D.C. Dynamic Braking of Sinle-Phase Induction Motor

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It is well-known that the method of predetermining the d-c braking torque-speed curve of the poly-phase induction motor by using equivalent circuit is fairly accurate.
The object of this present paper is to show that this equivalent circuit method given for the poly-phase induction moton can also be applicable in the case of the single-phase induction motor.

1. Theory

(A) Equivalent circuit

The equivalent circuit of a single-phase induction motor is shown in Fig. 1, a rather more general form than usually adopted. The quantities V_{2p}, V_{2N}, X_1, X_2 and X_m are all based on the unit angular frequency w_s, while the stator supply is at angular frequency w_1, the rotor speed is w_2 and the positive rotor currents are of angular frequency (w_1-w_2), and the negative rotor currents are of angular frequency (w_1+w_2). For simplicity, the stator/rotor ratio is taken as unity. Fig. 1 shows the actual value of the e.m.f. and the reactance for the assumed condition.

The torque exerted on the rotor is proportional to $\Phi_{2p}I_{2p}\cos\phi_{2p}$ and $-\Phi_{2N}I_{2N}\cos\phi_{2N}$ and since Φ_{2p} can be taken as proportional to V_{2p}, similaly Φ_{2N} proportional to V_{2N}, the torque expressed in synchronous watts, based on synchronous speed w_s, is given by

$$T = V_{2p}I_{2p}\cos\phi_{2p} - V_{2N}I_{2N}\cos\phi_{2N}$$

The equivalent static circuit is then derived by dividing the positive rotor resistance, reactance and e.m.f. by $(w_1-w_2)/w_s$ and the negative rotor resistance, reactance and e.m.f. by $(w_1+w_2)/w_s$, so that the actual rotor circuit is replaced by two flux linkage with anglar frequency w_s. The stator circuit is also modified similarly, dividing its voltage, resistance and reactance by w_1/w_s. This leaves the currents and phase angle unchanged.

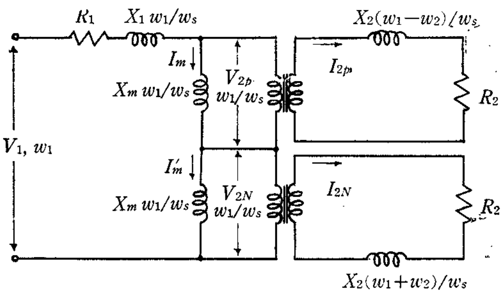

Fig. 1. General circuit of single phase induction motor.

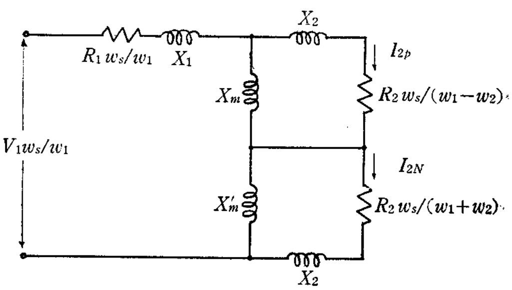

Fig. 2. General equivalent circuit.

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The resultant circuit is shown in Fig. 2, in which the angular frequency throughout is w_s.

The torque T, expressed in synchronous watts referred to the synchronous speed w_s, is now given by the power dissipated in the rotor resistances, $R_2w_s/(w_1-w_2)$ and $R_2w_s/(w_1+w_2)$, so that

$$T=I_{2p}^2R_2w_s/(w_1-w_2)-I_{2N}^2R_2w_s/(w_1+w_2)$$

The circuit shown in Fig. 2 is valid for any values of w_1 and w_2. Under dynamic-braking conditions the stator current is direct, i.e. $w_1=0$ and the equivalent stator applied voltage and resistance become infinite.

When $w_1=0$, the effective rotor resistance become $-R_2(w_s/w_2)$ and $R_2(w_s/w_2)$, therfore the torque:

$$T=-I_{2p}^2R_2(w_s/w_2)-I_{2N}^2R_2(w_s/w_2)$$

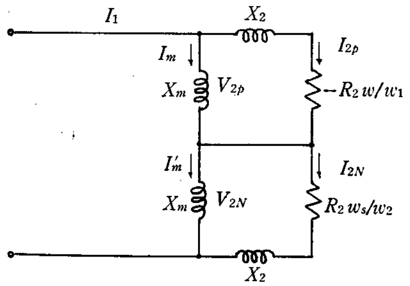


Fig. 3. Dynamic-braking equivalent circuit.

The stator impedance and voltage need not be shown and Fig. 2 can be further simplified to Fig. 3.

(B) Torque equation

In Fig. 3, if the negtive sign of positive rotor resistance is omitted, the positive rotor circuit impedance is equal to the negative rotor circuit impedance.

Therefore

$$I_{2p}=I_{2N}=I_2 \qquad V_{2p}=V_{2N}=V_2$$

$$I_{mp}=I_{mN}=I_m$$

$$I_1=I_m+I_2 \qquad I_m=V_2/jX_m$$

$$I_2=V_2/\{R_2(w_s/w_2)+jX_2\}$$

$$\therefore\quad I_1=I_2(R_2(w_s/w_2)+jX_2)/jX_m+I_2$$

$$=I_2[\{R_2(w_s/w_2)+j(X_2+X_m)\}/jX_m]$$

$$I_2=\frac{I_1\,jX_m}{R_2(w_s/w_2)+j(X_m+X_2)}$$

$$I_2^2=\frac{I_1^2X_m^2}{\left(R_2\dfrac{w_s}{w_2}\right)^2+(X_2+X_m)^2}$$

The torque

$$T=-2I_2^2\,R_2(w_s/w_2)=\frac{-2I_1^2X_m^2R_2(w_s/w_2)}{\left(R_2\dfrac{w_s}{w_2}\right)^2+(X_2+X_m)^2}$$

the maximum value of T is found to occur when

$$R_2(w_s/w_2)=(X_2+X_m)$$

and

$$T_{max}=\frac{-I_1^2X_m^2}{(X_2+X_m)}$$

2. Confirmation of Theory

(A) Experiment

The capacitor-start single-phase induction motor, detailed in Table 1, was coupled to a separately excited d-c machine.

The armature current of the d-c machine was supplied to a Ward-Leonard set and the field current of the d-c machine was maintained constant to allow subsequent torque calibration of the machine. The direct stator current of the single-phase induction motor was maintained in a fixed value, while the speed of the single-phase induction motor and the d-c machine was varied by adjustment of the armature current of the latter via field regulator of the Ward-Leonard set. The dynamic-braking torque was measured by the input to the d-c driving machine, i.e. the total input torque minus the loss torque gave the net dynamic-braking torque, when $I_1=0$, the d-c driving machine input for each speed was shown the loss torque.

Table 1. Capacitor-start single-phase induction motor

Rating	200 Watt, 100 Volt, 1 Phase, 4 pole, 50~60 ~
Machine constant	$R_1=1.6\ \Omega$, $R_2=0.8\ \Omega$ $X_2=1.0\ \Omega$ $X_m=23.0\ \Omega$ $X_1=2.0\ \Omega$

(B) Test result

It was found that lack of agreement between the theoretical and experimental torque-speed curve Fig. 4, increased with speed. It was pointed out by Butler that stray loss constituted the chief source of the lack of agreement for poly-phase induction motor.[1]

It is surmised that in a single-phase induction motor this chief source is similar. But it is very difficult to derermine the stray loss characteristic of single-phase induction motor, and so we did not confirm this. The rotor iron loss is neglected in the equivalent circuit, but the result, measured the rotor iron loss, account for very litlle of the discrepancy.

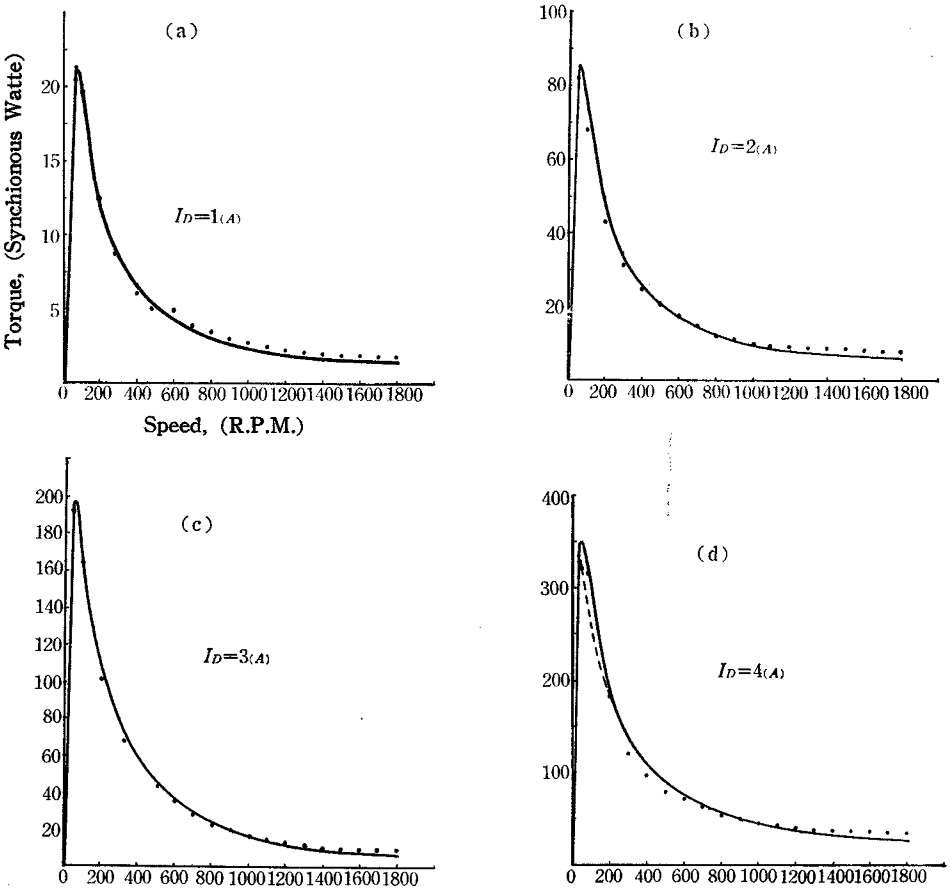
The magnetization characteristic of the single-phas induction motor is shown in Fig. 5. When the d-c exciting current I_m is larger than 3A, staturated condition begines and X_m is variable. For those saturated condition, the graphical construction shown by D. Harrison is valid.[2] In Fig. 4. (d), (e) it is shown that the effect of saturation cannot be ignored without serious error.

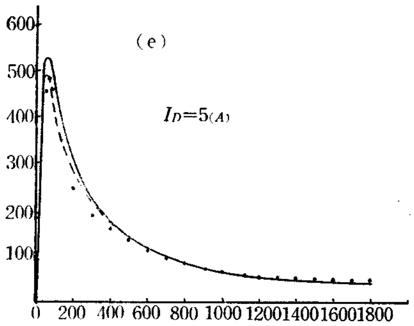
3. Conclusion

The d-c dynamic braking torque-speed curve of a single-phase induction motor can be predicted with good accuracy by the method of equivalent circuit, and the curve is similar in shape to that of a poly-phase induction motor, in despite of the difference of the motoring curve in shape.

References

1) D. Harrison, P. I. E. E. **103,** part A (1956).
2) O. I. Butler, T. A. I. E. E. **77,** (1956).





—— Theoretical braking curve ignering saturation effect

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• Experimental point

Fig. 4. Torque-Speed Curve.

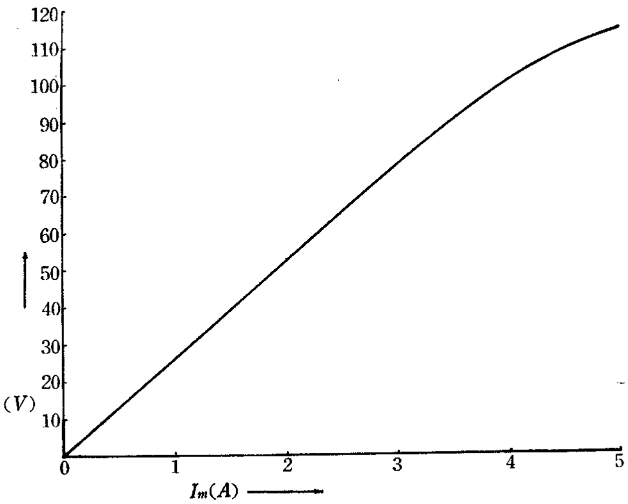

Fig. 5. Saturation Curve.