The Study of Direct-Coupled Magnetic Amplifier with the Thyratron

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(Received January 31, 1956)

Authors have devised a new magnetic amplifier circuit which is direct-coupled with thyratrons, the operation and the experimental results of which are described in this paper. Though this circuit is constructed with usual transformers' cores, it shows such characteristics as those of magnetic amplifiers with superior cores.

Because of using usual transformers' cores this circuit needs low cost, furthermore this circuit has high input impedance.

1. Introduction

Recently, together with the development of the automatic control systems, in that field, the applications of magnetic amplifiers are increasing and many investigations are being attempted.

Magnetic amplifiers have some superior qualities compared with electronic amplifiers, but they need high cost to be constructed with superior cores. Furthermore, the magnetic amplifier has another essential defect, that is low input impedance. As many input devices driving servoamplifiers are most accurate when coupled to a high impedance, it is frequently desirable to use vaccum tubes or transistors as inputs to magnetic amplifiers.

Authors had been endeavouring for the actualization of the following ideas,[1] that is to say, we can get a magnetic amplifier such as may be constructed with usual transformers' cores, yet it shows superior characteristics as same as a magnetic amplifier which is constructed with superior cores, moreover high input impedance. Then authors have devised a magnetic amplifier circuit which is direct-coupled with thyratrons and got satisfactory results. This paper reports the operation and experimental results of this circuit.

2. Circuit and illustration of operation

The basic circuit of the above direct-coupled magnetic amplifier with thyratrons is shown in Fig. 1.

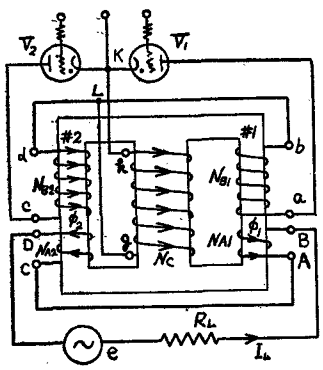

Fig. 1. Basic circuit of direct-coupled magnetic amplifier with thyratrons.

On two outside legs ♯1. and ♯2. of a shell type core, two output windings N_{A1}, N_{A2}, and two secondary windings N_{B1}, N_{B2} are set, moreover, on the center leg one more winding N_C. Number of turns of above each winding are n_{A1}, n_{A2}, n_{B1}, n_{B2} and n_C respectively, and then $n_{A1}=n_{A2}$, $n_{B1}=n_{B2}$.

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Not only two windings N_{B1} and N_{B2} are the secondary of two output windings N_{A1} and N_{A2} respectively, but also they supply the anode voltage to the thyratron V_1 and V_2, furthermore feed rectified current to the N_C winding through each thyratron.

The operation of this circuit is considered of a combination of the following two phenomena; one is the short circuit phenomenon of transformer and few variation of magnetic flux. Fig. 2 shows a circuit in which the load current is controlled by means of the periodic short circuit of transformer and short circuit period is easily controllable because of employing of thyratron. On the assumptions that the exciting impedance of transformer is large enough and the short circuit impedance is negligible compared with the load resistance R, the applied voltage of the load is shown by the hatched portion of supply source voltage e in Fig. 3. Thus the load current is controlled according to the firing angle of thyratron.

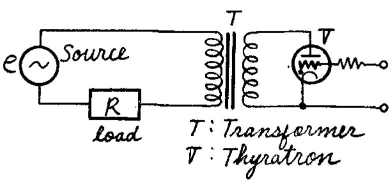

Fig. 2. This circuit illustrates that the load current is controlled when the secondary winding of the transformer T is shorted by the control of thyratron V.

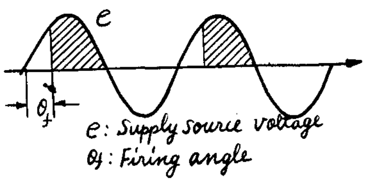

Fig. 3. The voltage wave form of the load R in Fig. 2. on the assumption that exciting impedance of the transformer T is infinity and short circuit impedance is zero.

The other phenomenon, few variation of magnetic flux, that is to say, the impedance of coil on the core decreases to very low amount when the core flux stops the variation. When the variation of flux is canceled by the rectified current of thyratron, the period during the impedance of coil being low is controlled by the firing angle of thyratron.

The circuit in Fig. 1 is supplied by the sinusoidal voltage e. Because of the steady stage operation, all occurrences in this circuit must be periodic, more specifically, the period of the events in this magnetic amplifier is identical with the period of the supply voltage. Furthermore, because of the symmetry of the circuit with respect to the center leg of core, the occurrences in half-side of circuit are duplicated in another half-side after an interval of a half-period.

It is assumed that core flux ϕ_2 in the leg ♯2. equals a certain amount $\boldsymbol{\phi}_2$, and ϕ_1 in the leg ♯1. equals another value $\boldsymbol{\phi}_1$, moreover the supply voltage e begins to feed a positive potential to the anode of V_2 at $\omega t=0$.

The supply voltage e causes an exciting current to flow through both output windings before the thyratron rise up the fire; during interval $0<\omega t<\theta_f$. Because of core which has comparatively small exciting current, the voltage drop in the load resistance R_L is negligible. Thus the supply voltage is applied to the output winding in series, and by the reason of the identical condition of two output windings, one half of the supply voltage appears across each output winding.

As a result of the applied voltage e, the core flux ϕ_1 and ϕ_2 will vary each other. While flux ϕ_1 is increasing from $\boldsymbol{\phi}_1$, flux ϕ_2 is decreasing from $\boldsymbol{\phi}_2$. After the thyratron V_2

fires at $\omega t = \theta_f$, the winding N_{B2} is shorted by the thyratron through the impedance of the N_C winding, in consequence of which the impedance of the winding N_{A2} decreases suddenly because the ratio n_{B2} to n_{A2} is large number, and at that instant the large portion of supply voltage e is impressed to the other winding N_{A1}, furthermore the discharge current of the thyratron V_2 originates flux in the center leg through the N_C winding. Such flux passes through two outside legs, and that, as it is opposed to the variation of flux in the leg ♯1., the resultant flux varies hardly in the leg ♯1. Then the impedance of the winding N_{A1} decreases, too, and mostly the applied voltage e is impressed to the load resistance R_L. This situation continues while the thyratron V_2 maintains the discharge.

When the supply voltage changes the polarity and the thyratron V_2 finishes the discharge, above mentioned occurrences are repeated in the place of another half-side. Thus the load current is able to control by means of the thyratrons controlled by input signal.

3. Characteristics

Characteristics of load current; some experimental results on the condition that $n_{A1} = n_{A2} = 80T$, $n_{B1} = n_{B2} = 1600T$, $n_C = 800T$, supply voltage $E = 9V$ (rms) and $R_L = 3\Omega$ are shown in Fig. 4, Fig. 5 and Fig. 6.

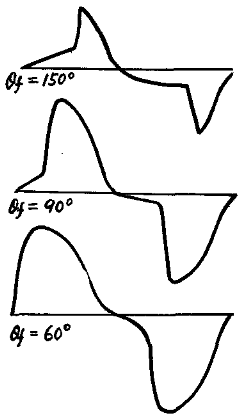

Fig. 4. The wave forms of load current.

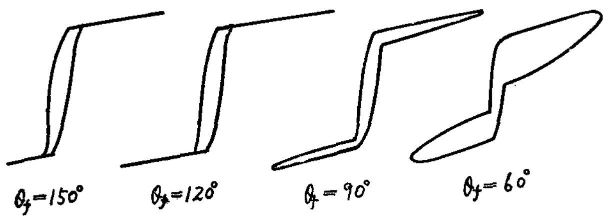

Fig. 6. Appearent hysteresis loops.

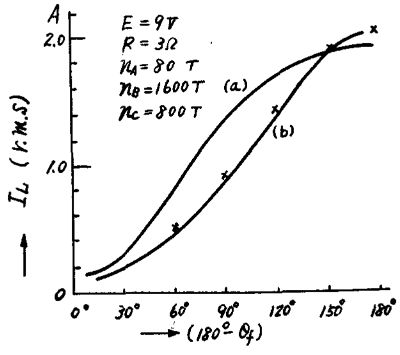

Fig. 5. The characteristics of load current I_L vs. firing angle θ_f of thyratron.

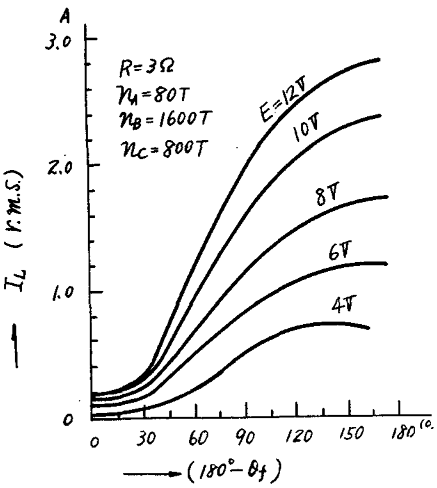

Fig. 7. The characteristics of load current vs. firing angle for various supply voltages.

The wave forms of load current at θ_f which are 60°, 90° and 150° are shown in Fig. 4. The curve (a) in Fig. 5. shows a characteristic of load current I_L (rms) vs. firing angle θ_f of thyratron, and the other curve (b) shows that on the same condition except such condition as two point K and L in Fig. 1 are shorted without connection of the N_C winding. In the case of curve (b) the wave forms of load current are inferior to what is shown in Fig. 4. Some appearent hysteresis loops shown in Fig. 6 are observed on oscilloscope. The characteristics of load current vs. firing angle for various supply voltage are illustrated in Fig. 7.

Area of the center leg and effect of N_C Winding; it is obvious that core flux in the center leg caused by both output windings cancels out each other during every exciting interval, because both output windings originate fluxes in opposite direction. As, after the firing of either thyratron, the core flux halts a certain amount in that leg and reaches another amount in the other, this circuit is sufficient to operate when the center leg has same area of an outside leg. Experimentally, there is no appreciable difference in characteristics for two devices in which the center leg has as same area as an outside leg or twice area.

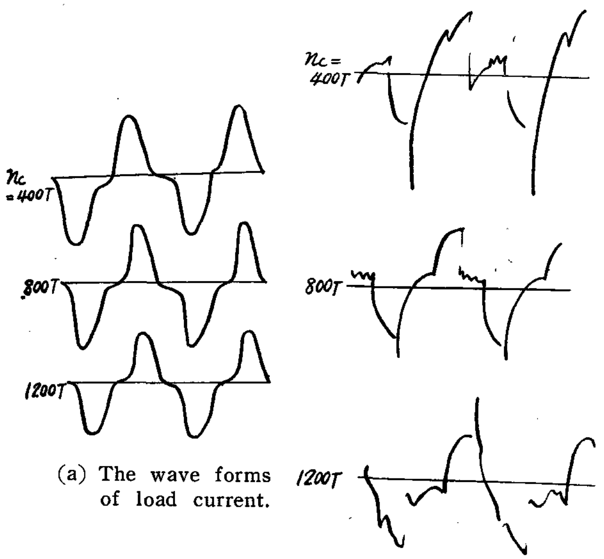

Fig. 8. The load current and voltage wave forms for various numbers of turns of N_c winding.

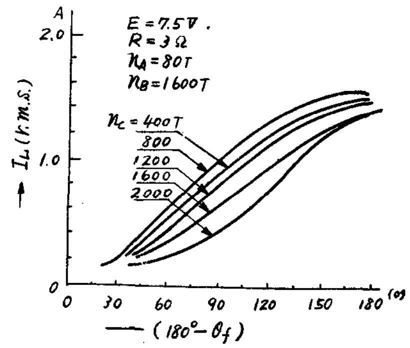

Fig. 9. The characteristics of load currents vs. firing angle for various numbers of turns of N_c winding.

As mentioned above, N_C winding produces core flux with the rectified current of either thyratron, as a result of which the core flux in the opposite side leg of the firing thyratron stops the variation. Therefore the characteristics of this circuit are governed sensitively by the number of turns of N_C winding.

Fig. 8 and Fig. 9 show some experimental results for various numbers of turns of N_C winding. When n_C is equal to one half of n_B, in Fig. 8 (a) the wave forms of load currents are similar to that of the magnetic amplifier with superior cores, moreover, Fig. 8 (b) shows some voltage wave forms of an output winding at $\theta_f=90°$ and illustrates that the impedance of the output winding in the leg where thyratron is discharging is nearly equal to that of the other leg in which flux variation is arrested. Fig. 9 illustrates that the best load current characteristic is obtained when N_C winding has one half turns of N_B winding.

4. In relation to design

As this circuit is constructed with usual transformers' cores, it is low cost although it include thyratrons and their accessaries.

The capacity of this circuit is limited by the rating of the arranged thyratrons, but number of turns of N_B winding had better determined as large as the rating of thyratron permits.

We may take number of turns of N_C winding somewhat more than one half of N_B winding and, in case of need, it is possible to adjust on optimum condition by means of a resistance connected to N_C winding in parallel.

There is the relation between peak voltage E_m of the supply voltage and maximum rating voltage E_t of the arranged thyratron as follow; $(E_m/2)(n_B/n_A) \leq E_t$. The maximum average value of load current is equal to $2E_m/\pi R$ and this circuit is able to operate continuously as far as the value of $2E_m n_A/\pi R$ is less than $2n_C I_t$, where I_t denotes the rating current of the average anode current of the arranged thyratron.

The relation between the supply voltage and number of turns of output winding may be determined by the same calculation as that of ordinal transformer.

5. Conclusion

The direct-coupled magnetic amplifier with thyratron in this paper has the following merits.

(1) Using the usual transformers' cores, this circuit needs no high cost.

(2) Obtainable a high input impedance.

(3) In spite that this circuit is constructed with usual cores, the characteristics are similar to that of general magnetic amplifiers with superior cores.

(4) They need not separate supply source for anode of thyratrons.

This circuit operate as an amplifier when thyratrons are controlled by signal voltage. Furthermore it is possible to amplify an extremely low frequency signal linearly when we adopt a special control method described in the reference (2), and feed full wave rectified current through the load.

References

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2) K. Miyakoshi, J. Hata, S. Minamoto: J. I. E. E. of Japan, **74**, 957 (1954).