MICROPROCESSOR SPEED CONTROL OF A D.C. MOTOR

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ABSTRACT

The paper presents the development of a microprocessor-based controller for a separately excited d.c. motor drive system. The motor speed is controlled by adjusting the armature voltage, using a single-phase half-controlled converter. The synchronising pulses needed for the converter are generated by the microprocessor.

Details of the required compatible hardware circuits and software programs are described. A mathematical model of the drive system is developed for steady-state and transient analyses.

Simulation and experimental results are presented to show the system performance. The experimental set-up and its mathematical model provide an excellent facility to study and develop advanced digital controllers for the drive system.

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INTRODUCTION

In recent years, there has been a considerable interest in the application of microprocessor-based controllers to industrial drive systems [1 - 4]. Employing a microcomputer or microprocessor as a controller unit for the speed control of d.c. motors provides great flexibility and simplicity of the hardware interface circuits. This is due to the possibility of changing the controlling software programs and the availibility of implementing advanced controllers for variable-speed drive systems.

The speed of a separately-excited d.c. motor can be varied by controlling the input armature voltage through a phase-controlled converter which is supplied from an a.c. source. Analysis and design of closed-loop systems have been described in [5 - 7]. State-feedback control of a single-phase thyristor-bridge d.c. motor is described in [8] , which presents simulation and experimental results using a microprocessor.

This paper presents the development of a microprocessor control scheme for a separately-excited d.c. motor drive system. The first phase of this research, which is the subject of this paper, is to build the laboratory open-loop basic system and to develop a mathematical model representing the system in steady-state and transient conditions. A ZILOG microprocessor system Z-80 is used to generate the synchronised pulses for a single-phase half-controlled converter. The ZILOG system is selected because of its efficient soft-ware instruction set and its duplicate register sets which facilitate very fast interrupt response. Emphasis is placed on minimization of the hardware requirements, with as many functions as possible being performed by software.

The validity of the mathematical model is demonstrated by comparing simulation and experimental results in steady-state and transient cases. Photographs of the practical recordering of the armature voltage and current wave-forms are also presented.

DRIVE SYSTEM DESCRIPTION

Fig. 1 shows a block diagram representation of the laboratory drive system. It consists of a 4 KW separately-excited d.c. motor driving a d.c. generator which supplies a resistive load. The armature of the motor is fed from a single-phase half-controlled thyristor bridge. The input a.c. supply voltage is fed to the converter power circuit and the zero-crossing sensor circuit. The latter consists of a step-down transformer feeding a zero- voltage comparator (operational amplifier 741) with a R-C circuit. The output of the zero-crossing sensor is a sequence of pulse readily synchronised with the zero-crossing of the a.c. supply voltage.

The firing angle of the converter is always calculated with respect to zero-crossing point of the input voltage. The detection of the zero-cross instant in the a.c. supply voltage occurs every half cycle. This crossing instant is used as a reference point to determine the firing angle. The synchronised pulses inform the microprocessor (ZILOG system - Z 80) the starting instants of the a.c. supply voltage. Upon receiving a synchronising pulse, the microprocessor immediately

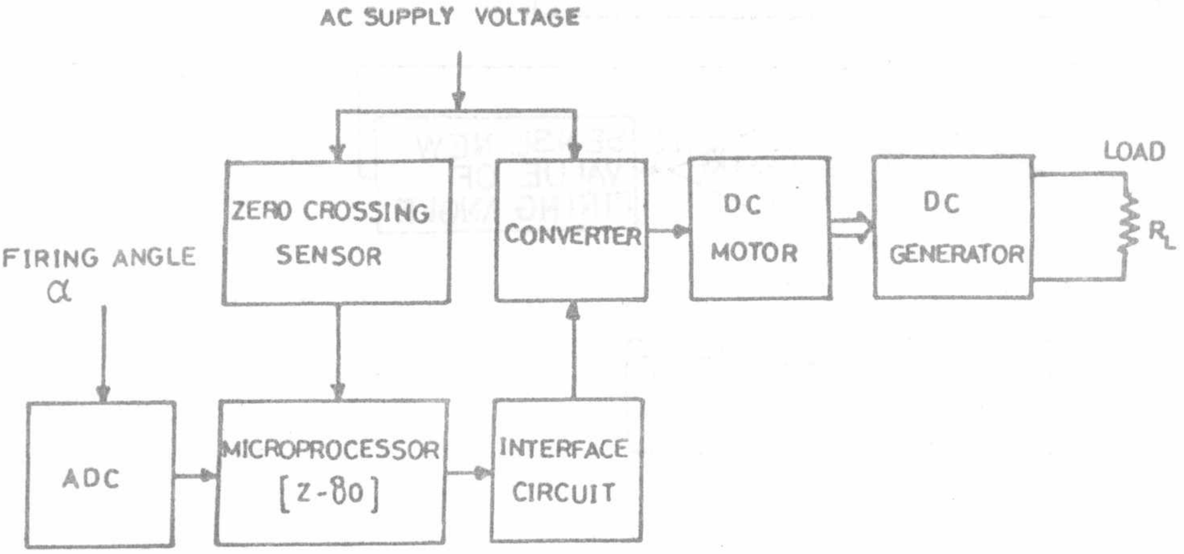

Fig. 1 Block diagram of the drive system

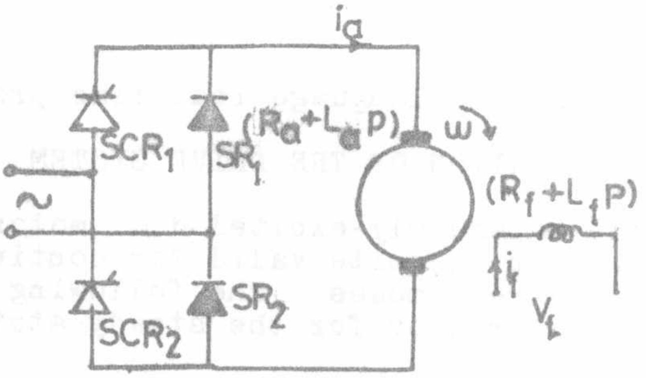

Fig. 2 Power circuit

loads the INTEL 8253 timer (compatible hardware interface) by the current value of the firing angle. The latter is fed to the microprocessor by an analogue-to-digital converter (ADC). The INTEL 8253 timer is driven by a fixed clock with a rate of 25.5 kHz. This clock starts to disaccount the desired firing angle. The output of the INTEL 8253 timer is used to trigger the two SCR elements of the single phase half-controlled converter. The motor converter circuit is shown in Fig.2. The advamtage of this converter scheme is the inherent existance of the free-wheeling diode. The isolation between the converter power circuit (high voltage and current) and the compatible hardware interface circuit (low voltage and current) is done by using a pulse transformer for each silicon controlled rectifier element (SCR).

Fig. 3 shows the flow chart of the assembly controlling program.

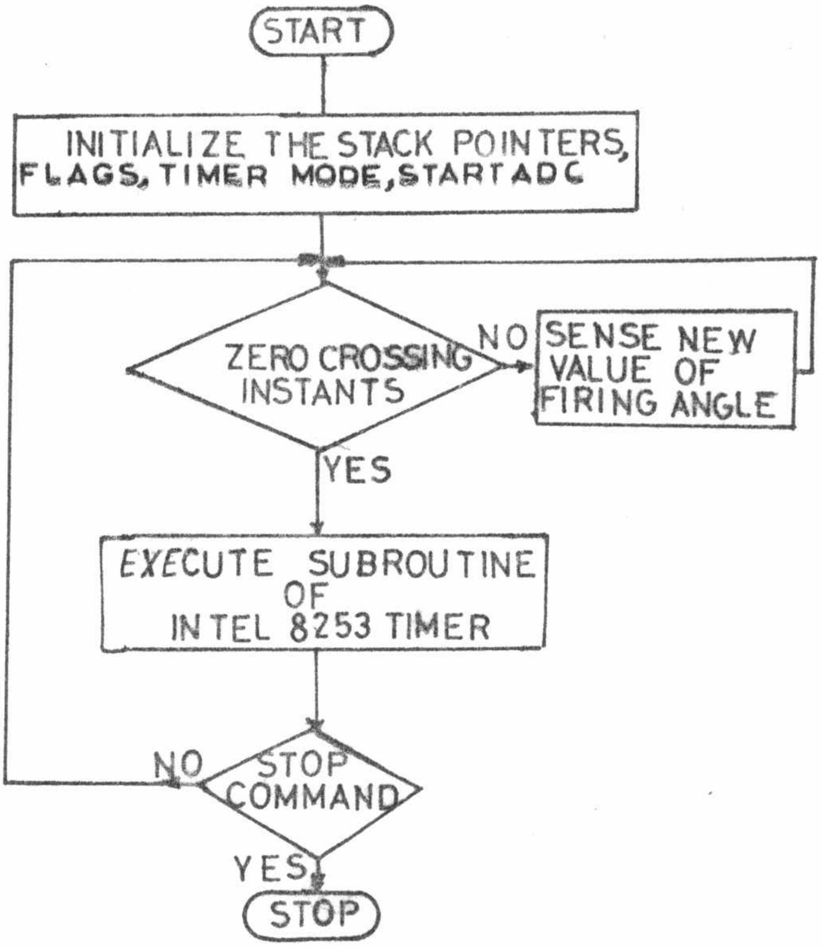

Fig. 3 Flow chart of the assembly language real-time program

MODELLING AND SIMULATION OF THE DRIVE SYSTEM

A mathematical model of the separately-excited d.c. motor driven by a single-phase converter is quite valid for continuous and discontinuous armature current modes. The following assumptions are taken into consideration for the steady-state and transient analyses:

1. The parameters of the motor are constant throughout the operating region.
2. The static friction is negligible.
3. The mechanical damping torque due to friction is linearly related to the angular velocity ω.
4. The effect of the armature reaction is readily compensated.
5. The voltage drop on the brushes is negligible.

Thus, the dynamical equations of the motor are :

$$e_a = L_a \frac{di_a}{dt} + R_a i_a + e_b \qquad \ldots(1)$$

$$e_b = K_b \omega \qquad \ldots(2)$$

$$T_m = T_L + B\omega + J \frac{d\omega}{dt} \qquad \ldots(3)$$

$$T_m = K_t i_a \qquad \ldots(4)$$

Where

ω = angular velocity, (rad/sec.)
K_b = back e.m.f. constant (volt-sec/rad).
T_m = motor torque (Nm).
K_t = torque constant (Nm/amp).

Equations (1) to (4) can be arranged in the following form, which is suitable for simulating the system dynamics using the fourth order Range-Kutta procedure :

$$\dot{X}_1 = C_1 X_1 + C_2 X_2 + C_3 T_L \qquad ...(5)$$

$$\dot{X}_2 = C_4 X_1 + C_5 X_2 + C_6 e_a \qquad ...(6)$$

Where

$$X_1 = \omega \ , \quad X_2 = i_a$$

$$C_1 = -B/J, \ C_2 = K_f/J, \quad C_3 = -1/J$$

$$C_4 = -K_f/J, \ C_5 = -R_a/L_a, \quad C_6 = 1/L_a$$

Three modes of operation are usually considered in the computer simulation programs. These are fully explained in [6] and summarized here for convenience:

Mode (1) Conducting: $\alpha < \omega t < \pi$ and $\theta_s < \omega t$

Thyristor SCR1 of Fig.2 conducts and the supply voltage is directly applied to the armature, i.e., in equation (6) we put $e_a = \sqrt{2}\ V \sin\omega t$. The duration of this mode is modified to $\alpha < \omega t < \beta$ if β is less than π , where :

β = extinction angle of the armature current.
α = firing angle.
θ_s = angle at which the back e.m.f. equals the supply voltage.

Mode (2) Free-wheeling : $\pi < \omega t < \beta$

In this case, the armature circuit is closed through SR1 and SR2 of Fig. 2, i.e. $e_a = 0$. Note that if $\beta < \pi$, this mode does not exist.

Mode (3) Coasting : $\beta < \omega t < \pi + \alpha$

During this interval, the armature current i_a is zero, and the motor coasts.

EXPERIMENTAL AND SIMULATION RESULTS

Fig. 4 shows photographs of the wave-forms of the armature current and voltage at different operating conditions. The discontinuity of the armature current is clearly shown. This is due to the very small value of the armature inductance.

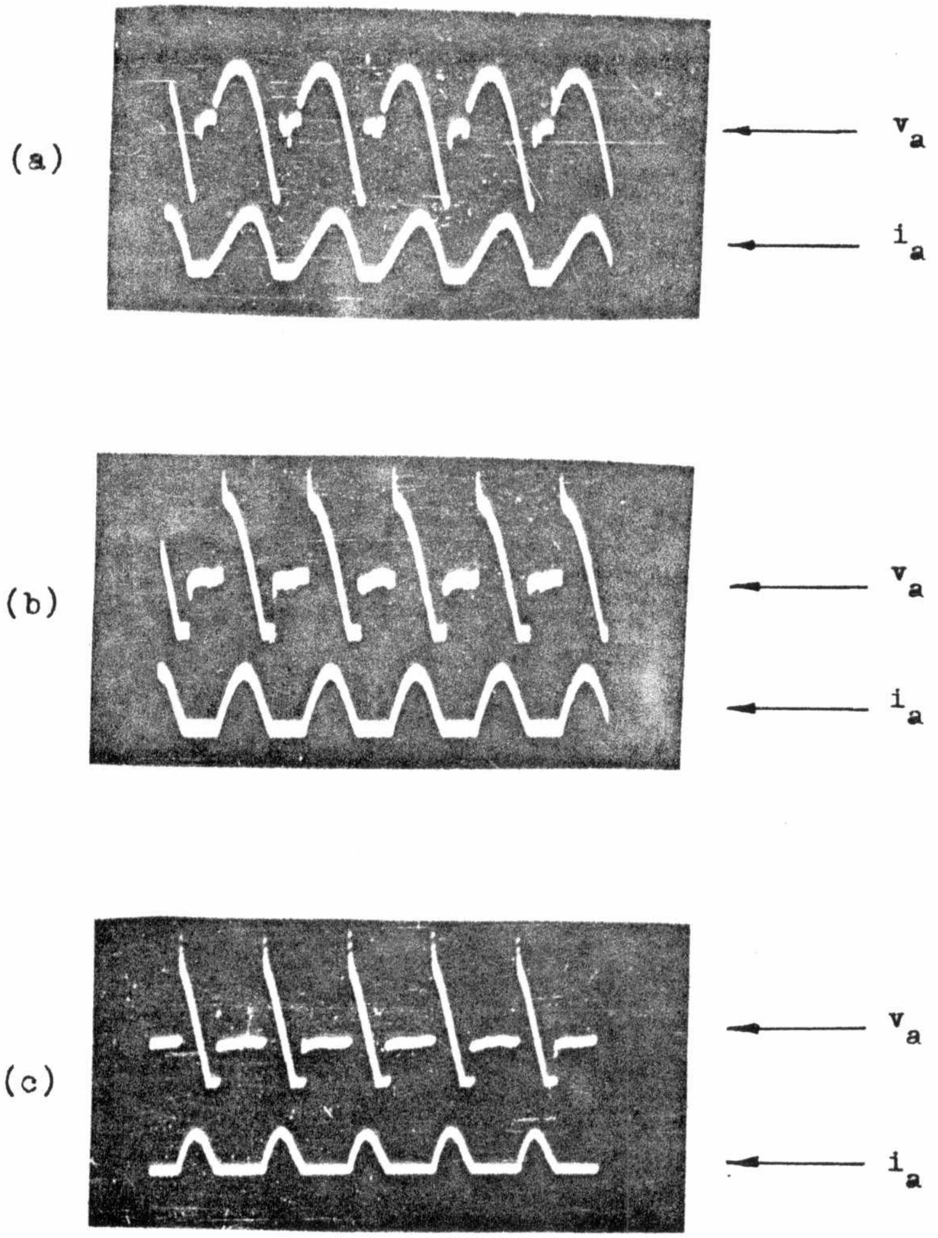

Fig.4 Armature voltage and current waveforms:

(a) $\alpha = 45^{0}$, N = 975 rpm, i_a(r.m.s.) = 33 amp.
(b) $\alpha = 90^{0}$, N = 760 rpm, i_a(r.m.s.) = 22 amp.
(c) $\alpha = 120^{0}$, N = 550 rpm, i_a(r.m.s.) = 10 amp.

Fig. 5 shows computed and experimental speed-torque characteristics of the drive system for various firing angles. The corresponding characteristic curves are very close, thus indicating the accuracy of the mathematical model in predicting steady-state performance. It is noticed that the speed largely drops as load-torque increases due to armature current discontinuity. This is an inferior characteristic compared to the operation of the same d.c. motor from a pure d.c. voltage source. This defficiency can however, be much improved by adding a series inductanee with the armature.

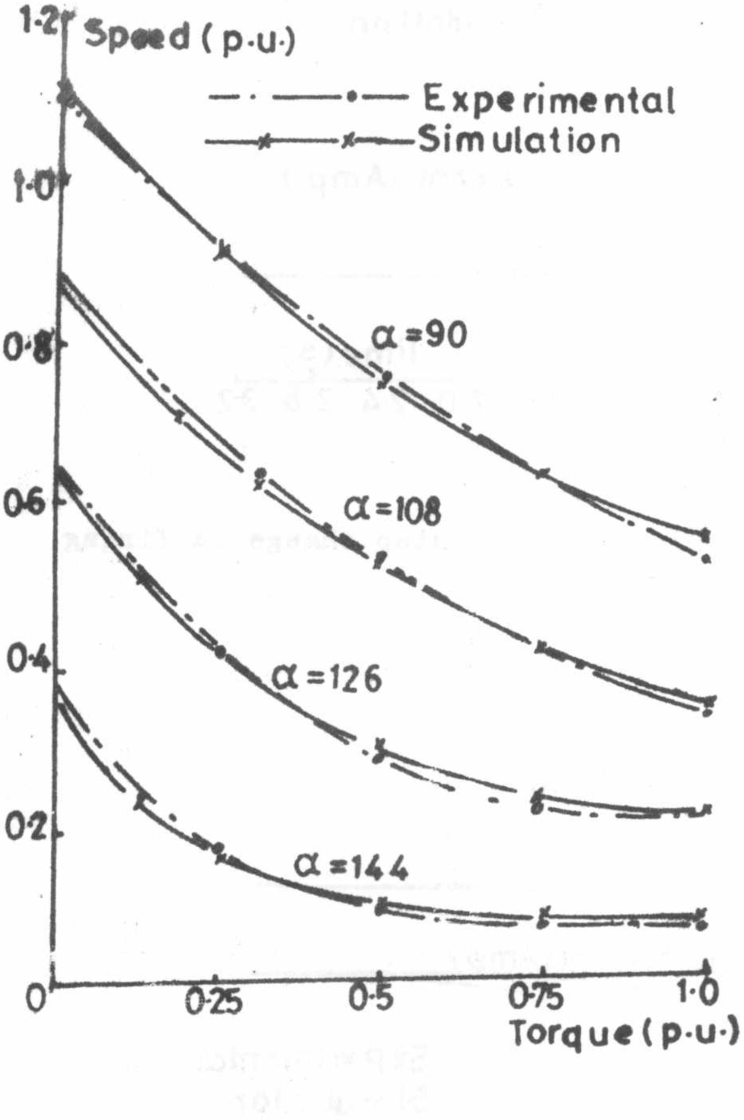

Fig. 5 Speed torque characteristics

Fig. 6 shows the system response to a step change in the firing angle from $\alpha = 90^{\circ}$ to $\alpha = 72^{\circ}$, at 50% loading. The recorded test and computed results are comparable. This indicates that the mathematical model is satisfactory for simulating transient response.

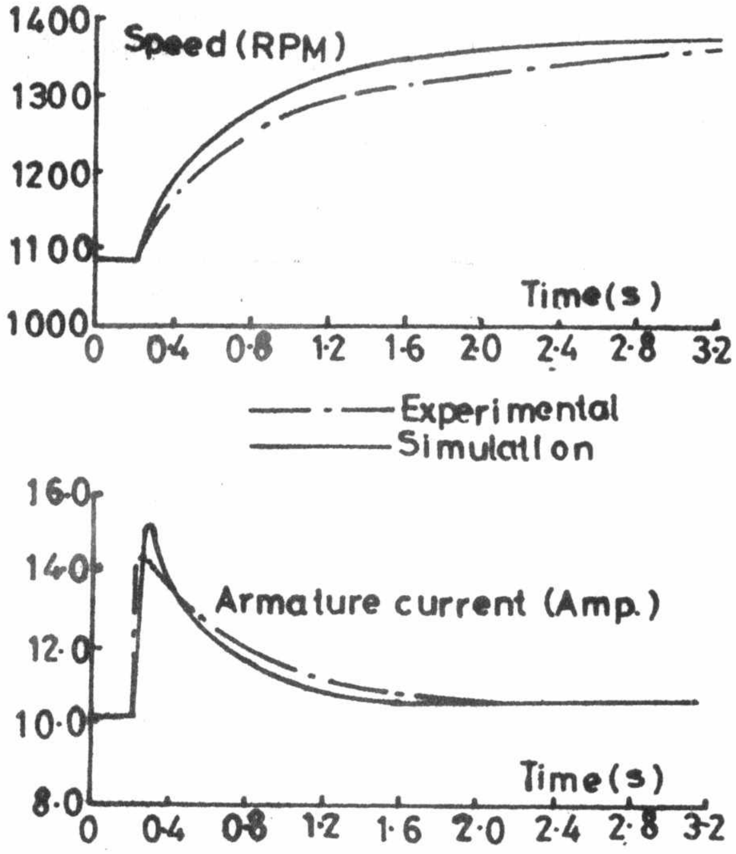

Fig. 6 Transient response to a step change in firing angle from 90° to 72°

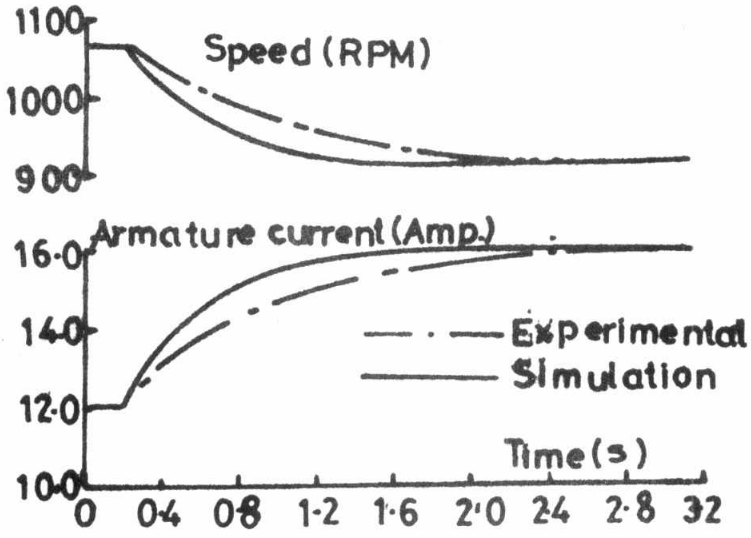

Fig. 7 Transient response to a step change in load torque

Finally, Fig. 7 shows the system response to a step increase in the load torque T_L from 50% to 75% of full load torque.

Again the experimental and computed results are very close, thus emphasizing model validity. It should be noted that the steady-state speed of this open-loop drive system droped from 1060 rpm to 910 as a result of the load increase. To obtain the initial speed at the new loading, we should decrease the firing angle. A closed-loop controller may be employed to maintain speed automatically.

CONCLUSIONS

The basic components of a microprocessor based controller has been assembled to provide (initially) open-loop speed control for a separately-excited d.c. motor drive system. The microprocessor generates the control pulses required for the single-phase half-controlled converter which supplies the armature of the d.c. motor. The compatible hardware components and the real-time software controlling programs provide great flexibility for speed control of the drive system.

The experimental results supported by simulation results have shown the successful operation of this open-loop control system. The mathematical model predicts the system performance both in steady-state and transient conditions with acceptable accuracy. This laboratory drive system and the simulation programs provide an excellent facility for training and research in this increasingly emerging field of interest.

Further analysis, design and implementation of advanced closed-loop control schemes are currently being persued by the authors. The preliminary results are most encouraging.

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