Microprocessor Based Speed Control of a Separately Excited Direct Current Motor

By :

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ÖZET

Bu tez çalışmasında bir doğru akım motor sisteminin mikroişlemciye dayanan hız denetimi tasarımlanmış ve gerçekleştirilmiştir.Motor üç evreli tam-denetimli bir köprü tarafından beslenmektedir.Köprü ateşleme açısı doğrudan bir mikroişlemci vasıtasıyle sağlanmaktadır.Kullanılan yaklaşım tamamiyle sayısaldır ve sistem Z-80 mikroişlemci üzerine kurulmuştur.

Mikrobilgisayar_ile gerçekleştirilen sayısal oransal-tümlevsel algoritma,mevcut yanılgıdan köprüyü sürmek için gerekli olan sayısal denetim gerilimini sağlar.Köprünün ıralığını doğrusallaştırmak için bir arcCosine tablosu kullanılmaktadır.

Sistemin kararlığı ve dinamik davranışı Z-domeninde incelenmiştir,ve elde edilen deneysel sonuçlar verilmiştir.

ABSTRACT

In this thesis a microprocessor based speed control system for a dc motor drive is designed and implemented. The motor is fed by a three-phase fully-controlled bridge the delay angle of which is set directly by the microcomputer.The approach used is entirely digital and the system is centered around a Z-80 microprocessor.

A digital PI (Proportional-Integral) algorithm implemented in the microcomputer acts on the error to result in the digital control voltage to drive the bridge.An inverse cosine look-up table is used to linearize the bridge characteristics.

The stability and dynamic behaviour of the system is analysed in Z-domain and the experimental investigations are given.

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INTRODUCTION

Direct current (dc) drives are extensively used in industry all over the world.The outstanding advantages of dc drives such as ease of control,precise and continous control of speed over a wide range will ensure their popularity for years to come.

The techniques of SCR control of dc drives have been developed rapidly since the first introduction of the SCR in 1957.Based on the available supply three basic methods i.e. Phase control,Integral cycle control and Chopper control are used.Phase control is the most widely used one,because in this method the output voltage can be varied smoothly over a wide range.However,the resulting power factor is low.The Integral control is not suitable for motor control applications due to the pulsations in the developed torque.If the available supply is a dc source,then dc choppers are used.They are designed to operate at as high frequency as possible to reduce the ripple in the output.This necessiates the use of high frequency SCR's. S ince the power switching elements have to be force commutated,the control circuitry is more complex as compared to phase control circuitry.The se factors make dc choppers significantly more expensive.Neverthless they are widely used.

The result of the tremendous progress in semiconductor and LSI technology has made digital electronic devices much more smaller,cheaper,faster and accurate and hence digital control systems more popularin the recent years.In many industrial control applications microprocessor based systems are now replacing the conventional analog and hard-wired digital control systems as they offer flexibility,reliability and better accuracy and resolution.

The research reported in this thesis follows this recent trend.The functions of the conventional circuits for the firing of a three phase fully-controlled bridge and the desired controller algorithm manipulation for the closed loop speed control of a dc motor are all realized by a microprocessor based system.

In chapter One a survey of speed control techniques of dc motors is given and a separately excited dc motor is modelized for analysis purposes.

In chapter two solid state dc drives with concentration on three phase semi and full converters are described.

In chapter three the design of a microprocessor based three-phase full-converter used for speed control of a dc motor is described and the design of various units as well as the pertinent software is given.

In chapter four the stability of the closed loop system is analysed in Z-domain and the experimental investigations are given.

CHAPTER ONE

DIRECT CURRENT MOTOR CONTROL

Direct current motors have been used in variable speed drives for a long time.The versatile control characteristics of dc motors have contributed to their extensive use in industry.DC motors can provide high starting torque and their speed variation range is large both above and below the rated speed.The methods of speed control of dc motors are simpler and cheaper than those of ac motors.Although commutators prohibit their use in some industrial applications,dc motors play a significant role in many industrial drives and are the dominant means of providing a controllable source of mechanical rotating power in industry.

1.1. Control Methods of a Separately Excited dc Motor

The equivalant circuit of a separately excited dc motor is shown in figure 1.1. in which R_a is the total armture circuit resistance and L_a is the total armature circuit inductance.

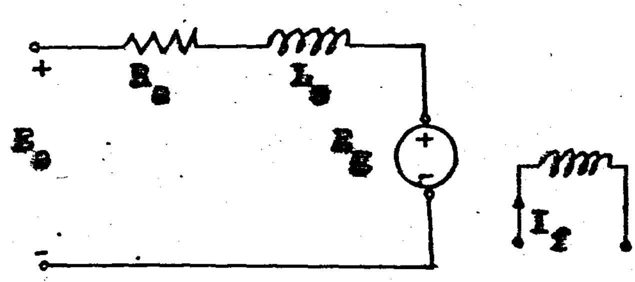


Figure 1.1. Equivalant circuit of a sep. exc. dc motor

The back em.f., E_g is generated by the rotation of armature in the stator flux field. It is proportional to the speed of armature and the field flux and can be represented by:

$$E_g=K_a.\phi_f.N \qquad (1.1)$$

The basic steady state armature circuit voltage equation is:

$$V_a=E_g+I_a.R_a \qquad (1.2)$$

The torque developed by the motor is directly proportional to the armature current I_a and the field flux, that is

$$T=K_t.\phi_f.I_a \qquad (1.3)$$

The simultaneous solution of the three equations yields for the basic speed relation in dc motors, that is

$$N=\frac{V_a-T(R_a/K_t\phi_f)}{K_a.\phi_f} \qquad (1.4)$$

where V_a =supply voltage

I_a =armature current

K_a =armature voltage constant

ϕ_f =field flux

K_t =motor torque constant

N =armature speed

T =produced torque

R_a =armature resistance

The first term in the above equation represents the theoretical no-load speed. The second term which is usually very small represents the speed drop produced by the armature current and hence the developed torque.

The equation 1.4. shows that the speed of a dc motor can be controlled by three methods.These are

1)By the armature voltage V_a which is nearly proportional to speed.

2)By the magnetic flux ϕ_f which is inversely proportional to speed

3)By the armature circuit resistance R_a which is proportional to the speed drop.

Armature voltage control is the most desirable and practical type of control.This type of control is the basis for static dc drive circuits.In this method the field flux is held constant at its rated value and hence the variation of the applied voltage results in a linear variation of speed from zero to the base speed.The motor is said to be operating as a constant torque drive.

Field control is accomplished by reducing the shunt field current while keeping the armature voltage at its maximum value .It is used to extend the speed above the rated value.The speed can not be changed quickly owing to the high inductance of the field winding.In this method the developed torque reduces as the speed increases.

Armature circuit resistance control is not practical except for the very small motors because of the power dissipations.

In fig. 1.2. the speed (N),torque(T) and horsepower variations are shown for two basic control techniques.

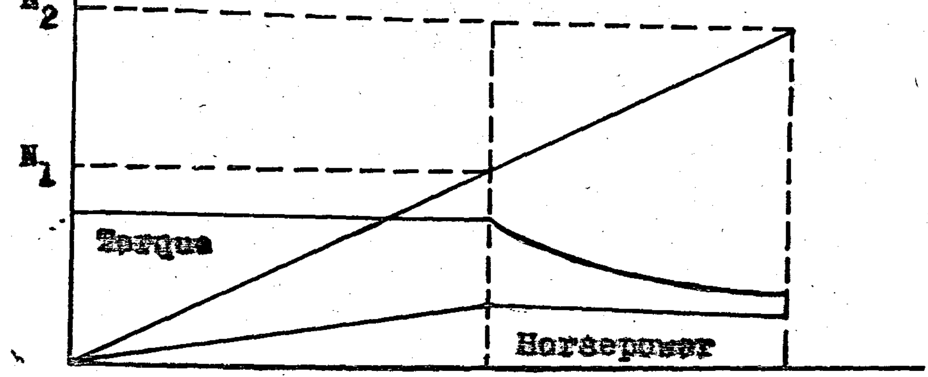


Fig. 1.2. Torque-Speed Variations of a Sep. Exc. dc Motor with Variable Armature Voltage and Field Control

1.2. Transfer function of a separately excited dc motor

Consider the separately excited dc motor with armature control as shown in figure 1.3.(a)

The voltage loop equation is

$$E_a = E_g + I_a R_a + \frac{dI}{dt} . L_a \quad (1.5)$$

The torque balance equation is

$$T_e = T_L + B.N + J \frac{d N}{d t} \quad (1.6)$$

where $T_e = K_a . \emptyset_f . I_a$ (1.7)

In the laplace domain the above equations can be written as

$$E_a(s) = E_g(s) + R_a I_a(s) + L_a s I_a(s) \quad (1.8)$$

$$E_g(s) = K_a \emptyset_f N(s) \quad (1.9)$$

$$T_e(s) = T_L(s) + B.N(s) + Js.N(s) \quad (1.10)$$

$$T_e(s) = K_a . \emptyset_f . I_a(s) \quad (1.11)$$

These relations are shown in block diagram form in Fig. 1.3.(b)

Note the feedback loop present in the form of the back e.m.f. This provides the moderate speed regulation inherent in the separately excited dc motor.

B=Friction Coefficient
J=Moment of Inertia

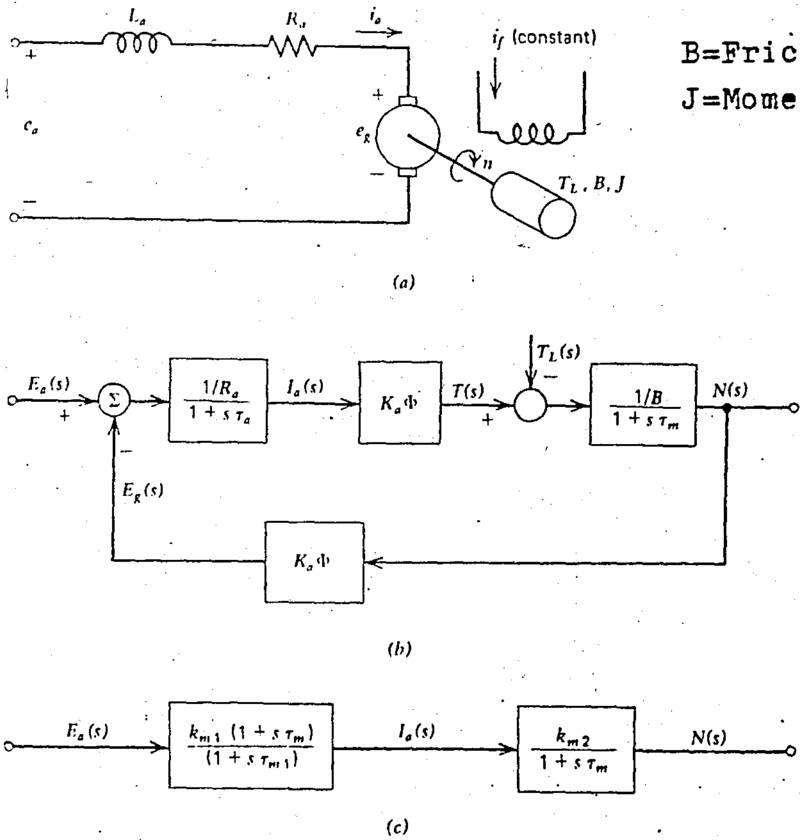


Fig.1.3. Development of motor transfer function

(a) Separately excited dc motor model

(b) Complete transfer function

(c) Simplified transfer function

If we neglect the load torque term then it is found

$$\frac{N(s)}{E(s)} = \frac{K_a \emptyset_f}{(K_a \emptyset_f)^2 + R_a B(1+sT_e)(1+ sT_m)} \qquad (1.12)$$

where T_e = Electrical Time Constant = $\frac{L_a}{R_a}$

T_m = Mechanical Time Constant = $\frac{J}{B}$

If $T_e \ll T_m$ (which is almost always the case), then T_e can be neglected and the expression (1.12) simplifies to

$$\frac{N(s)}{E_a(s)} = \frac{K_a\phi_f}{(K_a\phi_f)^2 + R_aB + sR_aBT_m} = \frac{K_m}{1 + sT_{ml}} \qquad (1.13)$$

where $$T_{ml} = \frac{R_aB}{(K_a\phi_f)^2 + R_aB} \times T_m$$

$$K_m = \frac{K_a\phi_f}{(K_a\phi_f)^2 + R_aB} \qquad \text{and } T_{ml} < T_m$$

Refering to Fig. 1.3.b.

$$\frac{N(s)}{I_a(s)} = \frac{K_a\phi_f/B}{1 + sT_m}$$

Therefore

$$\frac{I_a(s)}{E_a(s)} = \frac{N(s)}{E_a(s)} \times \frac{I_a(s)}{N(s)} = \frac{K_mB(1 + sT_m)}{K_a\phi_f(1 + sT_{ml})} \qquad (1.14)$$

Thus the motor can be represented, for voltage control analysis purposes, as two blocks as in fig. 1.3.c. or simply as a first order system as in fig. 1.4. where

$$K_{ml} = \frac{B}{(K_a\phi_f)^2 + R_aB}$$

$$K_{m2} = \frac{K_a\phi}{B} \qquad K_m = K_{ml} \cdot K_{m2}$$

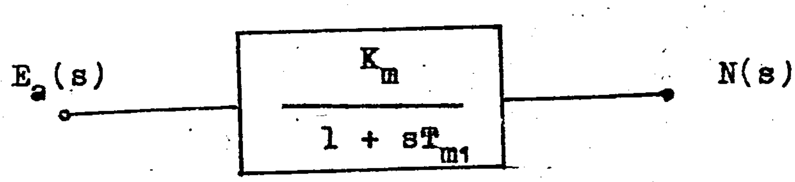


Fig. 1.4. Simplified Transfer Function of a Sep. Exc. dc Motor

There is one important point which should be considered, that is the transient values of armature current I_a in responce to an step input or a large change in E_a.By some simple manipulations this can be obtained as

$$\frac{I_a(t)}{I_a(\infty)} = 1 + \frac{T_m}{T_{ml}} \times e^{-t/T_{ml}} \qquad (1.15)$$

where $T_m/T_{ml} \gg 1$

Therefore it can be concluded that an step applied input voltage results in a large sudden change in armature current which decays slowly.This transient overcurrent is undesirable from the standpoint of converter rating and protection.This is particulary the case for starting or large changes.

It would,therefore,seem beneficial to limit the current to some maximum allowable value.This limitation is also done in our control system.Generally an inner current loop is used for this protection.This inner closed-loop modifies the dynamic response of the system.

Open loop operation of dc motors may not be satisfactory in many applications.A closed loop operation generally has the advantages of greater accuracy,improved dynamic response and reduced effects of disturbances such as loading.When the drive requirements include rapid acceleration or decleration, closed loop operation is necessary.Circuit protection can be provided in a closed loop operation.

CHAPTER TWO

SOLID STATE DC DRIVES

Availability of high-power thyristors in the early 1960s, brought about a revolution in industrial control equipment and drive system performance.During the decade of the 1960s, the attention of engineers designing high-capacity variable voltage dc supply systems was diverted from generating power using an M-G set to converting power using thyristors.Virtually all new variable-speed dc drives are thristor(SCR) converters.The M-G set that was used in variable-speed dc drives for over 50 years has been largely replaced by SCR converters.

The Ward-Leonard system uses a motor-generator (M-G) set to power the dc drive motor.The motor of the M-G set runs at constant speed.By varying the generator field excitation,the generator voltage is changed,which,in turn,can provide continous control of speed of the drive motor over a wide range. The M-G set system can provide speed variation both above and below the rated speed.In figure 2.1. a basic schematic diagram of the Ward-Leonard system is shown.

There are three types of solid state dc drives for obtaining a variable dc output voltage from a fixed ac or dc supply.These are phase control,integral cycle control and chopper control.In all these methods thyristors connect the supply to or disconnect it from the load terminals.

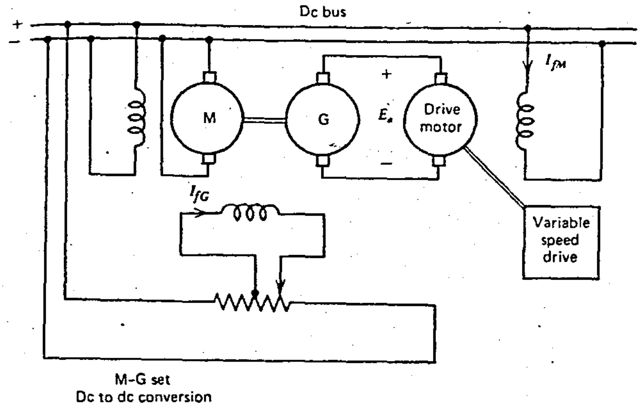


Fig. 2.1. Basic Schematic Diagram of the Ward-Leonard System.

The thyristor drive has the following advantages over the M-G system :

1) Basic operation is simple and reliable.

2) Minimal maintenance is required.

3) Operating eficiency is high above %95,because of the relatively low loses in SCRs.

4) Small size,less weight,and packaging flexibility result in reduced space requirement,lower initial cost,and lower installation and operating costs.

However it has the following disadvantages :

1) The higher ripple content of the convertor output adds to motor heating and commutation problem.The addition of an inductance in the armature circuit may be required to smooth out the ripple current.

2) The overload capability is lower than that of a comparable M-G set.

3) Distortion of the ac supply voltage and telephone

4) Under certain operating conditions,the power factor in the ac supply is low.

5) An M-G set can regenerate automatically.In the thyristor converter,complex control circuitry is required to achieve regeneration.Either a dual converter or a single converter together with a reversing switch of some kind is required to achieve regeneration.Both methods are complex and expensive.

2.1. Phase Controlled Converters

Converters change the ac input voltage to a controlled dc output voltage.In these circuits thyristor commutation is easily achieved by natural or line commutation.When an incoming SCR is turned on,it immediately reverse biases the outgoing SCR and turns it off.Therefore no additional circuitry is required for the commutation process.

Converters suffer from the low power factor operation at large firing angles.

Converters are broadly classified as single phase and three phase converters.The converter type used for a particular application depends on such factors as supply availability(One or Three phase),rating of the drive,amount of ripple to be tolerated,reversible or nonreversible drive,need for regeneration,etc.

Converters are also classified as semi and full converters.Semi-converters are one quadrant converters,that is,they have one polarity of voltage and current at the dc terminal.In these converters a freewheeling diode is usually connected across the load terminals in order not to lose the control.This diode dissipates the stored energy of the inductive load in the negative half cycles of the supply voltage and hence prevents the load voltage to become negative.Full-converters are two quadrant converters in which the load voltage polarity can reverse,but the current remains unidirectional because of the unidirectional operation of SCRs.Regeneration of power,which is the flow of power from the dc motor to the ac supply,is possible with full-converters.Where regeneration is not required,semi-converters are used for the sake of economy. Dual-converters,which are two bridges back to back, can operate in all four quadrants.

2.2. Three Phase Converters

Large-horsepower dc drives take power from three phase sources.In such drives the drive motor is controlled by three-phase phase-controlled converters.The ripple frequency of the motor terminal voltage is higher than that of the single-phase converters.Consequently the filtering requirements for smoothing out the motor current are less.The motor current is mostly continous,and therefor the motor performance is better compared to single-phase drives.

Three-phase Semi-converters and full-converters are most commonly used in practice.Dual-converters are used in reversible drives having very high power ratings.

2.2.1. Three-Phase Semi-Convertor Operation

These converters use three diodes and only 3 SCRs. The bridge output is controlled by adjusting the firing angles of SCRs,the diodes only provide a return path for the current to the most negative line terminal.In these converters the ripple of the converter output voltage is three times the supply frequency.

Figure 2.2. shows a three-phase semi-converter drive circuit and waveforms of voltages and currents for different firing angles.The diodes D1,D2,and D3 conduct during the intervals t_4 to t_6,t_6 to t_8,and t_2 to t_4,respectively. If the thyristors S1,S2,and S3 were diodes,they would conduct during the intervals t_1-t_3,and $t_3$to t_5,and t_5 to t_7, respectively.Therefore the references for the firing angles of S1,S2,and S3 are the instants t_1,t_3,and t_5,respectively,these are the crossing points of phase voltages V_a,V_b,and V_c.Each thyristor conducts for 120 degrees.

For firing angles greater than 60° the free-wheeling diode becomes active.For example for $\alpha=90^{\circ}$,during the interval $(\pi/6+\alpha) < wt < wt_4$,S1 and D3 conduct.Therefore motor terminal X is connected to phase voltage V_a,and terminal Y is connected to V_c.Thus the motor terminal voltage during this period is V_{ac} .At wt_4,E_a is zero,and from this time onward E_a tends to be negative.The free-wheeling diode D_{fw} thus becomes forward biased at wt_4,and motor current flows through it until the next thyristor S2 is turned on at$\pi/6+\alpha+2\pi/3$ .In the absence of the free-wheeling diode,free-wheeling action would have taken place through S1 and D1.However in order to avoid the so called " Half waving effect " an extra free-wheeling diode should be connected across the load terminals.

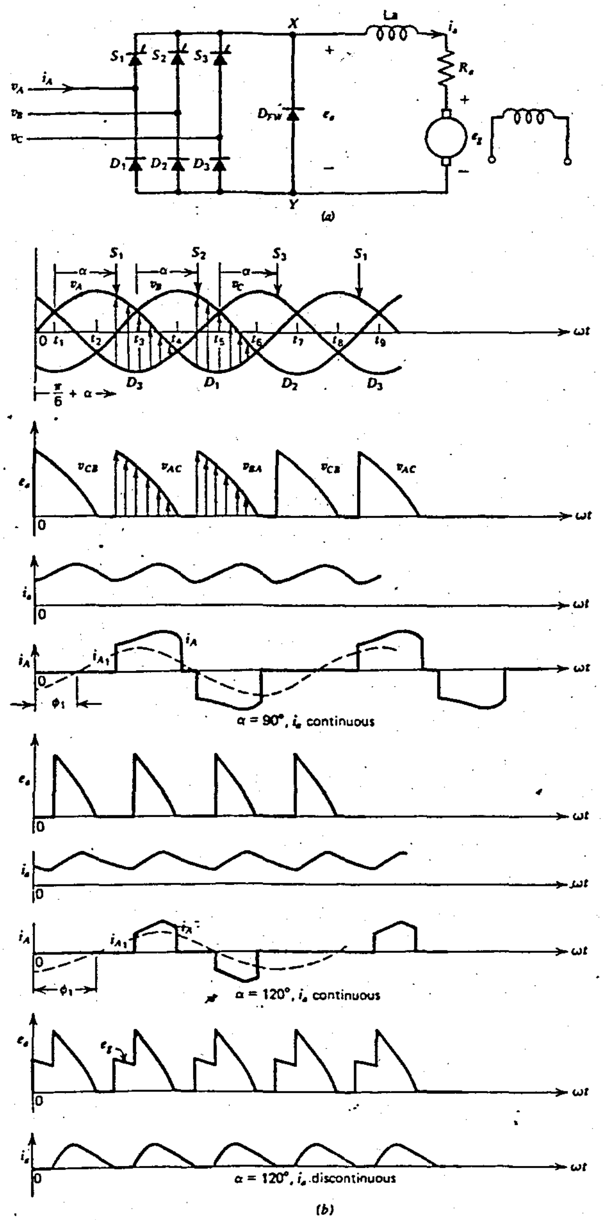


Fig.2.2. Three-phase semi-convertor dc drive.(a)Power Circit (b) Waveforms for different firing angles.

2.2.2. Three-phase Full-converter Operation

In these converters six SCRs are used. The SCRs are fired in sequence every 60 degrees and hence the ripple of the converter output is six times the supply frequency, thus the load current tends to be more continous than in case of semi-converters. This type of converters are primarily used where regeneration is required.

The firing sequence of the SCRs are as shown in fig. 2.3.

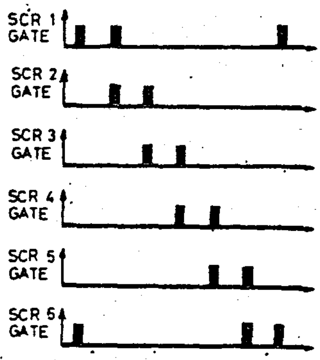


Fig. 2.3. SCR gate signals.

Figure 2.4. shows a full-converter drive circuit and the voltage and current waveforms for different firing angles.

During the interval $(\pi/6 + \alpha) < wt < (\pi/6 + \alpha + \pi/3)$, tyristors S1 and S6 conduct, and the motor terminals are connected to phase A and phase B, making $E_a = V_{AB}$. At $wt = \pi/6 + \alpha + \pi/3$, thyristor S2 is fired, and immediately SCR6 is reverse-biased and turns off. The current from S6 is transfered to S2, making the motor terminal voltage $E_a = V_{AC}$. This process repeates after every 60^{0} whenever a thyristor is fired.

In order to protect the SCRs against the $\frac{dV}{dt}$ effect a suitable snubber circuit should be connected across each thyristor.

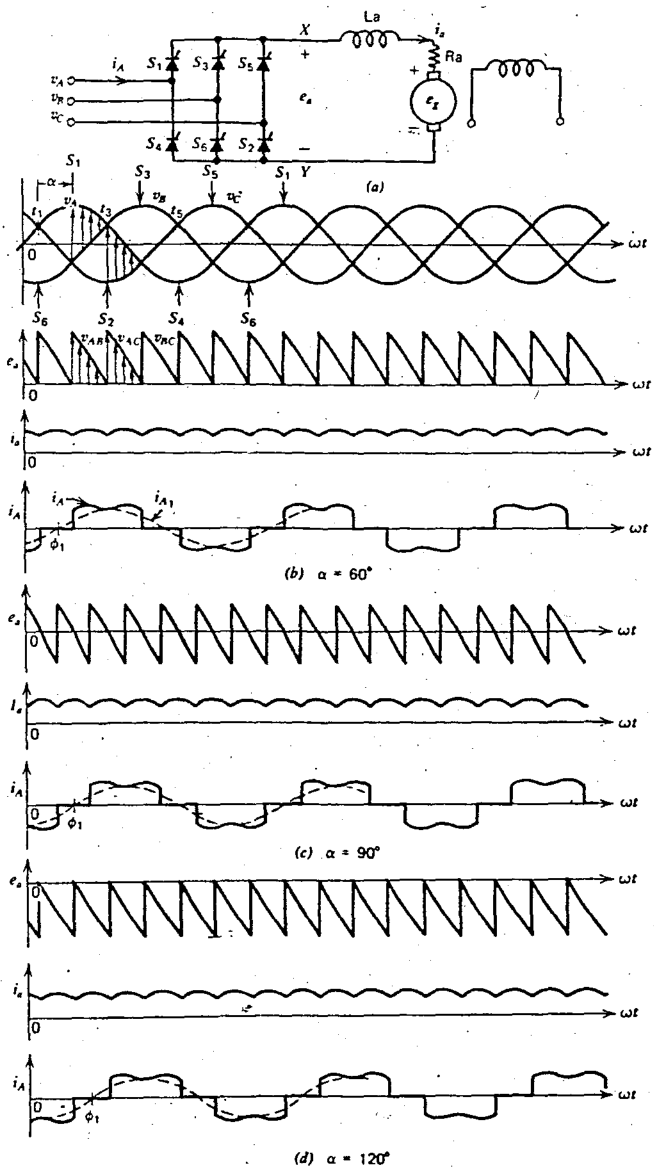


Figure 2.4. Three-phase full-converter drive system.

(a) Power circuit

(b) Waveforms at different firing angles.

The avarage value of the bridge output can be easily calculated for both semi and full converters.

Let the supply voltages be as follows:

$$V_A = \sqrt{2}\ V \sin wt$$

$$V_B = \sqrt{2}\ V \sin (wt - 2\pi/3)$$

$$V_C = \sqrt{2}\ V\ \mathrm{Sin}\ (wt + 2\ /3\ )$$

For semi-converter

$$E_a(\alpha) = \frac{3}{2\pi}\int_{\pi/6\ +\alpha}^{\pi/6\ +\alpha+2\pi/3} (\ V_A - V_c)\ d(wt)$$

$$= \frac{3\sqrt{6}\ V}{2\ \pi}\ (1 + \mathrm{Cos}\alpha) \qquad (2.1)$$

For full-converter

$$E_a(\alpha) = \frac{3}{\pi}\int_{\pi/6\ +\alpha}^{\pi/6\ +\alpha+\pi/3} (V_A - V_B)\ d(wt)$$

$$= \frac{3\sqrt{6}\ V}{\pi}\ \mathrm{Cos}\alpha \qquad (2.2)$$

The variation of $E_a(\alpha)$ with for both converters is shown in figure 2.5.

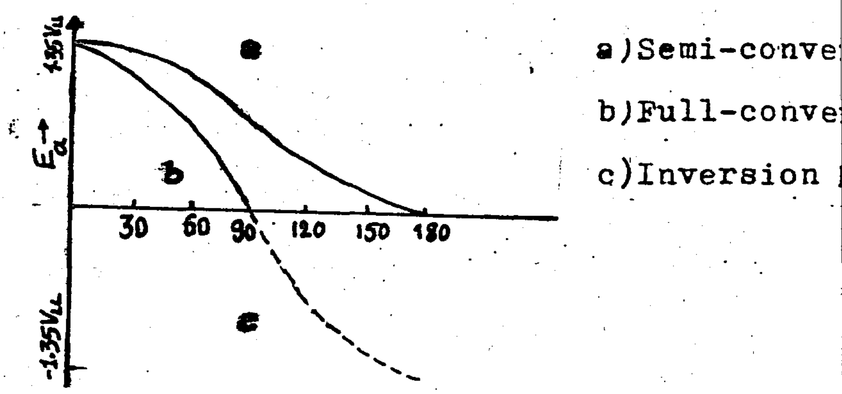


Fig.2.5. Avarage output voltage E_a as a function of firing angle in three-phase full and semi converters.

In the case of full-converters the motor terminal voltage can become negative for firing angles of greater than 90°. This is the inversion mode of operation of the converter.If the polarity of the back e.m.f. is reversed by reversing armature contactors or field current,power can be transfered from the motor to the ac supply.

In actual practice it is not possible to utilize the firing angle range from 0° to 180° .Owing to the time required for commutation and turn off time of SCRs,the maximum permissible value is of the order of 150 degrees.

CHAPTER THREE

Microprocessor Based Speed Control System for a Separately Excited DC Drive

In recent years significant progresshas been made in digital control systems.These systems have gained popularity and importance in all industrial applications due in part to the advances made in digital computers and more recently in microprocessors as well as the advantages found in working with digital systems.

In this chapter the design of a microprocessor based speed control of a dc motor fed by a three phase full-converter is described.The system is centered around a Z-80 based microcomputer with an external 6 bit counter,a PLL circuit,the synchronization circuit,an ADC and the pulse amplifier.The software used manipulates the PI control algorithm and keeps the desired speed constant irrespective of the disturbances.

3.1. Description of the system

A separately excited dc motor with the ratings of 3/4 HP , 125 V , 6 A,and 1450 rpm is being controlled by means of a three-phase full-converter the output voltage of which is directly controlled by a microcomputer.The advantage secured in the converter used is that the drive amplifier is digitally operated and the motor is the only analog device used in the system.Therefore no standard digital to analog concersion is required in the forward path of the closed loop system.

The actual speed of the motor is sensed by means of a 10 bit analog to digital converter(ADC).It is adjusted such that the speed is sensed with an overall resolution of 1.2 rpm/bit.

The clock frequency of the microcomputer used is 2.5 MGHZ.The system has two eight bit input ports and two eight bits output ports.The microcomputer does two main functions, first it does all the necessary calculations and the desired control algorithm ,second it outputs the desired command signals to fire the appropriate thyristors.

The reference speed is stored in the microcomputer memory.Provision is however made to increase or decdease this reference speed by checking whether certain keys of the keyboard are pressed or not.The output voltage of the bridge is made a linear function of the calculated control word by use of an inverse cosine look up table.

To protect the bridge against overcurrents an information of the status of the armature current is fed into the microcomputer,and in the occurance of the overcurrent a kind of ON-OFF control is performed.

In the design stage a minimization of the external hardware is aimed for and the software algorithm is developed accordingly.The software makes it possible to operate the closed loop system at different K_i and K_p ,just by storing the desired values in the appropriate memory locations.

The block diagram of the complete system is shown in figure 3.1. and in more detail in figure 3.2.

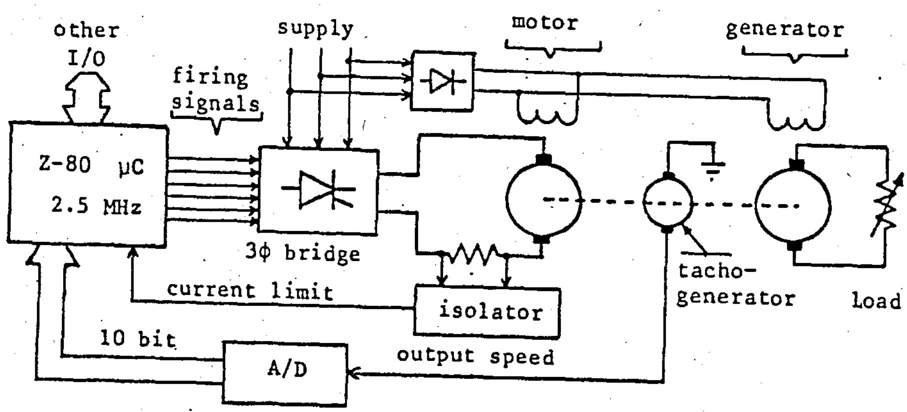


Figure 3.1. The block diagram of the overall set-up

The circuit details and the functions of each block diagram are explained.

3.1.1 Phase Information Circuit

In order to determine the appropriate thyristors to be fired at each interval,the microcomputer should be inputted with the information on the status of the line voltages.The circuit shown in figure 3.3. is used for this purpose.By means of three transformers connected in a suitable Δ - Y configuration producing the required 30° phase shift on the phase voltages,and three comparators,the TTL level signals S_A ,S_B , and S_C indicating the instantaneous polarities of the line voltages are produced.

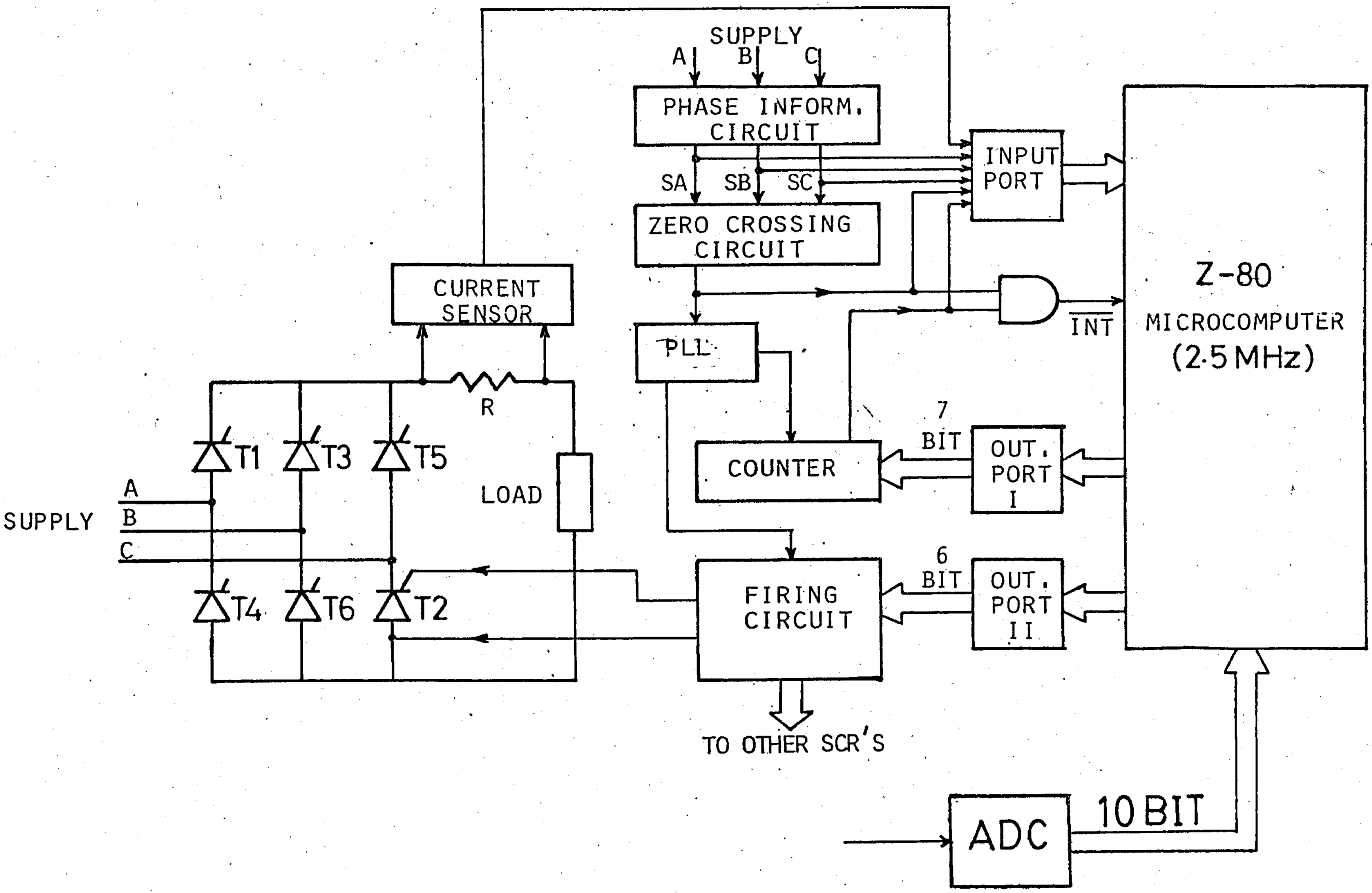

SUPPLY
A
B
C
PHASE INFORM. CIRCUIT
SA
SB
SC
ZERO CROSSING CIRCUIT
INPUT PORT
Z-80
MICROCOMPUTER
(2.5 MHz)
INT
CURRENT SENSOR
PLL
R
T1
T3
T5
T4
T6
T2
LOAD
SUPPLY
A
B
C
7 BIT
COUNTER
OUT. PORT I
6 BIT
FIRING CIRCUIT
OUT. PORT II
TO OTHER SCR'S
ADC
10 BIT

FIG. 3.2.

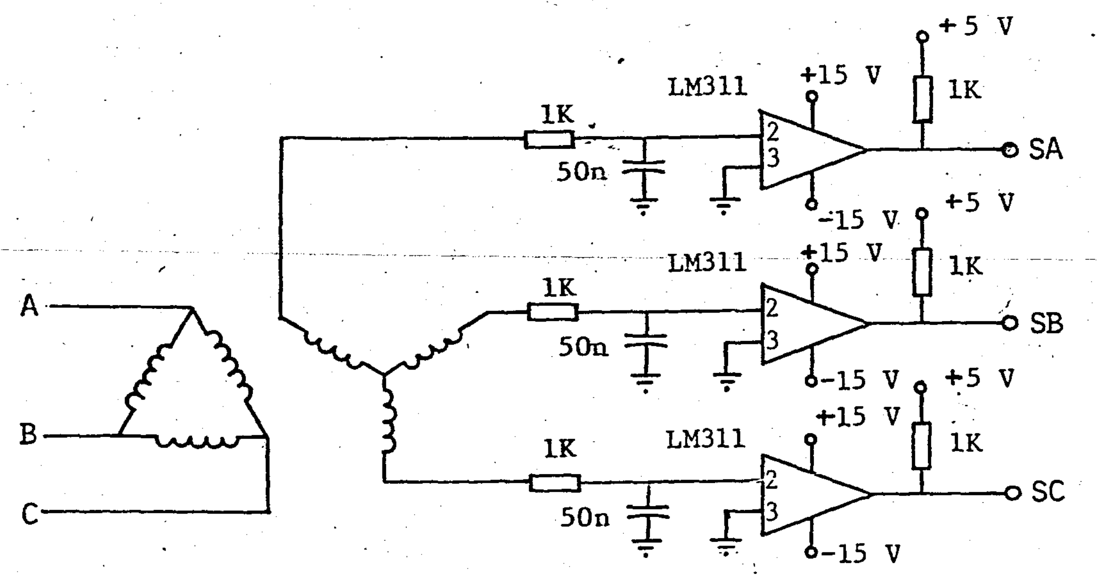


Figure 3.3. Phase Information circuit

3.1.2. Zero Crossing Circuit

The firing delay angle should be measured from the zero crossing instants of the line voltages, i.e. the zero crossing instants of S_A ,S_B, and S_C signals.

The circuit shown in figure 3.4. produces a very narrow pulse each time these signals reach the zero level. A monostable (74121) programmed to be sensitive to the falling edges of the input signal outputes a pulse the duration of which is adjusted according to the software requirements as will be explained later. The output pulse of the monostable is used as one of the interrupt sources as well as an input to the microcomputer.

The waveforms of S_A, S_B, S_C, and the zero-crossing interrupt in relation to the line voltages are shown in figure

3.4. Figure 3.4.g. shows the waveforms at the A1 input of the monostable ,the output of which is logically "Anded" with zero-count interrupt and is used as a base interrupt to the microcomputer.It should be noted that the frequency of the zero-cross interrupt is six times the supply frequency ensuring the six pulse operation of the three-phase full-converter.

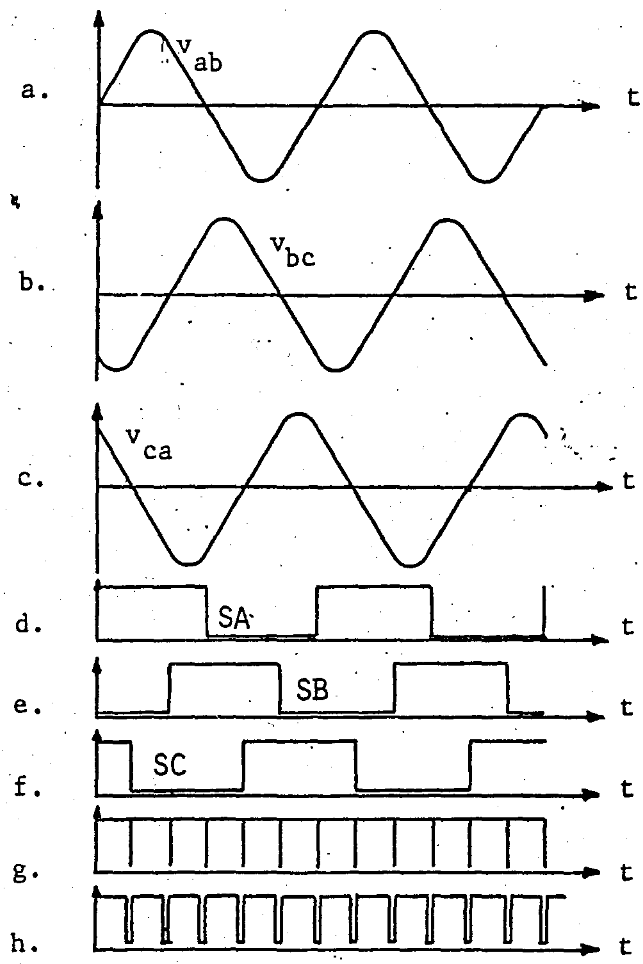
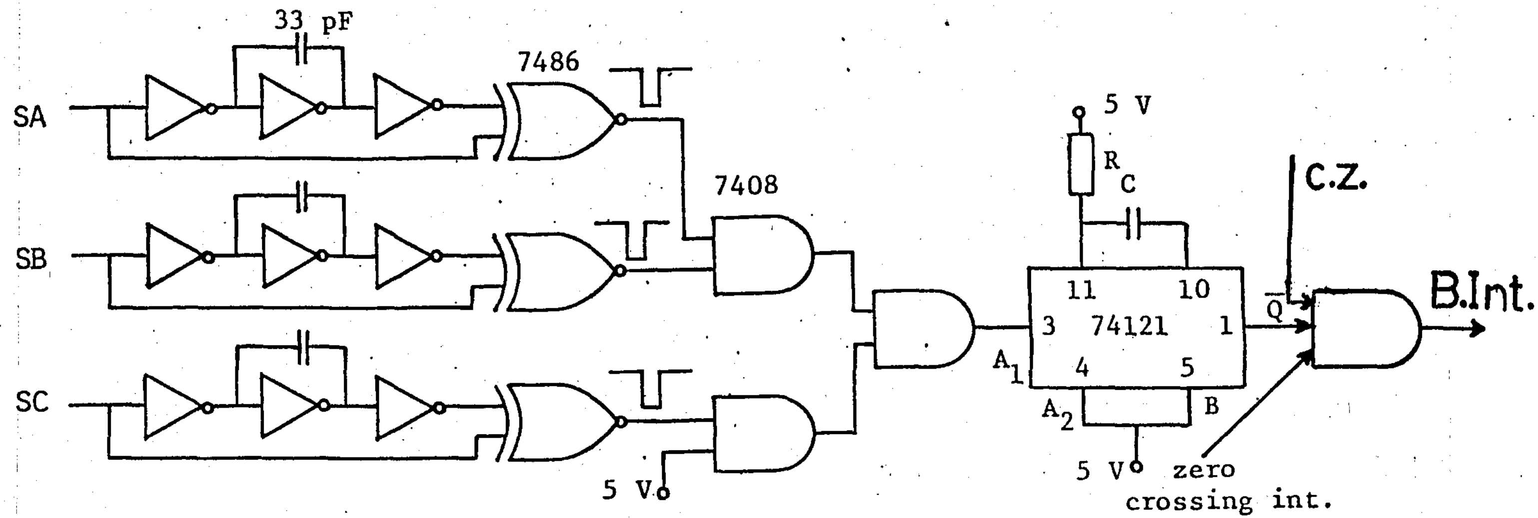


Fig.3.4. Output signals of phase information and zero-crossing circuits.



Zero-Crossing Circuit

3.1.3. Down Counter

On the occurance of a zero-crossing interrupt signal, a count value proportional to the delay angle calculated in the previous cycle, is loaded into a counter and the counter is enabled and the counting down starts. An external six bit programmable down counter with a resolution of 0.94 degree/bit is used for this purpose. In this way the microcomputer is freed from the counting duty and can perform the other functions such as the realization of the desired control algorithm and etc.

The delay angle is calculated in 8 bit word and is stored in the memory. The most two significant two bits (D_7 and D_6) indicate whether the firing delay angle is between $0^\circ - 60^\circ$ or $60^\circ - 120^\circ$ or $120^\circ - 180^\circ$. The last six bits indicate the amount of the delay angle after a zero crossing interrupt. Only these six bits are loaded to the counter and in the firing subroutine by means of the stored values of D_7 and D_6, the appropriate thyristors corresponding to the required delay angle are fired.

The maximum value of the firing delay angle is limited to 150°. Additionally the counts around 60° and 120° are prohibited to prevent the occurance of the zero crossing and count zero interrupts simultanously. These values are obtained experimently being four counts less than the maximum values of the count values in each range .

The physical realization of the down counter is shown in figure 3.5. The six bits of the output port one, shown in figure 3.2. represent the count value,the seventh bit is necessary to control the operation of the counter.During the loading of the counter with the count value this bit is pulled down to zero level for a short while.This causes the enable input of the first stage down to zero level and hence starts the counting down process. When the zero count is reached,the ripple clock output of the second stage counter goes high.A monostable produces a pulse to be used as the second source of interrupt to the microcomputer. The width of this interrupt signal is also adjusted according to the software requirements.

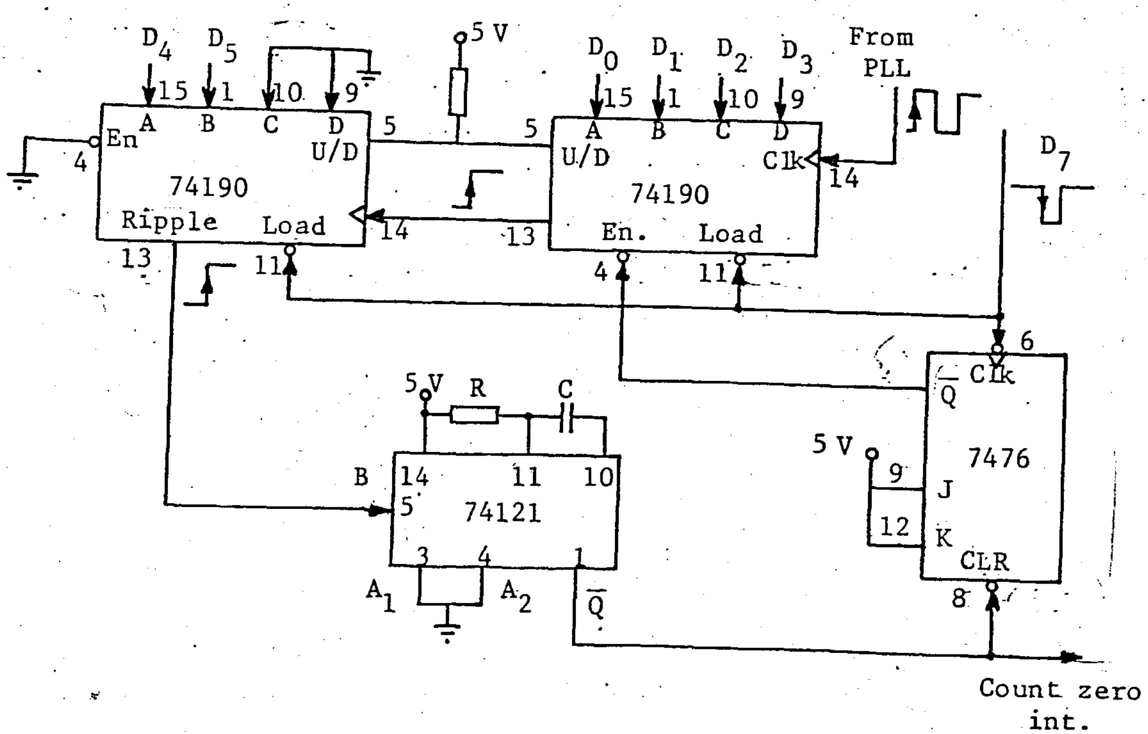


Figure 3.5. External down counter circuit

In order to synchronize the frequency of the clock input of the counter to the supply frequency a phase-locked loop circuit is used.

3.1.4. Phase-locked-loop (PLL) Circuit

The operation of the counter is synchronized to the supply frequency with the PLL circuit shown in figure 3.6. The input to the phase detector number two of MC4046 is the 300 Hz zero crossing signal.The components connected to pin number 13 constitute a low pass filter.The output of the voltage controlled oscillator (VCO) is at a frequency of 38.4 KHz. Q_A output of the first divider(19.2 KHz) is used as the clock signal of the down counter and also in the production of the triggering pulses for the thyristors.

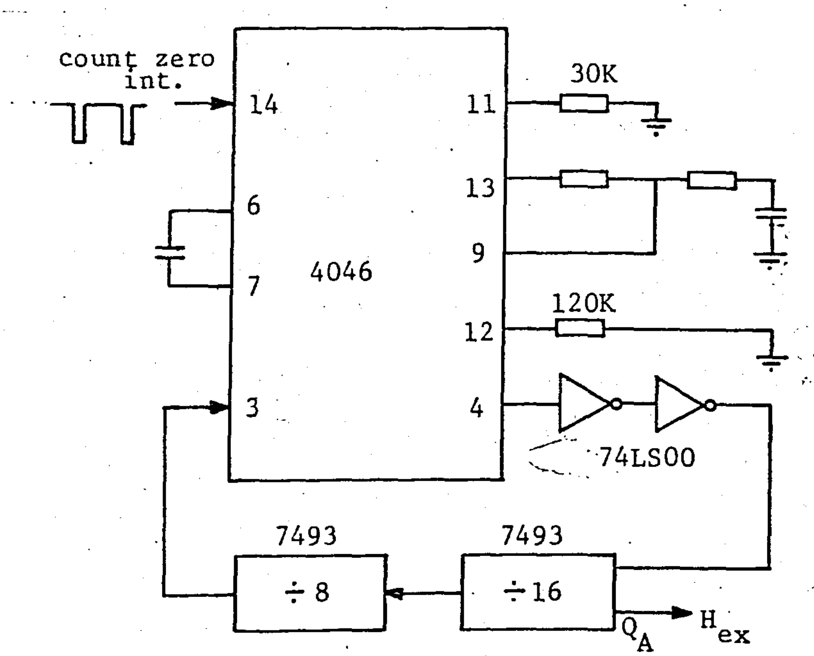


Figure 3.6. The PLL circuit

3.1.5. Firing circuit

The firing circuit for one of the SCRs is shown in figure 3.7. The isolation between the power circuit and the microcomputer is ensured by a pulse transformer.

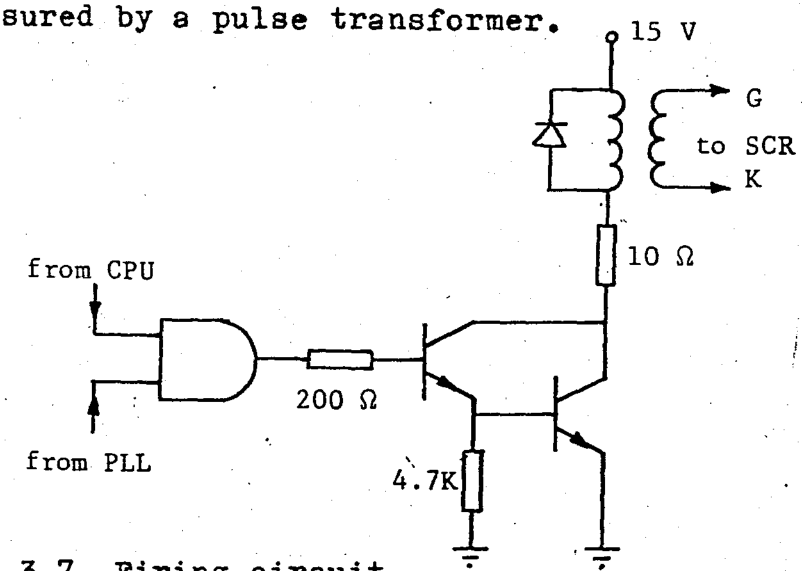


Figure 3.7. Firing circuit

The firing pulses outputted from the microcomputer should be long enough to turn the thyristors on. It is imperative that the firing program should be as short as possible. If the firing pulses are produced by software within the firing subroutine, the execution time will be rather long since it will have to cover the duration of the firing pulses. This will tend to decrease the maximum permissble count values at each range. Therefore a firing pulse output each interval is not cleared until the end of the next interval. In order to lower the gate drive requirements the microcomputer output signals are "Anded" with a clock frequency of 19.2 KHz.

3.1.6. Current Sensor Circuit

The circuit shown in figure 3.8. is used to protect the bridge against overcurrents.A small resistor of obout 0.35 ohm placed in series with armature of the motor provides a voltage proportional to the armature current.When the current level reaches a threshold value,adjustable by the potentiometer R_1 ,the output of the circuit goes low. This signal is used as an input to the microcomputer.It is checked in every interval,and if it is low the SCRs in that interval are not fired.

The isolation between the power circuit and the microcomputer is ensured by the opto-coupler used.

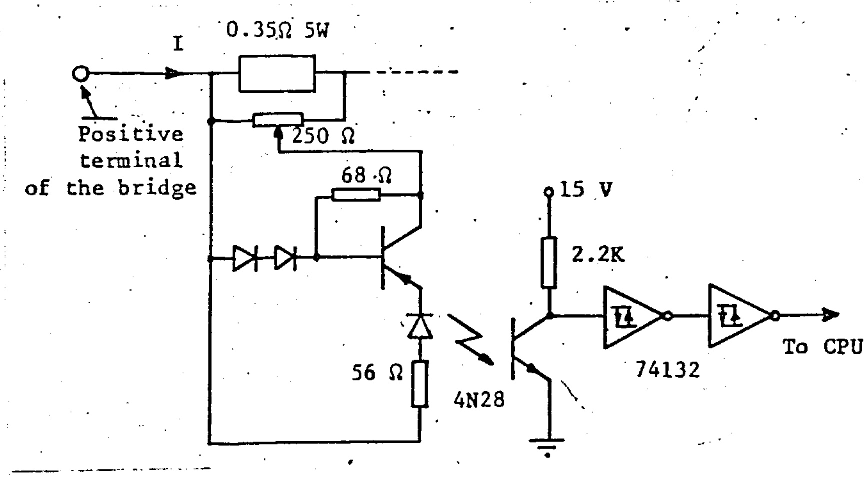


Figure 3.8. Current sensor circuit

3.1.7. Analog to Digital Converter Circuit

The dc output of the tachogenerator mounted on the shaft of the motor is converted to a dc signal between 0-10 volt by means of a voltage divider and is converted into a ten bit digital form and inputed to the microcomputer by means of the Datel ADC-856 analog to digital converter.

The ADC-856 is a 10 bit tracking type A/D converter, capable of supplying continously updated conversion data on full scale sinusoidal signals up to 300 Hz without the need for a sample and hold.When encoding a dc signal,the output of the tracking type A/D converters alternate between the two adjacent states.

The maximum clock input frequency of the ADC-856 is 1 MHz.A 10 MHz crystal oscillator is used and it is divided by twelve.

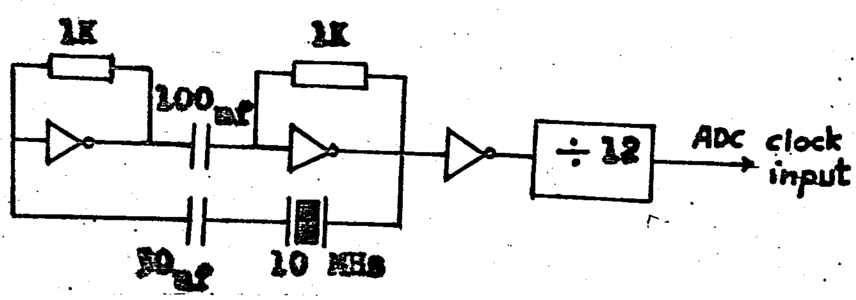


Figure 3.9. Clock Generator

By means of 10 LEDs connected to the A/D converter the speed of the motor is made visible.

3.2. Software

In the development of the software the following points are taken into consideration:

1) Precaution is taken to ensure that all the interrupts receive servicing appropriately.

2) The common proportional-integral control algorithm is implemented and precaution is taken to operate the system with different K_i and K_p values.

3) An inverse look up table is consulted to linearize the bridge output.

5) All the calculations are done in sixteen bit sign-magnitude.

3.2.1 PI Control Algorithm

The output of the PI controller in analog systems is:

$$U(t) \triangleq K_p e(t) + K_i \int e(t).dt \qquad (3.1.)$$

where e(t) is the instantanous value of the error.

The integral in the above equation can be written as:

$$X(t) = \int_{t_0}^{t} e(\tau).d\tau + X(t_0) \qquad (3.2.)$$

where t_0 is the initial time and $X(t_0)$ is the initial value of X(t).

To approximate the above integral in digital model, there are different rules one of which is the trapezoidal rule.

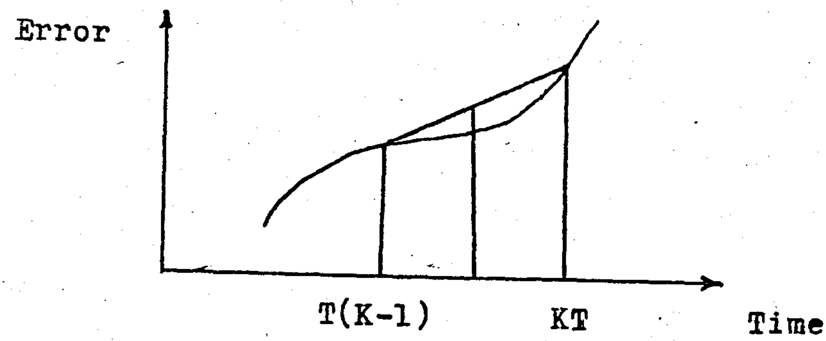


Figure 3.10. Trapezoidal approximation

Between the time intervals (K - 1)T and KT, where T is the sampling period, the definite integral in equation 3.2. can be approximated by the area of the shown trapezoid, that is :

$$\int_{K-1}^{K} e(KT)\, dT \simeq T\left[e(K) + e(K-1)\right]/2 \qquad (3.3.)$$

Since the integral evaluated in the interval between KT and (K + 1)T is used in (K + 1)T interval the equation 3.2. in discrete model can be written as :

$$X(K) = T\left[e(K) + e(K-1)\right]/2 + X(K-1) \qquad (3.4.)$$

and the controller output will be as :

$$U(K+1) = K_p.e(K) + K_i.X(K) \qquad (3.5.)$$

It is seen that the evaluation of the control word in each interval is straight forward and only the previous values of error and integral are needed. Also two multipication subroutines are required to multiply the calculated values of error and integral by K_p and K_i respectively,

Width of the Interrupt Pulses

In the system there are two sources of interrupt, zero crossing and count zero interrupts. From the time an interrupt pulse is generated to the time the cause of the interrupt is tested a certain amount of time passes. The width of the interrupt pulses should be adjusted accordingly. However they should not be so wide as to cause the occurrence of both pulses simultanously. Due to these considerations the width of these pulses are adjusted to fourty microseconds.

3.2.3 Linearization of Control

The output voltage of the three-phase full converter is:

$$V_o = \frac{3\sqrt{6}\, V}{\pi} \cdot \operatorname{Cos}\alpha = 1.35\, V_{LL} \cdot \operatorname{Cos}\alpha$$

where V_{LL} is the rms value of line to line voltage.

If the relation between the control word U, and firing angle α is linear then the relation between U and V_o will not be linear. Generally a linear relation between the control word and bridge output is highly desirable.

If α is obtained according to

α = arcCos (KU) then the bridge output will be:

$$V_o = 1.35\, V_{LL} \cdot \operatorname{Cos}(\operatorname{arcCos} KU) = 1.35 KU \cdot V_{LL} = K_c \cdot U \qquad (3.6)$$

In the software the positive values of U are limited to $+96_{dec}$ and is calculated from the equation 3.7. for different values of U and multiplied by $\frac{64}{60}$, the inverse of the counter resolution, and the inverse cosine look up table is constructed.

$$\alpha_{deg} = \operatorname{arc\,Cos} \frac{|U|}{96} \qquad (3.7)$$

The gain of the converter can be easily obtained,

$$V_o = 1.35 \, Cos(arcCos \frac{|U|}{96}).V_{LL} = 1.35 \times 100/96 \times U$$

$$\text{Gain of converter} = K_c = \frac{V_o}{|U|} = 1.4 \text{ Volt/bit}$$

The experimentally obtained bridge output as a function of control word using the inverse look up table is shown in figure 3.11.

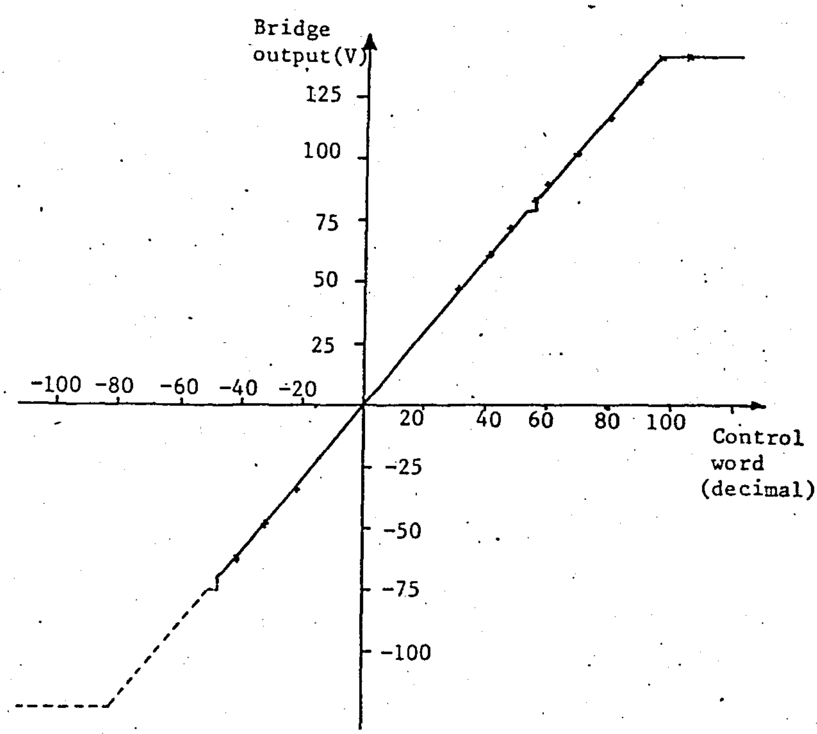


Figure 3,11. Variations of converter output as a function of control word

The whole range of the regeneration mode could not be tested due to the experimental difficulties.The dotted lines show the theoretically expected values.

It is seen from this figure that the control is smooth and linear except for the values of control word corresponding to firing delay angles around 60° and 120°. This is an outcome of the limits set.

3.2.4. The Flow-Chart

Z-80 microprocessor can operate in three different interrupt modes.For our application the most suitable one is the interrupt mode 1.In this mode an interrupt causes a restart to location ØØ38H ,In this way no additional external hardware is required to load the program counter with the interrupt vector.

The flow-chart of the program is shown in figure 3.12. When an interrupt is sensed,the starting address of the program is loaded into the program counter through the instruction in ØØ38H location.Since there can be two sources of interrupt,one due to count zero and the other due to the zero-crossing interrupt,the first thing to be done is to determine the cause of interrupt.For a zero-crossing interrupt,the count value calculated in the previous cycle is loaded into the counter and it is enabled.Then the firing pulses sent out during the previous cycle are cleared.The internal interrupt flip-flop is enabled and the main program is entered.In the main program the control word is calculated,the inverse cosine look up table is consulted,and the corresponding count value,which determines the delay angle in the next cycle is determined.The two most significant bits are stored in order to be used in the determination of the range of the delay angle, i.e. $0^\circ - 60^\circ$ or $60^\circ - 120^\circ$ or $120^\circ - 150^\circ$. The microprocessor then goes into HALT state.

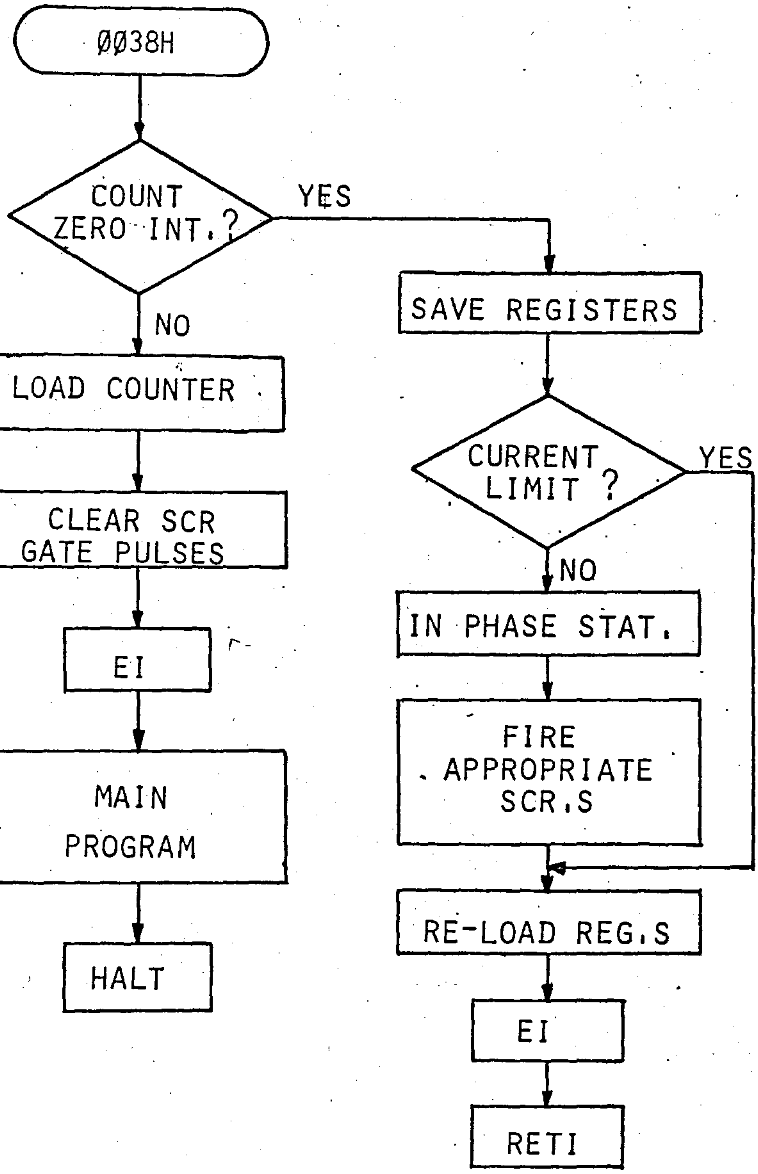


Figure 3.12. Flow-Chart

When the counter counts down to zero, a count zero interrupt is generated which causes the program to branch into the firing routine. Upon entering the firing routine, the registers are saved and then the armature current status bit is checked.In the case of occurence of overcurrent a return to the main program is made without firing any thyristor in that interval.Otherwise a fresh input of status of the line voltages is made.Using these information together with the stored range information the firing look-up table shown in table one is consulted and the appropriate thyristors are fired.

After reloading the registers with their previous values,the interrupt flip-flop is enabled.A return from interrupt instruction causes the program to go back either to the main program or HALT state.

INPUT					OUTPUT						RANGE
D7	D6	SA	SB	SC	SCR6	SCR5	SCR4	SCR3	SCR2	SCR1	
0	0	1	0	1	1	1	0	0	0	0	$0^0 - 60^0$
0	0	1	0	0	1	0	0	0	0	1	
0	0	1	1	0	0	0	0	0	1	1	
0	0	0	1	0	0	0	0	1	1	0	
0	0	0	1	1	0	0	1	1	0	0	
0	0	0	0	1	0	1	1	0	0	0	
0	1	1	0	1	0	1	1	0	0	0	$60^0 - 120^0$
0	1	1	0	0	1	1	0	0	0	0	
0	1	1	1	0	1	0	0	0	0	1	
0	1	0	1	0	0	0	0	0	1	1	
0	1	0	1	1	0	0	0	1	1	0	
0	1	0	0	1	0	0	1	1	0	0	
1	0	1	0	1	0	0	1	1	0	0	$120^0 - 180^0$
1	0	1	0	0	0	1	1	0	0	0	
1	0	1	1	0	1	1	0	0	0	0	
1	0	0	1	0	1	0	0	0	0	1	
1	0	0	1	1	0	0	0	0	1	1	
1	0	0	0	1	0	0	0	1	1	0	
OTHER COMBINATIONS					0	0	0	0	0	0	

Table 1.

Look-up Table For SCR Firing Pulses

```
3EBØ                LD     A,BØ             ;
32Ø7EØ              LD     (EØØ7),A
21E8Ø1              LD     HL,INTSRV
22391Ø              LD     (1Ø39H),HL
DD36ØØ4Ø            LD     IX,4ØØØH
DD36Ø4Ø6            LD     (IX+Ø4H),Ø6H     ;Firing Look-up
DD36Ø818            LD     (IX+Ø8H),18H     ;table
DD36ØCØC            LD     (IX+ØCH),ØC
DD361Ø21            LD     (IX+1ØH),21H
DD3614Ø3            LD     (IX+14H),Ø3
DD36183Ø            LD     (IX+18),3Ø H
DD36Ø5ØC            LD     (IX+Ø5H),ØC
DD36Ø93Ø            LD     (IX+Ø9H),3ØH
DD36ØD18            LD     (IX+ØDH),18H
DD3611Ø3            LD     (IX+11H),Ø3
DD3615Ø6            LD     (IX+15H),Ø6
DD361921            LD     (IX+19H),21H
DD36Ø618            LD     (IX+Ø6 ),18H
DD36ØA21            LD     (IX+ØA ),21H
DD36ØE3Ø            LD     (IX+ØE), 3ØH
DD3612Ø6            LD     (IX+12H),Ø6
DD3616ØC            LD     (IX+16H),ØC
DD361AØ3            LD     (IX+1A ),Ø3
DD36215F            LD     (IX+33d),95d     ;Inverse Cosine
DD36225F            LD     (IX+34 ),95       Look-up Table
........            ..     ...........
........            ..     ...........
DD367EØF            LD     (IX+126),15
DD367FØC            LD     (IX+127),12
DD218Ø4Ø            LD     IX,4Ø8ØH
DD36ØØØ8            LD     (IX+ØØ ),8
DD36Ø1Ø1            LD     (IX+ 1 ),1
DD36Ø2Ø1            LD     (IX +2 ),1
FB         HLT:     EI
76                  HALT

C3E3Ø1              JP     HLT
F5         INTSRV:  PUSH   AF
```

```
DBØ1                 IN    A,(Ø1H)
1F                   RRA
DA5DØ3               JP    C,FIRE         ; C.Z. Int. ?
1F                   RRA                  ; No
D2Ø4Ø2               JP    NC,MAIN        ; Both Ints. ?
3A89Ø3               LD    A,ALFA)        ;Load Counter
D3ØØ                 OUT   (ØØ),A
E67F                 AND   7F
D3ØØ                 OUT   (ØØ),A
CBFF                 SET   7,A
D3ØØ                 OUT   (ØØ),A
97                   SUB   A
D3Ø1                 OUT   (Ø1),A
FB                   EI
ØEØØ        MAIN:    LD    C,ØØ           ;Input Motor Speed
ED58                 IN    E,(C)
DBØ1                 IN    A,(Ø1)
E6CØ                 AND   CØ
Ø7                   RLCA
Ø7                   RLCA
47                   LD    B,A
7B                   LD    A,E
E6Ø3                 AND   Ø3
57                   LD    D,A
7B                   LD    A,E
E6FC                 AND   FC
BØ                   OR    B
5F                   LD    E,A
37                   SCF
3F                   CCF
2A7EØ3               LD    HL,(SETSPD)
ED52                 SBC   HL,DE          ;Calculate Error
2282Ø3               LD    (NEWERR),HL
ED5B8ØØ3             LD    DE,(OLDERR)
CD2FØ3               CALL  ADDTIN
Ø6Ø3                 LD    B,Ø3
CB7C                 BIT   7,H
```

```
CA75Ø3                  JP     Z,POS          ;Divide β by 8
37          NEG:        SCF
CB1C                    RR     H
CB1D                    RR     L
1ØF9                    DJNZ   NEG
CDØ2Ø3      DEVM:       CALL   MULTP1         ;Mult. X(K) by Ki
ED5B84Ø3                LD     DE,(OLDITG)
CD2FØ3                  CALL   ADDTIN
2286Ø3                  LD     (NEWITG),HL
2A82Ø3                  LD     HL,(NEWERR)
CD29Ø3                  CALL   MULTP2         ;Mult. e(K) by Kp
ED5B86Ø3                LD     DE,(NEWITG)
CD2FØ3                  CALL   ADDTIN
CB7C                    BIT    7,H            ; U positive ?
C29AØ2                  JP     NZ,UNEG
7C                      LD     A,H
264Ø                    LD     H,4ØH
1121ØØ                  LD     DE,33
FE6Ø                    CP     96
D295Ø2                  JP     NC,UPLMT
6F          LOOKUP:     LD     L,A
19                      ADD    HL,DE
7E                      LD     A,(HL)
47          DELAY:      LD     B,A
E6CØ                    AND    CØ
Ø7                      RLCA
Ø7                      RLCA
3288Ø3                  LD     (RANGE),A      ; Store range inf.
78                      LD     A,B
E63F                    AND    3F
F68Ø                    OR     8ØH
3289Ø3                  LD     (ALFA),A
2A82Ø3                  LD     HL,(NEWERR)
228ØØ3                  LD     (OLDERR),HL
2A86Ø3                  LD     HL,(NEWITG)
2284Ø3                  LD     (OLDITG),HL
CD1EØØ                  CALL   BRKEY          ; Shift+Break ?
CA51Ø3                  JP     Z,MODIFY       ;
```

```
CDC6Ø2                  CALL  SPCHNG      ;Shift+T Pressed?
CA41Ø3                  JP    Z,PCHNG
CDE4Ø2                  CALL  SNCHNG      ;Shift+G Pressed?
CC4AØ3                  CALL  Z,NCHNG
F1          BACK:       POP   AF
ED4D                    RETI              ;End of Main Prog.
3E6Ø        UPLMT:      LD    A,96        ;Limit U positive
C361Ø2                  JP    LOOKUP
7C          UNEG:       LD    A,H
2F                      CPL
3C                      INC   A
FE3F                    CP    3F
D2C1Ø2                  JP    NC,UNLMT

47          REGN:       LD    B,A
3E6Ø                    LD    A,6ØH
8Ø                      ADD   A,B         ;Find U negative
47                      LD    B,A
E6ØF                    AND   ØF
CABCØ2                  JP    Z,CORECT
78                      LD    A,B
FE8Ø        RLMT:       CP    128        ;2nd range limits
D264Ø2                  JP    NC,DELAY
FE7B                    CP    123
DA64Ø2                  JP    C,DELAY
3E7B                    LD    A,123
C364Ø2                  JP    DELAY
78          CORECT:     LD    A,B
3C                      INC   A
C3ADØ2                  JP    RLMT
3E3F        UNLMT:      LD    A,3F       ;Max. Firing Set15Ø
C3A2Ø2                  JP    REGN

3EF8        SPCHNG:     LD    A,F8
32ØØEØ                  LD    (EØØØ),A
ØØ                      NOP
3AØ1EØ                  LD    A,(EØØ1)
2F                      CPL
E621                    AND   21H
```

```
C2D8Ø2                  JP    NZ,2NDP         ;Shift pressed ?
C601                    ADD   A,Ø1            ;No
C9                      RET
3EF2       2NDP:        LD    A,F2            ;T Pressed ?
32ØØEØ                  LD    (EØØØ),A
ØØ                      NOP
3AØ1EØ                  LD    A,(EØØ1)
E6Ø4                    AND   Ø4
C9                      RET

3EF8       SNCHNG:      LD    A,F8
32ØØEØ                  LD    (EØØØ),A
ØØ                      NOP
3AØ1EØ                  LD    A,(EØØ1),A
2F                      CPL
E621                    AND   21H
C2F6Ø2                  JP    NZ,2NDN         ;Shift Pressed ?
C6Ø1                    ADD   A,Ø1            ;No
C9                      RET
3EF4       2NDN:        LD    A,F4            ;G Pressed ?
32ØØEØ                  LD    (EØØØ),A
ØØ                      NOP
3AØ1EØ                  LD    A,(EØØ1)
E6Ø4                    AND   Ø4
C9                      RET

3A8AØ3     MULTP1:      LD    A,(Ki*5)
EB         INITAL:      EX    DE,HL
Ø6Ø8                    LD    B,Ø8            ;8 Bit Multiplier
21ØØØØ                  LD    HL,ØØØØ         ;Init. Value Zero
37         CONT:        SCF
3F                      CCF
ED5A                    ADC   HL,HL
E218Ø3                  JP    PO,MLT          ;Enter Mult. Routine
FA3DØ3     LIMIT:       JP    M,PLMT          ;Overflow then limit
C339Ø3                  JP    NLMT
17         MLT:         RLA
D226Ø3                  JP    NC,SHIFT
```

```
37                      SCF
3F                      CCF
ED5A                    ADC    HL,DE
E226Ø3                  JP     PO,SHIFT
C312Ø3                  JP     LIMIT
1ØE3       SHIFT:       DJNZ   CONT
C9                      RET
3A8BØ3     MULTP2:      LD     A,(Kpx1/16)     ;Get Kp Value
C3Ø5Ø3                  JP     INITAL

37         ADDTIN:      SCF
3F                      CCF
ED5A                    ADC    HL,DE
E24ØØ3                  JP     PO,EXACT        ;No Overflow Then OK
FA3DØ3                  JP     M,PLMT
21Ø18Ø     NLMT:        LD     HL,8ØØ1H        ;Neg. Limit Value
C9                      RET
21FF7F     PLMT:        LD     HL,7FFF         ;Pos. Limit Value
C9         EXACT:       RET

21DØØ1     PCHNG:       LD     HL,Ø1DØ         ;Change Setspeed
227EØ3                  LD     (SETSPD),HL
C392Ø2                  JP     BACK

21BØØ1     NCHNG:       LD     HL,Ø1BØ         ;Change Setspeed
227EØ3                  LD     (SETSPD),HL
C9                      RET

214124     MODIFY:      LD     HL,2441H        ;Modify Monitor
22391Ø                  LD     (1Ø39),HL       ;Program
97                      SUB    A               ;Clear Fire Pulses
D3Ø1                    OUT    (Ø1),A
C3ØØ6Ø                  JP     BRK

CB3C       POS:         SRL    H               ;Divide Pos.β by
CB1D                    RR     L               ; 8
1ØFA                    DJNZ   POS
C337Ø2                  JP     DEVM
```

```
D9          FIRE:     EXX
DBØ1                  IN      A,(Ø1)
CB6F                  BIT     5,A
CA71Ø3                JP      Z,CRLMT
E61C                  AND     1C
2188Ø3                LD      HL,RANGE
B6                    OR      (HL)
6F                    LD      L,A
264Ø                  LD      H,4ØH
7E                    LD      A,(HL)
D3Ø1                  OUT     (Ø1),A
D9          CRLMT:    EXX
F1                    POP     AF
ED4D                  RETI
                      END


                      SETSPD:DEFW   Ø1CØ
                      OLDERR:DEFW   Ø3FF
                      NEWERR:DEFW   ØØØØ
                      OLDITG:DEFW   ØØØØ
                      NEWITG:DEFW   ØØØØ
                      RANGE :DEFB   Ø1
                      ALFA  :DEFB   AØ
                      BRK   :EQU    6ØØØH
                      BRKEY :EQU    ØØ1E
```

CHAPTER FOUR

STABILITY ANALYSIS

Figure 4.1. shows the discrete time model of the closed loop system,which is derived under the following assumptions:

1)The average armature voltage is maintained at a constant value for one sampling period.This can be modeled as a zero order hold.

2)The three-phase converter is assumed to operate as a linear power amplifier with no delay and with an overall gain of K_c=1.4 Volt/bit

3)Since the A/D converter operates at a high frequency ,in the analysis T' will not be included.K_t is the overall gain of tachogenerator and A/D converter being 8.2 bits/rad

4)Because of the time requirements for control algorithm manipulation,the calculated value of control word at every period is made effective in the next cycle.This is modeled as a delay element.

The analysis is done in Z-domain.Figure 4.2. shows the Z-domain equivalant of the closed loop system.

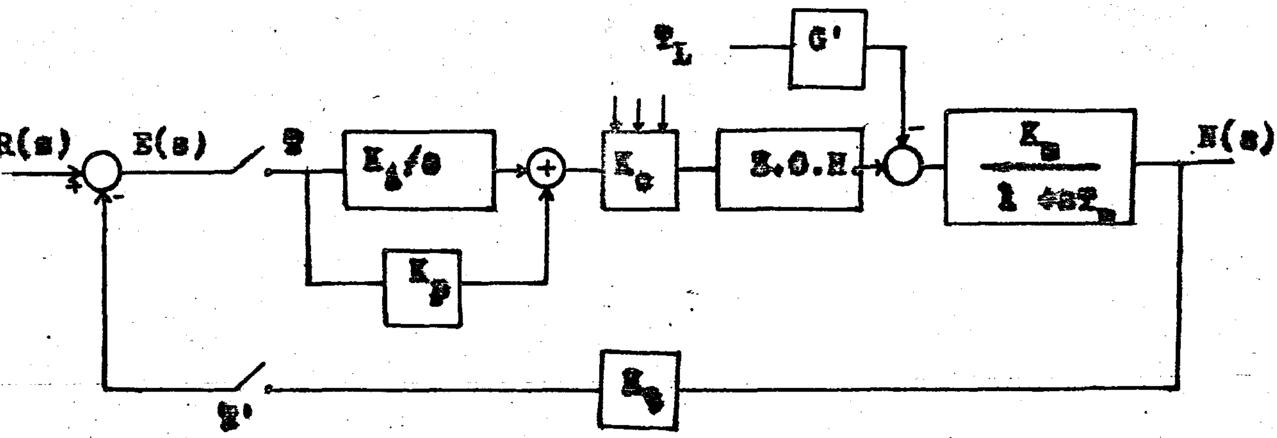


Figure 4.1. Discrete Time Model of The System

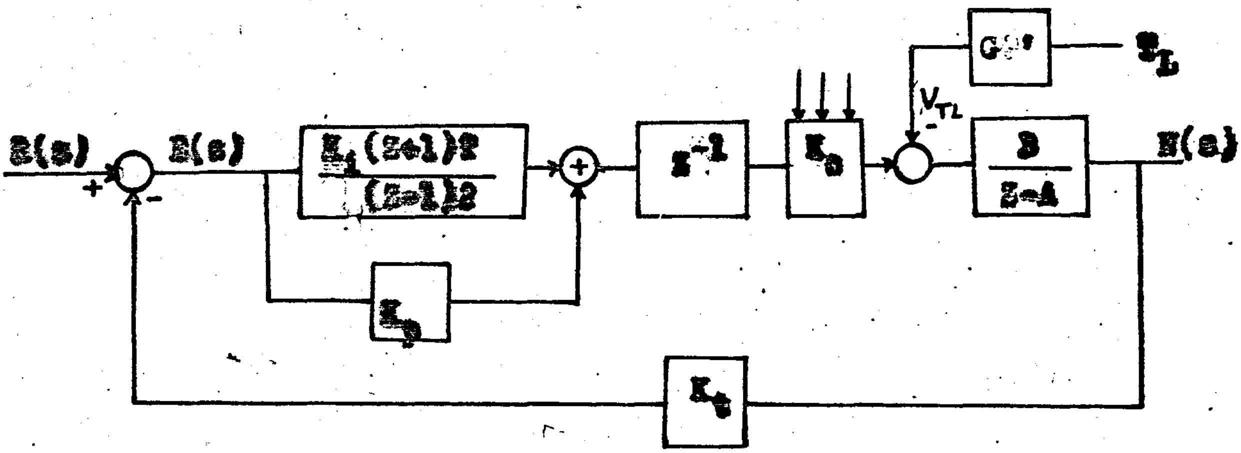


Figure 4.2. Z-domain Model of The System

Where T = Sampling period = 3.3 milisecond

$T_m = 0.46$ Sec.

$K_m = 0.93$ rad/V.s.

$B = K_m(1 - A) = 0.007$ rad/V.s.

$A = e^{-T/T_m} = 0.992$

If the load torque disturbance is neglected the transfer function can be easily calculated to be:

$$\frac{N(z)}{R(z)} = \frac{\hat{K}(Z - \alpha)}{G_d(z)} \qquad (4.1.)$$

where $$T_i = \frac{K_i T}{2K_p} = 0.016 \frac{K_i}{K_p}$$

$$\alpha = \frac{1-T_i}{1+T_i}$$

$$\hat{\bar{K}} = K_p K_c K_m K_t (1 + T_i) = 0.08\, K_p (1+T_i)$$

=Overall Gain of the system

$$G_d(z) = Z^3 - (A+1)Z^2 + Z(A+\hat{\bar{K}}) - \hat{\bar{K}}\alpha$$

The open loop transfer function is :

$$G_{op} = \hat{\bar{K}} \frac{Z-\alpha}{Z(Z-1)(Z-A)} \qquad (4.2.)$$

Figure 4,3. shows the root locus of the closed loop system.

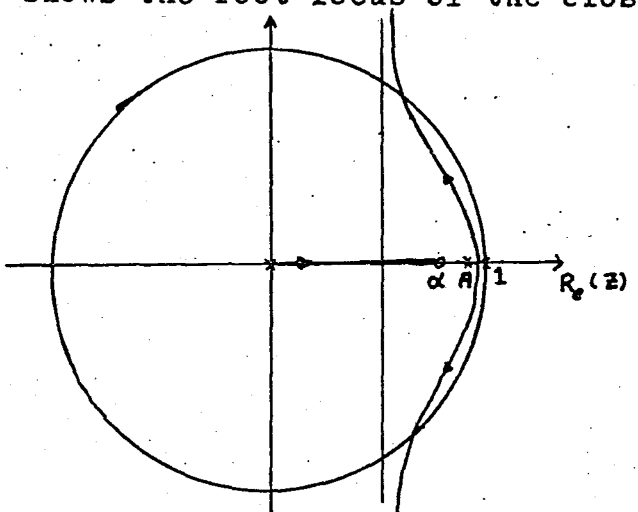


Figure 4.3. Root-locus of the system

The error can be easily calculated as :

$$E(z) = \frac{Z(Z-1)(Z-A)}{G_d(z)} \times R(z) \qquad (4.3.)$$

The steady state value of the error in response to an step reference input is obtained using the final value theorem.

$$\text{final error} = \lim_{Z \to 1} \frac{Z-1}{Z} \cdot \left[\frac{Z(Z-1)(Z-A)}{G_d(z)} \times \frac{Z}{Z-1} \right]$$

$$= \text{Zero}$$

The deviation of speed as a function of a load torque disturbance is also easily obtained to be :

$$N(z) = \frac{B.Z(Z-1)}{G_d(z)} \times V_{TL}$$

The steady state values of this deviation due to an step load torque disturbance is:

$$\text{S.S.deviation of speed} = \lim_{Z \to 1} \frac{Z-1}{Z} \cdot \left[\frac{BZ(Z-1)}{G_d(z)} \times \frac{Z}{Z-1} \right]$$

$$= \text{Zero}$$

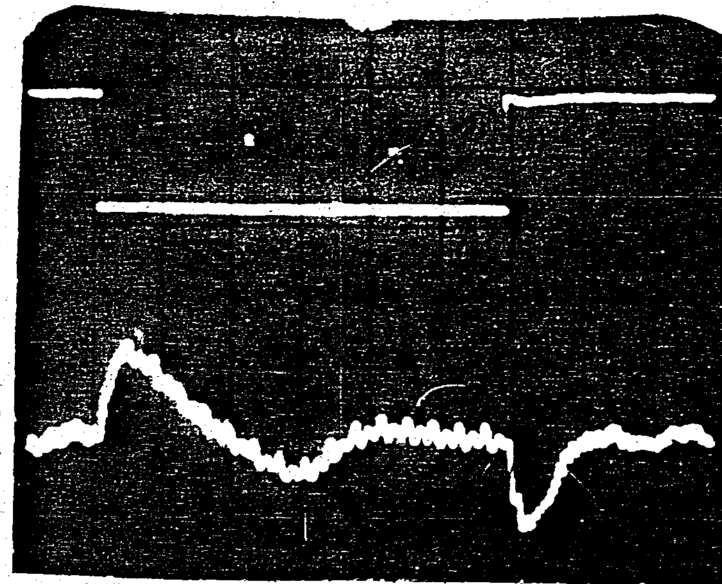
These calculated final values of error and speed deviation were expected, because of the Integral control algorithm used in the program.

4.2. Experimental Results

In figure 4.4. and 4.5. the response of the motor to a sudden change in load torque and in reference speed for two K_i and K_p values are shown. Depending on the desired dynamic response, the values of K_p and K_i can be calculated and the system can be operated with these values.

0 A

680
rpm



Response in sudden change in load.

Upper trace:Load current

Lower trace:Output speed

1 div=1 A,20 rpm,100 ms.

680
rpm

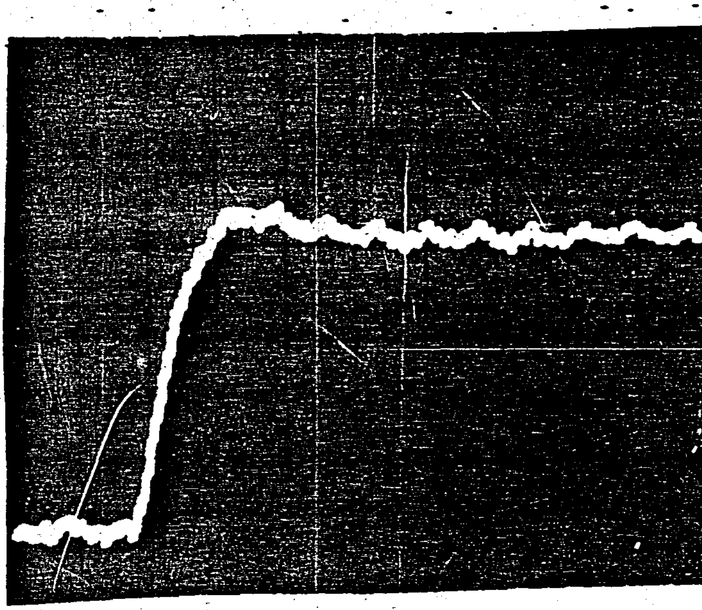
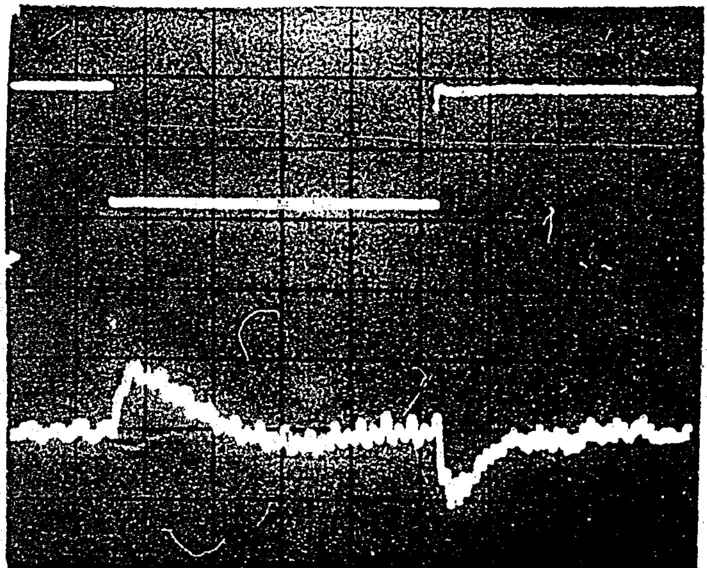


Fig.4.4Response to asudden change in reference speed

1 div.=20 rpm =0.2s ,load current 1.5 A

K_i=30 K_p=1.5



0 A

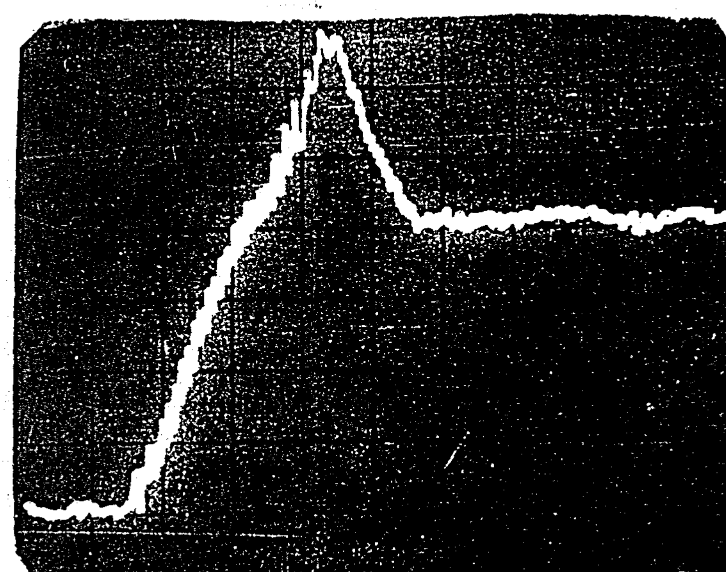
680 rpm

Response to a sudden change in load

Upper trace:Load current

Lower trace:Output speed

1 div.=1 A=20 rpm = 100 ms.



680 rpm

Fig.4.5. Response to a sudden change in reference speed

1 div=20 rpm =0.2 S,load current=1.5 A

$K_i=60 \quad K_p=3$

The obtained experimental results agree closely with the simulation results.The deviations can be thought as the approximations used in power amplifier,motor,and tachogenerator transfer functions.

CONCLUSION

In this thesis, the design,implementation and experimental results of a Z-80 based system for the firing of a three-phase full-converter,and one of its applications i.e. PI control of a separately excited dc motor has been explained .The approach used is all digital,simple and not requiring extensive hardware or any adjustment.

Since a PI control algorithm is used,the steady state error as well as the deviation of the speed due to the load disturbance are set to zero.

It is possible to control the motor using any type of control or design algorithm depending on the required dynamic and steady state performances only by a very small change in the software.

Four quadrant operation is a requirement which is mett quite often in industry.With the system described this is possible only by reversing the field or armature connections,but this is not a good solution.A better method would be the use of a dual converter.The system described can be easily modified both in hardware and software for this purpose.

The resolution of the firing angle of the bridge is 0.94 degrees which is suitable for many applications, If this resolution is not found satisfactory for a especial application,it can be reduced to 0.47 degrees by a modification in the sofware.This will necessiate an extra output pin and the twice of the clock frequency of the counter.Both are available in the system.

If a better Input-Output characteristics of the bridge is required without any back and front limits in all the firing angle ranges,it can be achieved at the cost of the increase complexity of the external hardware.(4)

A soft start routine can also be inserted into the program for automatic starting purposes if required.

All these explained possible modifications reveal the flexibility of microprocessor based control systems.

The use of microprocessor provides a very satisfactory solution in the application discussed.The task could also have been performed by a hard-wired system,but many of the conveniences and the flexibility obtained with the microprocessor based systems would have been lost,Although the use of microprocessor may not be economical,the vonveniences of operation of the system,the accuracy,reliability, and flexibility offered justify the cost.

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