A Microprocessor-based Speed Controller for DC Motors

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The introduction of microprocessors into electric vehicles has opened many interesting possibilities for improving the operation and maintenance of such automotive systems. On the other hand, microcomputer-based motor control systems are playing an ever increasing role in research on applied electronics. In this paper, a microcomputer-based digital dynamic control system (DDC) for a dc motor is described. The description includes motor identification and corrector digital implementation, as well as precision analysis of the control system. The influence of poles and corrector gain on the system response is also presented, this allows the choice of appropriate parameters for the design of a lag-lead controller. The application of such a controller with a low power dc motor verifies the theoretical approach and reveals the necessary information to analyse the speed control system stability of a chopper-fed dc motor using the same controller.

Introduction

LSI techniques development has caused digital electronic devices to become much smaller, faster and cheaper; consequently, the field of automotive electronics has been considerably broadened due to microcomputer utilization. In 1977 the first microprocessor was introduced in the Oldsmobile Toronado as part of the spark plug timing circuit. In these fuel-vehicles the microprocessor is delegated to perform the engine control and provide valuable information to the driver. On the other hand, microcomputer-based control for electric vehicles provides a higher efficiency, allowing speed adjustment or torque control. Namely, both ignition and timing control, as well as cylinder selection, which constitutes the main control tasks in a fuel-vehicle and are replaced by a closed-loop digital control in the electric vehicle. Moreover, by changing only the control programme, different services can be obtained with the same propulsion system. This versatility also allows to implement different kinds of electric vehicles (vans, cabs, airport trucks) with the same propulsion system. The low cost and feasibility of microprocessors is another significant reason for their use either as chopper-fed dc motor controllers or as inverter controllers when ac motors are used.

As regards the motor selection for an electric vehicle, it cannot be made by considering the motor services only, but must take into account the relationship between motor services and the associated electronic control. From the electronic control point of view, ac motor control is more complex. However, whereas a dc motor rarely has a conversion efficiency bigger than 85%, that of an ac motor is approximately 90%. Even allowing for important losses in the control system, the global efficiency of the propulsion system-control benefits by using ac. Finally, energy recovery is simpler for the dc motor which constitutes the best alternative when working at low voltages.

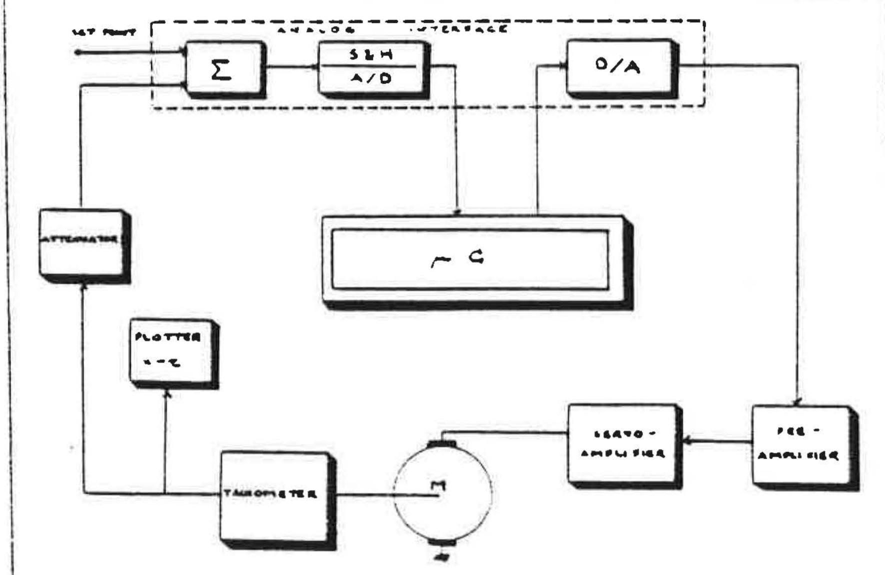

Fig. 1 Functional block diagram of the microcomputer speed control system

Digital system

This paper discusses a digital system which uses a Rockwell Aim-65 microcomputer to control the speed of a dc servomotor. For this application, the Rockwell Aim-65 microcomputer is used to implement the sampled-data feedback control, and the microcomputer speed control system is shown in Fig. 1. The actual speed is obtained by means of a tachogenerator. Its output is compared to the reference input and the error is then compensated by the microprocessor whose output provides the corrected control signal to the preamplifier. The servo-amplifier is driven by the preamplifier and provides the output signal to the motor.

DC motor model

An important element in the analysis and design of a speed control system is the choice of model for the

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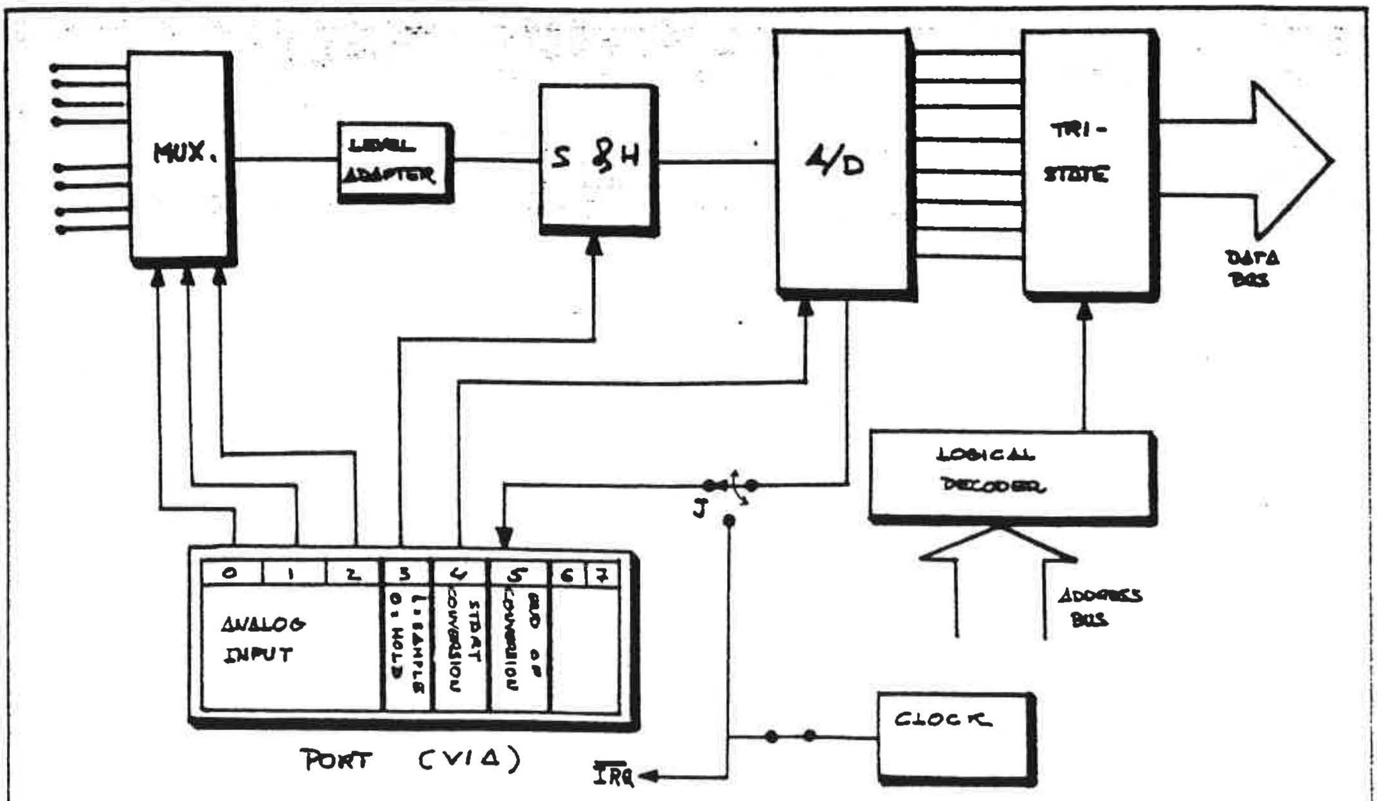

Fig. 2 Functional scheme of the analog interface used in the experiment

power actuator. Correct motor identification is the result of measuring the mechanical time constant as well as the static gain.

Mechanical time constant

A step input voltage is applied to the motor armature and the exponential rise of the motor speed is measured on an oscilloscope. Thus, by generating a low frequency pulse train in the D/A converter output, the corresponding tachometer output can be obtained being the time constant τ_M the time required for the tachometer voltage to rise to 63.2% of its final value.

Static gain

The motor static gain K_0 can be obtained by generating a signal in the D/A converter output and reading the corresponding tachometer output by means of the A/D converter.

Motor transfer function

Motor transfer function can be written:

$$\frac{\omega_0(s)}{V(s)} = \frac{K_0}{1 + \tau_e s}$$

where $K_0 \simeq 205$ rad.sec^{-1}/volt. and $\tau_e \simeq 0.25$ secs for the motor used in the experiment.

A/D Conversion Assembler Programme

Figure 2 shows the functional scheme of the analog interface for the Rockwell Aim-65 microcomputer system which has been developed in the Department of Systems Control (ETSIT, Barcelona). The design is easily adaptable to any other computer. It uses eight multiplexed inputs and one output, and has been designed to control low-power devices.

The microcomputer controls the analog input through the so-called VIA (a set of programmable input/output ports) by using an Aim-65 system. By means of the usuary subroutine the main programme in Basic makes the following sequence of assembler instructions for the A/D conversion:

```
        LDA  ≠DF
                   ; DEFINE VIA'S OPERATION MODE
        STA  A003
        LDA  ≠3F
                   ; SELECT ANALOG INPUT
        STA  A001
        LDA  ≠37
                   ; SAMPLE
        STA  A001
        NOP
        NOP
        LDA  ≠27
                   ; HOLD
        STA  A00
LEV1 :  LDA  A001
        SEC
        SBC  ≠07   ; END OF CONVERSION?
        BNE  LEV 1
        JMP  C0D 1   RETURN TO BASIC
```

Corrector Digital Implementation

By using the bilinear transformation a lag-lead controller has been programmed in the microcomputer, its transfer function being:

$$G_c(s) = K \frac{s + C}{s + p}$$

The corresponding Basic programme is given below:

```
5   DIM X <4>
7   DIM Y <4>
10  INPUT "TRNS. Z=1" ; FR
15  IF FR=1 GO TO 3ØØ
18  INPUT "SAMPLING PERIOD" ; T
20  INPUT "DELAY" ; Z
22  INPUT "C" =   ; C
24  INPUT "P" =   ; P
26  INPUT "K" = ; K
28  INPUT "DER=1, BILIN.=Ø" ; FT
3Ø  IF FT=1 GO TO 38
32  Q1 = <K*C*T-2*K>/<2+P*T>
34  Q2 = <2*K+K*C*T>/<2+P*T>
36  Q3 = <P*T-2>/<P*T+2>
38  FOR I = Ø TO 4
4Ø  X <I> = Ø
42  Y <I> = Ø
44  NEXT I
48  POKE 4Ø962, 255
5Ø  X <Ø> = X <1>
52  X <1> = X <2>
53  X <2> = X <3>
54  X <3> = X <4>
55  Y <Ø> = Y <1>
56  Y <1> = Y <2>
57  Y <2> = Y <3>
58  Y <3> = Y <4>
6Ø  POKE Ø4, ØØ
65  POKE Ø5, 12
7Ø  W = USR <R>
75  U = PEEK <4Ø959>
85  X <4> = <U-127> * Ø8
88  IF FR = 1 GO TO 35Ø
89  IF FT = 1 GO TO 25Ø
91  Y <4> = X <3> * Q1 + X <4>
    * Q2 - Y <3> * Q3
1ØØ FOR L=Ø TO Z
1Ø2 G = 3 * 5
1Ø4 NEXT L
11Ø O = <Y <4> * 13.5> + 127
12Ø POKE 4Ø96Ø , 0
15Ø GO TO 5Ø
25Ø Y <4> = Y <3> + K*X<4>-K*X<3>+K*C*T*X<4>
252 Y <4> = Y <4> / <1 + P*T>
255 GO TO 1ØØ
3ØØ INPUT NUM. COEFFICIENTS IN DECREASING ORDER : AØ, A1,
    A2, A3, A4.
31Ø INPUT DEN. COEFFICIENTS :BØ, B1, B2, B3, B4
32Ø GO TO 38
35Ø Y <4> = X<4>*A<Ø>+X<3>*A1+X<2>*A2
351 Y <4> = Y<4>*X<1>*A3+X<4>*A4
36Ø Y <4> = Y<4>-Y<3>*B1-Y<2>*B2-Y<1>*B3-Y<Ø>*B4.
37Ø Y <4> = Y<4> / 8Ø
38Ø GO TO 1ØØ
4ØØ END
```

Different tasks in this programme are explained as follows:

10–28 300–310	Input parameters
60–85	Sample error signal
32–58 91	Compute y(t)
110–120	Output to D/A converter
250–252	Correct the computation of y(t) by means of the bilinear transformation
310–380	Find y(t) by means of the z-transform
100–104	Delay introduced by the usuary to experiment the influence of the sampling period.

Options: – Direct computation (22, 24, 26).
- Computation by means of z-transform (1Ø, 3ØØ, 31Ø)
– Modify sampling time (2Ø).

Motor responses to a 5 volts-step in the set-point have been obtained for different values of p (figure 3) and K (figure 4).

Being the corrector gain a constant, the overshoot and damping frequency of the output will decrease if the corrector pole becomes more negative, as it can be seen in figure 3. On the contrary, a great increase of K makes the damping frequency component bigger when p and c are fixed (fig. 4).

Stability Analysis

Figure 5 shows the system block diagram where the microcomputer computation lag has been modelled by means of a delay block of T seconds.

Choosing c=4 its transfer function can be obtained, from the system block diagram as follows:

$$H(s) = \frac{e^{-Ts}\left(\frac{1-e^{-Ts}}{s}\right) K \frac{s+c}{s+p}\,\frac{Km}{\tau ms+1}}{1 + K_A K + e^{-Ts}\left(\frac{1-e^{-Ts}}{s}\right) K \frac{s+c}{s+p}\,\frac{Km}{\tau ms+1}}$$

$$= \frac{e^{-Ts}\,(1-e^{-Ts})\,K.820}{s^2 + sp + e^{-Ts}\,(1-e^{-Ts})\,K.15.38}$$

And its pulse transfer function:

$$H(z) = \frac{820K\,(z^2 + 2z + 1)}{(100 + 10p)z^3 + (10p - 100 + 15.38K)z^2 + 30.76Kz + 15.38K}$$

For particular values of K, p and c, the stability of such a system can be determined from the location of the roots of the characteristic equation

$$(100+10p)z^3 + (10p-100+15.38K)z^2 + 30.76Kz + 15.38z = 0$$

If the system is stable all the roots z_i of this equation will lie inside the unit circle, or $|z_i| < 1$.

Chopper-fed DC Motor

Figure 6 shows the functional block diagram of a dc motor which is fed by a chopper. Differences between this scheme and that in figure 1 can easily be established. Thus, preamplifier and servoamplifier are replaced here by pulse generator and chopper. From the point of view of stability it means that a new block diagram must be analysed. In which case, the chopper transfer function is determined by its duty cycle:

$$\frac{V(s)}{\theta(s)} = \frac{E}{2\pi}$$

where E represents the battery voltage.

Moreover, an important class of pulse generators can be modelled as a zero-order-hold circuit | 1 | whose transfer function can be written as follows:

$$G(s) = G_0\left(\frac{1-e^{-Ts}}{s}\right)$$

where T is the microprocessor sampling time.

By introducing both chopper and pulse generator transfer functions (fig. 5), the system characteristic equation can be obtained, in order to verify the stability of the system.

Conclusion

The application of a personal computer on a dc motor control has been described. The study shows that the control can be used satisfactorily in servomotor applications and as a speed control. As for its utilization in electric vehicles, the same concept applies. In this case, the power is supplied to the motor through a chopper (SCR or transistor), this being the pulse generator or interface between the microcomputer and the power stage. Stability analysis is also given when the pulse generator is modelled as a zero-order hold.

Real time control constitutes the most stringent demand on microprocessor based equipment. Computation lags, conversion times and operational accuracy acquire a relevant design significance. Hence, response speed problems will arise if the programme execution time is large. Therefore, maximum controlled motor speed will be determined by microprocessor minimum sampling time. This period is calculated by considering the A/D conversion time the control algorithm computation time and the D/A conversion time.

Finally, programming in Basic reveals that internal operations can be made with great accuracy at the expense of reducing processing speed. On the other hand, the use of assembler language improves the speed of response, while operations are made with large errors. Therefore, this trade-off between speed response and algorithm operations accuracy constitutes the first problem to be solved when designing a digital controller.

References

1 Linn, A. K. and Koespel, W. W., "A microprocessor speed control system". IEEE Trans. Ind. Electron. Contr. Instrum. Vol. IECI-24, No. 3, August 1977.

2 Cendagorta-Galarta, M. and Prats, J., "Vehiculo eléctrico con alimentación solar". Proyecto Fin de Carrera, ETSIT de Barcelona, 1980.

3 Modular Servo System MS150 Book 3 DC. Synchro S. AC, Advanced Experiments". Feedback Instruments Limited.

4 Cadzow, J. A. and Martens, H.R., "Discrete-time and Computer Control Systems". Prentice-Hall, INC. Englewood Cliffs, New Jersey.

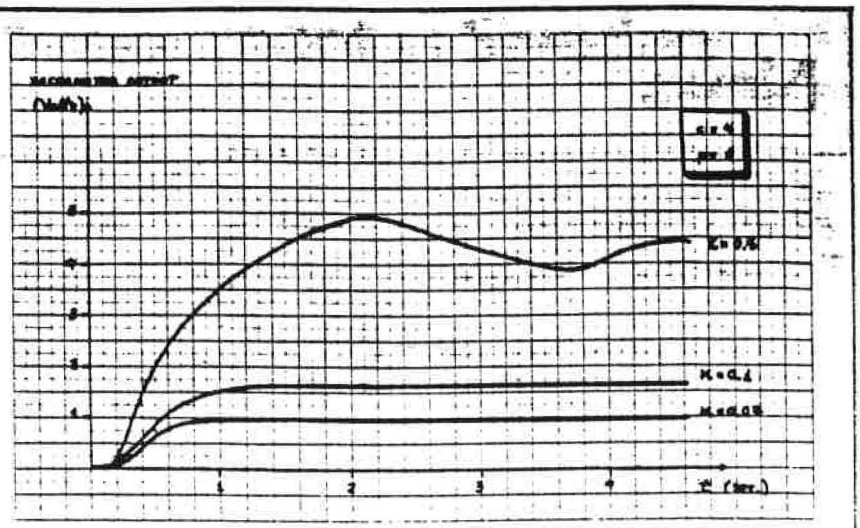

Fig. 4 Speed responses to 5 volts-step (K = 0.07, 0.1, 0.5)

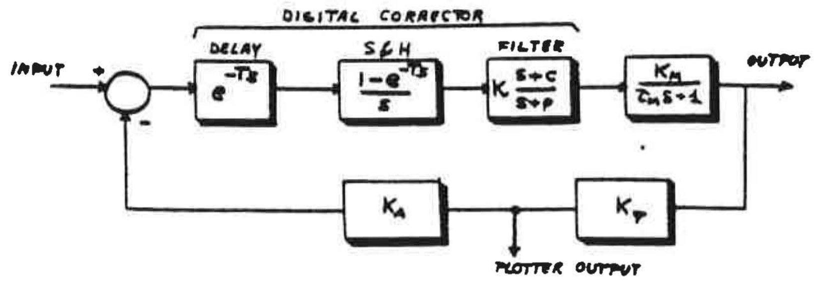

Fig. 5 System block diagram

where $\tau m \simeq 0.25$ secs
$Km \simeq 205$
$K_T = 25.10^{-3}$
$K_A = 0.75$
$T = 0.2$ secs.

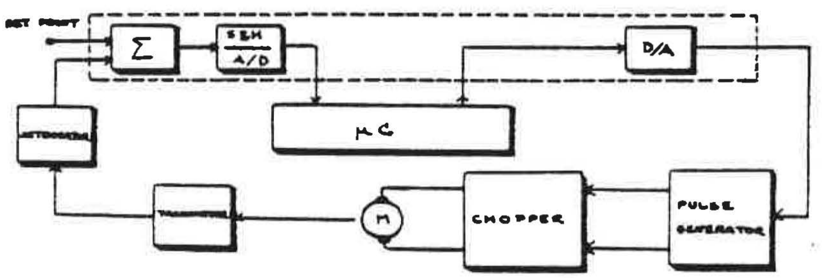

Fig. 6 Speed control system of a chopper fed dc motor

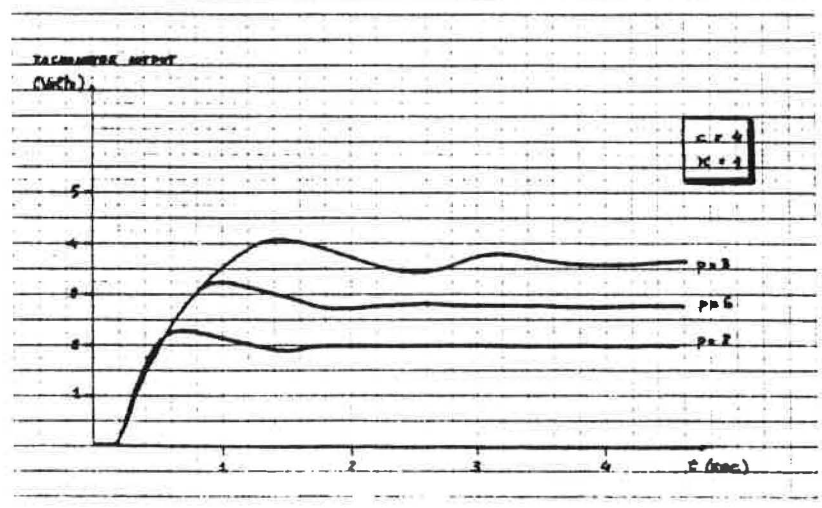

Fig. 3 Speed responses to 5 volts-step (p = 3, 5, 8)

EVC-Expo '83

Washington, DC (19 July 1983) – The Electric Vehicle Council announced today that 13 organisations are so far committed to exhibit products and services during the Council's Expo '83 Conference and Showcase. The international event will be held at the Hyatt Regency Hotel in Dearborn, Michigan from October 4 to 6, 1983.

Exhibitors:

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Ford Motor Company
Detroit Edison Company
Eaton Corporation
Long Island Lighting Company
Grumman Allied Industries, Inc
Alber Engineering, Inc
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