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1944

# DIRECTIONS
## FOR THE
# USE OF ARTILLERY INSTRUMENTS

## PAMPHLET No. 11

## The Twin Marchant Calculating Machine

1944



*By Command of the Army Council,*

[signature]

THE WAR OFFICE,
17*th June*, 1944.

22417

## CONTENTS



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The block for Fig. 1 was kindly provided by Dr. Comrie and that for Fig. 2 by Messrs. Block & Anderson, Ltd., who have been responsible for "twinning" single Marchant machines.

# DIRECTIONS FOR THE USE OF ARTILLERY INSTRUMENTS

## PAMPHLET No. 11

# THE TWIN MARCHANT CALCULATING MACHINE

## INTRODUCTION

1. Calculating machines in general offer the following advantages over logarithms—increase of speed and scope of calculation, diminution of effort and of fear of mistakes, a lowering of the grade of skill required and, finally, the employment of the more sensitive natural values of the trigonometrical functions instead of the logarithmic values. The object of this pamphlet is to give a general introduction to the Twin Marchant calculating machine. The elementary processes of addition, subtraction, multiplication and division are treated fully, and brief instructions on maintenance are given for instrument mechanics. This summary represents, apart from a few extensions of the fundamental processes, the full scope of the pamphlet. Details of the application of machine methods to technical problems are omitted and may be found in the appropriate technical pamphlet, notably in Artillery Training, Volume VI, Pamphlet No. 9, Computation.

## CHAPTER 1

## DESCRIPTION OF THE MACHINE (Fig. 1)

### Section 1.—SINGLE MACHINE

2. The twin machine consists of two single Marchant machines built together so that they can be driven by a single handle. In the early stages of training it is preferable to use the upper machine only, until the fundamental processes have been mastered. For this reason a description of the single machine is given first.

3. **Setting levers.**—Numbers are set on the machine by a series of nine setting levers, each of which, by means of its protruding

1—22417

handle, may be drawn down to any of the nine positions 1, 2, 3 ... 9. A number so set may be checked by reading, in one straight line, the red figures in the setting register on the top of the machine. The setting may be altered by changing the position of the levers, or may be cleared by sweeping them back to their uppermost position, either by hand or all together by means of the clearing bar which rests on the cover below the 9's and has a convenient lip to enable it to be moved easily by the thumb. It will be found that the setting levers will not remain half-way between two positions. They remain in position while the machine is in operation.

To facilitate the setting of long numbers there are two distinct aids. First, the columns are numbered from the right on a narrow strip attached to the clearing bar. Secondly, the setting handles are in mixed colours. The standard arrangement of white and green is as follows :—

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| W | W | W | W | G | G | G | G | G |
| 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |

A movable marker or decimal point on the number plate is a further help in identifying the positions in which numbers are to be set. Numbers should be set from left to right, *i.e.*, the order in which they are read, after the first lever to set has been determined. Setting from right to left, in order to avoid the trouble of determining where to begin the setting, is likely to lead to trouble by confusion with the normal left to right reading of numbers. In setting, the levers should be drawn down to the white figures engraved on the cover ; the setting register should not be used at this stage, but should be compared, immediately after the setting, with the number that was to be set.

4. **Main handle.**—The machine is operated by a handle on the right-hand side. In its neutral position the knob is at its lowest point. A forward turn of the handle adds the number set on the setting levers to a register—known as the product register—in the front of the machine. A backward turn leads to a similar subtraction. When a turn has been begun in either direction it must be completed ; in other words, reversal during a turn is mechanically impossible. If a turn is made inadvertently in the wrong direction the error is rectified by a turn in the opposite direction.

5. **Carriage.**—The product register is mounted in a carriage that can be moved laterally. An extended movement is made by pressing together the two levers at the left of the carriage, and drawing the carriage to the desired position. Smaller movements are made by means of the bean-shaped lever in the front of the machine. If pressed on either side, it will move the carriage one step and one only in the direction of pressure ; when it is released,

it is restored by spring pressure to its normal vertical position Thus by a series of quick movements of this lever, the carriage can be moved as many steps as desired. When the carriage is in its extreme left-hand position, the nine right-hand figures of the product register are in line with the nine setting levers.

6. **Product register.**—The product register contains thirteen numeral wheels, numbered, from right to left, on a narrow number plate just below the wheels. This plate acts as a slide for two movable markers, either of which can be used as a decimal point or to subdivide large numbers. The product register is cleared by a forward turn of the handle on its left. This handle cannot be reversed, and should never be turned short of or beyond its neutral position. The effect of turning short is that the product register will not be completely cleared; that of either fault is that the main handle cannot again be operated until the turn of the clearing handle is completed.

The product register, whose real function is to add and subtract numbers set on the setting levers, must have a means of carrying over tens from each numeral wheel to the one immediately to the left. This tens transmission, as it is called, is complete throughout the thirteen wheels of the register. Whenever there is a failure to complete the transmission because it comes to the left-hand end of the product register, warning is given by the ringing of a bell.

7. **Multiplier register.**—Another register on the right of the machine, known as the multiplier register, is provided to record the number of turns of the main handle. It has eight positions, numbered, from right to left, on a number plate just below the dials. This plate, like that of the product register and that of the setting levers (paras. 6 and 3), has a slide that carries a movable marker for use as a decimal point. As the carriage is moved into any one of the eight positions that it may occupy, a red pointer travels along the multiplier register, to indicate not only the position of the carriage, but also the particular wheel of the multiplier register that will be affected by handle turns. The multiplier register has tens transmission throughout. It is cleared by a complete forward turn of the rubber-edged clearing wheel on the right of the machine. Like the product register clearing handle, it cannot be reversed, and should never be allowed to overshoot its neutral position. In both cases, too, the correct return to neutral position is assisted by a strong spring-and-notch action.

8. **Sign lever.**—The direction in which the multiplier register turns is controlled in two ways, the first being the direction of turns of the main handle. The second is by a reversing lever that

projects through a slot in the cover just to the left of the multiplier register. The position at the lower end of the slot is marked × and that at the upper end ÷. When the lever is in the × or multiplying position, forward turns of the handle are added in the multiplier register, and *vice versa*; these conditions are reversed when the lever is in the ÷ or dividing position.

### Section 2.—TWIN MACHINE

9. The twin machine consists of two single machines mounted together on a common base. The front or lower machine will be referred to as the lower machine, and the other as the upper machine. The carriages are interconnected in such a way that they move together whenever the front one is moved by its controls. The machines are driven by a single handle, which operates through a gear-box on the right of the machine. This box is provided with a 3-way control lever. When this lever is in its left-hand position both machines turn in the same direction, and are said to be set parallel. When the lever is in its right-hand position the upper machine turns in the same direction as the handle, but the lower machine turns in the opposite direction; the machines are then said to be set opposite. When the lever is in the middle position, the lower machine is disconnected and does not turn, while the upper machine, as always, follows the direction of the handle turn. As only one multiplier register is needed, that of the lower machine has been eliminated.

10. The following abbreviations are used in the text:—

| | |
|---|---|
| M.R. | Multiplier Register. |
| S.Ls. | Setting Levers. |
| S.R. | Setting Register. |
| P.R. | Product Register. |
| U. | Upper (machine). |
| L. | Lower (machine). |

## CHAPTER 2

# FUNDAMENTAL PROCESSES

### Section 3.—CARE IN USE OF THE MACHINE

11. If the machine is misused in any way, a jam is very likely to occur. It may be possible to clear this immediately but as the operator increases his speed the more likely he is to cause damage by the jam. It is advisable, therefore, in the early stages to find

and thereafter avoid all movements that are likely to result in stoppages.

(*a*) Before each operation on the machine, the user should make sure that :—

(i) Both clearing handles for P.Rs. are in their neutral positions. If they are not, a strip of red will be visible at the right-hand end of the P.Rs.

(ii) Clearing wheel for M.R. is in neutral position.

(iii) Sign lever is fully in $\times$ or $\div$ position.

(iv) Carriage is fully in position (*i.e.*, not half-way between two positions).

(v) Gear change lever is fully in position.

(vi) Main handle is in its neutral position (*i.e.*, at the lowest point of its turn).

(*b*) *Main handle.*—No attempt should be made to turn the main handle unless all the above conditions are satisfied. Similarly no settings or changes should be made on the machine unless the handle is in its neutral position. When turns are made, they should be steady, not jerky, and *in no circumstances* should an attempt be made to reverse a turn that has been started. The turn must be completed and then a full reverse turn made. This lesson cannot be overstressed with beginners.

(*c*) *Carriage.*—No attempt must be made to move the carriage whilst the main handle is being turned. This is a fault which often develops as the operator passes from the beginner's stage.

(*d*) *M.R. clearing wheel.*—The M.R. should be cleared by rolling the wheel along the palm of the hand.

(*e*) In the event of a jam no force must be used, but all the points under (*a*) must be carefully checked.

(*f*) *Transport of machine* :—

(i) While the machine is in transit all operating and clearing handles should be in their neutral positions.

(ii) The gear change lever should be in its left-hand position.

(iii) The carriage should be in its extreme right position.

(*g*) When the machine is not in use it must be covered by the rubber cover which is provided for the purpose. At night or for transport purposes, the metal cover also should be used.

2a—22417

## Section 4.—ADDITION AND SUBTRACTION

12. **General.**—The fundamental property of the machine is that a number set on the S.Ls. is added into the wheels of the P.R. immediately below the S.Ls. by a forward or positive turn of the handle, and subtracted by a backward or negative turn. It will be seen later that multiplication is performed by repeated addition, and division (in its usual form) by repeated subtraction. There is, however, ample scope for building up a calculating technique, sometimes of a novel character, from these simple basic operations.

13. Move the carriage to the extreme left and clear the machine. Set the first number to be added on the S.Ls., and check the setting by means of the S.R. Unless there are reasons to the contrary, it is customary to set numbers on the right of the S.Ls.; this tends to avoid confusion between ciphers that are significant and those that are not. It is for this same reason that the carriage is usually moved to the extreme left, although this is not essential. A positive turn of the handle transfers the number set to the P.R. The S.Ls. can then be cleared, a new number set, and the handle turned again, to show the sum of the two numbers in the P.R. The example shown alongside may be used to illustrate this process.

| |
|---:|
| 4365 |
| 6877 |
| 11242 |

14. Subtraction is similar in all respects, except that the handle is turned backwards. The order in which the items are set is immaterial. Thus in the example we may set 56683, turn backwards, set 72904, and turn forward to get the difference 16221.

| |
|---:|
| +72904 |
| −56683 |
| +16221 |

The algebraic sum of a series of positive and negative items is obtained by using forward turns for the positive items and backward turns for the negative. No alarm is to be felt if the bell rings at any stage. The procedure to be adopted with negative totals is described in the following section.

| |
|---:|
| +26381 |
| +17208 |
| −39815 |
| +50223 |
| −84679 |
| +92138 |
| +61456 |

15. Decimal fractions are added as readily as whole numbers but, as with pen and paper work, the decimal point must remain in a fixed position (determined by the largest number of decimals to be added) both on the S.Ls. and in the P.Rs.

| |
|---:|
| 123·456 |
| 67·2 |
| 0·079 |
| 376 |
| 6·14 |
| 18·702 |
| 591·577 |

## SECTION 5.—COMPLEMENTS AND THEIR CONVERSION TO DIRECT NUMBERS

16. The complement of the number may be defined as the amount to be added to that number to increase it to some specified amount. Thus the complement of 12 to 1000 is 988 and, conversely, the complement of 988 to 1000 is 12. In calculating machine work the specified amount is 1 more than the capacity of the register containing the number. Thus the capacity of a 13-column register is 9 999 999 999 999, which, when increased by 1, is $10^{13}$ or 10 000 000 000 000. Hence the complement of 12 would show as 9 999 999 999 988. For brevity we shall write complements as ...999 988 or ...988, where the three dots indicate 9s to the left until the capacity of the register concerned is attained.

If 12 be set in the S.R., and the handle turned backwards, the bell will ring, and the complement of 12, *i.e.*, ...999 988, will appear in the P.R. Hence the complement of 12 is a mechanical representation of $-12$. If we set 25, turn forward, then set 37 and turn backwards, the answer $-12$ will appear as ...999 988.

Complements can be converted into direct numbers mentally, by subtracting each digit, beginning at the left, from 9, except the last digit that is not zero, which is subtracted from 10. If the complement ends in one or more ciphers, the direct number will end with an equal number of ciphers. Thus :—

| Complement | Direct number |
|---|---|
| ...999 988 | 12 |
| ...982 941 | 17 059 |
| ...920 409 | 79 591 |
| ...992 400 | 7 600 |

The addition of a complement is equivalent to the subtraction of the direct number represented by the complement. Thus $37-12=25$ could be produced as follows :—

| | | | | | |
|---|---|---|---|---|---|
| + | | | | | 37 |
| + | 9 | 999 | 999 | 999 | 988 |
| | 10 | 000 | 000 | 000 | 025 |

The 1 that appears to the left of the setting capacity must be ignored.

## Section 6.—MULTIPLICATION

```
  123
  456
  ---
  738
 615
 ----
 6888
492
-----
56088
```

17. The long process of multiplying 123 by 456 is illustrated alongside, with the variant that an intermediate addition has been performed after the writing of the partial products $123 \times 6$ and $123 \times 5$. This process is followed precisely with the calculating machine. Clear the machine, bring the carriage to the extreme left-hand position, see that the sign lever is at $\times$, and set the multiplicand 123. To multiply by 6 it is only necessary to add 6 times, *i.e.*, to turn the handle 6 times, thus showing 738 in the right of the P.R. The number of handle turns is recorded in the right-hand or units position of the M.R.; an error is, of course, readily corrected by the appropriate forward or backward turns. The next step is evidently to multiply the multiplicand by 5 —which means 5 turns—and to produce the partial product 615 one place to the left. In other words, there must be a displacement of the multiplicand and product relatively to each other. This is effected by stepping the carriage one place to the right by means of the spacing lever in front of the machine. When this has been done, the unit figure of the multiplicand is in line with the tens figure of the product, and the moving red pointer in the M.R. is in front of the second or tens position. Five forward turns now produce the partial product—really $123 \times 50$ or 6150—but, as it is being produced, it is also being added to the partial product (738) already in the P.R., so that the machine now shows $123 \times 56$ or 6888, with 56 in the M.R. From the principle of this process it is obvious that the final operation consists of stepping the carriage once more to the right and turning 4 times, to produce 456 in the M.R. and 56088 in the P.R.

18. It is preferable to learn to multiply from left to right, *i.e.*, in the order of the digits of the multiplier. The carriage must first be placed so that the red pointer in the M.R. has at least as many positions to its right (including the position pointed to) as there are digits in the multiplier. Unless there are good reasons to the contrary, the best practice is to allow just as many positions in the M.R. as there are digits in the multiplier.

Example :—$87\ 659 \times 6\ 034 = 528\ 934\ 406$.

Set the multiplicand 87 659 and check, as before. Move the carriage so that the red pointer points to the fourth position digit (the thousands) of the M.R. Turn six times, press the spacing lever twice to the left to bring the pointer to the tens position, turn three times, press the spacing lever to the left again, and turn four times.

All the turning should be done without taking the eye from the calculating sheet. At the end of the process take in the entire multiplier in one glance and compare it with the number now showing in the M.R. Any error can be corrected by making the requisite forward or backward turns in the appropriate positions. Thus, if it is seen in the M.R. that 6024 has been turned into it instead of 6034, bring the red pointer to the figure 2 by pressing the spacing lever once to the right and give one forward turn to the main handle.

## SECTION 7.—SHORT-CUTTING IN MULTIPLICATION

19. It is evident that multiplication by 9 can be effected by multiplying by 10 (*i.e.*, one turn in the tens position) and then making a negative turn in the units position. This makes two turns instead of nine—a saving of seven turns. In like manner turns can be saved by this process, which is known as short-cutting, on other high digits. Thus :—

| *Digits* | *Entered as* | *Turns made* | *Turns saved* |
|---|---|---|---|
| 9 | 10—1 | 2 | 7 |
| 8 | 10—2 | 3 | 5 |
| 7 | 10—3 | 4 | 3 |
| 6 | 10—4 | 5 | 1 |

If there are several high digits in juxtaposition, the saving is even greater, for two reasons :—

(1) Only one extra forward turn is required for each group of high digits.

(2) In each such group the number of turns required for each digit except the last is the complement of the digit to 9, not to 10 as in the above table. Thus the number 16273849 would require 40 turns without short-cutting, or 2+**4**+3+**3**+4+**2**+5+**1**=24 with short-cutting, where bold type indicates backward turns, *i.e.*, a saving of 1+3+5+7=16 turns.

A little trial will soon convince one that short-cutting on a 5 that is preceded or followed by a higher digit also saves turns. Hence the working rule is : Short-cut on 6, 7, 8 and 9 always, and on 5's (whether occurring single or in a group) that are preceded or followed by a higher digit. Thus to multiply any number by 1655597289 the turns required are +2, −3, −4, −4, −4, 0, −3, +3, −1 and −1.

20. Short-cutting should always be done from left to right, without taking the eye from the written multiplier. The mental process is easy, as there is no need to formulate in advance the number of turns required for each position. While doing any digit, the operator decides the number and direction of turns for the next digit. The small digits 0, 1, 2, 3 and 4 are entered always by forward turns ; if the following digit is one subject to short-cutting, an extra forward turn is made. The large digits 6, 7, and 8 are entered always by backward turns ; if the following digit is

one subject to short-cutting, the number of turns required is the complement to 9 ; otherwise it is the complement to 10.

It is very important that the multiplier be compared, at the end of the multiplication, with the number in the multiplier register. The habit of short-cutting soon becomes instinctive ; it should be instilled into every new operator from the beginning. The percentage of turns saved by short-cutting varies with the length of the multiplier, being greater the longer the multiplier ; however, the average percentage saving may be regarded as being not less than 40.

21. The examples below may be used to practise multiplication. They can be done both ways, *i.e.*, either factor may be chosen as the multiplicand.

| | | | | |
|---|---|---|---|---|
| 428 735 | × | 234 912 | = | 100 714 996 320 |
| 628 913 | × | 327 644 | = | 206 059 570 972 |
| 739 898 | × | 241 572 | = | 178 738 639 656 |
| 385 594 | × | 725 556 | = | 279 770 040 264 |
| 403 020 | × | 209 908 | = | 84 597 122 160 |
| 922 857 | × | 399 898 | = | 369 048 668 586 |
| 171 819 | × | 111 789 | = | 19 207 474 191 |
| 367 425 | × | 829 384 | = | 304 736 416 200 |

## SECTION 8.—MULTIPLICATION OF DECIMAL FRACTIONS

22. If two quantities involving decimals are multiplied, the number of decimals in the product will be the sum of those in the multiplicand and multiplier (*cf.* para. 25). In the machine language this rule becomes :—Number of places in M.R. + number of places in S.Ls. = number of places in P.R. This rule has always to be satisfied on the machine, independently of the actual process involved. *Any* two of the above quantities may be known and the third deduced by the rule. Thus, if there are three decimals in the multiplicand and four in the multiplier, there will be seven in the product.

Example :—576 387·36 × 0·034 173 = 19696·88525328

The multiplication is done in the ordinary way. Two decimals are indicated in the S.R., six in the M.R. and eight in the P.R., although by no means all of the eight need be retained in use.

23. If multiplicands and multipliers with varying numbers of decimals are being used, it is often advantageous to fix the number of decimals in the S.R. at the highest number occurring in any multiplicand, and the number in the M.R. at the highest occurring in any multiplier. The number of decimals in the P.R. is then fixed accordingly. The multiplicands and multipliers are then entered so that their decimal points are correctly placed, and the products are read off against the fixed decimal point in the P.R.

24. Example :—

$$\begin{array}{rcl} 6{\cdot}17342 & \times & 284{\cdot}117 \\ 0{\cdot}02714 & \times & 0{\cdot}6902 \\ 0{\cdot}417 & \times & 0{\cdot}0038 \\ 197{\cdot}18 & \times & 13{\cdot}172 \end{array}$$

Here we have five decimals in the S.R., four in the M.R., and nine in the P.R. The products are then formed as follows :—

$$\begin{array}{rcll} 6{\cdot}17342 & \times & 284.1170 & = 1753{\cdot}974 \\ 0{\cdot}02714 & \times & 0{\cdot}6902 & = \quad 0{\cdot}018732 \\ 0{\cdot}41700 & \times & 0{\cdot}0038 & = \quad 0{\cdot}001585 \\ 197{\cdot}18000 & \times & 13{\cdot}1720 & = 2597{\cdot}3 \end{array}$$

The number of decimals retained in the products varies according to requirements or according to the number of significant figures in the factors.

## Section 9.—MULTIPLICATION CAPACITY

25. Although there are nine S.Ls. and eight positions in the M.R., they cannot all be used in any one calculation as there are only thirteen positions in the P.R. Suppose we multiply two numbers containing $n$ and $m$ digits respectively. The product will contain $n+m-1$ or $n+m$ digits. In other words, the number of digits in a product is either equal to the sum of the number of digits in the multiplicand and multiplier or is one less.

If the capacity of the P.R. is exceeded during a multiplication, the bell rings as a warning. Sometimes, when there can be no doubt about the first figure of a product, it is possible to get an extra figure, but the process must be used with caution.

26. The capacity can, however, be increased for occasional large multiplications by doing the work in two stages. As an example, consider 824 513 917 × 76 364 281 on a 13-column P.R. Set the multiplicand and multiply by as many figures of the multiplier as can be used without exceeding the capacity of the P.R.—here four. Thus we find

824 513 917 × 7636 = 6 295 988 270 212

Had we multiplied by 76 360 000, the first four figures of the product, namely 6295, would have been lost. They can, however, be noted now, together with the first few succeeding figures—here 988. If we clear the M.R. and P.R., and repeat the multiplication thus far with 7636 in the left of the M.R., the figures 988 will appear in the extreme left of the P.R., and will thus afford confirmation that we have used the same multiplier on both occasions and sensed correctly the figures that would be lost on the second occasion. As we turn in the next figure of the multiplier, the lost figures may be increased by 1, or may be decreased by 1 if the multiplication was broken at an impending short-cut. In the first case, the figures on the left at the end of the multiplication are less than those before the break ; in the second case, they are greater. Here we are not short-cutting at the break, and have changed 988 to 341, so the complete product is 62 963 412 446 198 677.

### Section 10.—DIVISION (First Method)

27. There are two methods of division. The first, and that most frequently used, is known as " tearing down " because, as will be seen shortly, the dividend is torn down by the divisor.

```
456)118647(260·19078
     912
     ----
     2744
     2736
     ----
        870
        456
        ---
        4140
        4104
        ----
          3600
          3192
          ----
           4080
           3648
           ----
            432
```

Consider the adjoining example, which has been done by the long-hand method and will be followed step by step on the machine. First move the carriage to its extreme right position. Set the dividend 118647 on the S.Ls. with its first digit directly above the left-hand numeral wheel of the P.R. and check by the S.R. By turning the handle once forward bring the dividend into the extreme left of the P.R.

Clear the S.R. and M.R. and set the M.R. sign lever to ÷. Now set the divisor. If its first digit is less than the first digit of the dividend, the first digit is set in line with the first digit of the dividend ; otherwise it is set one place to the right.

If the first digits of the dividend and the divisor are the same, succeeding digits must be examined until we see which is the greater. In this case we set 456 with the 4 in the fifth column and the S.R. shows 45600.

28. The first operation is obviously the multiplication of 456 by 2, and the subtraction of the resulting product 912 from 1186, the first four figures of the dividend. Hence we must make two backward turns—two to perform the necessary multiplication and backward for subtraction. The M.R. having been reversed, automatically adds negative turns, and so shows 2 at the end of this operation. The P.R. shows the remainder 274. We now " bring down the next figure " by stepping the carriage one place to the left, *i.e.*, by pressing the spacing lever to the left. The P.R. has now 2744 in line with the divisor 456, so that six backward turns will multiply 456 by 6 and subtract the product from 2744, leaving the remainder 8. The six turns are recorded in the second position from the left of the M.R., *i.e.*, the position to which the red pointer points. Actually it is not necessary to estimate before turning what the next figure of the quotient will be ; we simply

turn backwards and watch the remainder (or the first few figures of it if the divisor is long) until it is less than the divisor, and stop at that point. Thus as we turn backwards in the second position the successive remainders are 2288, 1832, 1376, 920, 464 and 8. If too many turns are made, the bell will ring and 9's will appear in the left of the P.R.; the error is rectified by turning the handle forward again.

29. The remainder is now so small that the carriage must be stepped twice before the dividend is again greater than the divisor. By continuing the process, we obtain the quotient shown, and a remainder of 432. If the last figure of the quotient is to be rounded off, we examine the remainder mentally and see if it is greater than half the divisor. If it is, as in this example, one more backward turn is made before copying the quotient, which now becomes 260·19079.

At this stage the operator must be warned against the slovenly habit of replacing the watching of the changing remainder by listening for the bell, and making a forward correcting turn after each ringing. It is easily seen that this increases by two the number of turns per digit of the quotient. In the watching method the average number of turns in each position is 4·5, so that increasing this to 6·5 means an unnecessary increase of 45 per cent.

30. As a second example, to illustrate certain further principles, the division alongside may be performed.

```
123)63748329(518279·09
    615
    ---
     224
     123
     ---
     1018
      984
     ----
       343
       246
       ---
        972
        861
        ---
        1119
        1107
        ----
          1200
          1107
          ----
            93
```

First, even if the 8-figure dividend is set on the eight right-hand S.Ls., it cannot be entered into a 13-column P.R. if the carriage has been moved to the extreme right. It can, however, all be entered from position 6, *i.e.*, that in which number 6 on the carriage number plate is directly below number 1 on the clearing bar number plate. If the M.R. sign lever is still in the division position, column 6 of the M.R. and all columns to the left will show 9's (*i.e.*, −1). This does not matter, because this register must in any event be cleared after turning in the dividend.

If eight figures are required in the quotient, the carriage is stepped to position 8, and the divisor set, beginning in column 6, so that 123 is in line with 637. As the last remainder 93 is more than half the divisor, one more backward turn is made before copying the quotient, which thus becomes 518279·10, the last cipher being significant.

## SECTION 11.—SHORT-CUTTING IN DIVISION

31. Just as in multiplication, it is possible to short-cut in division but, as it is not quite so simple, it should be deferred until the division processes have been mastered.

32. If the first two figures of the quantity remaining on the P.R. are slightly less than the first two figures of the divisor, and it is obvious that the next figure of the quotient will be 8 or 9, time can be saved by giving the handle one extra turn backward. This fills the left-hand numeral wheels of the P.R. with a series of 9s. Now step the carriage one place (or two if necessary) to the left and turn the handle forward until the 9s clear from the P.R.

As any decision to short-cut must be quickly made, it is not considered advisable to short-cut unless in cases where the required figure of the quotient is obviously 8 or 9. Any endeavour to short-cut on the border line cases is not a real gain, as the machine operator will frequently pause to consider which method to adopt.

## SECTION 12.—DIVISION (Second Method)

33. The second method is known as " building up ". The first method already described can be symbolized by

$$\frac{a}{b}=c$$

*i.e.*, we ask how may times does $b$ go into $a$, and so get the answer $c$. The building up method is symbolized by

$$a=bc$$

*i.e.*, we ask by what number must $b$ be multiplied to give $a$, and so get the answer $c$.

In the second example (para. 30) set the divisor 123 on the right of the S.Ls., check and bring the carriage to its extreme right position with the sign lever set to ×. We have now to turn the handle forward until we have developed the dividend in the P.R. Five turns give 615 and six give 738, so we adopt five turns for the first digit of the quotient. Step as before and make two turns, getting 6396 as the nearest approach to 6374. As this is too great, we turn backwards twice in the next position, and get 63714. In the next position we make three forward turns, in the next two backward turns, and in the next one backward turn ; we have now produced 63748317, which a single forward turn in the next position brings to 6374832930. Even one turn in the next position will spoil this approximation, so we have now found the desired quotient, with its final significant 0. It will be found helpful to split the written dividend up into groups, and to divide the product register by decimal pointers in the same way, in order to facilitate the matching.

34. In the first example,* the first two figures (26) of the quotient produce such a good approximation (11856) to the leading figures of the dividend that we step two positions, to bring the 4 of the divisor in line with the last figure of the built-up dividend, before we make two forward turns and produce 118651·2, which is too large. A single backward turn in the next position produces 118646·64. One forward turn in the next position leaves 118647·096. We can now treat 96 as the remainder in tearing down division and continue as if we were using that process. Note that the process finishes with the quotient 260.19079 in the M.R., and the positive remainder 24 in the P.R., whereas the tearing down process yielded the remainder +432 for the quotient 260·19078, or the remainder −24 (*i.e.*, 432−456) for the quotient 260·19079. This is because one process is really the inverse of the other. As the correction for a large building up remainder is in the opposite direction from that for a large tearing down remainder, error and confusion are avoided if a division is never finished with a remainder greater than half the divisor ; in other words, such a remainder must be converted into a smaller negative remainder by an appropriate turn of the handle before the quotient is copied.

35. The following examples may be practised by either of the foregoing methods :—

224616÷43783 = 5·1302104
0·0845÷0·264647 = 0·31929325
40·765÷564·37 = 0·072230983
77·9÷8843·434 = 0·00880880
3900÷6·37 = 612·24490
0·00982864÷2445·67 = 0·0000040187924
543·9÷604300 = 0·00090004964
21722·57÷47090000 = 0·00046129900
8097120·569006÷0·735547 = 11008298
6·25÷0·000233208955 = 26800
90·74÷0·65638072 = 138·243
52÷23 = 2·2608696

## CHAPTER 3

# PRACTICAL CALCULATION

### Section 13.—INTRODUCTION

36. The following processes are simple extensions of the fundamental processes already described. They help to illustrate machine technique and will later form part of more complicated computations.

* *See* para. 27.

Apart from Section 2, which deals with the assembly of the twin machine from two single machines, all the processes so far described in the present pamphlet have been those feasible on a single machine. The same being largely true of the present chapter, the great extra weight and bulk of the twin machine clearly need justification. Doubtless not every type of user needs the twin machine but the justification for its existence is that many types of computation can thereby be shortened. Some of these computations are fully described in A.T. Vol. VI, Pamphlet No. 9, Computation, and a simple example follows here in Section 18.

## SECTION 14.—ADDITION AND SUBTRACTION INVOLVING CONSTANTS

37. (*a*) Several different values are to be subtracted from a constant value.

Example :—

| | | | |
|---|---|---|---|
| 57565 | 57565 | 57565 | 57565 |
| −27815 | −18905 | −31785 | −29550 |
| 29750 | 38660 | 25780 | 28015 |

All registers are cleared and the carriage placed in its extreme left position. The constant minuend 57565 is set on the S.Ls. and transferred to the P.R. by a forward turn. The S.Ls. are then cleared to receive the first subtrahend, namely 27815 ; this will be subtracted by a backward turn. After the difference 29750 is copied, the constant 57565 is immediately restored by a forward turn. Then the S.Ls. are cleared to receive the second subtrahend, and the cycle of operations is repeated until all the required differences have been formed and copied.

(*b*) A constant is to be subtracted from several different values.

Example :—

| | | | |
|---|---|---|---|
| 3850 | 4365 | 5450 | 5725 |
| − 375 | − 375 | − 375 | − 375 |
| 3475 | 3990 | 5075 | 5350 |

All registers are cleared and the carriage placed in its extreme left position. The constant subtrahend 375 is set on the S.Ls. and entered negatively into the P.R. by a backward turn. The S.Ls. are then cleared and the first minuend 3850 is set and entered into the P.R. by a positive turn, thus producing the first difference 3475. Having copied this difference we restore the original negative contents (...999 625) of the P.R. by a backward turn. The S.Ls. are then cleared to receive the next minuend, and the cycle of operations is repeated until all the required differences have been formed and copied.

If, in either of the examples considered, some of the results are positive and some negative, we may divide the data into two series, one of which is treated by method (*a*) and the other by method (*b*).

Example :—

| | | | |
|---|---|---|---|
| +57565 | +57565 | +57565 | +57565 |
| −27815 | −68905 | −31785 | −89550 |
| +29750 | −11340 | +25780 | −31985 |

The first and third items would be done by method (*a*), and the second and fourth by method (*b*), after the signs of the minuend and subtrahend have been reversed.

The same principles may, of course, be applied to additions involving constants.

## SECTION 15.—SUMMATION OF PRODUCTS

38. The multiplications are done in the usual way, but the P.R. is left uncleared after each multiplication to accumulate the products and thus show the total at the end of the operation. If any of the products are negative the sign lever is switched to ÷, *i.e.*, the position in which it counts negatively, and the multiplication done by backward turns, thus forming the product and subtracting it.

$$\begin{aligned} &36{\cdot}75\times\ 1{\cdot}35\\ +&19{\cdot}24\times 71{\cdot}38\\ +&61{\cdot}87\times 19{\cdot}07\\ -&\ 3{\cdot}92\times 56{\cdot}51\\ -&41{\cdot}16\times 12{\cdot}89\\ =&1850{\cdot}7530 \end{aligned}$$

39. In this, the machine has a great advantage over logarithmic computation. It gives far wider scope in the selection of formulæ and often means that a solution is possible by a more direct method. This should be borne in mind when a first attempt is made to compute by machine a problem which has always previously been done by logarithms. On occasion, too, a method can be used which is peculiar to machine computation and has no parallel in logarithmic methods.

## SECTION 16.—CONTINUED MULTIPLICATION

40. Continued multiplication of the type $A\times B\times C\times \ldots$ can be done by forming intermediate products in the P.Rs. and resetting these on the S.Ls., *e.g.*

$$367\times 423\times 87\ 975=13\ 657\ 326\ 975.$$

Form the product $367\times 423$ (=155 241) in the ordinary way. Clear the S.Ls., set the product 155 241 as the new multiplicand and check the setting by a backward turn, which should clear the P.R. Now clear the M.R. and produce in it the third factor 87 975. The final result 13 657 326 975 will then appear in the P.R.

This method can easily be extended to the multiplication of any number of factors.

## SECTION 17.—SQUARE ROOTS

41. The method of extracting square roots to be described depends on the mathematical fact that, if D is an approximate square root of $x$ and if $Q = x \div D$, the mean of D and Q is a closer approximation that is correct to *twice as many figures* as are correct in the original approximation. Hence the process consists in finding an approximation, dividing the radicand or number whose root is required by this approximation, and then taking the mean of divisor and quotient.

42. To illustrate this principle, suppose we wish to find the square root of 453278 without any aid other than the machine. The number is, as usual, split into groups of two digits reckoned from the decimal point, thus : 45 32 78. From our knowledge of the squares of the numbers 1 to 9, we see that the leading figure of the square root is 6, although the root is actually nearer 7 than 6. Dividing the first three figures mentally by 7, we get the quotient 65. The mean of 70 and 65 is 67 or 68, but where a doubt occurs the lower figure is to be taken—here 67.

If we divide the radicand by 67, and stop after four significant figures, we get as the quotient 6765. The mean of divisor (now regarded as 6700) and quotient is easily taken mentally ; the leading figures 67 are the same, so it is only necessary to divide the remaining figures of the quotient by two to get 6732 (as before, taking the lower figure when the last digit of the quotient is odd).

If we divide the radicand by 6732, and stop after eight significant figures, we get as the quotient 6733 1848. The first four digits of the mean are obviously 6732, and there is a 1 to carry in the division, so that the remaining digits are obtained by dividing 11848 by two. Hence the complete mean, with the decimal correctly placed, is 673·25924, which is correct to the last decimal.

43. In actual practice, if the extraction of roots is to be performed frequently, we resort to various aids that will give a 3-figure or 4-figure approximation immediately. Thus we may use a graph, a slide rule, or tables. An R.A. slide rule will give a 3-figure approximation, but the last figure cannot be relied on as accurate. Thus if we find 674 in the present example and divide by this, the quotient is 672·519, so that the second approximation is 673·259. Note that nothing need be written except the answer. In all cases the result can be checked by squaring

### Section 18.—SIMULTANEOUS MULTIPLICATION AND DIVISION

44. With the twin calculating machine it is possible to perform a calculation of the type $\frac{ab}{c}$ in one operation. If $a$ be entered into the P.R. of the upper machine and $c$ set on its S.Ls., it is evident that division would yield $a \div c$ in the M.R. If, while this division is being performed, the lower S.Ls. contain $b$, and if the machines are set to turn in opposite directions, the lower machine will be turning forward while the upper machine is turning backwards during the division, and thus will show in its P.R. at the end of the operation, $b \times \frac{a}{c}$ or $\frac{ab}{c}$. This process lends itself to the formula $b = a\frac{\sin B}{\sin A}$ in the solution of plane triangles.

45. Example : $\frac{69471 \times 52306}{72553} = 50084.$

Set 69471 in the U.P.R., followed by five ciphers. Then set 72553 on the U.S.Ls. and 52306 on the lower. Set the machines opposite, and divide on the upper machine. The M.R. shows 0·95752 and the L.P.R. shows 50084.

### Section 19.—DIVISION OF NEGATIVE NUMBERS

46. In a calculation like $\frac{a-b}{c}$ or $\frac{ab-cd}{e}$ it may happen that the numerator is negative, and hence appears in the P.R. as a complement if developed on the machine. Instead of being gradually broken down to zero by backward turns, it must now be brought up to zero by forward turns, with the sign lever in the $\times$ position. As far as the P.R. is concerned, the situation is identical with that of a negative remainder in tearing down division (Section 10). The P.R. is therefore brought to as near zero as possible by a series of least remainders and the quotient is read in the M.R.

## CHAPTER 4

# MAINTENANCE OF THE MACHINE

### Section 20.—INTRODUCTION

47. These notes are intended only for instrument mechanics responsible for the maintenance of Twin Marchant machines.

Computers have no actual maintenance tasks to perform but must remember that the behaviour of the machine depends entirely on the way it is treated. If the instructions given under Sec. 3 are carefully carried out the machine should give little trouble.

It is not intended that this should be a complete manual for repair of the machine since major repairs can be done only after special training. On the other hand, these notes may help to keep the machines working freely under difficult conditions of dust and damp.

## Section 21.—LUBRICATION

48. For lubrication the following rules should be followed :—

(*a*) Very little oil is necessary ; too much oil will do more harm than good.

(*b*) Only the finest grade of machine oil should be used.

(*c*) The carriage slides must not be oiled.

(*d*) The main points requiring a few drops of oil from time to time are those marked on Fig. 2.

(*e*) The mechanism of the gear-box (seven gear spindles) and the main crank handle require some oil from time to time. For this operation it is necessary to remove the cover encasing the gear-box ; instructions how to do this are given in para. 51.

## Section 22.—TAKING OFF COVER PLATES

49. **Removing top numeral plates**

(*a*) Take off the clearing bar for the setting levers by removing two screws and nuts on left-hand side, disconnecting bar from right-hand anchor-lever and pulling slightly towards the left.

(*b*) Remove the four cover screws, one at each corner.

(*c*) Place the setting levers in the " 1's " position and lift the cover bodily.

This procedure applies to both upper and lower machine.

50. **Replacing top numeral plates.**—When either of the top numeral plates is replaced make sure that the S.L. clearing bar anchor-levers are first threaded through their respective slots on the cover itself. In the case of the top cover it is also necessary to ascertain that the sign lever protrudes through its slot before pushing

the cover into position and checking at the same time that the red pointer in the front of the M.R., which indicates the position of the carriage, protrudes through its slot.

51. **Removing gear-box cover**

(*a*) Remove the clearing wheel for the M.R.

(*b*) Remove the main operating handle (4 B.A. hex. head screw).

(*c*) Remove the knob from the control lever (right-hand thread).

(*d*) Remove the two cover screws, which are situated at the extreme upper and lower corners.

(*e*) The gear-box cover can now be removed entire by raising the control lever clear of the gate with the left hand, and slightly pulling the cover away from the machine, at the same time tilting the bottom of the cover upwards and outwards.

In the ordinary way no attempt should be made to dismantle the gear-box mechanism further; any such job usually requires the attention of specialist mechanics.

6/44—(22417) 11552/9562 500 5/45 K.H.K. **Gp. 8/8**

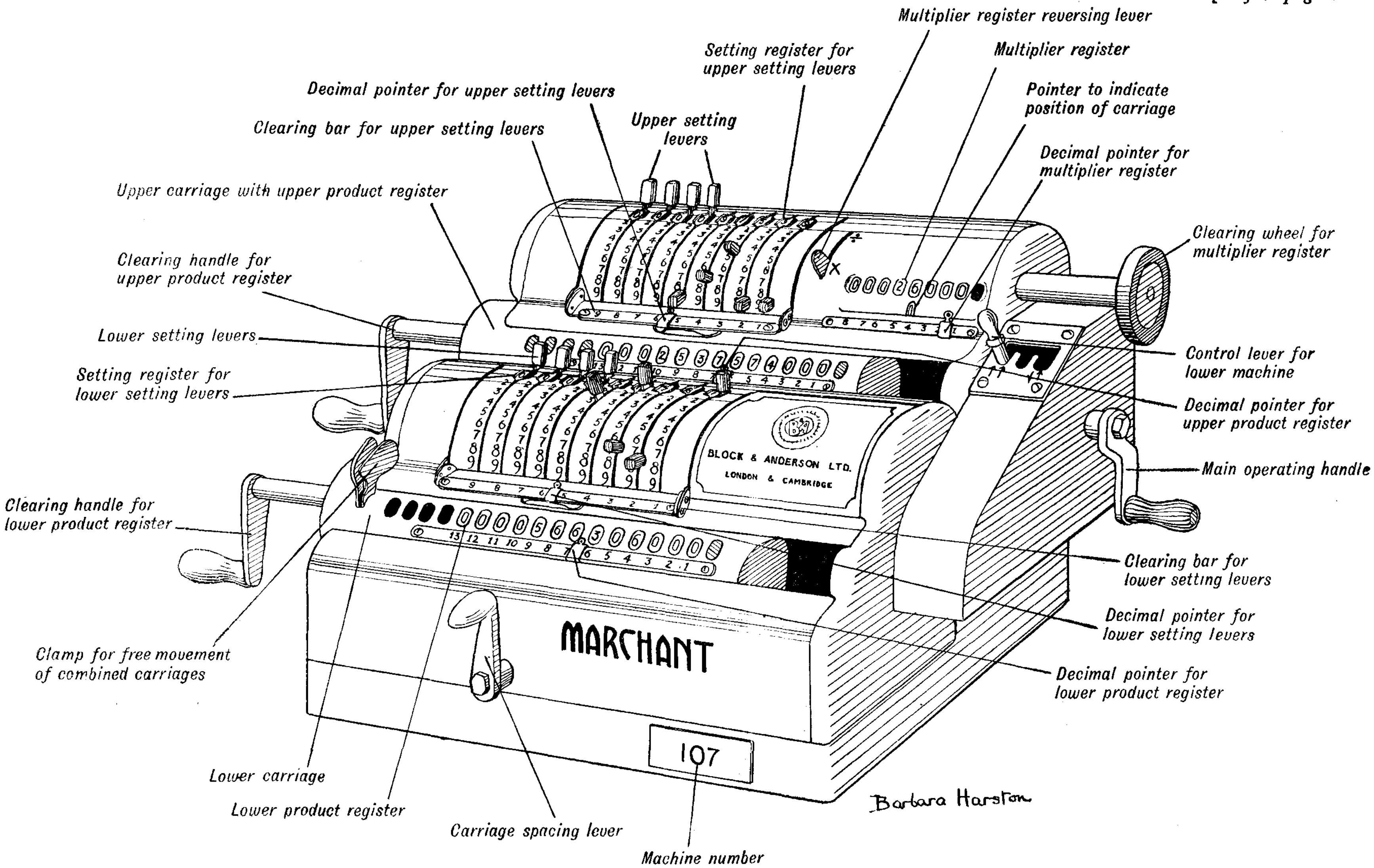
Multiplier register reversing lever
Multiplier register
Setting register for upper setting levers
Decimal pointer for upper setting levers
Pointer to indicate position of carriage
Upper setting levers
Clearing bar for upper setting levers
Decimal pointer for multiplier register
Upper carriage with upper product register
Clearing wheel for multiplier register
Clearing handle for upper product register
Lower setting levers
Control lever for lower machine
Setting register for lower setting levers
Decimal pointer for upper product register
BLOCK & ANDERSON LTD.
LONDON & CAMBRIDGE
Main operating handle
Clearing handle for lower product register
Clearing bar for lower setting levers
Decimal pointer for lower setting levers
MARCHANT
Clamp for free movement of combined carriages
Decimal pointer for lower product register
107
Lower carriage
Barbara Harston
Lower product register
Carriage spacing lever
Machine number

**Fig. 1**

22417

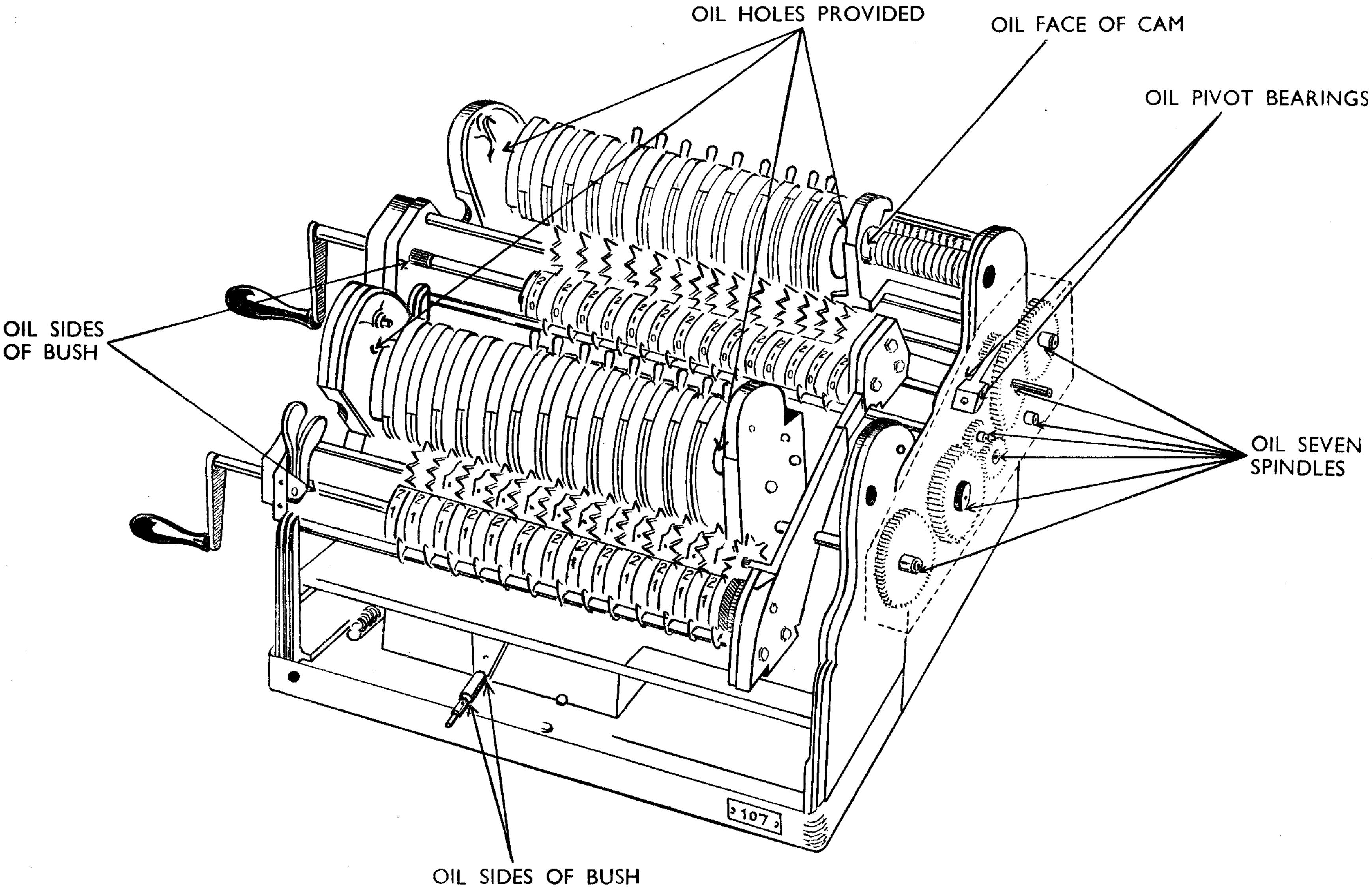
OIL HOLES PROVIDED
OIL FACE OF CAM
OIL PIVOT BEARINGS
OIL SIDES OF BUSH
OIL SEVEN SPINDLES
107
OIL SIDES OF BUSH

**Fig. 2**

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