(D R A F T)

Sept. 3, 1930

A. Description of System.

This cryptograph consists of the following principal parts:

1. A keyboard.
2. A bank of 26 small lamps, 4-volt.
3. A rotatable cipher wheel.
4. A key-tape transmitter.
5. Certain associated solenoids and relays, and a small electric motor.

The general nature of these parts and their functions will be described briefly.

1. The Keyboard:

The keyboard, shown at 1 in Fig. 1, is provided with the standard arrangement of keys. Each of the latter operates an electrical contact, as shown schematically for the "Q" and "U" keys. Keyboards of this type are well-known in the art. It is not provided with any printing mechanism in the model under consideration.

2. The Light Bank:

This consists simply of a bank of 26, 3½-volt lamps, two of which are shown at 10 in Fig. 1. The other 24 are wired in homologous manner to that shown for these two, one terminal being connected to a common conductor, 9, the other, to individual binding posts on a plate 4, to be described below.

3. The Cipher Wheel:

The cipher wheel is shown at 2 in Fig. 1. This wheel consists of 52 brush-type

contacts arranged in two rings or sets of 26 each. One set is placed on the obverse face, 3, of the wheel 2, the contacts being arranged equidistant from one another in a circle around the circumference of the face. The other set is similarly placed on the reverse face, 5, of the wheel. The contacts on the obverse face are connected to those on the reverse face by means of flexible conductors which pass through the interior of the wheel, as shown schematically in Fig. 1. The cipher wheel is fixed upon the shaft 7 which is driven by a motor operated coiled spring 8. The contacts of the obverse face, 3, of the cipher wheel press against ball-bearing type contacts arranged on the fixed plate 4; the contacts of the reverse face, 5, of the cipher wheel press against ball-bearing type contacts arranged on the fixed plate 6. The plates 4 and 6 each contain 26 contacts arranged in a circle. The cipher wheel rotates between these fixed plates 4 and 6 so that each contact on the two faces of the cipher wheel presents itself in turn to each contact on plate 4 and plate 6, respectively, as the cipher wheel rotates. The contacts of plate 6 are respectively connected by conductors to the contacts of the keyboard 1; the contacts of plate 4 are respectively connected by conductors to 26 lamps only two of which are shown at 10. As shown in Fig. 1, when the key "Q" is depressed, assuming the cipher wheel to be in the position indicated in

the figure, a circuit is established as follows:

From positive pole of battery 11 through conductor 12, closed contact at the "Q" key, conductor 13, contact 14 on fixed plate 6, contact 15 on cipher wheel 2, conductor 16, contact 17 of cipher wheel 2, contact 18 of plate 4, conductor 19, through lamp 20, conductor 21 to negative of battery 11. Lamp 20 has a translucent glass window before it, on which a letter is painted, say the letter "W". Hence, depression of the key"Q" on the keyboard gives the cipher resultant "W", under the conditions specified.

Suppose that the key "W" of the keyboard is depressed, instead of "Q". By following the path set up, it will be seen that the "Q" lamp will be lighted. Thus, reciprocity is established between the keys on the keyboard and the lamps so that if, for example, Q= W, in enciphering, W= Q in deciphering. The same reciprocal relationship can be established throughout the alphabet by connecting the flexible conductors in the interior of the cipher wheel in an appropriate manner to paired contacts on the obverse and reverse faces of the cipher wheel.

If the cipher wheel were stationary, the relationship between the key depressed and the lamp illuminated would be fixed for each wiring of the interior of the cipher wheel.

But the cipher wheel is rotatable and hence this relationship can be made variable. The manner of its variation and its control will now be presented.

The rim or tire of the cipher wheel is provided with 130 pins arranged in 5 sets or rings of 26 each. These pins can be elevated into operative positions or left remaining in inoperative positions in groups of fives transversely to the tire, in accordance with the permutations of the 5-unit or Baudot code. To explain what is meant we may say that according to the Baudot code, the permutation of elements for the letter A, for example, ~~are~~ is represented thus: 1 2 3 4 5 + + - - - . For our purposes we will let the + sign indicate that a pin is to be elevated into its operative position; the - sign, that it is to be left in its inoperative position. In Fig. 2 there is shown a side elevation of a section of the tire of the cipher wheel, with the pins now being described. The pins indicated by dotted lines in the figure represent pins which have been left depressed in their inoperative positions; the pins indicated by whole lines represent pins which have been elevated into their operative positions. The permutations represented in the figure correspond to the Baudot signals for the letters Y, Z and A. The order of the letters in the figure is, of course, only illustrative, since all the pins can be arranged in operative or inoperative positions to correspond with any sequence of

signals of the Baudot code. This sequence may be varied at will.

The function of the pins on the tire is to control the set of 5 contact-levers shown at 22 in Fig. 1. These contact-levers operate the contacts associated with them in such a way then when a pin is in its operative position and can therefore present itself to the contact-lever, it presses against the latter and causes it to make contact at the right. Normally these contact-levers are held against the left contact, by the action of individual retractile springs. Pins in their inoperative position do not, of course, act upon these contact-levers. The function of the latter will be explained presently.

On the rim of the cipher wheel, and near the edge of the reverse face, 5, [illegible] there is a toothed ring, or ratchet wheel, shown in Fig. 3. This ratchet wheel contains 26 teeth, labeled 23. Associated with the ratchet wheel is the pawl shown at 24, Fig.3. The ratchet wheel and pawl, together with solenoid 25 and its armature 41, Figs. 1 and 3, control the movement of the cipher wheel in its rotation. The movement of the cipher wheel is step-by-step, at intervals which will be explained subsequently in discussing the way in which the whole system functions.

4. The Key-Tape Transmitter.

The key-tape transmitter, 26, Fig. 1, is a standard tape transmitter such as is employed with printing telegraph equipment of the Western Electric or Morkrum type. It need not be explained, being well-known in the art. Sufficient to say here that a key-tape bearing characters in the Baudot Code is passed through this transmitter, setting up contacts inside it in accordance with the Baudot Code. The transmitter is, of course, also provided with a tape-stepping magnet, 27, the function of which is to move the tape forward at proper intervals.

5. Operation of System:

The key-tape transmitter, 26, functions jointly with the set of contacts and contact-levers at 22, in the following manner:

Note relay 28, which is energized by current from battery 29, through a path which includes all the contacts and contact-levers of 22 and 26. Note also the illustrative set-up of contacts and contact-levers at 22 and 26 in Fig. 1, in which a specific case is presented. It is assumed there that the arrangement of operative pins on the cipher wheel which are at that moment presenting themselves to the contact-levers of 22 corresponds to the Baudot permutation for letter "Z". At the same moment the permutation

set-up within the key-tape transmitter, 26, also corresponds to the letter "Z". Note that in view of the manner in which the contacts and contact-levers of 22 and 26 are interconnected, the circuit from battery 29 through relay 28 is completed only when the whole set of electrical connections established at 26 coincides with the whole set of connections established at 22. Hence, if "Z" is set up in key-tape transmitter, 26, relay 28 will operate only when "Z" is set up at 22. Similarly if any other letter, say "X", is set up at 26 relay 28 will operate only when "X" is set up at 22. The complete path of the current when such coincidence of connections at 22 and 26 is established is as follows:

From positive of battery 29 along conductor 30, through all contact-levers and appropriate contacts of 26 and 22, conductor 31 to back contact 32, of armature 33, winding of relay 28, conductor 34, to negative of battery 29. It is obvious that since the armature 33 and back contact 32 of relay 28 forms part of the circuit for energizing relay 28, as soon as the relay has received an impulse and armature 33 is attracted the circuit for energizing relay 28 is broken at contact 32. If not prevented from falling back into its normal position under the tension of its retractile spring, armature 33, on release of relay 28 would reestablish contact at 32 and would set up a chattering.

But the mechanical arrangements are such that when armature 33 is first drawn up to relay 28 it passes by and is immediately engaged by lever 35 and held from returning to its retracted position where it can reestablish contact at 32, until lever 35 is displaced by mechanical action to be described later. Armature 33 of relay 28 also controls the solenoid 25, already referred to, which in turn controls the rotation of the cipher wheel, 2, in the following manner:

The motor-operated coiled spring, 13, tends to rotate the ciper wheel in the direction indicated by the arrow, say to the right. This rotation is step-by-step, controlled by the ratchet and pawl referred to above, in this manner:

Assume 22 and 26 set up to different permutations so that relay 28 is not energized and hence contact 36 is closed. A current starts from positive of battery 37 through conductor 38, closed contact 36, conductor 39, back contact 40, armature 41, conductor 42, winding of solenoid, 25, conductor 43, to negative of battery 37. A momentary impulse passes through 25 and causes armature 41 to be attracted, breaking the circuit at back contact 40, whereupon armature 41, under action of its spring, returns and again closes

the circuit at 40. However, the mechanical arrangement is such that the momentary attraction of armature 41 releases the pawl, ~~18~~ 24, associated with the ratchet on the cipher wheel and thus allows the cipher wheel, driven by coiled spring ~~10~~ 8, to advance one step. Thus, the cipher wheel continues to move, one step at a time, as long as contact 36 of relay 28 remains closed. When, however, contact 36 is opened, under the action of relay 28, and is held open by lever 35 as described above, solenoid 25 cannot operate to withdraw armature 41, and hence the pawl 24 cannot be released, whereupon the cipher wheel cannot advance any further. As stated before, the first impulse through relay 28 causes armature 33 to be attracted, to pass by lever 35, which then engages the armature. Thus contact 36 remains open as long as lever 35 engages and holds it. It is only within this period, when the cipher wheel is stationary, that the keyboard, 1, can be manipulated, the mechanical arrangement being such that the keys of the keyboard are locked except when the cipher wheel is stationary.

Suppose now a key is depressed. The cipher resultant will be determined by the position of the cipher wheel at this time, because the circuit established through the cipher wheel depends upon the exact relative position of this wheel with respect to plates 4 and 6.

When a key is depressed, the cipher resultant is shown by the illuminated lamp; the latter continues to be illuminated so long as the key is held down.

We return now to relay 28 and its other armature 43. The latter controls the operation of the tape-stepping magnet 27 of the key-tape transmitter 26, in the following manner:

The tape-stepping magnet 26 is actuated by battery 44, but the circuit is normally open at contact 45. When relay 28 is energized, however, contact 45 is momentarily closed, allowing tape-stepping magnet 27 to function. This causes the key tape to step forward to the next position. It will remain in that position until the next time relay 28 is energized.

There now remains to be described only how lever 35 is controlled.

The keyboard is provided with a universal bar, operable by every key. When a key is depressed and then released, the universal bar, near the close of its upward swing on return to normal position, actuates the lever 35, and causes it to be withdrawn from its engagement with armature 36. This immediately returns to its normal, retracted position, allowing contacts to be reestablished at 32 and 36. In the meantime the tape-stepping magnet having been actuated as described above, one of two things can happen

as regards the set up of connections in key-tape transmitter 26: either a new set of connections has been established, or, by chance , the same set as before has been established. These two cases are described in turn:

(1) If a new set has been established, say a set corresponding to the Baudot signal for "X", the connections no longer match those set up at 22, which, as we have seen, correspond to the letter "Z". Consequently, immediately upon closing of contact 36, solenoid 25 begins to function, allowing the cipher wheel to step forward. It will continue to do so until that set up of pins on the tire corresponding to letter "X" presents itself to the contact-levers of 22, whereupon relay 28 is energized and the cycle has been completed.

(2) If, by chance, the next character on the key tape is the same as before ("Z" again), relay 28 is immediately energized. Solenoid 25 does not get a chance to function and the cipher wheel is held in place. Two letters are therefore enciphered at the same position of the cipher wheel. Of course, if the key tape consists of a series of "Zs" the cipher wheel will remain in position during the encipherment of a corresponding number of letters.

B. Mechanical Details.

The following represent tentative ideas regarding the physical construction of the cryptograph.

The entire mechanism can probably be mounted upon a wooden base not more than 12 inches long by 12 inches wide. All parts should be rugged in construction, suitable for withstanding more or less rough usage in operation and transportation in the field.

The keyboard need be no larger than that of a portable typewriter of any standard make. The 26 contacts can be mounted vertically at the rear of the keyboard and set in a horizontal line.

The light bank can be mounted above and to the rear of the keyboard, and made to slope backward about 30^{0} from the perpendicular. The light bank need be no larger than 9 inches long by 4 inches wide. The lamps and the windows in the front panel of the light bank should be arranged to correspond with the standard keyboard. The lamps should be of the standard 3.5-volt type.

In back of the keyboard and under the light bank, firmly mounted upon the base board are the key-tape transmitter, the cipher wheel, the motor, and associated mechanisms.

Nothing more need be said about the key-tape transmitter. A standard Western Electric or Morkrum-Kleinschmidt transmitter will serve the purposes admirably.

The cipher wheel should be made of durable material but should weigh as little as possible so as not to require a great deal of power to rotate it. In dimensions it should be not more than 6 inches in diameter and 2 inches in thickness. It should be mounted upon the shaft in either a horizontal or vertical position, whichever seems most practicable. The motor which operates the coiled spring that drives the cipher wheel should be of the smallest capacity consistent with its load, and should be of the 110-volt, 60 cycle type. The speed of rotation of the cipher wheel should be at least 25 revolutions per minute; a speed of 40 per minute would be highly desirable advantageous.

Standard relays and solenoids may be employed to perform the functions indicated in the preceding section.

It should be possible to remove the cipher wheel very easily, in order to change set-up of pins, or connections inside it.

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A. Description of System.

This cryptograph consists of the following principal parts:

1. A keyboard.
2. A bank of 26 small lamps, 4-volt.
3. A rotatable cipher wheel.
4. A key-tape transmitter.
5. Certain associated solenoids and relays, and a small electric motor.

The general nature of these parts and their functions will be described briefly.

1. The Keyboard:

The keyboard, shown at 1 in Fig. 1, is provided with the standard arrangement of keys. Each of the latter operates an electrical contact, as shown schematically for the "Q" and "W" keys. Keyboards of this type are well-known in the art. It is not provided with any printing mechanism in the model under consideration.

2. The Light Bank:

This consists simply of a bank of 26, 4-volt lamps, two of which are shown at 10 in Fig. 1. The other 24 are wired in homologous manner to that shown for these two, one terminal being connected to a common conductor, 9, the other, to individual binding posts on a plate 4, to be described below.

3. The Cipher Wheel:

The cipher wheel is shown at 2 in Fig. 1. This wheel consists of 52 brush-type

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contacts arranged in two rings or sets of 26 each. One set is placed on the obverse face, 3, of the wheel 2, the contacts being arranged equidistant from one another in a circle around the circumference of the face. The other set is similarly placed on the reverse face, 5, of the wheel. The contacts on the obverse face are connected to those on the reverse face by means of flexible insulated conductors which pass through the interior of the wheel, as shown schematically in Fig. 1. The cipher wheel is fixed upon the shaft 7 which is driven by a motor-operated coiled spring, 8, the motor not being shown. The contacts of the obverse face, 3, of the cipher wheel press against ball-bearing type contacts arranged on the fixed plate 4; the contacts of the reverse face, 5, of the cipher wheel press against ball-bearing type contacts arranged on the fixed plate 6. The plates 4 and 6 each contain 26 contacts arranged in a circle. The cipher wheel rotates between these fixed plates 4 and 6 so that each contact on the obverse face, 3, of the cipher wheel presents itself in turn to each contact on plate 4, and each contact on the reverse face, 5, of the cipher wheel presents itself in turn to each contact on plate 6, as the cipher wheel rotates. The contacts of plate 6 are respectively connected by conductors to the contacts of the keyboard 1; the contacts of plate 4 are respectively connected by conductors to 26 electrical elements which may be small lamps, relays, or solenoids, only two of which are shown at 10. For the sake of simplicity, it will be assumed that the electrical elements are lamps. As shown in Fig. 1, when the key "Q" is depressed, assuming the cipher wheel to be in the position indicated in

the figure, a circuit is established as follows: from positive pole of battery 11 through conductor 12, closed contact at the "Q" key, conductor 13, contact 14 on fixed plate 6, contact 15 on cipher wheel 2, conductor 16, contact 17 of cipher wheel 2, contact 18 of plate 4, conductor 19, through lamp 20, conductor 21 to negative of battery 11. Lamp 20 has a translucent glass window before it, on which a letter is painted, say the letter "W". Hence, depression of the key"Q" on the keyboard gives the cipher resultant "W", under the conditions specified.

Suppose that the key "W" of the keyboard is depressed, instead of "Q". By following the path set up, it will be seen that the "Q" lamp will be lighted. Thus, reciprocity is established between the keys on the keyboard and the lamps so that if, for example, Q= W, in enciphering, W= Q in deciphering. The same reciprocal relationship can be established throughout the alphabet by connecting the flexible conductors in the interior of the cipher wheel in an appropriate manner to paired contacts on the obverse and reverse faces of the cipher wheel.

If the cipher wheel were stationary, the relationship between the key depressed and the lamp illuminated would be fixed for each wiring of the interior of the cipher wheel.

But the cipher wheel is rotatable and hence this relationship can be made variable. The manner of its variation and its control will now be presented.

The rim or tire of the cipher wheel is provided with 130 pins arranged in 5 sets or rings of 26 each. These pins can be elevated into operative positions or left remaining in inoperative positions in groups of fives transversely to the tire, in accordance with the permutations of the 5-unit or Baudot code. To explain what is meant, we may say that according to the Baudot code, the permutation of elements for the letter A, for example, is represented thus: 1 2 3 4 5 + + - - - . For our purposes we will let the + sign indicate that a pin is to be elevated into its operative position; the - sign, that it is to be left in its inoperative position. In Fig. 2 there is shown a side elevation view of a section of the tire of the cipher wheel, with the pins now being described. The pins indicated by dotted lines in the figure represent pins which have been left depressed in their inoperative positions; the pins indicated by whole lines represent pins which have been elevated into their operative positions. The permutations represented in the figure correspond to the Baudot signals for the letters Y, Z and A. The order of the letters in Figure 2 is, of course, only illustrative, since all the pins can be arranged in operative or inoperative positions to correspond with any sequence of

signals of the Baudot code. This sequence may be varied at will.

The function of the pins on the tire is to control the set of 5 contact-levers shown at 22 in Fig. 1. These contact-levers operate the contacts associated with them in such a way then when a pin is in its operative position and can therefore present itself to the contact-lever, it presses against the latter and causes it to make contact at the right. Normally these contact-levers are held against the left contact, by the action of individual retractile springs. Pins in their inoperative position do not, of course, act upon these contact-levers. The function of the latter will be explained presently.

On the rim of the cipher wheel, and near the edge of the reverse face, 5, there is a toothed ring, or ratchet wheel, shown in Fig. 3. This ratchet wheel contains 26 teeth, labeled 23. Associated with the ratchet wheel is the pawl shown at 24, Fig. 3. The ratchet wheel and pawl, together with solenoid 25 and its armature 41, Figs. 1 and 3, control the movement of the cipher wheel in its rotation. The movement of the cipher wheel is step-by-step, at intervals which will be explained subsequently in discussing the way in which the whole system functions.

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4. The Key-Tape Transmitter.

The key-tape transmitter, 26, Figure 1, is a standard tape transmitter such as is employed with printing telegraph equipment of the Western Electric or Morkrum type. It need not be explained, being well-known in the art. Sufficient to say here that a key-tape bearing characters in the Baudot Code is passed through this transmitter, setting up contacts inside it in accordance with the Baudot Code. The transmitter is, of course, also provided with a tape-stepping magnet, 27, the function of which is to move the tape forward at proper intervals.

5. Operation of System:

The key-tape transmitter, 26, is associated and functions jointly with the set of contacts and contact-levers at 22, in the following manner:

Note relay 28, which is energized by current from battery 29, through a path which begins at conductor 30 and includes all the contacts and contact-levers of 22 and 26, and emerges along conductor 31. Note also the illustrative set-up of contacts and contact-levers at 22 and 26 in Figure 1, in which a specific case is presented. It is assumed there that the arrangement of operative pins on the cipher wheel which are at that moment presenting themselves to the contact-levers of 22 corresponds to the Baudot permutation for letter "Z". At the same moment the permutation

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set-up within the key-tape transmitter, 26, also corresponds to the letter "Z". Note that in view of the manner in which the contacts and contact-levers of 22 and 26 are interconnected, the circuit from battery 29 through relay 28 is completed only when the whole set of electrical connections established at 26 coincides with the whole set of connections established at 22. Hence, if "Z" is set up in key-tape transmitter, 26, relay 28 will operate only when "Z" is set up at 22. Similarly if any other letter, say "X", is set up at 26 relay 28 will operate only when "X" is set up at 22. The complete path of the current when such coincidence of connections at 22 and 26 is established is as follows:

From positives of battery 29 along conductor 30, through all contact-levers and appropriate contacts of 26 and 22, conductor 31 to back contact 32, of armature 33, winding of relay 28, conductor 34, to negative of battery 29. It is obvious that since the armature 33 and back contact 32 of relay 28 forms part of the circuit for energizing relay 28, as soon as the relay has received an impulse and armature 33 is attracted, the circuit for energizing relay 28 is broken at contact 32. Since armature 33 is under tension of a retractile spring, if not prevented from being pulled back into its normal position ~~under the tension of its retractile spring, armature 33~~, on release of relay 28, armature 33 would reestablish contact at 32 and would set up a chattering.

(4)

But the mechanical arrangements are such that when armature 33 is first drawn up by relay 28 it passes by and is immediately engaged by lever 35 and held from returning to its retracted position where it can reestablish contact at 32, until lever 35 is displaced by mechanical action to be described later. Armature 33 of relay 28 also controls the solenoid 25, already referred to, which in turn controls the rotation of the cipher wheel, 2, in the following manner:

The motor-operated coiled spring, 8, tends to rotate the ciper wheel in the direction indicated by the arrow, say to the right. This rotation is step-by-step, controlled by the ratchet and pawl referred to above, in this manner:

Assume the contact levers at 22 and 26 set up to different permutations so that relay 28 is not energized and hence contact 36 is closed. A current starts from positive of battery 37 through conductor 38, closed contact 36, conductor 39, back contact 40, armature 41, conductor 42, winding of solenoid, 25, conductor 43, to negative of battery 37. A momentary impulse passes through 25 and causes armature 41 to be attracted, breaking the circuit at back contact 40, whereupon armature 41, under action of its spring, returns and again closes

the circuit at 40. However, the mechanical arrangement is such that the momentary attraction of armature 41 releases the pawl, ~~12~~ 24, associated with the ratchet on the cipher wheel and thus allows the cipher wheel, driven by coiled spring, ~~35~~ 8, to advance one step. Thus, the cipher wheel continues to move, one step at a time, as long as contact 36 of relay 28 remains closed. When, however, contact 36 is opened, under the action of relay 28, and is held open by lever 35 as described above, solenoid 25 cannot operate to withdraw armature 41, and hence the pawl 24 cannot be released, whereupon the cipher wheel cannot advance any further. As stated before, the first impulse through relay 28 causes armature 33 to be attracted, to pass by lever 35, which then engages the armature. Thus contact 36 remains open as long as lever 35 engages and holds it. It is only within this period, when the cipher wheel is stationary, that the keyboard, 1, can be manipulated, the mechanical arrangement being such that the keys of the keyboard are locked except when the cipher wheel is stationary.

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The tape-stepping magnet 26 is actuated by battery 44, but the circuit is normally open at contact 45. When relay 28 is energized, however, contact 45 is momentarily closed, allowing tape-stepping magnet 27 to function. This causes the key tape to step forward to the next position. It will remain in that position until the next time relay 28 is energized.

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as regards the set up of connections in key-tape transmitter 26; either a new set of connections has been established, or, by chance , the same set as before has been established. These two cases are described in turn:

(1) If a new set has been established, say a set corresponding to the Baudot signal for "X", the connections no longer match those set up at 22, which, as we have seen, correspond to the letter "Z". Consequently, immediately upon closing of contact at under action of the universal bar, the circuit for energizing solenoid 25 is closed at 36, solenoid 25 begins to function, allowing the cipher wheel to step forward. It will continue to do so until that set up of pins on the tire corresponding to letter contact at 36 is broken, solenoid 25 deenergized "X" presents itself to the contact-levers of 22, whereupon relay 28 is energized, and the cycle has been completed.

(2) If, by chance, the next character on the key tape is the same as before ("Z" again), relay 28 is immediately energized. Solenoid 25 does not get a chance to function and the cipher wheel is held in place. Two letters are therefore enciphered at the same position of the cipher wheel. Of course, if the key tape consists of a series of "Zs" the cipher wheel will remain in position during the encipherment of a corresponding number of letters.

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Standard relays and solenoids may be employed to perform the functions indicated in the preceding section.

It should be possible to remove the cipher wheel very easily, in order to change set-up of pins, or connections inside it.

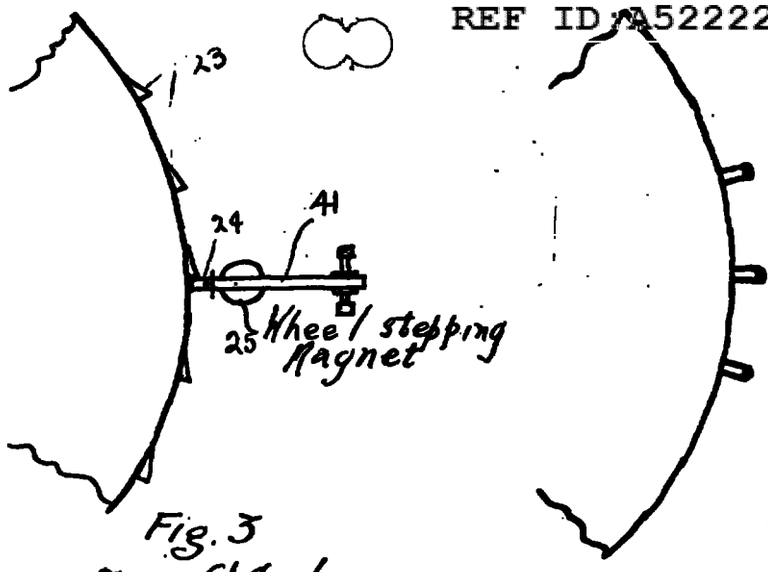

Fig. 3
Plan of Wheel stepping Pawl

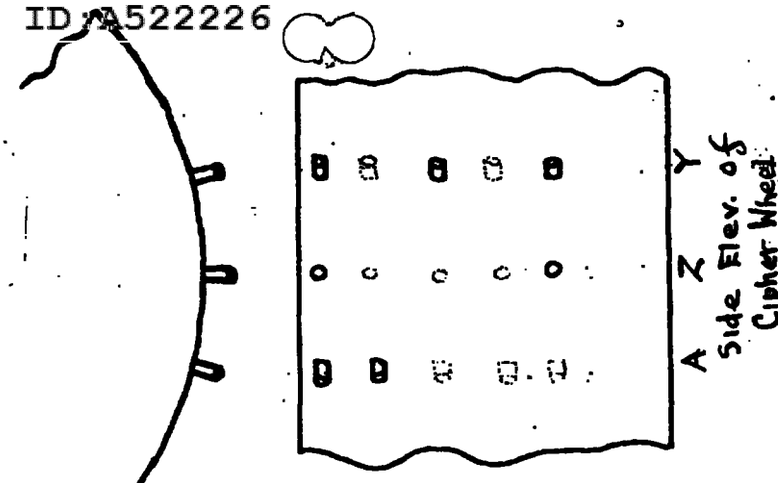

Fig. 2.