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A Study on the Constant Speed Control of Induction Motor Using Inverter

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〈Abstract〉

This paper introduces one easy constant speed control method in squirrel cage induction moror which means constant slip control by current sensing from d. c. line and shows the possibility of *this method theoretically.*

인버터로 사용한 유도전동기 정속도제어에 관한 연구

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(1985. 9. 26. 접수)

〈요 약〉

본 논문에서는 농형유도전동기를 일정속도로 제어하기 위해 인버터의 직류입력에서 전류를 검출하여 일정슬립 운전 개념을 실현시키는 방법을 소개하고 그 이론적인 고찰을 행했다.

I. Introduction

The majority of industrial drives use electric motors since they are controllable and readily available. In spite of the hardness of the speed control, most of these drives are based on a. c. induction motors because such motors are rugged, reliable and relatively inexpensive.

Also, with the development of the powersemiconductor, speed control of the induction motor has been easily possible by means of inverter. [1]

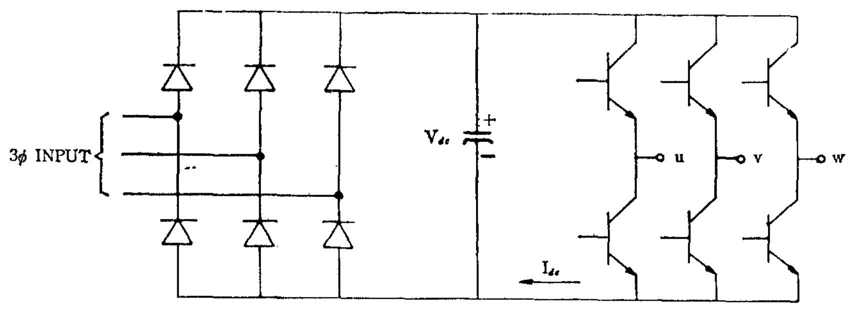

Fig. 1. DC link P. W. M. transistor inverter

Traditionally, thyristor inverter has been used to control the speed, but, now transistor inverter has covered the speed control in the small and medium capacity motor. [2]

Fig. 1 shows a power circuit often employed for controlling the speed of a.c. motors.

The fixed voltage and frequency, AC supply is rectified and smoothed to give a fixed voltage DC supply. This is converted to a variable frequency, variable-voltage AC supply by means of transistor inverter.

In practical applications, reducing the speed variance is very important in manufacturing process. Hence many methods have been introduced to maintain constant speed. [3]-[6]

But these methods have some complicated control section, and the price is high.

This paper introduces one easy control method which means constant slip control by sensing d.c. line current for maintaining constant speed.

This article begins by considering the principles of a.c. induction motor and shows the possibility of this constant slip control theoretically.

Ⅱ. A.C. Induction Motors

The three phase a.c. induction motor consists of a wound stator connected to a three-phase a.c. supply, and a squirrel-cage rotor with no external connections.

Fig. 2 shows the equivalent circuit of the induction motor referred to stator.

The stator currents produce a rotating magnetic flux, with a speed of synchronous speed N_s given by:

$$N_s = \frac{f}{p} \times 60 \text{ rev./min.} \qquad (1)$$

where f = stator frequency;

p = number of pole-pairs.

Motor torque is produced by the interaction of stator flux and the rotor currents, the torque contribution T of each rotor conductor being proportional to the product of air-gap flux and in phase rotor current, i.e.

$$T = K\phi I_2 \cos\theta_2 \qquad (2)$$

where K = constant; ϕ = air-gap flux per pole; $\cos\theta_2$ = rotor power factor.

For small slip s, $\cos\theta_2 = 1$, and the torque equation becomes

$$T = K\phi I_2. \qquad (3)$$

But $I_2 = \frac{sE}{[r_2'^2 + (sx_2')^2]^{1/2}}$, $\phi \propto \frac{E}{f}$. (4)

Then $T = K' \frac{E}{f} \cdot \frac{sE}{[r_2'^2 + (sx_2')^2]^{1/2}}$. (5)

Under normal running condition $r_2' \gg sx_2'$.

Hence motor torque can be given by:

$$T = K''\left(\frac{E}{f}\right)^2 \cdot \frac{sE}{r_2'} \qquad (6)$$

or $T \propto s$ if E/f is constant.

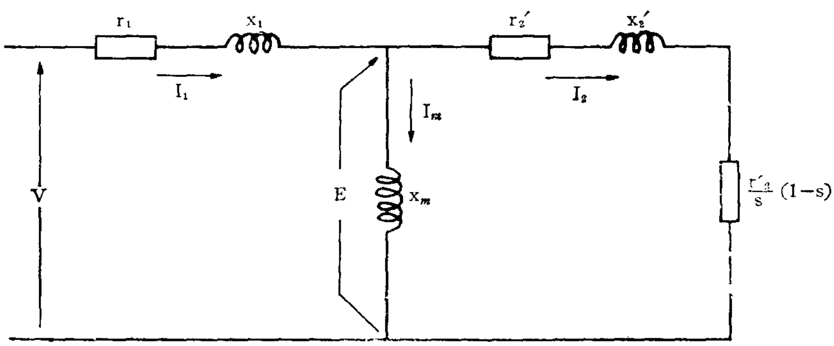

Fig. 2. Equivalent circuit of the induction motor referred to stator

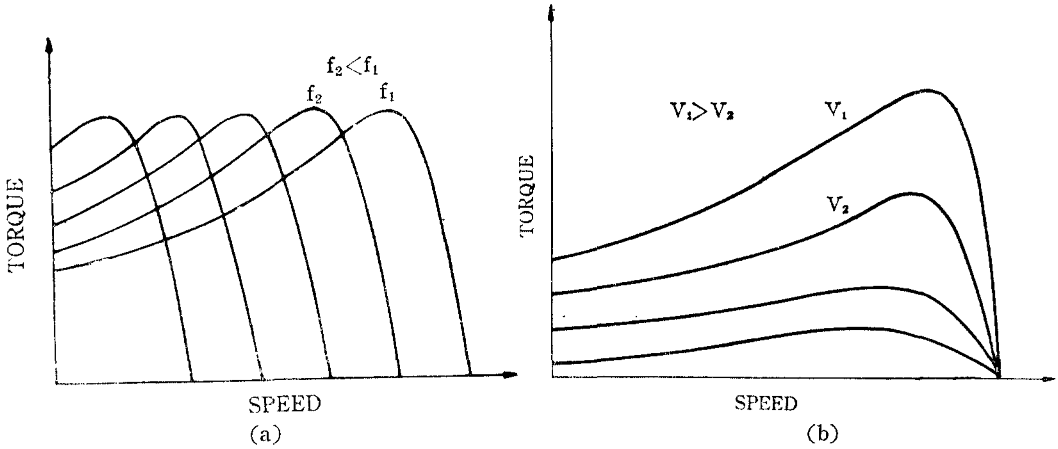

Fig. 3. Torque-speed characteristics

Thus torque can be varied by varying slip.

Fig. 3 shows ideal torque-speed characteristics of the motor. Frequency control with constant E/f is shown in (a) and the other is voltage control with constant frequency.

If ω_s and ω denotes synchronous and rotor angular frequency, then

$$s=\frac{\omega_s-\omega}{\omega_s} \qquad (7)$$

Mechanical power output,

$$P_m=T\omega \text{ (syn. watts)} \qquad (8)$$

and the power received by rotor from the stator,

$$P_2=T\omega_s \text{ (syn. watts).} \qquad (9)$$

From Eq. (7) and (9),

$$P_m=(1-s)P_2. \qquad (10)$$

Ⅲ. Control Principles

From Eq. (2) it is clear that torque developed by the motor can be controlled by varying air-gap flux, rotor current, stator current and phase angle θ.

However rotor current and phase angle θ is determined by slip s.

We can control the torque of an induction motor by means of inverter.

In current source inverter[6] torque is controlled by varying stator current and slip, while in voltage source inverter[7] air-gap flux and slip control is used. In this article, to maintain constant speed drive at the desired frequency voltage source P.W.M. inverter[8] is used.

From Eq. (6) provided that E/f is fixed, variation of the slip depends on the load torque. At higher values of voltage, stator impedance drop is small and thus air-gap flux can be denoted as V/f, i.e. $E/f\simeq V/f$.

Then Eq. (6) can be rewritten as following;

$$T=K''\left(\frac{V}{f}\right)^2\cdot\frac{sE}{r_2'}. \qquad (11)$$

Actually, this equation is generally adopted for controlling contant air-gap flux because it is very hard to detect electromotive force E. At the fixed stator frequency which is desired, speed regulation means slip regulation caused by torque variation. But, if $(V/f)^2$ can be adjustable with the torque variation, it may be possible to maintain constant slip. This means that it is possible to keep constant rotor speed in spite of torque variation.

Fig. 4 shows slip variation owing to step change in supply voltage and load torque.

At the load torque T_1 motor is driven normally with the supply frequency$=f$ and supply voltage$=V_1$.

In that time if load torque is changed to T_2,

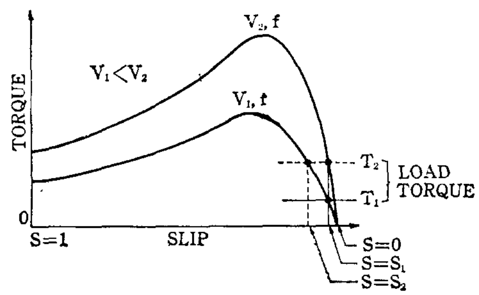

Fig. 4. Slip variation owing to step change in voltage and load torque

slip will increase to s_2 from s_1. Thus rotor speed is reduced.

To make slip its initial value s_1, supply voltage must be increased to V_2. In the opposite case similar description may be done.

Thus it is needed to control supply voltage automatically for maintaining constant rotor speed.

This can be carried out by means of inverter.

Assuming there is no switching loss in inverter and stator loss is constant, d.c. power will be equal to the sum of the power derived from the stator and the power stator loss, i.e.

$$P_2+P_{SL}=\frac{1}{m}V_{dc}\ I_{dc} \qquad (12)$$

where P_{SL}=stator loss per phase;

V_{dc}=converter output voltage;

I_{dc}=d.c. line current;

m=number of stator phase.

From Eq. (9), (10) and torque equation, mechanical power output P_m and power derived from stator P_2 are proportional to $\left(\frac{V}{f}\right)^2$ in the case of the constant slip, i.e.

$$P_2 \propto P_m \propto (V/f)^2 \propto T \qquad (13)$$

Also from Eq. (12), power derived from the stator can be found by subtracting stator loss from the d.c. power. The d.c. power can be known by sensing d.c. line current I_{dc} because in voltage source P.W.M. inverter V_{dc} is constant, and subtraction can be done by a proper design using I.C. circuits. Thus it may be said that to maintain constant slip means to control inverter output voltage V automatically at the setting frequency according to torque variation which can be detectable from d.c. line current.

In order to perform above mentioned control principles, design methods will be briefly described at below, but actual performances are skipped in this paper.

Ⅳ. Proposed Drive System

A block diagram of the system is shown in Fig. 5.

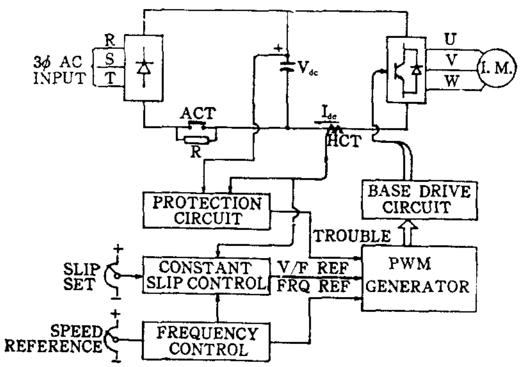

Fig. 5. Drive system block diagram.

The three phase mains input is connected to the bridge rectifier. The d.c. voltage V_{dc} is smoothed by a capacitor input filter (a choke input filter may be used for higher powers), and then applied to the inverter. The outputs from the three phases of the inverter consist of sine-wave-weighted pulse-width-modulated waveforms at the selected frequency; this gives sinusoidal motor currents with low harmonic content. D.c. current is detected by H.C.T. (Hole effect Current Transformer), and it is applied to protection circuits and constant slip control circuits simultaneously. Design topics are constant slip control circuits.

It includes analogue or digital divider in order to obtain torque variation at the setting frequency; mechanical output will be obtained by proper methods through subtraction form d. c. current, and this will be devided by the reference frequency signal. Finally, divided result determines V/f ratio and it will be applied P. W. M. generator with frequency reference.

P. W. M. generator is generally designed by one-chip microprocessor or custom L. S. I. which is already programmed to generate P. W. M. waveforms.

P. W. M. outputs are applied to base drive circuits, which amplify P. W. M. outputs in order to drive power transistors and isolate control circuits from power circuits.

V. Conclusions

It has been discussed about to maintain constant motor speed at the setting frequency theoretically. To achieve this purpose constant slip control was proposed and d. c. line current may be used in actual design. Hence control circuits can be simple and cost will be lower.

If high accuracy is not needed, this control method may be very useful.

To improve the accuracy, more detail information may be needed about motor loss and characterastics. But these informations can be obtained easily with more careful study in addition to determination of inverter capacity.

In this paper, basic design ideas were proposed with the form of block diagram. Now it is project how to realize these ideas experimentally and how to carry out commercial applications.

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