Unique Characteristics of a D-C Motor Having a Magnetic Amplifier

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Characteristics of a d-c motor are decided by the relation between the armature current and the field curret. By using a magnetic amplifier between armature and field circuit, both current may have specific relations, therefore a motor will operate under the unique characteristics.

1. Preface

Although considerable work has been done on the operation of adjustable speed d-c motors with armature or field power suppling by saturable reactors (hereinafter referred to as s.r) and magnetic amplifiers(1)(2) (hereinafter referred to as m.a), there is little information available on the combined control of armature and field power. As the characteristics of a d-c motor are decided by the relation between the armature current and the field current, the combined control of armature and field current may produse the unique characteristic of a d-c motor.

From this point of view, we reported previously the following two methods:

(1) the field current is controlled by the s.r whose control current is propotional to the armature current of the motor.

(2) the armature current is controlled by the s.r whose control current is propotional to the field current of the motor.

In the first method, when the s.r is operating in the propotional region, the motor has series characteristics, while the reactor saturated, the motor may operate as a separately excited motor and has a constant speed chracteristics.

Here, we tried to have the reverse characteristics of the motor i.e. when s.r is saturated the motor has a series characteristics, while s.r is non-saturated the motor has a constant speed characteristics. By attending a magnetic amplifier cascade to the s.r circuit which discussed previously(3)(4)(5) attaind this object. The circuit construction and simplified analysis are analogous to the references.

2. Circuit Construction and Principle

The basic circuit construction being shown in Fig.1. S.R and m.a are used three legged units and simboles are as follows:

s.r ; n_c=control winding number of turns
n_l=out put winding number of turns
V_{ac}=a-c supply voltage

m.a ; N_c, N_c'=control winding number of turns
N_L=out put winding number of turns
N_B=bias winding number of turns

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N_F =feed back winding number of turns
V_{AC}=a-c supply voltage

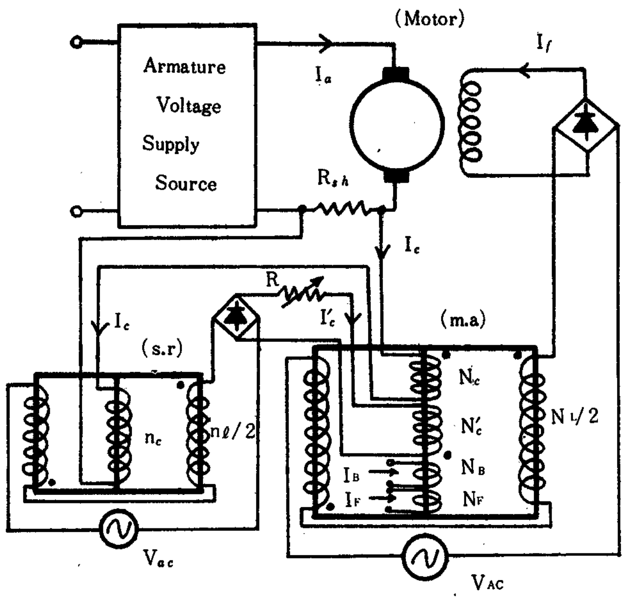

Fig. 1. Circuit construction for d-c motor having a magnetic amplifier

As shown in Fig. 1, control current I_c of s.r and m.a which is proportional to the armature current I_a of the motor are branched from a resistance R_{sh}. The out put current I_c' of the s.r is also fed to the other control winding of the m.a as the control current. The two m.a control ampere turns I_cN_c and I_c' N_c' are connected in opposit polarity.

As long as the m.a control ampere turns have following relation,

$$I_cN_c - I_c'N_c' = 0 \tag{1}$$

the armature current has no effect on the m.a out put circuit which is the motor field circuit. Consequently, the armature current is independent of the field current and the motor has shunt characteristics in this period.

Being the s.r is designed so that it may saturate above any armature current, in this saturating region, s.r out put current I_c' is held constant and Eq. (1) is no longer valied. Therefore, armature and field current have propotional relations, the equal ampere turn's law of a m.a, and the motor has the series characteristics. The limit of the armature current satisfing Eq. (1) are adjustable by regulating the rheostat R connected in series with s.r out put circuit. This allows the motor to have shunt or series characteristics on any armature current.

2.1 Diagrammatic Illustration of Operation

A schematic diagram is pictured in Fig. 2 together with the motor characteristics, idealized s.r and m.a characteristics with adjusted resistance as the parameter. A d-c motor with the circuit construction as shown in Fig. 1 may have following various unique characteristics;

1). when the s.r is operating in the region of propotional current operation as shown straight line $a-b$ in Fig. 2-(a), Eq. (1) is satisfied. The m.a out put current I_f, motor field current, is only influenced by the bias ampere turns I_BN_B and is independent of the motor armature current. The motor field current is held constant as drawn by the straight line $a'-b'$ in Fig. 2-(b). Therefore the motor has shunt characteristics as shown straight line $a''-b''$ in Fig. 2-(c).

2). while the s.r is operating in the saturated region, out put current I_c' is constant, straight line $b-c$ in Fig. 2-(a), and independent of armature current. In this region, m.a out put current is linearly propotional to the armature current and the motor has series characteristics which appear as the curve $b''-c''$ in Fig. 2-(c) corresponds to the straight line $b'-c'$ in Fig. 2-(b).

3). by adjusting the rheostat R, operating mode of the s.r is variable on any armature current. This causes the motor to operate with series or shunt characteristics on any load, as shown in Fig. 2.

4). applying feed back, the m.a characteristics are influenced, the motor series characteristics themselves are adjustable. They are shown in dotted line in Fig. 2.

5). by regulating the bias ampere turns I_BN_B or motor armature supply voltage V_a, any shunt characteristics are available.

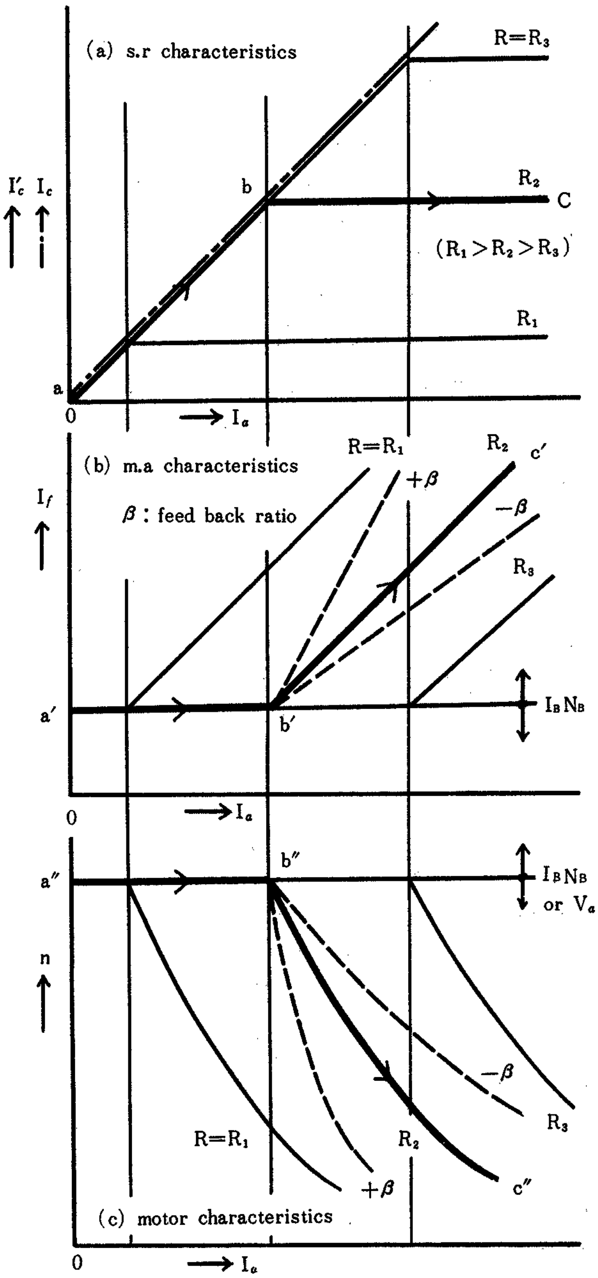

Fig. 2. Relations of s.r, m.a, and motor characteristics

2.2 Analysis

Brief analysis will be presented on how the torque vs. speed characteristics of the motor are modified in the following regions: the s.r is saturated and is non saturated. To simplify the analysis assume that s.r and m.a cores have linear magnetization characteristics with zero loop width. When the m.a is operating in the region of proportional current operation, equal ampere turns equation is

$$I_fN_L = I_cN_c - I_c'\ N_c'\ \pm I_BN_B \pm I_fN_F \tag{2}$$

where I_f is motor field current and I_B is m.a bias current. Algebraic signs are decided as follows; positive bias or feed back ampere turns are given respect to the control ampere turns I_cN_c are plus, negative bias or feed back ampere turns are minas.

2.2.1 Shunt Characteristics Operation

When the s.r is operating in the region of propotional current operation, the average control winding ampere turns I_cn_c and average load winding ampere turns $I_c' \, n_l$ are equal,

$$I_cn_c = I_c' \, n_l \tag{3}$$

where $I_c = K_aI_a$ (K_a : constant) (4)

substitution of Eq. (4) in Eq. (3), total control ampere turns of m.a gives

$$I_cN_c - I_c' \, N_c' = I_aK_a(N_c - n_c/n_l \times N_c') \tag{5}$$

As the s.r and m.a windings are designed to satify following relation,

$$N_c/N_c' = n_c/n_l \tag{6}$$

Eq. (5) reduse to zero. This means that the armature current has no effect on the m.a out put and is independent of the motor field current. Therefore the motor has shunt characteristics.

Neglecting the hysteresis and saturation of field core and armature reaction, the field flux ϕ is linearly proportional to the field current,

$$\phi = K_\phi I_f \ (K_\phi : \text{constant}) \tag{7}$$

Voltage equation of the motor armature circuit is

$$V_a = I_aR_a + K_nK_\phi \, n \, I_f \tag{8}$$

where R_a : armature circuit resistance n : motor speed
V_a : armature supply voltage K_n: counter-emf. constant

The same assumption gives for the motor torque

$$T = K_T\phi I_a \ (K_T : \text{constant}) \tag{9}$$

From Eqs. (2), (5), (6), (8), and (9) speed vs. torque equation reduse to

$$n = K_1(V_a - K_2T) \tag{10}$$

where $K_1 = 1/K_nK_\phi K_BI_B$, $K_2 = R_a/K_TK_\phi I_f$, $K_B = N_B/N_L$, $N_f = 0$

Generally, armature circuit resistance R_a is negligible small and the motor speed only depends on the armature voltage and bias current. This shows the shunt motor characteristics.

2.2.2. Series Characteristics Operation

When the armature current becomes large enough to saturate s.r, whose out put current will be held on the constant saturating current, one of the control ampere turns of m.a is constant and the other increase proportional to the armature current. Then, in this period, Eq. (1) is no longer valid and the m.a equal ampere turns equation is

$$I_fN_L = I_aK_aN_c \pm I_BN_B \pm I_fN_F \tag{11}$$

where algebraic signs have the same meanings as in Eq. (2). Substitution of Eq. (11) in Eqs. (8) and (9), torque vs. speed equation, which shows the series motor characteristics is given

$$T = K_3(V_a/n)^2 \mp K_4(V_a/n)I_B \tag{12}$$

where K_3 and K_4 are following constants:

$$K_3 = K_T/K_\phi K_n^2 K_a K_c\,,\quad K_4 = K_T K_B/K_n K_a K_c\,,\quad K_c = N_c/N_L\,,\quad K_B = N_B/N_L$$

In Eq. (12), armature circuit resistance R_a is neglected also, and the motor field current is not fed back to the m.a feed back winding.

3. Experimental Results

The tested d-c motor is rated at 100 watt, 100 volt, and 2 ampere with series field winding. The s.r and m.a used in all of this work have the following constants, s.r: $n_l=240+240=480$ turns, $n_c=1000$ turns, $V_{ac}=50$ volt, m.a: $N_L=140+140=280$ turns, $N_c=420$ turns, $N_c'=200$ turns, $N_f=100$ turns, $V_{AC}=70$ volt. Armature voltage supply source is a constant voltage device such as magnetic amplifier or silicon controlled rectifiers with appropriate feed back control circuit. Control current I_c of the s.r and m.a is branched from armature current by the shunt resistance $R_{sh}=5$ ohms. The motor is loaded on the magnetic brake device.

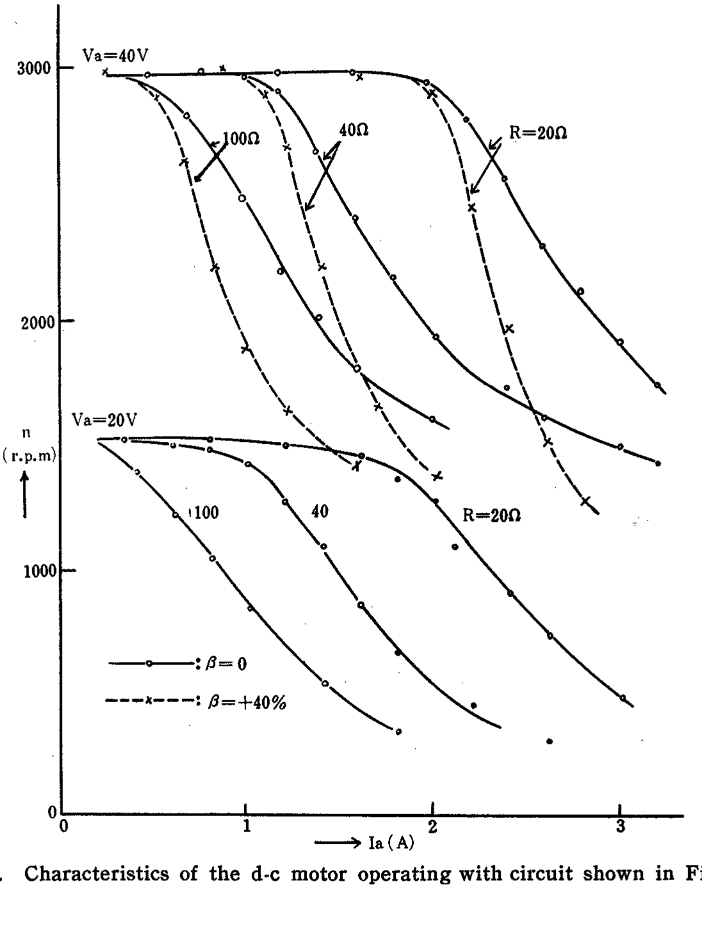

Fig. 3. Characteristics of the d-c motor operating with circuit shown in Fig. 1

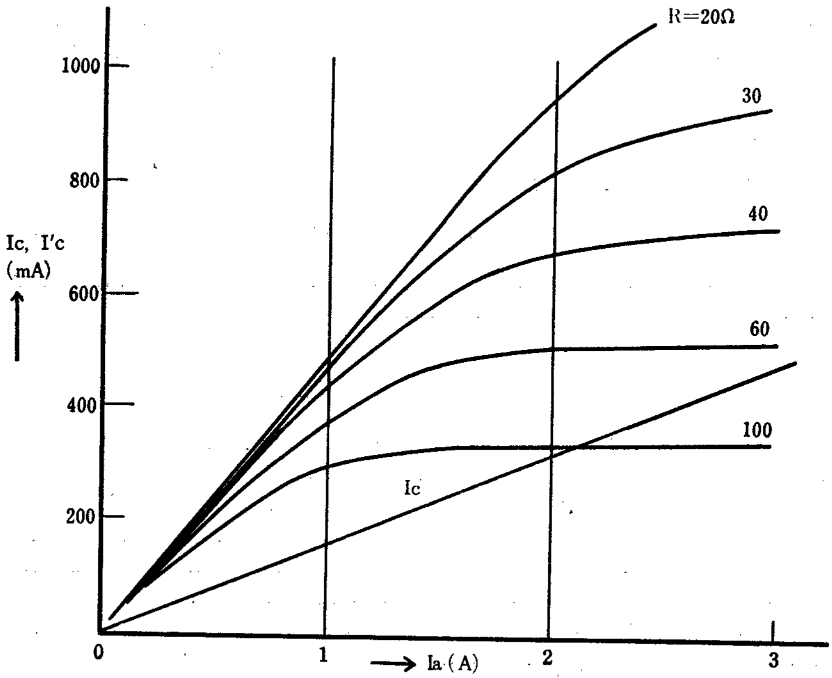

Fig. 4. Control characteristics of s.r

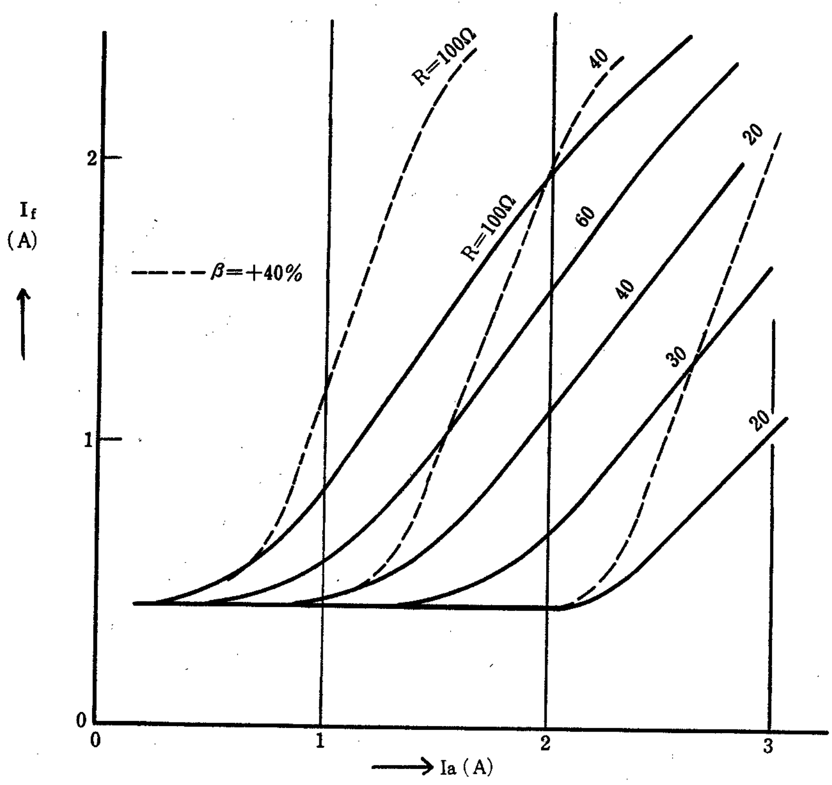

Fig. 5. Control Characteristics of m.a

Armature current vs. speed characteristics for the circuit shown in Fig. 1 appear as in Fig. 3 where each curve is drawn for a constant value of armature supply voltage and bias ampere turns with adjusted resistance as the parametere. Dotted lines denote positive feed back characteristics by the 40% feed back ratio. Control characteristics of the s.r and m.a for this drive are shown in Figs. (4) and (5) for references.

4. Conclusion

A d-c motor with this discribed circuit construction in which only a s.r is added to the former circuit has the shunt characteristics on a light load and the series characteristics on a heavy load contrary to the previous paper. Combined circuit of these would be possible to have a motor any characteristics on any load. Therefore the motor widely available for the primemover of machine tools and conveyers.

Although, silicon controlled rectifiers are applicable instead of the s.r and m.a, reactors are multi-input devices and they may be of wide application.

5. Acknowledgements

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6. References

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