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DIGITAL SIMULATION FOR SWITCHED-MODE CONTROL OF DC MOTOR

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ABSTRACT:

A digital simulation routine for a switched-mode control type of a DC drive is given. This type of digital control is applied to the high power side of the motor represented by the armature. However, the technique can be effectively applied to the field circuit as well.

A modulated square wave voltage is used as an input. The instantaneous speed is controlled by creating a dead-band zone around its desired value while this speed is not allowed to get out of this zone. Consequently, the stability of the closed-loop system is ensured.

1. INTRODUCTION:

In many industrial purposes DC motors are widely used. Much attention has been focussed upon the designing of control schemes for these motors(1,2,3,4). The need for accurate and fast control schemes makes the use of switched-mode devices in such processes is much desirable. Techniques using this type of control havebeen suggested by number of authers(2,3,4). Most of these techniques describe conventional analogue methods. Some digital control schemes have been also presented(5,6). It has been shown that the digital approach eliminates measurments nonlinearity and ensure exact setting for the controlled output(7). Further investigations have been carried out to study the dynamic performance of the switched-mode controlled motor using digital simulation routines(6).

This paper describes a digital routine for this type of control. However, the technique as presented differs from those cited before in that it is based on the dead-band philosophy which ensures the stability of the closed-loop system. The algorithm as presented can be viewed as a digital version of the analogue set up for the micro turbine controller(3). The proposed technique although possesses the gains of the previous digital techniques,it is much simple to apply and does not require extensive logic statements.

2. DEAD-BAND CONTROL:

Dead-band control may be applied on a circuit where any sudden change in its input will result in an exponential change in its output. Field and armature circuits of a seperately excited DC motors exhibit this type of characteristics.

The dead-band control technique may be explained with reference to figure(1). The motor speed has to be controlled about a desired value ω_D. This can be achieved by creating a dead-band zone around the speed response. The instantaneous value of this response is then compared with the value ω_D. When the speed exceeds the upper band, the armature voltage is set equal to zero allowing the speed to fall exponentially. Conversely when this speed falls below the lower band,the voltage is applied on the circuit allowing the speed to rise exponentially again. By this way the speed is not allowed to get out of the dead-band zone marked by $\omega_D+\Delta\omega$ and $\omega_D-\Delta\omega$. $\Delta\omega$ represents a small deviation from the desired speed. The expected response is shown in figure(1).

It is worth noting that the width of the dead-band determines the switching frequency ,which is defined as twice the time taken to change the state of the circuit from zero voltage to the none-zero one. Conversely,if the switching frequency is defined $\Delta\omega$ can be determined.

3. MATHEMATICAL FORMULATION OF THE PROBLEM:

The performance of the separately excited DC motor under voltage control of both armature and field windings can be explained by the following equations

$$V_a = E_b + R_a\, i_a + L_a\, p\, i_a \qquad (1)$$

$$V_f = R_f\, i_f + L_f\, p\, i_f \qquad (2)$$

$$T = Jp\omega + T_1 \qquad (3)$$

$$E_b = K_a \omega \qquad (4)$$

$$T = K_t\, i_f\, i_a \qquad (5)$$

where, $K_a = M_f\, i_f$, and

$p = d/dt$

Equation(2) may be rewritten as;

$$i_f = \frac{V_f / R_f}{1 + p\tau_f} \qquad (6)$$

where , τ_f is the field time constant $= L_f / R_f$

Equation(6) shows that the field current under transient conditions changes exponentially with time constant τ_f . The field current may be maintained around a desired value 'i_{fd}' using the dead-band method as will be explained.

The equation describing the DC motor with constant field current have the form;

$$V_a = K_a\omega + i_a(R_a + p\, L_a) \qquad (7)$$

$$i_a = (T_1 + J\, p\omega) / K_T \qquad (8)$$

where, $K_T = K_t\, i_f$

Substitution of equation(8) into equation(7) gives

$$\omega = \frac{V_a / K_a - \tau_m (1 + \tau_a p) T_1 / J}{1 + \tau_m p (1 + \tau_a p)} \qquad (9)$$

where, $\tau_a = \frac{L_a}{R_a}$ and is defined as the armature time constant, and

$\tau_m = J R_a / K_T K_a$ is the mechanical time constant.

The armature time constant τ_a is usually much smaller than the mechanical time constant. In addition, the transient analysis of a control system is usually made for the condition when the applied torque is zero or constant. In either case $T_1 = 0$ (8)

Hence equation(9) may be approximated to

$$\omega \simeq \frac{V_a}{K_a(1+\tau_a\, p)(1+\tau_m\, p)} \qquad (10)$$

Equation(10) reveals that a DC motor with armature voltage control is a combination of an electrical stage with time constant τ_a and a mechanical stage with time constant τ_m. The time constant of the armature circuit may be neglected entirely reducing equation(10) to the following simple exponential form;

$$\omega \simeq \frac{V_a/\,K_a}{1+\tau_m\, p} \qquad (11)$$

Integration of equation(11) gives the instantaneous value of the speed ω. This speed when compared with a desired speed, ω_D which is calculated from the steady state operation, gives a means of controlling the motor speed. This may be arranged as follows;

$\omega > \omega_D + \Delta\omega$ $\quad V_a$ = zero
$\omega < \omega_D - \Delta\omega$ $\quad$ Va = none-zero

Consequently, the speed is not allowed to exceed above or fall below a desired speed by more than a certain amount $\Delta\omega$. Therefore, the closed-loop system stability is ensured.

4. SOLUTION-PROCEDURE CONSTRUCTION:

The procedure of performing the dead-band digital control technique is carried out as follows:

i- Perform a single integration step on the differential equation(6).

ii- Compute the instantaneous value of the speed.

iii-Compare this value with the desired value, accordingly select a state for the armature voltage necessary to perform the integration (i.e. $V_a = 0$ or $V_a \neq 0$).

iv- Plot or print out the result.

An algorithm using Trapezoidal rule or Runge-Kutta fixed step is recommended for the integration technique. Techniques with variable step is not suitable for this work. The length of the integration step 'Δt'should be related to the switching frequency 'f'and this may take the form of;

$$\Delta t = 1/\, n.f$$

where,n is an integer number depend on the accuracy required for the controlled variable. By this way any distortion resulted from the integration routine is avoided.

A flow chart indicating the computational procedures of the Fortran program is shown in figure(2).

5. NUMERICAL EXAMPLE:

A certain 55kw drive system whose parameter are taken as$^{(5)}$:

V_a = 400 v, i_a = 137.5 A , = 157.1 rad/s , R_a =0.09716 ohm , L_a =0.0055675 H, J =1.7522 kg.m^2 ,K_a =2.4611 v.s/rad ,and K_T =2.547 N.m/ A

With the assumption that the field current is held constant and only control of the armature circuit is made. The switching frequency is taken as 800 Hz.This value is suitable for practical implementation in order to limit the over-heating of the machine caused by the pulse modulated voltage. The response of the system before and after a step change of 5% on the mechanical torque is shown in figure(3).

6. CONCLUSION:

A digital computer program simulating the controlled DC motor that is driven by switched-mode devices is described. Such a program enables a very accurate investigation of the dynamic performance of this type of motors. The program also facilitates designing the digitally controlled drives. The physical phenomena associated with motors under various operating enviroments can be closely observed. The proposed technique ensures the stability of the closed-loop system.

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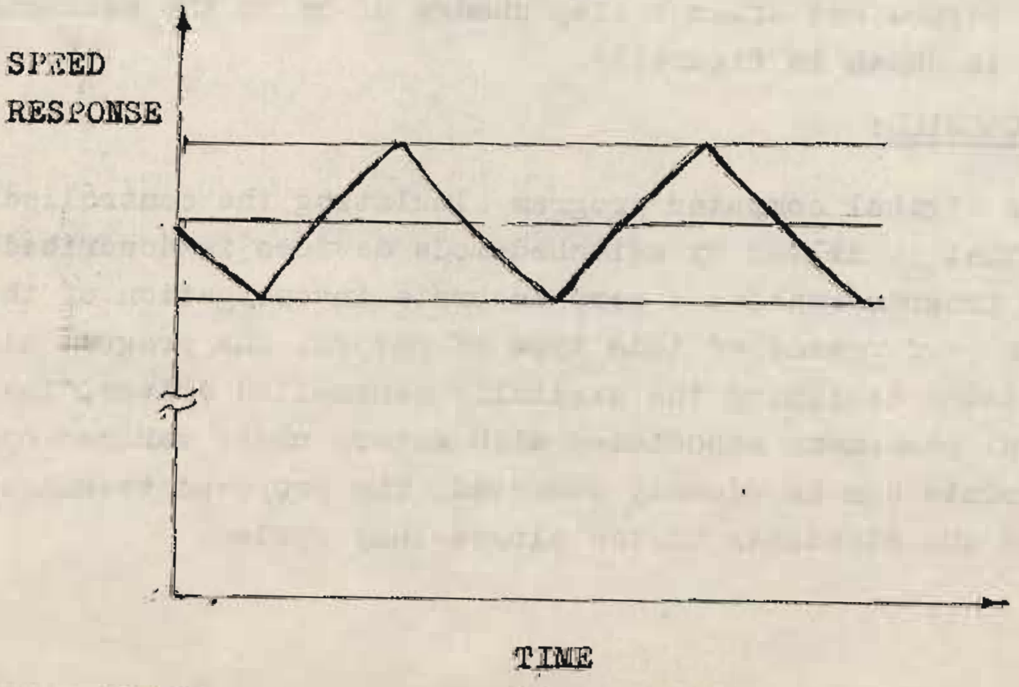

FIGURE 1 THEORETICAL SPEED RESPONSE SHAPE

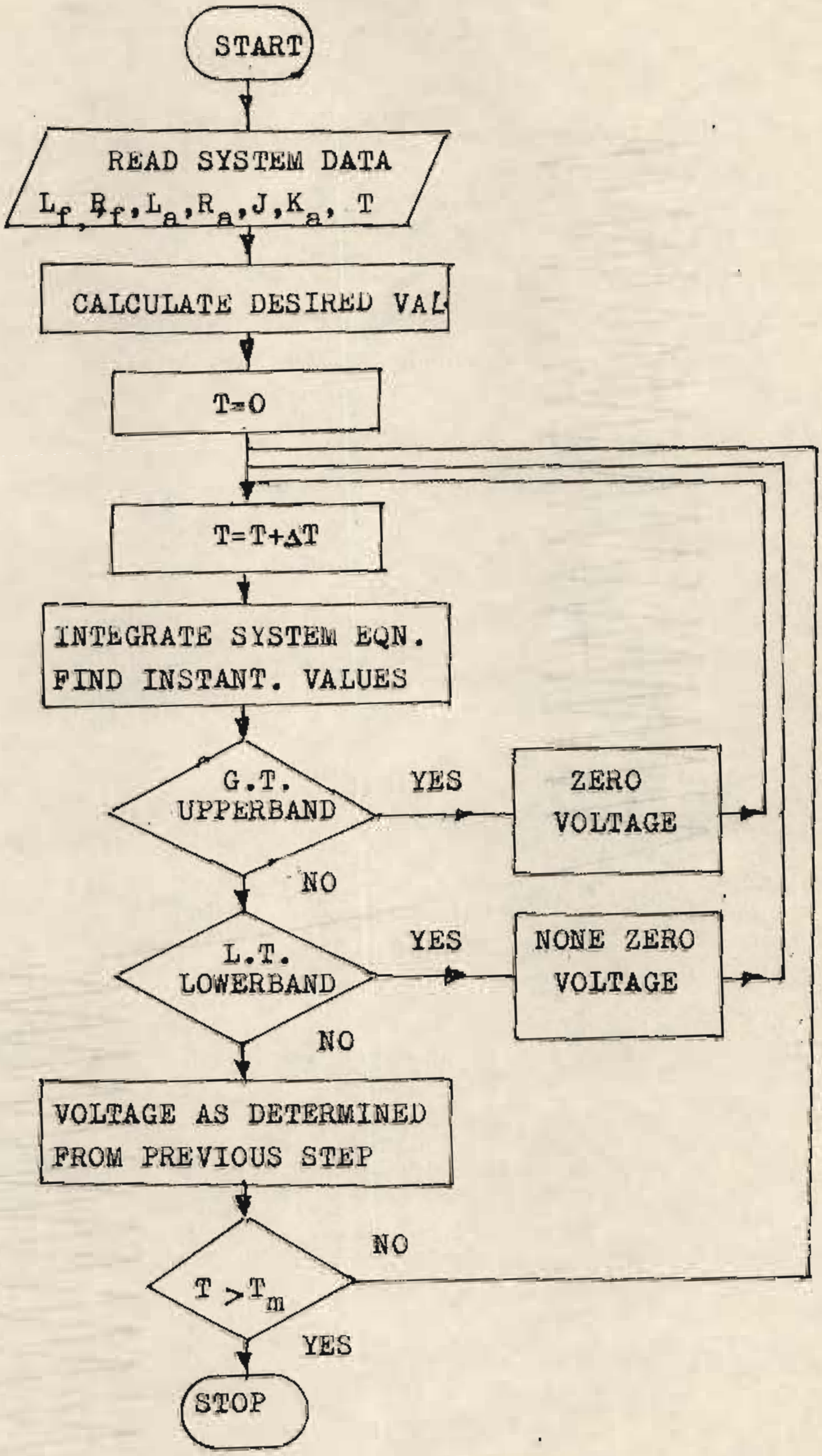

FIGURE.2 DIGITAL COMPUTER FLOW CHART FOR CONTROLLED DC MOTOR

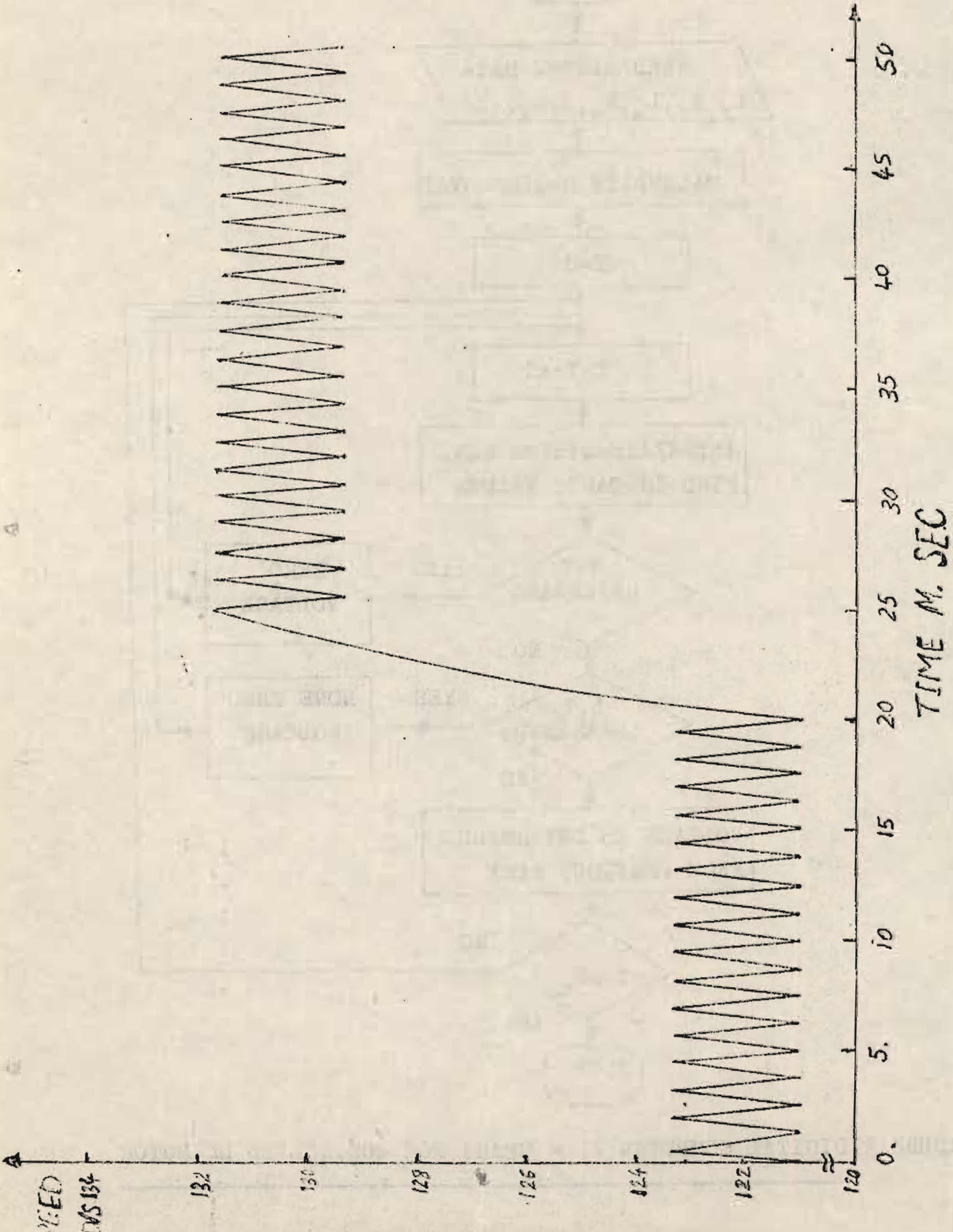

FIGURE (3): TIME RESPONSE OF THE SPEED.