, from the position it has received through the setting of the index, is rotated, when the cylinder is caused to revolve, by as many teeth as the cylinder bears in the plane corresponding to the digit set. The same amount of rotation is also received by the square axle which carries the pinion, and with it the pair of bevel wheels (7), which slide likewise on this axle. By means of this sliding it is now possible to transfer the rotary motion of the square axle in either the one or the other direction to the vertical axle (8), which bears at its upper end the figure disc. In the position represented in the diagram the figure disc will turn in a positive direction, *i.e.* the digits will appear in an ascending series at an indicator hole situated above it. If, however, the bevel wheels slide so that the other one engages the vertical shaft, the numbers will appear in a descending series. In each case, in the transition from 9 to 0 or from 0 to 9, the axle (8) will make a complete revolution, and the finger attached to it (9)

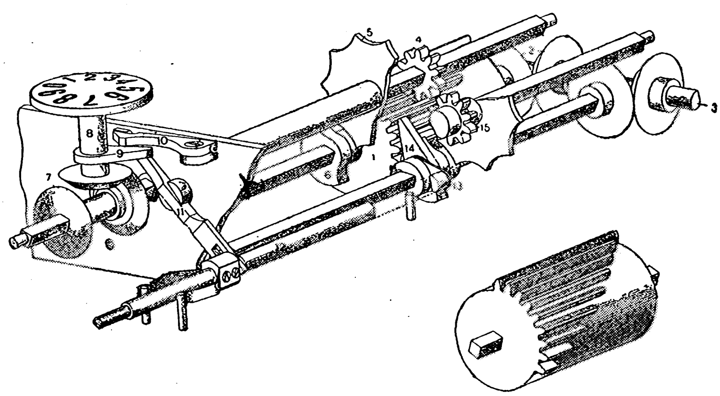


FIG. 2.

will press the nose-shaped end of the lever (10) backwards. The lever (10) operates in turn on one end of the lever (11), which is pivoted in the middle, the lower end of which is fork-shaped and fits with this fork into a notch in the sliding rod (12). The latter is kept in whichever position it may take up by springs for the purpose, and has at the rear end a fork which adjusts, according to the movement of the rod (12), the single tooth (14). This slides on the square axle of the stepped cylinder in the adjacent place. In the normal position, that is, so long as there is no contact between (9) and (10), the plane in which the single (14) tooth turns is behind the plane of the pinion which is fixed on the " setting " axle of the place immediately above, so that when it turns no engagement with this wheel results. But if the rod (12) is pushed forward, the tooth (14) will in turning engage with the teeth of (15), and thus turn the " setting " axle of the place immediately above one-tenth further round, which results in the raising or lowering of the following place by a unit, as the case may be.

Besides these parts, which are absolutely necessary for the counting and carrying, there must also be provided other contrivances to destroy the momentum of the rotating parts when the handle is turned quickly. This safeguard is carefully executed in the "Archimedes." There are also safeguards which prevent a displacement of the reversing lever, when the crank is not at rest.

The axles (8), which carry the figure discs, are not situated together with the other parts immediately in the body of the machine, but under a hinged plate or carriage (fig. 3), which may be lifted up and which may be slid along its axis. By sliding the plate from place to place in the row, the axles of the

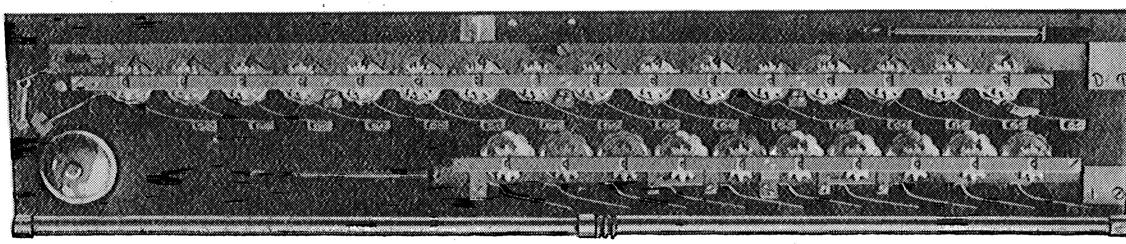


FIG. 3.

setting mechanism may be brought into gear with all the figure discs of the counting mechanism.

In the above-mentioned hinged and sliding plate there is also, in models B and C of the "Archimedes," above the row of indicator holes of the product-register, a second row of holes to register the number of turns, called also the quotient-register. On account of difficulties of construction, this mechanism has in almost all Thomas machines no carrying arrangement. But in the "Archimedes" this difficulty has been solved. The advantage of the solution is extremely important, especially in contracted methods of calculation.

(2) **Colt's Calculator.** Abridged from the German of PAUL VAN GÜLPEN

The Teetzmann calculating machine "Colt's Calculator" is a new type of the old Odhner calculating machine. The characteristic features of all

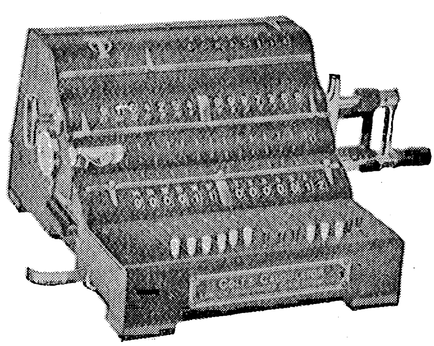


FIG. 4.

machines built on the Odhner system are toothed wheels with a variable number of teeth, in contrast to the Thomas system, which employs stepped cylinders or reckoners. The disadvantage resulting from this arrangement of the Thomas machine, namely, that the individual digits of large numbers are, as a result of the size of the cylinders, separated from one another, and therefore difficult to read, was successfully avoided by the thin, close-set parallel discs of the Odhner system. The teeth of these discs gear with narrow toothed wheels which carry figures on their rims, so that the numbers, standing close together as if printed, are shown clearly to the eye of the operator.

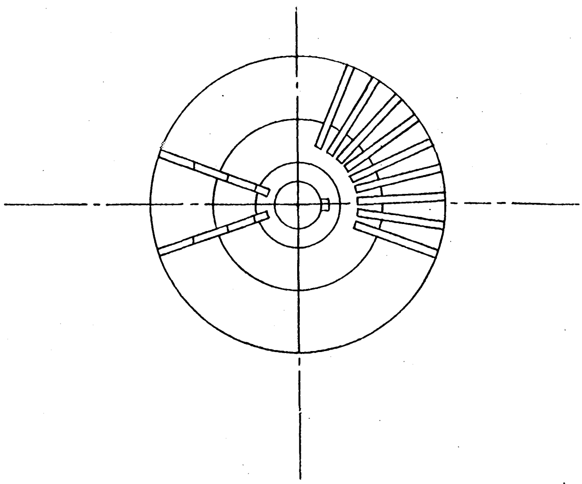


FIG. 5.—Metal Disc.

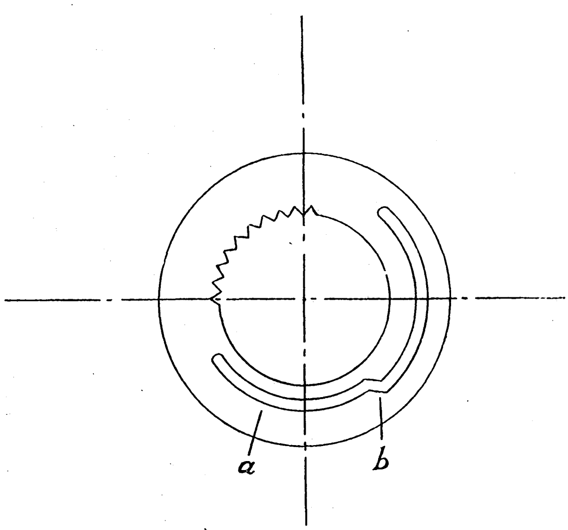


FIG. 6.—Covering Disc.

The Odhner toothed wheel consists of two parts, a metal disc with slots and a thin covering disc with a raised centre, attached so as to turn on the other (figs. 5 and 6).

In the slots of the metal disc lie steel " fingers " with a projecting catch—the movable teeth of the toothed disc.

The catches of these fingers project into the slot (*a*) in the covering disc, and follow the slot when the disc is turned. In so doing the catch follows the crossing (*b*), and so has its distance from the centre increased or decreased. As a result of this the top part of the " finger " projects from the rim of the disc as a tooth, or conversely is withdrawn. It is obvious that by a corre-

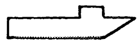


FIG. 7.—Finger.

sponding turning of the covering disc the number of teeth on the disc may be altered from 0 to 9.

A further advantage of the Odhner arrangement was, that positive operations could be carried out by turning the handle to the right and negative ones by turning it to the left, an arrangement which seems natural, while in the Thomas system the moving of a separate lever from addition to subtraction and *vice versa* has to be carried out every time.

These advantages of the Odhner system caused many manufacturers, after the expiry of the patent, to develop the system further, and there are various machines of this type on the market.

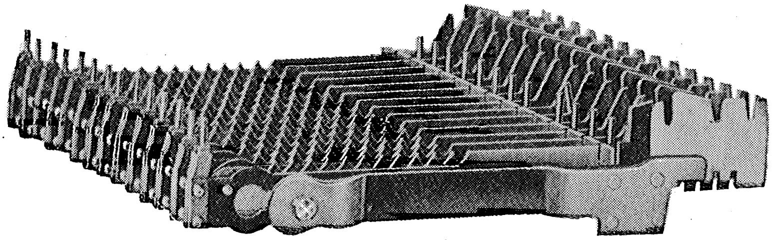


FIG. 8.—The Setting Mechanism.

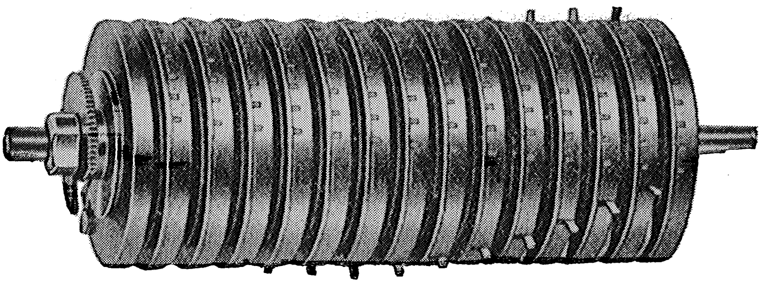


FIG. 9.—Counting Mechanism.

In all of them, however, there persists this defect, that in order to set the number of teeth on the toothed disc, the covering disc must be turned directly. In doing so the hand setting the figures must be continually raised, as a result of which the arm tires, and the number set, which must be glanced over rapidly to test the accuracy of the setting, is frequently covered.

The Teetzmann calculating machine " Colt's Calculator " makes use of a sliding bar to set the teeth, the contrivance which had worked so well in the Thomas mechanism. Hence resulted a material advantage in the manufacture of the machine, its division into the three following groups, independent of one another :—

The setting mechanism (fig. 8).

The counting mechanism (fig. 9).

The sliding carriage (fig. 10).

The setting mechanism consists of fourteen long sliding bars, which are pivoted on an axis situated in the front part of the machine. If these bars are set in position, the slots in the spade-shaped end engage with corresponding small catches in the covering discs. By pulling the bar backwards and forwards the covering discs are turned, and in this way the desired number of teeth is caused to project, corresponding to the amount of the forward push. A special toothed gearing on the sliding bar engages simultaneously with gear wheels which are fitted with digits, thus registering the number of teeth set on the disc, and likewise the number set in the calculating mechanism.

The calculating mechanism is thus coupled with the setting mechanism during the operation of setting. In order to count, the former mechanism must of course be set free again. This putting out of gear of the setting

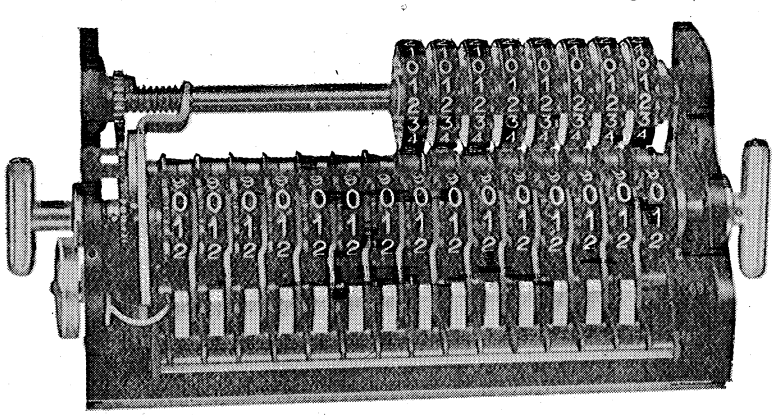


FIG. 10.—Sliding Carriage.

mechanism is accomplished automatically in the pulling forward of the driving handle. The counting itself is carried out by causing the toothed discs to revolve. In each complete revolution of these discs the projecting teeth engage with the wheels of the sliding carriage, situated opposite, and fitted with digits on their rims, and turn these wheels as many steps further on as there are movable teeth projecting. The number which appears finally indicates the result.

So far the problem of mechanical calculation appears extremely simple, nor do any difficulties appear so long as the result remains under 10; these difficulties first make their appearance in the carrying.

Supposing that the *figure* disc on the extreme right of the sliding carriage stands with the 6 in front, and that the corresponding *toothed* disc has four teeth projecting, then a revolution of the *toothed* disc in a positive direction would move the *figure* disc four figures further on, and accordingly after the 9 the figure 0 would appear. In order to obtain the correct result 10, the next figure wheel on the left must also be influenced, *i.e.* be moved on one step. This purpose is served by the carrying arrangements, on the faultless operation of which the accurate working of the machine depends.

While in all other machines of the Odhner type the most important of these contrivances, the so-called carrying lever, is in the form of a hammer, in the case of the Teetzmann calculating machine it takes the shape of a bar sliding horizontally on two rollers. In the figure of the sliding carriage this bar can be seen clearly beneath the figure discs. As soon as the figure wheel is so moved that the 9 changes to 0, or *vice versa*, this carrying bar is pushed forward by a bent lever. The wedge-shaped point of the carrying bar presses in this position a movable pin or " finger " (the carrying pin) into the plane of the teeth of the next toothed disc, and thus causes the next figure wheel to be turned a step forward or backwards.

With the introduction of this sliding bar Teetzmann & Co. appear to have solved successfully the most difficult problem of the calculating machines of the Odhner type.

The method of setting the figure wheels at zero, which operation is necessary before beginning each new calculation, has been altered little in principle from that invented originally by Odhner. It consists in arranging the shafts so as to be movable with respect to the figure wheels, of which they form the axles. If the shaft is slid sideways a little and at the same time turned through 360°, by turning a key, small pins on the shaft catch on corresponding pins on the wheel and carry round the figure wheel, until the 0 appears again in front. In this " clearing " operation the releasing of the brake-springs, situated beside the toothed gearing of the figure wheel for the purpose of preventing " skipping " while counting, causes a clicking noise. Also, these springs oppose a certain resistance to the turning of this shaft. In " Colt's Calculator " all the brake-springs are raised at the beginning of the clearing operation, so that the clearing proceeds quietly and smoothly.

A description of the construction of the inner parts of the machine has now been given. Viewed from the exterior, what strikes one is the absence of the long dust-collecting slot in the upper part of the cover, which could be dispensed with on the introduction of the setting lever, and also the clear, close-set number-register. The figure wheels, which in other machines frequently consist of rubber with sunk digits filled up with composition, are formed of a metallic alloy, in which the digits stand out in bold relief from a black-enamelled background. As the whole number-register, set almost perpendicularly to the line of sight, is contained within a rectangle of 13 by 17 cm., all three rows can easily be taken in at one glance.

The back of the machine consists of transparent " cellon," a non-inflammable substitute for the highly inflammable celluloid, a change which has been made in the interest of smokers. Thus it is always possible to have a view of the interior of the machine, without first having to unscrew the cover.

The machine is constructed with great care, and the parts are interchangeable. It is dispatched in a dust-proof case, in which it is hung by strong springs to prevent damage by shock.

The manipulation of calculating machines is so widely known that an explanation would be superfluous. The longest multiplications and divisions may be effected in the shortest time almost without possibility of error. The brain is rested instead of being fatigued by the calculation, and the operator has the comforting assurance that no errors have escaped him.

Apart from the four simple rules of arithmetic for which calculation with the machine means simply increase of speed, calculations are made possible by the machine which on paper must be broken up into distinct computations.

(3) **The Brical Adding Machines.** The British Calculators, Ltd.

The Brical machine is a little instrument designed for adding £ *s. d.*, weights and measures, or decimal coinage. The simplest form of the machine consists

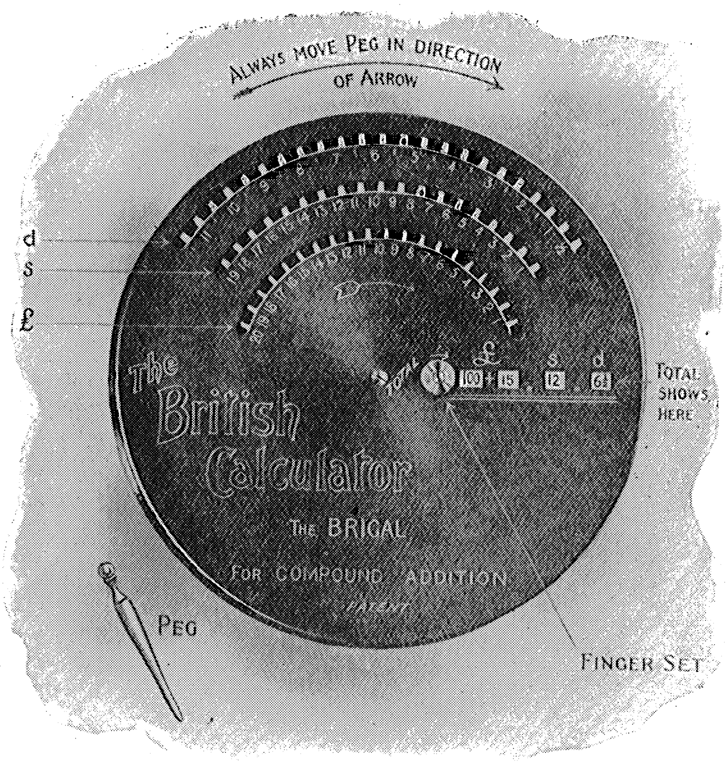


FIG. 11.

of three concentric rings, the outer circumference of each ring having a series of notches or teeth. The largest ring represents pence and halfpence, the same being printed from ½d. to 11½d. twice round the wheel, which has forty-eight teeth, each tooth representing ½d. The next sized wheel or ring is for shillings, each tooth representing a shilling, and the third wheel is for pounds, each tooth representing a pound. The wheels have no common axis, but are mounted on small bearing studs, and a slotted lid covers the whole. The slots in the lid are so arranged that the outer wheel shows up to 11½d., the shillings wheel up to 19s., and the pounds wheel up to £25. There are three squares just large enough to show one figure on each wheel, and the total added is read from these slots. The lid is engraved under each slot for £ *s. d.*, the figures coinciding with the spaces on the wheels. Presuming the outer wheel is moved by a peg for a space of four teeth, this would show 2d. in the before-mentioned square: the shillings and the pounds wheels are operated in the same manner. When 11½d. is recorded on the pence wheel, and another ½d. added, the total shows 1s., as there is a small pin on the wheel which comes into contact with a lever having a pawl fixed to it, which engages with the teeth on the shillings wheel. The pin on the outer wheel moves the lever the space of one tooth, so that 1s. is recorded on the total. The transfer from shillings to pounds is obtained by a similar lever and pin on the shillings wheel. The wheels are independent of each other, so that pounds, shillings, and pence can be added in any order. In order to record a large amount, several wheels can be used for the pounds, one representing units, the next tens, and so on, the transfer being obtained in each case by means of a pin and lever as before mentioned.

(4) **Brunsviga Calculating Machine.** Grimme, Natalis & Co., Ltd.

On the 21st March 1912 the *Brunsviga Calculator* celebrated its twentieth year of existence, and at the same time also celebrated the completion of the 20,000th machine in the factory.

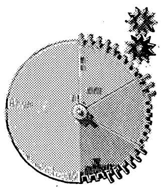


FIG. 12.—Pin Wheel of Polenus.

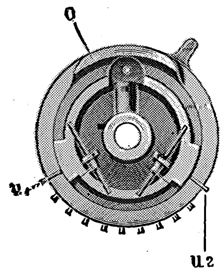


FIG. 13.—Pin Wheel of W. T. Odhner.

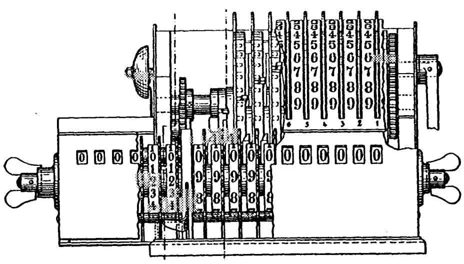


FIG. 14.—Patent Odhner of 1891.

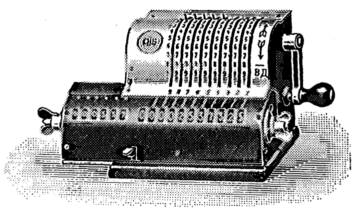


FIG. 15.—Odhner Machine.

In the second half of the last century the Russian engineer, W. T. Odhner, invented and constructed the first model of the calculating machine of the "pin wheel and cam disc" type, now universally known as the "Brunsviga." Odhner's idea, viz. the use of pin wheels, had been described already by Polenus in his *Miscellaneis*, in 1709, and also by Leibnitz in one of his Latin treatises.

The firm of Grimme, Natalis & Co., Braunschweig, Germany, in the person of their Technical and Managing Director, Mr F. Trinks, recognised the importance of Odhner's invention and acquired it on the 21st March 1892.

Odhner constructed his machine according to his German patent of 1891.

As is usual with such early constructions, the original model still showed many deficiencies, but Mr Trinks succeeded, by numerous inventions and improvements, in raising the Brunsviga to its present level of technical perfection.

The development of the Brunsviga Calculator is best illustrated by the fact that since 1892, when first its manufacture was taken up, the firm of Grimme, Natalis & Co. have registered :

130 German patents.
300 patents in other countries.
220 German registered designs.

Most of these are Mr Trinks' own inventions, and for this reason the machine is to-day named " Trinks-Brunsviga Calculator."

The principle on which all Brunsviga machines are constructed is as follows :—

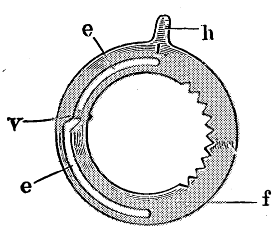


FIG. 16.

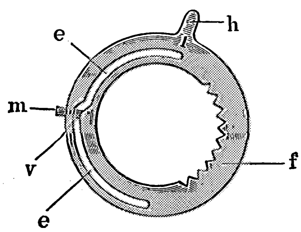


FIG. 17.

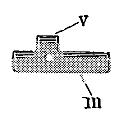


FIG. 18.

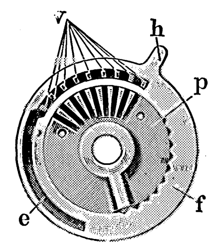


FIG. 19.

The pin wheels shown in fig. 13, whose adjustable pins *m* (figs. 17 and 18) are set by the lever *h*, are mounted on a common shaft worked by a crank. There are nine pins which can be made to project from the pin wheel as required, and when the crank is turned to rotate the shaft, these pins gear with small toothed wheels i^1, i^2 (figs. 20 and 21), which in turn gear with the number wheels E.

These number wheels E (figs. 20 and 21) carry the figures 0–9 on their periphery, and are placed on a common spindle parallel to the pin-wheel shaft.

The setting of the pins *m* (figs. 17 and 18) is produced by actuating the handle *h* of the revolving disc *f* (fig. 19), which causes the shoulders *v* (figs. 16, 18, and 19) of the pins *m* (figs. 17 and 18) to be moved into the curved groove *e* (fig. 19).

For instance, to set three pins by means of the lever *h*, pull the lever *h* until three pins project from the pin wheel, and by revolving the crank once the number wheel E of the product register is moved three places, thus the product register which previously showed an 0 now shows a 3. By turning the crank three times the sum $3+3+3$ or 3×3 is carried out and the numbering wheel registers the product 9.

In case the product consists of several digits, as in 3×4, the tens carrying device comes into operation.

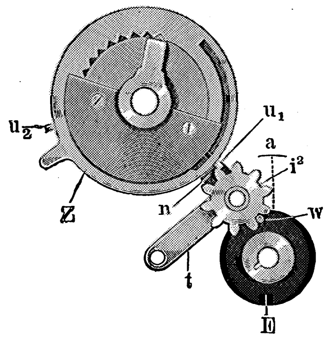


FIG. 20.

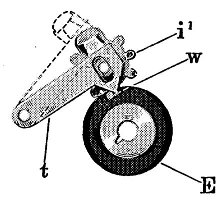


FIG. 21.

The pin *w* of the number wheel E displaces the hammer-shaped lever *t* (fig. 21) in such a way that the laterally movable pin u_1 (fig. 20) on the pin wheel Z engages with the next toothed wheel i^2 and moves this one tooth forward.

The product register is mounted on a longitudinally movable slide or carriage, arranged in front of the machine, which permits the carrying out of sums of multiplication and division in a manner corresponding to calculating with the pen on paper.

The revolutions of the crank are registered by another set of number wheels, which can also be fitted with the tens carrying device. The second counter registers in case of multiplications the multiplier, and in divisions the quotient.

Another important mechanical part is the zeroising of the registers, or, in other words, the device which brings the number wheels E back to zero. Having carried out a calculation, it is necessary, before starting a new calculation, to set the registers to "o," viz. the number wheels in the product register and in the multiplier or quotient register must be zeroised. This zeroising mechanism is illustrated in fig. 22.

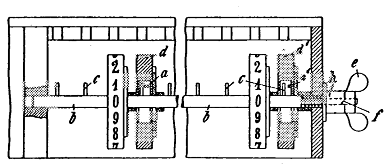


FIG. 22.

The shaft *b* of the counting register carries small pins *c* which rotate with this shaft. The butterfly nut *e* which is fixed to the shaft *b* is provided with a slant *f*; this slant *f* corresponds with a similar slant on the shoulder *h*. When turning the butterfly nut *e* its slanting side *f* glides on the corresponding slant of the shoulder *h* up to the flat top of the shoulder, which causes the shaft to be moved laterally to the right side.

The pins *c* moving with the shaft come into gear with the number-wheels *d*, d^1, which are loosely arranged on the shaft and engage pins *a*, a^1 carried by these number wheels. As soon as the pins *c* of the shaft engage the pins *a*, a^1 of the number wheels, the latter rotate on the shaft until the butterfly nut *e* (having completed one full revolution) drops back into its original position.

By this movement of the butterfly nut *e* the shaft also slides laterally back to its normal position, and at the same time the number wheels register "0." The number wheels, which are arranged loosely on their shaft, are kept in their respective positions by means of anchor-shaped pawls and springs.

In order to remove the friction of the pawls on the number wheels and to eliminate the noise caused by zeroising, Mr Trinks has invented a device

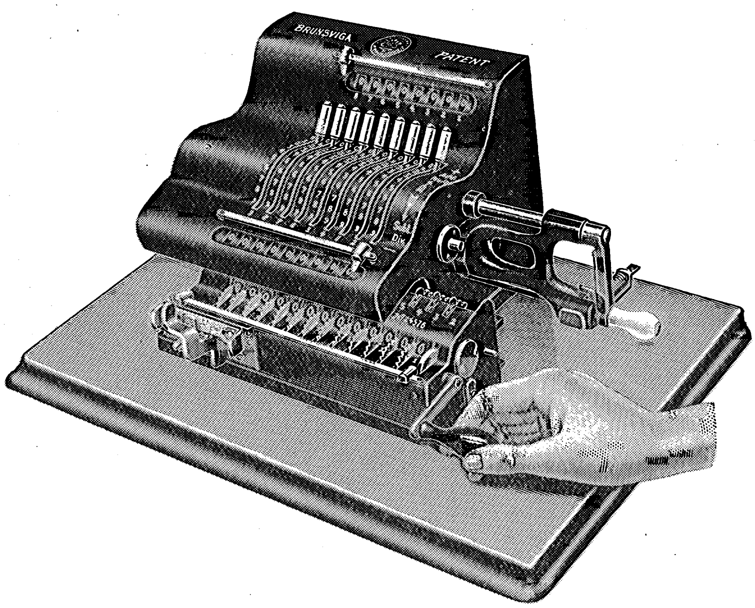


FIG. 23.—Improved Noiseless Zeroiser.

which disengages the pawls from the number wheels when the latter are being zeroised. The pawls are thrown out of gear by this device and the number wheels are brought to zero by means of toothed segments (fig. 23).

The zeroising crank is fixed on the right-hand side of the carriage, and the zeroising is effected by a half revolution of this crank. The machine is further perfected by ingenious locking devices which exclude incorrect results caused by faulty handling. The crank cannot be turned unless the carriage is in its correct position, and the carriage cannot be moved laterally when the crank is out of its normal position. Further, a reversing lock prevents the reversing of the crank (once a revolution has been commenced) until a complete revolution has been performed.

The machines with the long setting levers (fig. 24) are fitted with a similar locking device which locks the setting levers whilst the handle is being revolved.

The year 1907 brought a notable improvement of the machine with the invention of the above-mentioned long setting levers, a patent of Mr Trinks (fig. 24). This arrangement not only facilitates the handling of the Brunsviga, but also enables the operator to have the calculation always in view for control.

Fig. 25 gives an illustration of the whole of the mechanism of the Brunsviga model J with the cover plates removed. The value set by means of the setting mechanism is made visible in a special register or indicator D. This is shown in a straight line of figures and serves as a perfect control to the operator.

The setting levers can be put back to zero singly or simultaneously by means of the crank E on the left side of the machine.

The multiplier register C is zeroised by the butterfly nut F, and the product register B in the carriage is zeroised by the butterfly nut G.

A new type, the miniature machine, Brunsvigula, was created in 1909, which does away with the noise associated with the working of the old patterns,

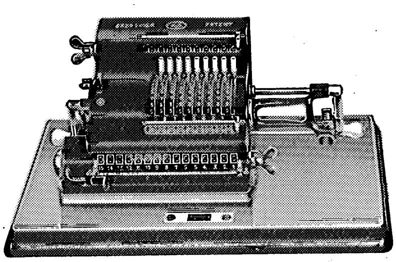


FIG. 24.

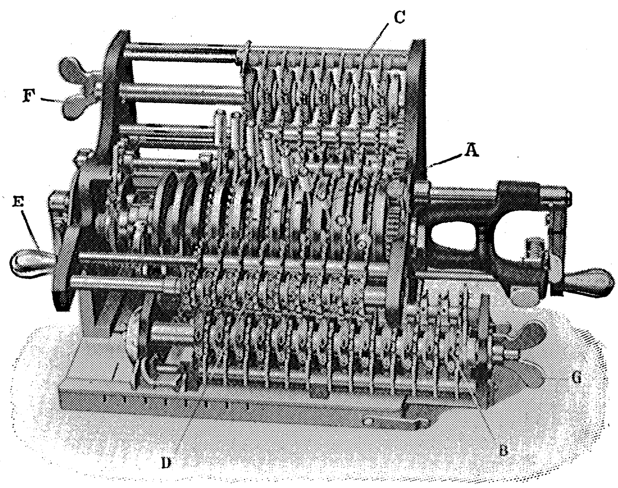


FIG. 25.

and thus renders the machine more handy to the operator. The machine is about one-half the size of the former type of the same capacity, and its construction necessitates the employment of highly trained mechanics, as the working parts are very small and must be manufactured with extreme accuracy.

The Trinks-Arithmotype was invented in 1908, as the first printing calculator for the four rules of arithmetic. This machine prints the factors as well as the product (fig. 26).

The principle of the printing mechanism in the Arithmotype is illustrated in fig. 27. The long setting lever h is connected with the segment z_1, which gears by means of a small pinion with the disc T, and which, therefore, moves the disc T by as many units as the setting lever is being moved.

The disc T on the shaft A carries on its left periphery types T^1 with the figures 0 to 9. The actuating of the setting lever sets these types to the respective figure which appears in front of the ribbon, and types the sum on the paper roll W when this is being moved in the direction of the arrow.

The contact of the paper roll with the types is effected automatically by each revolution of the crank of the machine, which at the same time advances the paper roll from line to line.

A patented device is utilised to transfer the product from the product register to the setting levers, which makes it possible to print the product in addition to its factors.

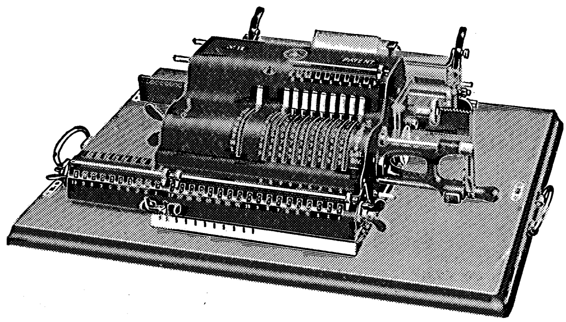


FIG. 26.

A special lever is fitted on the side of the setting levers which prints with each single factor the signs +, −, ×, ÷, £, lbs., etc., as the case may be.

A further new type of the Brunsviga is the Trinks-Triplex (fig. 28), which, as is implied by its name, is really three machines in one. It may be used either as one machine with twenty-digits capacity in the product, or the product register may be split and the machine used as two registers that are

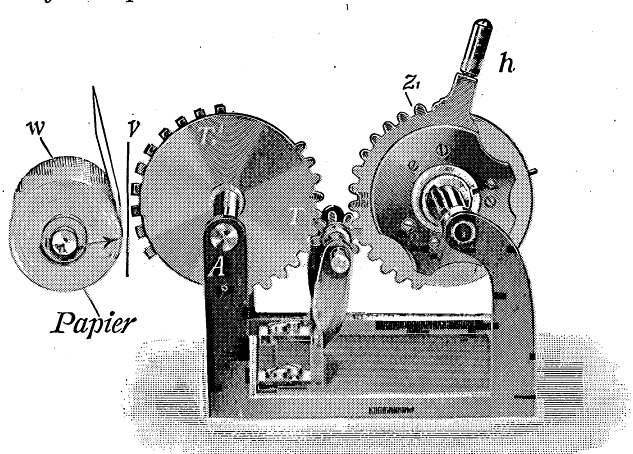


FIG. 27.

actuated by one handle. For instance, two separate multiplications can be carried out at the same time by turning the handle, and by a special device the product register can be zeroised as a whole or in separate parts.

The latest product of the factory is the machine as illustrated in fig. 29.

This is a Brunsviga miniature type with long setting levers, with the product register arranged above the setting levers and with the product counter fitted with a tens carrying mechanism.

This model claims to be the most perfect machine of the Odhner system hitherto constructed.

The multiplier register carries both white and red figures on the number wheels; white figures are registered when the machine is adding or multiplying, and red figures are registered when the machine is subtracting or dividing.

A slide provided with show-holes is operated automatically by the crank in order to display either the white or red figures of the register. This is performed without any special gearing by the hand of the operator. This automatic device affords a perfect check to the operator.

The tens carrying mechanism of the Brunsviga, also of the Brunsvigula, extends now up to twenty digits, whereas the Odhner machines only carried to ten figures.

Another interesting invention is the Automatic Carriage, which performs the shifting of the slide or carriage from one digit to another in either direction

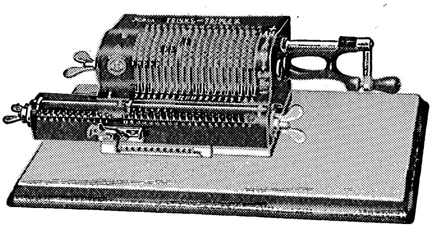


FIG. 28.

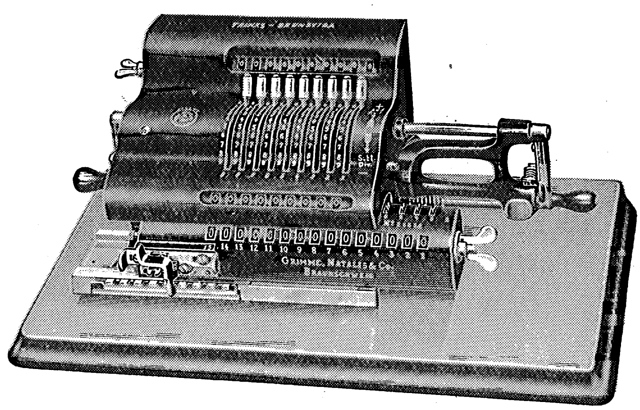


FIG. 29.

by means of a single pressure of the finger. This Automatic Carriage improvement is of great advantage, since it ensures the carriage being moved into the position desired, without necessitating the movement being watched by the operator.

The calculating principle of the Brunsviga differs from that of most other machines in so far that it follows in a natural manner the ordinary course of calculating by effecting plus and minus calculations without any change of gear.

The increasing values, viz., the results of addition and multiplication, are produced by revolving the handle in the forward (plus) direction, and the diminishing results, or the products of subtraction and division, are produced by revolving the handle in the reversed (minus) direction.

The Brunsviga Calculating Machine was first introduced into Great Britain twenty years ago at the Oxford meeting of the British Association, at which the late Marquis of Salisbury presided.

After a most careful inspection of the machine the Marquis expressed himself as being much impressed with the ingenuity of the inventor and the probable great usefulness of the machine.

The machine was one of the earliest manufactured, its number being 123, and by the courtesy of the owner (who has had the machine in daily use ever since), this machine will be exhibited at the Napier Tercentenary Celebration.

(5) The Burroughs Adding and Listing Machine.

Reprinted from *Engineering*, May 3rd, 1907.

On this and the following pages we give illustrations of an extremely efficient adding machine, which is very extensively used in banks and clearing-houses both in this country and abroad. The machine is of American origin, but is manufactured at Nottingham by the Burroughs Adding-

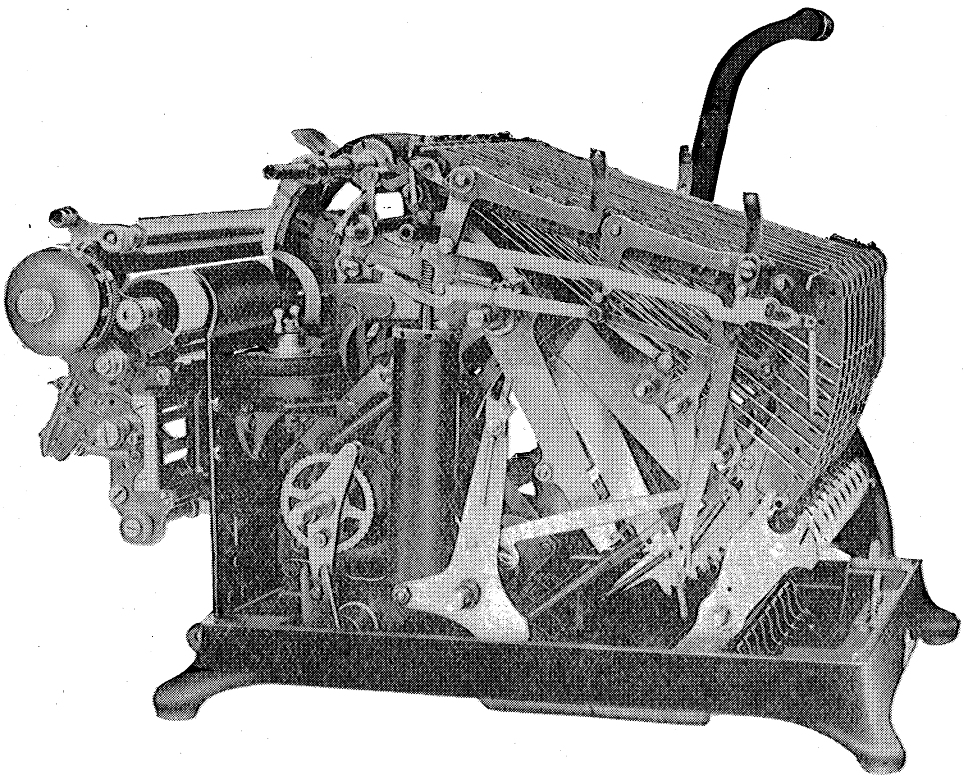


FIG. 30.

Machine, Limited, from whose works the whole of the large Continental demand is met, as well as the needs of the British market. The machine is intended to print down a column of figures, such as £ *s. d.*, and then almost automatically to print at the bottom of this column the sum total, thus relieving the clerk of all the labour of addition. In principle the machine is quite simple, the apparent complication visible in fig. 30 being due, in the first place, to the repetition of similar parts, inseparable from a machine of this kind; and, secondly, to the provision of various details, designed to make impossible the improper working of the machine by a careless or indifferent operator.

Each essential element of the machine consists of lever A (fig. 31), pivoted near the middle, carrying at the one end a set of figures from 0 to 9, held in slides by springs, whilst the other end is attached to a segmental rack B, with which a number-wheel C can be thrown in or out of gear. The upper end of this rack is arranged to move between a couple of guide-plates D. It will be seen that a curved slot is cut in these guide-plates which is concentric with the point of oscillation of the lever A. Into this slot fits a projection from the top of the rack B, and as the other end of this rack is secured to the lever A, any possible motion up and down between its guide-plates is a true circular motion about the pivot of A. A number of slots are, it will be seen, cut in the right-hand edge of the guide-plates D, and in these slots lie the ends of a number of wires, as shown. If a key is de-

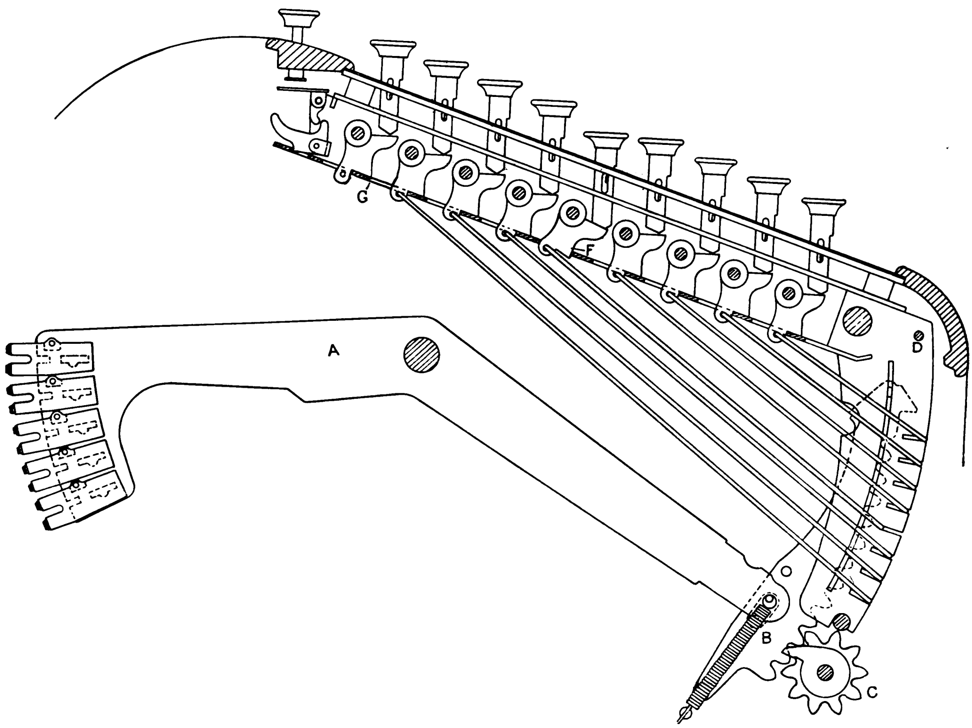


FIG. 31.

pressed, the corresponding wire moves to the left, and its bent-in end is pulled to the bottom of its slot, in which position it catches the projection shown at the top of the sector B, and thus limits its possible downward movement. With the rack thus arrested the other end of the lever A is raised, so that, of the different figures it carries, that corresponding to the key depressed on the keyboard is in position for printing. This printing is effected by the release of a small spring-actuated hammer, which, striking the right-hand end of the type-block, which, as already stated, slides in a slot in A, and is normally held back by a spring, drives it forward against the type-ribbon and paper.

The same effort which produces the downward movement of the rack throws out of gear with it the number-wheel C, which therefore undergoes no rotation during this downward motion. After the operation of printing is effected, however, the rack is raised again to its topmost position ;

but prior to being permitted to take this upward movement, the wheel C is thrown into gear with it, and hence, by the time the rack is restored to its original position, this wheel will have been turned through a number of teeth equal to the number of the key originally depressed. If the series of operations just described is repeated, a second figure will be printed on the paper, and the number-wheel fed forward an additional number of teeth. Hence, if a set of these wheels is arranged in series, with suitable provision for "carrying" from one wheel to the next, as in an ordinary engine-counter, the wheels will show at any time the total of all the figures successively printed on the paper; and by suitable means this total can, moreover, be printed on the paper below the column of separate items.

This latter operation is effected by depressing the totallising key, shown at the far side of the keyboard in fig. 30, which is arranged so that no other key on the board can be depressed at the same time. The effect of the depressing of this key is to prevent the number-wheels C being thrown out of gear before the downward motion of the racks. These wheels are fitted with pawls, which prevent them being rotated backwards beyond the zero position. Thus, if in the totallising movement a wheel indicated 5, the rack in its descent would turn it back through five teeth, and would then be unable to descend further, just as if in the case previously described the wire corresponding to the number 5 key had been moved back in its slot. Hence the type end of the lever A will be in position to print the number 5, which was that on the counter. At the same time it will be seen that this counter-wheel C has been moved back to its zero position, and if moved out of gear before the racks are raised again, will read zero at the completion of the operation. Thus the taking of a total clears the machine, setting all the number-wheels to zero.

Whilst the essential principles of the machine are as just described, many safeguards are necessary to ensure its proper working. The latter involves on the part of the attendant two distinct operations. In the first place, the amount to be recorded is "set" by depressing a key on the keyboard. By pulling back the handle shown to the side of the machine in fig. 30, this sum is then printed on the paper at the back of the machine, and on the return stroke of this handle the number on the keyboard is transferred to the number-wheels, as just explained, and at the same time the keys depressed in setting the keyboard are released and return to their normal positions.

The depression of a key has three distinct results. In the first place, it moves the corresponding stop-wire to the back of its slot, as already explained. Secondly, it locks every other key in the same column; and, thirdly, it withdraws a catch which would otherwise prevent the descent of its corresponding sector B.

The locking of every other key in the same column is effected by the device shown in fig. 31. The tail of each, it will be seen, rests on the horizontal arm of a small bell-crank, the other end of which is connected to the stop-wire. As the key is depressed, the vertical leg of the bell-crank moves to the left, and carries with it a sliding-plate G, through a slot in which the lower arm of the bell-crank passes, as indicated at F (fig. 31). In the position shown, key No. 5 being depressed, the sliding-plate G, moving to the left, has brought solid metal under the noses of each of the other bell-cranks ; so that, as will be seen, it is impossible to depress any other key till the plate has been restored to its original position. This sliding-plate is constantly impelled to the right by a spring, and would fly back when the pressure on the key was removed, were it not locked by a pawl at its left-hand end. After an item has been printed, the final motion of the machine lifts this pawl, letting the plate slide back, in doing which it

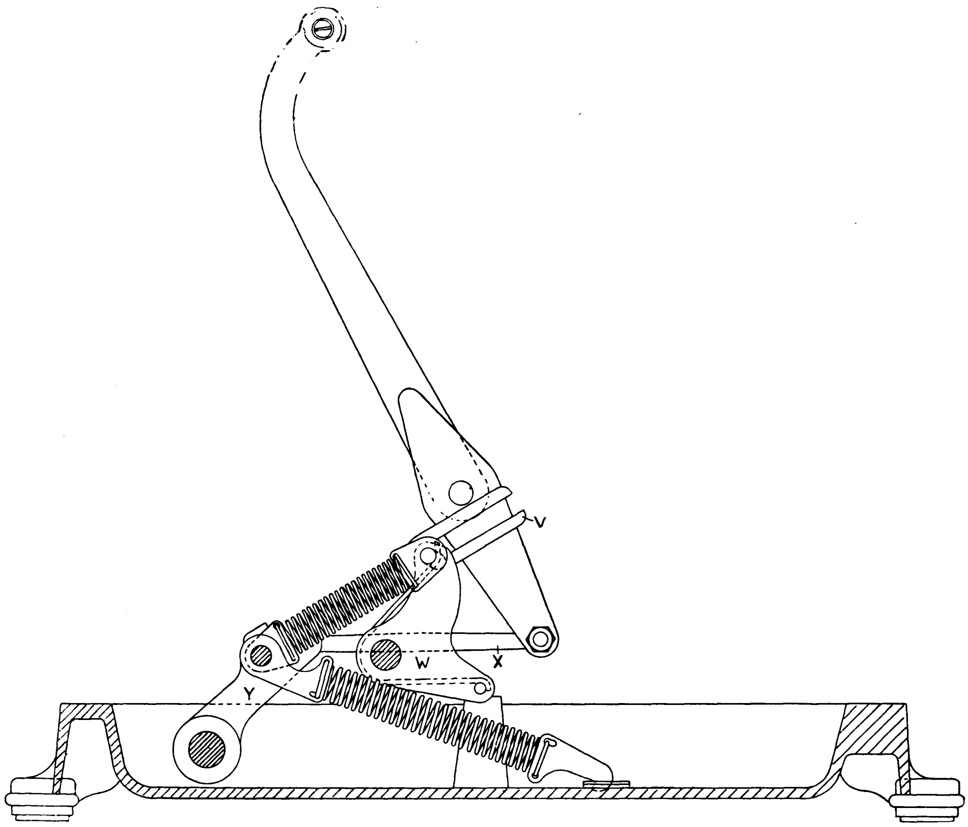


FIG. 32.

carries with it the depressed key, restoring this to its normal position. At its forward end, this plate, in being moved back by the depression of a key, carries with it, by means of a projection, the stop which, as already stated, would otherwise prevent the downward motion of the sector.

This stop, when a figure has been set, is prevented from flying back by a pawl, and this pawl is released, bringing the stop into its normal position simultaneously with the release of the sliding-plate at the end of an operation of the machine. In certain cases it is convenient to be able to repeat a number several times in succession, without resetting it. This is effected by depressing the special key, shown to the right of the keyboard in fig. 30. The depression of this key prevents the pawls which hold the sliding-plate G, on the depression of a key, from being raised at the end of an operation of the machine, and consequently any depressed keys remain down. Provision of this nature is possible, since but very few of the various motions of the machine are positive in character, but are effected through the medium of springs. Summing up, it will be seen that the depression of a key has but three simple results. All further operations are effected by pulling back to the limit of its travel the side handle shown in fig. 30, and letting it return of its own accord. The effect of pulling over this handle is to throw into tension a series of powerful springs in the base of the instruments; these springs acting then as driving power to the main shaft of the machine. The rate at which they succeed in effecting the different operations is governed by an oil dashpot, and hence sufficient time is ensured for all the successive operations of printing and totallising to be effected in due order. It is therefore impossible for a careless operator to damage the machine by seeing how fast he can "buzz it round." The force operating the machine is quite independent of that which he exerts on the handle, and cannot exceed the tension of the springs. A notched plate is, however, attached to the handle-spindle, and, moving with it, ensures by engagement with pawls that the handle shall be pulled over to the limit of its travel every time, before being allowed to return. The handle, though it does no direct driving of the mechanism, does govern some of the movements made, since the possible motion of the spring-actuated driving-shaft cannot exceed that allowed by the motion of the handle, and the latter must therefore be carried to the end of its travel before the spring-driven shaft can effect its full travel. Moreover, if this handle is out of its normal position, it throws up a bar extending right across the machine, which locks all the keys, and prevents any being depressed until the handle is restored to its position of rest.

Referring to fig. 32, it will be seen that the handle, by means of the link X, pushes over the lever Y. This lever is pulled towards the front of the machine by four strong springs hooked into the bottom plate, as indicated, and, by a set of springs, such as Z, pulls over, in its turn, the bell-crank W. It is this crank which really actuates almost the whole of the mechanism of the machine. It is coupled to Y by springs, as already stated, and moves to the left under the influence of these only. Its return stroke to the right is, however, made under the thrust of the fork V, which is pivoted to Y. Hence the driving power of the machine on its return stroke is provided by the springs connecting the lever Y with the base of the machine, and in the forward stroke by the springs between Y and W. On both strokes, therefore, the machine is spring-driven. A dashpot, not shown in this figure, but clearly visible in fig. 30, which represents the machine partially dismantled, controls the speed of the machine on both strokes.

We have already explained that in the operation of listing a series of items which are ultimately to be added up, the first action of the machine is, through suitable linkwork, to shift all the number-wheels clear of the descending racks. To this end the whole set are mounted on a frame extending right across the machine. This frame is itself mounted on pivots, so that it can be swung in or out from the racks. As soon as the handle has been moved over to the full extent of its travel it is automatically locked here, and prevented from returning until the operation of printing has been effected. On the return stroke of the machine the wheels are swung into gear with the racks, which, in ascending, turn these wheels round through a number of teeth equal to the number of notches, past which the rack has been allowed to fall till brought up by the stop-wire. In order that these wheels shall always show the total sum registered by the machine, a " carrying device " is necessary from the wheel corresponding to the units place, to the tens place, and so on. This carrying device consists, in the first place, of a cam or long tooth—keyed to the number-wheel C, fig. 31. This cam does not, as in an engine-counter, rotate directly the wheel next above it,

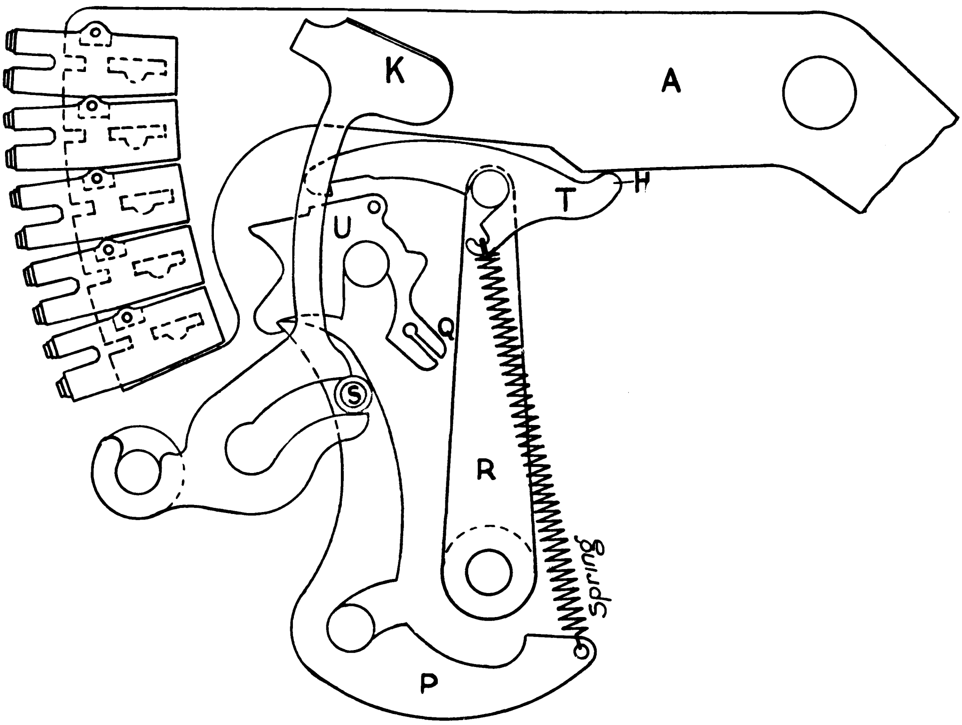


FIG. 33.

but merely releases a stop, which, when no total is being carried, limits the rise of the succeeding rack. Hence, if a " carrying " operation is to be made from the units to the tens wheel, the cam on the former displaces a stop in the path of the tens rack, and, as a consequence, on the return stroke of the machine, the tens rack rises beyond its normal position to a height equivalent to the pitch of its teeth. While the racks are rising (during the operation of listing) the number-wheels, as already stated, are in gear with the racks ; hence, in the above case, the tens wheel rotates one tooth more than it otherwise would have done.

In the operation of totalling, it will be remembered that the relation of the number-wheels to the racks is reversed ; that is to say, they remain in gear during the down stroke of the racks, and are thrown out of gear on the return. As the racks in totalling fall to a distance limited by the wheels rotating backwards to the zero position, it is essential that these racks shall be in normal position before a total is effected, and hence provision is made by which, if any rack is in the high position due to its having "carried over" from one wheel to the next, a stop is thrown into action which makes it impossible to depress the totalising key at the left hand of the machine. By making an idle stroke of the machine the racks are restored to the normal position, and a total can be taken. This idle stroke of the machine, moreover, feeds forward the paper on which the items are listed, so that a space intervenes between the list of items and the total printed by the next movement of the handle. This space serves the useful purpose of distinguishing a total from one of the individual items, the column of items being always separated from the total by this space.

We have said that in "carrying over," the rack which effects the operation rises one tooth beyond its normal position. This is possible, because, as will be seen from fig. 31, the rack is connected to the swinging beam A by a pin working in a slot. A spring tends to throw the rack up and bring the pin to the bottom of the slot. When no "carrying over" is to be effected, the beam A, in moving back to its normal position, carries with it the rack B, but the latter is stopped in its upward movement by a catch before the beam A has completed its stroke. This the latter does in stretching the spring connecting it with B, and comes to rest finally with the pin at the top of the slot. If, on the other hand, the long tooth on the preceding wheel has removed the stop in the path of B, the latter moves with A till the latter has completed its stroke and comes to rest with the pin at the bottom of the slot, and, therefore, one pitch above its normal position. Each of the swinging beams A is connected on its right-hand side with a spring, pulling it downwards. A bar extending right across the machine prevents any one of the beams descending, until it has been swung out of the way by pulling the operating handle. When this bar has been swung clear, any one of the beams which may have been released by the depression of a key is pulled down by its spring till brought to rest by the stop-wire connected to the depressed key. On the return stroke of the machine, the bar, already mentioned, is swung up to its original position, carrying with it all the beams which have been displaced; and when these are home, they are locked there by a set of pawls, each of which is released only by depressing one of the corresponding keys.

The swinging beams A are bent in the horizontal plane, so that whilst their type ends are set at $\frac{1}{8}$-in. centres, their other ends are $\frac{3}{4}$ in. apart. At its type end each beam has mounted on one side of it a set of five little blocks, which move in slots, and are held back towards the pivot of the beam by springs. Each block carries two types, the five giving all digits from 0 to 9, whilst a set of little hammers, spring-actuated, lie between each set of beams, and, if released, will drive forward the block in front and print the corresponding character on the paper. The release gear for these hammers is shown diagrammatically in fig. 33. There are a series of pawls T mounted side by side on a pin, which is carried by two links swinging about a centre R. If this link is swung forward, it can, it will be seen, catch a second pawl U, provided always that the forward end of T is allowed to fall behind the catch. If the main swinging lever A, fig. 31, corresponding to T, is in its normal position—that is to say, if no one of its corresponding keys has been depressed—the tail H of the pawl T is prevented from rising by the underside of this lever, and as a consequence its forward end cannot catch hold of U. Hence, on the return stroke of the frame on which T is mounted, U remains unaffected, and the striker P, which drives the type-hammer by the roller S, remains in place, and consequently no printing is accomplished as far as that particular element of the machine is concerned.

If, on the other hand, a key has been depressed on the board in the row corresponding to the pawl T, the sector end of the corresponding lever falls, and its type-carrying end rises, so that the tail H of the pawl T is no longer kept from rising. The main lever having been brought into position by the fall of the sector against its stop-wire, as already explained, the further operation of the machine swings forward the frame on which is mounted the pawl T, which, as its tail can now rise, grabs U, and, on its return stroke carrying this with it, releases P, which, driven forward by its spring, strikes the hammer sharply against the back of the type-block, and the corresponding character is accordingly printed. The arrangement of pawls and levers P, U, and T is repeated for each place in the pounds, shillings, and pence column, the whole set being mounted side by side. As stated above, the pawl U is, in general, never raised unless a key has been depressed in the corresponding column of the keyboard. If, however, it is desired to print the sum of £500, say, then it is convenient that the zeros shall be printed automatically, without requiring to be set on the keyboard, for which, in fact, no provision is made. To effect this the tail Q of U for the hundreds column has a projection on its right-hand side, which extends over the tail of the U pawl for the tens column. If, then, the U pawl for the hundreds column is raised by its corresponding piece T, its tail Q pushes down the tail of the U pawl for the tens column, and thus releases the corresponding striker P. Similarly, the raising of the U pawl for the tens column releases also the striker for the units column; and thus, in the case taken, the sum £500 will be printed, though only one key has been depressed on the keyboard.

(6) **The Comptometer.** Felt & Tarrant Mfg. Co.

The Comptometer was brought out about 1887 by the inventor, Mr Dorr E. Felt, Chicago, U.S.A., and is now manufactured and sold by the Felt & Tarrant Mfg. Co., Chicago.

It claims to be the first successful key-operated adding and calculating machine. Prior to its appearance some crank-operated machines had been manufactured and sold; but the practical operation of these machines was confined to calculations involving multiplication and division. It is designed to be rapid and efficient in all arithmetical operations. In calculating, the results are obtained by simply depressing the keys, without any auxiliary movements. This one motion is naturally conducive to speed, and for calculations with factors up to six by eight digits, which covers the range of the great majority of commercial problems, the Comptometer is highly satisfactory. The latest model embodies the principle found in the earliest models, *i.e.* a bank of keys actuating a series of segment levers which in turn actuate the numeral wheels of the register. A positive stop, thrown into position by the key, determines the length of travel of the lever. On the end opposite the fulcrum of this lever is a rack tooth segment which engages a pinion carrying a ratchet, which in turn engages a pawl fastened to a gear; this gear through a train of two other gears rotates the registering or accumulator wheel in accordance with the key struck.

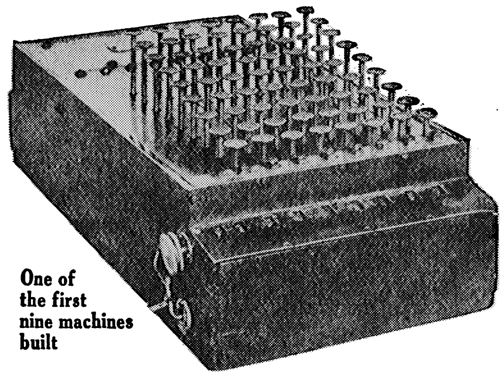


FIG. 34.—Early Type.

The carrying of tens is accomplished by power generated by the action of the keys and stored in a helical spring from which it is automatically released at the proper instant to perform the carry. To guard against over-rotation of the accumulators in either direction from the impulse of the prime movers or from that of the carrying mechanism, positive stops are also provided.

Improvements, however, have been added from time to time which, together with refinements of construction, have contributed much to the speed,

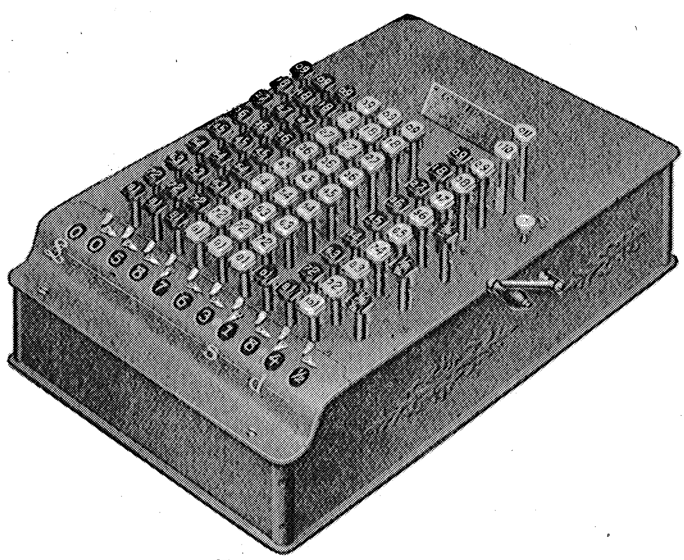


FIG. 35.—Modern Machine.

ease, and accuracy of operation in the modern machine. Notable among these improvements is the duplex feature introduced a few years ago. Prior to its invention only one key could be operated at a time. This meant that if a second key was struck before the one previously struck had returned to normal position an error might result; but with the duplex machine there is no need for the exercise of care in this respect, as it provides for the simultaneous operation of two or more keys in different columns. Besides simplifying the operation the duplex feature adds greatly to the speed and accuracy of the Comptometer. It facilitates calculations in multiplication and division in a remarkable degree, since as many keys as can be conveniently held by the fingers of both hands may be struck at the same time. Thus in multiplying, say, 47685 by 3457 it is only necessary to strike the keys representing the latter factor five times in the unit's position, eight times in the ten's position, six times in the hundred's position, and so on across, when the answer appears in the register.

The latest improvements in the Comptometer appear in a recent model known as the Controlled-Key Comptometer. In any machine not wholly automatic there is always a human element to be taken into account—an element always prone to error. It was for the purpose of eliminating, to the last possible degree, the chance of error from this source—errors due

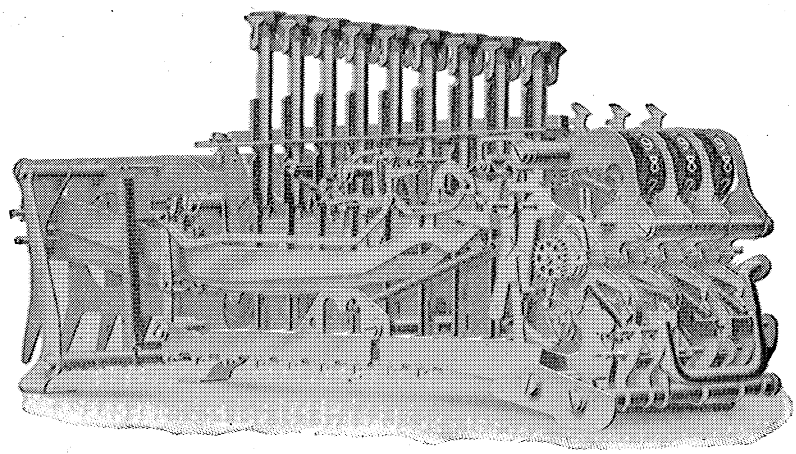


FIG. 36.—The Mechanism.

to the inexperience of beginners and the carelessness of experienced operators—that the Controlled-Key was devised. This safeguard consists of :—

1. Interference guards at the side of the keytops to prevent accidental depression of a key at either side of the one being operated.

2. The automatic locking of all other columns when a key in any column is not given its full down-stroke.

3. An automatic block against starting any key down again until the up-stroke is completed.

The illustration fig. 37 shows how the Controlled-Key acts under a fumbled stroke. It will be noted that in attempting to depress the white-topped key the stroke was misdirected so that the finger overlapped on the black-topped key far enough to touch and bear down on the interference guard. The black-topped key is not affected by this contact, because the Controlled-Key is built in two parts, and pressure on the part to which the interference guard belongs does not depress it. Unless a key is touched squarely enough to first depress the keytop to a level with the interference guard it will not go down. The effect of this is that in regular operation it is practically impossible to accidentally touch two keys at once so as to put them both down with one finger on the same stroke. Thus it can be seen how completely the Controlled-Key guards the operator against the consequence of fumbling.

In order to perform the proper functions and add correctly, the keys of the Comptometer must, of course, be given their full determined travel on both the up- and down-stroke. As with the typewriter, the operator soon learns the correct stroke, which quickly becomes an automatic habit, and is able to manipulate the keys at high speed with remarkable accuracy. A beginner, however, in trying to go too fast at the start, might by a slurred or partial key-stroke make it add a wrong amount. Such faults, whether due to inexperience or carelessness, are overcome by the Controlled-Key, which, if not given its full down-stroke, causes the keys in all the other columns to lock up instantly; and when the operator goes on to the next key after such a misoperation, he finds it will not go down. On looking at the answer register he sees in one of the holes a figure standing out of alignment toward him. This indicates the column in which the fault occurred. Now, by noting the last figure added in this column, he can tell at once which key was misoperated. Correction of the error is made by simply completing the unfinished stroke of the partially depressed key, after which the release key is touched to unlock the machine.

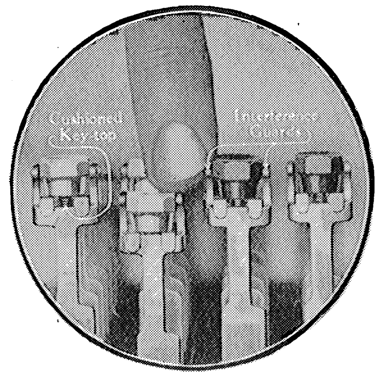


FIG. 37.—Interference Guard, and Cushioned Key-tops.

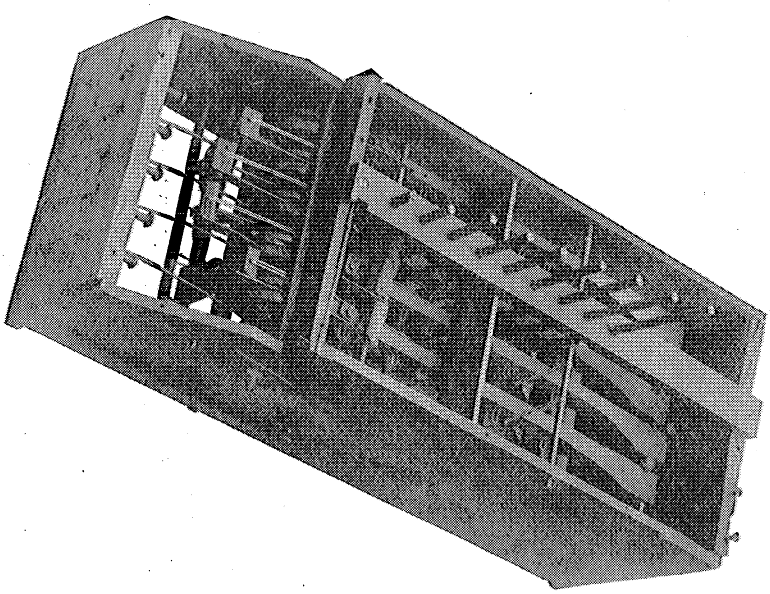


FIG. 38.—Macaroni Box.

Another safety feature of the Controlled-Key is its automatic prevention of an incomplete up-stroke. Should the operator, when striking the same key twice or more in rapid succession, attempt to start it down again before letting it clear up, he will find it impossible to do so. Once the key has started up, it automatically locks against reversal at any point short of its full upward travel.

Briefly summarised, the effect of the Controlled-Key is to automatically prevent the operator from accidentally overlooking any errors that may arise from imperfect operation.

The tendency in invention of office appliances is steadily toward more complete automatic control of mechanical functions, and in its development the Comptometer seems to have followed this line.

(7) **Layton's Improved Arithmometer.** Manufacturers: Charles & Edwin Layton.

In the year 1883 Messrs C. & E. Layton exhibited the first arithmometer of English manufacture as the agents of Mr S. Tate, and soon afterwards acquired the patents connected therewith.

The following is extracted from a paper read at the Society of Arts, 3rd March 1886, by Professor C. V. Boys, A.R.S.M., descriptive of this machine :—

"I have said that the machine referred to is in appearance identical with the de Colmar machine. This refers to the general design and to the outside. When opened, great differences are at once apparent, the most important being the substitution of the best English for what can hardly be considered the best foreign work. It is impossible to speak too highly of the beautiful finish, the accuracy of construction, or the excellent materials which are employed in every part. So far the machine might be nothing more than the French machine better made. There are, however, improvements in detail in the design. In the first place, the erasing mechanism is, in practice, far more convenient than in the French machine. In the place of a long rack which pulls each dial round until, in consequence of an absent tooth, it stops at 0, an operation performed by twisting a milled head against a spring for one set of dials, and another in the same way for the other set, it is merely necessary to jerk a handle one way to erase one set of numbers, and the other way to erase the other set. The dials are brought accurately to zero by a long steel rod, acting on cams, exactly in the same way that the second hand of a stop-watch is set back to sixty.

"Another improvement is the removal of the stops, or cams and cam-guards, which prevent the dials and auxiliary arbors from overshooting their mark in obedience to their momentum. These guards, which act much in the same way that the Geneva stop prevents overwinding of a watch, suddenly bring the dials to rest. In place of these, a series of springs are employed, under which these parts move stiffly. This, at first sight, seems inadequate, in view of the great speed at which the machines are run. I have done my best to try and make one of these overshoot, but without success. I thought it would be interesting to find how far the dial must really move before the spring brings it to rest. I therefore made the following measures (on the C.G.S. system) :—The moment of inertia of the dial and its attachments is 10·9, and of the secondary axis and wheels 6·7. If we take a working speed of four turns of the handle a second, we shall find that the angular velocity of these parts is in radian measure 16π or $50 \cdot 4$, and therefore the energy of motion is 22,370 units. The springs are adjusted until they resist a force equal to the weight of a kilogram applied to the teeth, which represents a turning moment of 784,800 units. These figures make the greatest possible amount of overshooting to be about $1\frac{1}{2}°$. Now, as no error could be introduced unless an angle approaching 18° were reached, it is evident that the factor of safety is fully 10, and that any fears as to the efficiency of this break are unfounded. The break has been found an efficient means of checking the motion of heavier things than the wheels of a calculating machine.

"Against this break may be urged the fact that more mechanical work is spent in driving the machine, but this is so slight that it can hardly be urged with propriety. The remaining improvement relates to the method of holding the carrying arm in its working or its idle position. To what extent

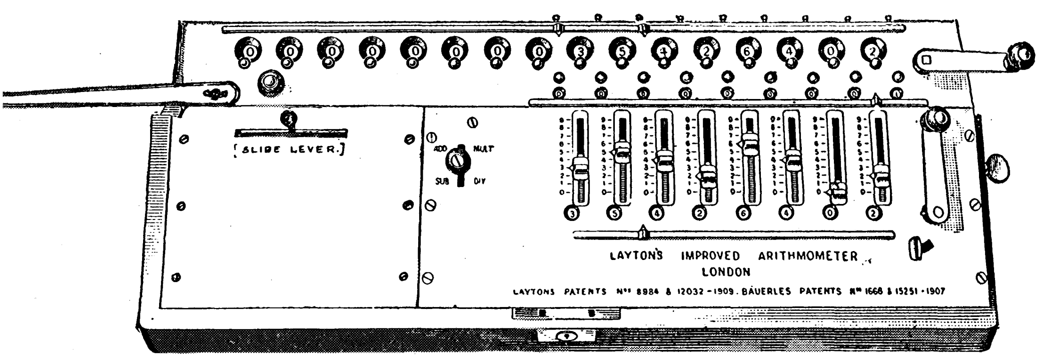


FIG. 39.

the old-fashioned double spring is likely to fail I am not in a position to say; I think I may safely say that the simple spring that takes the place of this double spring can never fail."

During recent times many other important patented improvements have been incorporated, and the instrument is now known as Layton's Improved Arithmometer.

1914 Model

Important New Features

Lightness.—Special attention is drawn to the introduction of modern alloys with small specific gravity combined with great strength, making the instrument much more convenient to use and handle. Without in any way impairing the strength, durability, or reliability of the machine, it has been found possible to produce an arithmometer of one-half the weight of the ordinary model, which is, therefore, much more convenient to carry. No alteration has been made in the size or shape of the instrument. The metal is non-rusting and not affected by acids. It is, therefore, particularly suitable for hot or wet climates. Machines constructed of this metal work with the minimum of noise and are light running.

The Markers.—Hitherto markers have been set to the figures required one by one, and have been returned to zero in like manner. The new invention allows these operations to be performed as before; but in addition a button is provided, which, on being pressed, returns all the markers to zero at once. Thus several operations are combined conveniently, and a fruitful source of error to following calculations avoided. The working parts of this device make it almost impossible for a marker to rest between two digits.

Show Holes in connection with the last invention have been added, so that the figures can be set more quickly by the markers and checked more easily.

The Slide Lever.—To move the slide in previous models of the arithmometer required two distinct movements, viz., to raise, and to propel. By means of an arrangement now invented, this double movement is performed by simply pulling a lever. The slide can be moved in either direction, and falls automatically into its correct position.

The Regulator.—Hitherto the handle has been actuated by the left hand, which is also needed for the slide. In practice this has been found to be inconvenient, particularly when the short method of multiplication is used. The new invention provides a method by which the regulator can be controlled by the right hand, as well as by the left hand as hitherto.

(8) **Hamann's "Mercedes-Euklid" Arithmometer.** By O. Sust, Kgl. Landmesser in Berlin. Translated by W. Jardine, M.A. From *Zeitschrift für Instrumentenkunde*, 1910.

Herr Ch. Hamann, of Friedenau, Berlin, is well known as the designer of the "Gauss" [1] arithmometer, whose easy manipulation has made it a favourite for certain kinds of computation. The same inventor has since designed another machine depending on the addition principle, which has now been placed on the market under the name of the "Mercedes-Euklid." [2] Its invention represents an attempt to overcome the numerous defects [3] in existing mechanical calculating systems, especially the incomplete carrying over of tens and the difficulty of division, both of which forced the user of the machines to be continually on guard, and consequently quickly tired him. In the Euklid, not only are these faults got rid of, but so many innovations and improvements have been carried out that it represents an entirely new design, differing fundamentally from those already in use. The mechanical carrying over of tens is continued right up to the highest place, so that correction of results is never necessary. Further, the quotient (or "rotation") mechanism is fitted with an arrangement for carrying over tens, which is

[1] Berlin, Kgl. Landwirtschaftliche Hochschule, June 1910. Compare the descriptions in the *Zeitschrift für Instrumentenkunde*, xxvi., S. 50, 1906; xxix., S. 372, 1909.

[2] The machine is protected by D.R.P. No. 209,817, and the notification number 35,602. It is sold by the "Mercedes" Bureau—Maschinen Ges. m. b. H., Berlin S.W. 68, Markgrafenstrasse 92/93.

[3] Compare O. Koll, *Die geodätischen Rechnungen mittels der Rechenmaschine*, Halle, 1903, Vorwort, Abschnitt 4; also the report "Neuere Rechenhülfsmittel" in *Z. f. I.*, xxx., S. 50, 1910, in which mention is made of the tables of O. Lohse and reference made to the disadvantages of detailed division with calculating machines, which disadvantages cannot be quite got rid of by the use of tables of reciprocals.

found to be especially useful in some kinds of calculation. Owing to the proportionately small size of the machine, a desirable compactness is obtained, and, at the same time, attention is paid to the convenient arrangement and easy manipulation of all levers. Provision is also made for every means of ensuring against incorrect manipulation. A special merit is the noiseless action, which permits of the use of the machine in large offices without thereby disturbing those working near. In spite of all these advantages, considerations might be raised against the introduction of a new addition arithmometer, since serviceable multiplication machines have been constructed [1] which demand, in general, less crank-turning than this one to form a product. But this disadvantage is small in comparison with its noiseless action, and with the further advantage which the Euklid possesses that an entirely automatic division of any chosen numbers may be per-

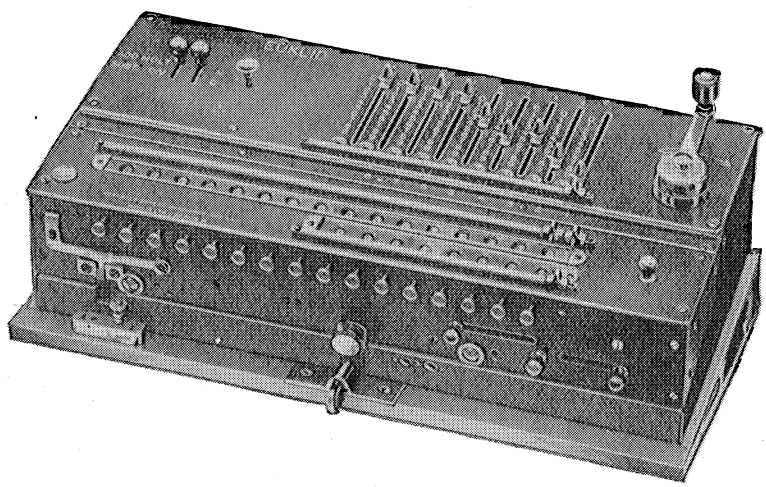


FIG. 40.—($\frac{1}{4}$ actual size.) Appearance of the machine.

formed without any attention on the part of the user of the machine. The most conspicuous defect of all systems hitherto constructed is thereby got rid of.

Fig. 40 shows the external appearance of the machine. The rectangular metal box, which is so arranged on a wedge-shaped base that the upper part is slightly tilted towards the front, is about 37 cm. long, 18 cm. broad, and 8 cm. high; it weighs 12 kg., so that the machine is easily carried about and may be set up anywhere. The upper part to the left of the crank K contains the slot mechanism, the ingenious arrangement of which made it possible to place the nine slots at intervals of only 16 mm. apart. The numbers indicated by the zigzag line of markers F are shown again in a straight line in the corresponding viewholes M. In the forepart we see the two rows of viewholes (P and Q) of the product and quotient mechanism (closed against dust by glass strips). The carriage containing this mechanism, as in all calculating machines, can be pushed for multiplication and division purposes in a longitudinal direction to positions opposite the slot mechanism. On pushing,

[1] Multiplication machine of Steiger and Egli, described in *Z. f. V.*, xxviii., S. 674, 1899. Compare also Koll, S. 20 of same.

the sliding carriage moves, without jumping or rattling, on rollers along guides in the machine frame, in such a way that the possibility of dust entering the mechanism is reduced to a minimum. Every calculation is begun with the highest place, and the carriage is pushed for this purpose to the right by means of the knob G_2 until it reaches the desired position. The succeeding motion towards the left during the calculation is self-acting. The sliding knobs G and G_1 are used for the effacement of the quotient and product. The following more detailed description will explain the manipulation and working of the pair of operating levers U and U_1, as well as of the other single parts of the machine.

The action of the slot mechanism, which rests on an entirely new principle, is explained by the diagrammatic fig. 41. Under the markers F (fig. 40) lie, parallel to each other and prevented by guides from being laterally displaced, ten racks Z_i, which are linked to a proportion lever H. The motion of a connecting rod *pl* from the crank axle is communicated to this lever, causing

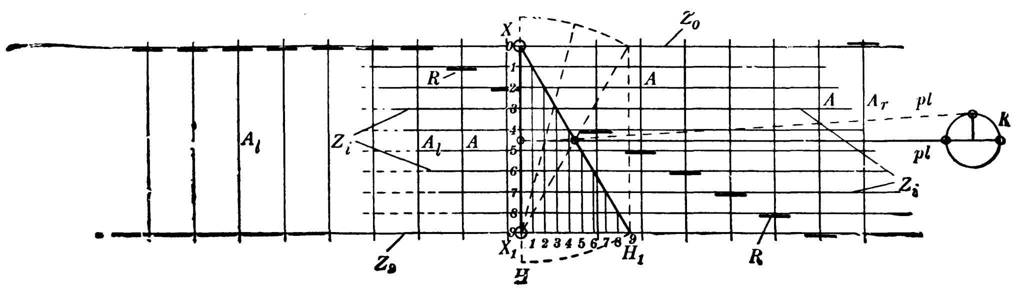


FIG. 41.—Action of the slot mechanism.

it to swing round one of its extremities, *e.g.* X, so that the racks Z_i are displaced by an amount corresponding to their distance from the pivot of the lever. In all addition processes this pivot lies on the rack Z_0; the lever then turns from H to H_1, and gives to the racks displacements corresponding to their numbering. If now, by means of the markers F (fig. 40), the ten-toothed pinion wheels R, travelling along square axles A, are placed over the corresponding racks, then they rotate by so many units in either direction. A special coupling secures that only a forward motion is communicated to the mechanism, while a reverse motion has no effect. By using the racks of the slot mechanism and dispensing with a reversing movement of the carriage, which would demand a more complex arrangement for the carrying over of tens, the slot mechanism becomes especially useful for the carrying out of subtractions. The procedure [1] previously followed in calculating with other machines of substituting for the reverse process in subtraction and division the process of setting up and adding the complements [2] of the tens is put to practical use in the simplest possible manner. By means of a reversing gear, the pivot of the lever may be placed on the rack Z_9 at the point X_1, so that this rack, which previously covered the greatest distance

[1] W. Veltmann, "Über eine vereinfachte Einrichtung der Thomasschen Rechenmaschine," *Z. f. I.*, vi., S. 134, 1886.

[2] Hr. Hamann has applied the same principle in the "Mercedes-Gauss," where the mechanical process is really less simple.

(nine units) now stands still, while Z_0 is moved through nine units. In both cases, and naturally for all intervening racks, the sum of the two motions will be nine units. A simple example will explain this process. Let the six markers F to the right be placed on the number 249,713, and the rack Z_0 be locked, then a turn of the crank will cause this value to appear on the carriage indicators P, which previously showed the value 0. To subtract the same number, we now reverse, so that the lever H rotates about X_1 on Z_9. In this way the nines complement 750,286 is added, and as result we get 999,999 instead of 000,000. The error arising in this way is got rid of by raising the units place by one. This is done by an attachment on the rack Z_0, which causes an axle A_r, situated to the right of the last of the slot axles and fitted with a rigidly attached wheel, to make a complete revolution in every subtraction, and so effects a carrying over of tens to the left, thereby raising the units place by one. Further, to the left of the nine slots, and opposite the viewholes of the carriage, lie other axles A_l, with fixed pinion wheels, which all turn when Z_0 is displaced (and therefore in all subtractions) by nine teeth, equal to nine-tenths of their circumference, whereupon nines appear opposite them in the carriage viewholes. Through the progressive carrying over of the ten these are all finally changed into nothings, and the correct result is got. The subtraction of the two equal numbers is carried out by the machine in the following manner :—

$$
\begin{array}{r}
249\ 713 \\
+\left\{\begin{array}{r} 750\ 286 \\ \ldots 999\ 000\ 001 \end{array}\right. \\
\hline
|\ \ldots 000\ 000\ 000
\end{array}
$$

The one disappears, as it is carried over to the end part of the mechanism.

The reversing process is brought about by the lever U (figs. 40 and 43), which pushes the bolt *s* into a corresponding opening in the rack Z_0 or Z_9, while it leaves the others free. If, as in fig. 43, the rack Z_9 is locked, the pivot of the proportion lever H lies on it, and therefore subtraction results. The position of the bolt *s* can only be changed when the racks are in their initial position, as otherwise it finds a check in the opposing racks. A movement of the crank, on the other hand, can only follow if the lever U is completely shoved home, as otherwise both racks are locked by the bolt *s*. Consequently the reversing lever is converted into a safeguard against improper usage. The number cylinders in the viewholes M, which show in a straight line the numbers already indicated by the markers F, are fitted on axles W_s (fig. 42) provided with a slow worm. Against these press a pointer which is attached to the markers. A displacement of the marker F therefore causes a rotation of the axle, whose amount corresponds to the displacement, *i.e.* a change from one number to the next on the number cylinder is coincident with a displacement of the marker by a unit. In order that they may be set more easily and definitely, the markers F are provided with rollers which are pressed by a spring into grooves on the underside of the cover. The racks are set in motion by the connecting rod *pl* from the shaft W_1, which is coupled by toothed wheels to the crank shaft W. The action of the slot mechanism is rendered more free and less liable to friction by a suitable arrangement of the proportion lever H.

Exactly opposite the slot axles lie, in the forepart of the machine, the axles a_1 of the carriage mechanism; both carry on their facing ends similar

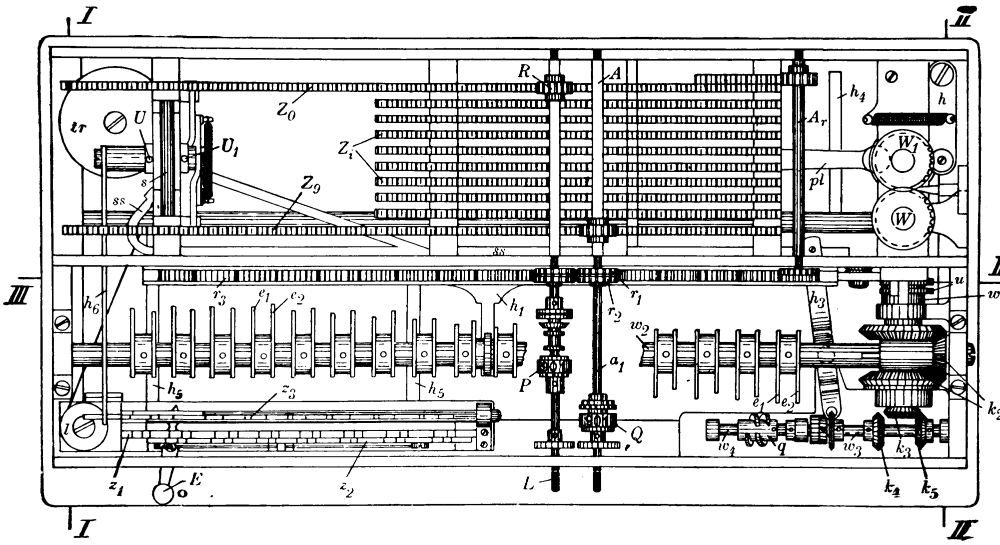


FIG. 42.—($\frac{1}{3}$ actual size.) Appearance of the whole machine from above after removal of the cover. The proportion lever and all the slot and carriage axles except two are omitted.

ten-toothed wheels r_1 and r_2. Under these are placed on the beam b (fig. 44) broader cog wheels r_3, which can be engaged simultaneously with r_1 and r_2 and thereby rigidly connect both sets of axles. Now the horizontal axle w_1 is connected with the crank axle through the bevel wheels k_1 and k_2; it

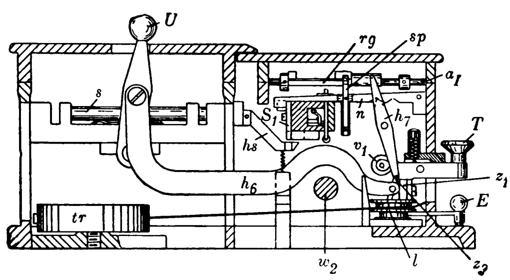


FIG. 43.—($\frac{1}{3}$ actual size.) Side view (Section I I of fig. 42) to illustrate the reversing process.

carries two discs u, on which two rollers, the ends of a lever, move in such a manner that during a turn of the crank they execute an entirely constrained to-and-fro motion which is communicated through the lever connection h_1, h_2 (fig. 44) to the beam b. The action is such that during the first half of a crank turn the beam b is pressed upwards, the coupling established, and the forward motion of the wheels of the slot mechanism communicated to those of the carriage; but then, at the moment the former wheels cease to revolve before the next half of the turn, the beam is depressed and the coupling released during the return motion. On the beam being lowered a pin *st* catches in a gap of the coupling wheels, so that they maintain their correct position until they are re-engaged. The to-and-fro movements communicated to the racks by the crank through the connecting rod are not uniform, but are quickened towards the middle of the crank turn, and fall off finally to zero. This circumstance is one of far-reaching importance in the whole construction of the machine. For the rotation of the axles in the slot and carriage mechanisms falls off simultaneously towards the end, so that the latter, on uncoupling, immediately stand still, and no kind of inertia effects can possibly appear. Therefore to secure the axles a_1 in their positions a catch d_1 is sufficient. This catch is pressed by a spring against a toothed wheel near the number cylinder and springs against it immediately a number appears in the viewhole P. The ends of the carriage axles project out of the machine : we can set up numbers in division, etc., by means of them. Special safeguards are provided here to prevent a rotation past 9, which would cause a carrying over of ten.

From what has been said, the number cylinders in P are rotated during the first half of the crank turn by the amount of the digits set up in the corresponding places on the slots (in subtractions it is their nines comple-

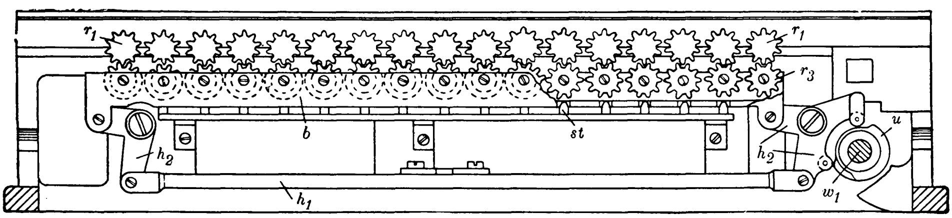


FIG. 44.—($\frac{1}{3}$ actual size.) Coupling as seen from above (Section III III of fig. 42).

ments) ; the second half of the crank turn is reserved for the completion of the process (which has been " prepared for " already) of carrying over the tens, and the raising of the next highest place in the passage from 9 to 0 in the carriage mechanism. This is carried out in the following manner. To the axis a_1 (figs. 45 and 46) there is freely attached a clutch m, with a disc p_2, from which projects a pin, passing through an opening in the disc p_1, this latter being rigidly attached to the axle. If the number cylinder in the viewhole P turns from 9 to 0, the pin thereby comes into contact with an attachment c on the machine frame, and is pushed along over its sloping surface so that the clutch is displaced along the axle. It is held firm in this new position by the spring catch i, lying behind the disc p_3. The completion of the process of carrying over the ten is effected from the axle w_2, which is coupled to the horizontal axle w_1 by the bevel wheels k_2. As the circumferences of these wheels are in the ratio 2 : 1, the axle w_2 makes two revolutions with one crank turn. On it are set spirally a number of eccentric pairs e_1, e_2, one pair under each carriage axle. Being linked to the lever h_1 (fig. 42), the axle, like the lever, is slightly displaced longitudinally at the beginning of the first revolution, but at its second revolution it is brought back to its old position, so that the eccentrics are now under the cams f_1, f_2 (figs. 45 and 46), and, instead of passing them as they did previously, they force them upwards by their further rotation. The cams f_1 now move over the surfaces O of the fixed frame. If they experience no resistance, they rise perpendicularly and are then immediately drawn back to their initial position by the spring *fh*, after the eccentrics have passed by them. If, however, a process for carrying over a ten has been initiated, the corresponding cam f_1 strikes against the projecting flange *fl* of the clutch *m*, is tipped by it to the side, and with the tooth *y* advances by a unit the cog wheel on the neighbouring axle. This procedure is represented in fig. 46 by the highest cam. Meanwhile the eccentric e_2, which lags behind the previous one by a small amount, has elevated the cam f_2; this meets an arm of the catch *i*, releases it, and

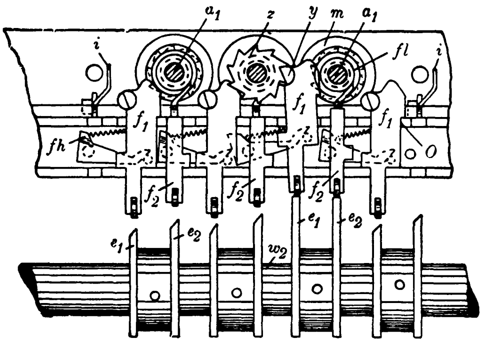


FIG. 45.—($\frac{2}{3}$ actual size.)

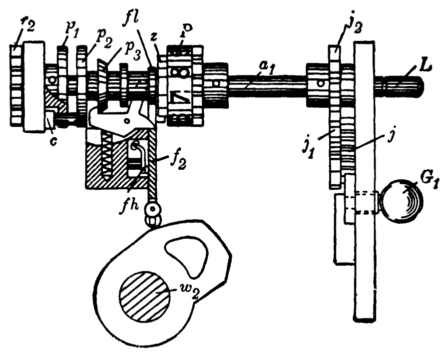


FIG. 46.—($\frac{2}{3}$ actual size.)

Mechanism for carriage of tens (front and side view).

pushes the clutch back by means of a lever into its initial position. The cam f_1 is thereby set free and falls according to the run of the eccentric. Since the eccentrics are arranged spirally, the carrying over of tens goes on continuously from the lowest place, and may proceed through the whole mechanism. The process of carrying over a ten can only take place during the second half of the calculation, when the coupling bar is off. The double rotation of the shaft w_2, however, makes it possible to spread the eccentrics over almost the whole periphery of the axle w_2, and to give them correspondingly smaller radii. After giving the preceding description it is unnecessary to emphasise the fact that all parts of the operation of carrying over tens are performed automatically, and therefore we get a safe guarantee that the action is free from error.

The number cylinders of the quotient, which indicates the number of crank revolutions in single positions of the carriage, and can be seen in the row of viewholes Q, are attached to cylindrical collars H_1 on the axles a_1, and in consequence of this arrangement (a very handy one for the calculator) appear in the same line with the markers and the carriage figures. This mechanism is driven from the axle w_3 (fig. 42), which is coupled by means of an intermediate wheel with the eccentric shaft w_2, and thereby also with the crank handle. This shaft can be displaced longitudinally and carries the two bevel wheels k_4 and k_5, which may in turn be engaged with k_3, and on its left end a gear wheel which drives the shaft w_4 higher up (fig. 47). With chosen adjustments of all these wheels, w_4 makes with one crank turn a revolution (direct or reverse, according as the wheel k_4 or k_5 is engaged). The reversing takes place by means of the reversing lever U_1 at one end of a lever; a rod *ss* (fig. 42) communicates the latter's motion to the lever h_3, which engages with a clutch on the shaft w_3, and displaces it to one side or the

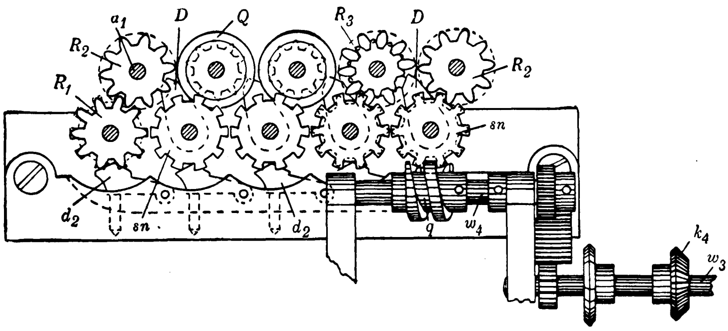


FIG. 47.—($\frac{2}{3}$ actual size.) Quotient mechanism.

other. A spring causes the reversing lever to spring easily into its end position, so that it is held firmly there. Similar precautions are taken as in the case of the lever U to prevent turning of the mechanism when the setting up is incorrect. Reversal during a calculation is likewise impossible.

The worm on the shaft w_4 drives the ten-toothed cog wheel *sn* above it a tooth further at every revolution. This, together with a cog wheel R_1, and a fixed projecting arm D, lies on a sleeve revolving on a fixed axle. Above this, finally, on the main carriage axles, are seated collars H_1, carrying the two cog wheels R_2 and R_3 near the number cylinders. These parts act in the following way :—The two toothed wheels R_1 and R_2 engage with each other (left of fig. 47). At every turn of the worm the number cylinder Q is advanced a unit. If thereby a passage from 9 to 0, or by reverse motion from 0 to 9, takes place, the arm D catches in the cog R_3 of the next highest place and advances or retracts it one digit. As in the product mechanism, springs d_2 press against the teeth of the wheels R_1, so that the correct position of the gear wheels and of the numbers in the viewholes is maintained. In order that a displacement of the carriage and its accompanying mechanism past the non-movable driving screw *q* may be possible, the latter is provided with a slot, which in normal positions of the crank lies in the plane of the cog wheels *sn*, and through which therefore they pass freely.

The "carrying over of tens" in the quotient is an outstanding feature of the new machine, and is of extreme importance in the process of "contracted multiplication." It is generally the custom with an addition machine to carry out the multiplication of a number of several digits (say 299, for example) so that it is multiplied by 300 and then one subtracted in the units place. The older machines, however, indicated as the multiplier a number 301 instead of 299, and the one was differently coloured to distinguish the subtraction part. It fell to the calculator, then, to carry this number in his head, to convince himself of the correctness of his operation. In the application of this method of calculating, it is only necessary with the "Euklid" to reverse both levers U and U_1 in subtraction, placing U on subtraction, U_1 on C, *i.e.* correction for the multiplier (fig. 40), and then to turn so many times, until the desired multiplier appears in Q.

The carrying over of tens in the quotient was absolutely necessary in automatic division (mentioned above), and the fundamental idea will be here briefly indicated, so that the mechanism required may be afterwards described in detail. Let the division of a number a by b give in the quotient the first two numbers c and d, and the corresponding remainders r_c and r_d; then we get the equation—

$$\frac{a}{b}=c\cdot 10^n+\frac{r_c}{b}=c\cdot 10^n+d\cdot 10^{n-1}+\frac{r_d}{b}, \qquad (1)$$

or

$$\frac{a}{b}=(c+1)\cdot 10^n-(10-d)\cdot 10^{n-1}+\frac{r_d}{b}. \qquad (2)$$

In equation (2) we are given the mathematical expression for the procedure in automatic division. Instead of subtracting the divisor at each place so many times from the dividend, till we get a positive remainder, which is smaller than the divisor—in the first place c times, in the second d—we carry out the subtraction $(c+1)$ times in the first place and get a negative remainder $\frac{r_c-b\cdot 10^n}{b}$, to which we add in the next place so many times, until the remainder is again positive, that is, according to equation (2), $(10-d)$ times. The same process is repeated in the third and fourth places, and so on. In the carrying out of such divisions with our calculating machine, after setting up the dividend and divisor, we displace the carriage until we bring their highest places opposite each other, place the lever U on subtraction, U_1 on N (*i.e.* normal position or addition of the crank turns), and then turn the crank so many times—$(c+1)$—until the dividend is negative, which is indicated by a number of nines to the left of the carriage axles. In the mechanism we now get a self-acting check, which is only removed when both levers are reversed and U placed on addition, U_1 on C (correction for quotient), whereupon the carriage moves one place to the left. We now turn $(10-d)$ times, and get, on account of the carrying over of tens on, the quotient, its correct value cd in Q; during the last turn the dividend again becomes positive, and we get a check. Only on reversing again can we proceed, when the process just described is repeated. We see from this that the machine must be provided with a contrivance for advancing the carriage one place automatically on reversal; further, we must get a check on the crank if either nines appear on the left of the carriage in subtraction, or the nines change to nothings in addition.

The arrangements for automatic displacement of the carriage are represented in figs. 42, 43, 48, and 49. The carriage runs on rollers supported by guides in the frame. To it is attached a linked chain passing round a pulley *l*, and pulled by a strong spiral spring lying in the drum *tr*, so that the carriage is constantly drawn towards the left. Fixed to the base of the machine is a rack z_1, into which engages a projection V on the key T of the carriage. The teeth of the rack z_1 are sloped (fig. 48) on one side, so that the projection can move over them without resistance or displacement of the carriage to the right, while on the return motion it is pressed against their perpendicular side by a spring. A pressure on the key T removes the check, and the carriage can be pushed into any other required position, remaining there when the key is released. The distances between the teeth are equal to the distances between the axles of the carriage and slot mechanisms, and the key is so constructed that in every position of the carriage the cogs r_1

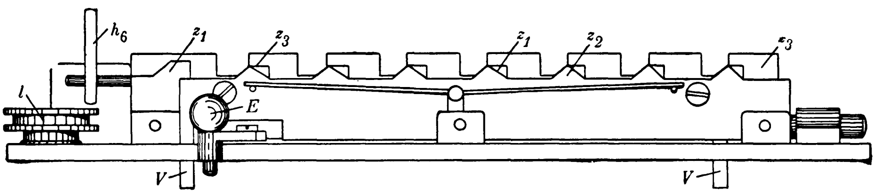


FIG 48.—($\frac{2}{3}$ actual size.) Displacement of the carriage (front view).

and r_2 on these axles are opposite each other. In multiplication we require an automatic displacement of the carriage from place to place; we use for this purpose a knob K_n on the cover of the slot mechanism, which can be placed, if required, to the left of the crank K, so that the displacement of the carriage during a calculation can be made easily with the thumb of the right hand, without letting go the crank. A quick pressure on this knob is transferred by the lever h_4 to the arms h_5 (fig. 42), the sloped teeth of which press against the projections V of a second rack z_2, placed in front of z_1, and displaceable vertically. These are raised up, and the projecting piece V is thereby disengaged from the rack z_1. The carriage is then displaced so far until V meets the vertical side of a tooth of the rack z_1, when it stops at the next place. z_2 meanwhile has returned to its former position under the action of two springs. In automatic division the displacement of the carriage must follow automatically on reversal of the lever U. This is effected by a swinging rack z_3, worked by the lever h_6 from the reversing lever, which acts on the roller U_1, and releases T. This rack has openings corresponding to those in the rack z_1. If, on reversing, the key T is released, the carriage moves to the left until the roller springs into one of these openings and prevents further motion. After the rack has swung out to its fullest extent, the projection V can engage in the next hole, and complete displacement is got. As it is not desirable in every kind of calculation to have the carriage automatically displaced, a contrivance for longitudinal displacement of z_3 is provided, which causes the roller v_1 to face the openings, thereby preventing the lateral motion of the rack having any action on the roller. This longitudinal displacement is effected by a lever E, which can be put in either of the two previously described positions (figs. 48 and 49). To guard against displacement of the carriage

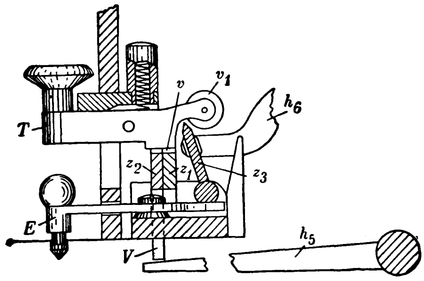


FIG. 49.—($\frac{2}{3}$ actual size.) Displacement of carriage (side view).

during a calculation, and also to prevent turning the crank in an incorrect position of the carriage, there is attached to the frame of the slot mechanism, underneath the crank axle, a lever *hs* (fig. 43). A roller at one end of it is pressed by a spring against a disc p_4 on the crank axle, and springs into a notch of p_4 in the normal position of the crank. The other end of this lever is fitted with a projecting piece, which faces a rail S fixed to the frame of the carriage. This rail is fitted with notches, at distances from each other equal to those of the carriage axles, into which the projection engages in the correct

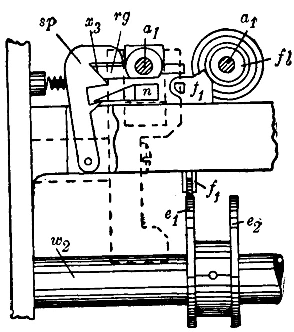


FIG. 50.—($\frac{2}{3}$ actual size.) Last carriage axle with fittings for automatic check (front view).

position of the carriage, if a turn of the crank presses the lever *hs* downwards from the disc p_4. A displacement of the carriage during a crank turn is thus made impossible. If the carriage is incorrectly displaced, the crank is prevented from turning, since the lever strikes against the rail S.

At the same time the lever *hs* serves as a brake on the crank in automatic division. For this purpose there lies alongside S a second rail S_1, fitted with sloped teeth, which is displaced slightly in its longitudinal direction at each crank turn by the projection, which is likewise fitted with a sloping surface. The check now takes place in the following way :—The carriage axle, lying to the extreme left, is provided, like the others, with all the arrangements for carrying over tens. To the left of it is an auxiliary axle fitted with a bolt *rg* (figs. 50 and 51), which can turn round the axis or be displaced along it; it is displaced on reversal from U by a lever h_7 (fig. 43) attached to the swinging rack z_3; in subtraction taking up the position of figs. 43 and 51; in addition, on the other hand, coming nearer the forepart of the carriage. In carrying out a division, the divisor is subtracted as many times as it is contained in the corresponding place in the dividend. As the machine does this by adding the tens complements (compare the example on p. 107), there appear first in the higher places of the carriage a number of nines, which become nothings on carrying over ten. If this continues up to the highest place, a process for carrying over ten will also be initiated here, and the flange *fl* will strike against the cam f_1, which is here fitted with two small projections. On being elevated by the excentric e_1, this is tipped slightly to the left, and passes

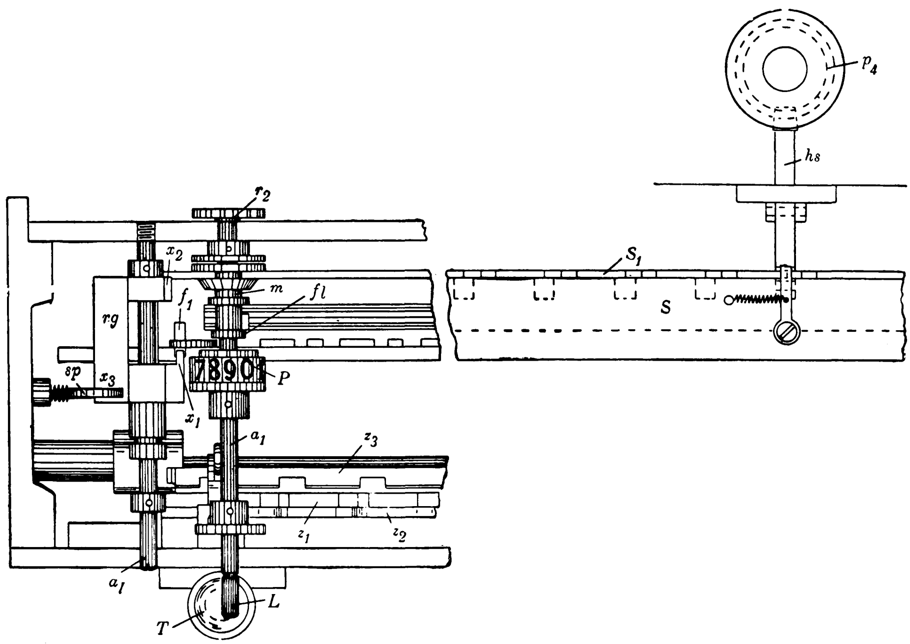


FIG. 51.—($\frac{2}{3}$ actual size.) Last carriage axle with the fittings for automatic check (appearance from above).

without touching the projection x_1 of the bolt *rg*. This takes place at every turn, as long as the dividend is still positive; but if a still further subtraction of the divisor is carried out, then the nines remain in the carriage mechanism, no ten is carried, and the cam rises vertically, meets the bolt at x_2, and tips it round, as shown in fig. 51. This procedure is reversed in the second part of automatic division, the addition of the divisor to the next lowest place in order to correct the quotient. The surface x_2 of the bolt then faces the cam and is not touched by it, as long as there is no ten carried over. As soon, however, as the negative dividend again becomes positive by adding the divisor to it sufficiently often, in place of nines, nothings appear again with the progressive carrying over of ten; the projecting flange *fl* now thrusts the cam f_1 aside, and this latter tips the bolt round at x_2. A check to the crank is thereby got in both cases. For the bolt *rg*, on being tipped round, presses with its sloping surface x_3 the hook *sp* against a spring. This releases a swing lever *n*, which is pivoted to the forepart of the machine, from a small projection of the hook, and inserts it by means of a spring in an opening of the movable rail S_1 (fig. 43). This is thereby secured against longitudinal displacement; the lever *hs* in consequence remains immovable, and so checks the turning of the crank. The removal of the check takes place during reversal; the lever h_7 through its motion raises the bar *n* and replaces it in its initial position, in which it is held fast by the hook *sp*. If a pull on the crank were to be transferred to the mechanism after a check had been imposed, then injurious results would easily follow improper usage. To prevent this, the crank is constructed in a special way. To the crank shaft is fixed a disc t_1, and above it a rotary disc t_2, to which is attached the crank K (fig. 52); between them is placed a spiral spring which takes up the strain on the crank and carries it over to the axle. With a greater resistance in the mechanism it is contracted, and a pin is pressed by a sloping surface inside t_2 into a depres-

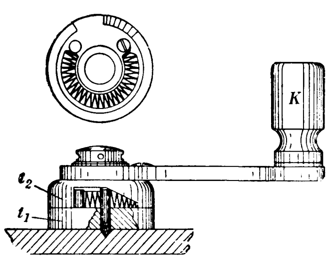


FIG. 52.—($\frac{1}{2}$ actual size.) Construction of the crank.

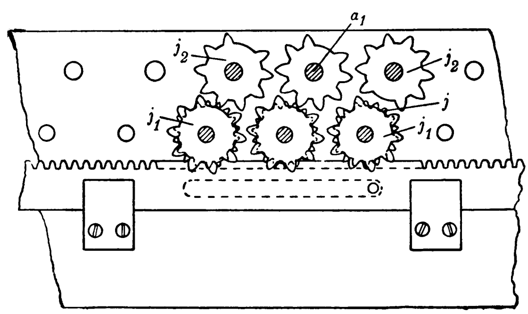


FIG. 53.—($\frac{2}{3}$ actual size.) Effacer.

sion in the top of the machine. This then takes up any further strain on the crank, and possible injurious effects are avoided. A reverse turn of the crank, which the internal construction of the machine will not allow, is prevented by a pin which is pressed by a spring against the discs *p* (fig. 42). On turning the crank in the right direction, it is pushed back; on reversing the crank, it falls between these discs and keeps them immovable. To keep the crank in its normal position there is also provided a spring lever *h* (fig. 42) whose rotating end carries a roller, which fits into a depression in the axle W_1, when the crank takes up its initial position.

The last essential part of the machine which requires mention is the "effacer." This is put in action for each of the product and quotient mechanisms by pulling aside the knobs G and G_1. A rack and pinions *j* (fig. 53) engaging with it are thereby set in motion. The axles of these pinions carry in addition a ten-toothed wheel j_1, which engages with the wheel j_2 on the axle a_1 of the product mechanism. A tooth is absent in both, so that in certain positions we have a gap between them. When the rack is not in motion, the hole in j_1 is opposite the toothed wheel j_2, which can then move freely. On being displaced, however, j_1 engages with the toothed wheel j_2 and rotates it until its hole comes underneath, when contact with j_1 ceases. All the number cylinders are simultaneously put back to zero. Pulling on the knob G similarly effaces the quotient or multiplier Q. Both knobs are then brought back to their initial position by means of springs; G at the same time can be used as a handle to pull back the carriage to its normal position. In conclusion, it may also be mentioned that all parts of the machine which have stronger demands made on them, such as the main axles, the racks for displacement of the carriage, the eccentrics, etc., are made of hardened steel, so as to ensure durability. Further, we must refer to the fact that the machine permits of an extended use by the provision of a second slot mechanism in front of the carriage mechanism. Thus products of the form $a \times b \times c$ can be formed, without necessitating a new setting up of the product $a \times b$, and in the adding of simple products not only the sum but the simple products can be read off. In general, the most involved calculations can be easily and quickly carried out. Improved machines are also in process of construction, and will shortly be put on the market.

It is astonishing with what speed and accuracy the machine completes all kinds of calculation, and especially automatic division. The striking innovations introduced into the Euklid, opening up entirely new fields to machine calculation, will assure it a prominent place among mechanical aids to calculation.

(9) **The "Millionaire" Calculating Machine.** O. Steiger, Patentee.

This machine is used for working out all calculations which can be made by the four rules of arithmetic. Its principal advantage consists in the simplicity and rapidity with which multiplications, divisions, square roots, and compound rules may be treated.

For each figure of the multiplier or quotient only *one* rotation of the crank is necessary, while the displacement of the product takes place simultaneously and automatically.

In the representation of the machine in fig. 1 there may be distinguished:—

The *regulator* U, by means of which the machine is adjusted for the different kinds of calculations. It is placed in the position marked A, M, D, S (Addition, Multiplication, Division, Subtraction), according to the calculation required.

The *crank* K, which is turned once in the direction of the arrow for each figure in the multiplier or quotient, or for every addition or subtraction.

The *multiplication lever* H, which is in one of the positions 0 to 9 according to the multiplier or quotient. (For additions or subtractions it is placed on "1.")

The *markers* "*e*—*e*."—The amount to be added or subtracted, the multiplier or divisor are placed in position by sliding the knobs down the vertical rows of figures until the points are opposite the figures required; the *control dials* "e^1—e^1" form a valuable check, since they repeat in a straight line the numbers recorded by the markers "*e*—*e*."

Row of control dials "*f*—*f*," which show automatically the multiplier or the quotient while the crank is being turned.

Row of result dials "*g*—*g*," which register the amount, remainder, product, or dividend. The numbers may also be placed by hand by turning the knobs of the dials.

Effacer of result numbers R
Effacer of control numbers C } These knobs are drawn to the ends of their slots and then brought back *gently* to their former positions.

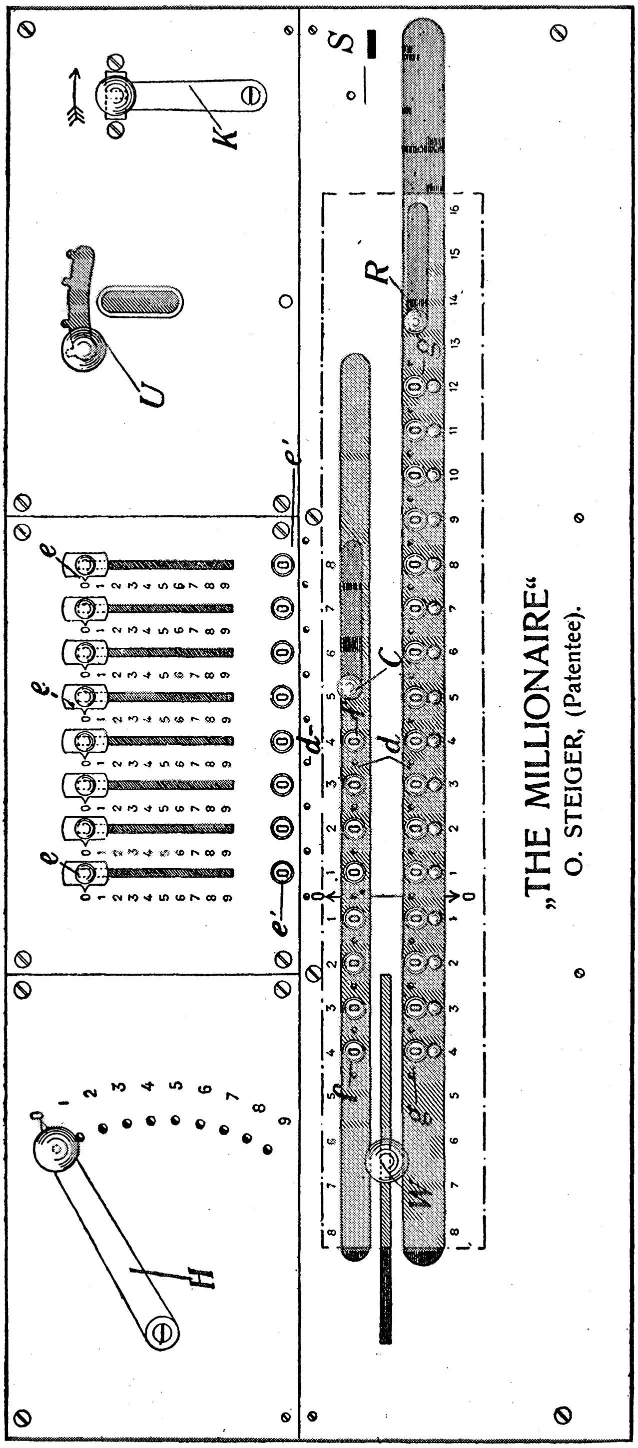


FIG. 54.—"Millionaire" Calculating Machine.

Carriage - shifter W, which serves to place the registering part of the apparatus (hereafter called the "recorder"), comprising the result and control dials, in one of the eight possible positions.

The "Millionaire" calculating machine is a true multiplying machine, while the other systems of calculating machines in use are only addition machines, and as such carry out multiplication by a series of additions. (Subtractions and divisions may be regarded as additions and multiplications in the negative sense, and are therefore not further considered.) Clearly a multiplying machine which can only be used for the multiplying digit "1" is merely an addition machine.

In the "Millionaire" calculating machine are comprised three principal pieces of mechanism (see figs. 55, 56, and 57):—

(1) The multiplying mechanism.
(2) The carrying mechanism.
(3) The recorder, which is itself divisible into two parts, whereof one (viz., *g—g*) registers the product, while the second (*f—f*) is only for convenience, since it indicates the multiplier, but as such is not absolutely essential to the multiplying machine.

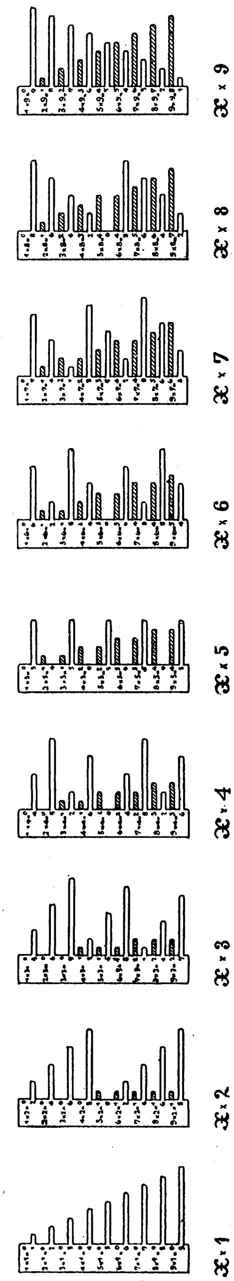


FIG. 55.—The Tongue-plates of the Multiplying Pieces for the Factors 1 to 9.

The *multiplying mechanism* consists of the so-called multiplying pieces and their supporting mechanism, which permits of motion :

(1) in the vertical direction ;
(2) in the horizontal direction lengthwise ;
(3) in the horizontal direction diagonally.

The multiplying pieces, which form the most essential part of the machine, consist of (fig. 55) nine tongue-plates, of which

the first gives the products of 1 to 9 times the number 1,
the second gives the products of 1 to 9 times the number 2,

and so on, the ninth the product of 1 to 9 times the number 9, so that the whole multiplication table is represented. Each of these products is expressed by two elements (tongues), of which one gives rise to the tens and the other to the units.

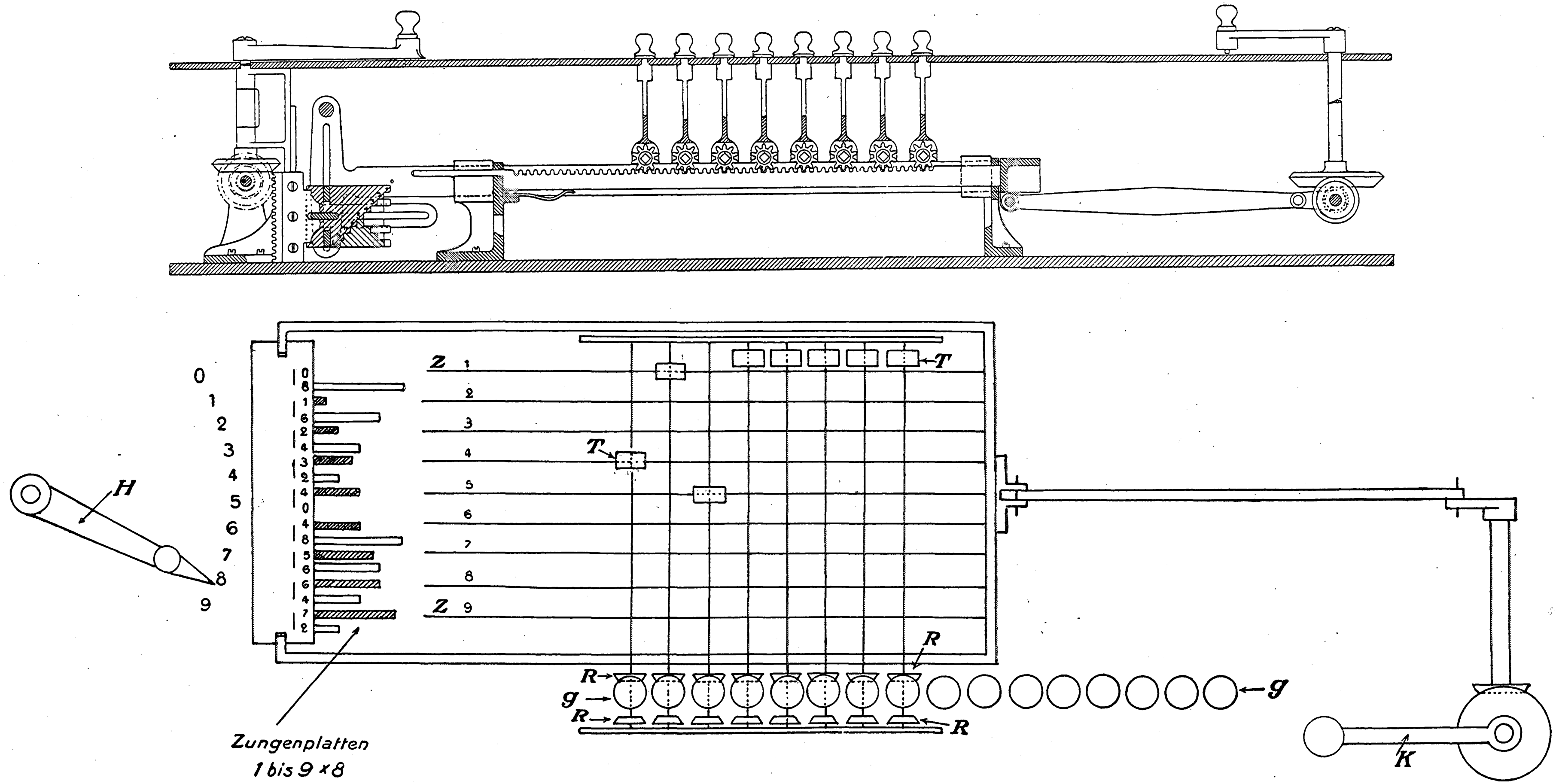
All the tens of a tongue-plate form a group by themselves, as also the whole of the units, and these groups act one after another, with the carrying mechanism and the recorder.

An inspection of fig. 55 shows each individual product ; thus on plate 7 for the factor 6 we have 4 tens and 2 units, the product $7 \times 6 = 42$.

The *carrying mechanism* consists of :—

(*a*) Nine parallel toothed racks Z.
(*b*) The transverse axes, along which the pinions T are displaced by the knobs *e* on the indicating plate of the machine, and are thereby caused to engage with any one of the nine toothed racks, corresponding with a given position of the multiplicand.

On each of these axes is a pair of bevel wheels R, which can be moved along the axis. They transfer to the recorder the rotations of the pinions T, which correspond to the longitudinal motion of the racks.



FIGS. 56 and 57.—Mechanism of the "Millionaire" Calculating Machine.

By means of corresponding mechanisms for inward and outward movements these bevel wheels are periodically engaged and disengaged with the recorder, so that the latter is influenced only during the forward displacement of the toothed racks.

The ends of the racks rest against either the tens or the units group of the tongues of a tongue-plate. The change of the groups is accomplished through the small horizontal diagonal displacement of the multiplying pieces, while the adjustment of the various tongue-plates is secured by the movement of the lever H over a scale. By each turn of the crank K, *i.e.* by multiplication by a given factor, the racks are displaced first to the tens and then to the units.

Since the tens and units of the multiplying pieces are represented by equal length-units, it is necessary, after carrying over the tens-value, to displace the recorder one place to the left, so that the units-value is registered one place to the right of its ten-value.

The action of the calculating machine is thus explained. To make it clearer, an actual example will be taken.

Let it be desired, for instance, to multiply 516 by 8. Then by displacement of

the 1st knob *e*	(from the left)	the pinion T	is moved	to	the	rack	5
,, 2nd ,,	,,	,,	,,	,,	,,	,,	1
,, 3rd ,,	,,	,,	,,	,,	,,	,,	6

The multiplier is then set on the number 8 of the scale by the lever H, whereby the tongue-plate x by 8 is placed against the racks. During one rotation of the crank K the multiplying-piece is twice thrust against the racks Z, and these are displaced corresponding to the tens and units of the product of 1 to 9 times 8.

In our case, by means of the racks	5	1	6	
the products	$5 \times 8 = 40$	$1 \times 8 = 08$	$6 \times 8 = 48$	
are carried over, so that the apparatus first registers the tens . .	4	0	4	
to which, after these have been moved one place to the left, units are added		0	8	8
to obtain		← 1		
the product	4	1	2	8

For every rotation of one of the figure-dials of the recorder in the positive or negative sense above 0 (or 10) ± 1 is added to the next left-hand dial.

The following summary shows the sequence of the various operations in the calculating machine during one rotation of the crank :—

Rotation of the crank K from 0°–360°.	
0°	Coupling of the bevel wheels of the carrying mechanism with the recorder.
0°–90°	Carrying over of the tens and addition to the amount already recorded, giving the tens.
⟶	Uncoupling of the bevel wheels from the recorder.
90°–180°	Idle return-stroke of the racks. Displacement of the recorder to the left. Carrying over of the tens resulting from the addition.
⟶	Coupling of the bevel wheels with the recorder. Diagonal displacement of the multiplying pieces.
180°–270°	Carrying of the units and addition to the tens already obtained.
⟶	Uncoupling of the bevel wheels from the recorder.
270°–360°	Idle return-stroke of the racks and carrying of the tens obtained by addition.
⟶	Diagonal displacement of the multiplying pieces to their original position.

The construction of the " Millionaire " calculating machine is strong and reliable. The machine has been on the market for fifteen years, and as early as 1912 there were over two thousand in use.

Examples to illustrate Speed

(*a*) Multiplications :

350·729 × 357	= 125210·253	in 2 or 3 seconds.
18769423 × 23769814	= 446145693597322	,, 6 ,, 7 ,,
$716^2 \times 535^2$	= 798881	,, 8 ,, 9 ,,

(*b*) Eight factors ; leading digits :

$$\left.\begin{array}{r} 125 \times 37572 \\ 4212 \times 8014 \\ 9 \times 277 \\ 50803 \times 7899 \end{array}\right\} = 439746858 \text{ in 30 or 35 seconds.}$$

(10) The Thomas de Colmar Arithmometer.

The first machine to perform multiplication by means of successive additions was that of Leibnitz, which was designed in 1671 and completed in 1694. It employed the principle of the "stepped reckoner." This model was kept first at Göttingen and afterwards at Hanover, but it did not act efficiently, as the gear was not cut with sufficient accuracy. This was long before the days of accurate machine tools.

The first satisfactory arithmometer of this nature was that of C. X. Thomas, which was brought out about 1820. It is usually called the Thomas de Colmar Arithmometer. It is still a useful machine, but its place is now being taken by lighter and better types.

The fundamental principle of the mechanism is illustrated in the diagram. C is the carriage, which, when raised, may slide and turn about a horizontal axis. It carries on its face the product holes, and the multiplier holes, with their indicators, and also two milled heads M, which engage with racks and springs for clearing the digits.

On the body of the machine there are from six to ten slots bearing on their edges the multiplicand digits, with studs S, which are set to the required values.

Any stud S shifts, by sliding, the pinion B′ along its axis *b*, so as to engage with the requisite number of the unequal teeth on the barrel of the stepped reckoner A. The cross-section of the axis *b* is square. H is the handle by which the machine is worked. It rotates the vertical spindle shown, and the pair of bevel wheels at its base drive the stepped reckoner A. Thus B′ for

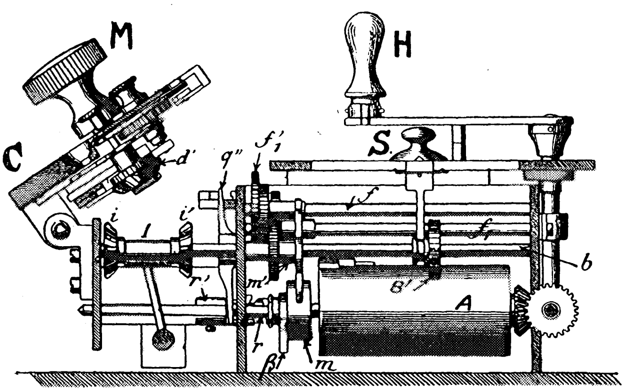


FIG. 58.—L. Jacob, *Le Calcul Mécanique*. (Doin, Paris).

one revolution of H gives a rotation to *b* corresponding to the digit at which S is set.

If the carriage C is lowered so that the bevel wheels *d′* and *i′* engage, this rotation is conveyed through *d′* to the indicators of the product holes, where the result appears. Multiplication is thus performed by successive additions.

For subtraction the sleeve I is pulled by a small lever along the axis of the shaft *b*, so that the other edge of *d′* engages with *i*, and thus a negative rotation is communicated to the indicators of the corresponding product holes. Division is effected by successive subtractions.

For the carrying device there is a cam on the spindle of the number wheel of the product indicator in the sliding carriage. As the indicator number changes from 9 to (1) 0, a pin on this cam shifts a lever in the body of the machine. This moves a sliding piece which, by a suitable arrangement, rotates the next indicator axle by one tooth and so produces the required result.

In some of the recent forms of Thomas Arithmometer there are twenty product holes.

The Tate Arithmometer is similar in construction to the Thomas. See *Die Thomas'sche Rechenmaschine*, by F. Reuleaux, 2nd ed., Leipzig, 1892.

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

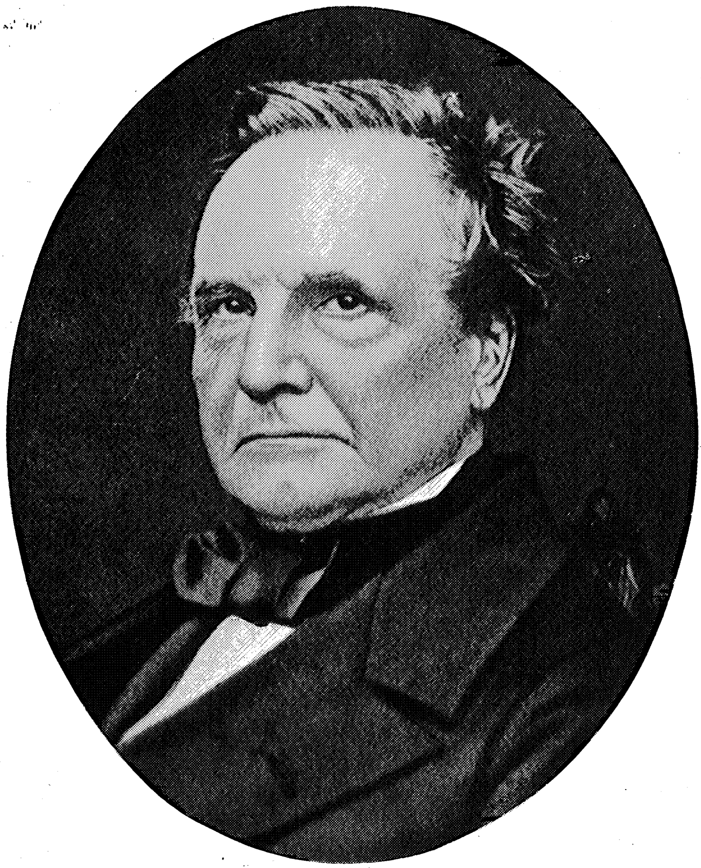
Automatic calculating machines on being actuated, if necessary, by uniform motive power, and supplied with numbers on which to operate, will compute correct results without requiring any further attention. Of course many adding machines, and possibly a few multiplying machines, belong to this category; 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 $\div$ 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

$$+ \quad \times \quad - \quad \div$$

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 $\dfrac{a(b+c)}{d-e}$ 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,

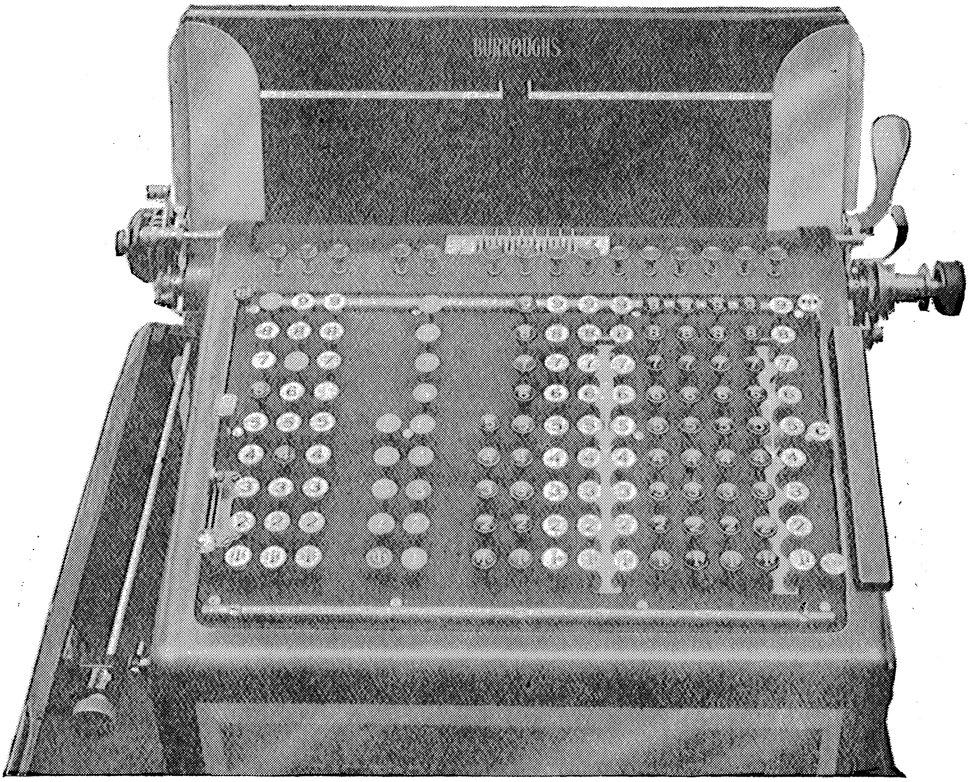


FIG. 1.—The Keyboard.

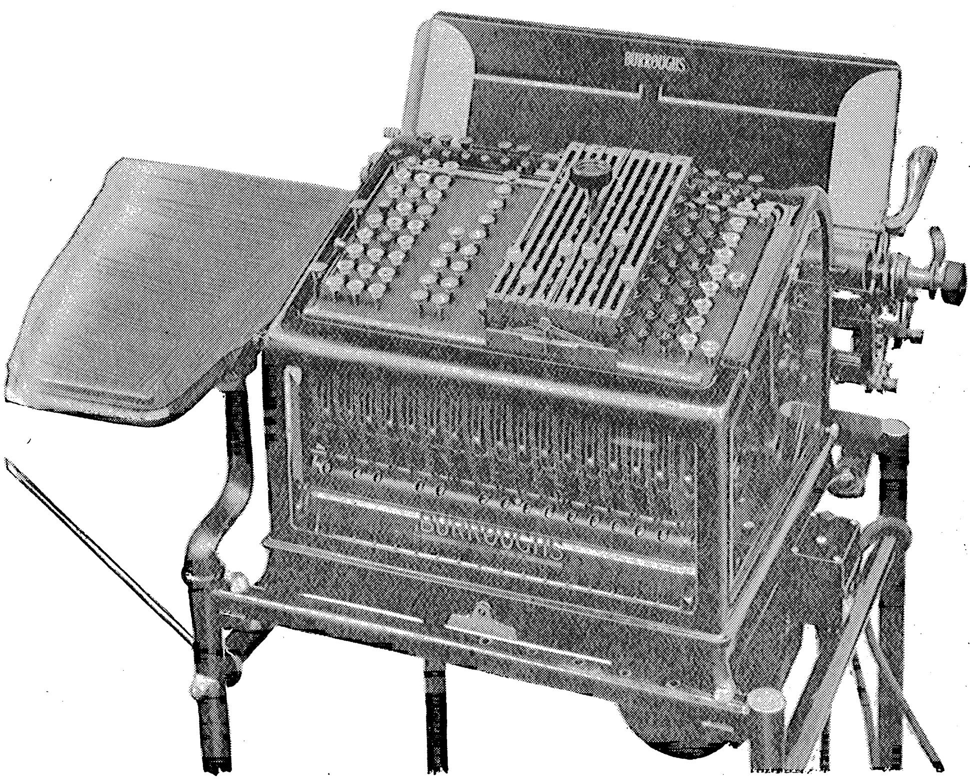


FIG. 2.—The Keyboard, showing the Multiplying Device.

seconds, and fractions. Its full capacity is shown by the figures $999^h\ 59^m\ 59^s{\cdot}999\ 9999\ 9$. Within these limits it will work to any degree of accuracy required, great or small. It will also record the result either to that same degree of accuracy (number of figures) or to any lesser degree. Thus, the machine may allow for a greater number of digits than it is required to record

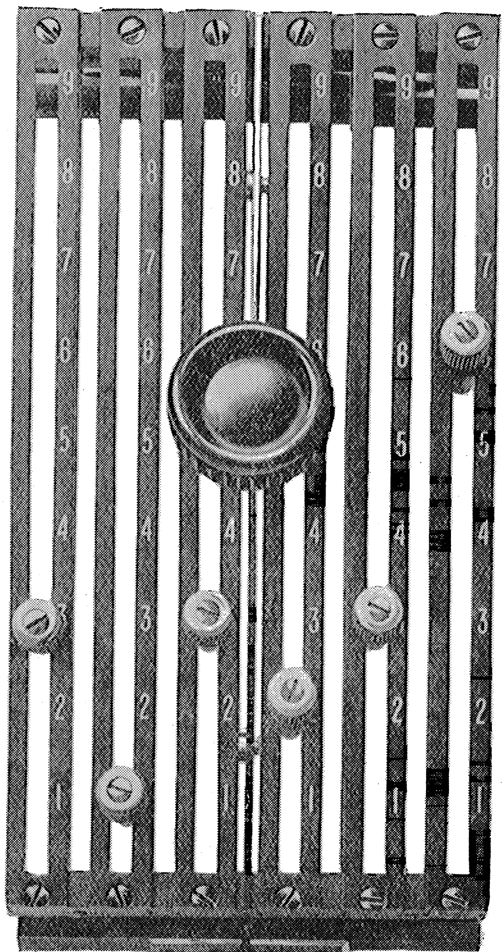


FIG. 3.—The Multiplying Device.

in the result. This feature is of obvious utility in table-making. The machine will *subtract* as well as add.

In particular, the machine fulfils the special purpose for which it was designed, namely, the production of serial quantities (for example, ephemeris quantities), of which every eighth, tenth, or twelfth (as the case may be) has been previously computed in full, but the last digit, *only*, of the seven, nine, or eleven intermediate quantities found accurately in groups by a pair of "graphs." Examples occurring in practice are:

The daily Heliocentric Places of Venus, computed first at eight days,
,, ,, ,, Mars ,, ,, twelve days,
and the Moon's Hourly Places, computed first at twelve hours.

Another example is the production of the Sun's Co-ordinates for noon and midnight from the original computations for noon only. In this case also it suffices to predetermine the last digit, and the last digit only, of the midnight quantities and entrust the completion to the machine.

In some cases (for instance, the Heliocentric Places of Uranus and Neptune) the quantities may be very nearly in arithmetical progression, that is, the First Differences may be very nearly constant. It is therefore desirable that all the Keys, except the one for the last digit, should be depressed in one operation only, so as to obviate needless attention, repetition, nerve action, loss of time, and danger of error. This assistance is given by an accessory, by means of which a set of key-depressors act collectively instead of human fingers acting individually (see fig. 3).

An example of actual work done on this machine is shown in the illustration below, with accompanying explanation.

EXAMPLE OF INTERPOLATION COMPLETED BY A SPECIAL BURROUGHS MACHINE.

	Heliocentric Longitude of MARS.				Heliocentric Longitude of MARS.	
				(35 13,51)		
1923 Jan.13	(·31 21 51)	,31	(3,22)		31 21 51,31	1923 Jan.13
		9		35 10,29		
		0 4	3,24		31 57 01,60	14
		5		35 07,05		
		5 5	3,25		32 32 08,65	15
		0		35 03,80		
		5 6	3,26		33 07 12,45	16
		4		35 00,54		
		9 8	3,28		33 42 12,99	17
		6		34 57,26		
		5 8	3,28		34 17 10,25	18
		8		34 53,98		
		3 9	3,29		34 52 04,23	19
		9		34 50,69		
		2 1	3,31		35 26 54,92	20
		8		34 47,38		
		0 2	3,32		36 01 42,30	21
		6		34 44,06		
		6 3	3,33		36 36 26,36	22
		3		34 40,73		
		9 4	3,34		37 11 07,09	23
		9		34 37,39		
		8 4	3,34		37 45 44,48	24
		5		34 34,05		
1923 Jan.25	(38 20 18)	,53			38 20 18,53	1923 Jan.25

DATA. MACHINE WORK.

PROCESS :- First stage:- Second stage:-

```
35 13,51
    3.22   31 21 51,31
35 10,29-----35 10,29
    etc .  31 57 01,60
                 etc .
```

Illustration showing a wrong over-print during the second stage:-

34 34,05

An interesting use of the machine which is made possible by the device of "splitting," is the summing of two or more groups of terms at the same time. In this way the synthesis of small anharmonic quantities may be rapidly performed in conjunction with Professor E. W. Brown's device (*Monthly Notices of the Royal Astronomical Society*, vol. lxxii., No. 6, April 1912). It is well to notice that a mistake can easily be located without the need for doing the work again, seeing that all items are *recorded*.

Explanation of the Above Example.

By work previous to the machine 31° 21′ 51″·31 and 38° 20′ 18″·53 have been calculated from Newcomb's Tables for January 13 and 25 respectively.

Also, the last digits of the interpolated place for the intervening days have been predetermined, viz. 0.5.5.9.5.3.2.0.6.9.8, by (fundamentally) the well-known methods of interpolation, modified, however, to take advantage of the capabilities of the machine.

From the last digits of the longitude the last digits of the first and second differences are written down.

The process being supposed already complete up to January 13, it is then easily seen that the " 4 " of the second difference for January 14 means −3″·24, and all the second differences could now be easily set down in full.

The machine then builds up the first differences from the second differences, and subsequently the longitude from the first differences.

The guarantees of accuracy are:

(i) That the longitude calculated for every twelfth day is reproduced, *e.g.* 38° 20′ 18″·53 previously calculated from Newcomb's Tables is obtained by adding the first difference 34′ 34″·05 to 37° 45′ 44″·48.

(ii) When the human brain is relied upon to use differences, it is apt occasionally to make mistakes of the following nature:—34′ 34″·05 being taken as the quantity generated from the second differences, 34′ 34″·15 may be used as the quantity generating the interpolated longitude: and no record of the mistake is preserved. If the machine-operator makes a mistake of this nature, the result is that a " 1 " is printed over a " 0," as illustrated at the bottom of the example. This should not fail to catch the eye of the operator—in fact, a glance shows that in all the first differences of the example, the over-printed quantity is identical with the quantity below.

(2) Special Exhibition of the Nautical Almanac Anti-Differencing Machine. By T. C. Hudson, B.A., of H.M. Nautical Almanac Office; by the courtesy of P. H. Cowell, M.A., D.Sc., F.R.S., Superintendent of the Nautical Almanac.

III. Mathematical and Calculating Typewriters.

(1) The Hammond Typewriter Co., Ltd.

THE new Multiplex Hammond Typewriter will write in either of two languages at a time, or in two different styles of type in any one language by merely turning a button. It has 350 different sets of type distributed over thirty languages which may all be used on the same machine, owing to the unique *interchangeable feature of the machine.*

There is no loose type, with a character on each type bar, as in other writing machines. In the Hammond the type is cast all in one piece, as in a

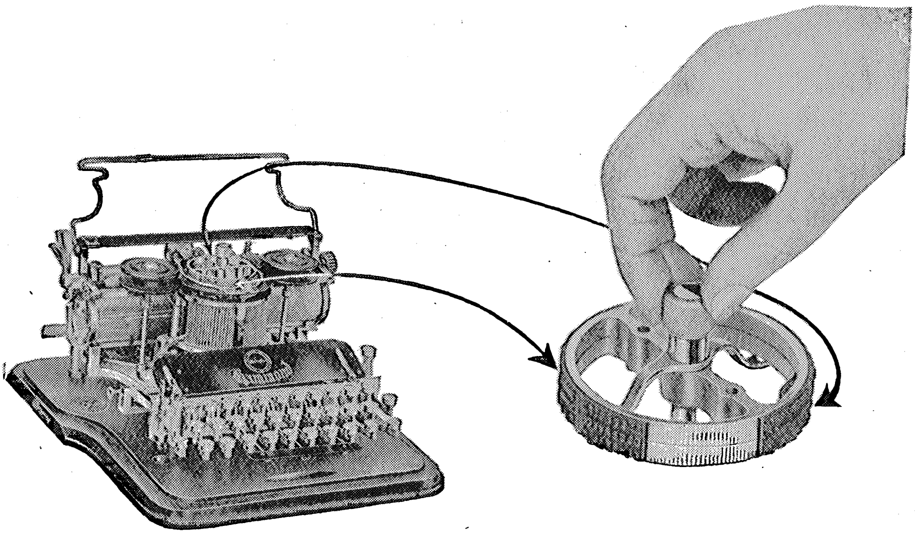


FIG. 1.

printing machine, and the operation of writing is performed upon a unique principle. Instead of type bars striking the paper through a ribbon, or by means of a pad, as in other machines, in the Hammond the paper is struck from *behind* with a constant blow, making every impression absolutely uniform, and giving any depth or intensity to the impression, according to the strength of the hammer blow, which can be varied by the operator at will.

This automatic action of the Hammond enables anyone who is not a typist to execute perfect work without any practice, because there is no touch *to learn, the impression being automatically uniform,* regardless of the operator's blow on the keys.

On one machine at one time there are always two different sets of type, each with either 90 or 120 different characters ; *instant change by the operator being possible*—even in the middle of a sentence.

The wide range of symbols provided makes it possible for the scientific man to write on the one machine almost any formula in mathematics, or to employ almost any language.

The Hammond Company show also a special mathematical model which will write any expression in the calculus and in higher mathematics generally, the same machine writing an ordinary letter in any language.

Greek, Turkish, Persian, Punjabi, Nagari, Arabic, Sanskrit, and many other Oriental languages are included. Where necessary the carriage operates in the reverse direction at the touch of a button.

It may be thought that such a versatile machine must necessarily be complicated, but, on the contrary, the Hammond claims to contain less than half the number of parts in any other standard typewriter. It is also portable.

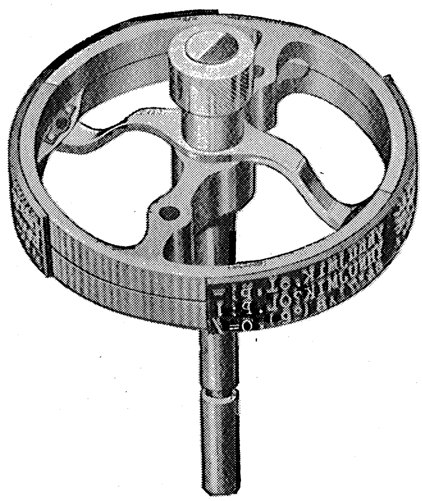


FIG. 2.

BARRETT ADDING MACHINE

The portable Barrett Adding and Computing Machine represents one of the most recent developments in calculating machines. It is simple in construction and claims to have 1100 parts less than the nearest competing machines.

No skilled operator is required, and the extreme portability of the Barrett enables it to be carried to the work.

It is made in over fifty different models, and in several styles, currencies, weights and measures.

EXHIBITS

1. One sterling, ten-column Barrett non-listing machine.
2. One decimal, ten-column, non-lister, with mezzanine keyboard.
3. One Mathematical Multiplex Hammond, containing *two complete sets of type, one for every expression* in higher or lower mathematics, and the other, one type out of 350 different styles in thirty languages.
4. One ordinary Multiplex Hammond, with universal keyboard, designed for scientific or professional use.

(2) The Monarch Wahl Adding and Subtracting Typewriter

This is an attachment to an ordinary correspondence typewriter, so arranged that the mechanism will add and subtract at will the figures placed in one or more columns as they are typed.

The actuator mechanism which lies in front of the machine is connected with the key levers which actuate the bars carrying the figures. The motion of these bars is communicated by the actuator to one universal gear wheel. When the key 1 is depressed, the universal gear wheel moves 1 tooth, and when the figure 9 is depressed, the universal gear wheel moves 9, and so on.

The other part of the mechanism is a totaliser which is carried on a truck immediately over the actuator, and is so arranged that the gears of the totaliser

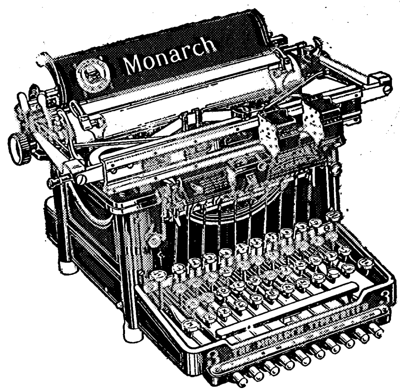


Fig. 3.

engage with the universal gear of the actuator. It will be seen that when the totaliser, which of course moves with the carriage, arrives at a position, say, for writing pounds, whatever amount is written will be recorded from the actuator to the totaliser.

The machine is fitted with a tabulating device which enables the operator, by a touch of the key, to place immediately the carriage carrying the totaliser in the correct position for typing predetermined amounts. For instance, if the operator wishes to write £342, 3s. 11d., he presses the tabulator key marked hundreds, and the carriage will then immediately travel to the correct position for writing the amount in question.

This tabulator works by means of stops which are carried in a magazine at the back of the tabulator. These stops, by one simple movement of the lever, are taken out of the magazine and deposited on the tabulator rack in any desired position. If it is desired to alter the setting of these stops, the " clear " lever will immediately take the stop off the rack and put it back in the magazine.

In the ordinary way the machine will of course add, but the mechanism can be reversed by a touch of the lever and the machine will then subtract.

There are numerous safeguards provided to prevent improper operation. If the operator starts to depress a figure key, the machine will automatically lock until that key has finished its complete movement, and, in a similar way, that particular key cannot be depressed a second time until it has completed entirely its first movement. The totaliser, which is locked on the totaliser bar, can be removed, but immediately it is removed from the machine all its wheels are locked, and they cannot be moved until the totaliser is put back on to the machine.

When a two-colour ribbon is used, the colour of the writing, which changes automatically with each movement of the subtracting lever, shows whether the machine is adding or subtracting, and distinguishes clearly the subtractions on the page from the additions.

The machine is also provided with a disconnecting lever, the movement of which disconnects entirely the adding actuator from the figure keys, so that the machine becomes an ordinary typewriter.

The typewriter portion of the instrument is actuated by a nearly horizontal lever of the second species, called the key lever. At one end is the key, which is depressed by the operator, and at the other a fulcrum which is not fixed, but movable. Between the two is an attachment to a bell-crank which works the type-bar.

A feature of the machine is this change of position of the fulcrum. This is effected by making the upper edge of the fulcrum end of the lever slightly convex upward, and engaging with the lower side of a fixed plate, either horizontal or slightly convex downward. As the key is depressed the fulcrum moves from a position near the bell-crank attachment to a position far away. Thus there is an easy start, as the inertia of the moving parts is overcome rapidly, and the type-bar gives its stroke at its greatest speed, so that a sharp impression is formed.