THE CONTACTLESS RELAYS

By

Akira Okamoto Hiroshi Kobayashi

(Development Div., Toyoda Works) (Controlling Planning Div., Central Technical Dep't.)

I. MAGNETIC AMPLIFIER TYPE

1. Operational principle of the magnetic amplifier

There are two types of the magnetic amplifier used for the contactless relays, the self-saturation circuit and the Ramey circuit (or the high response circuit).

The Fuji Denki Seizo K.K. has been employing the self-saturation circuit of the above two types. Therefore, this Articles will illustrate its operational principle in a brief description.

The fundamental circuit of the self-saturation circuit to be used for the contactless relays is of such a half wave type as shown in Fig. 1.

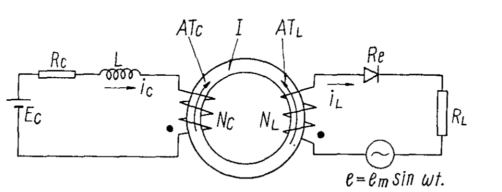

Fig. 1. Fundamental circuit of self-saturating type magnetic amplifier

This circuit consists of an iron core I being wound by the N_L turns of the load winding and the N_C turns of the control winding, and the load resistance R_L is connected to the load winding through the a-c power source and the half wave type metal rectifier. On the other hand, the d-c control source is connected to the control winding through the input resistance R_C and the reactor L (In some case, there is none of this L) in a series. As this core, the toroidal type or punched core is to be used. Now, let us take consideration on the operation of this core with assuming its magnetic characteristics as given in Fig. 2.

At first, let us observe the period (This is called the conducting period) in which the porality of the source voltage e is the positive direction of the half wave rectifier. If the bias of H_{dc} is given by the d-c excitation before this period starts, the magnetized state of the core must exists somewhere

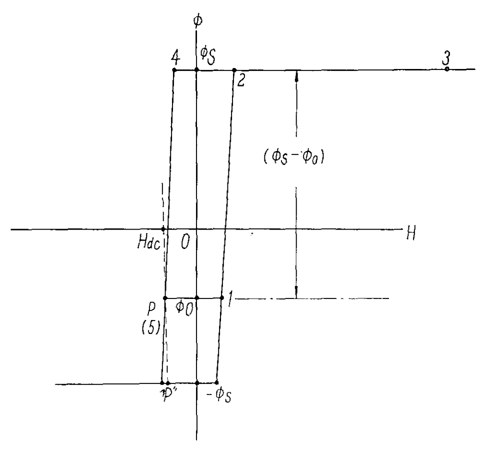

Fig. 2. Hysteresis loop of iron core used in magnetic amplifier

between P and P'. As will be made clear in the following description, if the magnetized state exists at the point P and the voltage e of the conducting period is given at the above P, the magnetized state is to change from the point P to $P \to 1 \to 2$, because the porality of the ampere turn of the load winding is made contrary to that of the ampere turn of the control winding. As there is little flux change to be produced between the two points, $P \to 1$, almost all of the source voltage e is to be impressed to the load resistance R_L. Then, if the excitation, or the magnetizing force from the current value dividing the source voltage e by the load resistance R_L, is to become larger than the width of the hysteresis, the magnetized state will begin to change as $1 \to 2$. Within this period, the following equation can be composed by the Faraday's law :

$$e = N_L \frac{d\phi}{dt} \times 10^{-8} + i_L R_L \quad \text{..............(1)}$$

In general, the core of the high quality has a quite small width of hysteresis, and has also a slight exciting current, so that both i_L and R_L in the equation (1) may be omitted.

Therefore, the equation (1) may become as follows :

$$e \fallingdotseq N_L \frac{d\phi}{dt} \times 10^{-8} \quad \text{.................(2)}$$

After integrating this equation (2),

$$\frac{10^8}{N_L}\cdot\int_0^t e\ dt=\int_{\phi_0}^{\phi} d\phi=\phi-\phi_0 \ \ldots\ldots\ldots\ldots(3)$$

is to be given. This equation (3) means that, if the voltage e is impressed to the load winding, the flux value starting at the value ϕ_0 is to be gradually increased along with the passing of the time. This course of the time is to be indicated by the process of $1 \rightarrow 2$ in Fig. 2 and by the course of $1 \rightarrow 2$ in the Fig. 3.

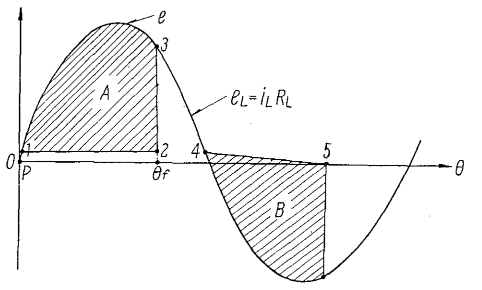

Fig. 3. Voltage wave form

If the flux value is to attain to the saturated value ϕ_s at this point after it becomes gradually larger, there is no more change in the magnetic flux, so that the counter voltage in the load winding is eliminated and almost all of the a-c voltage is to be impressed to the load resistance R_L.

Therefore, load voltage wave form is to have such a curve as in Fig. 3, making on abrupt increase from 2 to 3 at once, and entirely corresponding to the power source voltage wave form, up to the point of 4. The point (point of 2), where the iron core is saturated to have the current increasing in an abrupt way, is called the firing point, because it resembles to the firing of the thyratron or the mercury rectifier. The phase angle (or the firing angle) θ_f at this point can be introduced by the following formula deriving from the equation (3):

$$\frac{10^8}{\omega N_L}\int_0^{\theta f} e_m \sin\theta d\theta=\phi_s-\phi_0 \ \ldots\ldots\ldots\ldots\ldots(4)$$

and, solving the above-mentioned formula,

$$\frac{e_m\cdot 10^8}{\omega N_L}(1-\cos\theta_f)=\phi_s-\phi_0 \ \ldots\ldots\ldots\ldots(5)$$

is obtained. So, the value of θ_f is to be decided by ϕ_0, being determined by the d-c control current. In other words, if the value of $(\phi_s-\phi_0)$ is zero, θ_f becomes also zero and all of the conducting period of the source voltage is to be impressed to the load resistance R_L. If $(\phi_s-\phi_0)$ becomes equal to $\frac{e_m\cdot 10^8}{2\omega N_L}$, θ_f becomes to be π and the load voltage comes to be almost equal to zero. If the magnetic characteristic is to resemble to an ideal rectangular characteristic, the hysteresis width of the magnetic characteristic is to be narrow, and the inclination of the vertical part of the hysteresis is also abrupt and steep, so that the level of ϕ_0 may be varied from $-\phi_s$ to $+\phi_s$ even with the very slight d-c control ampere turns.

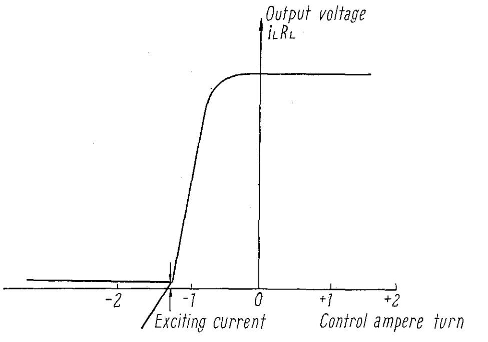

Fig. 4. Transfer characteristics of magnetic amplifier

The Fig. 4 is to illustrate the relation between this d-c control current and the load voltage (output voltage). Just as shown by this Figure, the flux has a saturated value after its firing angle. When the source voltage is reduced to arrive at the point of 4 in the Fig. 3, the magnetized state of the iron core comes to a point of 4 in the Fig. 2. So, if the source voltage becomes further small, the flux is also to be reduced and the magnetized state will take a course of $4 \rightarrow P$. This period is called a reset period. In order that the flux returns to its former position within this reset period, the voltage-time integral value having been supplied to the load winding during the conducting period, i.e. the area A of the Fig. 3 where the shade is marked, must become equal to the voltage-time integral value having been supplied to the load windings during the reset period, i.e. the area B of the Fig. 3, when the magnetized state of the core is reset through the conducting period, it comes downward along the upper curve of the hysteresis loop, so that the magnetized state may exist at the point P at the beginning of the conducting period, as have been stated in the foregoing lines.

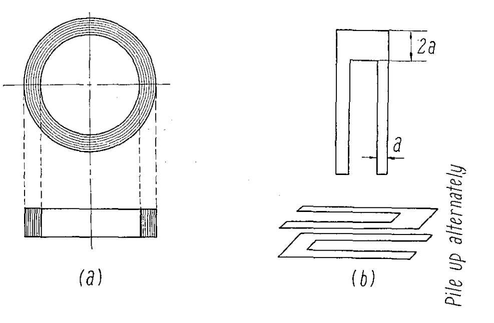

Fig. 5. Form of iron core used in amplifier

For the iron core commonly used for the contactless relays, the rectangular hysteresis iron core of 50% nickel-iron is applied. The form of this core is a toroidal one as in the Fig. 5 (a), or a punched one as in the same Fig. 5 (b). Of course, there is no air gap in the toroidal core. Even in the punched core, it may be considered that there is little air gap when this core is laminated with one another as shown in the Fig. 5 (b). Furthermore, the hysteresis of the iron core is nearly resembling to a toroidal type, and the punched core is preferable for the purpose of mass-production of the winding.

It is unnecessary to make any special amplification with a linearity, in case of applying the magnetic amplifier as a contactless relay, but it will do good only by switching ON and OFF. Therefore, such a circuit as shown in the Fig. 6 is used in order to securely switch it ON and OFF with a small control input. The principle of this circuit is the same with that of the Fig. 1. However, the input-output characteristic becomes as same as that of the relay as being illustrated in the Fig. 7 by the positive feedback winding of the N_f turns. The reason why N_f becomes a positive feedback is as follows :

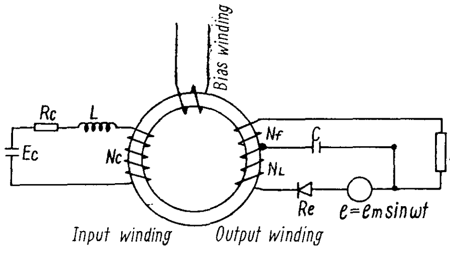

Fig. 6. Fundamental circuit of contactless relay

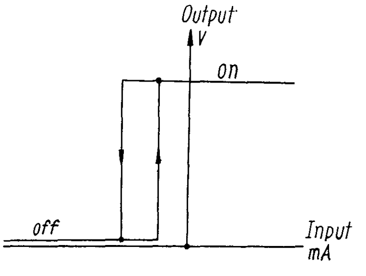

Fig. 7. Fundamental characteristics of contactless relay

During the conducting period, the electric charge is to be stored in C through the N_L winding after firing, and this charge is discharged to the load through the N_f winding within the following reset period, so as to prevent it from being reset. If the turning number of it is made more, the prevention from resetting is carried on in a very strong way and the resetting becomes impossible after firing just once. As a result of it, it becomes impossible to stop the output, unless the control input should be made considerably strong in negative power. Thus, such a characteristic as in the Fig. 7 is formed. It is required for the control input of $\pm 0.25 \sim 0.5$ AT approx. to shift the switch between " ON " and " OFF " in common case. Furthermore, in case of the 1 c/s response system using the commercial frequency for the voltage source, the output of 1 W approx. can be switched "ON" and "OFF", with the needed power of $0.5 \sim 1$ mW approx.

The insertion in a series of the reactor L into the control winding is aimed at preventing the induced voltage, from the load winding side during the conducting period before firing, from getting out into the control circuit. However, the above reactor will be unnecessary, as the induced voltage from the load winding side to the control winding side becomes smaller if the turning number N_c of the control winding is much smaller than that (N_L) of the load winding. Also, if the source voltage is made of a pulse wave form, the large voltage can be controlled by the small flux control, so that the retardation reactor of the control winding side may become unneeded. For this reason, there is very often used the pulse voltage source.

2. Contactless relays employing the magnetic amplifier

1) " And " circuit

In the contactless relay, such a circuit as connecting in a series several contacts A is called the " And " circuit, which will not act unless all of the several conditions are satisfied altogether. The Fig. 8 is an example of the " And " circuit formed by the self-saturation type magnetic amplifier. In this case, any of the conditions inserted from outside shall be altogether adjusted and changed on the base of a certain unit as becoming 2 mA, for example, per each condition. Then, the fundamental circuit of the Fig. 6 is moved by three units with the bias winding in a negative direction, so that this circuit may not act without adding three units,

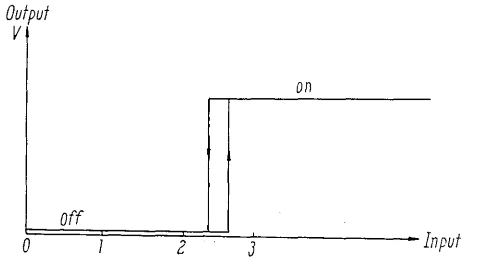

Fig. 8. Characteristic of " And " circuit

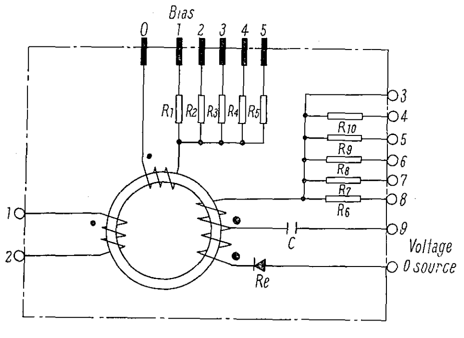

Fig. 9. The circuit used for "And", "Not", and "Memory" circuit

as shown in the Fig. 8. Therefore, if the bias winding is moved by four units in the negative direction, this circuit becomes the "4 And" circuit which does not act without adding four units.

Using the contactless relays of this type, various types of the "And" circuit can be formed by the adjustment of the bias, in the above-mentioned way. The actually formed and practically applied circuit is shown as in the Fig. 9.

2) "Not" circuit

As long as the contact type is concerned, this "Not" circuit corresponds to the one connecting the several contacts B in parallel.

In other words, this circuit has such a function that it cannot stop acting unless all of the conditions are satisfied entirely. In order to form this circuit, "And" circuit may be used just as it is, only with changing the bias in the positive direction. If the two units of bias are added in the positive direction, the "3 Not" circuit, which is off (opened) with the concentrated triple conditions, is to be formed as in the Fig. 10. It is far from saying that various kinds of "Not" circuit can be formed with different quantities of bias.

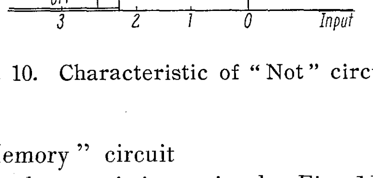

Fig. 10. Characteristic of "Not" circuit

3) "Memory" circuit

Such a characteristic as in the Fig. 11 may be given by using the circuit of the Fig. 9 and adding about 0.5 unit of bias in the negative direction. It can be used for making "Memory", as a result.

4) "Or" circuit

This circuit is equal to that of connecting the

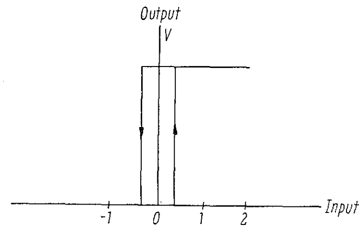

Fig. 11. Characteristic of "Memory" circuit

contacts A in parallel, and it may act with adding anyone of the several conditions. As shown in the Fig. 13, this circuit diagram consists only of the series resistor and the rectifying valve for preventing any interference. It may also be formed, even by giving bias as in the Fig. 12.

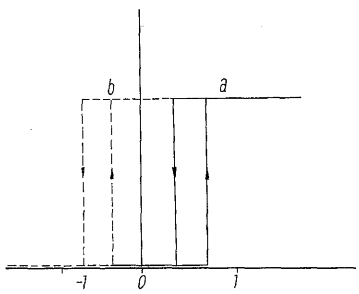

Fig. 12. Characteristic of "Or" circuit

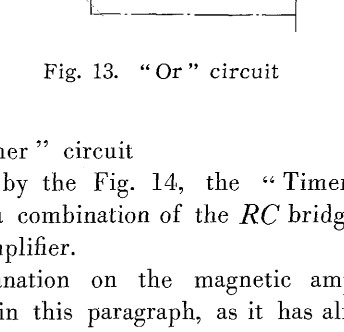

Fig. 13. "Or" circuit

5) "Timer" circuit

As given by the Fig. 14, the "Timer" circuit consists of a combination of the RC bridge and the magnetic amplifier.

The explanation on the magnetic amplifier will be omitted in this paragraph, as it has already been given before, but some brief description on the RC bridge is to be given in the following lines.

When d-c input is supplied with the bridge formed by R_7, R_8, R_T and C_T, so as to make the terminal 1 positive, the potential at the point P rises expotentially as shown in the Fig. 14. In this case, the time constant is $(R_T \times C_T)$. In the next, because the potential at the point Q is the constant

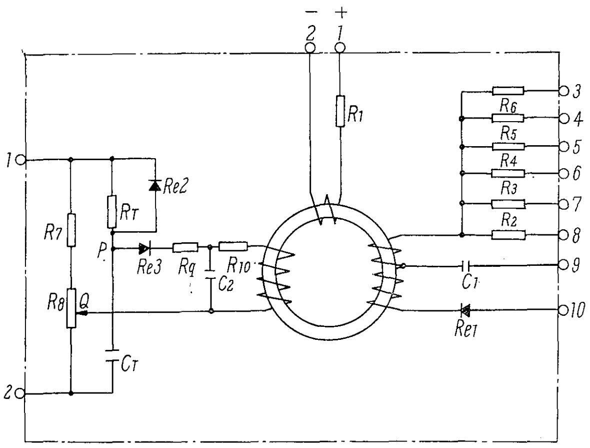

Fig. 14. "Timer" circuit

one which is decided by the position of the potentiometer of R_8, a d-c crurent flows to the magnetic amplifier input through the rectifier valve as shown in Fig. 15, when the potential of the point P rises to be higher than that of the point Q. Then, the magnetic amplifier is made in a position of "ON" with a time lag of T' seconds which is the time length of T_1, for which the potential at the point A becomes higher than that at the point Q, added to the short time length for which the potential at the point P exceeds the dead band. As the quantity of T_1' is decided nearly by that of T_1, so T_1' doesn't change very much even if the d-c input voltage might vary within a slight range. The rectifier valves Re_2 at the both ends of the time delay resistor are aimed at quickening the reset time of them.

In such a system as above, it is quite easy to get the time delay of $10\sim20$ seconds approx., and its reset time is less than 0.1 second approx.

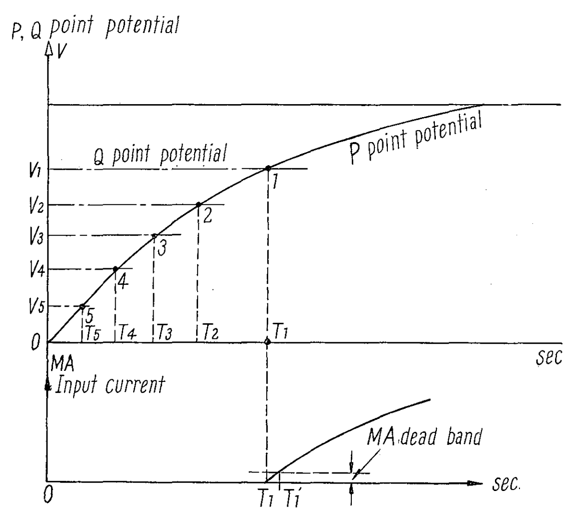

Fig. 15. Operation diagram of "Timer" circuit

II. TRANSISTOR TYPE

1. On the transistor

As the transistor has recently been used in a wide field for the vacuum tube, it seems to be unnecessary to describe on its operational principle. However, the graphical symbol of the transistor and its characteristics will be given in the following lines, for the needs of explaining transistor type circuit to be used.

The Junction type transistor is shown by Fig. 16 (a). And this is to be simplified on its illustration by Fig. 16 (b).

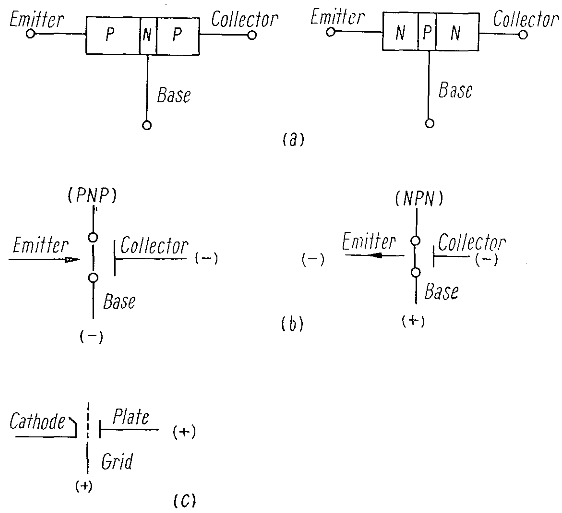

Fig. 16. Graphical symbol of transistor

This simplification was used by the *RCA* staffs at first; after then, it has been widely applied among many engineers, and it is quite resembling to the code of the electron tube of Fig. 16 (c). Therefore, this graphical symbol is applied hereinafter for its simplicity of observation.

Now, in case of the *NPN* type transistor, if there is the positive potential for the base corresponding to the grid, more than that for the emitter, the current passing through the collector becomes larger. At this time, the collector keeps the positive potential against the emitter to serve as same as the plate of the vacuum tube, and the emitter corresponds to the cathode. In this way, the *NPN* type transistor completely corresponds to the vacuum tube. However, in case of the vacuum tube, the input impedance of grid is very high enough to be considered as the voltage control. While, in the transistor, this input impedance is comparatively low, so that it may be better to be considered as the current control.

As illustrated in Fig. 16 (b), the current flows in the direction contrary to that of the vacuum tube, in the *NPN* type transistor. So, it is necessary to make the emitter corresponding to the cathode positive and to make the collector corresponding to the plate negative. Besides, the base of the transistor corresponding to the grid of the tube is to make this transistor " OFF " in the positive potential and to make it " ON " in the negative potential.

The transistor can make the power amplification 30～40 db per one stage, so that it is the most adequate to use it as the contactless relay in a practical way.

The contactless relay of the transistor type is to response even in a very short length of time as several μ seconds and even with very weak pulse, and has such advantageous points as transmitting many hundred and thousand signals at one time with one transmission line under the time division system in case of the tele-control.

It is often said that the transistor has a narrow range of tolerance against the temperature changes, but it can be covered by giving a comparatively wide range of tolerance under its designing. In other words, there might occur little inconvenience if it would be used by separating the " ON " and " OFF " with each other to some extent so as to look the current at zero emitter base voltage upon the " OFF " one. Furthermore, we can take greater expectation for the contactless relay of the transistor type, as the silicon transistor which is of high strength against the change of temperature has recently put to use.

2. Contactless relay using the transistor

The polarity of the *NPN* type transistor is contrary to that of the *PNP* type one. Therefore, the following description will be made under the *PNP* type.

In this case, the " OFF " and " ON " are to be represented as OV and V_S (−), respectively.

1) " Or " circuit

The diagram of this circuit is shown in Fig. 17. This is the same as Fig. 16, with only an exception of the diode in a different direction.

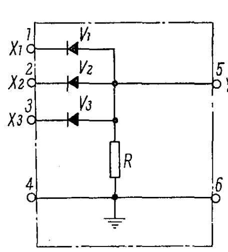

Fig. 17. " Or " circuit

2) " And " circuit

The diagram of the circuit is given by Fig. 18. In this case, as soon as the all inputs of X_1, X_2, and X_3 is made " ON " or V_S volts, the output of V_S (−) volts is to be produced at the terminal 5.

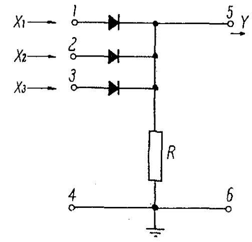

Fig. 18. " And " circuit

3) " Not " circuit

Fig. 19 gives the diagram of this circuit. If the voltage of V_S (−) is put at the terminal 2, the transistor TS is also put under the conducting state and the V_S at the terminal 4 before conducting state is changed to OV. In this way, the input X becomes V_S, while the output Y changes OV to make its signal contrary, so that the " Not " circuit may be formed.

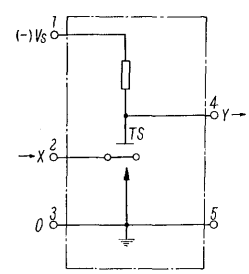

Fig. 19. " Not " circuit

4) " Inhibit " circuit

The structure of this circuit is quite the same as that of the " And " circuit. However, the polarity of one of several inputs is contrary to all the rest, which is called the " Inhibit " signal. So, in case where there is no " Inhibit " signal, all of the rest signal given at the same time are to produce a signal on the output. However, no signal can be produced on the output, whenever there is the " Inhibit " signal.

5) " Memory (Flip-flop) " circuit

Just as having been shown in Fig. 20, this circuit has only the two stable states where the left side transistor TS_1 is of " ON " and the right side one TS_2 is of " OFF " or vise versa. Therefore, it is called the two-stable circuit. Now, let us observe the case where the TS_1 is of " OFF " and TS_2, " ON ". As the TS_2 is in a saturated state, its collector voltage V_{C2} is equal to the emitter

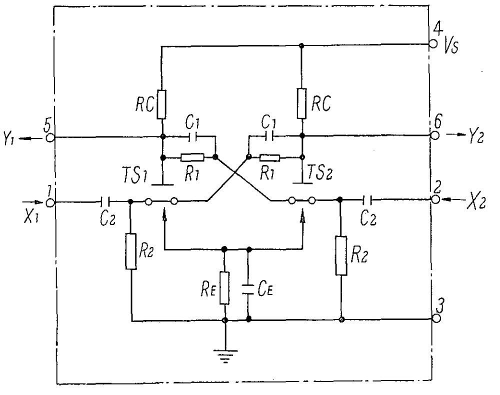

Fig. 20. "Memory" circuit (Flip-flop circuit)

voltage V_{E2}. Therefore, both the collector current I_{C2} and voltage V_{C2} can be as follows:

$$I_{C2}=\frac{V_S}{R_C+R_E} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(6)$$

$$V_{C2}=V_{E2}=V_S\frac{R_E}{R_E+R_C} \quad \cdots\cdots\cdots\cdots(7)$$

Therefore, the base voltage V_{B1} of TS_1 is as follows:

$$V_{B1}=V_{C2}\cdot\frac{R_2}{R_1+R_2} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots(8)$$

On the other hand, the emitter voltage V_{E1} of TS_1 is clearly equal to V_{E2} $(=V_{C2})$. So, the base voltage of TS_1 is of the positive potential higher than the emitter voltage, and the TS_1 is kept in the "OFF" state. For this reason, also its collector voltage is equal to V_S. This voltage is divided by R_1 and R_2 and applied to the base of TS_2. As the result of it, the following voltage must be put to the base of TS_2:

$$V_{B2}=V_S\frac{R_2}{R_1+R_2} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots(9)$$

(R_C is omitted)

However, as this transistor is in the "ON" state and the base, emitter and the collector of it are all in a short-circuit state, its base voltage V_{B2} must be equal to the emitter voltage V_{E2}. The base current is to flow as much as the enough amperes to fill up the difference between V_{B2} and V_{E2}, so the following equation is to be given, (according to the Huang-Tenbnun's Theorem):

$$I_{b2}=\frac{V_S\dfrac{R_2}{R_1+R_2}-V_{E2}}{\dfrac{R_1\cdot R_2}{R_1+R_2}} \quad \cdots\cdots\cdots\cdots(10)$$

And, in order that the TS_2 is in the saturated state, the following relation must be composed as a condition.

$$\beta_2\cdot I_{b2}>I_{C2} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(11)$$

(β_2 is the value of current amplification gradient.)

The following samples of the actual figure value are to be given for the OC–76 type transistor:

$R_C=3\,\text{k}\Omega$, $R_E=600\,\Omega$, $R_1=R_2=30\,\text{k}\Omega$,
$C_1=1{,}000\,\text{pF}$, $C_E=5{,}000\,\text{pF}$.

In case where TS_1 is in the "OFF" state, TS_1 becomes in the "ON" state as soon as the negative pulse is supplied from the input 1. As a result, the TS_2 base is to become in the positive potential more than the emitter and the TS_2 is changed in the "OFF" state and holds this state even when the negative pulse is put off. If the negative pulse is supplied from the input 2, the TS_1 takes the "OFF" state and the TS_2, the "ON" state, once again.

When the positive pulse is given from the input 2, TS_2 is made in the "OFF" state in a moment, and the collector voltage is changed to V_S. So, the negative voltage is impressed to the TS_1 base and the TS_1 is shifted in the "ON" state, so that it may hold this state even after the positive pulse is eliminated.

Then, this is recovered to a former state when the positive pulse is supplied from the input 1.

The C_1 is aimed at quickening the transient phenomena from the "ON" state of it to the "OFF", and vise versa. And the C_E is used for a by-pass on the transient time.

6) Monostable multivibrator (One shot multi.)

As shown in Fig. 21, this circuit has the only one stable state where the left side transistor TS_1 becomes in the "OFF" state and the right side transistor TS_2 becomes in the "ON" state. And this is called a monostable circuit.

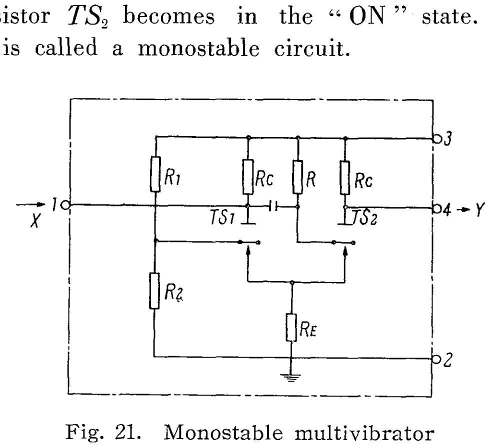

Fig. 21. Monostable multivibrator
(on shot multivibrator)

As the TS_2 is in a saturated state, its collector voltage V_{C2} is equal to the emitter voltage V_{E2}. So, the collector current I_{C2} and its voltage V_{C2} are as follows:

$$I_{C2}=\frac{V_S}{R_C+R_E} \quad \cdots\cdots\cdots\cdots\cdots\cdots(12)$$

$$V_{C2}=V_S\cdot\frac{R_E}{R_C+R_E}\,(=V_{B2}=V_{E2}) \quad \cdots\cdots\cdots(13)$$

Therefore, the base current I_{b2} by R is as follows:

$$I_{b2}=\frac{V_S-V_{B2}}{R} \quad \cdots\cdots\cdots\cdots\cdots\cdots(14)$$

So, the condition for making TS_2 saturated is given by the following relation:

$$\beta_2 I_{b2} > I_{C2} \quad \text{..........................(15)}$$

On the other hand, the TS_1 base voltage V_{B1} is given by the following equation:

$$V_{B1} = V_S \cdot \frac{R_2}{R_1 + R_2} \quad \text{....................(16)}$$

Thus, the condition for keeping TS_1 always in the " OFF " state is as follows:

$$V_{B1} > V_{E1} \, (= V_{E2}) \quad \text{.......................(17)}$$

Both the TS_1 and TS_2 terminals of the condenser C are connected to the voltages V_S and V_{E2}, respectively. So, the charge is kept accumulated as shown in the figure. In this state, the positive pulse given by input is to join into the TS_2 base through C_1 and TS_2 becomes in the " OFF " state in a moment and I_{C2} becomes zero. Therefore, V_{E1} and V_{E2} become the earth potential. Then, the base of TS_1 is changed in the negative potential more than that of the emitter, so that the TS_1 changes its state to " ON ". As the result, the potential at the TS_1 terminal rises and that at the TS_2 terminal also rises, so that the charges accumulated in the C may join into the base of TS_2 to keep it in the " OFF " state. However, the charge of C is to be discharged through R, so that the TS_2 recoveres its " ON " state after a certain length of time, and the TS_1 holds the " OFF " state. So, its operating time is to be decided by the multiplied product of C and R.

7) Astable multivibrator

This is commonly called a multivibrator of which circuit is shown by Fig. 22, where the TS_1 and TS_2 repeat with each other the " ON " and " OFF " states by the time constant of discharge of C and R. Therefore, the rectangular wave can be obtained from the output and its period is given by the following equation:

$$T \doteqdot 1.4\, C \cdot R \quad \text{.............................(18)}$$

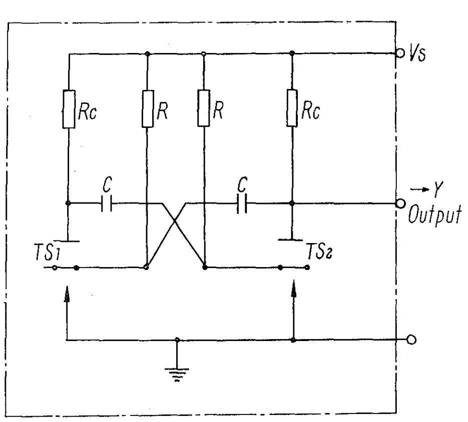

Fig. 22. Astable multivibrator

8) Schmitt circuit

This circuit is used when the sinesoidal wave is changed to the rectangular wave, or when the weakened wave is corrected to the rectangular wave. Fig. 23 is to give a diagram of this circuit.

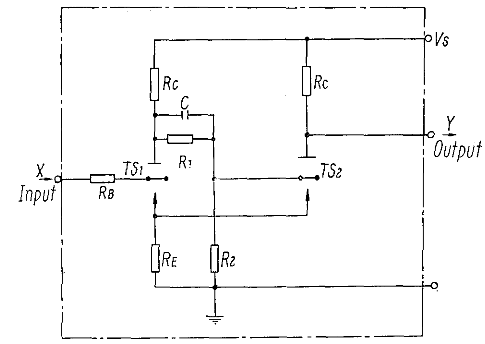

Fig. 23. " Schmitt " circuit

When there is no input given, the TS_2 is in the " ON " state, while the TS_1 is in the " OFF " state. The TS_2 is in a saturated state, and its collector current I_{C2} and its collector voltage V_{C2} are as follows:

$$I_{C2} = \frac{V_S}{R_C + R_E} \quad \text{..........................(19)}$$

$$V_{C2} = \frac{V_S \cdot R_E}{R_C + R_E} \, (= V_{E2} = V_{B2}) \quad \text{........(20)}$$

On the other hand, the TS_1 is in the " OFF " state so that its collector voltage V_{C1} is equal to V_S. Therefore, the base current I_{b2} of the TS_2 becomes as follows:

$$I_{b2} = \frac{V_S \cdot \dfrac{R_2}{R_1 + R_2} - V_S \dfrac{R_E}{R_C + R_E}}{\dfrac{R_1 \cdot R_2}{R_1 + R_2}} \quad \text{...(21)}$$

Therefore, the condition for making TS_2 saturated is as follows:

$$\beta_2 \cdot I_{b2} > I_{C2} \quad \text{.......................(22)}$$

Next, if the negative input voltage is given from the emitter voltage, the TS_1 becomes in the " ON " state. And its collector voltage V_{C1} becomes as follows:

$$V_{C1} = V_S \cdot \frac{R_E}{R_C + R_E} \quad \text{....................(23)}$$

As this voltage is divided by R_1 and R_2 and it is applied to the base of TS_2 so that TS_2 is changed in the " OFF " state. Therefore, its collector voltage V_{C2} becomes V_S. If the input voltage becomes more positive than the emitter voltage, the TS_1 circuit recovers the " OFF " state and the TS_2 circuit is reset in the " ON " state. For example, if the sinesoidal wave is put in as the input voltage, the rectangular wave is given as in Fig. 24.

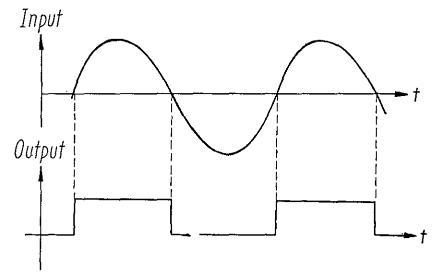

Fig. 24. Operation diagram of "Schmitt" circuit

9) D-c amplifier

We have the two types of the d-c amplifier for power amplification, i.e. the emitter earth type and collector earth type, under the earth system of a-c signal.

(1) Emitter earth

The connecting circuit of this type is shown by Fig. 25, and the emitter potential V_E is given by the breeders R_3 and R_4.

$$V_E = V_S \cdot \frac{R_4}{R_3 + R_4} \quad \text{....................(24)}$$

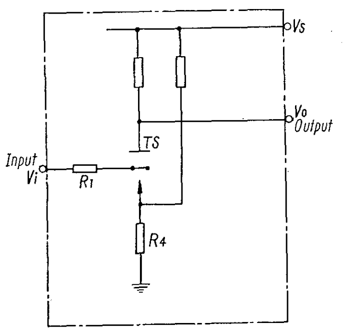

Fig. 25. "Emitter earth" circuit

Therefore, if the input voltage V_i is more negative than V_E, the transistor holds "ON" state and it keeps the "OFF" state under the condition that the V_i is more positive than V_E.

In the "OFF" state, it is clear that the output voltage V_0 is equal to V_S.

In case of the "ON" state, its base current I_b is as follows :

$$I_b = \frac{V_i - V_E}{R_1} \quad \text{....................(25)}$$

and, the collector current of β times as much as the above current is to flow. However, the maximum value $I_{C\,max}$ of the collector current is as follows :

$$I_{c\,max} = \frac{V_S - V_E}{R_2} \quad \text{....................(26)}$$

Therefore, this transistor holds a saturated state if $\beta I_b > I_{C\,max}$, and the collector current has $I_{c\,max}$, so that the collector voltage is equal to the emitter voltage. And output voltage V_0 is also equal to V_E. Besides, in case of the emitter earth state, V_i shifts its phase to reverse and it is represented by V_0.

(2) Collector earth

The connecting circuit of this type is illustrated as in Fig. 26. If the negative input voltage is given, the voltage of base is more negative potential than the emitter voltage, so that the transistor is put in the conducting state, and the emitter current flows into R_1 and it continues to attain the balanced state until the emitter potential becomes equal to V_i. In this case, its collector current is given by the following equation :

$$I_C = \frac{V_i}{R_1} \quad \text{.......................(27)}$$

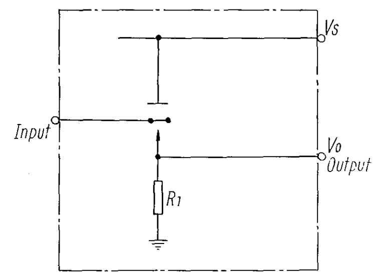

Fig. 26. "Collector earth" circuit

In other words, the output voltage V_0 is equal to V_i and in-phase.

10) Time relay

This circuit is a combination of the integral circuit of RC and the schmitt circuit as shown in Fig. 27.

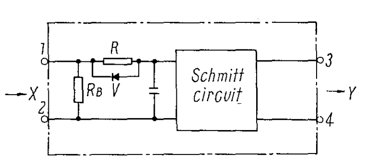

Fig. 27. "Timer" circuit

If the input X is given between two terminals 1 and 2, the voltages between the both terminals of C rise along with the course of time by a constant $T_0 = RC$. When the schmitt input attains to V_B, the schmitt output changes abruptly to the "ON" state and becomes as shown by Fig. 28 (b). If both the d-c voltage source for the input X and the bias V_B of the schmitt circuit are obtained from the same d-c power source, the timing T becomes unvariable for the voltage of this d-c power source, so that a considerable accuracy of it may be secured. The length of timing is between several seconds and 20 secondes.

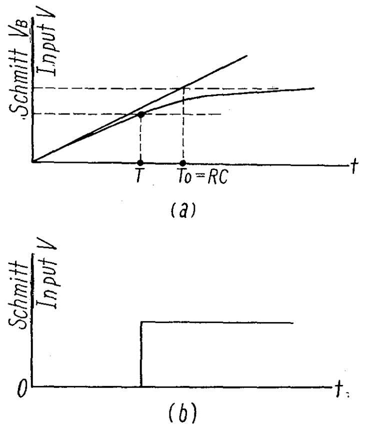

Fig. 28. Operation diagam of "Timer" circuit

III. EXAMPLE OF PRACTICAL APPLICATION

The contactless relay is adequate to the complex sequence or to such sequence as with much frequency of the operation, and is applied properly for the case requiring a high reliance under the unfavourable circumstances. It seems to be used widely in every field of such fields as the tool machine, chemical industry, paper industry, printing industry iron and steel industry, coal industry, electric railway, and so on. Under the title of this section, however, only one example of this application is shown by the centralized control of the coal selector.

Furthermore, the magnetic amplifier type can be used for a different object from that or those of the transistor type, and the both can also be put in use for the same purpose.

Fig. 29 is to be illustrated as a sample common to the above two types.

This circuit is an example of the centralized control of the conveyer system of the coal selector. This figure is the system diagram for operating the six motors in such ways as serial start, serial stop,

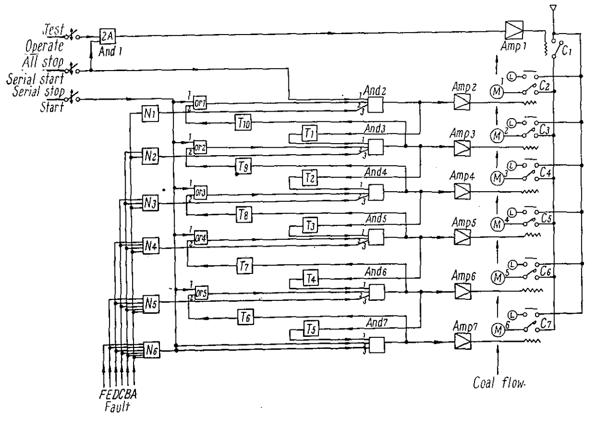

Fig. 29. Sequence diagram of belt conveyer systems

all stop, fault stop (stopping the system operation after the fault machine) and so on. This is able to check up whether or not the serial stop and start might act well in the actual case, by operating the test circuit before the practical operation. The coal selector is needed to start in series from its end with a certain interval of time, and to stop after the coal has been entirely removed out of the conveyer. For this purpose, the selector must stop operating in order from its coal-loading side with a proper interval. This is called the serial start or stop.

In order to make the serial start, the test of this start must be undergone by putting the order switch S_1 in the "Test", S_3 in the "Start" and S_2 in the "Serial start", respectively. At that time, the "And 1" circuit is in "OFF" and the voltage source contactor is kept open. The signal order from S_2 is conducted to the "And 2" circuit which is the triple "And" circuit. Therefore, if this circuit has no fault, the three inputs 1, 2, and 3 of the "And 2" circuit are all in the "ON" state. Therefore, the output of the "And 2" circuit is amplified by the "Amp 2" and holds the switch C_2 in the "ON" state. The output of "And 2" circuit also flows through the timer T_1 and, with delay of T_1 seconds, makes the input 1 of the "And 3" circuit and the switch C_3 in the "ON" state. In this serial way, this output makes in the "ON" state all of the switches, as C_4 after T_2 seconds, C_5 after T_3 seconds, C_6 after T_4 seconds, and C_7 after T_5 seconds. And the serial start of this selector is made, with confirmation of each action of the pilot lamp. Then, if the switch S_3 is opened under this state, the input, of the O_r gate is in the "OFF" state from O_{r1} to O_{r5}. However, the other input 2 of the timers $T_5 \sim T_{10}$ is impressed to these O_r gates, so that the O_r gate output is kept in the "ON" state still more. And now, the "And 7" circuit is changed to the "OFF" state as the input 2 is "OFF". Then, the timer T_6 becomes "OFF" after T_6 seconds, so that the "And 6" circuit and switch C_6 become "OFF" after T_6 seconds when the "And 7" circuit changes to the "OFF" state. Then, C_5 becomes "OFF" by T_7; C_5, by T_8; C_4, by T_9; and C_2, by T_{10}, respectively in series. In this way, the serial stop is checked.

After the checking is finished, the "And 1" circuit is made "ON" by putting the S_1 to "Operation", S_2 to "Serial start" and S_3 to "Start"; and the C_1 voltage is put in. Therefore, the six motors are put to start in order of $1 \sim 6$ with the pre-set interval of time.

When the serial stop is carried on, it is sufficient only to put the S_3 to the "Serial stop".

In order to stop entirely the operation with any fault on its operation, it is required to put the S_2 to the " Entire stop ". At that time, the " And 1 " circuit becomes " OFF " and opens the C_1, and all the rest of "And" circuits 2–7 are put " OFF " at the same time in their order. And all the motors stop its operation entirely. Furthermore, the resistance of the integral circuit is made the diode-shunting, in order to quicken the resetting of $T_1 \sim T_5$. Therefore, all motors also stop entirely, if the a-c current is interrupted to flow in a short length of time, and they are put to start again in serial way with recovery of the a-c source.

If any motor, for example No. 3 motor, goes out of work on the operation, the motors from No. 3 to No. 6 stop entirely at one time.

The above mentioned example is only the simple sequence. As the strenuous efforts are now made in order to improve the order switches S_1, S_2 and S_3 to be of contactless type, it is possible to make all parts contactless except the switch under the present state. For this reason, we can realized such a control as with high reliance and very little fault.

The transistor type and magnetic amplifier type have particular characteristics. The transistor type is to be properly used for such a tele-control as making various controls with small quantity of transmission line, while the magnetic amplifier type is adequate for such devices as being easily receiving induction or guidance from outside with unlimitted quantity of the transmission line. However, the both types are sometimes used altogether and, in case where it is required for the output of transistor to make large, this output is amplified by the magnetic amplifier, as one of the various systems used in practice.

The trends of this field is likely to employ the transistor type for all sorts of apparatus and device, along with the progress of the transistor, especially with the development of the silicon transistor, although this Article has shown the present stage of this field.