AN INGENIOUS CALCULATING MACHINE

A Machine Which with Any Digit Multiplier Requires but One Turn of the Crank to Obtain the Product—Mechanism not so Complex as it Appears

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When a machine designed to perform the four elementary arithmetical operations with rapidity and accuracy, and capable of handling a pretty good-sized string of figures, is opened up so as to disclose its multiplicity of wheels, bars, cranks, rods, springs, pawls, framework, racks, and other mechanical elements of shining brass, steel, aluminum and iron, it looks to the uninitiated like a somewhat formidable task to unravel the complicated relations between all these parts, and to find out how they perform operations which are usually accomplished by the human mind in a still more mysterious manner. When one attempts to make clear the principles upon which such a machine works, it is difficult to avoid making the exposition as formidable in appearance, with its diagrams, details, numerous reference letters, etc., as the machine itself; in fact, of the two, the written article is likely to look less inviting. However, anyone who is interested in calculating machines, or who derives a pleasure from the mental exercise, will be well repaid if he has a little patience and follows through the movements in the ingenious machine which is the subject of this article; an effort will be made to make the principles clear, using a few simple examples, without entering upon an exhaustive study of the mechanical construction, or considering all the minor details, such as interlocking and safety devices. It should be remembered that the appearance of complexity is in part due to the repetition in the machine, several times over, of certain sets of parts, exactly alike and performing exactly the same functions in their particular places.

The standard size of the "Millionaire" calculating machine, shown in Figs. 1 and 2, is capable of multiplying together factors each having eight places of figures and giving a product having 16 figures. Larger and smaller sizes are also made. The largest one can reach 10 places each in the multiplier and multiplicand, and 20 places in the product. The machines can also add, subtract and divide.

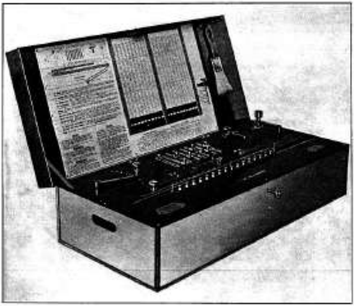

FIG. 1. MILLIONAIRE CALCULATING MACHINE WITH 16 PLACES IN THE PRODUCT

GENERAL VIEW OF THE MACHINE

Fig. 2 is a view looking down on top of the machine, showing all the handles for operating it and all the indicators of figures. Fig. 3 is a line drawing giving a similar view with reference letters. This is a portion of the machine with which everyone must become familiar, even if he desires only to operate the machine without understanding its internal mechanism. The following are the parts referred to:

K, the crank which sets the machine in motion after all the settings have been made for any desired operation. It should be stated that the machine illustrated is operated by hand power. One turn of the crank about its vertical axis, in a clockwise direction, is made for each operation, and the crank is normally in the position shown, which we shall call "at home." No other part should be moved or have its adjustment changed, except when the crank *K* is at home.

U, the regulator lever. There are four positions for this, and it is placed in one of the notches marked *A*, *M*, *D*, or *S*, according to whether it is desired to have the machine perform addition, multiplication, division or subtraction.

In the middle of the back portion of the cover is a row of slots extending from back toward the front, with figures from 0 to 9, and extending through each slot is a handle and pointer or "marker" *e*. In front of the slots are openings (*e'*) through which appear the figures corresponding to the positions of the markers, the object of these being to permit reading the amount set up on the markers in one straight line instead of a zigzag one. The markers *e e* are used to set the amount to be added in addition, the subtrahend in subtraction, the multiplicand, or the divisor.

H, which may be called the multiplication lever, is set in the position corresponding to the multiplier or quotient; in addition and subtraction it is placed at the figure 1.

We now come to the traveling parts. In the front portion of the cover there are long slots, through the back one of which appears a portion of the traveling carriage having openings *f f*. Through these are shown figures on the indicator dials, which show automatically the multiplier or the quotient. This is a convenience, not an absolute necessity, for the operator could carry these figures in his head, or write them down with a pencil. It is a useful check upon the movements he has gone through in operating the machine.

Showing through the front slot is a very important row of dials, viz., the result dials *g g*. Upon these appear the amount in addition, the remainder in subtraction, and the product in multiplication. In division the dividend is set up on them, usually by turning the stems of the dial spindles individually by hand.

W is a knob for shifting the carriage by hand.

C and *R* are the "effacing knobs," by the sliding of which to the right, the dials *ff* and *gg*, respectively, are all set to 0.

Between the individual dials of the three rows *e'*, *f* and *g* are holes for removable studs, used for marking the decimal points.

THE INTERIOR

Upon opening the machine up, we find in the front the traveling carriage, upon which the *ff* and *gg* dials are mounted, which connect the cross-head 5 to the pusher frame, is a group of nine sliding racks *Z*; and back of them one fixed rack. These racks all have the same number of teeth, and with the exception of the fixed one are subject to varying amounts of travel by action of the rack-pusher plates. There are nine horizontal rows of pusher plates of varying lengths, as shown in Figs. 6 and 7.

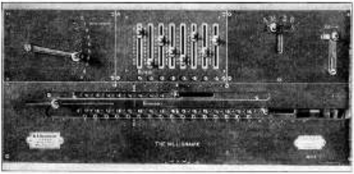

FIG. 2. VIEW SHOWING TOP OF THE 8-PLACE FACTOR, 16-PLACE PRODUCT, MACHINE

two shafts 2 and 3 with gearing, clutches, cams, etc. Fig. 4 is from a photograph showing the mechanism left after removing the top plate and the markers *e e*, the front, back and ends of the case, the traveling carriage and the front shaft 3. In the back left-hand corner is the "pusher frame," the position vertically of which depends upon the position of the lever *H*; this frame has a small transverse motion produced by the cam 4 on the left-hand end of the shaft 2, and has a stroke back and forth produced by its connection to a cross-head 5, which in turn is caused to reciprocate by the crank 6 and connecting rod 7 in the right-hand back corner. (Refer also to the diagram, Fig. 6.) Lying between two long bars 8,

In the middle of the length of the machine, just above the racks, are several horizontal square shafts 9, having pinions 10 which slide on them under the control of the markers *e e*, so that any of them may mesh with any one of the racks. In Fig. 21 is shown one of the shafts with its pinions. When the markers *e e* are set at 0, the pinions are in mesh with the fixed rack, which serves merely to hold them in their normal positions. The shafts have at their back ends rose-wheels with ten notches, and pawls, so as to make them stop and hold them at the proper divisional points of their revolution. To the left of the square shafts is a round shaft 11 (Fig. 4), with a pinion always in mesh with the No. 1 rack, that is, the sliding rack farthest back. This shaft is for driving the indicating dials *ff*, as will be explained later. The front ends of the shafts extend underneath the carriage, where they serve to drive the dials of the carriage by means to be explained later.

At the right-hand end of the machine is a vertical shaft carrying the hand crank *K*, which, as already stated, drives the whole machine. The method by which it drives the horizontal axis crank 6 and connecting rod 7 are pretty well indicated in Figs. 6, 9 and 19. The bevel gears by which it drives the shaft 2 are well shown in Figs. 4, 8 and 19. The method by which the shaft 3 running along just inside the front of the box is driven is apparent in Fig. 8.

The following table is given for reference, to make it easier to understand the relative motions: it shows the number of revolutions made by the principal shafts to one revolution of the crank *K*, which may be called one cycle of movements:

Mark.	Direction of Shaft.	Number of Revolutions per Cycle.
K	Vertical	1
1 (Crank Shaft).	Horizontal	2
2 (Helical Cam Sh't)	"	1
3 (Cam-drum Sh'ft)	"	1

The effect of the variations in the position of the regulator lever *U* and the mechanism which it controls will be described later.

Fig. 5 shows the traversing carriage and the cam-cylinder shaft 3 removed from the machine. The openings for the *ff* and *gg* dials are visible in the top plate, also the projecting "effacing knobs" *C* and *R*, and the carriage-shifter knob *W*. At the left is a bell which rings when the machine has reached its limit or when a mistake is made in division, and in front on the shaft 3 is the cam cylinder, the object of which is to "carry the tens" in the operation of the *gg* dials, as will be explained later.

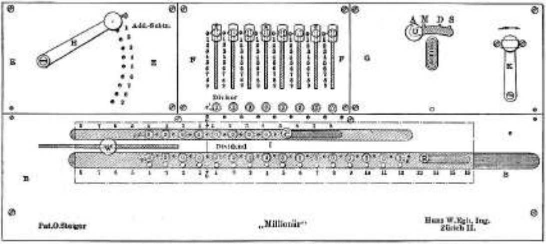

FIG. 3. PLAN OF TOP OF MACHINE, SHOWING OPERATING HANDLES, INDICATING DIALS, ETC.

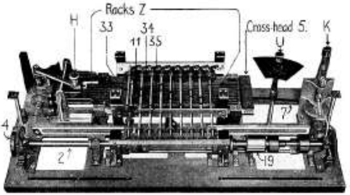

FIG. 4. BASE-PLATE AND MECHANISM; TRAVELING CARRIAGE AND FRONT SHAFT REMOVED

THE PRINCIPAL GROUPS OF MECHANISM

It is believed that the action of the mechanism can be most readily made clear by taking up one group at a time and examining its performance during the different arithmetical operations.

The principal groups of mechanism are partly shown diagrammatically in Fig. 6 and are, first, a mechanical multiplication table, which is one of the most prominent features of the machine, and which consists of a series of vertical notched or stepped plates, here called rack-pusher plates; for each multiplier there are two plates—one for the tens and one for the units—which act one after the other. The range of this table is from 0×0 to 9×9, inclusive. This part of the mechanism also includes the means for giving the required motions to the pusher plates. Second, a transferring mechanism, which transfers the partial products to the third mechanism. The second consists of the racks, pinions and square shafts. The third is the combining and registering mechanism, which is mostly carried by the sliding carriage. This takes the partial products from the transferring mechanism and combines them so that the result is exhibited on a row of dials. There is, furthermore, the indicating mechanism which has already been referred to as a useful auxiliary.

THE RACK-PUSHER PLATES

Fig. 7 is a series of horizontal sections through the battery of pusher plates, which are arranged vertically in pairs, the tens plate of each pair being toward the back of the machine, and being indicated on the diagram by cross-hatching. The

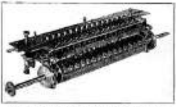

FIG. 5. TRAVELING CARRIAGE AND FRONT SHAFT 3

units plate of each pair is toward the front of the machine, and is indicated by being left without section-lining. The tens and units notches for each product are on the same level. It will be seen that at some levels the plates are in some places notched back to the datum line, so that no tongues project; for instance, in the top row, where the multiplier is one, there are no tens tongues at all, which of course follows from the fact that the highest possible product here is $9 \times 1 = 9$, hence no tens are required. The rack pushers are all fixed together like one body, and make two outward (toward the right-hand end) strokes per cycle. During the first stroke the tens plates are opposite the racks and push them, if there is any pushing to be done; during the second stroke the battery of pushers is shifted over by the cam 4, Figs. 3 and 8, so that the units plates come opposite the racks and push them. The shifting is so timed that it occurs when the pushers are not touching the racks. The mechanism by which the crank *H* regulates the hight of the battery of pusher plates and therefore the level (Fig. 7) which comes into action with the racks, is partly visible in Figs. 4 and 9, consisting of bevel gears and two pinions on a horizontal axis, driving two parallel vertical racks. A horizontal notched locking bar is operated by the motion of the cross-head 5, Fig. 9, sliding through the notches in a vertical square-toothed rack, which rises and falls with the pusher frame. This prevents vertical motion of the pusher frame except when the crank *K* is at 0 or 180 degrees; of course there is very little chance of an attempt being made to move the handle *H* in the latter case.

It is believed that the explanation of the action of the pushers will now be intelligible. This will be followed by tracing the action through the racks, pinions, and square shafts to the carriage mechanism, until the result is shown on the dials *g g*.

As may be seen from Fig. 2 and Fig. 3, when it is desired to perform addition or subtraction the handle *H* is placed at the No. 1 hole, so that the battery of rack pushers is in the next to lowest position. We will speak of the two outward strokes which occur in the first and second revolutions of the crank 6 as the "first push" and the "second push," respectively.

ADDITION

First push—The upper row of pushers, shown in Fig. 7 as the one-multiplier row, is opposite the racks. As there are no tens tongues at this level, no racks are pushed.

Second push—The pusher frame is

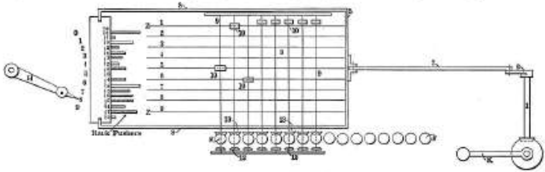

FIG. 6. DIAGRAM REPRESENTING THE MULTIPLICATION RACK-PUSHERS (AT "X 8 LEVEL"), THE TRANSFERRING MECHANISM, AND THE BEVEL-GEARS OF THE REGISTERING MECHANISM

shifted over by the cam 4, Fig. 8, and the units pushers or tongues are brought in line with the racks, and

No. 1 rack is pushed to the right one tooth,

No. 2 rack is pushed to the right two teeth,

No. 3 rack is pushed to the right three teeth,

etc., to

No. 9 rack is pushed to the right nine teeth.

The racks remain in these positions until the cross-head 5, upon its return motion to the left, hits the right-hand ends of the racks, starting with No. 9, which is sticking out the farthest, and pushes them all back to their normal positions.

ACTION OF THE RACK PINIONS, SQUARE SHAFTS, AND THEIR BEVEL GEARS IN PERFORMING ADDITION

When by means of the markers *c c*, the pinions 10 have been placed in engagement with any of the moving racks, they are, on the second push, caused to rotate as many teeth as the racks with which they meshed have slid. This, of course, causes the square shaft 9 and the two miter gears on it (see 12 and 13, Figs. 6 and 10) to turn the same amount.

Normally, the vertical miter gears 12 and 13 are not in engagement with the horizontal miter gear 14 on the *g* shaft which lies between them. However, in addition or multiplication, they are caused, twice in the cycle, to slide forward on the square shaft, that is toward the front of the case, so that the back miter gear 13, meshes with the horizontal miter gear 14, as indicated in Fig. 10. In performing addition, there is during the first half of the cycle, as explained under pusher-plate action, no rack movement and hence no rotation; during the second half the rotation which the square shaft receives from the rack is communicated to the vertical shaft and causes an increase in the number shown at *g g*. Before the backward movement of the racks and square shafts, the miter gears have been returned to their normal positions and thus thrown out of mesh with the horizontal miter gear 14, so that the backward motion is not communicated to the dials *g g*. This sliding motion of the miter gears on the square shafts is produced by a brass bar, which lies between them and which makes two "round trips" per cycle, being moved by two curved iron arms which reach up around the shaft *z*. These arms are mounted on a horizontal rock shaft 15, which runs along the floor of the machine below the carriage but does not slide with the carriage. At its right-hand end this rock shaft carries a rocker arm 16, Fig. 10, with two cam rolls. For addition and multiplication the one on the left is in engagement with the cam 17; for division and subtraction the one on the right is in engagement with the cam 18, and these two cams are shifted along the shaft with the clutch 19, by the movement of the lever *U*. The left-hand elevation in Fig. 10 is an end view of the cam 17 and indicates the direction of engaging movement of the miter gears 13, when addition or multiplication is being performed. It will be remembered that the shaft upon which these two cams are mounted makes one revolution per cycle, or in other words, its motion is synchronous with that of the hand crank *K*. During the first quarter turn of *K*, the gears 13 and 14 are brought into engagement by the action of the cam shown; during the next quarter turn the cam causes them to be disengaged; and during the third and fourth quarters the meshing and unmeshing is repeated.

During division or subtraction the two lever arms make two round trips per cycle in the opposite direction, because this time they derive their motion from the cam 18. Thus it is, this time, the front miter gears 12 which are brought into mesh with the horizontal miter gears 14, so that the turning of the dials *g g* is in the opposite direction, or backward, during division or

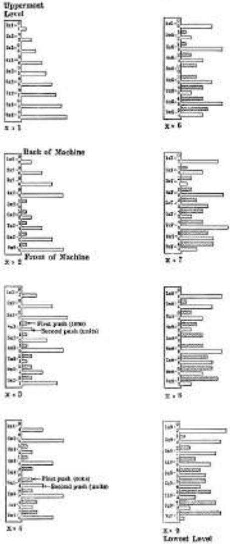

FIG. 7. HORIZONTAL SECTIONS (LOOKING DOWNWARD) THROUGH THE RACK-PUSHERS AT THE DIFFERENT LEVELS CORRESPONDING TO THE DIFFERENT DIGIT MULTIPLIERS

subtraction. The second elevation in Fig. 10 is an end view of the cam 18, which produces this action. It will be noticed that the rolls of the two cams are not in line with each other.

ACTION OF THE PUSHER BARS AND SUCCEEDING PARTS IN SUBTRACTION

The minuend is indicated on the *g g* dials, either having remained there from some previous operation or being placed there by turning the projecting handles or on the third and fourth square shafts, so that the third pinion meshes with the No. 4 rack and the fourth pinion with the No. 6 rack. The pushers are raised to No. 1 (addition and subtraction) notch. Upon turning the crank *K* the racks are pushed exactly as in addition, but since it is the miter gears 12 that are in mesh this time, as described in the preceding section, the dials *g g* are turned backward, the decimal counting mechanism being thrown into

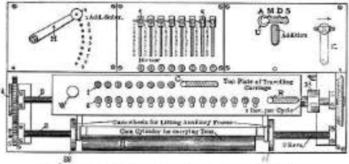

FIG. 8. PLAN OF MACHINE AFTER REMOVAL OF TOP PLATE B, SHOWING TRAVELING CARRIAGE

stems on the *g g* shafts. The subtrahend, or number to be subtracted, is indicated by the markers *e e*, which slide the pinions on the square shafts. The carriage is placed to bring the decimal points correctly in line one above the other. The lever *U* of course is at "S."

Example: 412 — 46 = ? We will set the 412 on the third, fourth and fifth *g g* dials, counting from the left, and the 46 action at the change from 0 to 9, so that the remainder near the end of the operation reads 476, which is changed, when the cams on the cam drum 21 come around and hit the two pins 30 corresponding to the third and fourth *g g* dials, to 366. The action of this decimal-counting mechanism or ten-carrying mechanism will be explained in detail later on. The *f* dial shows "1."

ACTION OF THE PUSHER BARS AND SUCCEEDING PARTS IN MULTIPLICATION

To illustrate the working of the machine, we will start at the simplest possible case and advance to more complicated ones, all of them, however, much simpler than the machine would ever be used for, but being sufficient for this purpose.

Example: 1 × 1. Carriage at extreme right. Left-hand sliding pinion in mesh with rack 1. Pushers raised to second notch on the vertical rack. During the latter part of the first half-revolution the carriage moves one step to the left, as explained under carriage travel.

During the second half-revolution the pushers are shifted over by the cam 4, Figs. 4 and 8, so that the top row of pushers is in line with the racks, and the racks are pushed just as in addition or subtraction, viz.:

Rack 1 moves to the right one tooth,
Rack 2 moves to the right two teeth,
etc., to
Rack 9 moves to the right nine teeth.

After the movement of the carriage, the second *g* dial is in line with the left-hand square shaft, so this dial is rotated to 1, which is the product (see "Action of the Rack Pinions, Square Shafts, and their Bevel Gears."). Also, the first or left-hand *f* dial is brought in line with the round shaft (see "Drive of the Dials *f f*"), and it is rotated one unit during the outward stroke of the rack 1, thus indicating the multiplier.

Example: 1 × 2. Everything as before, except that the pushers are raised up to the third (or "2") notch. This

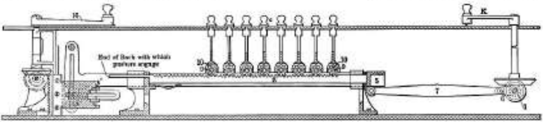

FIG. 9. LONGITUDINAL SECTION NEAR NO. 9 RACK, SHOWING PUSHERS, RACK, CRANK, AND CROSS-HEAD, SQUARE SHAFTS AND PINIONS, MARKERS, ETC.

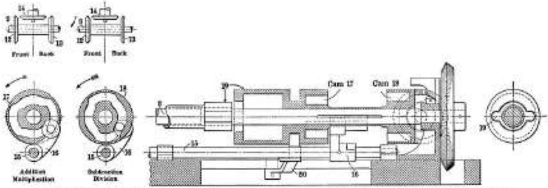

FIG. 10. CLUTCH CONTROLLING CARRIAGE TRAVEL; AND CAMS WHICH SLIDE THE BEVEL GEARS ON THE SQUARE SHAFTS

time something happens on the first half revolution, or first outward stroke of the pushers. The racks Nos. 5 to 9 inclusive are pushed one notch to the right *before* the carriage moves, which is therefore equivalent, in its effect on the reading of the result dials, to ten *after* the carriage moves. However, as no pinions are meshing with these racks (the multiplicand being only 1) this does not have any effect on the dials. The carriage, of course, traverses one pitch distance as before.

On the second half revolution, the pushers have shifted over horizontally backward, the second row, counting downward, coming into action.

Rack No. 1 is pushed two notches to the right, causing the left-hand *f* dial to be turned to 2, thus indicating the multiplier. Simultaneously, the second g dial from the left is turned to show the figure 2 through the round opening above it, thus indicating the product. The following are the amounts of movements of the racks at the second push:

No. 1	2 notches			
2	4	"		
3	6	"		
4	8	"		
5	0	"	which, added to the equivalent ten of the previous push, gives	10
6	2	"		12
7	4	"		14
8	6	"		1
9	8	"		1

Hence it will be seen that the aggregate equivalent movement of any rack, when the multiplier is 2, is twice as many teeth as the number to which that rack corresponds.

Rack No. 1 being the only one meshing with one of the pinions on the square shafts, that pinion is turned three notches, and the corresponding *g* dial shows the figure 3 as the product. The *f* dial also shows 3 as the multiplier.

A little study of a table like the above throws much light on the principle of the machine.

Example: 1 × 9. Compare the table with the last or bottom row of pusher tongues in Fig. 7.

Rack Number.	First Push.	Equivalent.	Second Push.	Aggregate.
1	0	0	9	9
2	1	10	8	18
3	2	20	7	27
4	3	30	6	36
5	4	40	5	45
6	5	50	4	54
7	6	60	3	63
8	7	70	2	72
9	8	80	1	81

As before, the second *g* dial shows the product, in this case 9, and the first *f* dial shows the multiplier 9.

Example: 2 × 1. Left-hand pinion in mesh with rack 2. Pushers raised up to second ("1")notch. First half-revolution, no racks pushed; carriage shifts over one step. Second half-revolution, action of racks same as in example 1 × 1, that is, each one is pushed to the right as many teeth as the number to which it corresponds. Rack 2 is therefore moved two teeth, and turns the pinion two teeth, which turns the dial *g* to the figure 2, the product. Rack 1 moves one tooth, which turns the pinion on the round shaft one tooth, which turns the dial *f* to 1, the multiplier.

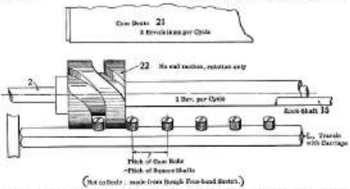

FIG. 11. INVERTED PLAN NEAR LEFT END OF CARRIAGE, SHOWING HELICAL CAM WHICH GIVES THE CARRIAGE TRAVEL.

Example: 1 × 3.

MOVEMENT OF RACKS EXPRESSED IN NUMBER OF TEETH.

Rack Number.	First Push.	Equivalent.	Second Push.	Aggregate.
1	0	0	3	3
2	0	0	6	6
3	0	0	9	9
4	1	10	2	12
5	1	10	5	15
6	1	10	8	18
7	2	20	1	21
8	2	20	4	24
9	2	20	7	27

Example: 9 × 9. Left-hand pinion in mesh with rack 9. Pushers raised up to tenth ("9") notch. The movements of the racks are the same as in the example 1 × 9. As the pinion of the square shaft is this time in mesh with rack 9, which is pushed eight teeth in the first half revolution by the tens pushers, the left-hand *g* dial which is in line with this shaft is turned to show "8." During the remainder of the first half-revolution the carriage is stepped forward one place.

During the second half-revolution, as shown in the previous example, the No. 9 rack is pushed one tooth. As the second *g* dial is now in line with the square shaft driven from rack 9, the second *g* dial is caused to turn to show "1," thus causing the product 81 to show through the face of the machine. During the second half revolution also, the No. 1 rack moves nine teeth to the right, as in the example 1 × 9, so the *f* dial is caused to turn to 9, indicating the multiplier as before.

Example: 12 × 24. Carriage at the extreme right.

First cycle: Pinion on first (left-hand) square shaft in mesh with rack 1. Pinion on second square shaft in mesh with rack 2.

First we multiply by 2; pushers are raised up to "2" notch.

First half revolution, racks 5 to 9 inclusive are pushed one notch to the right, as in the example 1 × 2. As nothing is in mesh with them, no dials are turned. The carriage shifts.

Second half-revolution, the racks are shifted again as in example 1 × 2; as No. 2 moves two teeth before No. 1 starts to move, the third *g* dial is rotated to 2. At this point No. 1 starts moving also, and No. 1 and No. 2 simultaneously move two teeth. The first of these makes a third *g* dial move to "3," while the second *g* dial moves to "1." The next tooth makes the third *g* dial move to "4," and the second one to "2." Also the two-tooth motion of rack 1 causes the left-hand *f* dial to turn to "2." The return of the racks completes the first cycle.

Second cycle. The only change made is to raise the pushers up to "4" notch by movement of the multiplier lever *H*.

MOVEMENT OF RACKS FOR THE WHOLE CYCLE, MULTIPLIER = 4.

Rack Number.	First Push.	Equivalent.	Second Push.	Aggregate.
1	0	0	4	4
2	0	0	8	8
3	1	10	2	12
4	1	10	6	16
5	2	20	0	20
6	2	20	4	24
7	2	20	8	28
8	3	30	2	32
9	3	30	6	36

As the two racks with which the pinions are engaged are not moved during the first half-revolution, there is no effect on the dials. The carriage steps forward, bringing the fourth *g* dial in line with the second square shaft, that is, the one having its pinion in mesh with No. 2 rack.

During the second half revolution No. 2 rack moves eight teeth, so the fourth *g* dial is turned to "8." No. 1 rack moves four teeth, the shaft whose pinion is meshing with this rack is now in line with the third g dial, which was showing "4." The additional movement of four teeth which it now gets makes it read 4 + 4, or "8." The second g dial remains at "2." The product shown is therefore 288. The round shaft is in line with the second f dial, which turns to the same figure as the number of teeth moved by No. 1 rack, viz., "4," thus, when read in connection with the first f dial, causing the multiplier 24 to be shown through the face of the machine. The completion of the crank rotation returns the pushers and racks home.

Whenever the movement of a g dial, added to the amount which it had already turned, causes it to turn from 9 to 0, the decimal-counting mechanism ("carriers of ten") is caused to act in a manner which will be described under that heading.

ACTION OF THE PUSHER BARS AND SUCCEEDING PARTS IN DIVISION

The regulator lever U on "D," the dividend on line gg, the first figure to the left to be on the second dial g, carriage to the extreme right, and divisor indicated by the markers e, starting at the left.

Example: $\frac{352}{22} = 16$

First cycle. We take for the trial quotient 1 by inspection, set the pushers at the "1" hole by the lever H, and turn the crank. During the first half-revolution, the only effect is to advance the carriage one step. During the second half revolution, the second and third g dials (figures 3 and 5 of the dividend) are turned backward two teeth by motion of rack 2, so that they now read 1 and 3 and the new dividend 132 shows on the gg line. At the same time the first f dial is turned to 1, the partial quotient.

Second cycle. By inspection, or by the use of the convenient table inside the cover of the machine, we see that the probable figure of the quotient is now 6. We set the pushers to the "6" hole notch, turn the crank, and the result of the two pushes of the racks is to turn the dials gg backward, subtract 6 times 22 from 132, leaving 0 as the remainder. It is thus seen that division is a combination of multiplication and subtraction. The second f dial is turned to 6, thus indicating 16 as the quotient.

It is evident that the lever H may be set at the No. 1 hole, and division performed by successive subtractions, as is the only way possible in some machines; however, the method described will usually be found more rapid.

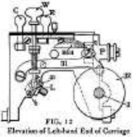

FIG. 12
Elevation of Left-hand End of Carriage

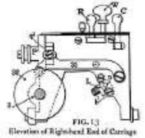

FIG. 13
Elevation of Right-hand End of Carriage

FIG. 14 Plan of Bar with Carriage-Feed Cam Rolls

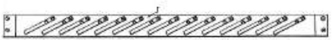

FIG. 15 Stop Springs for the Ten-carrying Rock-Shafts (Plan)

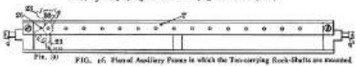

FIG. 20 FIG. 16 Plan of Auxiliary Frame in which the Ten-carrying Rock-Shafts are mounted

DETAILS OF THE TRAVELING CARRIAGE

THE CARRIAGE TRAVEL

During addition or subtraction the carriage does not travel.

During multiplication or division it travels one place to the left for each cycle of movements.

19, Figs. 4 and 10, is a clutch under the control of the lever U, through the arm 20, which is mounted on the same shaft as U. The clutch, like the lever, has four positions. When it is in either of the two extreme positions, the mechanism which causes the carriage traverse is disengaged. When it is in either of the two intermediate positions, the carriage is driven by the helical cam 22, Figs. 11 and 17. In Fig. 17 is shown the helical cam developed. Fig. 11 shows the position of the parts when the carriage is at the right-hand end of its travel and the crank K is at home. This view is a plan, looking up through the bottom of the machine, and it shows the bar L (detailed in Fig. 14) with its cam rolls, the spacing center to center of which is equal to the distances center to center of the square horizontal shafts 9, and as the carriage is fed to the left one pitch distance at each cycle, it is evident that the shafts then come in line with the gg dials one place to the right of the ones with which they were first in line. The shaft 2 makes one revolution per cycle, and the cam roll, which was in the central portion of the groove, remains at rest until the inclined portion of the groove reaches it, when it is caused to move to the left a distance equal to the distance between the centers of the cam rolls on the bar L. At the same time the next roll to the right enters the right-hand inclined groove, so that when the revolution of the shaft ceases, the first roll has emerged to the left of the cam, and the second now stands in the idle portion of the groove, the same as the first one did at the start. The carriage travel takes place during the latter part of the first half-revolution of the crank K, the carriage remaining stationary during the second half-revolution.

HAND TRAVEL OF THE CARRIAGE

This is effected by pushing down on the knob W and sliding the carriage to any desired position. The action is made plain by referring to Fig. 12. The knob W is screwed to the upper end of a square rod, having a spring to keep it pushed up, and a jaw on its lower end. This jaw takes hold of a little crank pin m, belonging to a crank (see Fig. 14) carried on the end of the bar L, upon which are mounted the rolls which mesh with the helical groove. When the knob W is pushed down, the bar L is rotated about 80 degrees, throwing the rolls out of engagement with the helical groove, and leaving the carriage free to be traversed by hand.

THE MECHANISM FOR CARRYING TENS

This consists of means by which at the proper time a dial g may produce rotation of one index figure in its neighboring dial. It does this by automatically setting the mechanism so that it may be acted upon by cams on the cylindrical surface of the drum 21 as they come around.

The mechanism can be seen in vertical section in Fig. 17; Fig. 20 is a plan of part of it with the corresponding cams represented in the same horizontal plane in order to illustrate their action on the pin in the swinging rocker arm. Figs. 12, 13, 15, 16 and 21 also show some details.

When a dial g changes from 9 to 0, the wing 25 on the spindle of the dial g swings the arm 26 over and this swings the arm 23 which is on the same shaft, so that the teeth on 23 are nearly in mesh with the gear wheel 27 on the next *g* spindle. Then when the brass cam 28 comes around, it moves the pin 30 over a little farther and with it the rock shaft 24, and the segmental gear 23, causing the next dial *g* to rotate one tooth. When the restoring cam 29 comes along, the pin 30, the rock shaft, and its arms, are restored to normal position, but in the meantime the frame *T* carrying the rock shafts is raised up so that the segment 23 is not in mesh with the gear 27 during the backward motion.

The rising and falling of the auxiliary carriage *T*, Fig. 16, and the mechanism just described which it carries (consisting of the rock shafts, arms and segments, their pawls, click springs, stop pins, etc.), is effected twice per cycle by means of the trunnions *q* and *q'*, which are embraced by the ends of the levers 31, Figs. 12, 13 and 17, at the ends of the carriage, which have at their outer ends cam rolls engaging with the cams 32, Figs. 5, 8, 12, 13 and 18, which give them a radial motion. When this frame is raised up, the segments 23 are out of mesh with the gear wheels 27. The frame is raised up about the beginning of the revolution of the cam drum and stays up for a little over one-half revolution, and then drops down, staying down until near the end of the revolution, when it starts up again, being part way up when the crank *K* is at home. As the cam-drum shaft makes two revolutions per cycle, the frame, as stated above, rises and falls twice per cycle.

During subtraction and division the action, of course, works the other way from that in addition and multiplication, the change being from 0 to 9 instead of from 9 to 0; and the arms of the rock shafts are swung in the opposite direction, the cams 28 and the working surfaces of the restoring cams 29 being in pairs, and the segments 23 having teeth on both sides of the center lines, so as to make full provision for accomplishing this.

The cams 28 are not arranged in a straight line parallel to the axis of the cylinder, but are located along a helical line on its surface. This has two advantages: it reduces the amount of power required to operate the machine, as the rock shafts are swung one at a time, instead of all at once; and it permits of carrying a ten through an entire series of figures, one after another, as would be required, for instance, when the transferring mechanism adds 1 to a number 999,999 already on the result dials.

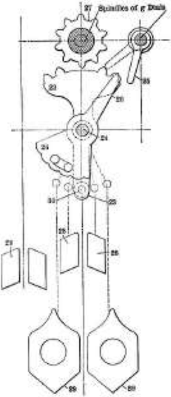

FIG. 20. PART OF THE MECHANISM FOR CARRYING TENS ON THE DIALS *gg*

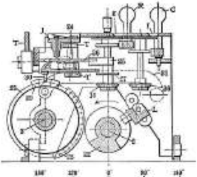

FIG. 17 Transverse Section through Travelling Carriage; and Development of Helical Cam

FIG. 18 One of the two Cams which move the frame T vertically

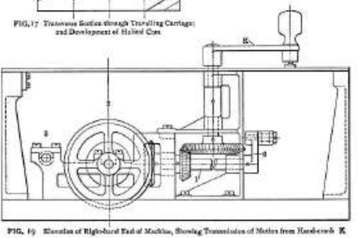

FIG. 19 Elevation of Right-hand End of Machine, Showing Transmission of Motion from Hand-crank K

THE DRIVE OF THE DIALS *ff*

To the left of the square shafts is a round shaft 11, Fig. 4 (not shown in Figs. 6 and 9), having near its back end a pinion permanently meshing with rack 1. This pinion also meshes with a gear on the parallel shaft 33 above it, which carries on its forward end a gear 34 driving another gear 35 below it, mounted on the back end of the short square shaft in line with the round shaft 11 first mentioned. This last shaft has two miter gears mounted on it, similar in arrangement to the gears 12 and 13 on the square shafts 9 which drive *g g*; but in this case the miter gears are farther back, so as to be below a horizontal miter gear (36, Fig. 17) on the lower end of one of the *f* shafts, whichever one the position of the carriage causes to be in line. The motion of the rack 1 is thus communicated to the dial *f*, so that in addition or subtraction *f* is caused to turn one unit for each cycle, and in multiplication *f* turns as many units as are in the multiplier, or in division as many units as are in the partial quotient. In the latter case the carriage steps forward one place for each cycle or turn of the crank *K*, hence the same *f* dial is not turned twice in succession. This turning of the *f* dial is done during the second half-revolution of the crank *K*, as during the first half revolution the No. 1 rack is not moved. The dial *f* does not move backward when the rack is pushed back by the cross-head, because by that time the miter gear on the short square shaft has been moved out of engagement with the horizontal miter gear on the *f* shaft. The motion of these two miter gears back and forth on their short square shaft is exactly the same, synchronous with and produced by the same mechanism as the motion of the miter gears 12 and 13 on the square shafts 9, which actuates the dials *g g*, and which is described under the head "Action of the Rack Pinions, Square Shafts and their Bevel Gears," so that during addition or multiplication the dials *f f* are turned in one direction and during division or subtraction they are turned in the other direction. The dials *f f* are graduated from 0 to 9, and then back again; that is, every

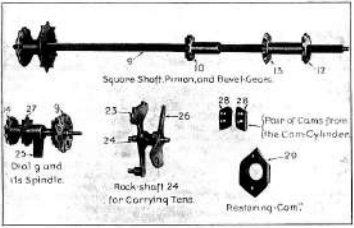

FIG. 21. A FEW OF THE PARTS OF THE CALCULATING MACHINE

figure except 0 and 9 is duplicated on the dial, because of its motion in opposite directions during multiplication and division. The dials *g g* read merely from 0 to 9.

TABLE OF EVENTS

The following parallel shows the relative succession of the different functions in the machine during one turn of the crank *K*:

0 degrees—Engagement of the bevel gears of the transferring mechanism with the register mechanism.

0 degrees to 90 degrees—Transfer of the ten values and commencement of the action of the registering mechanism.

Disengagement of the bevel gears from the register works.

90 degrees to 180 degrees—Return in idleness of the racks; shifting of the carriage and the register works to the left. Completion of the registering of the tens.

Engagement of the bevel gears with the register works. Shifting of the multiplication-table structure.

180 degrees to 270 degrees—Transfer of the unit values and commencement of the action of the registering mechanism.

Disengagement of the bevel gears from the register works.

270 degrees to 360 degrees—Return in idleness of the racks; combination of the units values with the tens values by the registering mechanism.

Shifting of the multiplication-table structure or pusher plates to the original position.

REFERENCE MARKS

To facilitate reference to the illustrations, the following table of the symbols employed throughout all the cuts is given here:

B Top plate, front.
C Effacing knob for dials *f*.
E Top plate, left back.
F Top plate, center back.
G Top plate, right back.
H Multiplication lever.
I Stop-spring supporting bar.
K Hand crank.
L Carriage-feed cam-roll bar.
R Effacing knob for dials *g*.
T Auxiliary frame.
U Regulator lever.
W Carriage-shifting knob.
Z Racks.
c Markers.
c' Marker dials.
f Indicating dials.
g Result dials.
w Crank on end of *L*.
u Trunnions for *L*.
q q' Trunnions for *T*.
1 First horizontal shaft (crank shaft)
2 Second horizontal shaft (helical-cam shaft)
3 Third horizontal shaft (cam-drum shaft)
4 Pusher-shifting cam on end of shaft 9
5 Cross-head.
6 Crank on shaft 1.
7 Connecting rod.
8 Bars connecting cross-head to pusher frame.
9 Square or pinion shafts.
10 Sliding pinions.
11 Indicator shaft.
12 Front miter gear on square shaft.
13 Back miter gear on square shaft.
14 Horizontal miter gear on shaft of *g* dial.
15 Horizontal rock shaft.
16 Rocker arm on 15.
17 Addition-multiplication cam.
18 Division-subtraction cam.
19 Clutch.
20 Clutch-shifting arm.
21 Cam cylinder or drum.
22 Helical cam for feeding carriage.

MECHANISM FOR CARRYING TENS

23 Rocker-arm and spur-gear segment.
24 Rock shaft.
25 Wing on *g* dial spindle.
26 Rocker-arm and rose-wheel segment.
27 Spur gear on *g* dial spindle.
28 Cam for carrying tens.
29 Restoring cam.
30 Pin in rocker arm 23.
31 Lever for lifting auxiliary carriage.
32 Cam for lifting auxiliary carriage.

33 Shaft driven from shaft 11.
34 Gear on front end of 33.
35 Gear driven by 34.
36 Gear on lower end of *f* spindle.