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A MICROPROCESSOR AIDED DC DRIVE IN THE DISCONTINUOUS CURRENT MODE

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ABSTRACT

In this paper, a DC drive system which employs a relatively cheap microprocessor is built and tested considering the discontinuous current mode of operation. Hardware interfacing between the microprocessor and peripheral circuits is developed. Properly shaped and correctly timed firing pulses are produced via the software instructions and control components. In order to obtain fast response and correct speed, a P.I controller and speed feedback are employed. Test results are reported, and it is shown that the system can operate at fixed steady-state speed with acceptable over-shoot during disturbances.

1. INTRODUCTION

The choice of drive motors for industrial applications is subjected to environmental and operating conditions. In that respect, DC motors are so well suited to many industrial drives. Also, speed control schemes for DC motors are, in general, simpler and less in cost than those of AC motors for a comparable performance.

In principle, most DC drives are speed conrolled via the regulation of armature voltage supplied by thyristor converters[1-8]. The firing angle of the thyristor rectifier is varied in response to an error signal resulting from the reference and feedback speed levels. Systems as such, are usually designed to operate at constant excitation. However, in order to achieve fast response and better performance, the error signal is fed to a controller, the output level of which dictates the firing angle of the converter; a microprocessor may aid preoducing correctly shaped and timed firing pulses[3].

When the speeds of a number of drive motors must be synchronized to each other or to a clock signal, the phase locked loop principle could be applied [1,2]. In such an application the speed is sensed digitally via the motor shaft[4]. This method of speed control may provide good results but employs complex circuitry.

In recent years, microprocessors have rapidly penetrated new applications including DC drives [5-8]. This has allowed the control scheme to be implemented in the software which may be modified to obtain different drive characteristics with minimal or no change in the hardware. However, the cost of microprocessor -based control system is high, but may become cost competitive in the near future due to the fall in the price of such equipment.

In this paper, a DC drive system using a relatively cheap microprocessor is built and tested. The system control is built considering the discontinuous current mode of operation. The motor field is separately excited and the armature is fed from a single--phase thyristor bridge controlled by the microprocessor. Details of the experimental system are considered subsequently.

2. THE DRIVE SYSTEM COMPONENTS

A schematic diagram of the DC drive including the control components is shown in Fig. 1. The motor field is supplied using uncontrolled single-phase bridge rectifier. The armature voltage is regulated by phase control of a single-phase thyristor bridge in response to the system control components.
A speed feedback using tachogenerator in addition to a compensation circuit (a controller) are introduced to improve response and accuracy of the system. The type and parameters of such a controller are determined using to transfer characteristic of the drive system. The controller output is fed to the microprocessor (MP) via an analog-to-digital converter (ADC). Also, the MP is kept continuously informed about the zero crossings of the supply voltage wave via a synchronizing circuit. With the aid of a developed software program, the MP will act producing firing pulses at the correct delay in accordance with the speed reference and operating conditions. Firing

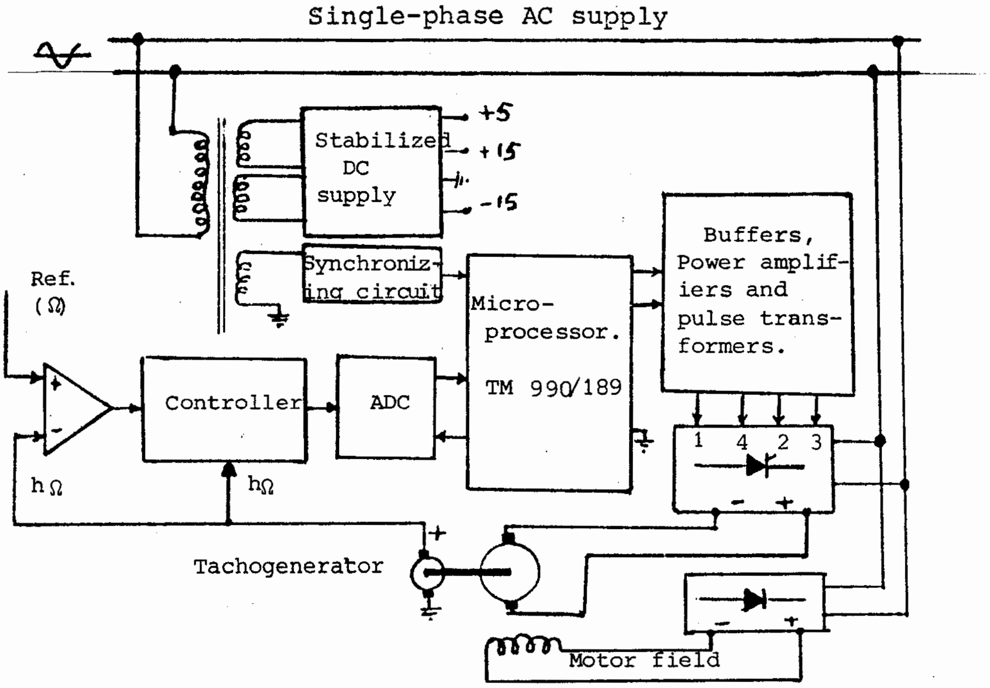


Fig. 1: A schematic diagram of the experimental system.

pulses from the MP are fed to the thyristor gates via suitable buffers, power amplifiers and pulse-transformers.

3. THE CONTROLLER TYPE AND PARAMETERS

If the armature reaction is neglected, the drive motor of Fig. 1, can be treated as a linear system producing the well known block diagram representation shown in Fig.2. The motor equations in the S-domain can be easily written, from which the speed is obtained as,

$$\Omega(s) = \frac{(V_a(s)/k) - R_a r_r(s)(1+T_e s)/k^2}{1+T_{em}s + T_e T_{em} s^2} \qquad (1)$$

$T_e=L_a/R_a$ is the electric time constant, and $T_{em}=R_aJ/k^2$ is the electromechanical time constant. If the drive motor is required to be of constant speed, the armature voltage should be regulated according to Eqn. (1). Due to variations in the operating conditions, feedback loop and controller, as shown in Fig. 2, may provide automatic speed control against changes in operating conditions, e.g. the motor speed can be forced to follow the reference.

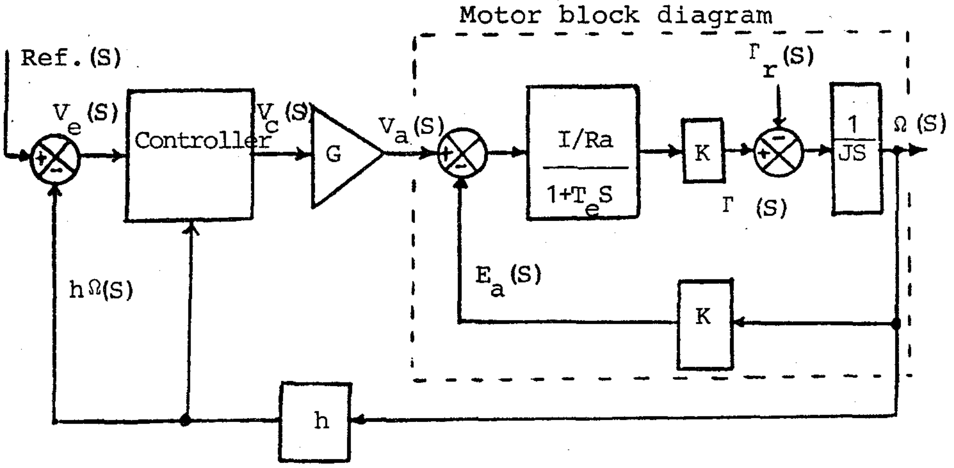


Fig. 2: Block diagram of the DC drive system.

In this investigation, the motor is operated in the discontinuous current mode, which may, in general, result is a nonlinearity in the gain, G, of the thyristor rectifier. Experimental results[3] have shown that, using a ramp voltage, V_r, to produce firing pulses delayed according to the DC control voltage, V_c, gives a nearly constant gain for firing delay above 90°. Thus, for $\alpha > 90°$ the transfer characteristic of the employed rectifier can be represented by constant gain, G, using this type of firing angle control.

If a proportional controller having a gain K_c is used, then from Eqn.(1) and Fig.2, it could be shown that,

$$\Omega(S) = \frac{[\text{Ref.}(s)/h] - [R_a(1+T_eS)\Gamma_r(S)/K\ K_cGh]}{1+(K/K_cGh)+(K\ T_{em}/K_cGH)S+(KT_{em}T_e/K_cGh)S^2} \qquad (2)$$

For the drive system, T_{em} is very large compared to T_e. Also; $K/K_cGh << 1$, and so Eqn.(2) can be reduced to the form,

$$\Omega(S) = \frac{[\text{Ref.}(S)/h] - R_a\Gamma_r(S)(1+T_eS)/K\ K_cGh}{1 + (K\ T_{em}\ /\ K_cGh)\ S} \qquad (3)$$

This is a first order system of time constant proportional to $1/K_c$. It follows that, for a constant load torque, the system response following a step change in the reference speed will be faster for large values of K_c. However, if the reference is fixed, e.g. constant speed is desired, Eqn.(3) indicates that there may be variations in the speed for a varying load torque. Using the final value theorem for examination of Eqn. (3), if at fixed reference a step change in load torque is applied, the motor speed will deviate from its initial value by an amount proportional to $1/K_c$. Thus, a proportional controller may result in faster response but the speed decreases as the load troque increases.

Following a similar procedure as above, an integral type controller (1/TS) will force the speed to follow the reference, but the system may not be stable always. However, a proportional plus integral (P.I) controller can be designed to provide for fast response and constant speed with reasonable overshoot during disturbances.

A block diagram of the control system is shows in Fig. 3, from which the system transfer function can be easily written. Since T_{em} is much greater than T_e, the system transfer function can be reduced to the form,

$$\frac{\Omega(S)}{\text{Ref.}(S)} = \frac{1/h}{1+(T+KT/K_cGh)S + (KT\ T_{em}/K_cGh)S^2} \qquad (4)$$

$$= \frac{1/h}{1+(2\eta/\rho)S + (1/\rho^2)S^2} \qquad (4')$$

Put the two system poles in the form,

$$S = -\eta\rho \pm j\rho\sqrt{1-\eta^2}$$

Taking the two system poles for a damping ratio of 0.707, which is generally used, and making direct correspondence with Eqn. (4') there results,

$$T + TK/Gh\ K_c = \sqrt{2}\ /\ \rho \qquad (5)$$

and,

$$T\ T_{em}\ K/Gh\ K_c = 1/\rho^2 \qquad (6)$$

Solving Eqns. (5) and (6) for T and K_c gives,

$$T = (\rho\ T_{em}\ \sqrt{2} - 1)/\rho^2 T_{em} \qquad (7)$$

and,

$$K_c = (\rho\ T_{em}\ \sqrt{2} - 1)\ K/Gh \qquad (8)$$

For the experimental system, ρ=120 rad/S has been found suitable. Considering the system parameters and constants (listed in the appendix), the controller gain and time constant are K_c=88.5 and T=11.46 ms. The employed controller circuit is shown in Fig. 4. The zener diode is used as a limiter to the control voltage V_c such that it should never rise above that value which corresponds to nearly zero

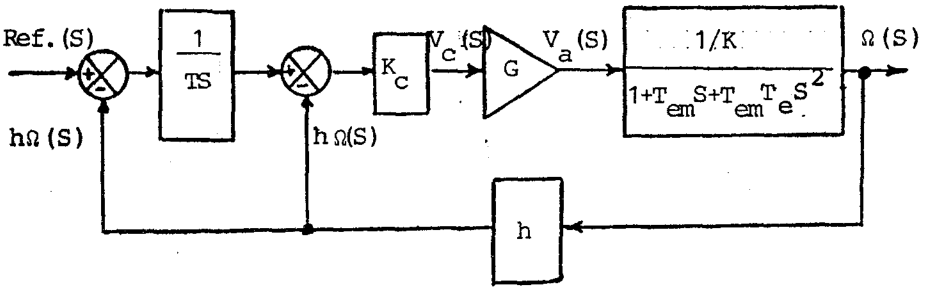


Fig. 3: Complete block diagram of the experimental system.

firing angle. This gurantees stable operation during large disturbances.

4. DIGITAL CONTROL OF THE THYRISTOR BRIDGE

Consider the block diagram shown in Fig. 3, and the schemstic diagram of Fig. 1. The reference voltage is compared with that detected via the motor shaft; the resulting error signal acts on the integral part of the controller, where the output of which is also compared with the speed feedback. The voltage resulting from this stage acts on the proportional part of the controller producing the control voltage, V_c. This arrangement for the P.I controller is practically used to achieve faster response.

The analog signal V_c is fed to the MP via an ADC, which converts it to a digital 8-bits. For accurate firing, a synchronizing circuit (zero-crossing detector) is also used with the MP to predict the required firing angle in every half-cycle. Details of the ADC and the zero-crossing detector could found in Ref. [3]. The MP produces firing pulses as being instructed by the software; sample results of this action are shown in Fig. 5. However, a brief descripsion of the software mechanism is given below, but the complete list of the program is included in reference [3]. Nevertheless, the flow chart is given is Fig. 6.

An already available MP was employed with the system. That is TM 990/189, which is built around Texas corporation's TMS 9980A MP chip. The execution speed of this type is enough to apply the software technique for generation of the required firing pulses.

At every zero-crossing of the AC voltage wave a pulse is fed to the MP from the synchronizing circuit. Also, the half-cycle of the 50 Hz AC supply is divided into 255 sampling intervals via the

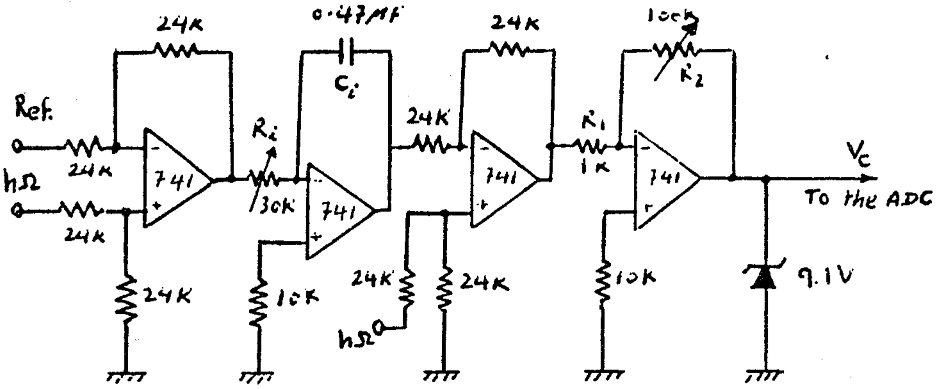


Fig. 4: Details of the P.I controller circuit.

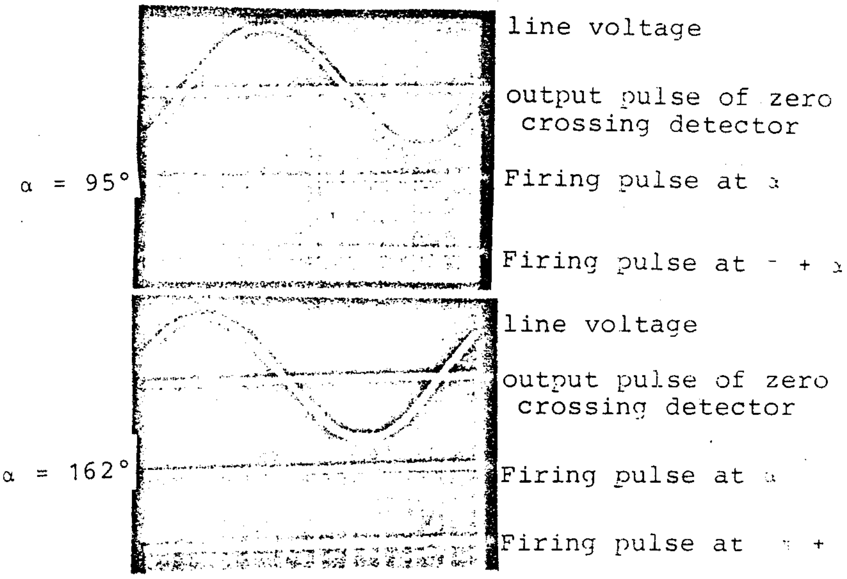


Fig. 5: Gate pulses generated by the microprocessor.

software instructions, e.g each sampling interval represents 0.7 degree. The ADC converts V_c to a digital 8-bits which is fed to the MP, and stored in a register called the control register. The height of the ramp voltage V_r is also represented by a count in a register called ramp counter. This count is taken to be 255_{10} (or FF_{16}), and at every sampling interval the count in the ramp counter is decremented by one and compared with the contents of the control register. This operation continues until the count in the ramp counter equals that in the control register; at that instant a firing pulse is produced by the MP and test is then made considering the next synchronizing pulse.

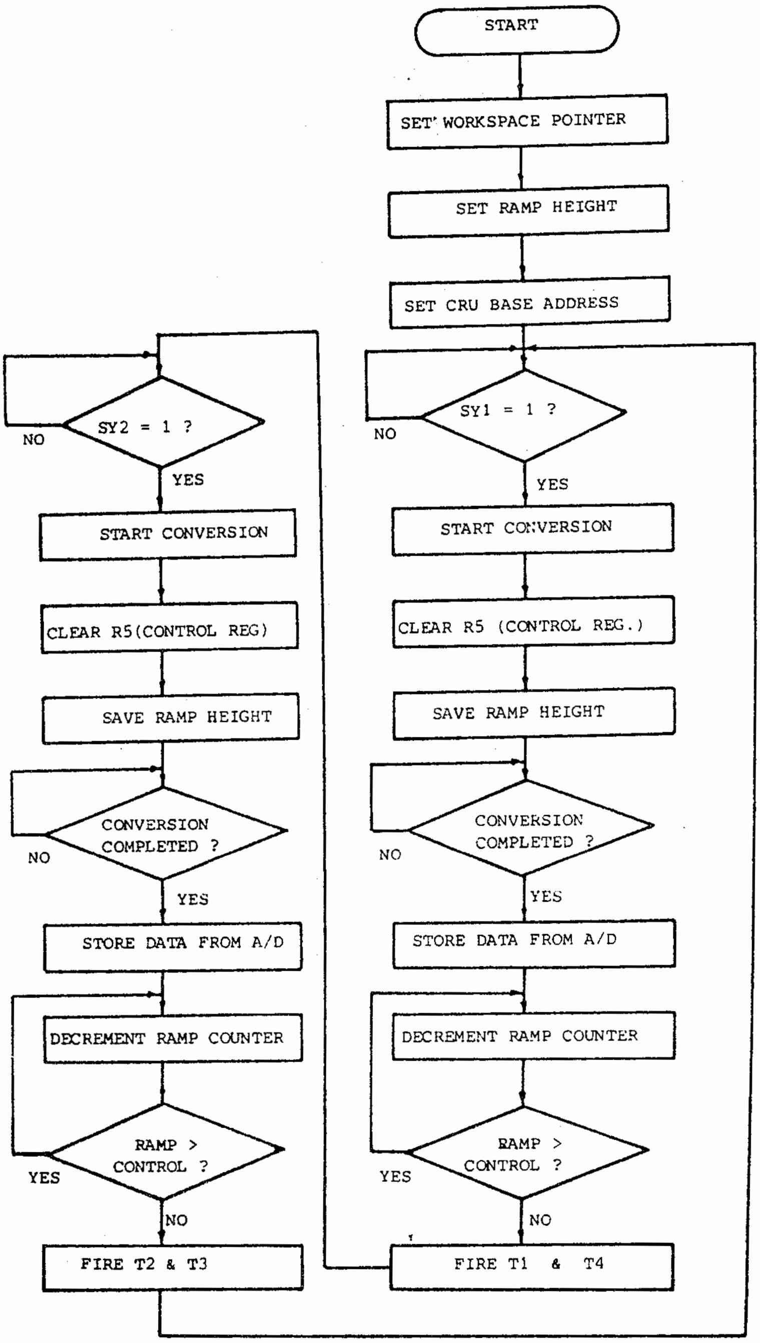


Fig. 6: Flowchart of a microcomputer program for firing the thyristor bridge.

In the software program, the decrement loop for the ramp counter is precisely time-adjusted by software instructions to be executed every 39µs(0.7°). This eliminates the need for hardware external clock signal of 25.5 KHz for sampling. However, the flow chart of Fig.6, was translated into assembly and machine language, and loaded into the MP via the Keyboard. The program is memory was dumped into the cassette interface and saved using an audio cassette where it can be stored into memory again via the Keyboard.

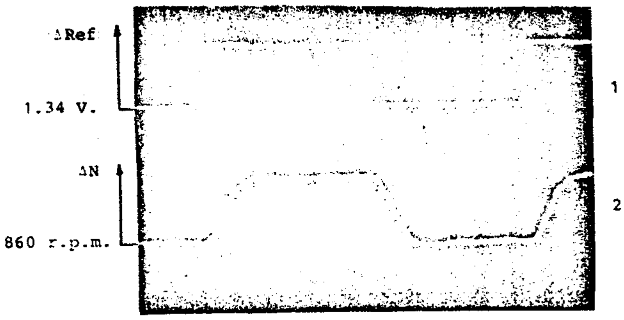
5. RESULTS

Throughout the experimental work the motor field current was maintained at the rated value(0.42A). A DC generator of the same rating and mechanically coupled with the motor was used as a load. Field currents were fixed, and so the armature currents were taken as a good indication for the torque. In order to start the motor from rest without being overcurrent, the reference voltage / speed was gradually increased from zero to the desired level.

The system was successfully operated and controlled in the discontinuous current mode of operation, considering different steady-state speeds and loading conditions. Whenever the system was subjected to step changes in the speed reference, the new speeds were obtained within reasonable transient periods. Similar results were obtained when the system was subjected to load changes(sudden changes in the generator load resistance). The observed behaviour of the system indicated acceptable overshoot and time response, which verifies the theoretically predicted controller parameters.

A storage osciloscope was used to record the system behaviour during the transient periods. Figure, 7, shows the recorded speed response when the reference was suddenly changed. It shows clearly that the system can follow the desired speed smoothly, accurately, and within reasonable time. The repetitive sudden changes in the reference indicate that the speed rise (or fall) by the same amount lasts the same time at every corresponding change.

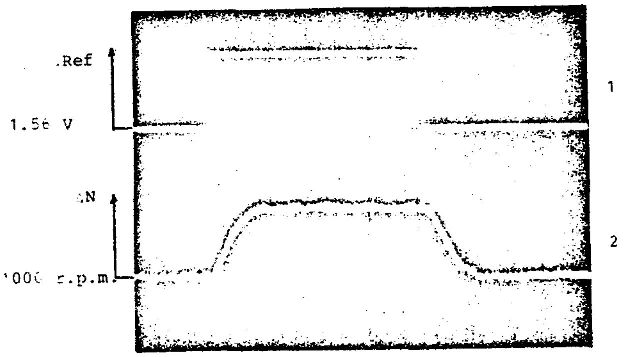
The motor current, in response to step changes in the reference, is shown in Fig.8. The effect of motor speed in quite obovious; due to energy demand of the rotating mass, if the reference change is towards a higher speed higher current is drawn, and vice versa if lower speed is ordered via the reference. The effect of armature circuit time constant is not noticeable since this is very small.



(a)

ch1 : 0.2 V/div , ch2 : 125 r.p.m/div

time base : 10 m.s/div.



(b)

ch1 : 0.2 V/div , ch2 : 125 r.p.m./div.

time base : 10 m.sec/div.

Fig. 7: Speed response to a step change in reference.

The effect of load increase on motor speed is as shown in Fig. 9. A change in the load torque would affect the motor speed for only a transient period beyond which the original speed was regained. Also, the armature current pulses are identical in the steady state; in this test the average current was increased from 4A to 5.5 A. The reported results show the accuracy of firing and the effectiveness of the controller. However, when the load was similarly reduced, the recorded speed and current of Fig.10, were obtained. Nevertheless, the encountered speed drop in Fig. 9, and speed rise in Fig. 10, during the transient period are due to the effect of energy storage components of the system.

6. CONCLUSIONS

A DC drive system incorporating a relatively cheap microprocessor and supplied by a single-phase

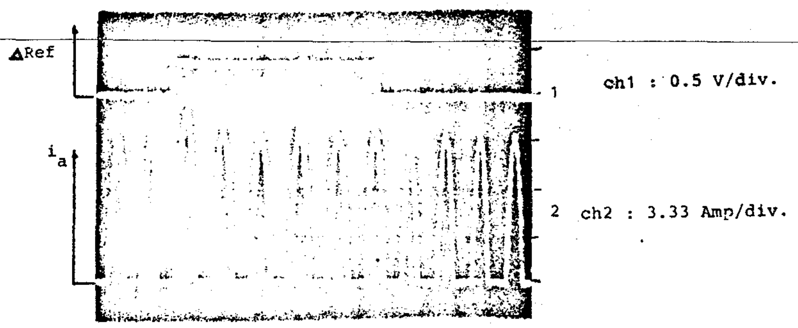


Fig. 8: Current response to a step change in reference.

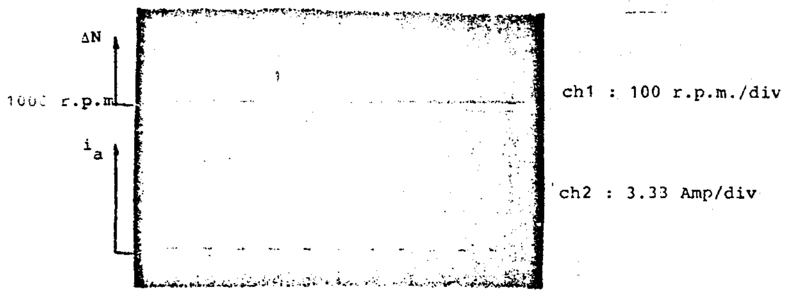


Fig. 9: Response of the system to a step increase in load.

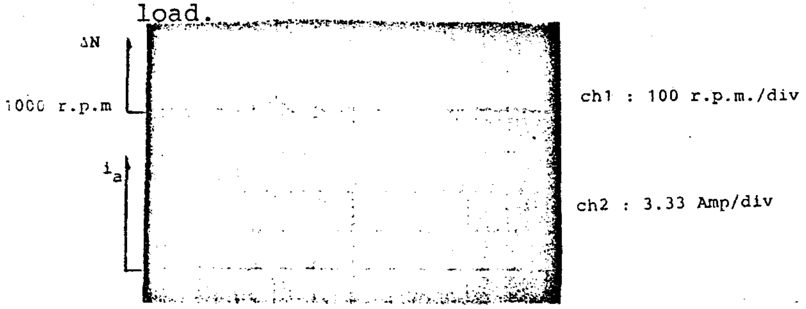


Fig. 10: Response of the system to a step decrease in load.

thyristor bridge whose current is normally discontinuous has been built and tested. Interface between the MP and peripheral components has been implemented and software program for accurate firing of the thyristor rectifier has been developed. A P.I controller has been designed and shown to be effective in adjusting the motor speed according to the reference.
The reported results have shown that the experimental DC drive is of satisfactory performance and accurate speed regulation.

LIST OF MAIN SYMBOLS

E_a = back e.m.f (K).
G = gain of the thyrostor converter (V_a/V_c).
h = gain of the tachogenerator.
I_a, V_a = armature current, voltage.
J = moment of inertia, kg.m².
K_c = controller gain.
L_a, R_a = armature circuit inductance, resistance.
T = time constant of the controller.
α = firing angle.
Γ = developed motor torque ($K\ I_a$).
Γ_r = load torque.

APPENDIX

Constants and parameters of the experimental system.

R_a = 3.34 ohms , L_a = 0.0368 Hen.
K = 2 volt/rad./sec., h = 0.015 Volt/rad./Sec.
J = 0.26 kg.m² , G = 54
T_e = L_a/R_a=0.011 Sec., T_{em} = R_aJ/K^2=0.217 Sec.
T = 0.01146 Sec. , K_c = 88.5

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REFERENCES

1. Le-Hug H.,"A synchronous thyristorized d.c. motor drive",IEEE Transactions, Vol. IA-15, No.2, 1979, PP. 183-188.
2. Bose D.K. and Jentzen K.J.,"Digital speed control of a d.c. motor with phase-locked loop regulation", ibid, Vol. IECI-25,1978, PP. 10-13.
3. Ghazy A.,"A digital technique for speed control of d.c. motor drives", M.Sc. Thesis, Menoufeya University, Egypt, 1985.
4. Maloney T.J. and Alvarado F.L.,"A digital method for d.c. motor speed control", IEEE Transactions, Vol. IECI-23, 1976, PP. 44-46.
5. Ohmae T. et al.,"A microprocessor-controlled fast response speed regulator with dual mode current loop for DCM drives", ibid, Vol. IA-16, 1980, PP. 388-394.
6. Saito K. et al.,"Application of fully digital speed regulator to tandem cold mills",ibid,Vol.IA-20,1984,PP.785-794.
7. Harker S.C.and McNulty P.T.,"Implementation of a fully microprocessor-controlled paper machine drive system",ibid, PP. 367-371.
8. Stoji'c M.R.,"Design of the microprocessor-based digital system for d.c. motor speed control", ibid, Vol. IECI-31, No. 3, 1984, PP. 243-248.