Microcomputer-Controlled Universal Motor

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ABSTRACT

This paper presents an experimental and simulation study for the speed control of a universal motor using ON/OFF method for the input d-c voltage. A microcomputer-based system is proposed which requires minimum hard-ware compared to conventional analog controllers. Fast-switching semiconductor devices such as MOSFETs can be used for this method of speed control. The controller is based on continuous adaptation for the dc chopper duty ratio in order to readjust the motor speed. Transient and steady state behaviors of ON/OFF speed control of the universal motor performance are presented. The proposed study incorporated the effect of load torque disturbances. The results show that the proposed control method is simple and useful for industrial applications which need variable speeds with good motor performance.

Keywords

Microcomputer, ON/OFF control, MOSFET and universal motor.

1. INTRODUCTION

Universal motor is a series uncompensated machine. It is usually built for fractional horse-power sizes. Universal motors belong to the series commutation machines family, which can operate satisfactorily from either d-c or a-c supply mains. They are normally used to drive portable apparatus (like hand tool machines, vacuum cleaners and most domestic apparatus) [1], [2].

Robust controllers that guarantee both transient and steady-state response of d-c servo mechanism systems motor within specified bounds under large plant uncertainty due to parameters and load variations have become an important issue in recent years [3].

Recently, a modeling and simulation study [4] of a closed loop speed control scheme for a MOSFET chopper-fed series motor, using a non-linear discrete model has been presented. In that study, conventional analog PI controller parameters for speed are determined using the recurrence matrix. The scheme is suitable for battery powered urban electric vehicles and small traction systems.

This paper presents the design and implementation of a microcomputer based digital closed loop speed control for the universal motor. The ON/OFF control method is used for adopting the motor input voltage to keep its speed within the desired value. Simulation and experimental results have shown the effectiveness of the proposed simplified model.

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2. DESCRIPTION OF THE SYSTEM

A schematic diagram for the proposed robust control system of the universal motor is shown in Fig. 1. It consists of four main units:

- Universal motor.
- Microcomputer.
- MOSFET switch.
- D-C power supply.

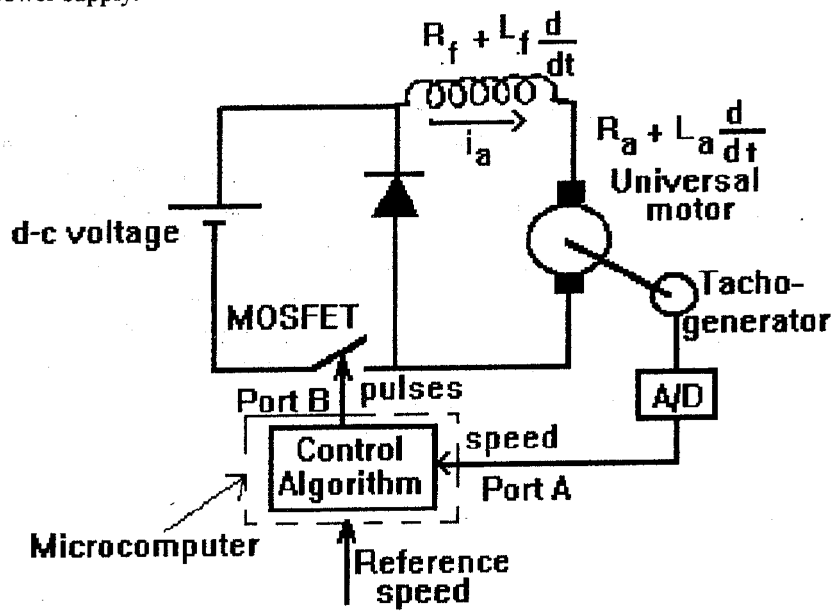

Fig. 1 The proposed control system

The chopper-fed loaded motor usually has two successive switching intervals:
1st interval - MOSFET switch is ON & freewheeling is OFF;
2nd interval - MOSFET switch is OFF & freewheeling is ON.
The performance equations for each interval are expressed in the following form:

Interval 1

During this interval, MOSFET switch is ON while the freewheeling diode is not active. The following Equations represent motor operation:

$$v = (L_f + L_a)\frac{di_a}{dt} + (R_f + R_a)\, i_a + e \qquad (1)$$

$$e = -k_1\, \omega_m\, i_a \qquad (2)$$

$$T_e = T_L + J\frac{d\omega_m}{dt} + K_2\, \omega_m \qquad (3)$$

$$T_e = -K_1\, i_a^2 \qquad (4)$$

[5]

Interval 2

During this interval, MOSFET switch is OFF while the freewheeling diode is active. The following Equations. represent motor operation:

$$0 = (L_f + L_a)\frac{di_a}{dt} + (R_f + R_a)\, i_a + e \qquad (5)$$

$$e = -\, k_1\, \omega_m\, i_a \qquad (6)$$

$$T_e = T_L + J\frac{d\omega_m}{dt} + K_2\, \omega_m \qquad (7)$$

$$T_e = -K_1\, i^2_a \qquad (8)$$

The motor speed is fed-back through an Analog to Digital (A/D) converter to a 16-bits port A of microcomputer (XT). The proposed system uses real-time microprocessor control to compare the motor speed (ω_m) with the reference speed (ω_{ref}). ω_{ref} is set externally and fed via an A/D converter and stored in a certain memory location. The microcomputer output is obtained from port B, interfaced and used to drive the chopper MOSFET switch according to the following rules:

$\omega_{ref.} > \omega_m$ MOSFET switch ON.

$\omega_{ref.} \leq \omega_m$ MOSFET switch OFF

This method of control is called ON/OFF control. or Bang-Bang control or Hysteresis control [6], [7].

3. MICROCOMPUTER CONFIGURATION

Microcomputer as shown in Fig. 2a consists of two min parts. The first is the CPU unit which includes the 8088 microprocessor, 8087 coprocessor, 16 K dual-port RAM, 16 K EPROM, 8254 Programmable Interval Timer (PIT), and 8259 Programmable Interrupt Controller (PIC). The second is named I/O unit which may include programmable digital I/O controller, programmer duty-cycle controller, quadrature photoencoder decoder, A/D, D/A -------- etc. depends on various applications [8].

In the present study, two-ports RAM memory architecture have been adopted for the microprocessor. This RAM-based microprocessor controller has advantages of flexibility and modularity. The proposed control structure can be easily implemented on this Hardware architecture.

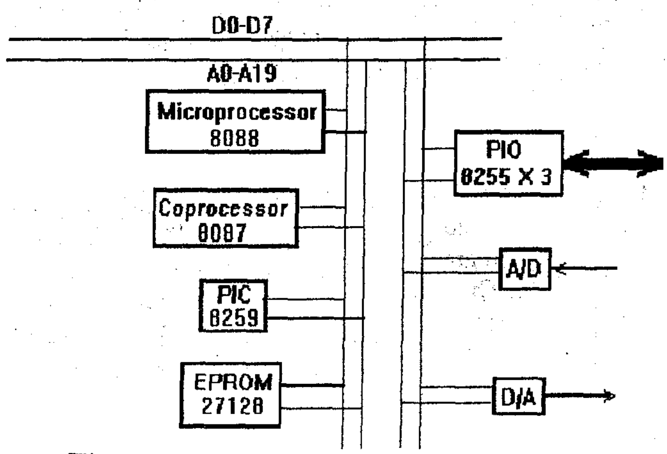

Fig. 2a Microcomputer configuration

4. SIMULATION AND EXPERIMENTAL RESULTS

A computer program is written to simulate the motor performance. It is based on the performance Eqns.(1-8) for its two different switching intervals which are numerically integrated using 4th order Runge-Kutta method. The motor parameters are listed in Table1.

TABLE 1 Motor parameters

Motor parameter	Value
Rated current	2.5 Amp.
Rated power	1/2 HP
Equivalent resistance (Req.)	7.2 ohm
Equivalent inductance (Leq.	44.5 m.H.
K1	0.2 ohm.sec./rad.
K2	0.004 joule.sec./rad.
No. of poles	2

The general flowchart of the control program experimentally is shown in Fig.2b.

Figures 3&4 show the simulation and experimental results for transient and steady state performance of the uncontrolled motor loaded with loaded torque = 0.1 Nm. The good matching between the results indicates the accuracy of the simulation model. On the other hand, the predicted and experimental results for the dynamic performance of the motor under the proposed closed loop controller are shown in Figs. 5&6 respectively. Both the two sets of results are comparable. A good steady-state speed without ripples is observed.

The motor is subjected to a sudden change of load torque, the simulation and experimental results are shown in Figs. 7&8 respectively. The load torque changed from 0.2 N.m. to 0.25 Nm., and ON/OFF control method is applied. A good agreement has been obtained between the two results and the speed of motor returned to its initial value. The motor terminal voltage is recorded and shown in Fig.9 at reference speed 940 rpm and input dc voltage of 20 volts using ON/OFF control method. Both the recorded motor speed and the MOSFET gate control pulses are shown in Fig. 10 a,b. On the other hand, Fig.11 a,b,c,d shows the recorded MOSFET drain-source voltage and the corresponding steady state motor speed at input d-c voltages of 22, 26, 33.5 and 36 volts respectively at constant reference speed of 940 rpm. From the introduced results, it can be concluded that the ON/OFF controller is suitable for any desired reference speed. A sudden decrease of the reference speed by 20% and maintained for 0.4 Sec. is represented in Fig. 12. The reference and actual motor speeds along with the input dc voltage are shown. It can be observed that the speed of the motor follows the reference speed.

5. Conclusion

The proposed method of speed control (ON/OFF control) has the advantage of robustness and modularity. An experimental prototype has been implemented to verify the proposed control scheme using assembly programming language. Simulation analysis has been carried-out and performed using Quick BASIC programming language to obtain the transient and steady state performance of motor with and without the proposed control method. Experimental results validate the effectiveness and simplicity of the proposed control scheme

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7. SYMBOLS

e: Rotational e.m.f.

i_a: Armature current

J: Moment of inertia constant.

K_1, K_2 : Motor constants.

L_a,L_f: Motor armature and field inductances.

L_{eq}. : Equivalent inductance = $L_a + L_f$

R_a , R_f: Motor and field armature resistance.

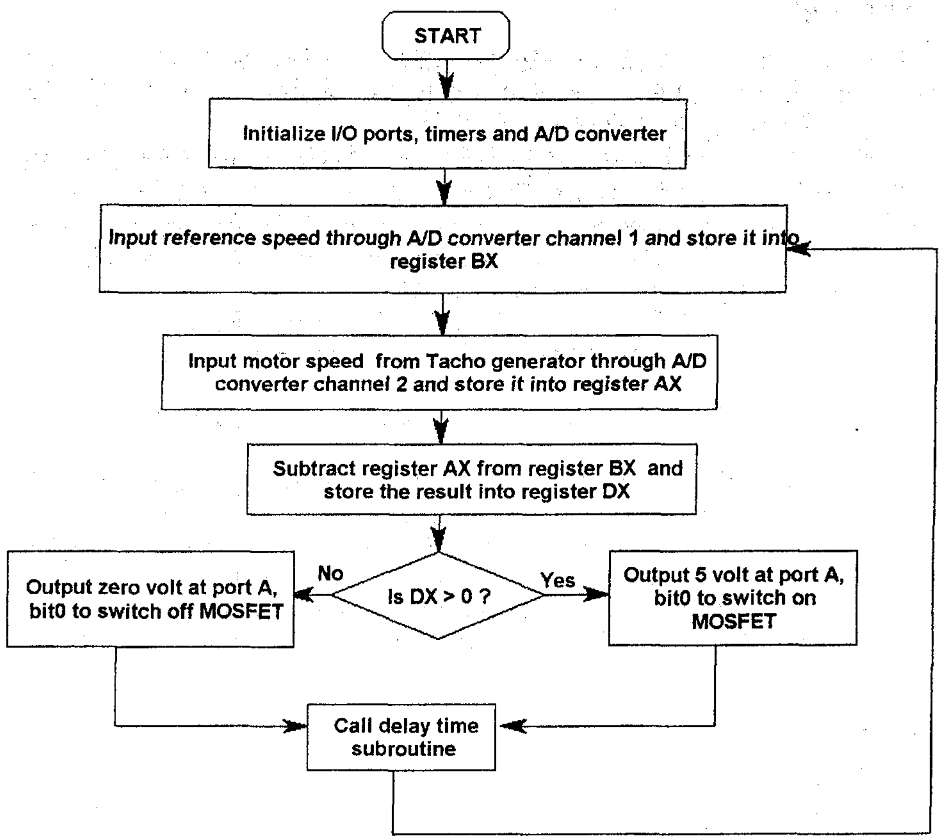
R_{eq}. : Equivalent motor resistance = $R_f + R_a$

T_L: Load torque.

T_e: Electromagnetic torque.

ω_m: Motor speed.

v: Motor input voltage.



Main program

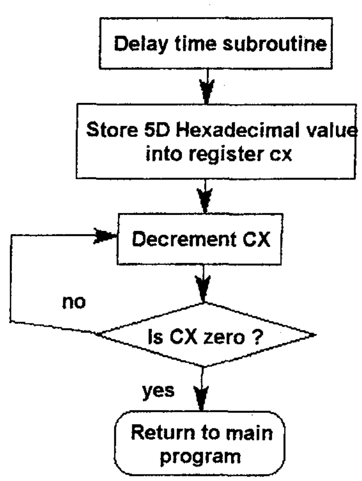
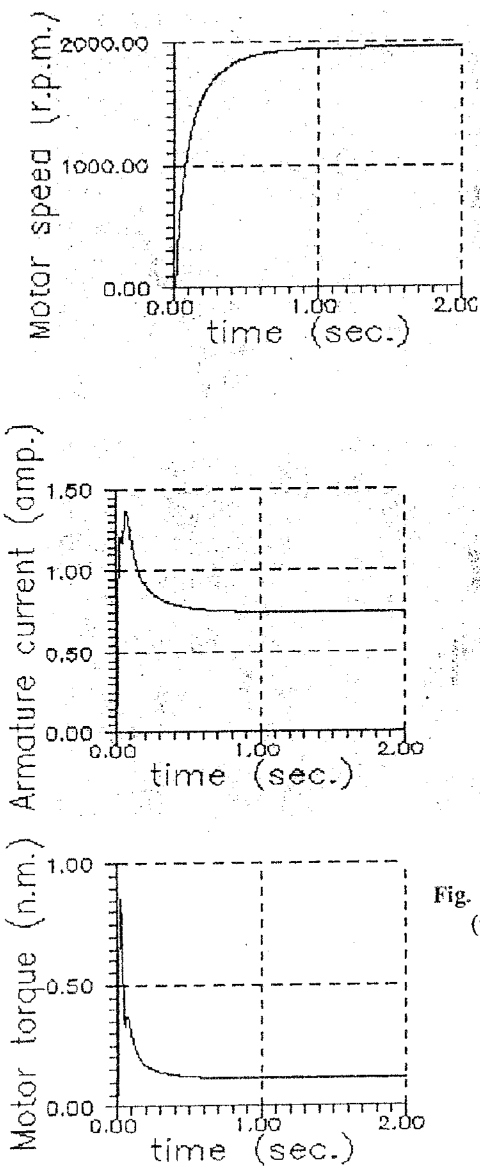
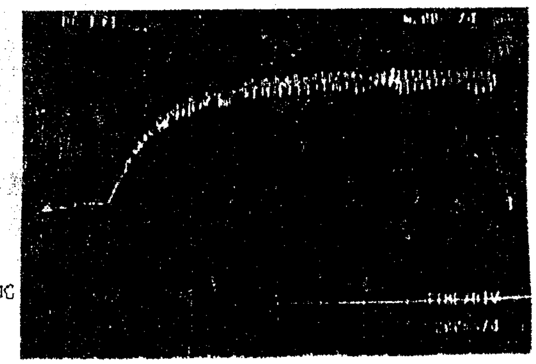
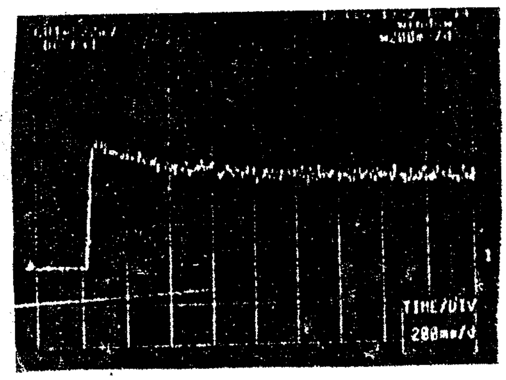


Fig. 2b A flow chart of control program





671.7 r.p.m./div, 200 m.sec./div



0.375 amp./div

Fig. 4 Motor start-up characteristic and steady state (without controller) and input voltage = 36 volt. (Experimental results)

Fig. 3 Motor start-up characteristic and steady state (without controller), and input voltage = 36 volt. (Simulation results)

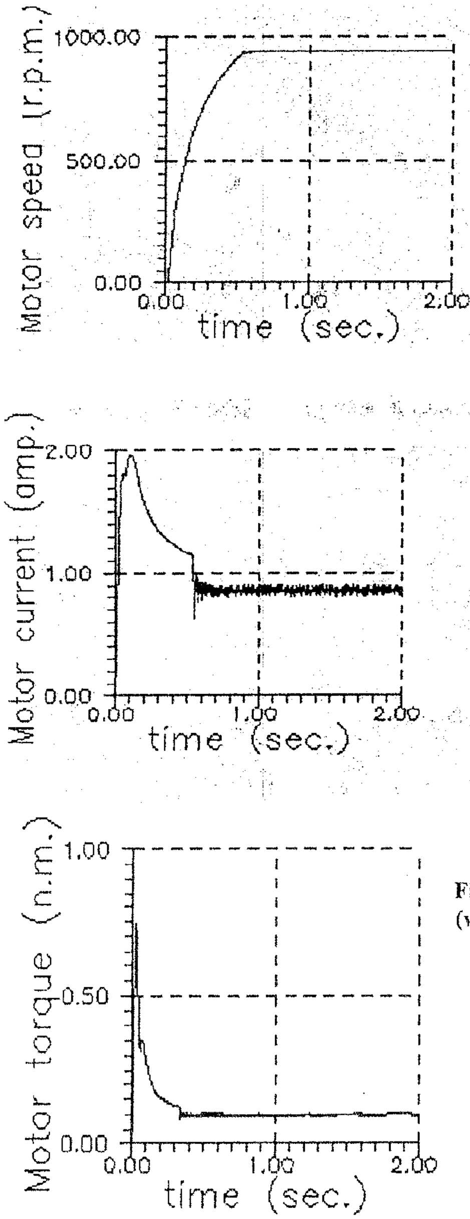
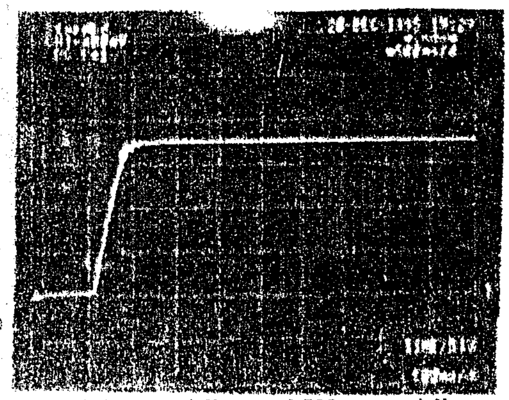
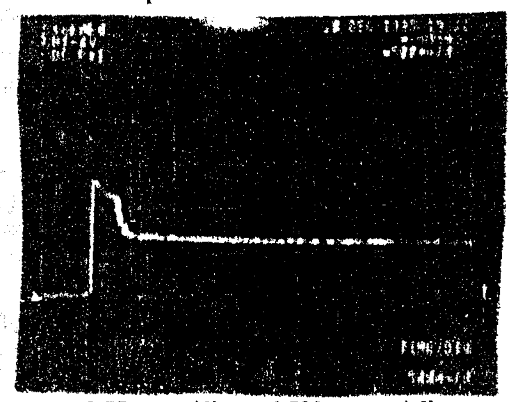


Fig. 5 Simulation results of motor performance (with ON/OFF controller) at input voltage =32 volt. and Reference speed = 940 r.p.m.



268.4 r.p.m. / div. and 500 m.sec. / div.



0.75 amp. /div. and 500 m.sec. / div.

Fig. 6 Experimental results of motor perfo -rmance (with ON/OFF controller) at input voltage = 32 volt. and reference speed = 940 r.p.m.

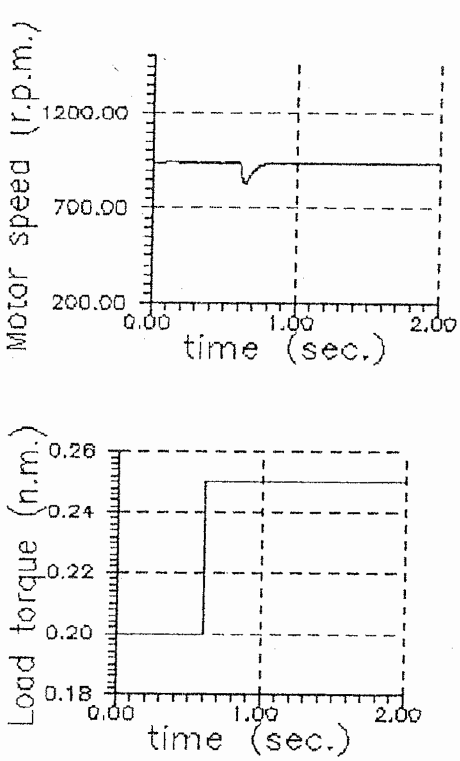
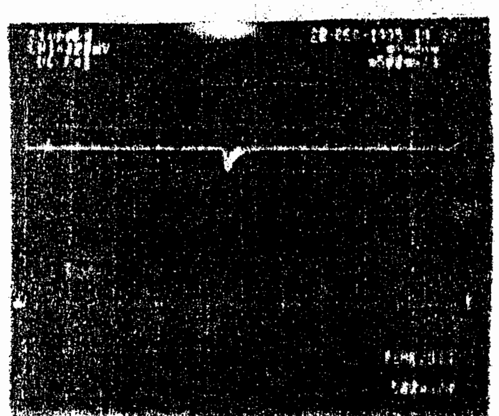
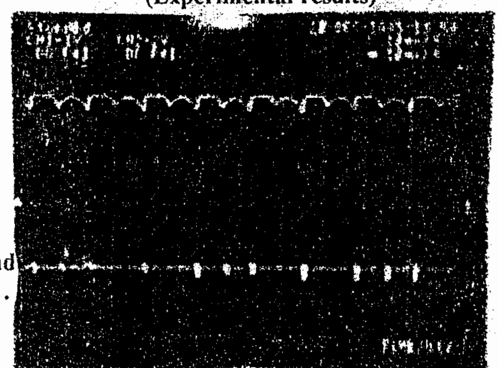


Fig. 7 Motor speed performance if load torque is positive stepped up , reference speed = 940 r.p.m.and input voltage = 32 volt. and ON/OFf control is used . (Simulation results)

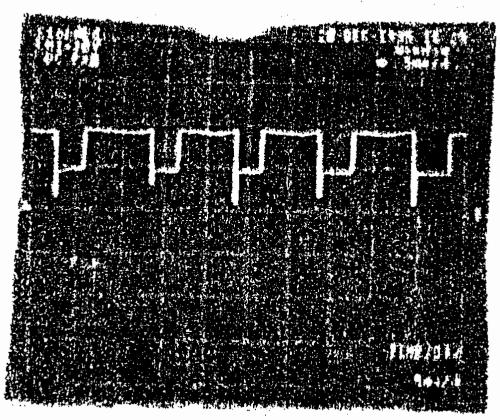


268.58 r.p.m/div., 500 m.sec. /div.

Fig. 8 Motor speed performance if load torque is positive stepped up , reference speed = 940 r.p.m., input voltage = 32 volt.. and ON/OFF control is used (Experimental results)

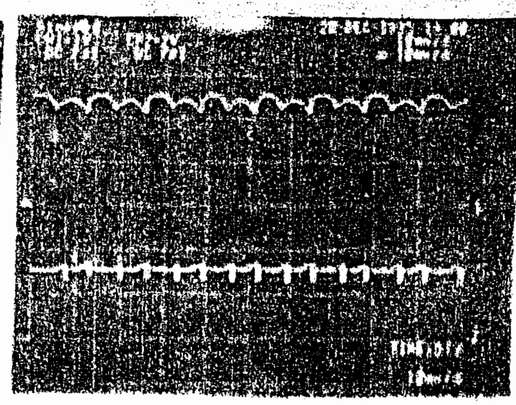


(a) at input voltage = 32 volt
671 r.p.m./div., 10 m.sec. /div.



10 volt. / div. , 10 m.sec. /div.

Figure 9 The motor terminal voltage at input motor voltage = 20 volt. and reference speed = 940 r.p.m. (Experimental results)



(b) at input voltage = 28.8 volt
671 r.p.m./div., 10 m.sec. /div.

Figure 10 Steady state speed and Required pulses to MOSFET gate at Reference speed = 1650 r.p.m. (Experimental results)

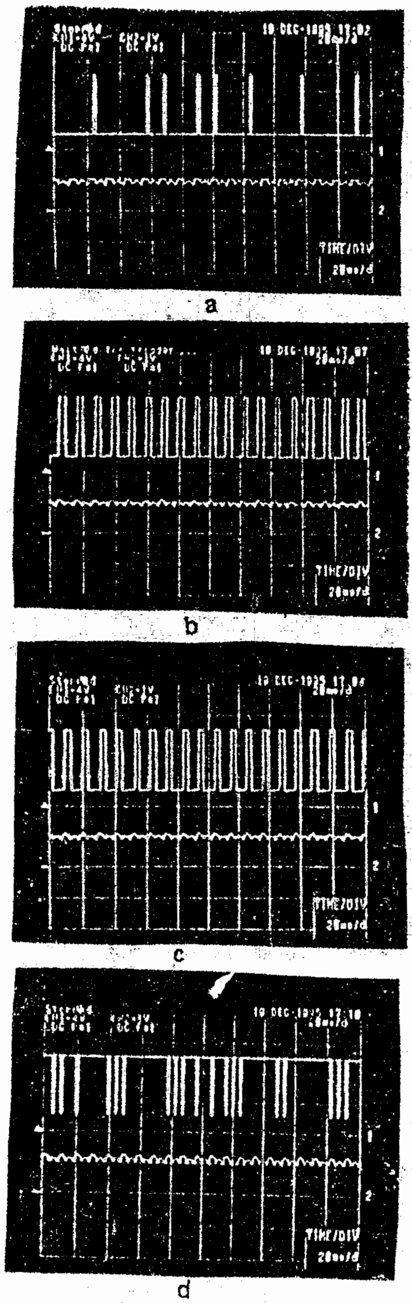


Fig. 11 a,b,c,d

channel 1 Drain-Source voltage of MOSFET

channel 2 steady state motor speed control

reference speed = 940 r.p.m.

(a) at input d-c voltage = 22 volt.

(b) at input voltage=26 volt.

(c) at input voltage=33.5 volt.

(d) at input voltage = 35 volt.

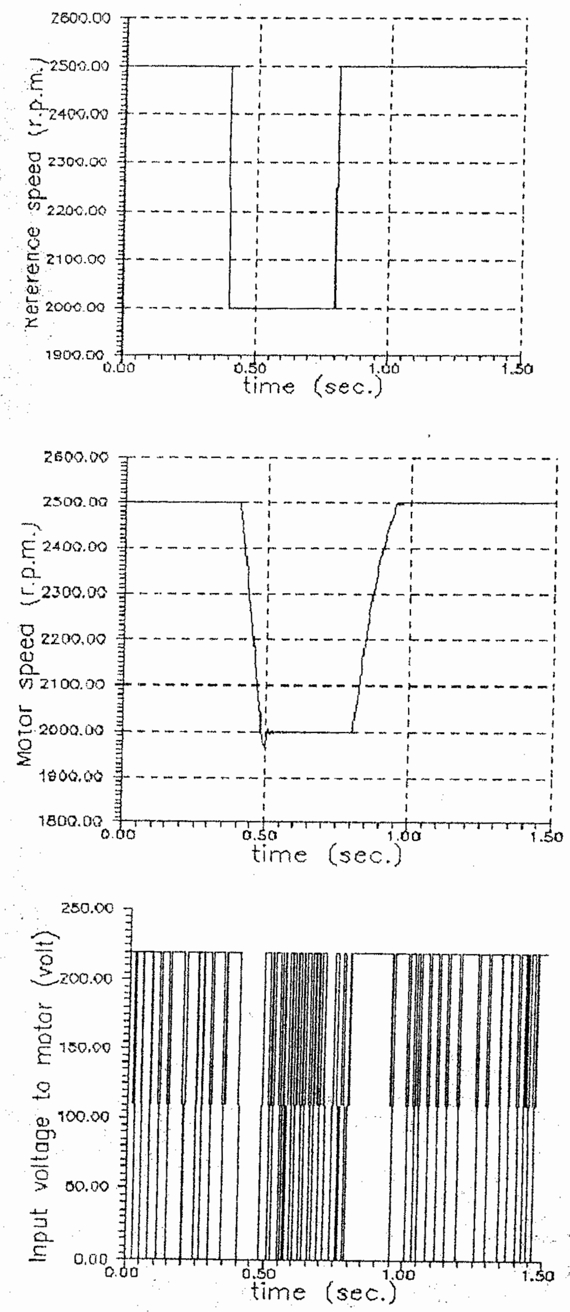


Fig. 12 Transient and steady state motor speed if reference speed has been changed from 2500 r.p.m. to 2000 r.p.m. and fixed for 0.4 sec. then return back to 2500 r.p.m.

التحكم فى المحرك المتعدد التغذية بإستخدام الميكروكمبيوتر

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ملخص البحث

يتناول هذا البحث إستخدام طريقة من طرق التحكم فى سرعة المحرك المتعدد التغذية وهى ON/OFF وتعتمد على توصيل الجهد الكهربى المستمر للمحرك عندما تكون سرعة المحرك أقل من السرعة المحددة (المطلوبة) وقطع الجهد الكهربى المستمر عنه عندما تكون سرعة المحرك أعلى من السرعة المحددة وذلك بإستخدام ترانزيستور يتم توصيله على التوالى مع المحرك ويتم التحكم فى تغذيته بإستخدام الميكروكمبيوتر وهى طريقة ذات فاعلية عالية ٠
ولإثبات صحة التحليل النظرى للنظام المقترح والذى يتكون من :

- المحرك الكهربى
- ترانزيستور من نوع MOSFET
- مصدر للجهد الكهربى المستمر
- ميكروكمبيوتر

أخذت النتائج المعملية عند البدء والإستقرار ووجد تقارب بين النتائج المعملية والنظرية ٠
ولقد أوضحت النتائج أن الطريقة المقترحة فى التحكم يمكن أن تستخدم فى التطبيقات الصناعية التى تحتاج لسرعات متغيرة مع أداء جيد للمحرك ٠