IMPLEMENTATION OF SLIDING MODE CONTROL FOR A CHOPPER FED SEPARATELY EXCITED DC MOTOR USING A PERSONAL COMPUTER

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ABSTRACT
A personal computer based sliding mode control for a chopper fed separately excited DC motor is presented. The switching vector is designed using projector theory and a boundary layer control is implemented to minimize chattering. The data acquisition system developed around the IBM compatible personal computer feeds relevant data into the microprocessor and after execution of the control algorithm, the processor controls the duty-ratio of the chopper through a direct digital control scheme. A user friendly software is developed, in which the programs for various standard routines are written in assembly language and its binary files obtained after assembling and linking are called from Turbo Pascal Program. The predicted and experimental characteristic curves are observed on the monitor and are transferred to the plotter for further reference. The experimental setup has been fabricated and tested in the laboratory environment and the results are compared with those obtained with the state feedback control. The results are found to be satisfactory and a close agreement is observed between the predicted and the measured responses.

INTRODUCTION
DC motors are widely used in industries both in the open-loop as well as closed-loop configurations. Many of these applications require high performance controllers, and variable structure controller is a topic of recent interest [1,2,3,4]. Variable structure controllers possess several attractive advantages like good transient performance, insensitivity to parameter variations as well as to external disturbances, compared with conventional controllers.

The application of microprocessors has totally replaced the analog control circuits for implementing the complex control algorithms. Recently, the use of personal computer (PC) has opened up a new area in computerised control for electric drives and power system networks [5]. In the present paper, the design of a sliding mode controller for a chopper fed separately excited DC motor and its implementation using a personal computer is presented. A detailed simulation study has been carried out for predicting the performance of the machine. A data acquisition system is developed around the PC for sensing speed as well as armature current and also for outputting signal for varying the duty-ratio of the chopper. The software is written partly in Turbo Pascal and the rest in assembly language for an effective user interaction. Experimental investigations are carried out to test the behaviour of the machine for a step change in speed as well as in torque and also for sensitivity to parameter variations. A state feedback controller has been designed by placing the (n-m) poles of the system exactly at the same location as that of the sliding mode controller. The experimental results thus obtained are compared with the simulation results as well as those obtained with state feedback control.

SYSTEM MODELLING AND SYNTHESIS OF CONTROLLER

The model of the plant with the controller is as shown in Fig. 1. The DC motor is modelled in the state space form as a linear time invariant system as:

\[
\begin{align*}
X_1 &= \begin{bmatrix} -R/L & -R/L \end{bmatrix} X_1 + \begin{bmatrix} 1/L \end{bmatrix} u + \begin{bmatrix} 0 \end{bmatrix} \frac{1}{1/T} \begin{bmatrix} 1 \end{bmatrix} \cdot \cdot \cdot (1)
\end{align*}
\]
where,

\( X_1, X_2 \) are the deviations in current and speed from their steady state values,

\( R \) is the armature resistance,

\( L \) is the armature inductance,

\( K \) is the back e.m.f. coefficient,

\( J \) is the moment of inertia,

\( \frac{B}{J} \) is the viscous friction coefficient,

\( u \) is the controllable input, and

\( T_l \) is the disturbance input.

The control plays the role of forcing the state to reach the sliding mode. The control function has the following form:

\[
U = \begin{cases} 
\frac{\partial f}{\partial x} - \lambda \text{sgn}(x) & \text{if } S(x) > 0 \\
\text{sgn}(x) & \text{if } S(x) < 0 
\end{cases}
\]

The limiting values of \( \epsilon, \text{ and } \lambda \) are defined as:

\[
\epsilon_\infty > \frac{1}{b}(-a, +c, a, -c, c, c, \ldots) \quad \text{and} \quad \epsilon_\infty < \frac{1}{b}(-a, +c, a, -c, c, \ldots) \quad \ldots (7)
\]

It has been observed that this discontinuous control action results in chattering in the vicinity of the steady state operating point due to nonideal switching. To avoid this undesirable phenomenon, the discontinuous feedback control is approximated by a linear high gain control \([7]\).

In the vicinity of \( S(x) = 0 \) ie \( S(x) < \delta \) where, \( \delta > 0 \) is a small scalar is approximated as:

\[
\delta \approx = h*S_t(x) \quad \ldots (8)
\]

where \( h \) is a large scalar gain.

In the present paper, the design of \( S \) has been carried out using projector theory suggested by El-Ghezawi et al\([8]\). The eigenvector matrix \( W \) as suggested in \([8]\) is obtained by solving

\[
AW - WJ = BL \quad \ldots (9)
\]

where \( J \) is an \( (n-m)x(n-m) \) matrix specifying the eigenvalues of the system.

\( L \) is an arbitrary \( mx(n-m) \) matrix to provide a linear combination of columns of \( B \).

\( A \) & \( B \) are system matrices.

The generalised inverse of \( B \) denoted by \( B^* \) is obtained by taking the first \( m \) rows of the inverse of the matrix \([B^*W]\). The product \( PB^* \), \( P \) being an arbitrary \( mn \times mn \) non-singular matrix, gives the hyperplane matrix \( S \).

**SYSTEM ARCHITECTURE**

The block diagram of the experimental setup is shown in Fig.2. The DC motor is fed from a chopper as shown in Fig 3. The chopper is designed to operate at 200 Hz frequency and the input voltage to the motor is controlled by varying the duty ratio of the chopper. The hardware part of the control system comprises of the Intel 8088 microprocessor and associated circuitry, along with the data acquisition module's. This module consists of a 14 bit A/D converter (ADC) cara, an input-output (i/o) card consisting of 8253 programmable counter/timer chip and 8255 programmable peripheral interface chips. The first, second and third counters of the 8253 chip operate in modes II, I and IV respectively. All the three counters run at a clock frequency of 1.19 m*s\(^{-1}\). Since the gate of the first counter is held high, the
output goes low after a preset time of every 5 mSec for one period of clock pulse. The output of counter I is connected to the gate of counter II, which is in the programmable one shot mode. As soon as the gate goes high, the counter II value reaches zero. The output of counter II and its inverted signal are connected to the auxiliary and main SCRs respectively, after proper amplification and isolation. Thus the chopper would be turned ON for a period depending upon the value loaded in counter II. The output of counter II is connected to one of the 8255 ports in order to check the status of the signal. The schematic diagram depicting this arrangement is shown in Fig. 5. This scheme relieves the CPU from generating trigger pulses and the PC can thus be spared while the machine is running. Also, this direct digital control scheme avoids the

Fig. 2. Experimental set-up.

Fig. 3. Chopper-motor drive system.

calculation of speed, current sensing, initialisation of counters and ports etc., are written in assembly language of 8088. These programs are next assembled, linked and the binary files are created using the EXE2BIN program. Turbo Pascal program calls these programs

Fig. 4. Flow chart of the main program.
APPLICATION TO DC MOTOR DRIVE

The parameters of the DC motor under test are given in Table-I. The coefficient matrices as expressed in equation (1) are computed as

\[
A = \begin{bmatrix} -14.21 & -27.19 \\ 3.97 & -0.042 \end{bmatrix}, \quad B = \begin{bmatrix} 7.54 \\ 0 \end{bmatrix} \quad \text{[10]}
\]

The controllability of the system is verified. In order to design the switching matrix \( C \), a transformation matrix \( M \) is chosen as:

\[
M = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}
\]

The eigenvalue of the system is placed at \(-2.0\), and the value of \( L \) as expressed in equation (9) is taken as 1.0. By solving equation (9) the eigenvector matrix is obtained as:

\[
W = \begin{bmatrix} -0.643 \\ -0.0045 \end{bmatrix}
\]

The value of \( P \) is 10 and \( C \), the hyperplane matrix is obtained as \([0.05696 \quad -8.391] \). Different values of \( \omega \) and \( \psi \) have been tried and the values 3.5 and -2.7 respectively are found to yield satisfactory results. In the vicinity of the sliding plane, the control is changed as referred in equation (8) with \( h=100 \), inorder to minimize chattering. An extensive digital simulation study has been conducted in the laboratory, considering the ON and OFF periods of the chopper separately. The e.m.f. and torque equations of the DC motor for both duty cycles as well as freewheeling intervals are given in Appendix-I. These equations are solved for their instantaneous values of speed and current using Runge-Kutta fourth order numerical integration method. The results obtained through simulation as well as experiments are stored in files. These files are called through Lotus 123 PILE IMPORT command and the graphs are plotted using GRAPHTEC MP2000 plotter.

TABLE-I

DC motor specification: 5 HP, 230V, 19.3 A, 1000/1500 rpm.

Parameters:
- Armature resistance \( R = 0.81 \) ohms,
- Armature inductance \( L = 57 \) mH,
- Moment of inertia \( J = 0.39 \) kg-m,
- Viscous friction coefficient \( = 0.0164 \) Nm./rad/Sec,
- Back e.m.f. coefficient \( K = 1.55 \) V/rad/sec.

SYSTEM RESPONSE

The controller presented in the preceding section is implemented and tested for both static and dynamic conditions, such as for step changes in load torque and reference speed. Fig.6 depicts the response of the system for a step change in speed by 20 rad/sec. when the motor is loaded at 30% full load at 80 rad/sec. The system stabilizes within 1.0 Sec. and the chattering is found to be minimum. A load of 40% of full load is suddenly applied on the machine while running at 105 rad./sec. on no load. The speed - time response is shown in Fig. 7. Further the sensitivity of the system to parameter changes is examined by a sudden change in the value of inductance in series with the

![Fig.6. Response of the system for a step change in speed.](image-url)
armature from its initial value of 57 mH to 80 mH. The speed-time oscillogram as shown in Fig.8 reveals that the response is better compared with the state feedback control. A fairly good agreement between the simulated and experimental results demonstrates the successful implementation of VSCS as discussed in the preceding section.

![Fig.7](image_url)  
**Fig.7.** Response of the for a sudden change in load.

![Fig.8](image_url)  
**Fig.8.** System response for a sudden change in inductance value.

CONCLUSION

The VSS controller presented in this paper yeilds a better dynamic performance as compared to the state feedback controller. The sensitivity property of the VSS controller is observed to be the principal attraction. The application of personal computer as a programmable controller for drives is found to be promising, yielding the following advantages:

1. A data acquisition system can be developed around a PC.
2. Assembly language programs can be executed easily, avoiding the difficulties involved in getting the machine code, storing in a ROM and subsequently getting executed through a kit.
3. Higher level language, assembly language or a combination of both can be used as a software tool.
4. Mathematical simulation, design of control functions, on-line control and performance analysis can be done one after the other.
5. The performance curves can be observed on the monitor while working, and can be transfered to the plotter/printer for further reference.
6. The capabilities of standard packages like LOTUS 123, WORDSTAR etc. can be exploited for performance evaluation.

The added advantages of excellent price/performance ratio, minimum service and maintenance and smaller physical dimension support the above mentioned arguments.

REFERENCES:

APPENDIX-I

Differential equations governing the behaviour of the motor for the ON period and OFF period of the chopper are as follows:

**ON period**

\[ \frac{di}{dt} = \frac{Ri + Kw V}{L} \]

**OFF period**

\[ \frac{dv}{dt} = \frac{Kv + Tw}{J} \]

\[ \frac{dw}{dt} = \frac{v}{J} \]
OFF period

\[
\frac{di}{dt} = - \frac{R_i}{L} \frac{K}{L} \frac{dw}{dt}
\]

During OFF period, for discontinuous operation \((i=0)\) the equations (A2) will become

\[
\frac{dw}{dt} = \frac{K}{J} \frac{i_{aw}}{J} + \frac{T_1}{J} \quad \ldots \quad (A3)
\]