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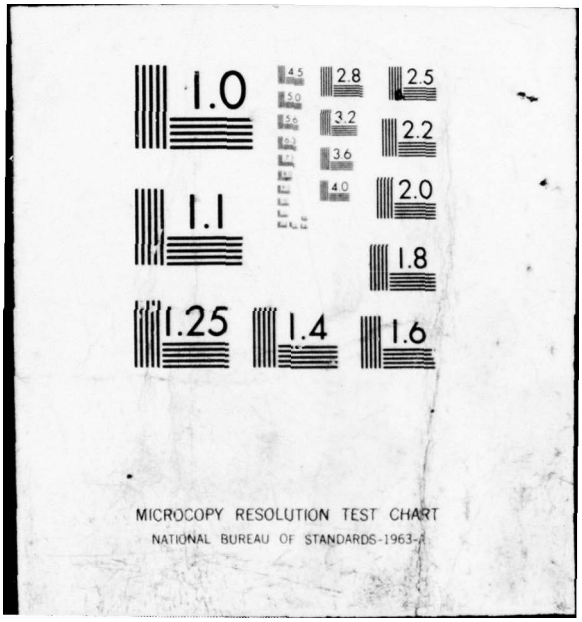
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A MICROPROCESSOR CONTROLLED MOTOR CONTROLLER FEASIBILITY STUDY

by

Arthur L. Gulovsen

January 1978

The Charles Stark Draper Laboratory, Inc.
Cambridge, Massachusetts 02139

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A microprocessor controlled motor controller feasibility study has been completed by the Charles Stark Draper Laboratory for the U. S. Navy.

In addition to verification of the concept of a microprocessor as the controlling element of a motor control system, design goals included the hardware realization of a control algorithm which maximizes system performance by minimizing harmonic, transient and steady state current, and also maximizes

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20. Abstract (Continued)

system reliability by limiting the stresses and overloads to each component.

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Publication of this report does not constitute approval by the U.S. Navy of the findings or conclusions contained herein. It is published for the exchange and stimulation of ideas.

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SUMMARY-CONCLUSIONS

1.1 Introduction

The Microprocessor controlled Motor Controller Feasibility study was conducted by The Charles Stark Draper Laboratory (CSDL) from December 1975 to January 1978. Design goals included the hardware realization of a control algorithm which maximizes system performance by minimizing harmonic, transient and steady state current, and also maximizes system reliability by limiting the stresses and overloads to each component. Verification of the concept of using a microprocessor as the controlling element of a motor control system was another goal.

1.2 Conclusions

Variable frequency control is a proven efficient method of controlling the speed of ac induction motors. Variable pulse per cycle control and transient speed control, as implemented in this microprocessor controlled motor controller system, provided significant improvement to induction motor speed control. The slip control and output frequency limit algorithm also improved motor speed system performance, to a lesser degree.

All design goals established for this feasibility study were attained.

A microprocessor controlled motor controller was designed, fabricated and debugged by CSDL and the microprocessor was programmed and debugged. The results of tests conducted with an ac induction motor verified improved motor performance and showed the concept of using a microprocessor for this type of application a definite success.

A FORTRAN model of the motor and controller was generated, and a simulation conducted on the CSDL Amdahl computer. The results gave further proof of the feasibility of the overall concept.

SECTION 2

CONTROL ALGORITHM BASIC DESCRIPTION

2.1 Variable Frequency Control

Variable frequency control has been proven as an efficient method of controlling the speed of ac induction motors. Frequency is easily varied over an 8 to 1 range and could be increased if desired. A constant volt-time product (modified by slip control routine) must be maintained at the motor input over the frequency range. This requirement causes some secondary problems and the control algorithm has been designed to alleviate them.

The best motor control performance results from incorporation of the following major features into the control algorithm:

(1) Variable pulse per cycle control

(2) Transient speed control

(3) Slip control

(4) Output frequency limit

The advantages of each feature are described below.

2.2 Variable Pulse Per Cycle Control

Pulse width modulation is used to maintain a constant volt-time product over the frequency range. With this type control the percent modulation varies directly with frequency while the harmonic content of the waveform is a function of the percent modulation. The harmonic content of the waveform at a particular frequency is a function of the number of pulses per cycle. By increasing the number of pulses per cycle in the lower frequency ranges, a reduction in the 5th and 7th harmonics may be achieved.

(a) Frequency of 45 to 60 Hz 1 pulse/cycle full pulse width

(b) Frequency of 30 to 45 Hz 2 pulse/cycle 1/2 pulse width

(c) Frequency of 10 to 30 Hz 4 pulse/cycle 1/4 pulse width

(d) Starting at 7.5 to 10 Hz 8 pulse/cycle 1/8 pulse width

Not only is the harmonic content reduced thereby reducing the heat dissipation of the motor, but motor cogging, a problem in the past, is also eliminated by applying more pulses of smaller pulse width during lower speed conditions.

2.3 Transient Speed Control

Starting and reversing motor currents can be 5 to 6 times full load running currents if maximum frequency is instantaneously applied or plug reversing of the motor is allowed. Starting and reversing motor currents may be reduced to 2.5 times full load running current if the frequency change applied to the motor is limited to a specified increment above or below the present motor speed. This approach essentially slews the motor to the desired operating speed. The torque created by the motor is greater than that of the brute force approach, therefore, the motor can be started and reversed faster while drawing less current.

It must be emphasized that direct plug reversing of a motor should be definitely avoided when designing a motor controller system.

2.4 Slip Control

Slip is determined by comparing the frequency applied to the motor with actual motor speed measured by a tachometer. Slip is usually controlled by varying the applied voltage, but in this case slip is controlled by varying the pulse width.

The torque-speed characteristic of a motor varies as the square of the applied voltage at a particular frequency. If the slip is too small (motor running close to synchronize speed) the applied voltage (pulse width) is decreased thereby lowering the torque-speed motor curve causing the motor to run slower. If the slip is too large, the pulse width is increased, increasing the torque-speed curve causing the motor to run faster.

The prime advantage of this type control is a reduction in motor current made possible by an improvement in power factor. With a motor running at ideal slip its power factor is about 0.85. Power factor decreases fairly rapidly at low slip approaching zero at synchronous speed, therefore, by controlling the pulse width applied to the motor its torque-speed curve is effected causing the motor to run close to its ideal slip. The result is a higher power factor and a lower motor current.

2.5 Output Frequency (Motor Speed) Limit

Motor temperature and average motor current are monitored. If exceeding a specified limit, the applied frequency is reduced. Alarms and motor shut downs would occur at still higher temperatures and currents. The applied frequency is similarly limited if the primary voltage source (a battery in this application) drops below a given value. Pulse width is reduced at higher battery voltage resulting in a constant volt-time product.

SECTION 3

BASIC SYSTEM DESCRIPTION

Figure 1 is a block diagram of the implementation of a control algorithm. The following is a description of the major elements.

The micro-computer's (microprocessor + memory) program is entered and altered by the operator via the teletype unit. Speed command, motor speed, motor current, motor temperature, and battery voltage are signal conditioned and then input to the micro-computer via the I/O circuitry. The micro-computer calculates frequency, number of pulses per cycle and pulse width and performs the real time generation of phase, frequency and pulse width control which are output via the I/O circuitry. The output interface electronics performs the additional timing and interlocks necessary for SCR commutation and control. The gate drive circuits provide the ground isolation and gate current drive required to turn the SCR's on. The SCR power stages deliver the 3 phase power to the motor.

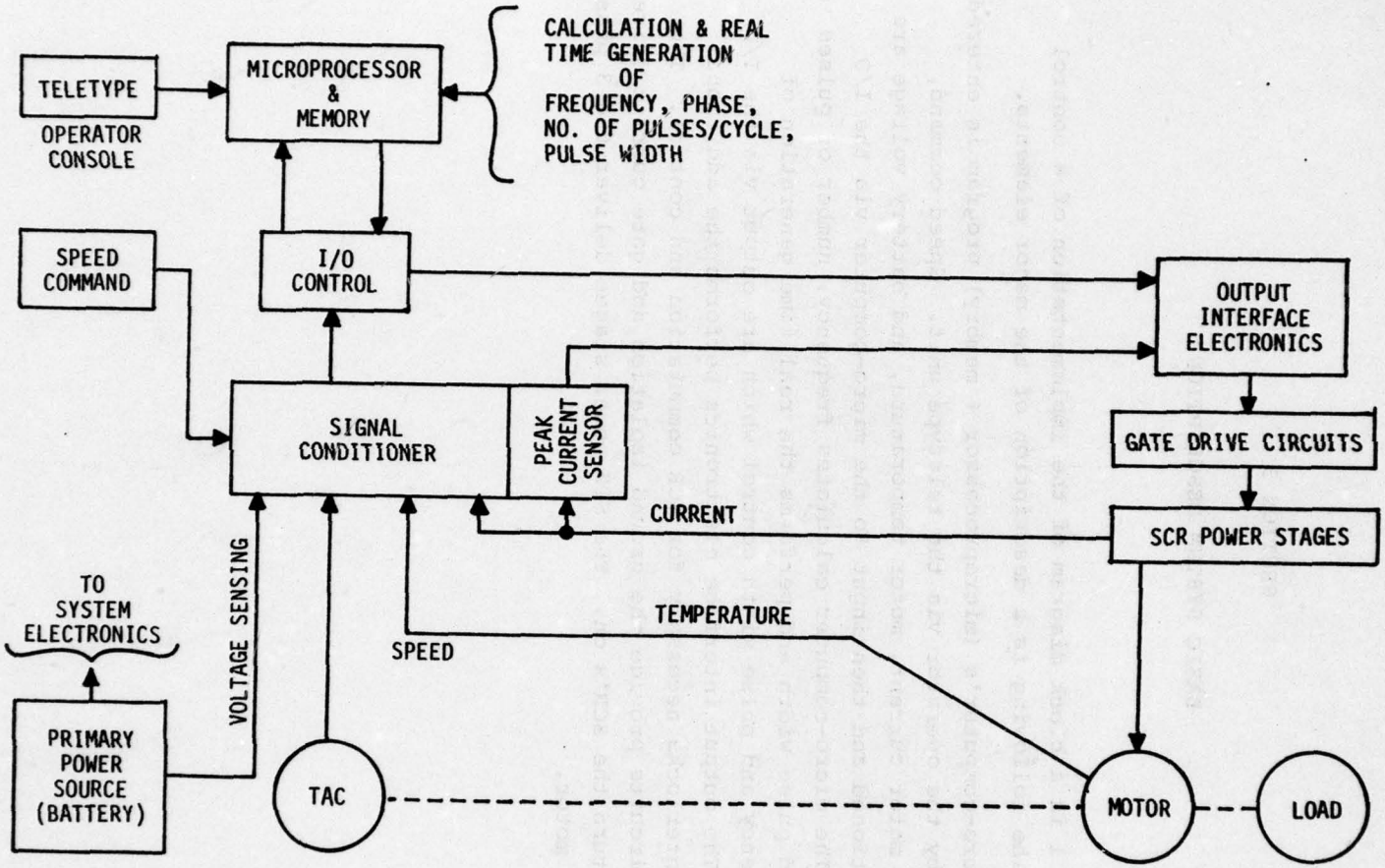


Figure 1. System block diagram.

SECTION 4

SOFTWARE DESCRIPTION

4.1 Overall Program Organization

The program is organized into an inner and outer loop configuration in which three main tasks are performed.

(1) Calculation of output frequency (FC), pulse width (PW); and the number of pulses per cycle (PC), based on input conditions, is performed in part of the outer-loop.

(2) The inner-loop under interrupt control performs the real time generation of phase frequency and pulse width.

(3) An additional calculation is performed in the outer loop which converts FC and PW to a set of parameters which is required for the function of the inner-loop.

The mnemonics for the microprocessor (BSR, JSR, RTS, etc.) are defined in the literature furnished with the processor and are not included in this report. The program flow diagram (Figure 2), should be referenced when reading the descriptions.

4.1.1 Parameter Calculations

(1) Input the present conditions

- (a) Operator speed command (Sc)
- (b) Motor speed (TAC)
- (c) Motor current and Temperature (IAVE & Temp)
- (d) Battery voltage (BPL)

(2) Calculate: based on input information

- (a) Output frequency command (Fc)
- (b) Number of pulse per cycle (# P/C)
- (c) Width of each pulse (PW)

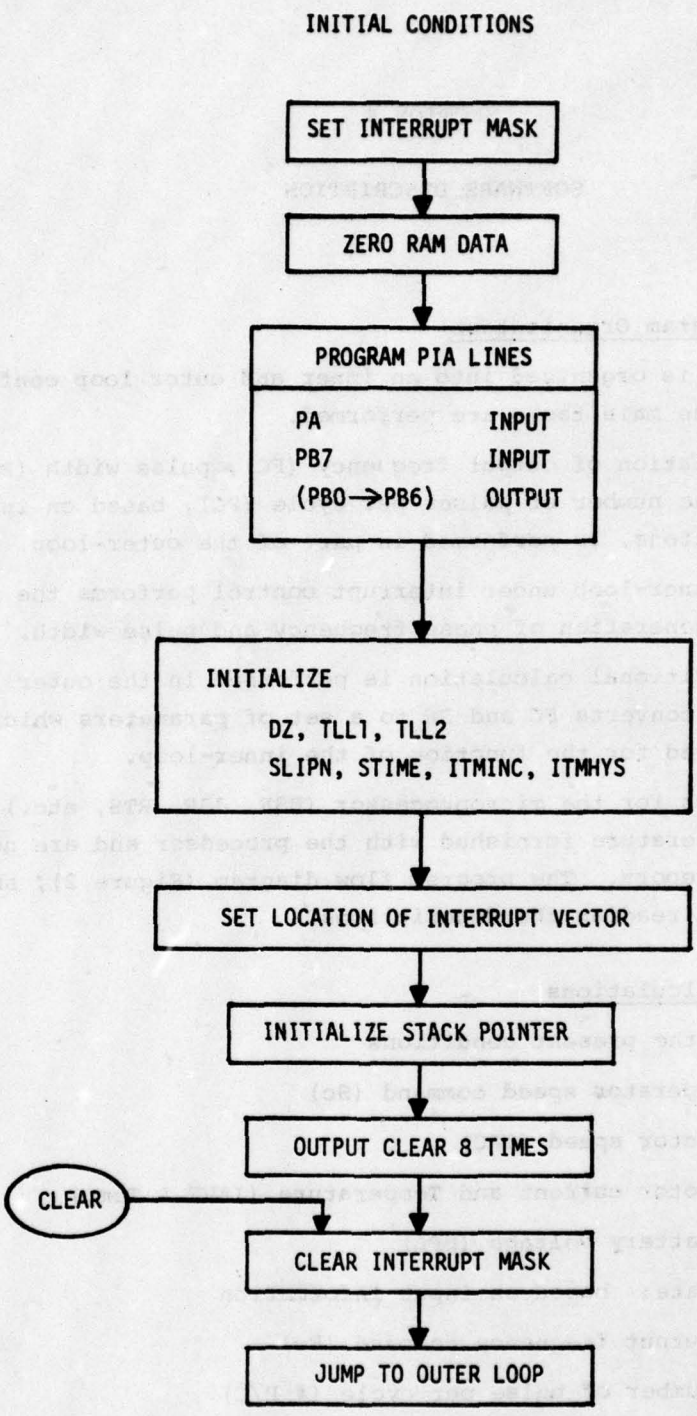


Figure 2. Initial conditions.

(3)* Calculate: based on pulse width.

(a) Pulse width counter (PWCNT).
The number of interrupts until the pulse width generator is evoked.

$$PWCNT \approx PW/\text{interrupt time}.$$

(b) Pulse width register (PWREG).
The time remaining to be counted down by the inner-loop pulse width generator.

$$PWREG = PW - PWCNT \times \text{interrupt time}.$$

(4)* Calculate: based on frequency and pulses per cycle.

(a) Frequency counter (FCCNT).
The number of interrupts until the frequency generator is evoked.

$$\text{Period} = \frac{1}{FC \times PC}$$

$$FCCNT = \frac{\text{Period}}{\text{interrupt time}}$$

(b) Frequency register (FCREG).
Represents the time remaining to be counted down by the inner-loop frequency generator.

$$FCREG = (\text{Period} - FCCNT \times \text{interrupt time}) \times FC.$$

*Note: There is a delay time (INDEL) which is subtracted from PW and Period in the above calculations. The delay is associated with the microprocessor interrupt and program execution times.

4.1.2 Real Time Generation of Phase, Frequency, and Pulse Width

(1) Frequency generation (FCGEN).
A timer which generates the period of the multiple pulse output frequency (FC x PC).

FCCNT is decremental after each interrupt. When the FCCNT equals zero the FC generator is evoked which counts down FCREG. When FCREG equals zero the processor outputs ϕA, ϕB, ϕC and PULSE commands.

(2) Pulse width generation (PWGEN).
PWCNT is decremental after each interrupt. When PWCNT equals zero the PW timer is evoked which counts down PWREG. When PWREG equals zero the processor outputs ϕA, ϕB, ϕC and $\overline{\text{PULSE}}$ commands.

(3) Three phase generation: (Based on # P/C and sign of Fc). (GENPH)
Determines if there is to be a phase change during the next pulse width cycle and the direction of phase rotation. The phase generation routine is executed following the frequency rate generator routine.

(4) Short pulse width generations (SHTPW).
Same as pulse width generation except it immediately follows the frequency generation executed when pulse width time is less than one interrupt plus delay.

(5) Inner loop program flow.
(a) PWGEN routine
(b) FCGEN routine
(c) SHTPW routine
(d) GENPH routine
(e) RTI (return from interrupt)

4.1.3 Data Definition

Input Data

(1)	SC	Speed Command magnitude input (1 bit = 1/4 Hz)
(2)	SCSGN	Speed Command sign input (CW/CCW)
(3)	TAC	Tachometer feedback magnitude input (1 bit = 1/4 Hz)
(4)	TACSGN	Tachometer feedback sign input (CW/CCW)
(5)	BPL	Battery voltage magnitude (1 bit = 1/2 V)
(6)	BPLSGN	Battery voltage sign
(7)	IAVE	Average motor phase current magnitude
(8)	IAVSGN	Average motor phase current sign
(9)	TEMP	Motor temperature magnitude
(10)	TEMSGN	Motor temperature sign

Output Data

(1)	Phase plus Pulse Command	4 bits of information - (QA, OB, QC, PULSE). Output occurs at the start and stop of pulse width (PW). Output rate is a function of frequency command (Fc) and number of pulses per cycle (PC)

(2)	Test	Internal program data (selected by operator) is outputted to a D/A. Used for program evaluation

Internal Data

(1)	PW	Pulse width (1 bit = 10 microseconds)
(2)	PWCNT	Number of interrupts prior to evoking PW timer
(3)	PWREG	Pulse width time remaining to be counted down by PW timer
(4)	FC	Frequency
(5)	DLTF	Used in FC hysteresis calculation
(6)	FCCNT	Number of interrupts prior to evoking FC generator
(7)	FCREG	Used with FC in the FC generator to real time frequency output
(8)	FCREGH	FCREGH used during FCCNT and FCREG calculations. FCREGH and FCREG are loaded with $104 = 260 2600 microseconds is the period of the maximum output frequency
(9)	FCINTR	Used during FCCNT and FCREG calculations FCINTR = interrupt time x FC
(10)	FCDEL	Used during FCCNT and FCREG calculations FCDEL = frequency delay time x FC
(11)	FCREM	Used during FCCNT and FCREG calculations FCREM is the lower 8 bit remained when FCINTR is calculated.
(12)	Phase	A three bit code which represents phase information
(13)	PHPONT	Points to one of six memory locations which store phase information
(14)	PC	Number of pulses per cycle - really the number of pulses per phase used in phase generated routine for incrementing PHPONT.
(15)	R	Remainder - used with PC in phase generation routine
(16)	SCTAC	Speed command minus TAC
(17)	DZ	Speed command dead zone - has hysteresis
(18)	TLL1	TAC dead zone (motor starting) - has hysteresis

(19) TLL2 — TAC dead zone (motor running) - has hysteresis.

(20) SLIPN — Used in slip control routine to increment the effects of (SCTAC/IDEAL SLIP) on pulse width.

(21) STIME — Used as delay in incrementing SLIPN in slip control routine.

(22) ISCALE — Used in frequency foldback due to current (IFOLD) routine. A time delayed increment of FC due to high current.

(23) ITMHYS — Used in IFOLD - equals either 1 or 2 seconds (hysteresis). High currents must be present for 2 seconds before foldback of frequency may occur. Enables normal current transients during motor slowing up or down.

(24) ITIME — Used in IFOLD. ITIME equals the length of time. IAVE is greater than the current limit. ITIME must be greater than ITMHYS before IFOLD routine may be evoked.

(25) ITMINC — Used in IFOLD. ITMINC causes a 50-millisecond time delay in the incrementing of ISCALE.

(26) MLTCAN — Used in multiply routine.

(27) DENOM — Used in divide routine.

(28) Zero — False data for programming convenience.

(29) Zero 1 — False data for programming convenience.

(30) data n — +data being calculated in the outer loop
data X — +data transferred from outer to a transfer state
data I — +data being used by inner loop

Outer loop	Xfr loop	Inner loop
PWCNT	PWCNTX	PWCNTI
PWREG	PWREGX	PWREGI
FCCNT	FCCNTX	FCCNTI
FCREG	FCREGX	FCREGI
FC	FCX	FCI
SCSGN	SCSGNX	SCSGNI
PC	PCS	PCI
		PHASE I

*PHASE is generated within the inner loop.

4.2 Subroutine Description

The following paragraphs describe the subroutines of the overall program. The referenced figures are flow diagrams for the subroutine.

4.2.1 Initial Conditions Routine

a. All memory data is initialized to zero except:

Dz = 8 Hz

TLL1 = 3 Hz

TLL2 = 5 Hz

SLIPN = MAX

STIME = 10 ms

ITMINC = 50 mx

ITMHYS = 2 sec

b. PIA is programmed:

PIAPA = Input

PIAPB7 = Input (Sign)

PIAPB(0→6) = Output

PlAPB(4,5,6) for decoding.

PlAPB(0,1,2,3) for data.

PB6	0	0	0	0	1	1	1	1
PB5	0	0	1	1	0	0	1	1
PB4	0	1	0	1	0	1	0	1
	Sc	TAC	B+	IAVE	Temp	Q+PW	Test LO Order	Test HI Order
	INPUT					OUTPUT		

c. Output clear command 8 times

Clear is defined as ϕA, ϕB, & ϕC all low. Therefore no frequency is applied. The motor is at a stand still, but the commutation capacitors are charged.

4.2.2 Input Subroutine

a. Speed command, tachometer, B+, Average current, and Temperature are input to the processor and stored in memory.

b. The sign of all inputs are tested and the magnitude complemented if negative.

c. The index register is used to load the input data into the correct location in memory.

4.2.3 IFOLD

The function of this routine is to limit long term motor current below a prespecified limit by reducing the speed command. Motor accelerating and decelerating currents exceed the current limit but do not cause a SC foldback unless they exist for a period longer than 2 seconds.

When the current limit is exceeded ITIME is incremented and compared to ITMHYS. ITMHYS is initialized to 2 seconds. If ITIME is less than ITMHYS the foldback of SC is bypassed. If ITIME exceeds ITMHYS, ITMHYS is set to 1 second.

Once ILIM and ITMHYS have been exceeded, SC foldback due to IAVE begins. The method of SC foldback is to compare SC to the ratio $\left(\frac{\text{IAVE - ILIM}}{\text{IMAX - ILIM}}\right)$ and if the input SC is greater, set SC to $\left(\frac{\text{IAVE - ILIM}}{\text{IMAX - ILIM}}\right)$. It is necessary to implement SC foldback in an incremental and time delayed fashion, otherwise large current transients due to rapid SC changes would result. The delay is implemented by preloading ITMINC to 25 and decrementing each pass through the outer loop. Assuming 2 milliseconds per pass, this results in a 50 milliseconds delay.

The incrementing of SC is implemented through the calculation of ISCALE.

If ISCALE is greater than $\left(\frac{\text{IAVE - ILIM}}{\text{IMAX - ILIM}}\right)$

then ISCALE = ISCALE - $\left[\left(\frac{\text{IAVE - ILIM}}{\text{IMAX - ILIM}}\right)\right]$ - ISCALE /8 .

If ISCALE is less than $\left(\frac{\text{IAVE - ILIM}}{\text{IMAX - ILIM}}\right)$

then ISCALE = 7/8 ISCALE.

With time ISCALE $\approx \frac{\text{IAVE - ILIM}}{\text{IMAX - ILIM}}$.

When current falls below ILIM and ITIME is less than ITMHYS, ISCALE is reduced as follows ISCALE = ISCALE/2.

4.2.4 Sc Foldback

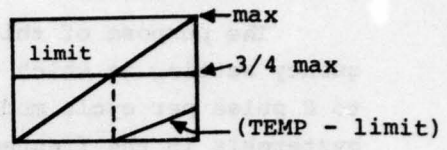
a. B+ and Temperature are tested for exceeding a prespecified limit. If so, speed command is limited.

b. A clear command is generated if an undervoltage condition exists.

c. Example of TEMP limit:

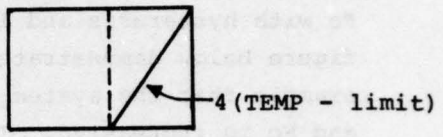
1) Subtract limit for TEMP

1a) Skip to end if less than limit

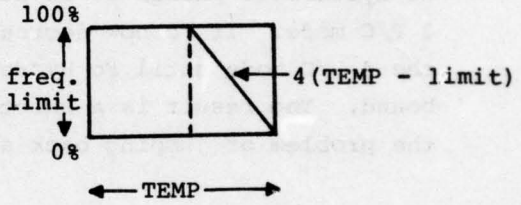


2) Scale (TEMP - limit)

Multiply by 4



3) Complement 4(TEMP - limit)



4.2.5 Set Condition

Frequency command Fc is generated as a result of series of tests which determine if the system is in a steady state, transient (starting, stopping or reversing) or zero rate condition.

If steady state condition	Fc = Sc
If transient starting condition	Fc = Tac + DLTUP
If transient stopping condition	FC = Tac - DLTDW
If transient reversing condition	1st Fc = Tac - DLTDW (sign = TAC sign)
	2nd Fc = Tac + DLTUP (sign = Sc sign)
If zero rate condition	Clear command issued
	DLTUP = 7.5 Hz
	DLTDW = 3 Hz

Hysteresis is incorporated to prevent chattering between the various conditions

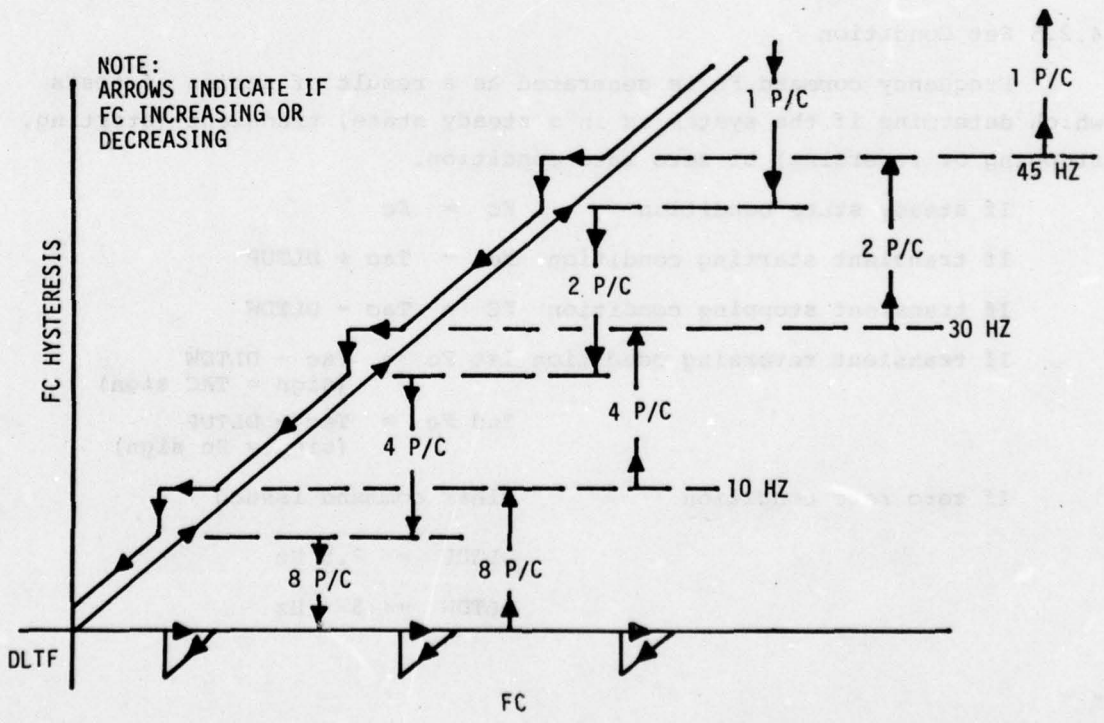
Sc dead zone (DZ = 7.5 and 8 Hz)

Tac low level (TLL_1 = 2.5 and 3 Hz)

(TLL_2 = 5 and 5.5 Hz)

4.2.6 Fc Hysteresis

The purpose of this routine is to insert hysteresis in the frequency setting at which the system switches from 1 to 2, 2 to 4, and 4 to 8 pulse per cycle mode (P/C). This is accomplished by inserting hysteresis in the frequency command (Fc), determining P/C based on Fc with hysteresis and later removing the hysteresis from Fc. The figure below demonstrates the operation of this scheme. Consider for example that the system is operating in the 4 pulse/cycle (4 P/C) mode and Fc is increasing. The system will remain in the 4 P/C mode until Fc Hysteresis passes 30 Hz at which time the system switches to the 2 P/C mode. If Fc now decreases, the system will not switch back to the 4 P/C mode until Fc Hysteresis passes through the calculated lower bound. The result is a smooth transition of Fc from 0 to 60 Hz, while the problem of jumping back and forth between P/C is eliminated.



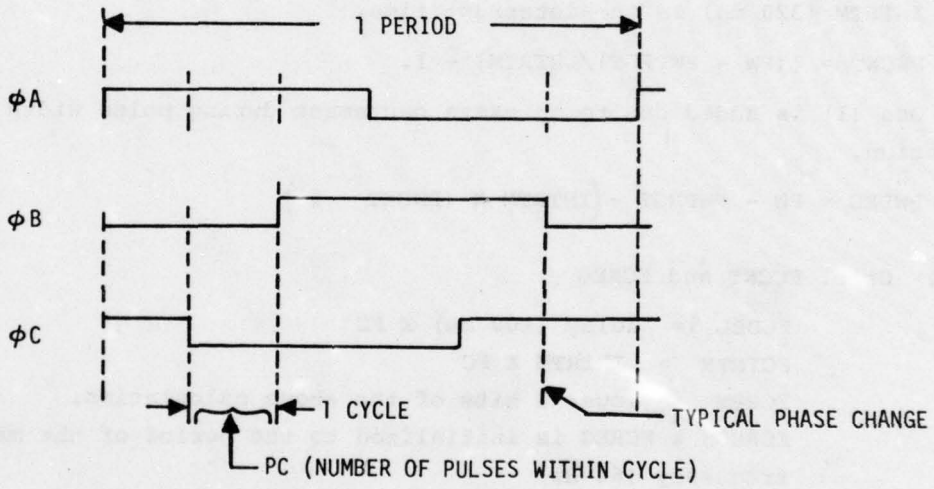
4.2.7 Adj FCREG, PC, PW

Frequency register (FCREGH and FCREG), number pulses per cycle (PC) and pulse width (PW) are generated as a function of frequency command (Fc) per the following table:

Fc	FCREGH & FCREG	PC	PW (ms)
45 to 70	104 H	1 (80_H)	2.55 (FF_H) ≈ MAX PW
30 to 45	82 H	2 (40_H)	1.27 ($7F_H$) ≈ MAX PW/2
10 to 30	41 H	4 (20_H)	0.63 ($3F_H$) ≈ MAX PW/4
Below 10	20 H	8 (10_H)	0.31 ($1F_H$) ≈ MAX PW/8

Hexidecimal

NOTE: Assuming the 4 PC mode, the processor will output four pulses of 0.63 ms to the motor between each phase change. There are six phase changes each complete period.



4.2.8 Slip Control

SLIPN is incremented every 10 ms as a function of slip (SCTAC). Pulse width (PW) is varied as a function SLIPN resulting in an effective reduction in output voltage. The object is to operate the motor near its ideal slip resulting in an improvement in power factor and a reduction in motor current. The square root (modified) of slip is calculated and multiplied by (PW). A modified square root routine is

used due to its simplicity and speed of calculation. An exact square root routine would take far too long to calculate and is not necessary.

The following indicates why the square root is used.

Output motor torque is a function of output voltage squared, ($T = k_1 V^2$). Output voltage is a function a pulse width, ($V = k_2 PW$). Therefore if we make pulse width a function of square root of slip ($PW = k_3 (Sc-TAC)^{1/2}$), then output motor torque will be a direct function of slip. $T = k\ (Sc-TAC)$

4.2.9 Adj PW for B+

Pulse width is adjusted for changes in B+ resulting in a constant output voltage to the motor independent of B+.

ADJ PW = $\frac{100V}{B+}$ (PW) for B+ between 100 to 128 Volts.

4.2.10 Calc. PWCNT and PWREG

PWPRGT (50 ms) is the PW program time delay.

INTRTM (320 ms) is the interrupt time.

PWCNT = [(PW - PWPRGT)/INTRTM] + 1.

One (1) is added due to an extra decrement during pulse width generation.

PWREG = PW - PWPRGT - (INTRTM X (PWCNT - 1))

4.2.11 Calc. FCCNT and FCREG

FCDEL = delay (100 ms) X FC
FCINTR = INTRTM X FC
FCREM = lower 8 bits of the above calculation.
FCREGH & FCREG is initialized to the period of the maximum frequency (64 Hz)
FCCNT = [(FCREG - FCDEL)/FCINTR] - 1.

One (1) interrupt is always intentionally missed during inner loop operation, therefore the minus one (-1).

FCREG = FCREG - FCDEL - ((FCCNT + 1) X FCINTR)

4.2.12 Test Output

One word of previously selected processor internal data is outputted via the PIA to a digital to analog (D/A) module. Used for evaluating algorithm or system performance.

4.2.13 Transfer Information

Outer loop information is transferred inner loop to an inbetween transfer state. Transfer may occur only immediately following a return from inner loop. This is accomplished by clearing "zero" and then testing for a change in "zero". The inner loop loads "zero" with #1. The purpose of this subroutine is to prevent an improper mix of new and old data being used by the inner loop.

4.2.14 Multiply Subroutine

Multiplies fractions or a fraction and a whole number. The steps are:

(1) The multiplicand is stored in A.
The multiplier is stored in B.

(2) The program branches to the multiply subroutine.

(3) The multiplicand is stored in memory (MLTCAN).

(4) The multiplication routine runs.

(5) The result develops in A.

(6) Branch back to main program. (Result is an A.)

4.2.15 Divide Subroutine

Numerator < Denominator

The steps are:

(1) The numerator is stored in B.
The denominator is stored in A.

(2) The program branches to divide subroutine.

(3) The denominator is stored in memory DENOM.

(4) The divide routine runs.

(5) The result develops in A.

(6) Branch back to main program. (Result is A.)

4.2.16 GENPH - Generate Phase Pointer and Phase

The phase pointer (PH PONT) points to one of six phase combinations stored in memory. As the PH PONT increments (1, 2, 3, 4, 5, 6, 1, 2, etc.) the phase combinations sequentially pointed to in memory represent a 3-phase clockwise rotation.

The phase pointer is incremented or decremented each time it is necessary to make a phase change. This is determined by multiplying (PC) by 2 and adding the results to (R) remainder. Each time a carry results the phase pointer is incremented or decremented depending on the sign of the frequency command (Sc Sign).

4.2.17 Output Information

Phase and PW are outputted to interface electronics by way of the PIA.

SECTION 5

HARDWARE DESCRIPTION

The Motor Controller, as implemented, required 5 standard rack mounted p.c. cards, 3 power output stages and six SCR driver cards.

The five p.c. cards are as follows:

A1 - TTY Interface

A2 - Computer Card

A3 - Input Card

A5 - Output Interface Card

A6 - Adapter and D/A Card

A detailed functional description of these cards follows.

5.1 TTY Interface, Card A1

This card contains provisions for reset, halt, single step operation, TTY interface, and overvoltage protection for the +5 volt supply. Since all but the overvoltage protection are essentially standard circuits taken from the Motorola "M6800 Microprocessor Applications Manual," or Motorola Engineering Note "100", only this circuit will be described here.

The overvoltage protection circuit utilizes a dual transistor (T_1) to compare Zener D3 voltage with the +5 volt supply output voltage. If the 5-volt output is above a predetermined level (approximately 6 volts), transistor T_2 is turned on applying the gate signal to SCR1. This signal causes SCR1 to turn on thereby shorting the output of the 5-volt supply to ground through current limiting resistor R23 and a 5 Amp. fuse. The 5 Amp. fuse will then blow disconnecting the +5 volt supply from the +5 volt bus. At this point, the +5 volt supply, regardless of its peak output level, is unable to damage circuitry connected to the bus.

5.2 Computer Card A2

The computer card consists of the following:

1. One (1) P.I.A. (A4) - MC 6820
2. One (1) MCM 6810 (A3) (128 x 8) Static RAM
3. One (1) MCM 6830L7 (A2 (1024 x 8) MIKBUG ROM

} Teletype Interface

4. One (1) MC6871A (A7) two phase 1MHz Clock
5. Eight (8) 2102-1 (1024 x 1) Static RAMS
6. Two (2) DM 8097 Tri-State Gates

} (1024 x 8) Static RAM

7. One (1) MC 6800 (A8) Microprocessing Unit
8. One (1) MC 6820 P.I.A. (A9) for Input/Output
9. One (1) 74LS138 Address Decoder (A1)
10. Two (2) Level Shifting buffers for "Register B" Output of the I/O P.I.A. (7417)(A6), (A10)
11. Two (2) 7400 Quad Gates for miscellaneous logic operations (A11), (A22).

It was found that the only problems encountered in implementing this card were the normal problems encountered when using unfamiliar circuits for the first time (e.g., misinterpretation of data sheet, polarity reversals, etc.). These problems were very quickly overcome and do not warrant discussion.

5.3 Input Card A3

Proper implementation of the algorithm developed for micro-computer control of the motor controller requires the continuous sampling of a number of variables such as: motor speed command, tachometer output, etc. Since all of these are most readily sensed as analog quantities, it remains for the controller to convert these quantities into a form suitable for communication with the microprocessor.

Communication with the MPU is provided by the Data Translation Inc., Model DT-830, 8-channel data acquisition module. This module consists of an 8-channel analog multiplexer, a sample and hold circuit; a 10-bit bipolar A to D converter and associated control circuitry. A 3-bit address is provided to the MUX address input line by the MPU PIA output lines PB4, 5, and 6. By means of this, it is possible to select any one of the eight input channels available; only five channels are

required for this application. A clock pulse derived from CB2 by card A6, Adapter and D/A card, ensures that the address information presented to the MUX has stopped changing before a convert command is issued to the DT-830.

When a convert command is received, the sample and hold circuit, which has been tracking the input analog signal, holds the input signal until the conversion is completed.

The 10-bit successive approximation A/D converter makes the data available through tri-state output gates. The MSB (pin 62) is connected to PB7 while the next 8 bits are sampled by the data bus (PA0 - PA7); the LSB is not used in this application. Provision is also made on the card to enable the application of external calibration voltages to the DT-830. This permits calibration of the unit without removing it from card A3.

The board also contains signal conditioning circuitry for the tachometer output voltage and a means of generating a speed command input to the MPU.

All that is needed for the tachometer signal conditioning is an operational amplifier having low pass filtering in both the input and output circuits and a dc gain which provides the proper scaling factor between tachometer output and A/D input.

The speed command is derived from the ±15-volt supplies using a potentiometer across two 5.1 volt Zener diodes thereby providing a continuously varying voltage from +5 to -5 volts. This voltage is applied to a rate limiting circuit which prevents application of a step change to the controller input. Provision has also been made to apply a step of either +5 volts or -5 volts by setting the pot to 0 volt and activating a three-position toggle switch.

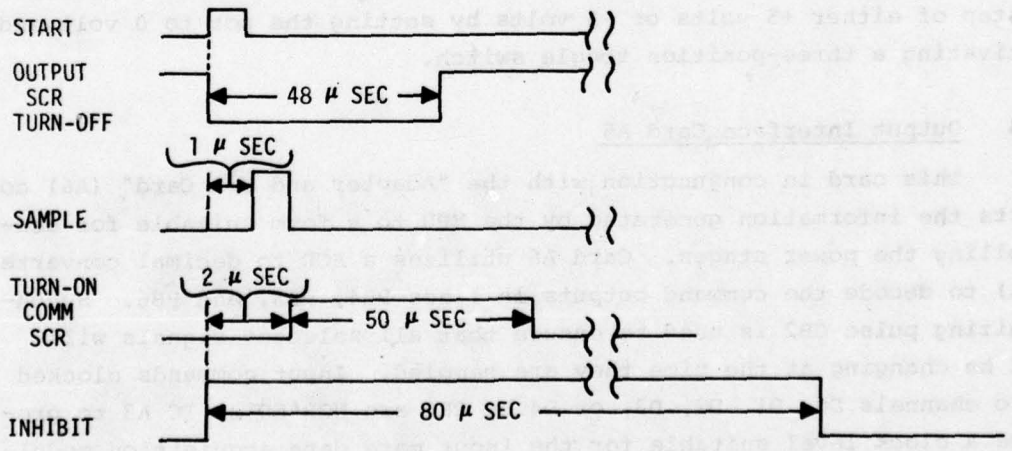
5.4 Output Interface Card A5

This card in conjunction with the "Adapter and D/A Card" (A6) converts the information generated by the MPU to a form suitable for controlling the power stages. Card A6 utilizes a BCD to decimal converter (A1) to decode the command outputs on lines PB4, PB5, and PB6. Synchronizing pulse CB2 is used to ensure that all selected signals will not be changing at the time they are sampled. Input commands clocked into channels D0, D1, D2, D3, or D4 by CB2 are NOR'ED by IC A3 to produce a clock level suitable for the input card data acquisition module.

Phase output sampling is selected by channel D5 which also produces the clock input necessary for the output card (A5). Calling up channels D6 and D7 of IC A1, permits the sampling of the data on lines PB0 through PB3 by the AD 7520 8-bit D/A converter IC (A7). With D7 sampling the higher order bits and D6 the lower order bits. ϕA, ϕB, ϕC information is operated on by the 8-channel data selector A9 to produce the ex or signal needed by output card A5. All of the signals produced by P.C. card A6 with the exception of the D/A output and the input clock are routed to Output Card A5 where they are used to generate the signals required by the power stage and power stage SCR drivers.

On card A5 the ϕA, ϕB, ϕC, PW and ex or information are combined by the quad and/or select gate (IC A9) to produce the waveform desired for the SCR gate drivers. This is accomplished by placing ϕA, ϕB, and ϕC information on the A inputs and the ex or information on the B inputs. The selection of the A or B inputs is then made to depend on the absence or presence of a "1" on the PW input. There is also a provision at this point to have a peak current limit condition or the "Clear" position of the "Clear-run" switch force the IC to select B inputs. At the same time the B inputs are forced to a "1" level.

The discussion up to this point has covered the generation of the proper waveforms to correctly operate the Power stage SCR drivers. If these stages are to function properly, the timing relationship between sample time, turn off of the output SCR's, and turn on of the commutation SCR's must be maintained. The correct timing is shown below:



Each time the clock input of Card A5 goes high, a 1 level is presented to the D Input of the MC 14015 dual 4-bit shift register (S.R.). This level is clocked into the S.R. by the 1 MHz clock Q2T. The inhibit pulse then removes the level to prevent multiple pulses from being loaded. Successive Q2T pulses shift this input pulse through the register and provide the output pulses shown above with the aid of three (3) one shot multivibrators. The main and commutate SCR pulses are nanded with the ϕA, ϕB,

5.5 SCR Driver Card

Each driver card consists of a main gate drive circuit and a commutate gate drive circuit. The commutate command is on the order of 50 milliseconds and, therefore, a pulse transformer with single ended drive is quite suitable. The main gate drive commands are much longer, therefore, a push-pull 25 KHz transformer coupled circuit with dc rectification in the secondary is utilized. Both circuits provide for gate current overdrive at turn-on. This insures higher di/dt SCR capability.

5.6 Interrupt Generation

A module-N-divider in conjunction with a one-shot generate a series of interrupt pulses at 320 milliseconds intervals. The timing of these pulses is reset at the start of each output pulse width. The function is implemented on card A1 and A6.

5.7 Power Stages

The McMurray Inverter was chosen as the power stage for this controller. The circuit is the classic McMurray circuit with the addition of a few added components dictated by real world practicalities.

Since the McMurray circuit has been described many times in the current technical literature, a description of its operation will not be included here.

The most noticeable deviation from the classic, is the inclusion of 40 μh inductors in the power stage (refer to the accompanying schematic). These pulus the RC snubbers across the individual SCR's were added to limit the reapplied dv/dt.

SECTION 6

SYSTEM SIMULATION

6.1 General Description

A FORTRAN model of the controller, motor and load was generated and a simulation was conducted on The Charles Stark Draper Laboratory Amdahl computer. The simulation helped verify the overall concept and led to refinements in the control algorithm. The simulation uncovered a basic flaw in a control function (IFOLD) and aided in finding a solution.

6.2 Model Organization

(1) CNTRl Subroutine - Models the control algorithm which exists in the microprocessor. The prime inputs are speed command (SC), Motor speed (TAC) and motor current (I). The prime outputs are frequency command (F) and Pulse width (PW).

(2) HRMNIC Subroutine - Determines the Fourier harmonics of the controller's output waveform which is delivered to the motor. The prime inputs are (F) and (PW) from which the shape of the waveform is determined and battery voltage (VB). The prime outputs are the Fourier voltage coefficients Vl, V5, V7, etc.

(3) MOTORZ Subroutine - Models the motor. The prime inputs are RMS voltage (V), harmonic number (N), frequency (F) and motor speed (STAC). The prime outputs are RMS motor torque (TQ), motor input current (Il), rotor current (I2), power factor (pf) and rotor loss (ROTL).

(4) MOTOR Subroutine - Passes the Fourier voltage coefficients (Vl, V5, V7, etc.) along with harmonic number, frequency and motor speed to the MOTORZ subroutine. Sums the resulting harmonic torques, currents, and rotor losses.

(5) LOADG Subroutine - Models a generator load. The prime inputs are motor torque (TORQ) and motor-load speed (RDTAC). The resulting output is the updated motor-load speed (RDTAC).

(6) LOOP Subroutine - Sequences the program through the subroutines and outputs the results to data files or the printer.

(7) MAIN Subroutine -

(a) Defines system parameters
(b) Establishes test conditions
(c) Calls loop a prescribed number of times

6.3 FORTRAN Model Program

Printout sheets for the FORTRAN model program are given in Appendix A.

6.4 Simulation Results

(1) Transient speed control

(a) The motor current is less, the motor torque is higher and the response of the motor faster by utilizing transient speed control versus allowing step speed command to be applied to the motor. The reduction in motor current is on the order of 2.5 to 1.

(b) DLTAUP = 7.5 Hz proved to be a good choice.

DLTADW = 3 Hz is a reasonable compromise. Initially it had been set to 7.5 Hz which did not reduce reversing currents sufficiently.

(c) TLL2 HYSTERESIS lowered to 5.5 and 5.0

(d) Motor starting: FC = BNDRYL + TAC.
Had been FC = BNDRYL.

(2) Multiple pulse per cycle boundaries - The frequency boundaries of the various pulse modes were adjusted to minimize motor current harmonics. The new boundaries are:

1 P/C	45 to 60 Hz
2 P/C	30 to 45 Hz
4 P/C	10 to 30 Hz
8 P/C	Below 10 Hz

(3) Slip Control - The basic approach functioned as designed. Some improvement in motor performance if PW was incrementally reduced in a delayed manner as a function of the ratio of slip/ideal slip.

(4) Current Foldback of Speed Command IFOLD - Significant changes were necessary to attain proper operation of this control function. Limiting speed command (SC) to the ratio of $\frac{IAVE - ILIM}{ILIM - IMAX}$ x MAX SC was found to be a sound concept. The simulation showed that large motor currents will occur unless the value of SC limit is incremented to its final value in a delayed fashion. Essentially what had been initially programmed was an unstable feedback loop and, therefore, compensation was required.

6.5 Simulation Curves

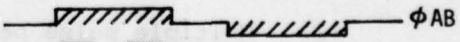
(1) Model Block Diagram (See Appendix A)

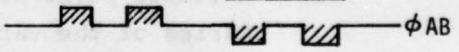
(2) Step Functions - speed, motor torque, and motor current are plotted vs time.

SF #1	SC = 0 to 60 Hz	No Controller	
	SC = +60 Hz to -60 Hz	No Controller	
SF #2	SC = 0 to 60 Hz	Controller	DLTUP = 7.5 Hz
	SC = +60 Hz to -60 Hz	Controller	DLTDW = 7.5 Hz
SF #6	SC = 0 to 60 Hz	Controller	DLTUP = 7.5 Hz DLTDW = 3 Hz
	SC = +60 Hz to -60 Hz	Controller	FINAL PARAMETER CONFIGURATION

(3) FOURIER Coefficients vs Percent Modulation

(a) Percent Modulation = (total pulse width/(2/3) period)* 100%

100% Modulation waveform 

50% Modulation waveform 

(b) 1st (V1) through 25th (V25) harmonic are plotted.

(c) Curves of 1, 2, 4 and 8 pulse modes are presented.

(4) Percent Harmonic at Various Pulse Modes vs. Frequency - Curves represent what the percent harmonic content would be if a fixed pulse mode were maintained over the full speed range.

(5) MOTOR Z Curves - Motor torque, current and power factor vs motor speed.

(a) Line frequency = 60 Hz

(b) Line frequency = 30 Hz

(c) Line frequency = 15 Hz

(6) ILIMIT

(a) Motor speed, torque and current vs. time.

(b) Test description

(1) Motor reverse from -60 Hz to 60 Hz @ T = 0

(2) Load torque increased step wise to exceed I limit @ T = 125

(3) Load torque increased further (time ramp) @ T = 300

(c) Controller configuration

(1) ILIMIT = .F. ILIMIT subroutine bypassed

(2) ILIMIT = 50 to 100 AMPS ILIMIT subroutine utilized

(d) Results

(1) Reversing current undisturbed by ILIMIT subroutine

(2) ILIMIT subroutine successfully limits motor current.

(7) Slip Control

(a) Motor torque, volts, current and PF vs time.

(b) Test description

(1) Normal load torque @ T = 0

(2) Incrementally reduces load torque @ T = 25

(c) Controller configuration

(1) Slip Control = .F. - slip control subroutine bypassed.

(2) Slip Control = .T. - slip control subroutine utilized.

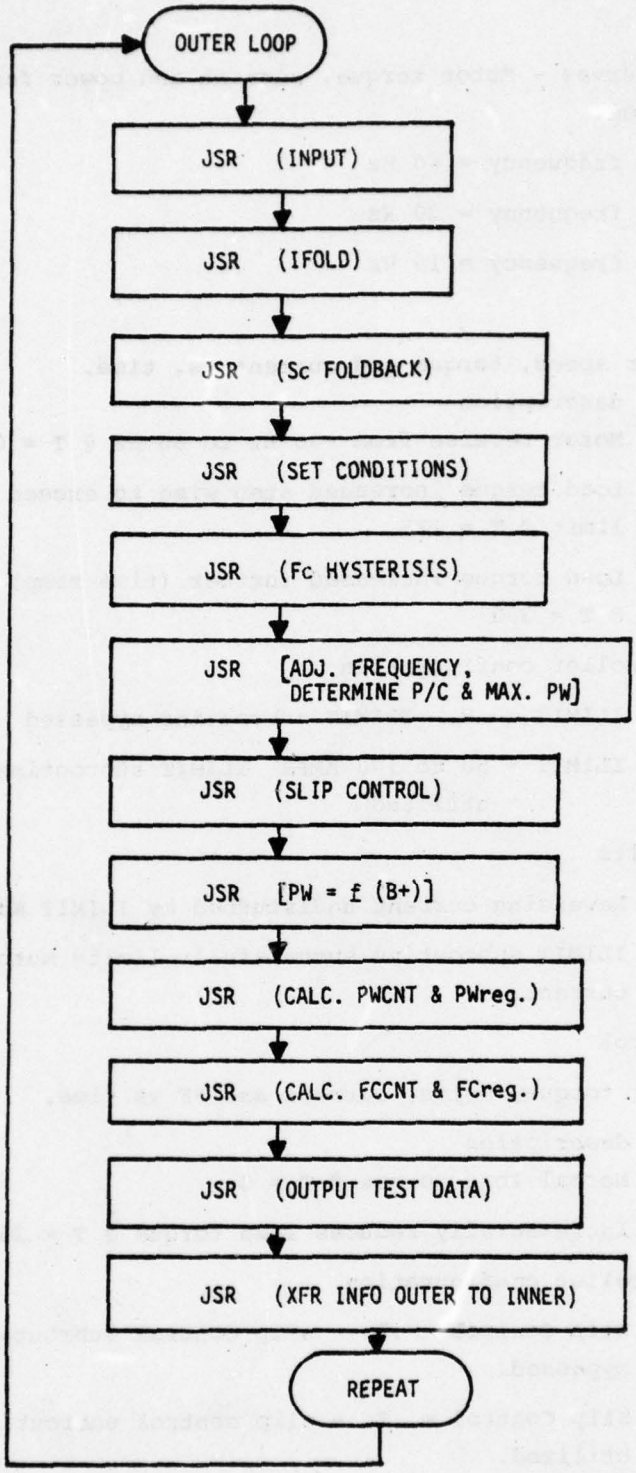


FIGURE 3. OUTER LOOP SUBROUTINE FLOW

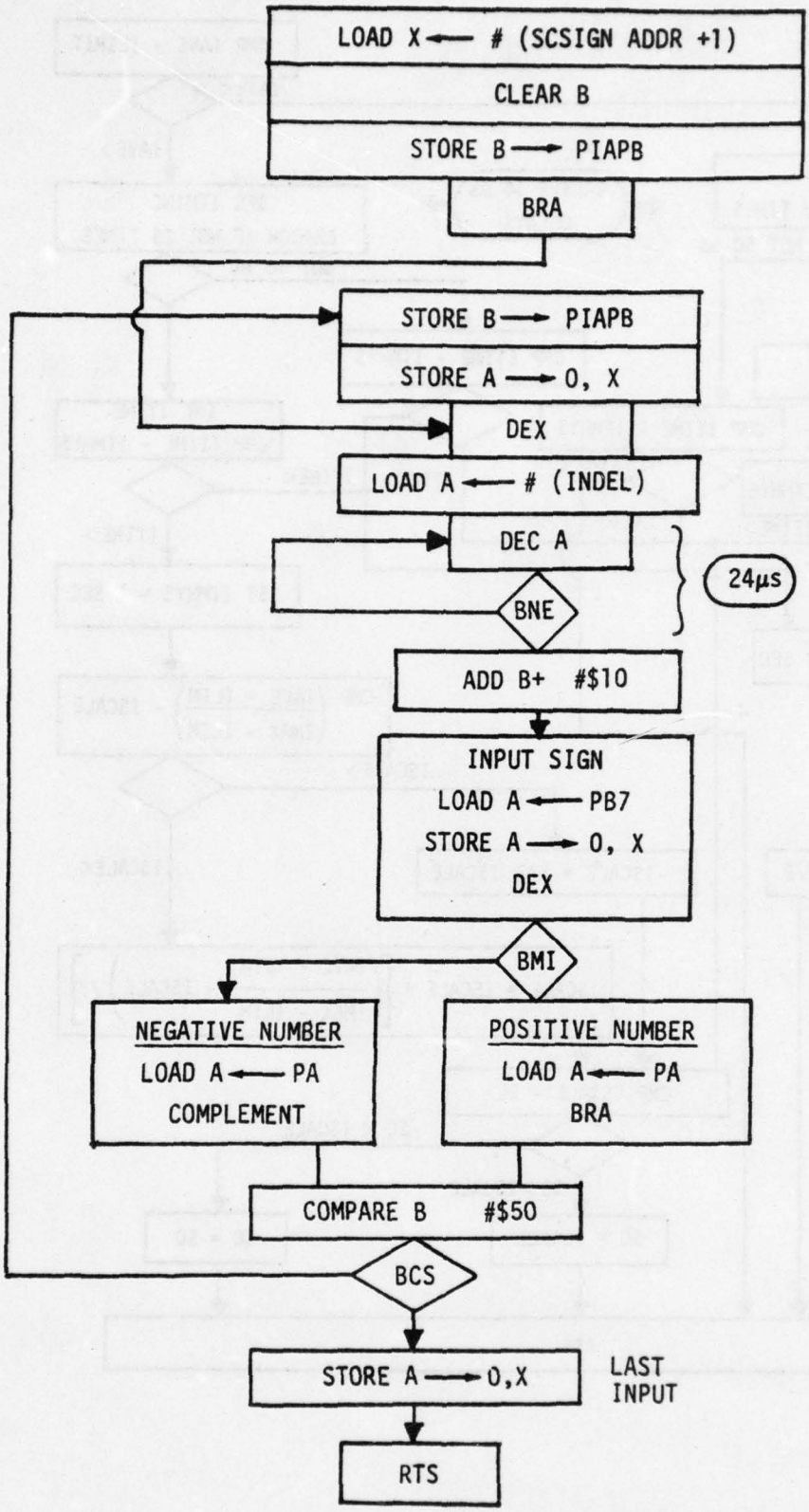


FIGURE 4. INPUT INFORMATION.

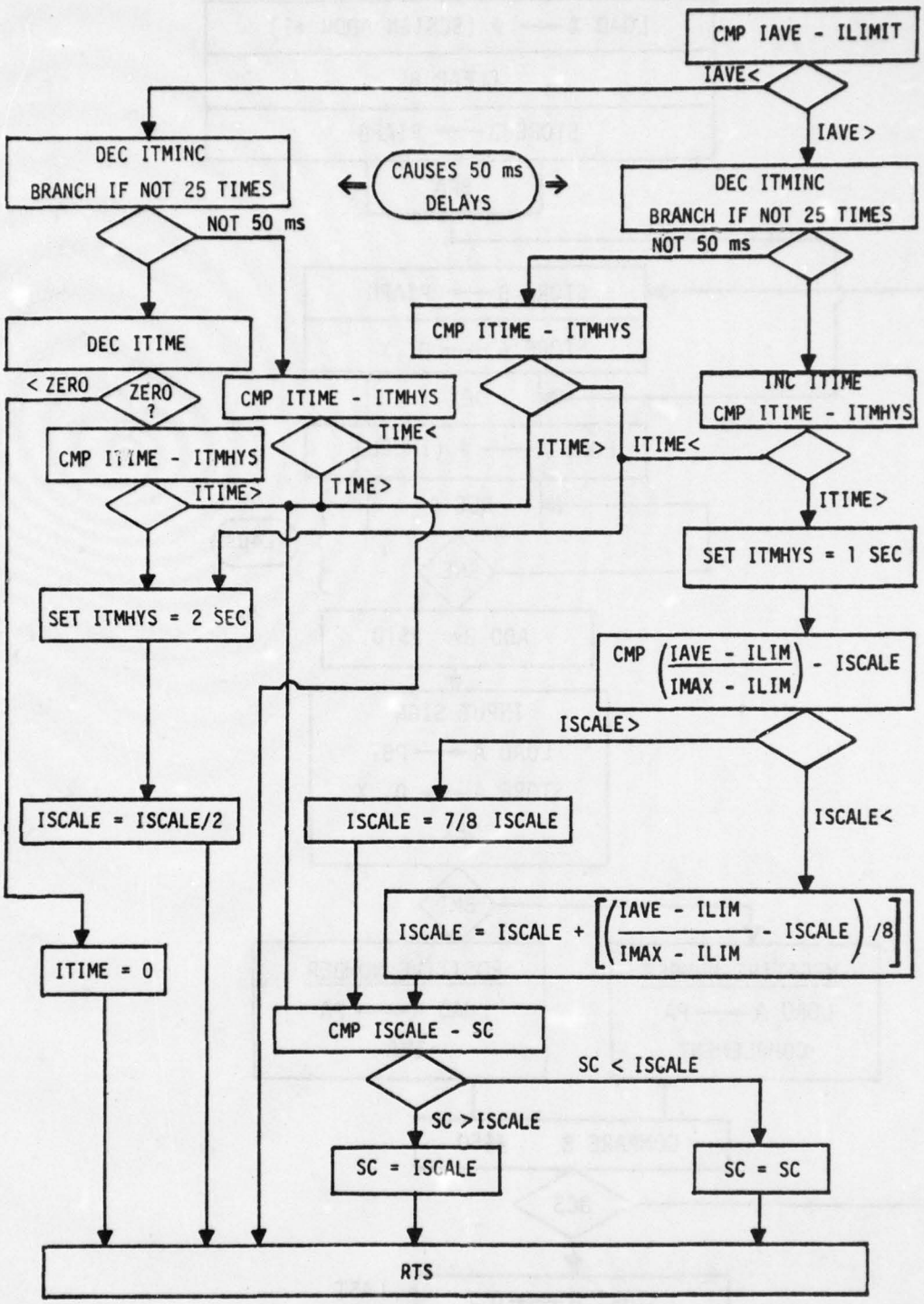


FIGURE 5. IFOLD.

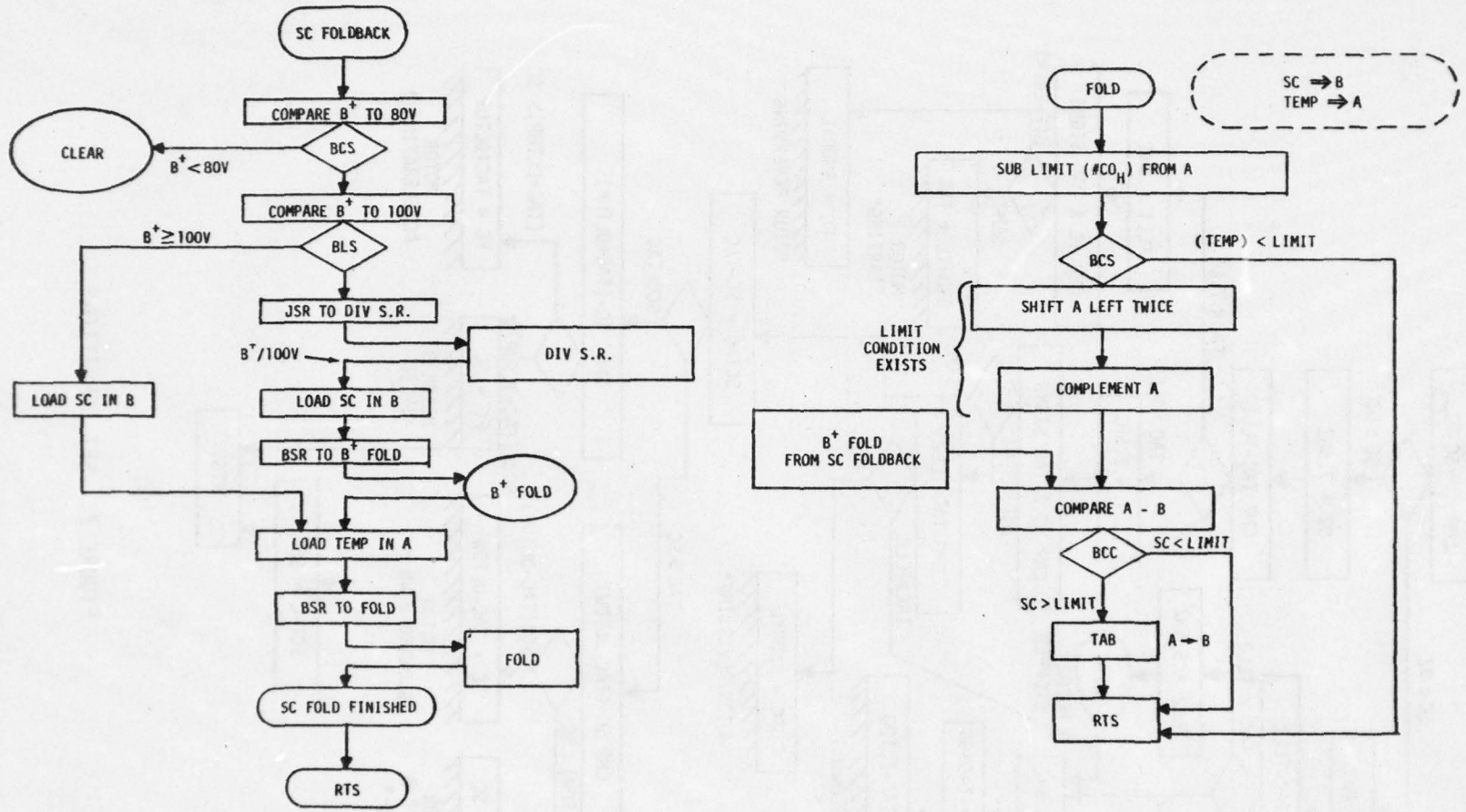


FIGURE 6. SC FOLDBACK B^+, IAVE, TEMP.

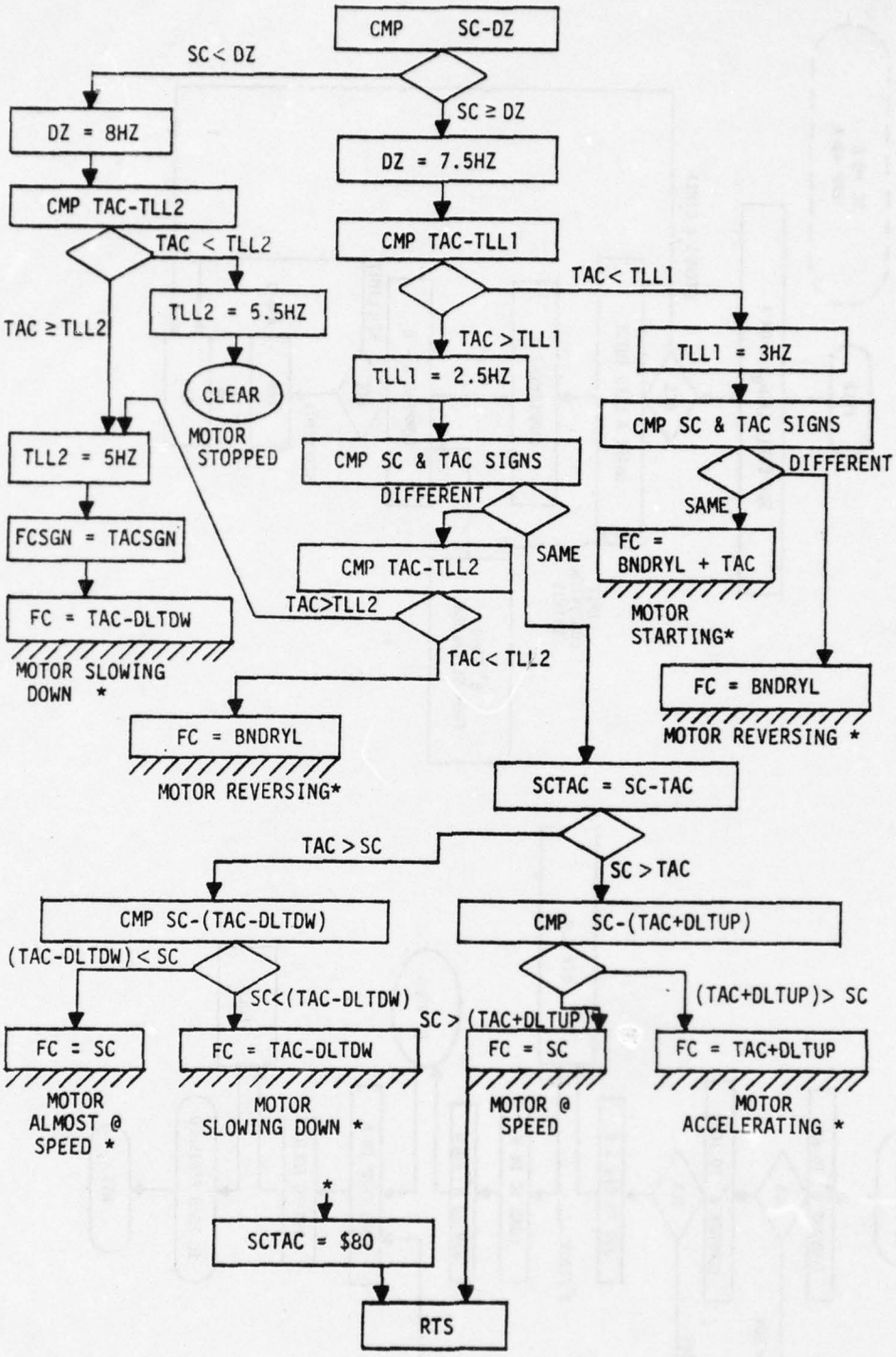


FIGURE 7. SET CONDITIONS.

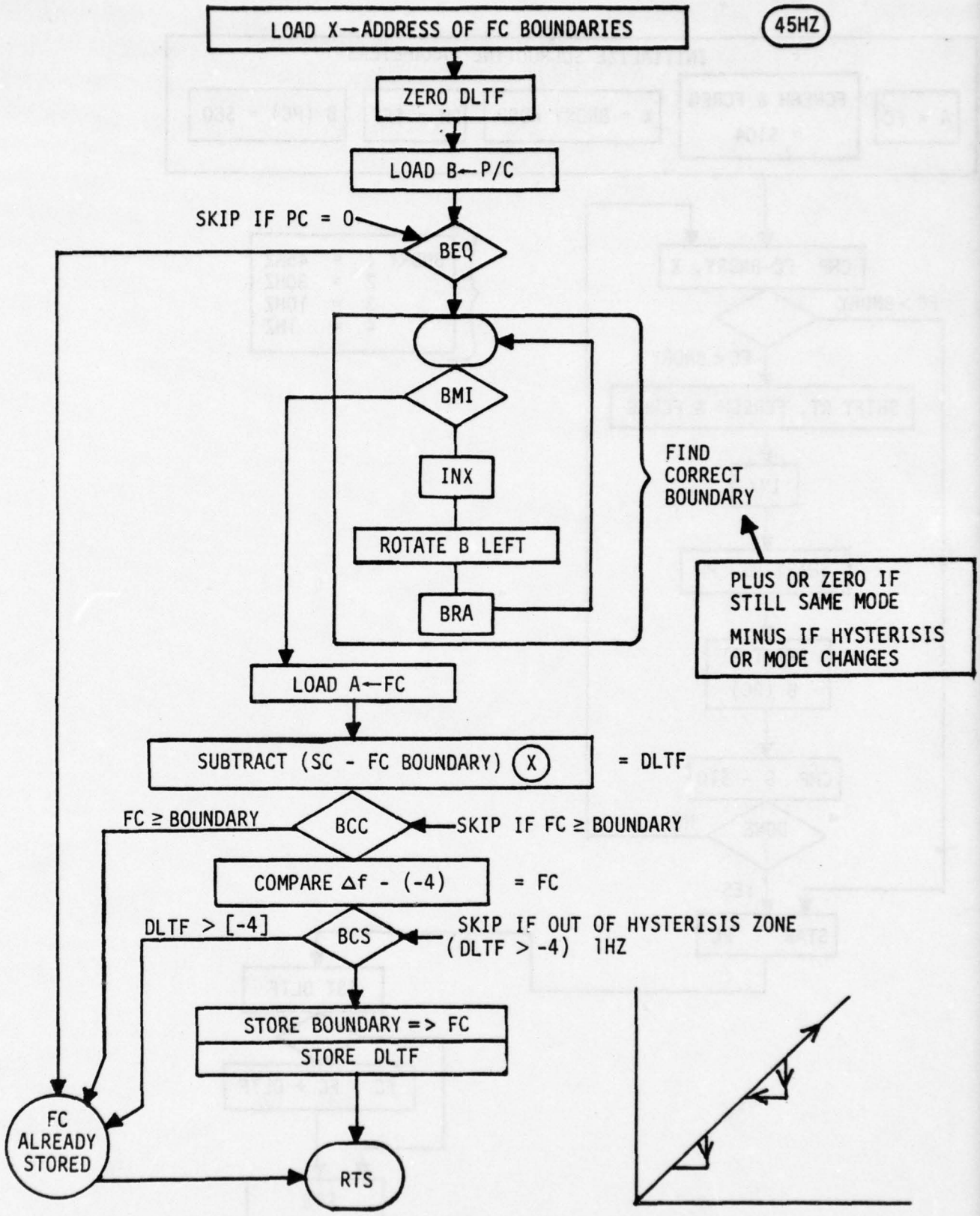


FIGURE 8. FC HYSTERESIS.

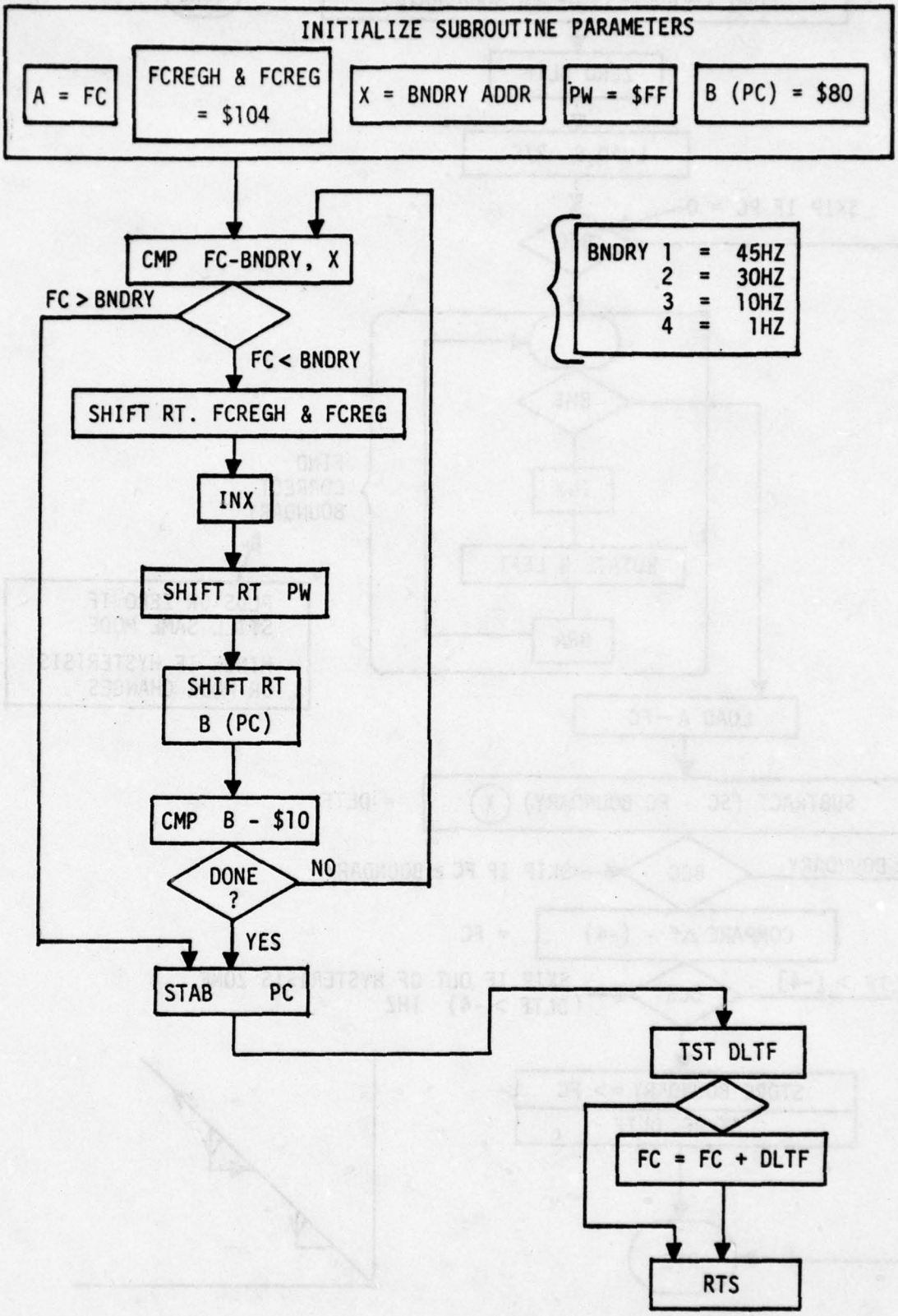


FIGURE 9. ADJ FCREG, DETERMINE PC & PW.

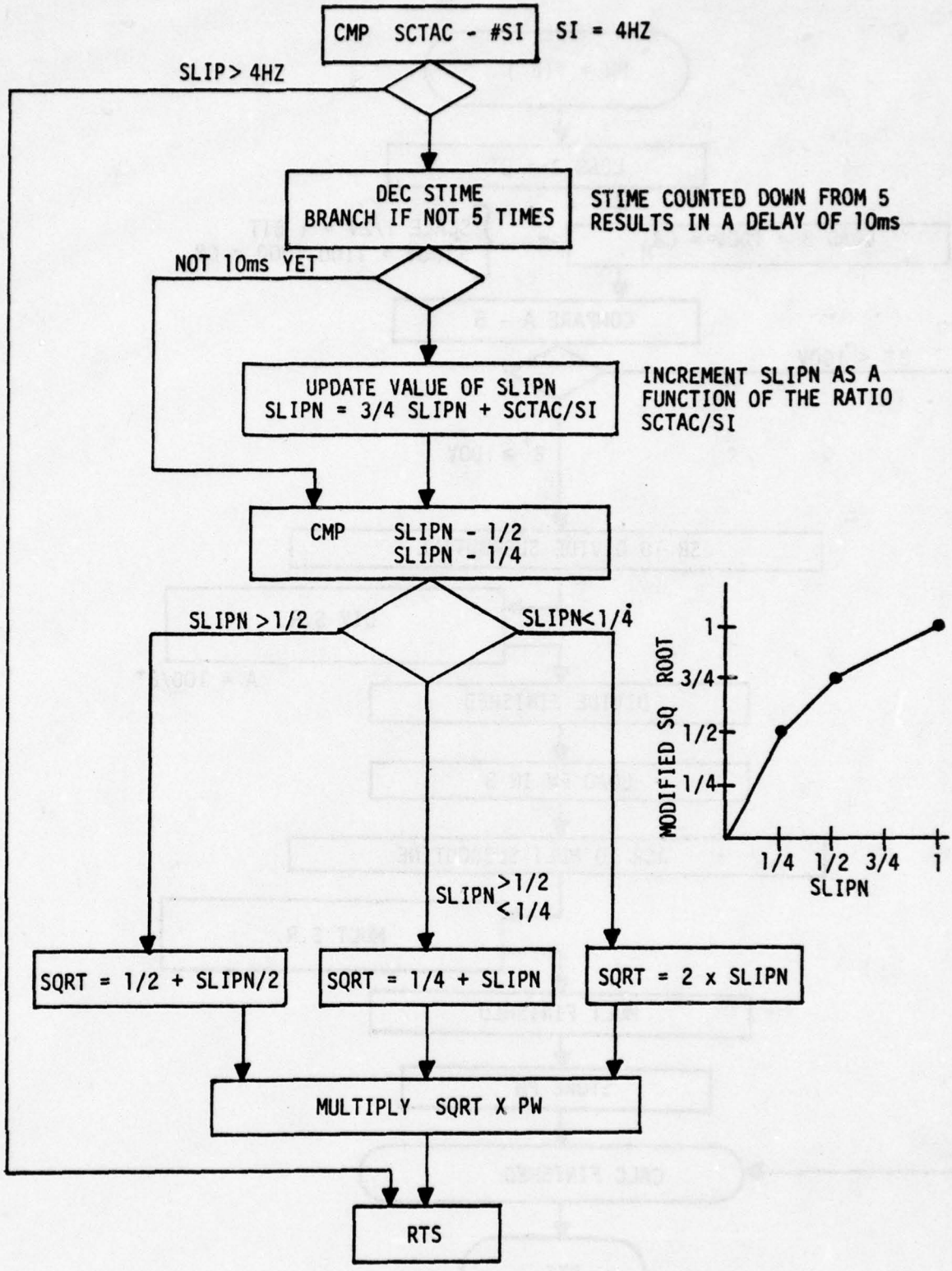


FIGURE 10. SLIPC.

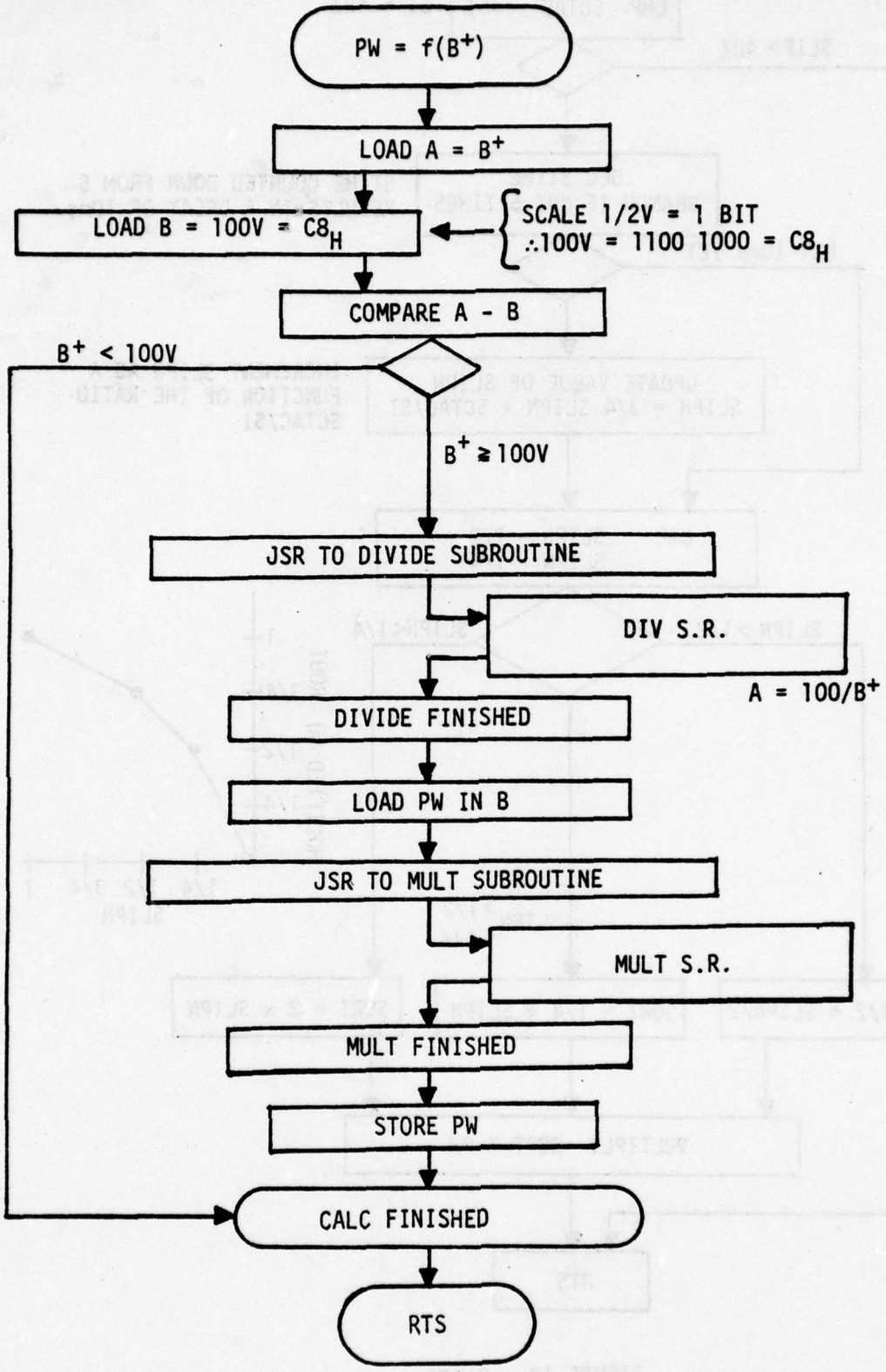


FIGURE 11. ADJUST PW FOR B^+ [100V TO 128V RANGE].

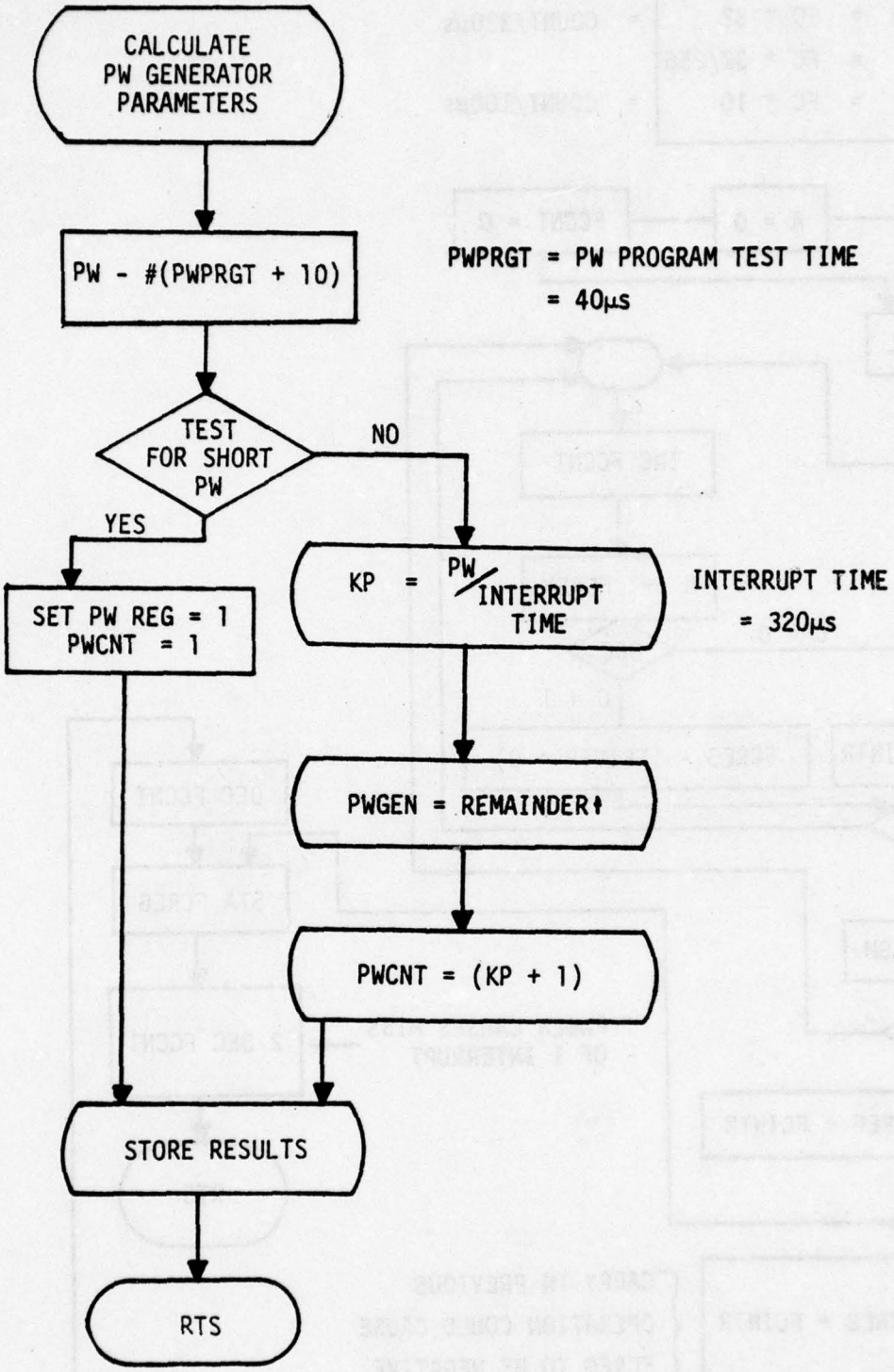


FIGURE 12. PWPT.

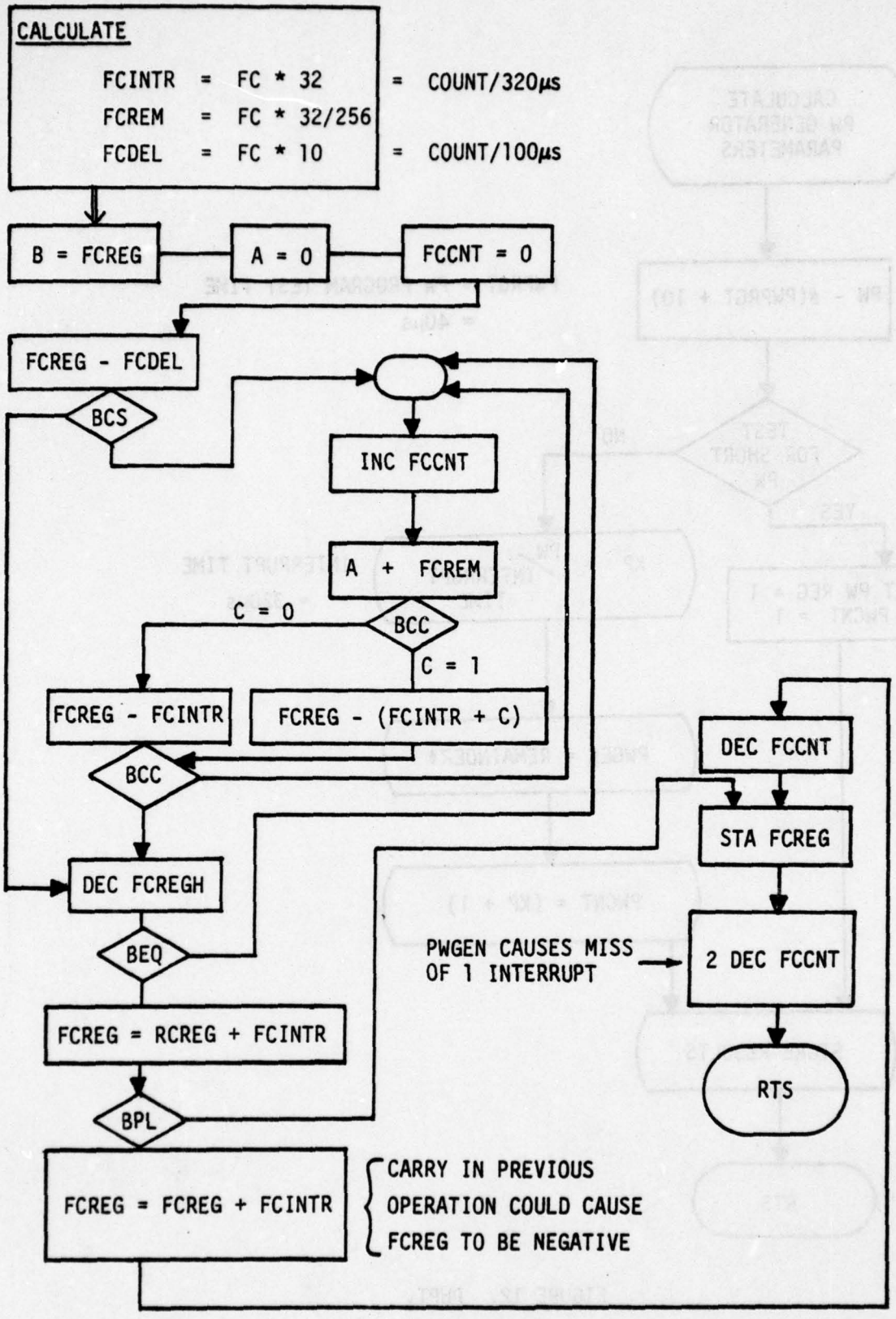


FIGURE 13. FC POINTER SR.

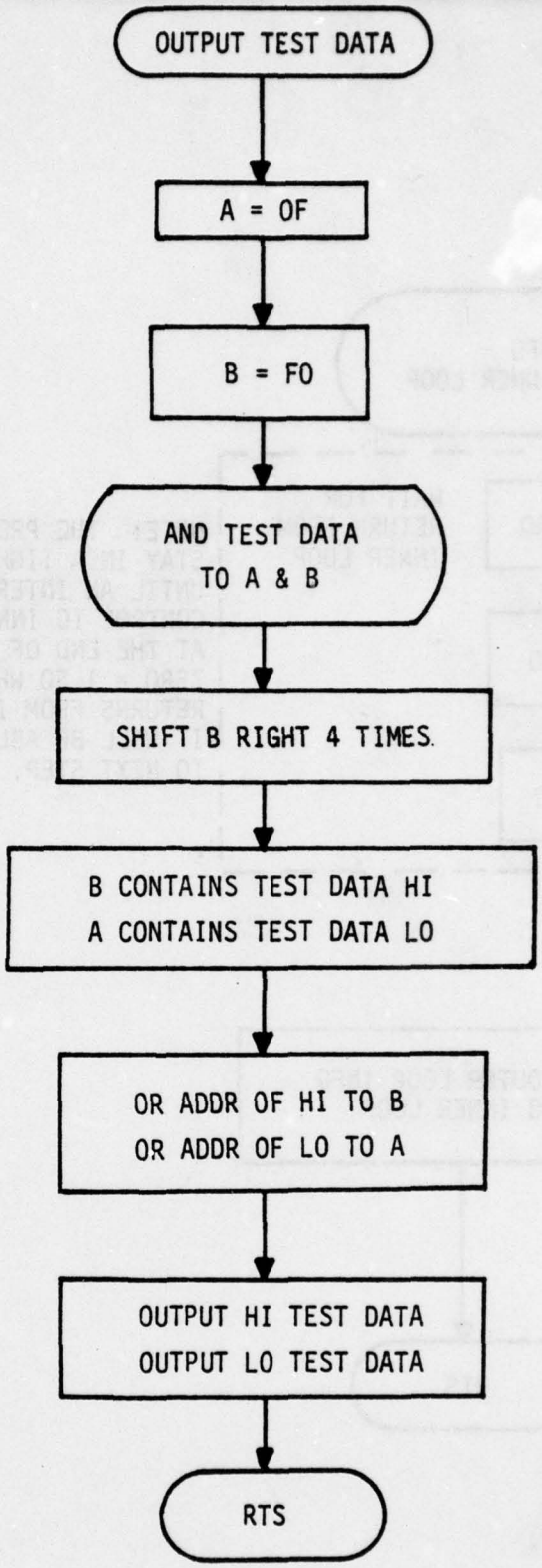


FIGURE 14. OUTPUT TEST DATA.

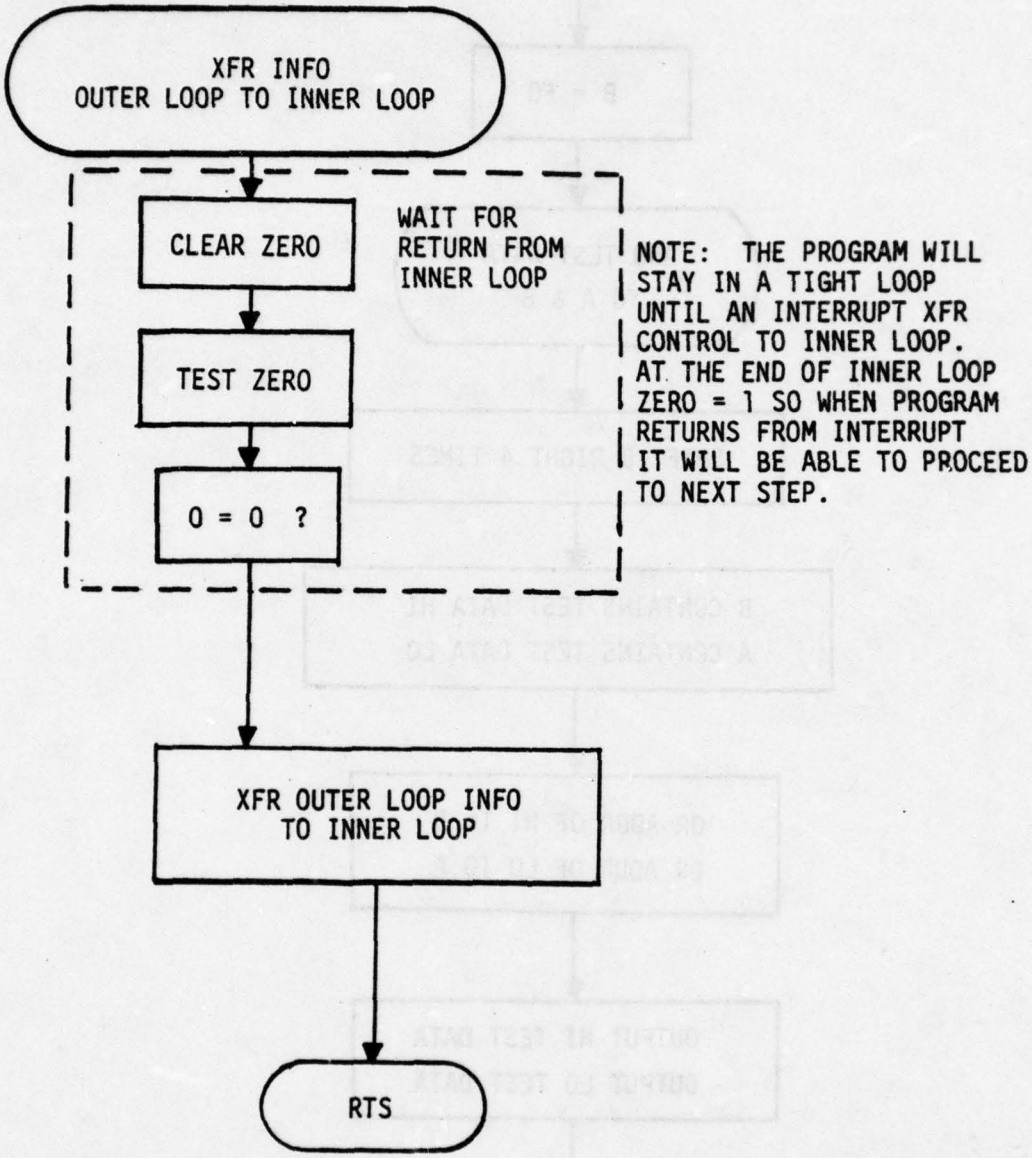


FIGURE 15. TRANSFER INFORMATION

1) NUMERATOR IN B
2) DENOMINATOR IN A
3) NUMERATOR < DENOMINATOR
4) STORE DENOMINATOR IN MEMORY
5) FORM RESULT IN A

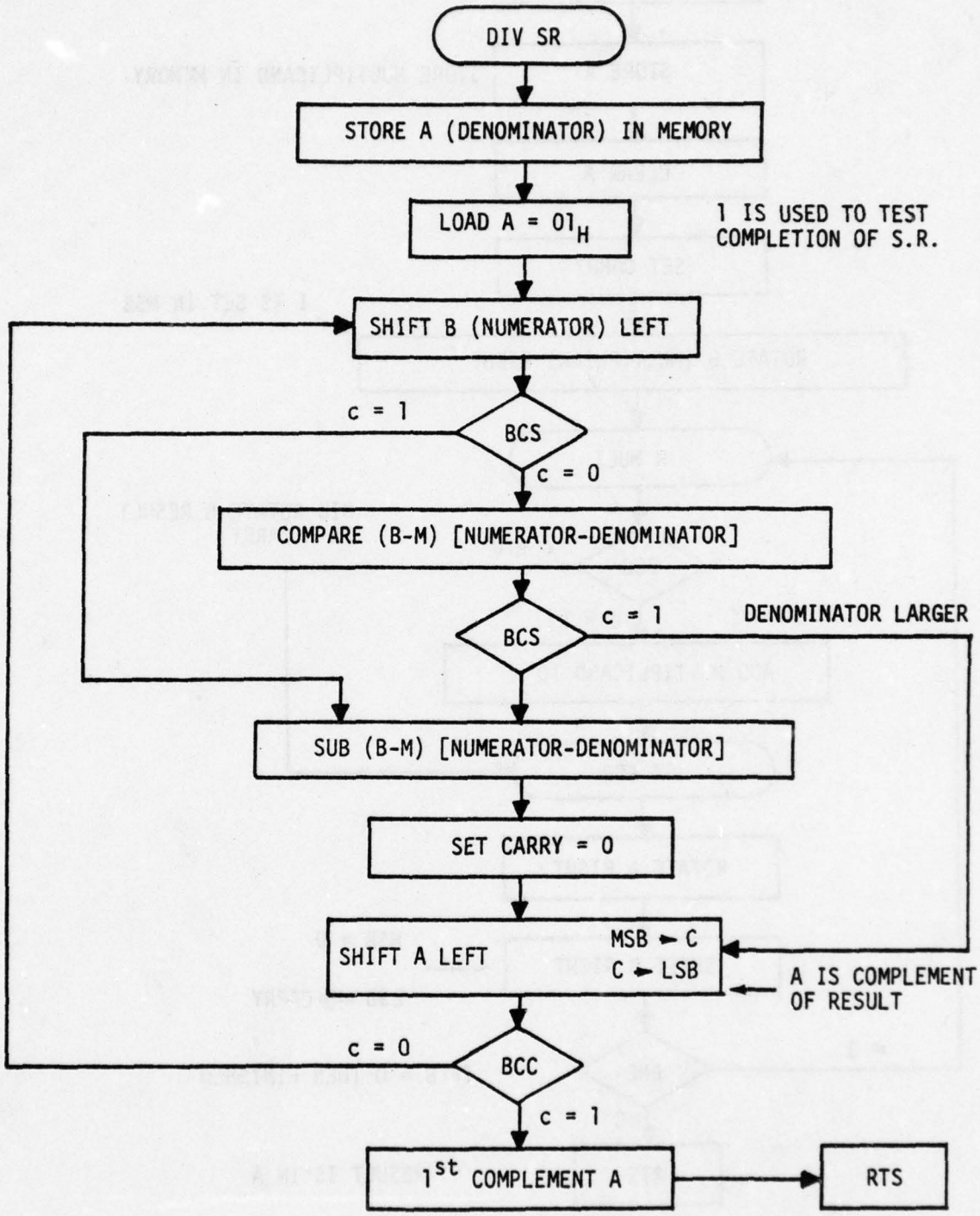


FIGURE 16. DIVIDE SUBROUTINE.

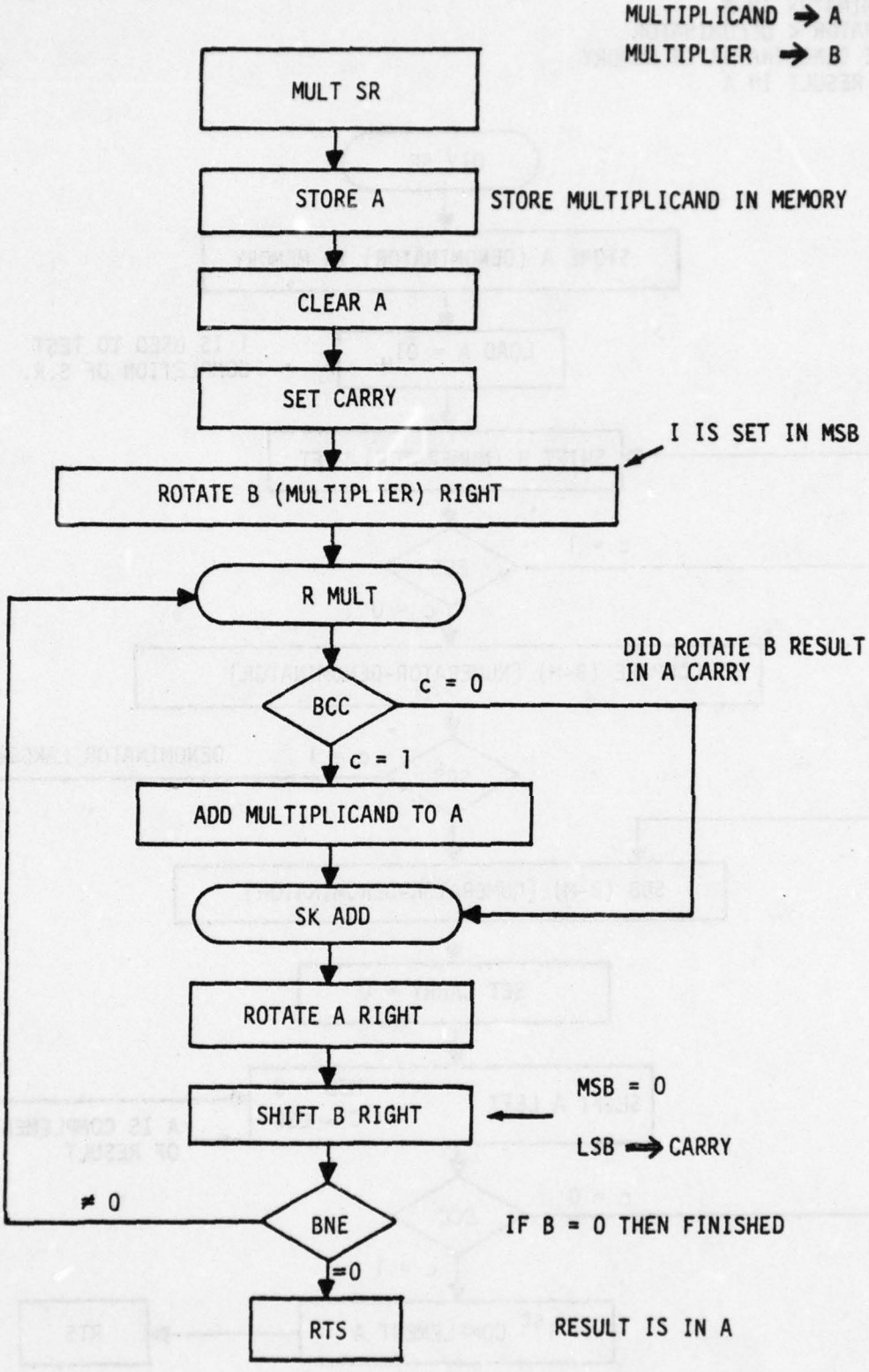


FIGURE 17. MULTIPLY SUBROUTINE.

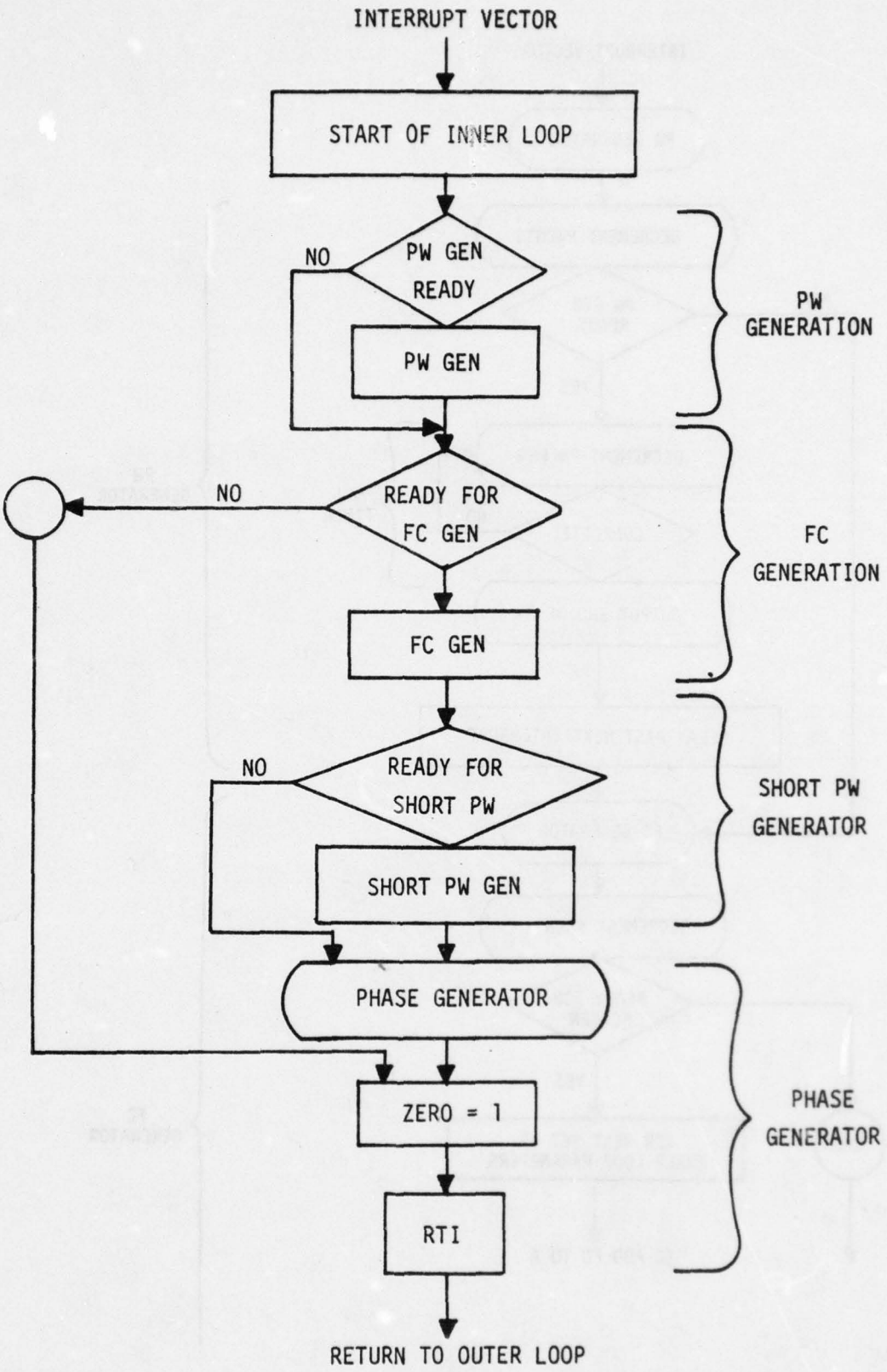


FIGURE 18. OVERVIEW OF INNER LOOP.

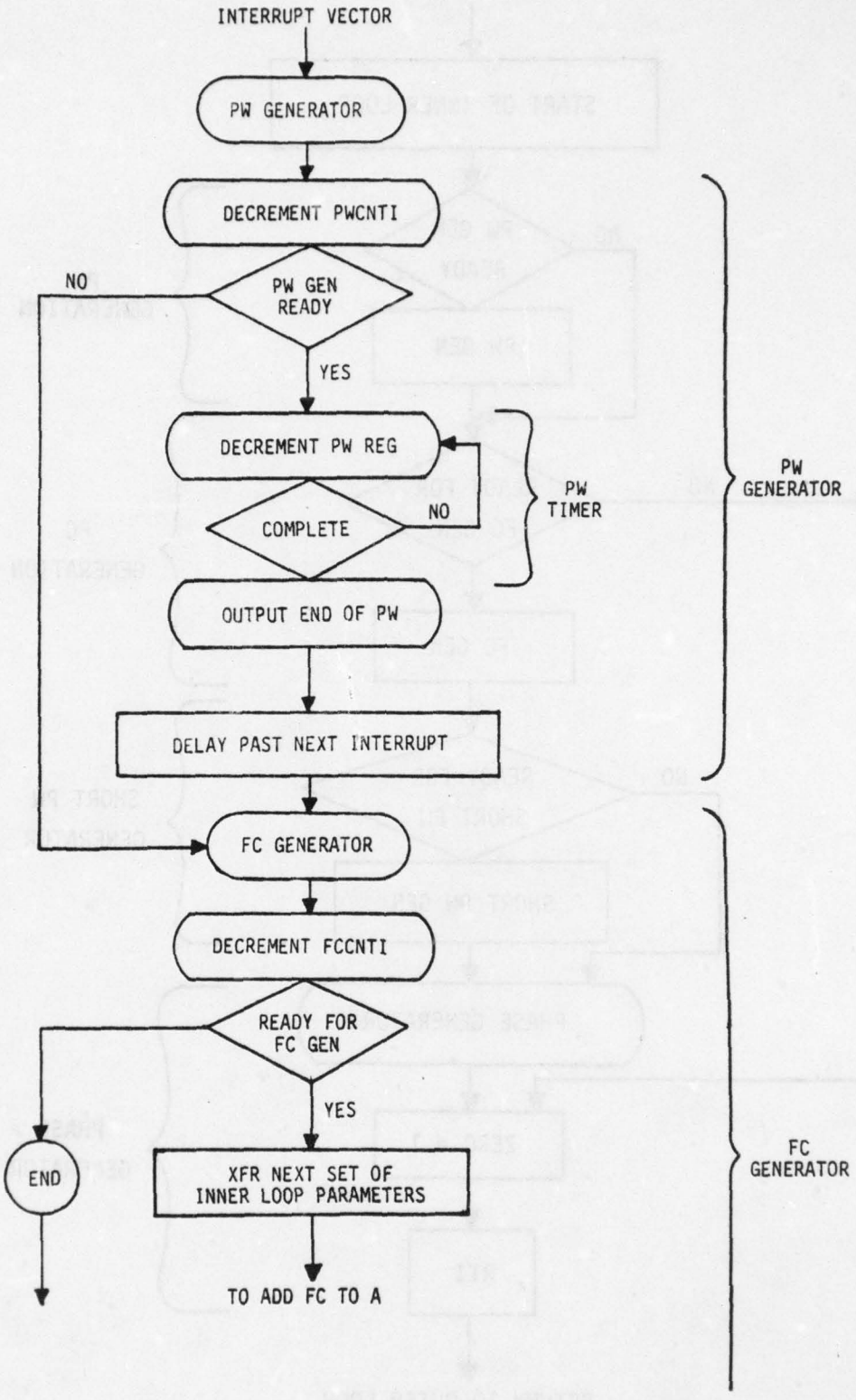


FIGURE 19. INNER LOOP 1.

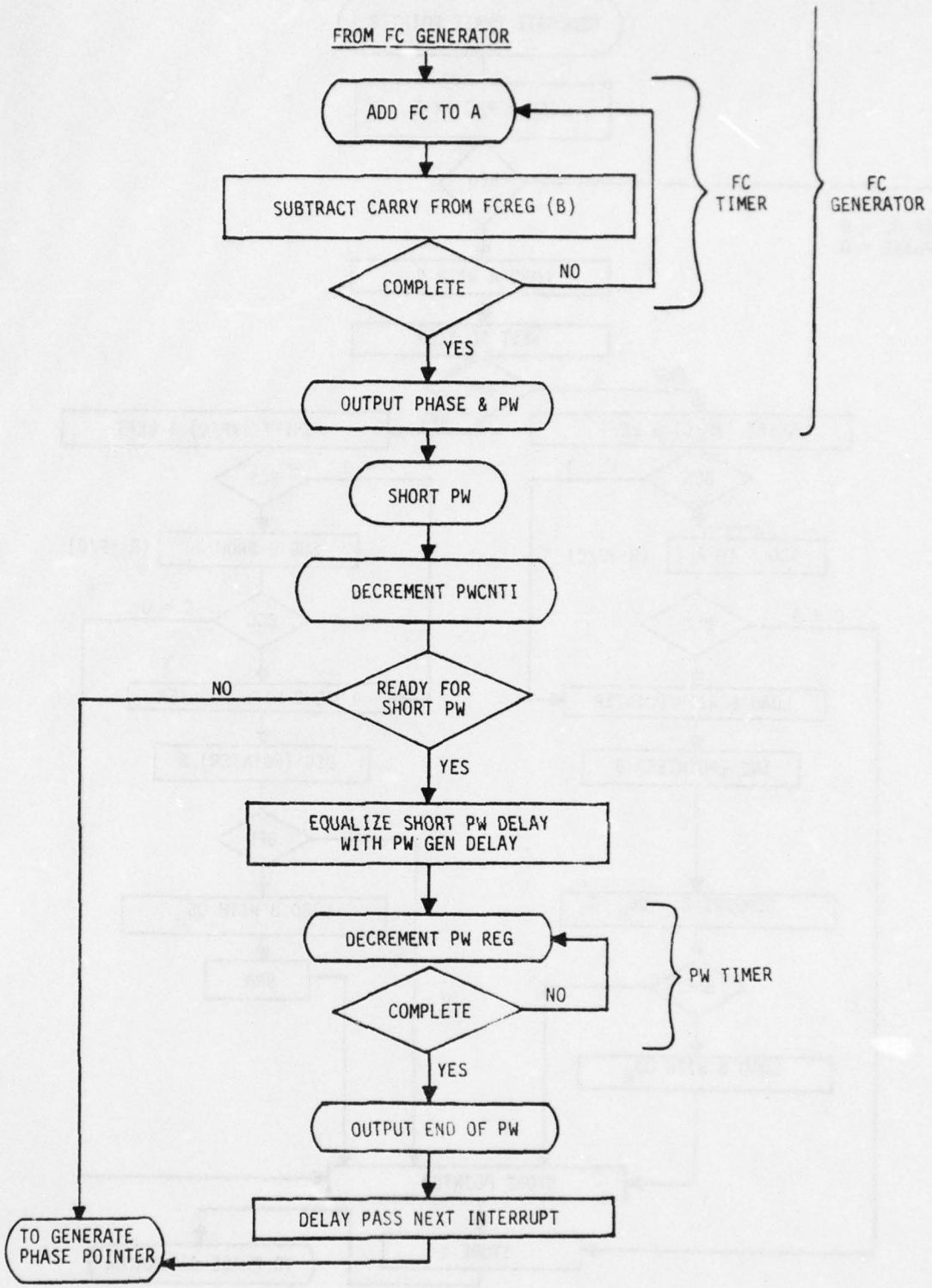


FIGURE 20. INNER LOOP 2.

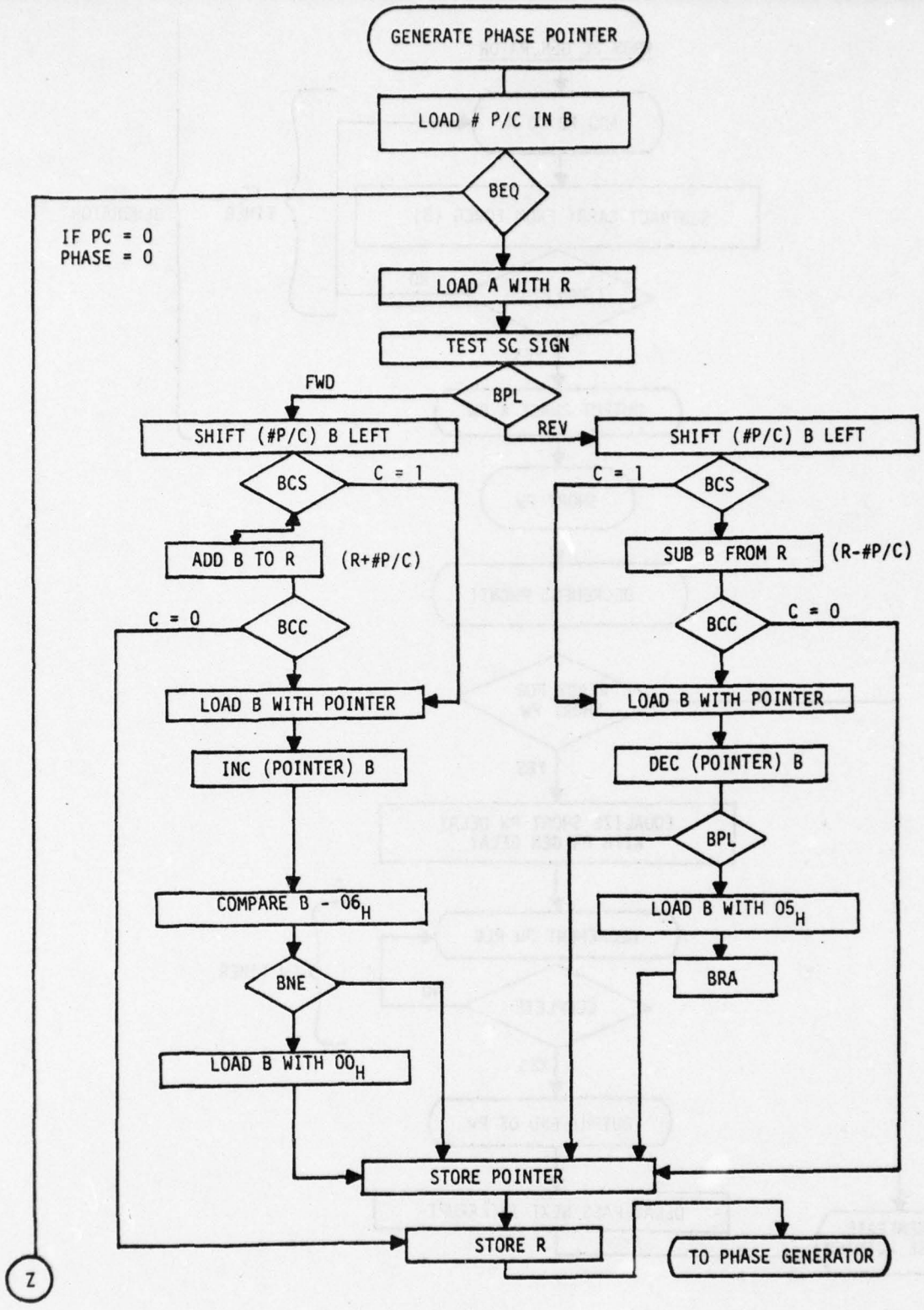


FIGURE 21. INNER LOOP 3.

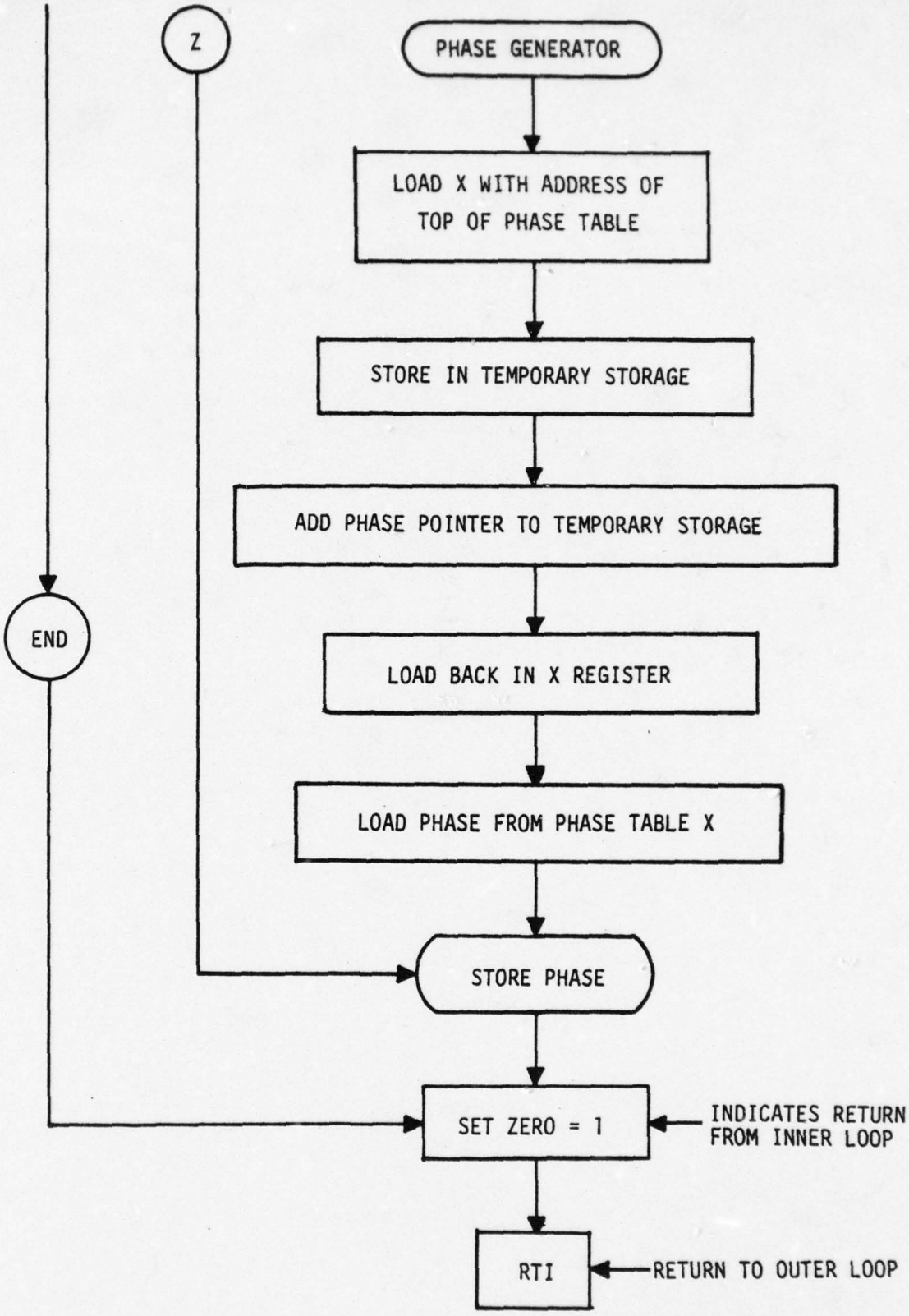


FIGURE 22. INNER LOOP 4.

APPENDIX A

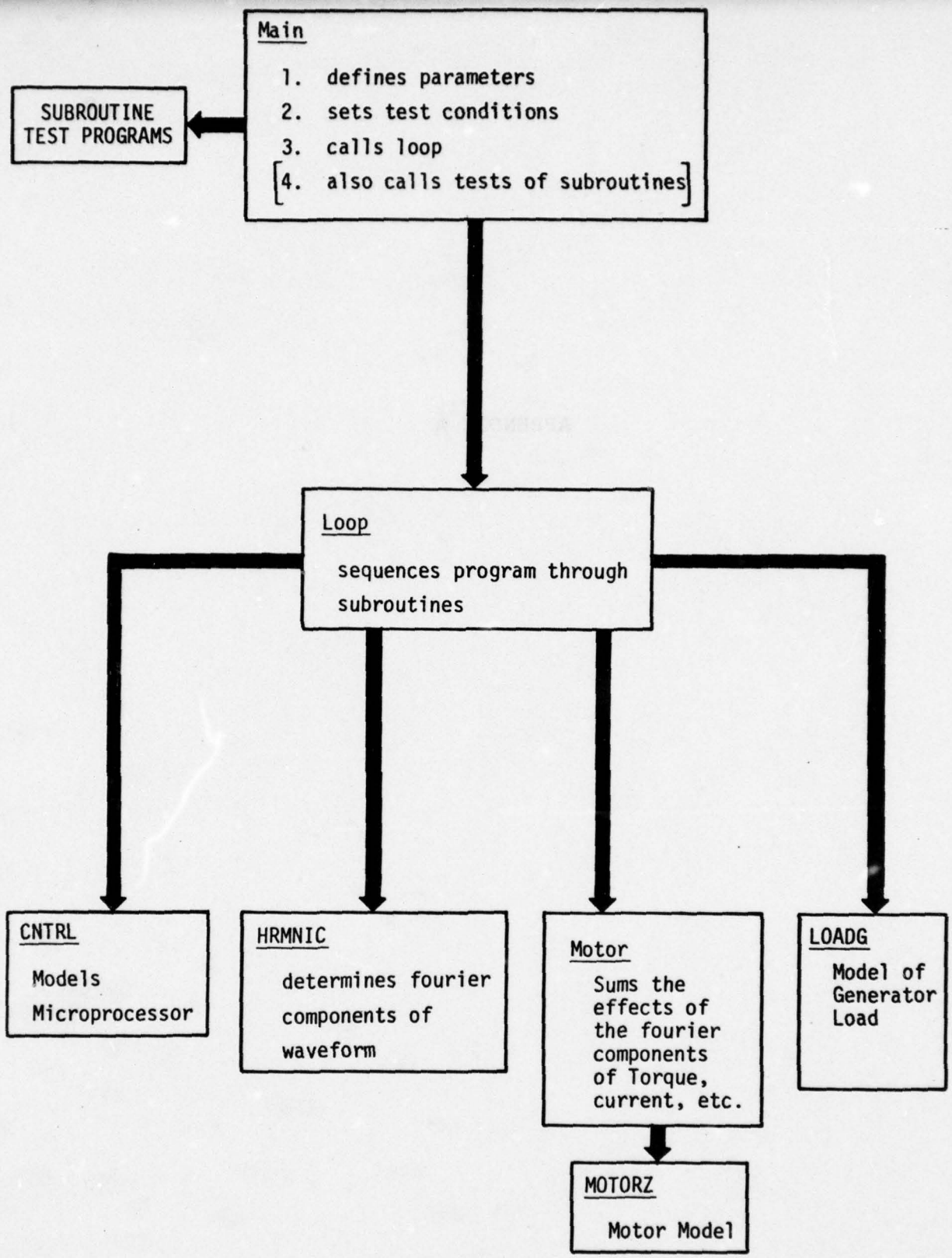


Figure 23. MODEL PROGRAM BLOCK DIAGRAM; SIMULATION PROGRAM FLOW

```
REQUESTED OPTIONS: MAP,XREF,NAME=MAIN,OPT=0

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF NOTERM

                C              TEST  TEST  TEST  TEST  TEST                                  00000010
                C     SIMULATION --- FORTRAN                                               00000020
                C         MICROPROSSER // MOTOR CONTROLLER                                 00000030
                C                                                                          00000040
                C         MC77SIM.FORT             TEST                                    00000050
                C                                      TEST                                00000060
                C                                        TEST                              00000070
                C                                          TEST                            00000080
                C         INITIAL CONDITIONS                                               00000090
                C                                                                          00000100
                C                                                                          00000110
                C                                                                          00000120
  ISN 0002            INTEGER DZLO,DZHI,TLL1LO,TLL1HI,TLL2LO,TLL2HI,DLTADW,DLTAUP,       00000130
                     1 BNDRY1,BNDRY2,BNDRY4,BNDRY8,HYST,ILIMIT,IMAX,SIDEAL               00000140
                C                                                                          00000150
  ISN 0003            REAL R1,L1,RMC,LM,R2,L2                                            00000160
                C                                                                          00000170
  ISN 0004            REAL KG,J,STCTQ                                                    00000180
                C                                                                          00000190
  ISN 0005            INTEGER SC,TAC,FC,PC,PW                                            00000200
  ISN 0006            REAL I1,I2,VB,F,TORQ,PF,ROTORL,TIME,DT,V1,V5,V7,V11,V13,           00000210
                     1     WTAC,RDTAC,DT,WDLTUP,WDLTDW,WSC,WBNDY1,WBNDY2,WBNDY4          00000220
  ISN 0007            LOGICAL FCSGN,INITC,SKIP,SKFOLD,SKSLIP                             00000230
                C                                                                          00000240
  ISN 0008            COMMON /ONE/ DZLO,DZHI,TLL1LO,TLL1HI,TLL2LO,TLL2HI,                00000250
                     1 DLTADW,DLTAUP,BNDRY1,BNDRY2,BNDRY4,BNDRY8,HYST,                   00000260
                     2 SKFOLD,SKSLIP,ILIMIT,IMAX,SIDEAL                                  00000270
                C                                                                          00000280
  ISN 0009            COMMON /TWO/ R1,L1,RMC,LM,R2,L2                                    00000290
                C                                                                          00000300
  ISN 0010            COMMON /THREE/ KG,J,STCTQ                                          00000310
                C                                                                          00000320
  ISN 0011            FOUR(A)=A*4.+.01                                                   00000330
  ISN 0012            FOURN(B)=B*4.-.01                                                  00000340
                C                                                                          00000350
                C        FIXED DATA                                                        00000360
  ISN 0013            DZLO=FOUR(7.5)                                                     00000370
  ISN 0014            DZHI=FOUR(8)                                                       00000380
  ISN 0015            TLL1LO=FOUR(2.5)                                                   00000390
  ISN 0016            TLL1HI=FOUR(3)                                                     00000400
  ISN 0017            TLL2LO=FOUR(10)                                                    00000410
  ISN 0018            TLL2HI=FOUR(11)                                                    00000420
  ISN 0019            DLTADW=FOUR(7.5)                                                   00000430
  ISN 0020            DLTAUP=FOUR(7.5)                                                   00000440
  ISN 0021            BNDRY1=FOUR(45)                                                    00000450
  ISN 0022            BNDRY2=FOUR(30)                                                    00000460
  ISN 0023            BNDRY4=FOUR(10.)                                                   00000470
  ISN 0024            BNDRY8=FOUR(7.25)                                                  00000480
  ISN 0025            HYST=FOUR(1.)                                                      00000490
  ISN 0026            ILIMIT=FOUR(50.)                                                   00000500
  ISN 0027            IMAX=FOUR(50.*4./3.)                                               00000510
  ISN 0028            SIDEAL=FOUR(5.)                                                    00000520
                C                                                                          00000530
```

```
                C                                                                       00000540
                C                                                                       00000550
                C       MOTOR PARAMETERS   R OHMS,  L HENERIES                          00000560
                C                                                                       00000570
                C                                                                       00000580
   ISN 0029             R1=.12                                                         00000590
   ISN 0030             L1=.00068                                                      00000600
   ISN 0031             RMC=.003                                                       00000610
   ISN 0032             LM=.013                                                        00000620
   ISN 0033             R2=.09                                                         00000630
   ISN 0034             L2=.00068                                                      00000640
                C                                                                       00000650
                C                                                                       00000660
                C       LOAD PARAMETERS                                                 00000670
                C                                                                       00000680
                C       I1=45AMP @ 60HZ @ 5%SLIP @ V=82VOLTS                            00000690
                C       I2=40AMPS                                                       00000700
                C       RDTAC=2*PI*WTAC                                                 00000710
                C       TORQ=3*I2**2*R2/(RDTAC*SLIP) =20. NEWTON-METERS                 00000720
                C       TORQ=J*RDTAC' + KG*RDTAC +STCTQ (STICTION TORQUE)               00000730
                C       RDTAC=2*PI*F*(1-SLIP)                                           00000740
                C       KG=(TQ-STCTQ)/RDTAC=21./377*.95 =.055 NEWTON-METERS-SEC**(-1)   00000750
                C       ASSUME: STCTQ=.2 NEWTON METERS OR 1% OF RATED TORQUE            00000760
                C       ASSUME: TIME CONSTANT=.3 SEC                                    00000770
                C       TIMEC=J/KG                                                      00000780
                C       J=KG*TIMEC =.055*.3 =.0165 NEWTON-METERS-SEC**(-2)              00000790
                C       MAX DT=.03SEC    USE DT=.01SEC                                  00000800
   ISN 0035             KG=.055                                                        00000810
   ISN 0036             J=.0165                                                        00000820
   ISN 0037             STCTQ=.2                                                       00000830
                C                                                                       00000840
                C                                                                       00000850
   ISN 0038             INITC=.FALSE.                                                  00000860
   ISN 0039             SKFOLD=.FALSE.                                                 00000870
   ISN 0040             SKSLIP=.FALSE.                                                 00000880
                C                                                                       00000890
                C                                                                       00000900
                C        MAIN PROGRAM                                                   00000910
                C                                                                       00000940
                C                                                                       00000950
                C                                                                       00000960
                C       TEST  SUBROUTINES                                               00000970
                C                                                                       00000980
   ISN 0041             CALL TCNTRL                                                    00000990
   ISN 0042             CALL THRM                                                      00001000
   ISN 0043             CALL TLOADG                                                    00001010
   ISN 0044             CALL TMOTZ                                                     00001020
   ISN 0045             CALL TMOTOR                                                    00001030
                C                                                                       00001040
                C        EXECUTE MC77SIM SIMULATION                                     00001050
                C                                                                       00001060
   ISN 0046             WRITE(6,1000)                                                  00001070
   ISN 0047             DO 101 K1=1,10                                                 00001080
   ISN 0048             WRITE(6,1001)                                                  00001090
   ISN 0049           101 CONTINUE                                                     00001100
                C                                                                       00001110
                C        STEP FUNCTIONS                                                 00001120
                C                                                                       00001130
```

```
ISN 0050          DO 100 K=1,10                                          00001140
                C                                                        00001150
ISN 0051          IF (K.EQ.1) SKIP=.FALSE.                               00001160
ISN 0053          IF (K.EQ.2) SKIP=.TRUE.                                00001170
ISN 0055          IF (K.EQ.3) DLTAUP=FOUR(3)                             00001180
ISN 0057          IF (K.EQ.4) GO TO 100                                  00001190
ISN 0059          IF (K.EQ.5) DLTAUP=FOUR(15.)                           00001200
ISN 0061          DLTADW=DLTAUP                                          00001210
                C                                                        00001220
ISN 0062          IF (K.LE.5)GO TO 120                                   00001230
                C         TEST ADJUSTED CONDITIONS                       00001240
ISN 0064          DLTAUP=FOUR(7.5)                                       00001250
ISN 0065          DLTADW=FOUR(3.)                                        00001260
ISN 0066          TLL2LO=FOUR(5.)                                        00001270
ISN 0067          TLL2HI=FOUR(5.5)                                       00001280
                C                                                        00001290
ISN 0068          IF (K.LE.6)GO TO 120                                   00001300
                C          TEST HARMONIC EFFECTS                         00001310
                C                                                        00001320
                C          TEST 1P/C MODE                                00001330
ISN 0070          BNDRY4=FOUR(7.5)                                       00001340
ISN 0071          BNDRY2=FOUR(7.75)                                      00001350
ISN 0072          BNDRY1=FOUR(8.)                                        00001360
                C          TEST 2P/C MODE                                00001370
ISN 0073          IF (K.GE.8) BNDRY1=FOUR(60.)                           00001380
                C          TEST 4P/C MODE                                00001390
ISN 0075          IF (K.GE.9) BNDRY2=FOUR(59.)                           00001400
                C          TEST 8P/C MODE                                00001410
ISN 0077          IF (K.GE.10) BNDRY4=FOUR(58.)                          00001420
                C                                                        00001430
ISN 0079        120 CONTINUE                                             00001440
                C                                                        00001450
ISN 0080          WDLTUP=FLOAT(DLTAUP)/4.                                00001460
ISN 0081          WDLTDW=FLOAT(DLTADW)/4.                                00001470
ISN 0082          WBNDY1=FLOAT(BNDRY1)/4.                                00001480
ISN 0083          WBNDY2=FLOAT(BNDRY2)/4.                                00001490
ISN 0084          WBNDY4=FLOAT(BNDRY4)/4.                                00001500
                C                                                        00001510
ISN 0085          WRITE(6,1002) K                                        00001520
ISN 0086          WRITE(6,1050) SKIP,WDLTUP,WDLTDW,WBNDY1,WBNDY2,WBNDY4  00001530
ISN 0087       1000 FORMAT ('1',1X,26HEXECUTE MC77SIM SIMULATION)        00001540
ISN 0088       1001 FORMAT (1X,26HEXECUTE MC77SIM SIMULATION)            00001550
ISN 0089       1002 FORMAT ('1',1X,16HSTEP FUNCTION # ,I2)               00001560
ISN 0090       1050 FORMAT (1X,5HSKIP=,L1,2X,7HDLTAUP=,F5.2,2X,7HDLTADW=,F5.2,2X,  00001570
                   1        7HBNDRY1=,F6.2,2X,7HBNDRY2=,F6.2,2X,7HBNDRY4=,F6.2)  00001580
                C                                                        00001590
ISN 0091          TIME=0.                                                00001600
ISN 0092          VB=105.                                                00001610
                C         NOTE: RMS VALUE @ 100 %MOD = 82 VOLTS          00001620
ISN 0093          DT=.01                                                 00001630
ISN 0094          WTAC=0.                                                00001640
ISN 0095          SC=FOUR(60.)                                           00001650
                C                                                        00001660
                C          INITIALIZE CONTROL SUBROUTINE                 00001670
ISN 0096          INITC=.TRUE.                                           00001680
ISN 0097          CALL LOOP(TIME,DT,VB,SC,WTAC,SKIP,INITC)               00001690
ISN 0098          INITC=.FALSE.                                          00001700
                C                                                        00001710
```

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LEVEL 2.2 (SEPT 76)          MAIN          OS/360  FORTRAN H EXTENDED          DATE 78.030/12.

 ISN 0099            DO 100 I=1,250                                              00001720
               C                                                                 00001730
 ISN 0100            IF (1.GT.100) SC=FOURN(-60.)                                00001740
 ISN 0102            IF (I.GT.200) SC=FOUR(0.)                                   00001750
 ISN 0104            IF (I.EQ.1)GO TO 110                                        00001760
 ISN 0106            IF (I.EQ.101)GO TO 110                                      00001770
 ISN 0108            IF (I.EQ.201)GO TO 110                                      00001780
               C                                                                 00001790
 ISN 0110          130 CALL LOOP(TIME,DT,VB,SC,WTAC,SKIP,INITC)                  00001800
               C                                                                 00001810
 ISN 0111            GO TO 100                                                   00001820
               C                                                                 00001830
 ISN 0112          110 WSC=FLOAT(SC)/4.                                          00001840
               C                                                                 00001850
 ISN 0113            WRITE(6,1010) WSC,WTAC,VB,TIME                              00001860
 ISN 0114            WRITE(6,1020)                                               00001870
 ISN 0115         1010 FORMAT (//,1X,3HSC=,F6.2,2X,4HTAC=,F6.2,2X,3HVB=,F5.1,2X, 00001880
                     1         5HTIME=,F4.2)                                     00001890
 ISN 0116         1020 FORMAT (/,1X,4X,4HTIME,3X,4HWTAC,4X,4HTORQ,6X,2HI1,5X,3HIH%, 00001900
                     1         4X,4HV1NM,4X,4HVHNM,5X,3HVH%,5X,3HEFF,6X,2HPF,5X, 00001910
                     2         3HI1H,4X,4HFREQ,6X,2HPW)                          00001920
 ISN 0117            GO TO 130                                                   00001930
               C                                                                 00001940
 ISN 0118          100 CONTINUE                                                  00001950
               C                                                                 00001960
               C          TEST SLIP CONTROL                                      00001970
               C                                                                 00001980
 ISN 0119          210 SKIP=.TRUE.                                               00001990
 ISN 0120            DLTAUP=FOUR(7.5)                                            00002000
 ISN 0121            DLTADW=FOUR(3.)                                             00002010
 ISN 0122            TLL2LO=FOUR(5.)                                             00002020
 ISN 0123            TLL2HI=FOUR(5.5)                                            00002030
 ISN 0124            BNDRY1=FOUR(45)                                             00002040
 ISN 0125            BNDRY2=FOUR(30)                                             00002050
 ISN 0126            BNDRY4=FOUR(10.)                                            00002060
 ISN 0127            BNDRY8=FOUR(7.25)                                           00002070
               C                                                                 00002080
 ISN 0128            DO 200 KSLIP=1,3                                            00002090
 ISN 0129            TIME=0.                                                     00002100
 ISN 0130            DT=.01                                                      00002110
 ISN 0131            VB=105.                                                     00002120
 ISN 0132            SC=FOUR(60.)                                                00002130
 ISN 0133            WTAC=57.                                                    00002140
 ISN 0134            KG=.055                                                     00002150
 ISN 0135            IF (KSLIP.EQ.2) SKSLIP=.TRUE.                               00002160
 ISN 0137            IF (KSLIP.EQ.3) SIDEAL=FOUR(3.)                             00002165
               C                                                                 00002170
 ISN 0139            IDEALS=SIDEAL/4                                             00002171
 ISN 0140            WRITE(6,1030) SKSLIP,IDEALS                                 00002180
 ISN 0141         1030 FORMAT ('1',1X,27HTEST SLIP CONTROL   SKSLIP=,L1,9H  SIDEAL=,I2) 00002190
 ISN 0142            WRITE(6,1020)                                               00002200
               C          INITIALIZE CONTROL SUBROUTINE                        00002210
 ISN 0143            INITC=.TRUE.                                                00002220
 ISN 0144            CALL LOOP(TIME,DT,VB,SC,WTAC,SKIP,INITC)                    00002230
 ISN 0145            INITC=.FALSE.                                               00002240
               C                                                                 00002250
 ISN 0146            DO 200 ISLIP=1,100                                          00002260
 ISN 0147            SC=FOUR(60.)                                                00002265
```

```
  ISN 0148           CALL LOOP(TIME,DT,VB,SC,WTAC,SKIP,INITC)                    00002270
  ISN 0149           IF (ISLIP.LT.25) GO TO 200                                  00002280
  ISN 0151           KG=KG-.001                                                  00002290
  ISN 0152           IF (KG.LT.0.0001) KG=.001                                   00002300
  ISN 0154         200 CONTINUE                                                  00002310
                   C                                                           00002320
                   C       TEST SC I FOLDBACK                                  00002330
                   C                                                           00002340
  ISN 0155           DO 300 KFOLD=1,3                                            00002350
  ISN 0156           TIME=0.                                                     00002360
  ISN 0157           DT=.01                                                      00002370
  ISN 0158           SKSLIP=.FALSE.                                              00002380
  ISN 0159           SC=FOUR(60.)                                                00002390
  ISN 0160           WTAC=-60.                                                   00002400
  ISN 0161           KG=.055                                                     00002410
  ISN 0162           IF (KFOLD.EQ.2) SKFOLD=.TRUE.                               00002420
  ISN 0164           IF (KFOLD.EQ.3) ILIMIT=FOUR(50.)                            00002423
  ISN 0166           IF (KFOLD.EQ.3) IMAX=FOUR(2.*50.)                           00002426
                   C                                                           00002430
  ISN 0168           WRITE (6,1040) SKFOLD                                       00002440
  ISN 0169        1040 FORMAT ('1',1X,28HTEST SC I FOLDBACK   SKFOLD=,L1)        00002450
  ISN 0170           WRITE (6,1020)                                              00002460
                   C       INITIALIZE CONTROL SUBROUTINE                       00002470
  ISN 0171           INITC=.TRUE.                                                00002480
  ISN 0172           CALL LOOP(TIME,DT,VB,SC,WTAC,SKIP,INITC)                    00002490
  ISN 0173           INITC=.FALSE.                                               00002500
                   C                                                           00002510
  ISN 0174           DO 300 IFOLD=1,360                                          00002520
  ISN 0175           IF (IFOLD.EQ.125) KG=.075                                   00002530
  ISN 0177           IF (IFOLD.GE.300) KG=KG+.002                                00002540
                   C                                                           00002550
  ISN 0179           SC=FOUR(60.)                                                00002555
  ISN 0180           CALL LOOP(TIME,DT,VB,SC,WTAC,SKIP,INITC)                    00002560
  ISN 0181         300 CONTINUE                                                  00002570
  ISN 0182           STOP                                                        00002580
  ISN 0183           END                                                         00002590
```

*****F O R T R A N C R O S S R E F E R E N C E L I S T I N G*****

SYMBOL	INTERNAL STATEMENT NUMBERS											
F	0006											
I	0099	0100	0102	0104	0106	0108						
J	0004	0010	0036									
K	0050	0051	0053	0055	0057	0059	0062	0068	0073	0075	0077	0085
DT	0006	0006	0093	0097	0110	0130	0144	0148	0157	0172	0180	
FC	0005											
I1	0006											
I2	0006											
KG	0004	0010	0035	0134	0151	0151	0152	0152	0161	0175	0177	0177
K1	0047											
LM	0003	0009	0032									
L1	0003	0009	0030									
L2	0003	0009	0034									
PC	0005											
PF	0006											
PW	0005											
R1	0003	0009	0029									
R2	0003	0009	0033									

```
 LEVEL 2.2  (SEPT 76)                    OS/360  FORTRAN H EXTENDED          DATE 78.030/12

REQUESTED OPTIONS: MAP,XREF,NAME=LOOP,OPT=0

OPTIONS IN EFFECT: NAME(LOOP) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF NOTERM

                C                                                                    00000010
                C                                                                    00000020
   ISN 0002           SUBROUTINE LOOP(TIME,DT,VB,SC,WTAC,SKIP,INITC)                 00000030
                C                                                                    00000040
   ISN 0003           INTEGER SC,TAC,FC,PC,PW,I                                      00000050
   ISN 0004           REAL I1,I2,VB,F,TORQ,PF,ROTORL,TIME,DT,V1,V5,V7,V11,V13,       00000060
                     1     WTAC,STAC,RDTAC,DT,PI,W,FWOUT,PWIN,EFF,FREQ,VRMS,       00000070
                     2     V1NM,VHNM,VHPCNT,I11,I1H,IHPCNT,FN,V17,V19,V23,V25      00000080
   ISN 0005           LOGICAL FCSGN,INITC,SKIP                                       00000090
                C                                                                    00000100
   ISN 0006           FOUR(A)=A*4.+.01                                               00000110
   ISN 0007           FOURN(B)=B*4.-.01                                              00000120
                C                                                                    00000130
   ISN 0008           IF (INITC) GO TO 105                                           00000140
   ISN 0010           TIME=TIME+DT                                                   00000150
                C                                                                    00000160
   ISN 0011           IF (SKIP)GO TO 105                                             00000170
   ISN 0013           FC=IABS(SC)                                                    00000180
   ISN 0014           FCSGN=.TRUE.                                                   00000190
   ISN 0015           IF (SC.LT.0) FCSGN=.FALSE.                                     00000200
   ISN 0017           PC=1                                                           00000210
   ISN 0018           PW=2560                                                        00000220
   ISN 0019           GO TO 115                                                      00000230
                C                                                                    00000240
   ISN 0020       105 IF (WTAC.GE.0.) TAC=FOUR(WTAC)                                 00000250
   ISN 0022           IF (WTAC.LT.0.) TAC=FOURN(WTAC)                                00000260
                C                                                                    00000270
   ISN 0024           I=FOUR(I1)                                                     00000275
   ISN 0025           CALL CNTRL (SC,TAC,FC,FCSGN,PC,PW,INITC,I,DT)                  00000280
                C                                                                    00000290
                C        CLEAR COMMAND                                               00000300
   ISN 0026       115 IF (FC.GT.0)GO TO 110                                          00000310
   ISN 0028           V1=0.                                                          00000320
   ISN 0029           V5=0.                                                          00000330
   ISN 0030           V7=0.                                                          00000340
   ISN 0031           V11=0.                                                         00000350
   ISN 0032           V13=0.                                                         00000360
   ISN 0033           V17=0.                                                         00000370
   ISN 0034           V19=0.                                                         00000380
   ISN 0035           V23=0.                                                         00000390
   ISN 0036           V25=0.                                                         00000400
   ISN 0037           F=0.                                                           00000410
   ISN 0038           GO TO 120                                                      00000420
                C                                                                    00000430
   ISN 0039       110 F=FLOAT(FC)/4.                                                 00000440
                C                                                                    00000450
   ISN 0040           CALL HRMNIC (F,PC,PW,VB,V1,V5,V7,V11,V13,V17,V19,V23,V25)      00000460
                C                                                                    00000470
   ISN 0041       120 STAC=WTAC                                                      00000480
   ISN 0042           IF (.NOT.FCSGN)STAC=STAC*(-1.)                                 00000490
                C                                                                    00000500
   ISN 0044           CALL MOTOR (V1,V5,V7,V11,V13,V17,V19,V23,V25,                  00000510
                     1            F,STAC,I1,I2,TORQ,ROTORL,PF,I11,I1H)              00000520
```

```
                C                                                                       00000530
   ISN 0045             IF (.NOT.FCSGN)TORQ=TORQ*(-1.)                                  00000540
                C                                                                       00000550
   ISN 0047             PI=3.1416                                                       00000560
   ISN 0048             RDTAC=2*PI*WTAC                                                 00000570
                C                                                                       00000580
   ISN 0049             CALL LOADG (TORQ,RDTAC,DT)                                      00000590
                C                                                                       00000600
   ISN 0050             WTAC=RDTAC/(2*PI)                                               00000610
                C                                                                       00000620
   ISN 0051             PWOUT=TORQ*RDTAC                                                00000630
   ISN 0052             VRMS=SQRT(V1**2+V5**2+V7**2+V11**2+V13**2                       00000640
                       1          +V17**2+V19**2+V23**2+V25**2)                        00000650
   ISN 0053             PWIN=3*I1*VRMS*PF                                               00000660
   ISN 0054             EFF=0.                                                          00000670
   ISN 0055             IF (ABS(PWIN).GT.0.) EFF=(PWOUT/PWIN)*100.                      00000680
                C                                                                       00000690
   ISN 0057             FREQ=F                                                          00000700
   ISN 0058             IF (.NOT.FCSGN) FREQ=F*(-1.)                                    00000710
                C                                                                       00000720
   ISN 0060             FN=F                                                            00000730
   ISN 0061             IF (FN.LT.0.01) FN=.01                                          00000740
   ISN 0063             V1NM=V1*60./FN                                                  00000750
   ISN 0064             VHNM=(SQRT(V5**2+V7**2+V11**2+V13**2+                           00000760
                       1          V17**2+V19**2+V23**2+V25**2))*60./FN                 00000770
   ISN 0065             IF (V1NM.LT.0.1) V1NM=.1                                        00000780
   ISN 0067             VHPCNT=(VHNM/V1NM)*100.                                         00000790
   ISN 0068             IF (I11.LT.0.1) I11=.1                                          00000800
   ISN 0070             IHPCNT=(I1H/I11)*100.                                           00000810
                C                                                                       00000820
   ISN 0071             WRITE(6,1001) TIME,WTAC,TORQ,I1,IHPCNT,V1NM,VHNM,VHPCNT,EFF,PF, 00000830
                       1              I1H,FREQ,PW                                      00000840
   ISN 0072             WRITE(14,1002) TIME,WTAC,TORQ,I1,IHPCNT,V1NM,VHNM,VHPCNT,EFF,PF, 00000850
                       1               FREQ                                            00000860
   ISN 0073          1001 FORMAT (1X,12F8.2,I8)                                         00000870
   ISN 0074          1002 FORMAT (8F8.2,F4.0,F4.2,F4.0)                                 00000880
                C                                                                       00000890
   ISN 0075             RETURN                                                          00000900
   ISN 0076             END                                                             00000910
```

*****F O R T R A N C R O S S R E F E R E N C E L I S T I N G*****

SYMBOL	INTERNAL STATEMENT NUMBERS						
F	0004	0037	0039	0040	0044	0057	0058	0060
I	0003	0024	0025					
W	0004							
DT	0002	0004	0004	0010	0025	0049		
FC	0003	0013	0025	0026	0039			
FN	0004	0060	0061	0061	0063	0064		
I1	0004	0024	0044	0053	0071	0072		
I2	0004	0044						
PC	0003	0017	0025	0040				
PF	0004	0044	0053	0071	0072			
PI	0004	0047	0048	0050				
PW	0003	0018	0025	0040	0071			
SC	0002	0003	0013	0015	0025			
VB	0002	0004	0040					
V1	0004	0028	0040	0044	0052	0063		

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 LEVEL 2.2  (SEPT 76)                    OS/360  FORTRAN H EXTENDED              DATE 78.030/12

 REQUESTED OPTIONS: MAP,XREF,NAME=CNTRL,OPT=0

 OPTIONS IN EFFECT: NAME(CNTRL) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                    SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF NOTERM

                      C                                                                    00000010
                      C                                                                    00000020
                      C                                                                    00000030
     ISN 0002               SUBROUTINE CNTRL (SC,TAC,FC,FCSGN,PC,PW,INITC,I,DT)           00000040
                      C        SET CONDITIONS                                              00000050
                      C                                                                    00000060
                      C                                                                    00000070
     ISN 0003               INTEGER SC,TAC,DZ,TLL1,TLL2,BNDRY,DLTF,FC,PC,PW,SCTAC,        00000080
                           1        I,ILIMIT,IMAX,SCFOLD,SIDEAL,SLTIME,DSCTAC,INCFLD      00000090
     ISN 0004               LOGICAL SCSGN,TACSGN,DSGN,FCSGN,SLIPC,INITC,                  00000100
                           1        SKSLIP,SKFOLD                                         00000110
     ISN 0005               REAL ITIME,DT,SCALE,SLIPN,SLIPSR,HYSTM                        00000120
                      C                                                                    00000130
                      C                                                                    00000140
                      C                                                                    00000150
                      C        MOTOR CONTROLLER FIXED DATA                                 00000160
     ISN 0006               INTEGER DZLO,DZHI,TLL1LO,TLL1HI,TLL2LO,TLL2HI,DLTADW,DLTAUP,  00000170
                           1 BNDRY1,BNDRY2,BNDRY4,BNDRY8,HYST                            00000180
     ISN 0007               COMMON /ONE/ DZLO,DZHI,TLL1LO,TLL1HI,TLL2LO,TLL2HI,           00000190
                           1 DLTADW,DLTAUP,BNDRY1,BNDRY2,BNDRY4,BNDRY8,HYST,             00000200
                           2 SKFOLD,SKSLIP,ILIMIT,IMAX,SIDEAL                            00000210
                      C                                                                    00000220
     ISN 0008               FOUR(A)=A*4.+.01                                              00000230
                      C                                                                    00000240
                      C           INITIAL CONDITIONS                                       00000250
     ISN 0009               IF (.NOT.INITC)GO TO 185                                      00000260
     ISN 0011               DZ=DZHI                                                       00000270
     ISN 0012               TLL1=TLL1HI                                                   00000280
     ISN 0013               TLL2=TLL2LO                                                   00000290
     ISN 0014               ITIME=0.                                                      00000300
     ISN 0015               HYSTM=1.                                                      00000310
     ISN 0016               INCFLD=0                                                      00000320
     ISN 0017               SCALE=0.                                                      00000330
     ISN 0018               SLTIME=0                                                      00000340
     ISN 0019               SLIPN=1.                                                      00000350
     ISN 0020               GO TO 500                                                     00000360
                      C                                                                    00000370
                      C                                                                    00000380
                      C        DETERMINE MAGITUDES & SIGNS OF SC & TAC                     00000390
     ISN 0021         185   MSC=IABS(SC)                                                  00000400
     ISN 0022               SCSGN=.TRUE.                                                  00000410
     ISN 0023               MTAC=IABS(TAC)                                                00000420
     ISN 0024               TACSGN=.TRUE.                                                 00000430
     ISN 0025               IF (SC.LT.0) SCSGN=.FALSE.                                    00000440
     ISN 0027               IF (TAC.LT.0) TACSGN=.FALSE.                                  00000450
                      C                                                                    00000460
                      C          SC I FOLDBACK  ROUTINE                                    00000470
                      C                                                                    00000480
     ISN 0029               IF (.NOT.SKFOLD) GO TO 420                                    00000490
     ISN 0031               IF (INCFLD.GT.0) GO TO 440                                    00000500
     ISN 0033               IF (I.GE.ILIMIT) GO TO 410                                    00000510
     ISN 0035               ITIME=ITIME-DT                                                00000520
     ISN 0036               IF (ITIME.GT.HYSTM) GO TO 450                                 00000530
```

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ISN 0038          IF (ITIME.LT.0.) ITIME=0.                                          00000540
ISN 0040          HYSTM=1.                                                           00000550
ISN 0041          GO TO 420                                                          00000560
ISN 0042      410 ITIME=ITIME+DT                                                     00000570
ISN 0043          IF (ITIME.GE.2.0) ITIME=2.0                                        00000580
ISN 0045          IF (ITIME.LT.HYSTM) GO TO 420                                      00000590
ISN 0047          HYSTM=.5                                                           00000600
ISN 0048          INCFLD=5                                                           00000610
ISN 0049      450 SCALE=SCALE+((FLOAT(I-ILIMIT)/FLOAT(IMAX-ILIMIT))-SCALE)/8.        00000620
ISN 0050      440 SCFOLD=FOUR(60.*(1-SCALE))                                         00000630
ISN 0051          INCFLD=INCFLD-1                                                    00000640
ISN 0052          IF (INCFLD.LT.0) INCFLD=0                                          00000650
ISN 0054          IF (SCFOLD.LT.0) SCFOLD=0                                          00000660
ISN 0056          IF (SCFOLD.GT.FOUR(60.)) SCFOLD=FOUR(60.)                          00000670
ISN 0058          IF (MSC.GT.SCFOLD) MSC=SCFOLD                                      00000680
ISN 0060          GO TO 430                                                          00000690
ISN 0061      420 SCALE=SCALE/8.                                                     00000700
ISN 0062      430 CONTINUE                                                           00000710
                C                                                                    00000720
                C                                                                    00000730
                C       PERFORM SET CONDITIONS ROUTINE                               00000740
                C                                                                    00000750
ISN 0063          SLIPC=.FALSE.                                                      00000760
ISN 0064          FCSGN=SCSGN                                                        00000770
                C                                                                    00000780
                C                                                                    00000790
ISN 0065          IF (MSC.LT.DZ)GO TO 100                                            00000800
                C                                                                    00000810
                C        SC .GE. DZ                                                  00000820
ISN 0067      101 DZ=DZLO                                                          00000830
ISN 0068          IF (MTAC.LT.TLL1)GO TO 110                                         00000840
                C                                                                    00000850
                C       SC .GE. DZ  &  MOTOR RUNNING                                 00000860
ISN 0070      102 TLL1=TLL1LO                                                      00000870
ISN 0071          DSGN=(SCSGN.AND.TACSGN).OR.((.NOT.SCSGN).AND.(.NOT.TACSGN))        00000880
ISN 0072          IF (.NOT.DSGN)GO TO 120                                            00000890
                C                                                                    00000900
                C       TACSGN=SCSGN                                                 00000910
ISN 0074      103 SCTAC=MSC-MTAC                                                   00000920
ISN 0075          IF (SCTAC.LT.0)GO TO 130                                           00000930
                C                                                                    00000940
                C       SC .GE. TAC                                                  00000950
ISN 0077      104 IF (MSC.LE.(MTAC+DLTAUP))GO TO 170                               00000960
                C                                                                    00000970
                C       MOTOR ACCELERATING                                           00000980
ISN 0079      105 FC=MTAC+DLTAUP                                                   00000990
ISN 0080          GO TO 190                                                          00001000
                C                                                                    00001010
                C       TAC .GT. SC                                                  00001020
ISN 0081      130 IF (MSC.LT.(MTAC-DLTADW))GO TO 165                               00001030
                C                                                                    00001040
                C       MOTOR SLOWING DOWN, TAC CLOSE TO SC                          00001050
ISN 0083      135 FC=MSC                                                           00001060
ISN 0084          GO TO 190                                                          00001070
                C                                                                    00001080
                C       SIGNS DIFFERENT                                              00001090
ISN 0085      120 IF (MTAC.GE.TLL2)GO TO 140                                       00001100
                C                                                                    00001110
```

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                C       REVERSE MOTOR                                          00001120
ISN 0087          150 TLL2=TLL2HI                                              00001130
ISN 0088              FC=BNDRY8                                                00001140
ISN 0089              GO TO 190                                                00001150
                C                                                              00001160
                C       MOTOR START COMMAND                                    00001170
ISN 0090          110 TLL1=TLL1HI                                              00001180
ISN 0091              FC=BNDRY8+MTAC                                           00001190
ISN 0092              GO TO 190                                                00001200
                C                                                              00001210
                C       MOTOR STOPING OR REVERSING                             00001220
ISN 0093          140 TLL2=TLL2LO                                              00001230
ISN 0094              FCSGN=TACSGN                                             00001240
ISN 0095              FC=MTAC-DLTADW                                           00001250
ISN 0096              SLIPC=.FALSE.                                            00001260
ISN 0097              GO TO 190                                                00001270
                C                                                              00001280
                C       MOTOR SLOWING DOWN                                     00001290
ISN 0098          165 FC=MTAC-DLTADW                                           00001300
ISN 0099              SLIPC=.FALSE.                                            00001310
ISN 0100              FCSGN=SCSGN                                              00001320
ISN 0101              GO TO 190                                                00001330
                C                                                              00001340
                C       SC .LT. DZ                                             00001350
ISN 0102          100 DZ=DZHI                                                  00001360
ISN 0103              IF (MTAC.GE.TLL2) GO TO 140                              00001370
                C                                                              00001380
                C       ISSUE CLEAR COMMAND                                    00001390
ISN 0105              TLL2=TLL2HI                                              00001400
ISN 0106              GO TO 500                                                00001410
                C                                                              00001420
                C       MOTOR CLOSE TO OR AT SPEED COMMAND                     00001430
ISN 0107          170 FC=MSC                                                   00001440
                C                                                              00001450
                C       SLIPC=.FALSE. MEANS SKIP SLIP CONTROL ROUTINE          00001460
ISN 0108              SLIPC=.TRUE.                                             00001470
ISN 0109          190 CONTINUE                                                 00001480
                C                                                              00001490
                C                                                              00001500
                C                                                              00001510
                C       FC HYSTERISIS                                          00001520
ISN 0110              IF (PC.GT.8)GO TO 220                                    00001530
ISN 0112              GO TO(231,232,220,234,220,220,220,238),PC                00001540
ISN 0113          220 WRITE (6,2000)                                           00001550
ISN 0114         2000 FORMAT (1X,9H ERROR PC)                                  00001560
                C       NOTE: MULT NOT PRESENTLY USED                          00001570
                C                                                              00001580
ISN 0115          231 BNDRY=BNDRY1                                             00001590
ISN 0116              MULT=1                                                   00001600
ISN 0117              GO TO 240                                                00001610
                C                                                              00001620
ISN 0118          232 BNDRY=BNDRY2                                             00001630
ISN 0119              MULT=2                                                   00001640
ISN 0120              GO TO 240                                                00001650
                C                                                              00001660
ISN 0121          234 BNDRY=BNDRY4                                             00001670
ISN 0122              MULT=4                                                   00001680
ISN 0123              GO TO 240                                                00001690
```

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                      C                                                          00001700
ISN 0124                238 BNDRY=BNDRY8                                         00001710
ISN 0125                    MULT=8                                               00001720
                      C                                                          00001730
ISN 0126                240 DLTF=FC-BNDRY                                        00001740
ISN 0127                    IF (DLTF.GE.0)GO TO 250                              00001750
ISN 0129                    IF (DLTF.LT.(-HYST))GO TO 250                        00001760
ISN 0131                    FC=BNDRY                                             00001770
ISN 0132                250 CONTINUE                                             00001780
                      C                                                          00001790
                      C                                                          00001800
                      C        DETERMINE #P/C &MAX PW                            00001810
ISN 0133                    IF (FC.GE.BNDRY1)GO TO 310                           00001820
ISN 0135                    IF (FC.GE.BNDRY2)GO TO 320                           00001830
ISN 0137                    IF (FC.GE.BNDRY4)GO TO 330                           00001840
                      C                                                          00001850
                      C        8 PULSE MODE                                      00001860
ISN 0139                    PC=8                                                 00001870
ISN 0140                    PW=320                                               00001880
ISN 0141                    GO TO 350                                            00001890
                      C                                                          00001900
                      C        1 PULSE MODE                                      00001910
ISN 0142                310 PC=1                                                 00001920
ISN 0143                    PW=2560                                              00001930
ISN 0144                    GO TO 350                                            00001940
                      C                                                          00001950
                      C        2 PULSE MODE                                      00001960
ISN 0145                320 PC=2                                                 00001970
ISN 0146                    PW=1280                                              00001980
ISN 0147                    GO TO 350                                            00001990
                      C                                                          00002000
                      C        4 PULSE MODE                                      00002010
ISN 0148                330 PC=4                                                 00002020
ISN 0149                    PW=640                                               00002030
ISN 0150                350 CONTINUE                                             00002040
                      C                                                          00002050
                      C        CORRECT FOR DLTF                                  00002060
ISN 0151                    IF (DLTF.GE.0)GO TO 370                              00002070
ISN 0153                    IF (DLTF.LT.(-HYST))GO TO 370                        00002080
ISN 0155                    FC=FC+DLTF                                           00002090
ISN 0156                370 CONTINUE                                             00002100
                      C                                                          00002110
                      C        SLIP CONTROL                                      00002120
                      C                                                          00002130
ISN 0157                    IF (.NOT.SKSLIP) GO TO 610                           00002140
ISN 0159                    IF (.NOT.SLIPC) GO TO 610                            00002150
ISN 0161                    IF (SCTAC.LT.SIDEAL) GO TO 620                       00002160
ISN 0163                    SLIPN=SLIPN+(1-SLIPN)/2.                             00002170
ISN 0164                    GO TO 630                                            00002180
ISN 0165                610 SLIPN=1.                                             00002190
ISN 0166                    GO TO 510                                            00002200
ISN 0167                620 SLTIME=SLTIME+1                                      00002210
                      C     IF (SLTIME.LE.3) GO TO 630                           00002220
ISN 0168                    SLTIME=0                                             00002230
ISN 0169                    SLIPN=SLIPN+((FLOAT(SCTAC)/FLOAT(SIDEAL))-SLIPN)/4.  00002240
ISN 0170                630 CONTINUE                                             00002250
ISN 0171                    IF (SLIPN.GT.1.0) SLIPN=1.0                          00002260
ISN 0173                    IF (SLIPN.LT.0.0) SLIPN=0.0                          00002270
```

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LEVEL 2.2  (SEPT 76)          CNTRL          OS/360  FORTRAN H EXTENDED          DATE 78.030/12

                C        CALCULATE MODIFIED SQUARE ROOT                              00002280
  ISN 0175            IF (SLIPN.GE.0.5) SLIPSR=(SLIPN/2.)+.5                         00002290
  ISN 0177            IF (SLIPN.LT.0.5) SLIPSR=SLIPN+.25                             00002300
  ISN 0179            IF (SLIPN.LT.0.25) SLIPSR=SLIPN*2.                             00002310
  ISN 0181            PW=PW*SLIPSR                                                   00002320
  ISN 0182            GO TO 510                                                      00002350
                C                                                                    00002360
                C           CLEAR CONDITIONS                                         00002370
  ISN 0183          500 FC=0                                                       00002380
  ISN 0184            PC=8                                                         00002390
  ISN 0185            PW=320                                                       00002400
  ISN 0186            FCSGN=.TRUE.                                                 00002410
  ISN 0187            SLIPN=1.                                                     00002420
                C                                                                  00002430
  ISN 0188          510 RETURN                                                     00002440
  ISN 0189            END                                                          00002450


                      *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL  INTERNAL STATEMENT NUMBERS
I       0002  0003  0033  0049
DT      0002  0005  0035  0042
DZ      0003  0011  0065  0067  0102
FC      0002  0003  0079  0083  0088  0091  0095  0098  0107  0126  0131  0133  0135  0137  0155  (
PC      0002  0003  0110  0112  0139  0142  0145  0148  0184
PW      0002  0003  0140  0143  0146  0149  0181  0181  0185
SC      0002  0003  0021  0025
MSC     0021  0058  0058  0065  0074  0077  0081  0083  0107
TAC     0002  0003  0023  0027
DLTF    0003  0126  0127  0129  0151  0153  0155
DSGN    0004  0071  0072
DZHI    0006  0007  0011  0102
DZLO    0006  0007  0067
FOUR    0008  0050  0056  0056
HYST    0006  0007  0129  0153
IABS    0021  0023
IMAX    0003  0007  0049
MTAC    0023  0068  0074  0077  0079  0081  0085  0091  0095  0098  0103
MULT    0116  0119  0122  0125
TLL1    0003  0012  0068  0070  0090
TLL2    0003  0013  0085  0087  0093  0103  0105
BNDRY   0003  0115  0118  0121  0124  0126  0131
CNTRL   0002
FCSGN   0002  0004  0064  0094  0100  0186
FLOAT   0049  0049  0169  0169
HYSTM   0005  0015  0036  0040  0045  0047
INITC   0002  0004  0009
ITIME   0005  0014  0035  0035  0036  0038  0038  0042  0042  0043  0043  0045
SCALE   0005  0017  0049  0049  0049  0050  0061  0061
SCSGN   0004  0022  0025  0064  0071  0071  0100
SCTAC   0003  0074  0075  0161  0169
SLIPC   0004  0063  0096  0099  0108  0159
SLIPN   0005  0019  0163  0163  0163  0165  0169  0169  0169  0171  0171  0173  0173  0175  0175  (
        0187
BNDRY1  0006  0007  0115  0133
BNDRY2  0006  0007  0118  0135
BNDRY4  0006  0007  0121  0137
BNDRY8  0006  0007  0088  0091  0124
```

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 LEVEL 2.2  (SEPT 76)                    OS/360  FORTRAN H EXTENDED          DATE 78.030/12

 REQUESTED OPTIONS: MAP,XREF,NAME=HRMNIC,OPT=0

 OPTIONS IN EFFECT: NAME(HRMNIC) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                    SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF NOTERM

                      C                                                                    00000010
                      C                                                                    00000020
                      C                                                                    00000030
   ISN 0002                SUBROUTINE HRMNIC (F,PC,PW,VB,V1,V5,V7,V11,V13,V17,V19,V23,V25)  00000040
   ISN 0003                INTEGER PC,PW                                                    00000050
   ISN 0004                REAL V1,V5,V7,V11,V13,V17,V19,V23,V25,F,DTR,DLTA,VK,VB,SUMA,     00000060
                          1     PERIOD,PCMOD                                               00000070
                      C                                                                    00000080
   ISN 0005                PERIOD=1000000./(6.*F)                                           00000090
   ISN 0006                PCMOD=(PC*PW)/PERIOD                                             00000100
   ISN 0007                DTR=3.1416/180.                                                  00000110
   ISN 0008                DLTA=60.*(1.-PCMOD)/(2.*PC)                                      00000120
   ISN 0009                VK=4.*VB/(3.1416*1.4142)                                         00000130
                      C        CALCULATE FOR EACH HARMONIC                                 00000140
   ISN 0010                DO 110 N=1,25,2                                                  00000150
   ISN 0011                IF (N.EQ.3)GO TO 110                                             00000160
   ISN 0013                IF (N.EQ.9)GO TO 110                                             00000170
   ISN 0015                IF (N.EQ.15)GO TO 110                                            00000180
   ISN 0017                IF (N.EQ.21)GO TO 110                                            00000190
   ISN 0019                SUMA=0.                                                          00000200
   ISN 0020                DO 120 J=1,PC,1                                                  00000210
   ISN 0021                ANGLEP=(30+(J-1)*60/PC+DLTA)*N                                   00000220
   ISN 0022                ANGLEM=(30+J*60/PC-DLTA)*N                                       00000230
   ISN 0023                SUMA=COS(ANGLEP*DTR)-COS(ANGLEM*DTR)+SUMA                        00000240
   ISN 0024              120 CONTINUE                                                       00000250
   ISN 0025                GO TO (131,110,110,110,132,110,133,110,110,110,134,110,135,     00000260
                          1       110,110,110,136,110,137,110,110,110,138,110,139),N       00000270
   ISN 0026              131 V1=VK*SUMA/N                                                   00000280
   ISN 0027                GO TO 110                                                        00000290
   ISN 0028              132 V5=VK*SUMA/N                                                   00000300
   ISN 0029                GO TO 110                                                        00000310
   ISN 0030              133 V7=VK*SUMA/N                                                   00000320
   ISN 0031                GO TO 110                                                        00000330
   ISN 0032              134 V11=VK*SUMA/N                                                  00000340
   ISN 0033                GO TO 110                                                        00000350
   ISN 0034              135 V13=VK*SUMA/N                                                  00000360
   ISN 0035                GO TO 110                                                        00000370
   ISN 0036              136 V17=VK*SUMA/N                                                  00000380
   ISN 0037                GO TO 110                                                        00000390
   ISN 0038              137 V19=VK*SUMA/N                                                  00000400
   ISN 0039                GO TO 110                                                        00000410
   ISN 0040              138 V23=VK*SUMA/N                                                  00000420
   ISN 0041                GO TO 110                                                        00000430
   ISN 0042              139 V25=VK*SUMA/N                                                  00000440
   ISN 0043              110 CONTINUE                                                       00000450
   ISN 0044                RETURN                                                           00000460
   ISN 0045                END                                                              00000470


                        *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
 SYMBOL  INTERNAL STATEMENT NUMBERS
 F       0002  0004  0005
 J       0020  0021  0022
```

REQUESTED OPTIONS: MAP,XREF,NAME=MOTOR,OPT=0

OPTIONS IN EFFECT: NAME(MOTOR) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF NOTERM

```
                C                                                                       00000010
                C                                                                       00000020
  ISN 0002            SUBROUTINE MOTOR (V1,V5,V7,V11,V13,V17,V19,V23,V25,              00000030
                     1                 F,STAC,I1,I2,TORQ,ROTORL,PF,I11,I1H)           00000040
                C                                                                       00000050
                C       CALCULATE MOTOR CURRENT I1, TORQUE T, POWER FACTOR PF,          00000060
                C          ROTOR LOSS  ROTORL                                           00000070
                C                                                                       00000080
  ISN 0003            REAL F,STAC,V1,V5,V7,V11,V13,I1,I11,I15,I17,I111,I113,          00000090
                     1     V17,V19,V23,V25,I117,I119,I123,I125,                       00000100
                     2     I2,I21,I25,I27,I211,I213,TORQ,T1,T5,T7,T11,T13,            00000110
                     3     I217,I219,I223,I225,T17,T19,T23,T25,                       00000120
                     4     ROTORL,ROTL1,ROTL5,ROTL7,ROTL11,ROTL13,                    00000130
                     5     ROTL17,ROTL19,ROTL23,ROTL25,                               00000140
                     6     PF,PF1,PF5,PF7,PF11,PF13,I1H,                              00000150
                     7     PF17,PF19,PF23,PF25                                        00000160
                C                                                                       00000170
                C       1ST HARMONIC                                                    00000180
  ISN 0004            N=1                                                             00000190
  ISN 0005            CALL MOTORZ(V1,N,F,I11,I21,STAC,T1,ROTL1,PF1)                   00000200
                C       5TH HARMONIC                                                    00000210
  ISN 0006            N=5                                                             00000220
  ISN 0007            CALL MOTORZ(V5,N,F,I15,I25,STAC,T5,ROTL5,PF5)                   00000230
                C       7TH HARMONIC                                                    00000240
  ISN 0008            N=7                                                             00000250
  ISN 0009            CALL MOTORZ(V7,N,F,I17,I27,STAC,T7,ROTL7,PF7)                   00000260
                C       11TH HARMONIC                                                   00000270
  ISN 0010            N=11                                                            00000280
  ISN 0011            CALL MOTORZ(V11,N,F,I111,I211,STAC,T11,ROTL11,PF11)             00000290
                C       13TH HARMONIC                                                   00000300
  ISN 0012            N=13                                                            00000310
  ISN 0013            CALL MOTORZ(V13,N,F,I113,I213,STAC,T13,ROTL13,PF13)             00000320
                C       17TH HARMONIC                                                   00000330
  ISN 0014            N=17                                                            00000340
  ISN 0015            CALL MOTORZ(V17,N,F,I117,I217,STAC,T17,ROTL17,PF17)             00000350
                C       19TH HARMONIC                                                   00000360
  ISN 0016            N=19                                                            00000370
  ISN 0017            CALL MOTORZ(V19,N,F,I119,I219,STAC,T19,ROTL19,PF19)             00000380
                C       23TH HARMONIC                                                   00000390
  ISN 0018            N=23                                                            00000400
  ISN 0019            CALL MOTORZ(V23,N,F,I123,I223,STAC,T23,ROTL23,PF23)             00000410
                C       25TH HARMONIC                                                   00000420
  ISN 0020            N=25                                                            00000430
  ISN 0021            CALL MOTORZ(V25,N,F,I125,I225,STAC,T25,ROTL25,PF25)             00000440
                C                                                                       00000450
  ISN 0022            I1=SQRT((I11**2)+(I15**2)+(I17**2)+(I111**2)+(I113**2)          00000460
                     1       +(I117**2)+(I119**2)+(I123**2)+(I125**2))                00000470
  ISN 0023            I2=SQRT((I21**2)+(I25**2)+(I27**2)+(I211**2)+(I213**2)          00000480
                     1       +(I217**2)+(I219**2)+(I223**2)+(I225**2))                00000490
  ISN 0024            I1H=SQRT((I15**2)+(I17**2)+(I111**2)+(I113**2)                  00000500
                     1       +(I117**2)+(I119**2)+(I123**2)+(I125**2))                00000510
  ISN 0025            TORQ=T1-T5+T7-T11+T13-T17+T19-T23+T25                           00000520
  ISN 0026            ROTORL=ROTL1+ROTL5+ROTL7+ROTL11+ROTL13+ROTL17+ROTL19+ROTL23+ROTL2500000530
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   ISN 0027          PF=PF1                                              00000540
   ISN 0028          RETURN                                              00000550
   ISN 0029          END                                                 00000560
```

*****FORTRAN CROSS REFERENCE LISTING*****

SYMBOL	INTERNAL STATEMENT NUMBERS															
F	0002	0003	0005	0007	0009	0011	0013	0015	0017	0019	0021					
N	0004	0005	0006	0007	0008	0009	0010	0011	0012	0013	0014	0015	0016	0017	0018	0
I1	0002	0003	0022													
I2	0002	0003	0023													
PF	0002	0003	0027													
T1	0003	0005	0025													
T5	0003	0007	0025													
T7	0003	0009	0025													
V1	0002	0003	0005													
V5	0002	0003	0007													
V7	0002	0003	0009													
I1H	0002	0003	0024													
I11	0002	0003	0005	0022												
I15	0003	0007	0022	0024												
I17	0003	0009	0022	0024												
I21	0003	0005	0023													
I25	0003	0007	0023													
I27	0003	0009	0023													
PF1	0003	0005	0027													
PF5	0003	0007														
PF7	0003	0009														
T11	0003	0011	0025													
T13	0003	0013	0025													
T17	0003	0015	0025													
T19	0003	0017	0025													
T23	0003	0019	0025													
T25	0003	0021	0025													
V11	0002	0003	0011													
V13	0002	0003	0013													
V17	0002	0003	0015													
V19	0002	0003	0017													
V23	0002	0003	0019													
V25	0002	0003	0021													
I111	0003	0011	0022	0024												
I113	0003	0013	0022	0024												
I117	0003	0015	0022	0024												
I119	0003	0017	0022	0024												
I123	0003	0019	0022	0024												
I125	0003	0021	0022	0024												
I211	0003	0011	0023													
I213	0003	0013	0023													
I217	0003	0015	0023													
I219	0003	0017	0023													
I223	0003	0019	0023													
I225	0003	0021	0023													
PF11	0003	0011														
PF13	0003	0013														
PF17	0003	0015														
PF19	0003	0017														
PF23	0003	0019														
PF25	0003	0021														

```
LEVEL 2.2  (SEPT 76)                    OS/360  FORTRAN H EXTENDED              DATE 78.030/12

REQUESTED OPTIONS: MAP,XREF,NAME=MOTORZ,OPT=0

OPTIONS IN EFFECT: NAME(MOTORZ) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF NOTERM

                C                                                                        00000010
                C                                                                        00000020
                C                                                                        00000030
   ISN 0002           SUBROUTINE MOTORZ(V,N,F,I1,I2,STAC,TQ,ROTL,PF)                    00000040
                C       CALCULATE MOTOR IMPEDANCE, CURRENT, POWER FACTOR,                00000050
                C                 AND ROTOR LOSS AT EACH HARMONIC                        00000060
                C                                                                        00000070
                C          --------R1---L1------+-----------L2------+                   00000080
                C           ------>              '    ----->         '                   00000090
                C               I1               RM       I2         '                   00000100
                C                                '                   R2/S<---+          00000110
                C                                '                     '     '          00000120
                C                                LM                          '          00000130
                C                                '                           '          00000140
                C          --------------------+-------------------------+               00000150
                C                                                                        00000160
                C                                                                        00000170
                C                                                                        00000180
   ISN 0003           REAL R1,L1,RMC,LM,R2,L2                                           00000190
   ISN 0004           COMMON /TWO/ R1,L1,RMC,LM,R2,L2                                   00000200
   ISN 0005           REAL RM,PI,W,ZPNR,ZPNX,ZPDR,ZPDX,ZPD,RP,XP,RI,XI,ZI,Z2,           00000210
                     1     TQ,SLIP,V,VP,F,ROTL,PF,I1,I2,ZP,STAC                        00000220
                C                                                                        00000230
                C     ZP=ZM*Z2/(ZM+Z2)                                                   00000240
                C                                                                        00000250
                C                                                                        00000260
                C        (RM+JWLM)*(R2/S+JWL2)                                           00000270
                C     ZP=---------------------                                           00000280
                C        (RM+R2/S)+JW(LM+L2)                                             00000290
                C                                                                        00000300
                C                                                                        00000310
                C        (RM*R2/S-(LM*L2)W**2)+JW(RM*L2+LM*R2/S)                         00000320
                C     ZP=-------------------------------------------                     00000330
                C        (          ) + (        )                                     00000340
                C                                                                        00000350
                C                                                                        00000360
                C        ( ZPNR + J ZPNX )     ( ZPDR - J ZPDX )                       00000370
                C     ZP=----------------   *  ------------------                      00000380
                C        ( ZPDR + J ZPDX )     ( ZPDR - J ZPDX )                       00000390
                C                                                                        00000400
                C                                                                        00000410
                C     ZPD=(ZPDR)**2 + (ZPDX)**2                                          00000420
                C                                                                        00000430
                C     ZP = RP + J XP                                                     00000440
                C                                                                        00000450
                C                                                                        00000460
   ISN 0006           IF (ABS(F).LT..01) F=.01                                          00000465
                C                                                                        00000470
   ISN 0008          12 RM=RMC*F**1.25                                                  00000480
                C                                                                        00000490
   ISN 0009           PI=3.1416                                                         00000500
   ISN 0010           W=2*PI*N*F                                                        00000510
                C                                                                        00000520
```

```
LEVEL 2.2  (SEPT 76)          MOTORZ          OS/360  FORTRAN H EXTENDED          DATE 78.030/12.

  ISN 0011            SLIP=(N*F-STAC)/(N*F)                                          00000530
  ISN 0012            IF ((SLIP.LT.0.0001).AND.(SLIP.GT.(-0.0001))) SLIP=0.0001      00000540
                C                                                                    00000550
  ISN 0014         13 ZPNR=RM*R2/SLIP-(LM*L2)*W**2                                   00000560
  ISN 0015         14 ZPNX=W*(RM*L2+LM*R2/SLIP)                                      00000570
  ISN 0016         15 ZPDR=RM+R2/SLIP                                                00000580
  ISN 0017         16 ZPDX=W*(LM+L2)                                                 00000590
  ISN 0018         17 ZPD=ZPDR**2+ZPDX**2                                            00000600
  ISN 0019         18 RP=(ZPNR*ZPDR+ZPNX*ZPDX)/ZPD                                   00000610
  ISN 0020         19 XP=(ZPNX*ZPDR-ZPNR*ZPDX)/ZPD                                   00000620
  ISN 0021         20 ZP=SQRT(RP**2+XP**2)                                           00000630
                C                                                                    00000640
                C        ZI=Z1+ZP =(R1+RP) + (X1+XP)                                 00000650
                C          = RI + J XI                                               00000660
                C                                                                    00000670
  ISN 0022         21 RI=R1+RP                                                       00000680
  ISN 0023         22 XI=W*L1+XP                                                     00000690
  ISN 0024         23 ZI=SQRT(RI**2+XI**2)                                           00000700
                C                                                                    00000710
  ISN 0025         24 I1=V/ZI                                                        00000720
                C                                                                    00000730
  ISN 0026         25 VP=I1*ZP                                                       00000740
                C                                                                    00000750
  ISN 0027         26 Z2=SQRT((R2/SLIP)**2+(W*L2)**2)                                00000760
                C                                                                    00000770
  ISN 0028         27 I2=VP/Z2                                                       00000780
                C                                                                    00000790
                C                                                                    00000800
                C          TORQUE IN NEWTON-METERS                                   00000810
  ISN 0029         28 TQ=3*(I2**2)*R2/(N*SLIP)                                       00000820
                C                                                                    00000830
  ISN 0030         29 ROTL=3*R2*I2**2                                                00000840
                C                                                                    00000850
                C        POWER FACTOR PF   1ST HARMONIC ONLY  < REMOVE C             00000860
                C     IF (N.GT.1)GO TO 300                                           00000870
  ISN 0031         30 PF=RI/ZI                                                       00000880
                C                                                                    00000890
                C 300 CONTINUE                                                       00000900
                C  31 WRITE(6,3336) RM,ZPNR,ZPNX,ZPDR,ZPDX,ZPD,RP,XP,ZP,RI,XI,ZI,Z2,I2  00000910
                C3336 FORMAT (/,1X,F9.3,F9.3,F9.3,F9.3,F9.3,F9.1,F9.3,F9.3,F9.3,     00000920
                C    1        F9.3,F9.3,F9.3,F9.3,F8.1)                             00000930
                C                                                                    00000940
  ISN 0032            RETURN                                                         00000950
  ISN 0033            END                                                            00000960
```

*****F O R T R A N C R O S S R E F E R E N C E L I S T I N G*****

SYMBOL	INTERNAL STATEMENT NUMBERS							
F	0002	0005	0006	0006	0008	0010	0011	0011
N	0002	0010	0011	0011				
V	0002	0005	0025					
W	0005	0010	0014	0015	0017	0023	0027	0029
I1	0002	0005	0025	0026				
I2	0002	0005	0028	0029	0030			
LM	0003	0004	0014	0015	0017			
L1	0003	0004	0023					
L2	0003	0004	0014	0015	0017	0027		
PF	0002	0005	0031					

```
 LEVEL 2.2  (SEPT 76)                    OS/360  FORTRAN H EXTENDED          DATE 78.030/12.07.57       PAGE   1

REQUESTED OPTIONS: MAP,XREF,NAME=LOADG,OPT=0

OPTIONS IN EFFECT: NAME(LOADG) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
                   SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF NOTERM FLAG(I)

   ISN 0002            SUBROUTINE LOADG(TORQ,RDTAC,DT)                                    00000010
                     C     POWER=V**2/R =((KV)**2/R)*RDTAC**2 =KG*RDTAC**2 =T*RDTAC       00000020
                     C     T=(JL+JM)*RDTAC'+KG*RDTAC+STCTQ =J*RDTAC'+KG*RDTAC+STCTQ       00000030
                     C     (RDTAC(T+DT)-RDTAC(T))/DT=-(KG/J)RDTAC(T)+(T-STCTQ)/J          00000040
                     C     RDTAC(T+DT)=(1-DT*KG/J)*RDTAC(T)+(T-STCTQ)*DT/J                00000050
   ISN 0003          REAL KG,J,DT,TORQ,RDTAC,STCTQ                                        00000060
   ISN 0004          COMMON /THREE/KG,J,STCTQ                                             00000070
   ISN 0005          IF(RDTAC.LT.0.) STCTQ=STCTQ*(-1)                                     00000075
   ISN 0007          RDTAC=(1-DT*KG/J)*RDTAC+(TORQ-STCTQ)*DT/J                            00000080
   ISN 0008          RETURN                                                               00000090
   ISN 0009          END                                                                  00000100


                      *****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
SYMBOL  INTERNAL STATEMENT NUMBERS
J       0003  0004  0007  0007
DT      0002  0003  0007  0007
KG      0003  0004  0007
TORQ    0002  0003  0007
LOADG   0002
RDTAC   0002  0003  0005  0007  0007
STCTQ   0003  0004  0005  0005  0007


                                                    /   LOADG /     SIZE OF PROGRAM 00017A HEXADECIMAL BYTES

     NAME    TAG   TYPE  ADD.       NAME    TAG   TYPE  ADD.       NAME    TAG   TYPE  ADD.       NAME    TAG   TYPE  ADD.
        J  F   C   R*4   000004       DT  F       R*4   000094       KG  F   C   R*4   000000       TORQ  F       R*4   000098
    LOADG          I*4   00009C    RDTAC SF       R*4   0000A0    STCTQ SF   C   R*4   000008


                                  *****  COMMON INFORMATION  *****

      NAME OF COMMON BLOCK  * THREE*   SIZE OF BLOCK    00000C HEXADECIMAL BYTES

     VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
          KG    R*4   000000            J    R*4   000004         STCTQ   R*4   000008


  COMPILER GENERATED LABELS

    LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR          LABEL  ISN   ADDR
   100001    2  0000C8       100002    6  0000D4       100003    7  0000F6

 *OPTIONS IN EFFECT*NAME(LOADG) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

 *OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF NOTERM FLAG(I)

 *STATISTICS*     SOURCE STATEMENTS =       8, PROGRAM SIZE =      378, SUBPROGRAM NAME = LOADG

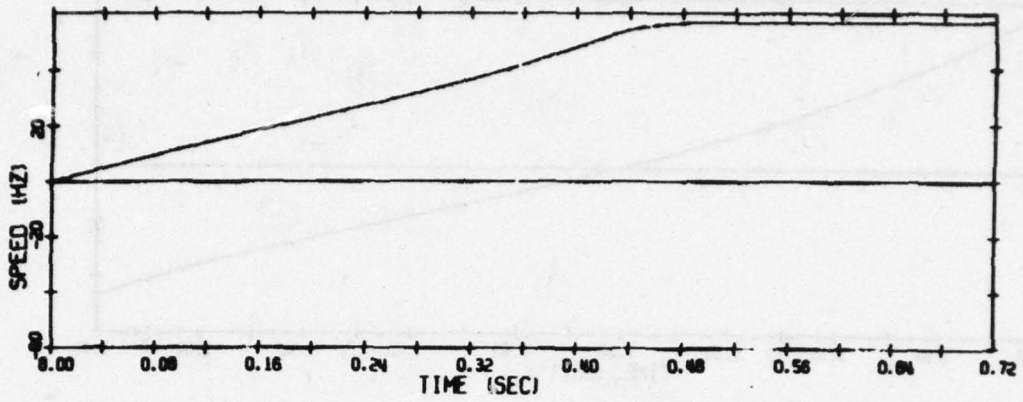
 *STATISTICS*  NO  DIAGNOSTICS GENERATED
```

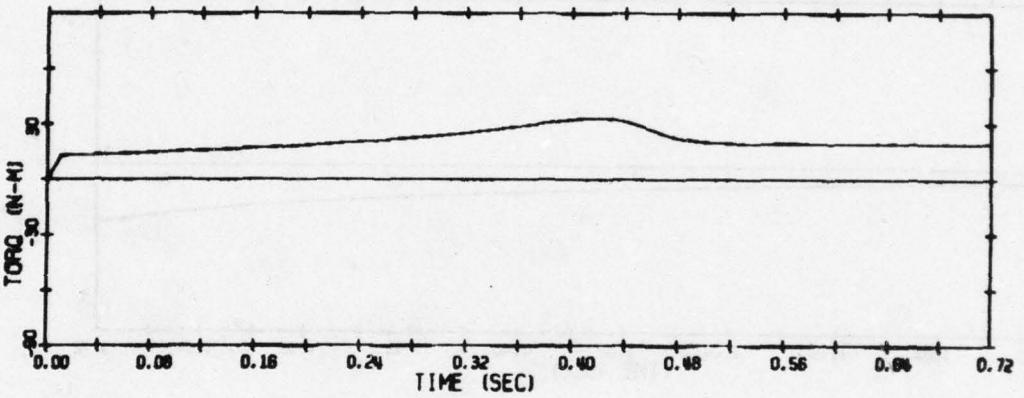
NO CONTROLLER

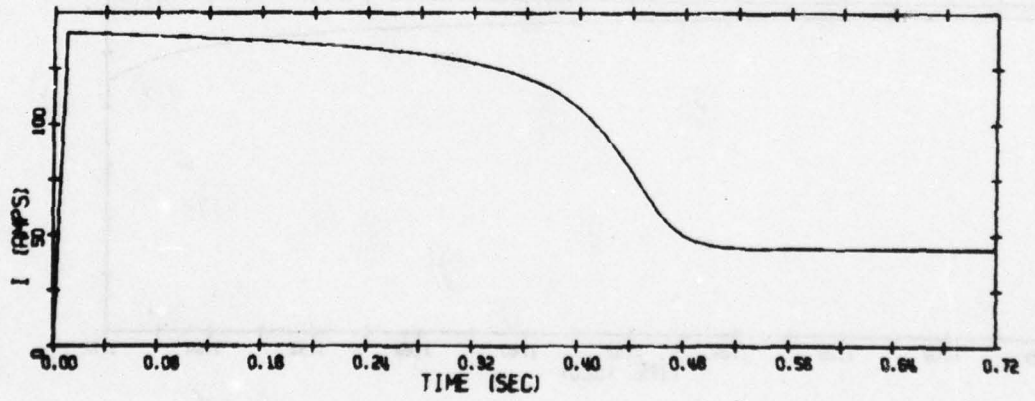
f = 0HZ TO 60HZ STEP

STEP FUNCTION # 1

10/21/77





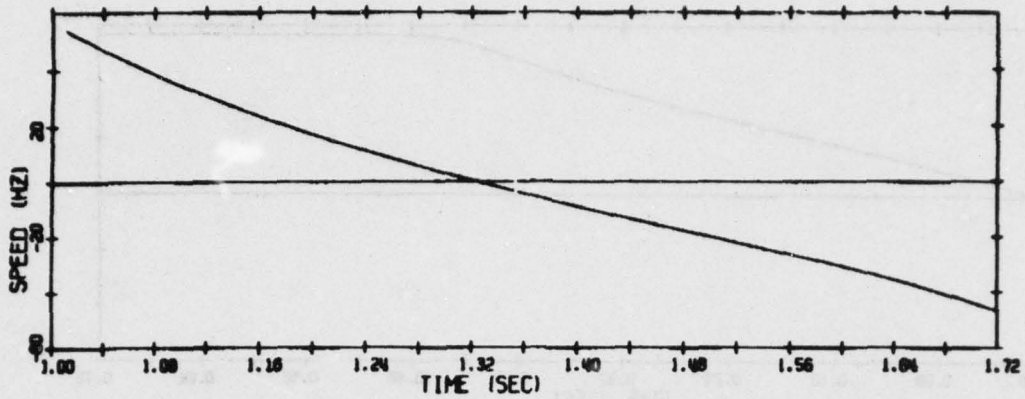


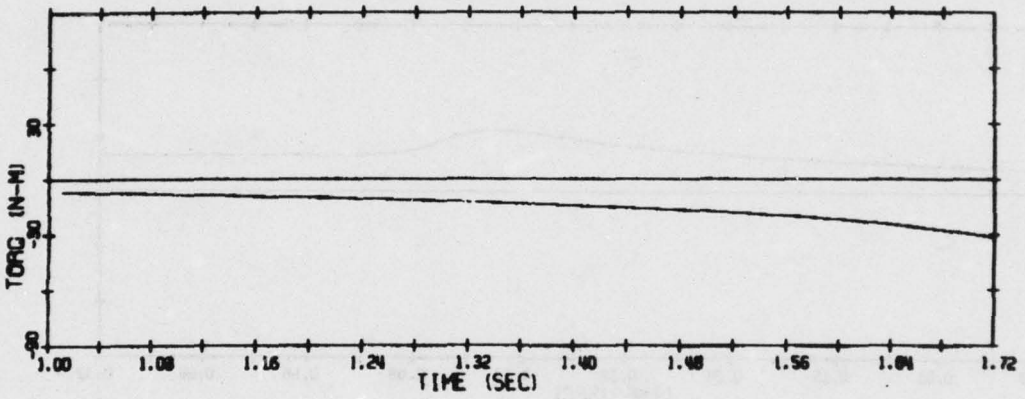
NO CONTROLLER

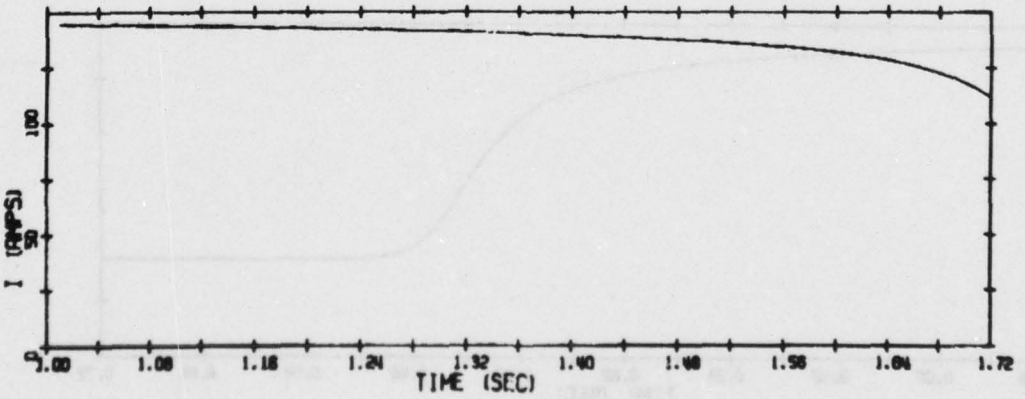
f = > + 60HZ TO - 60HZ STEP

STEP FUNCTION # 1

10/21/77



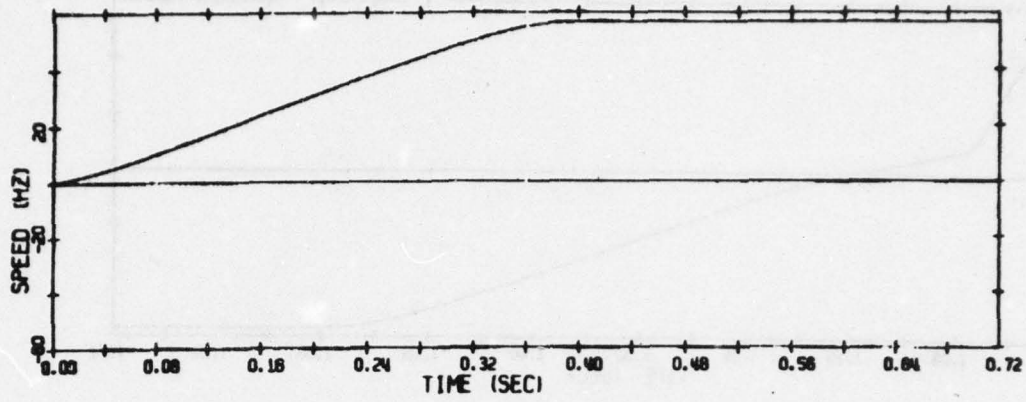


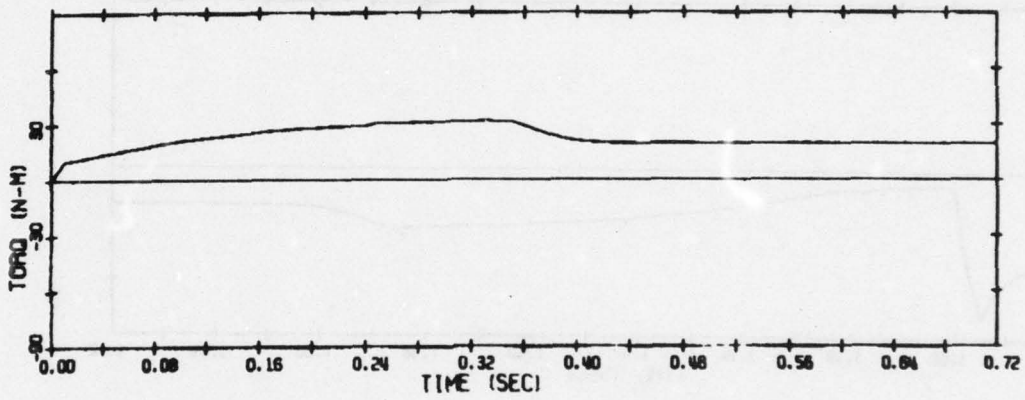


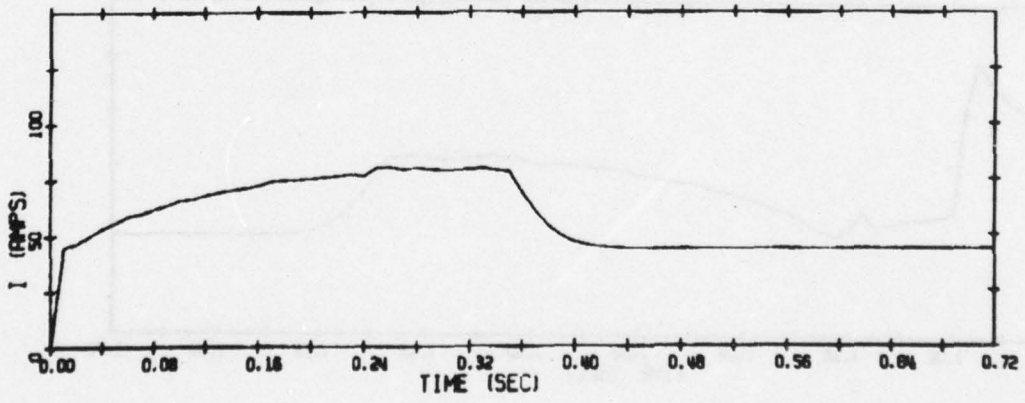
DLTAUP
DLTADW = 7.5HZ

STEP FUNCTION # 2

10/21/77



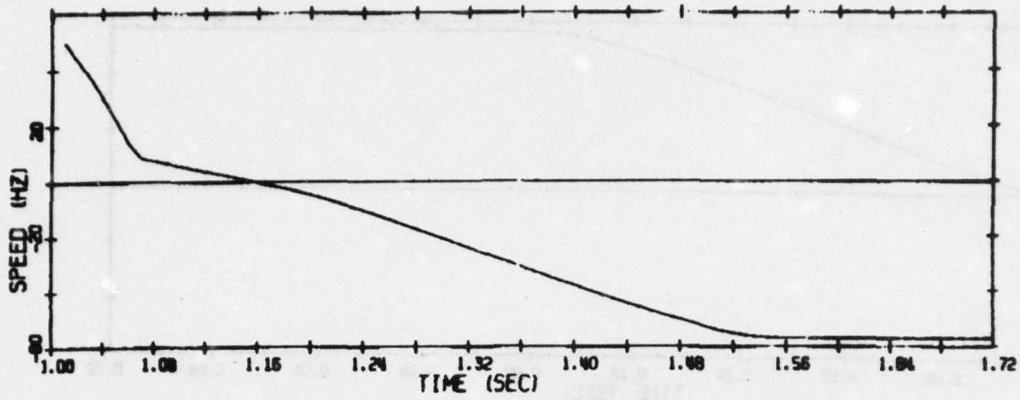


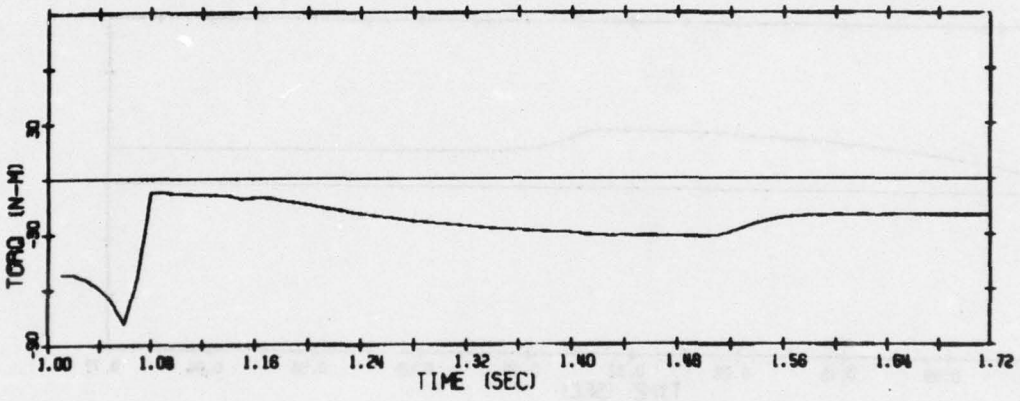


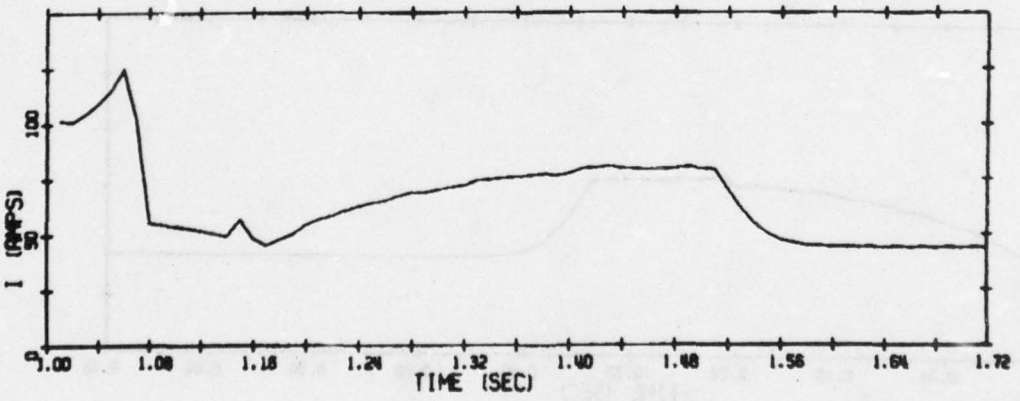
DLTAUP
DLTADW = 7.5HZ

STEP FUNCTION # 2

10/21/77







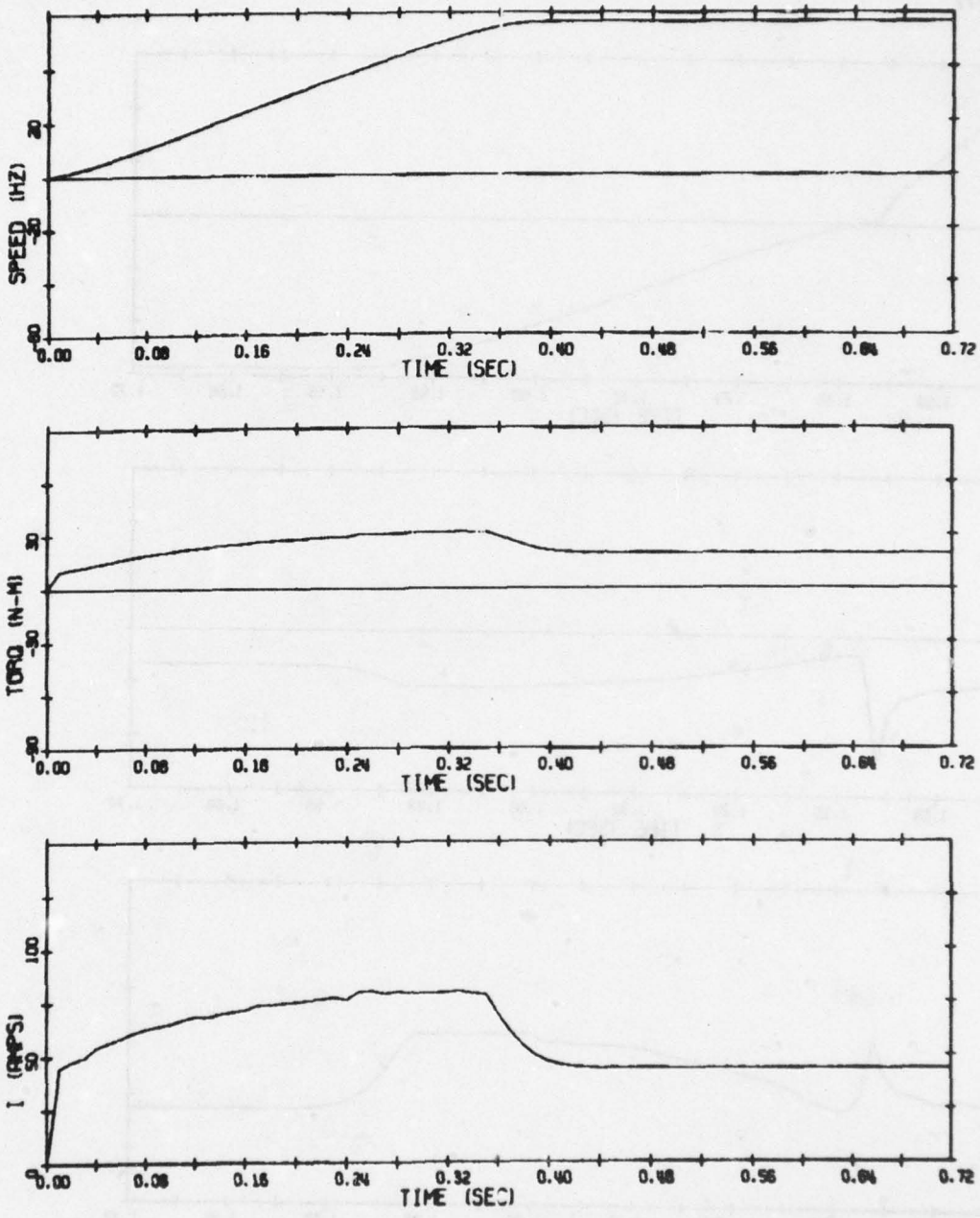
FINAL CONFIGURATION

DLTAUP = 7.5HZ

f START = TAC + 7.25HZ

STEP FUNCTION # 6

10/21/77

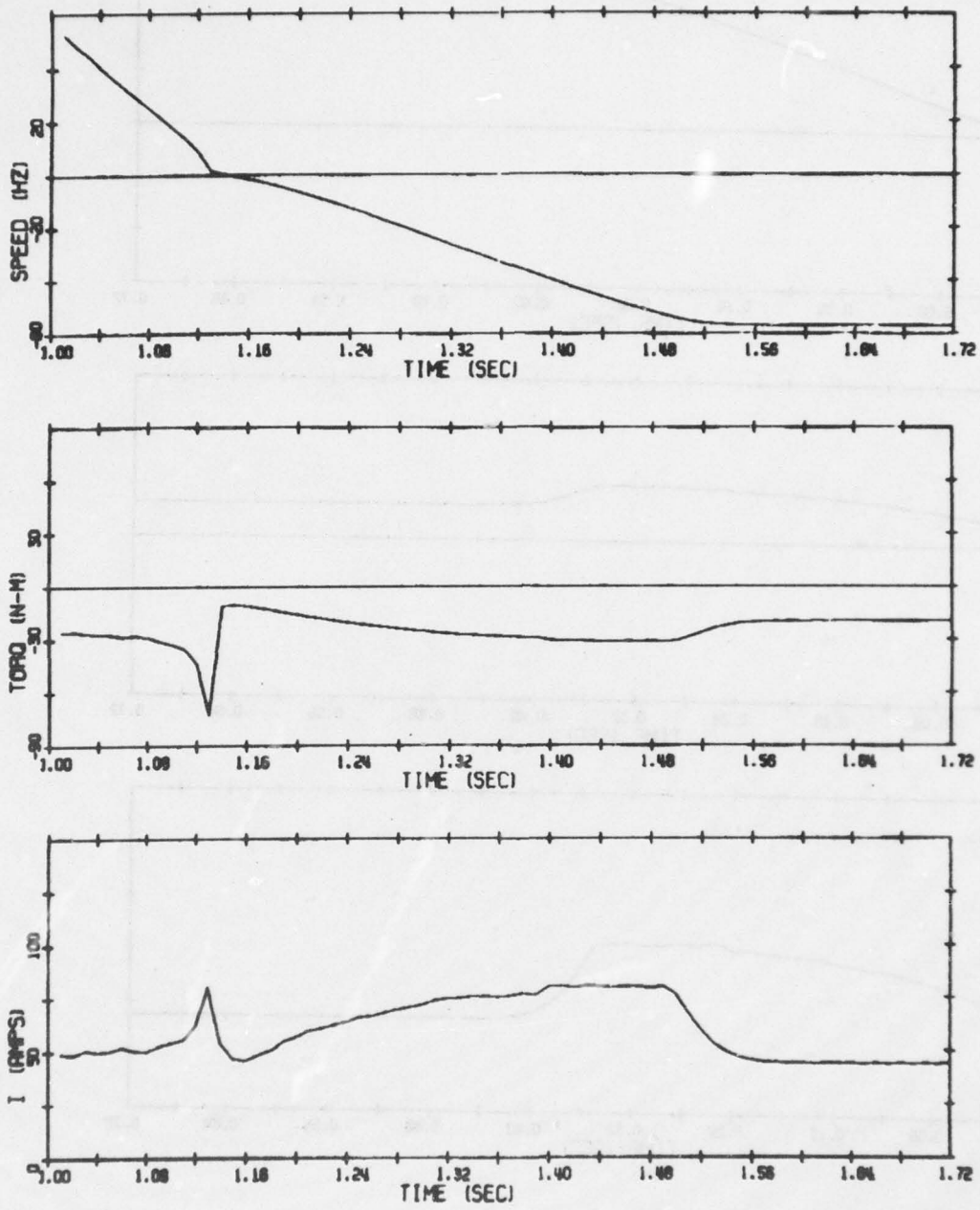


FINAL CONFIGURATION

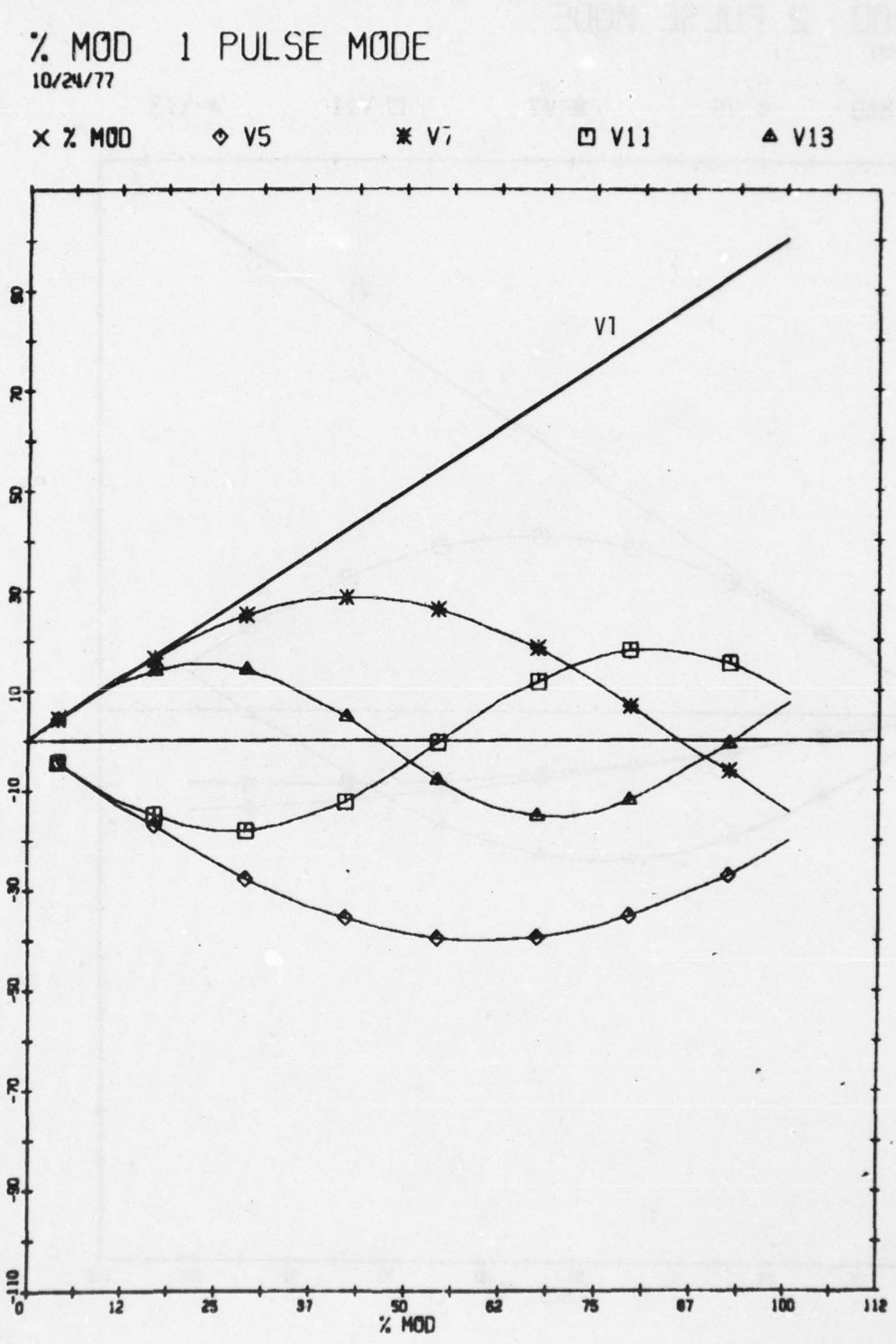
DLTAUP = 7.5HZ
DLTADW = 3HZ
TLL 2HI = 5.5HZ
TLL 2LO = 5.0HZ
f REVERSE = 7.25HZ (SIGNS DIFFERENT)
= TAC + 7.25HZ (SIGNS SAME)

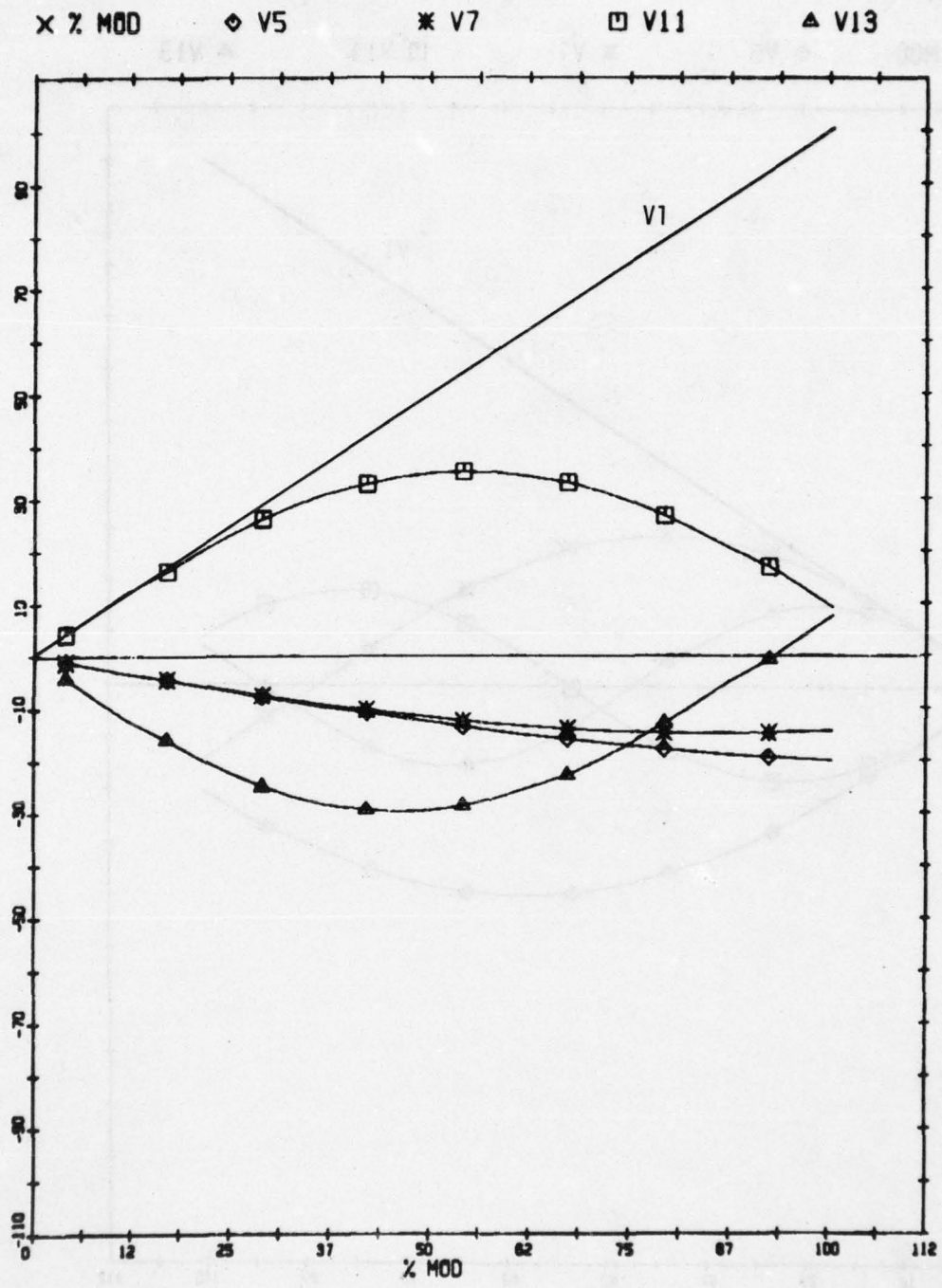
STEP FUNCTION # 6

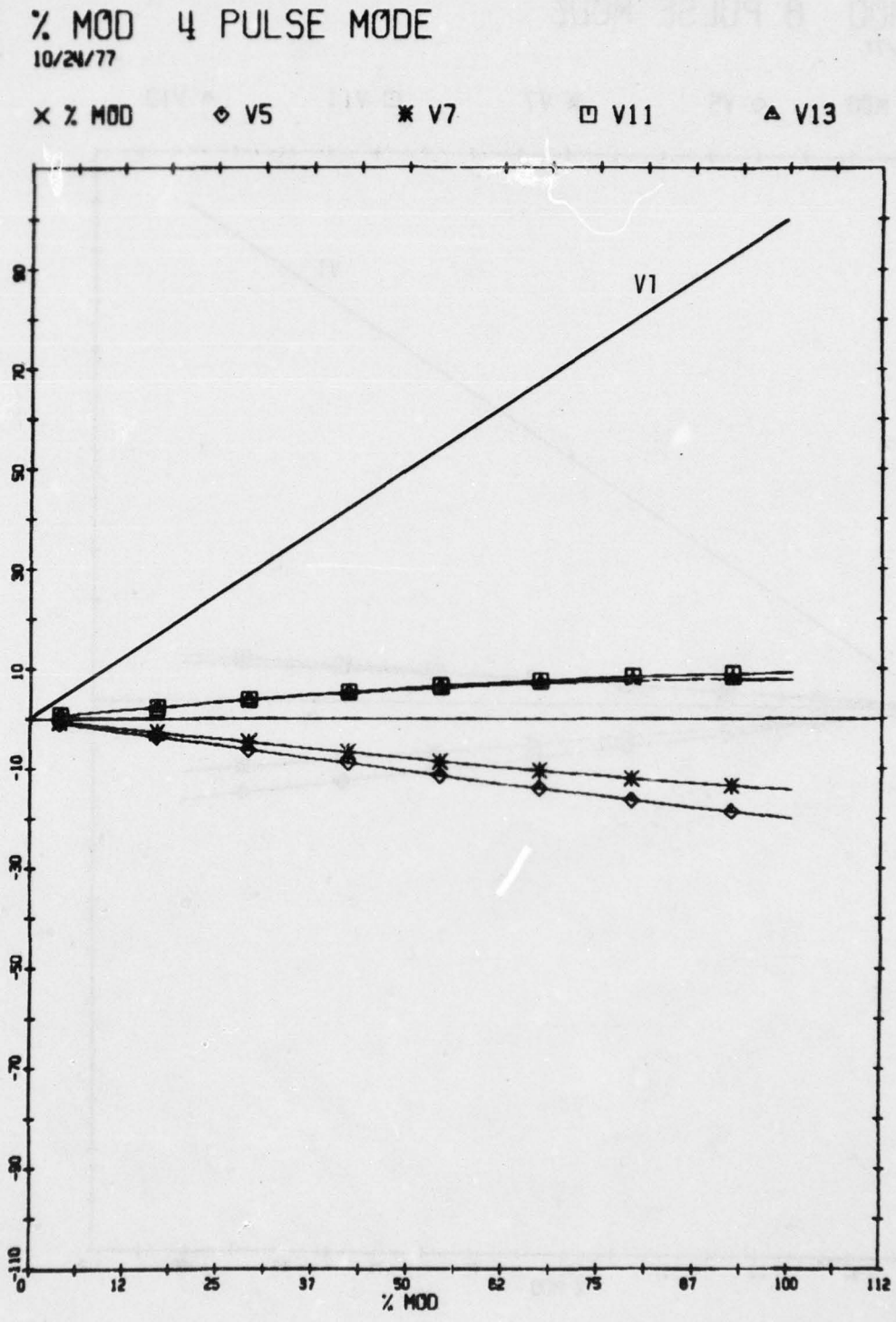
10/21/77

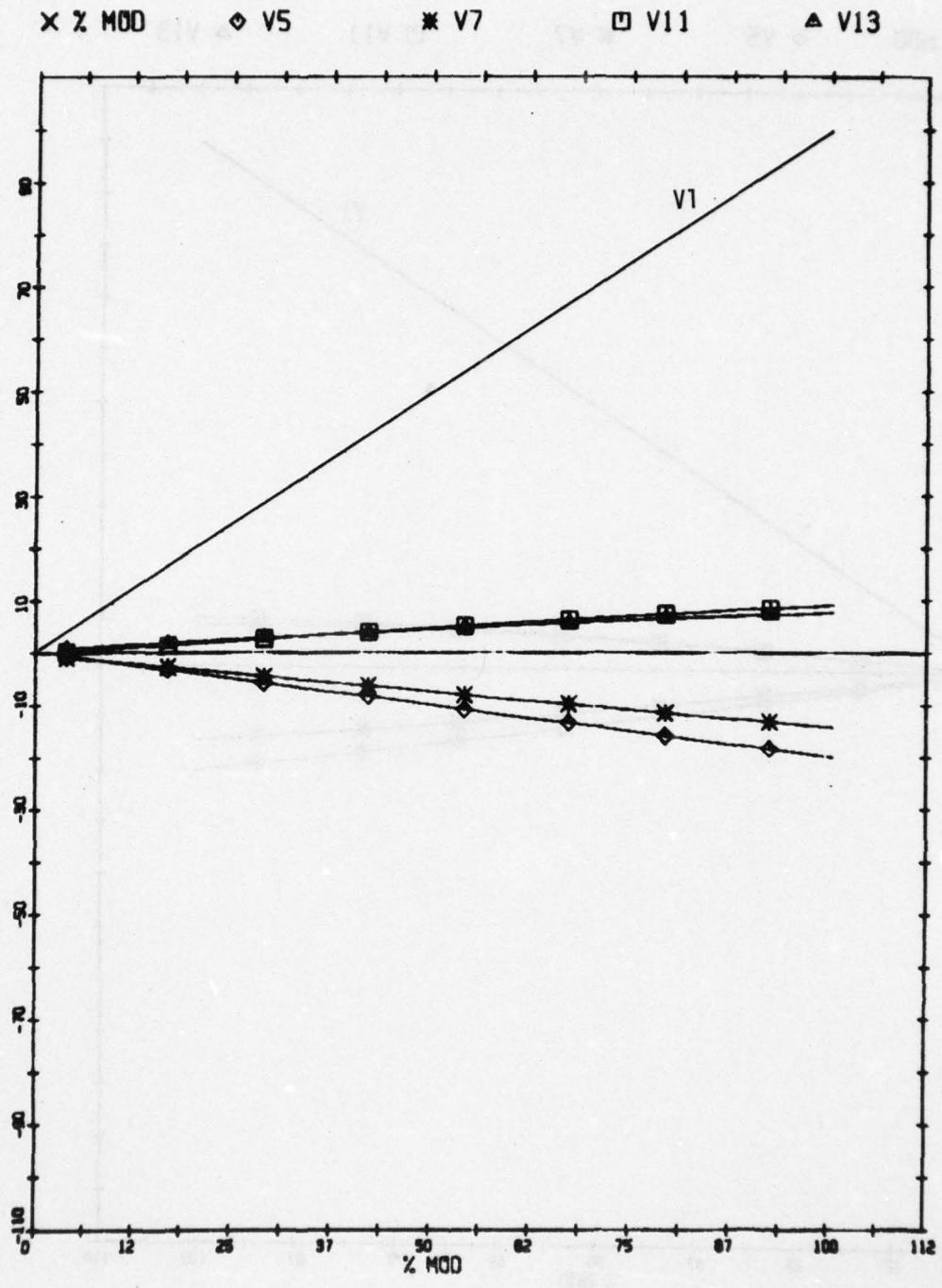


FOURIER COEFFICIENTS VRS % MODULATION



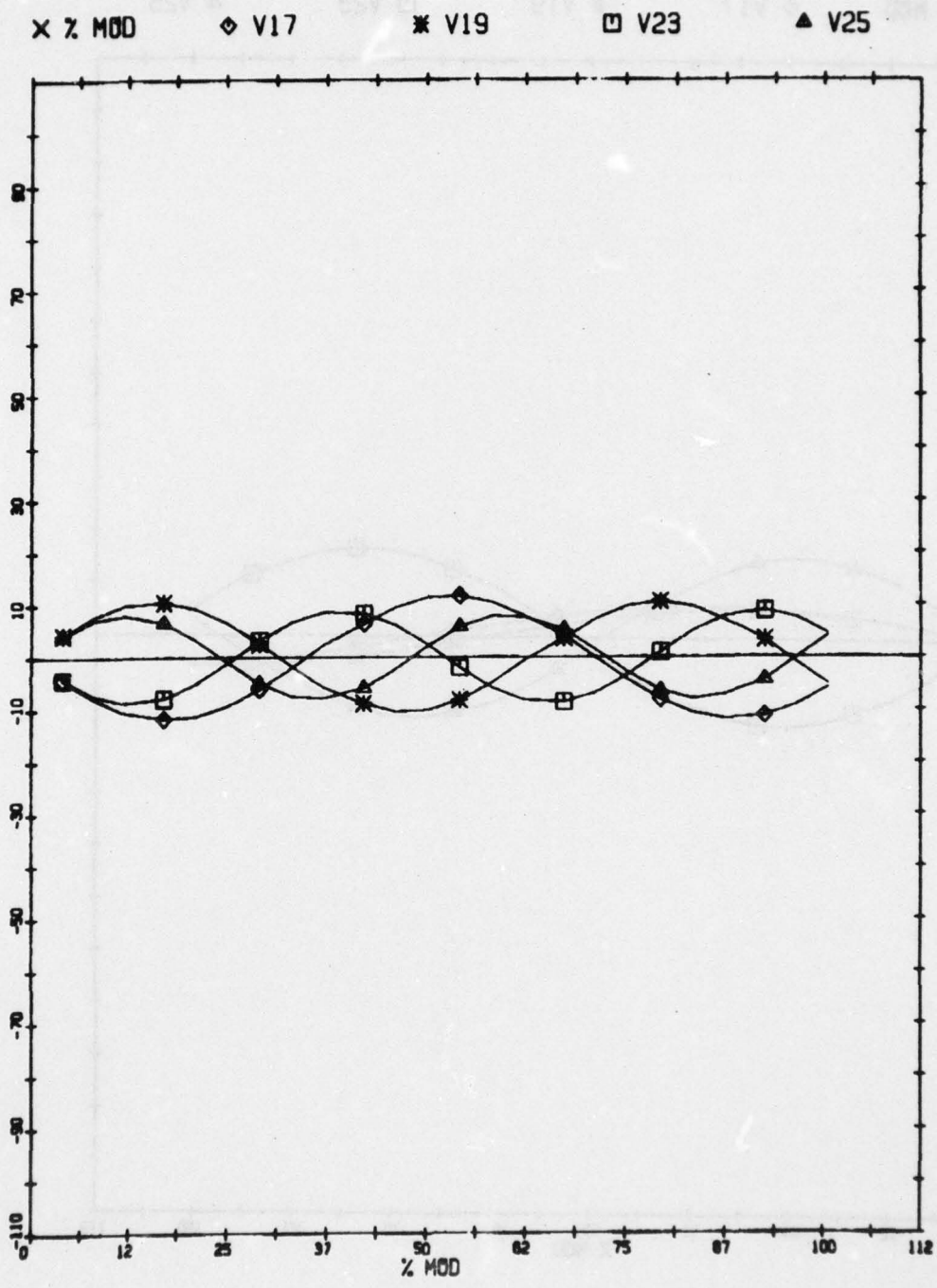

% MOD 2 PULSE MODE
10/24/77
X % MOD
◇ V5
✱ V7
□ V11
△ V13
V1
% MOD


% MOD 4 PULSE MODE
10/24/77
× % MOD
◇ V5
✱ V7
□ V11
△ V13
V1
% MOD


% MOD 8 PULSE MODE
10/24/77
X % MOD
V5
V7
V11
V13
V1
% MOD
0
12
25
37
50
62
75
87
100
112

% MOD 1 PULSE MODE

10/20/77



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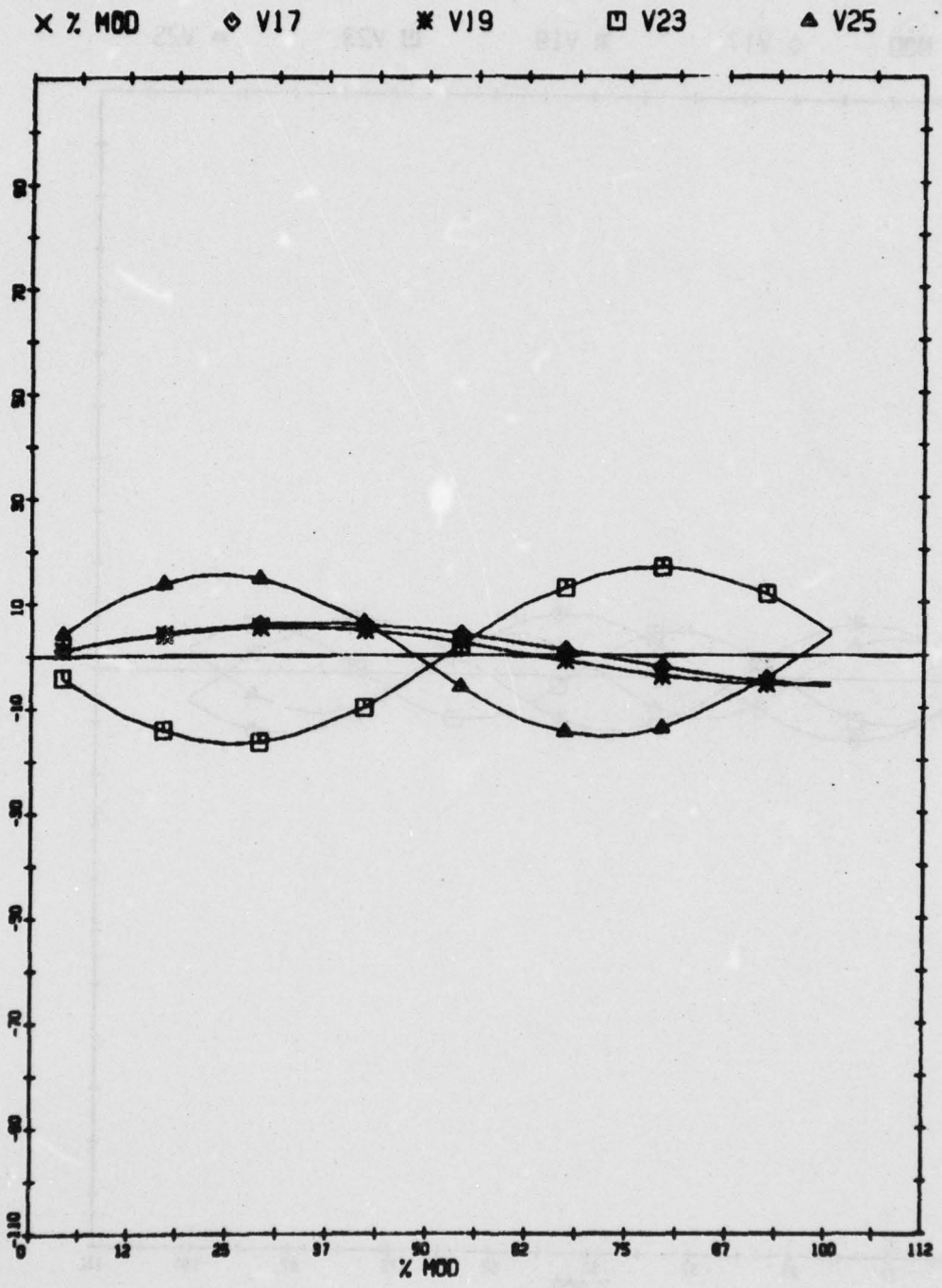
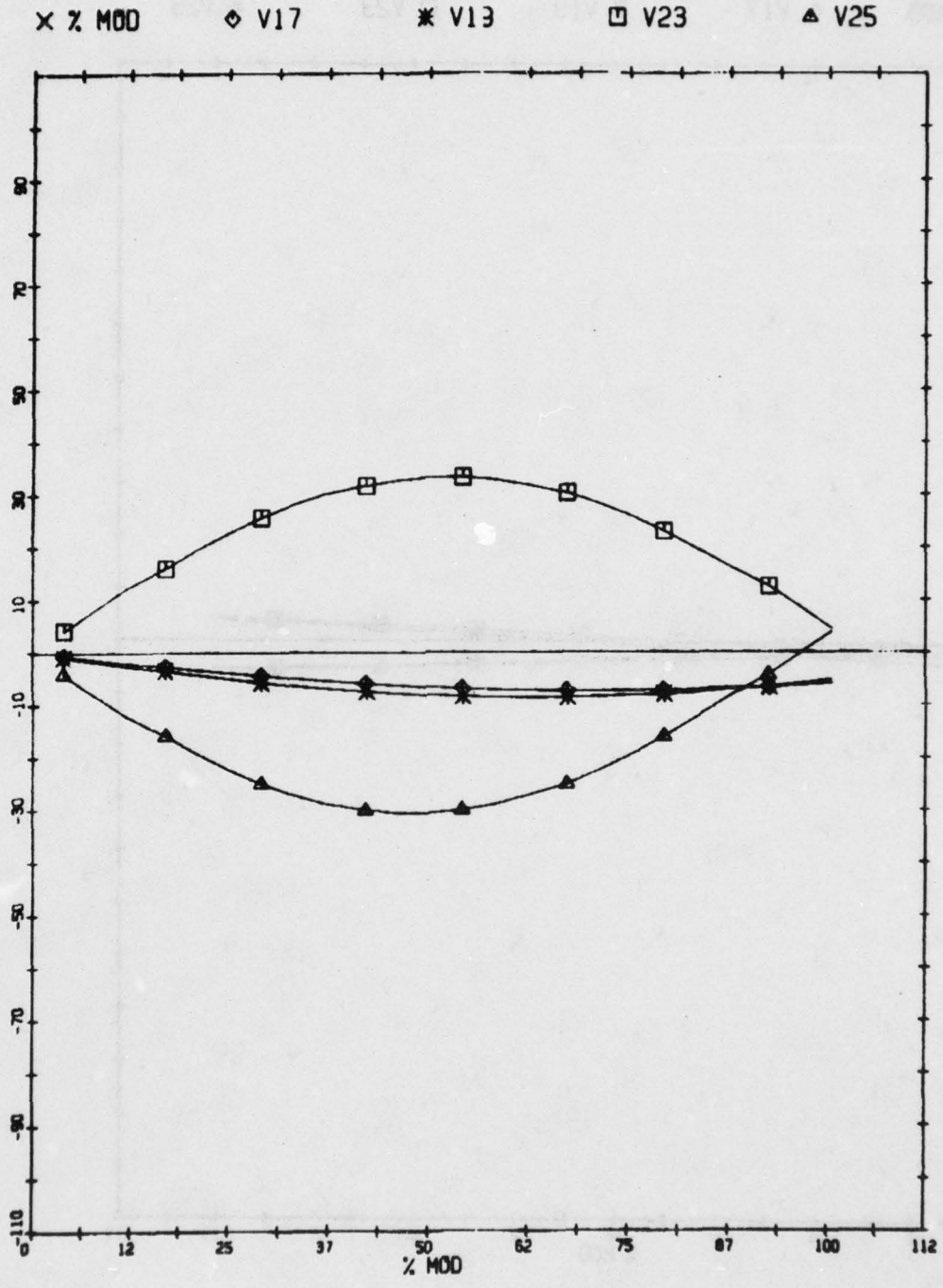
10/24/77



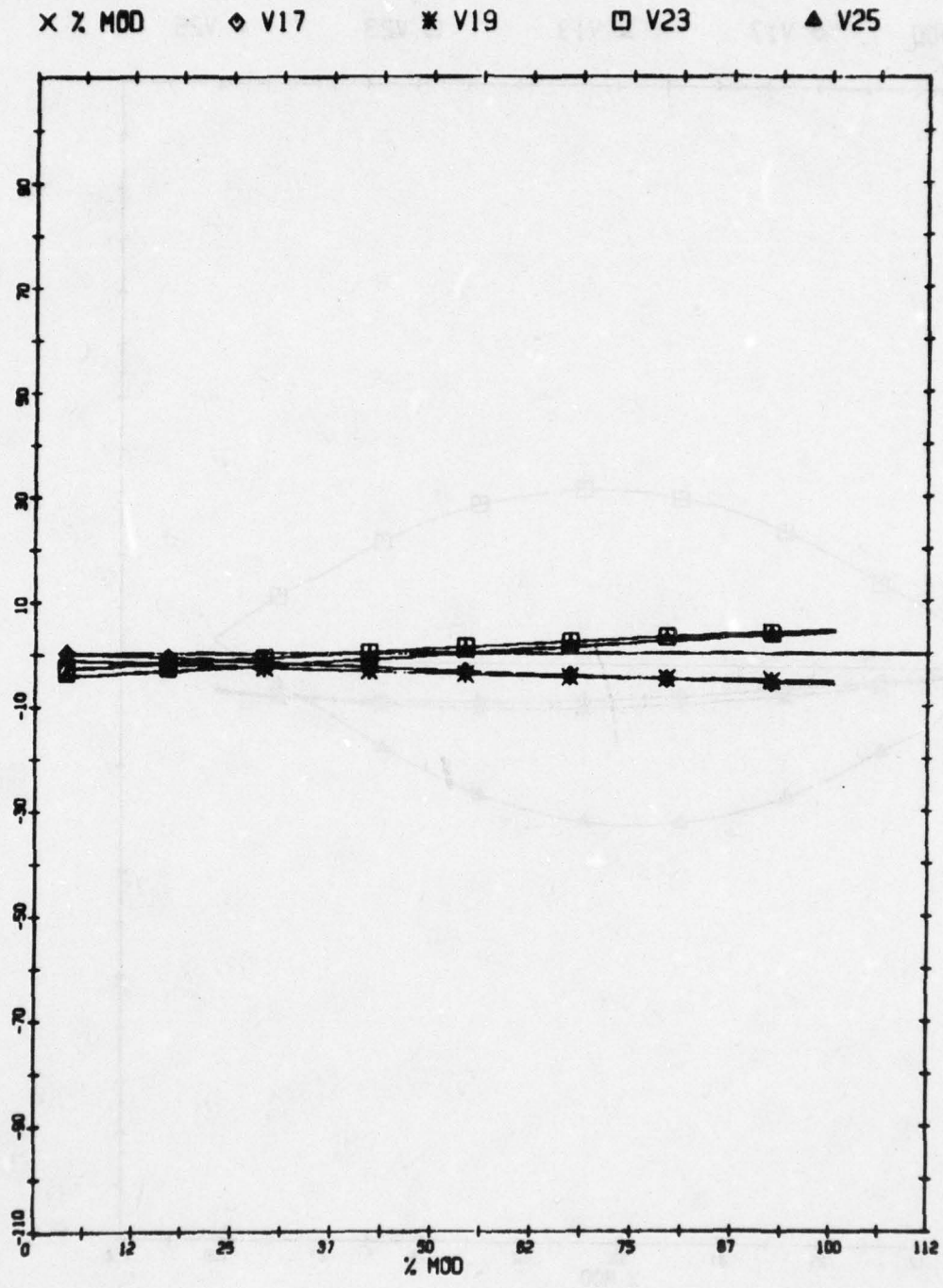
% MOD 4 PULSE MODE

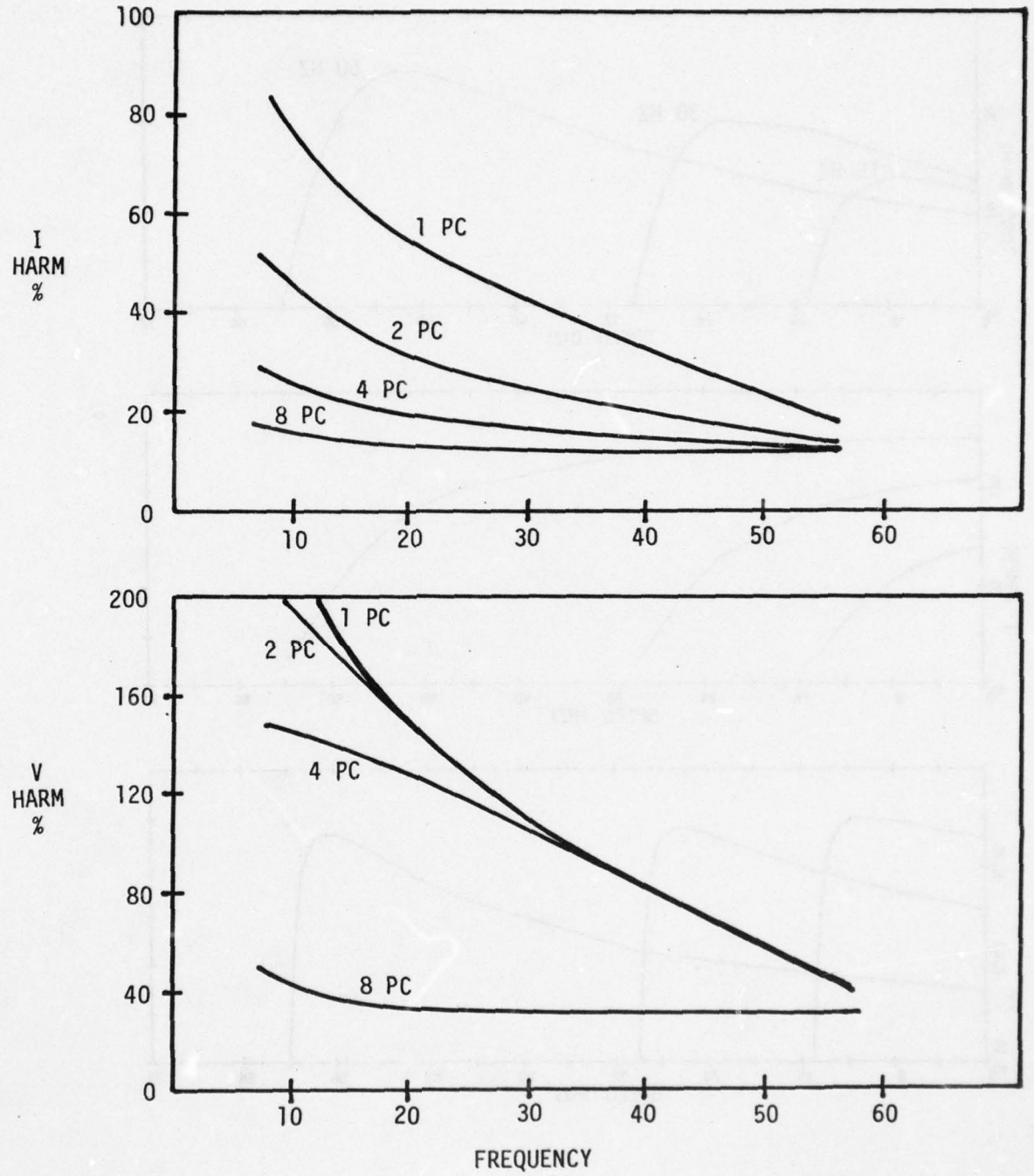
10/24/77



% MOD 8 PULSE MODE

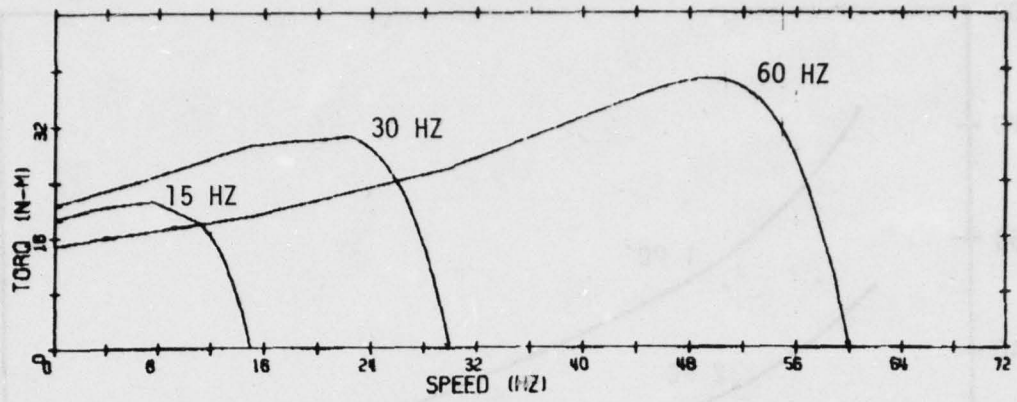
10/24/77

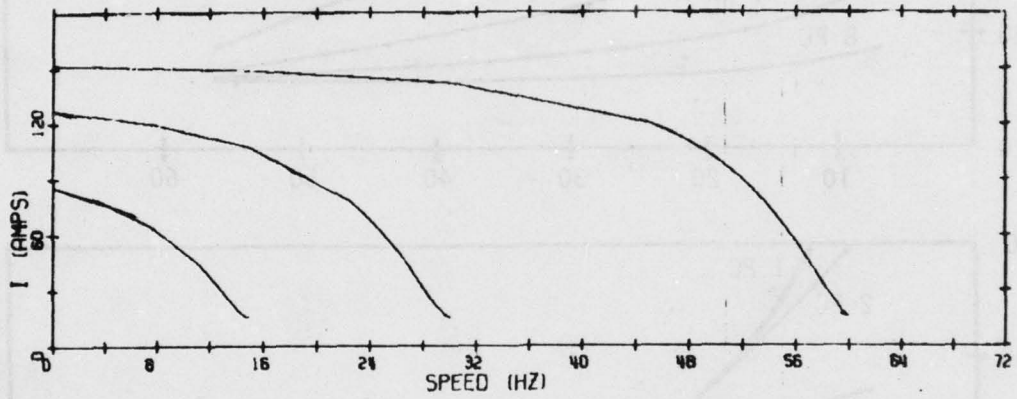


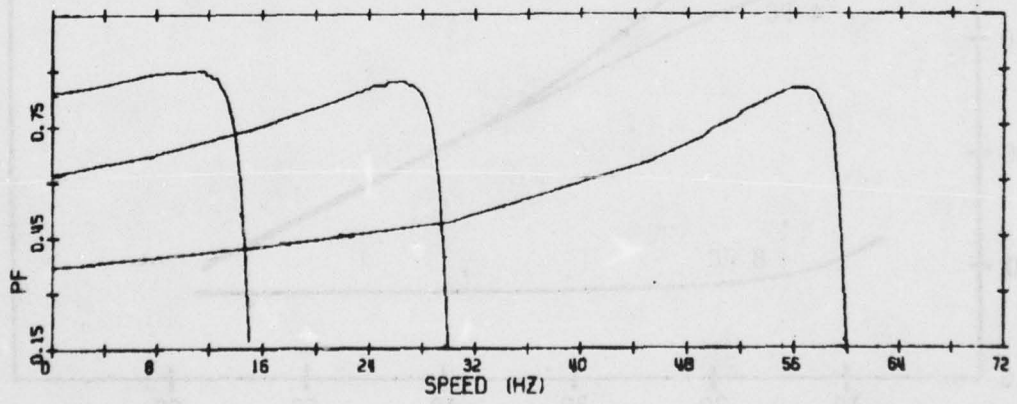

I HARM %
100
80
60
40
20
0
1 PC
2 PC
4 PC
8 PC
10
20
30
40
50
60
V HARM %
200
160
120
80
40
0
1 PC
2 PC
4 PC
8 PC
10
20
30
40
50
60
FREQUENCY

MOTORZ CURVES

10/17/77

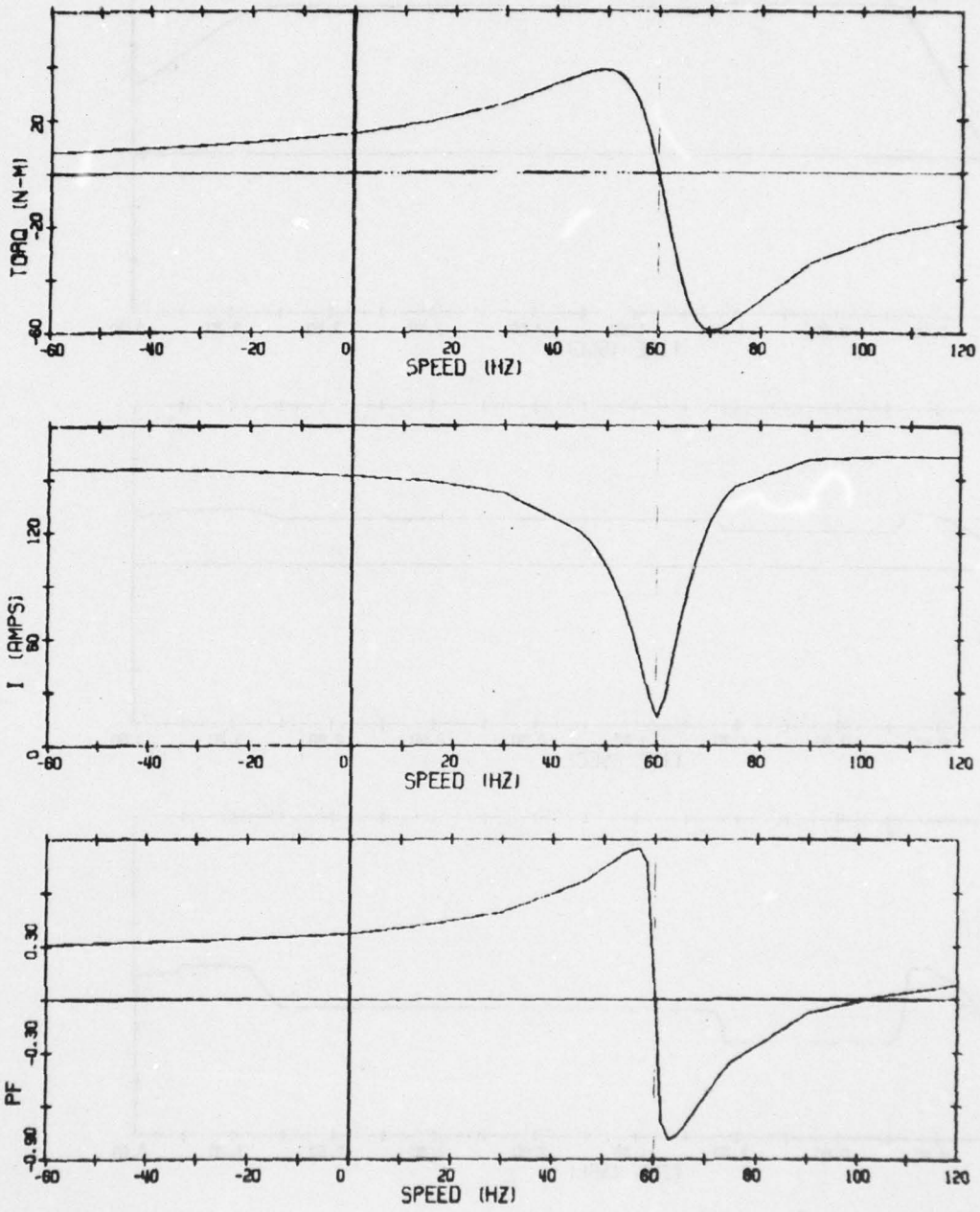




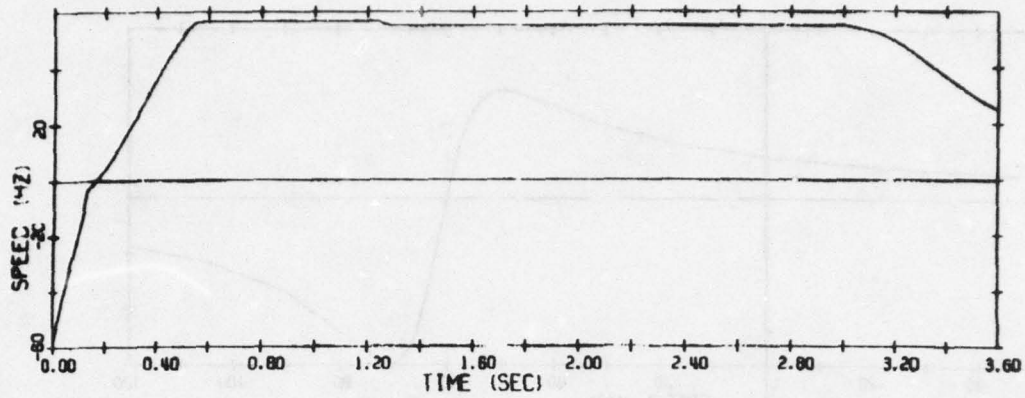


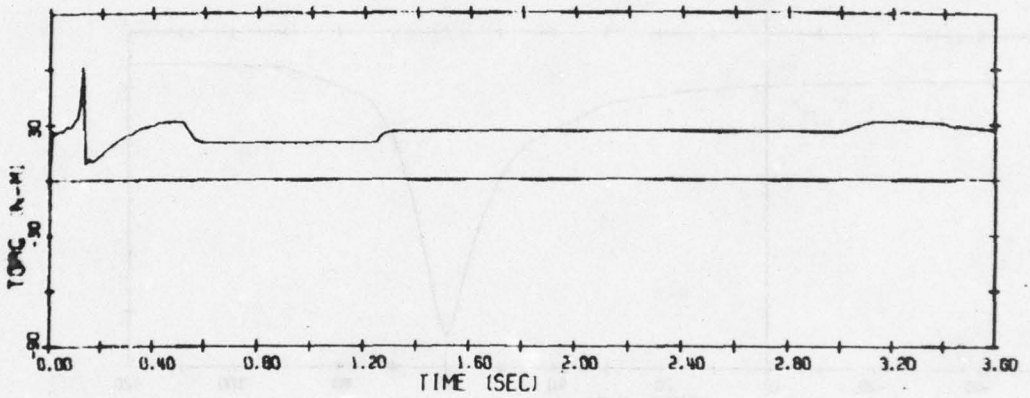
MOTORZ CURVES

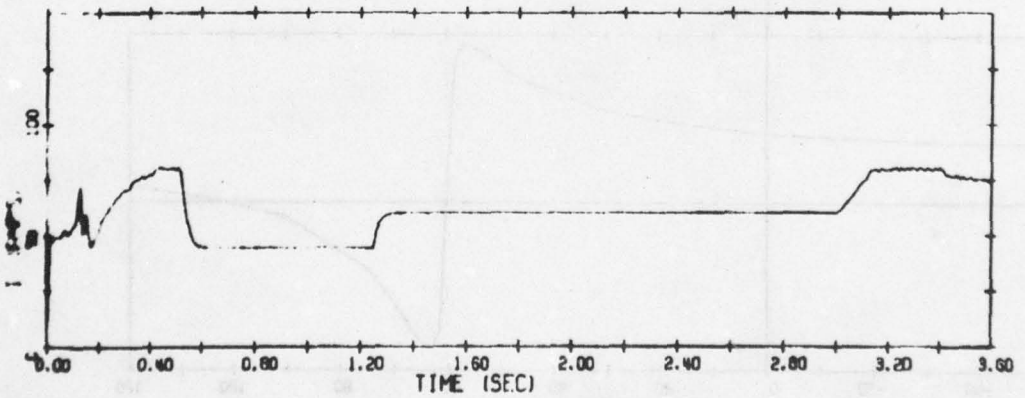
10/17/77



ILIMIT= .F.
11/7/77 INCREMENT SCFOLD

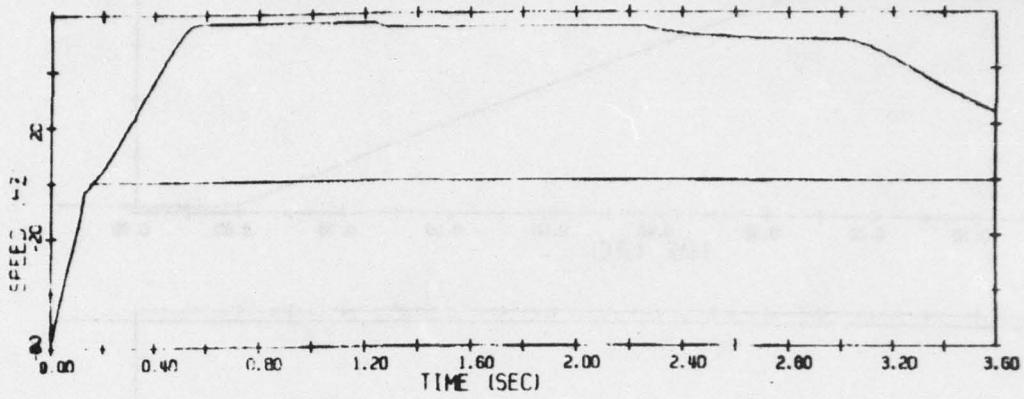


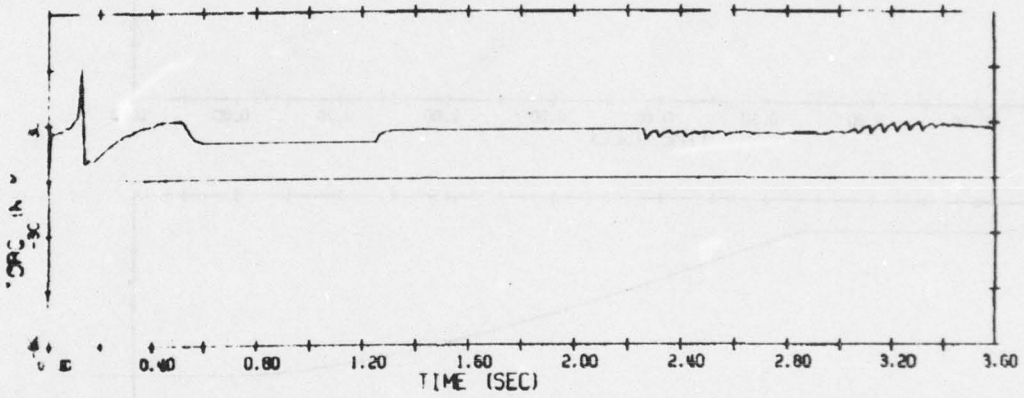


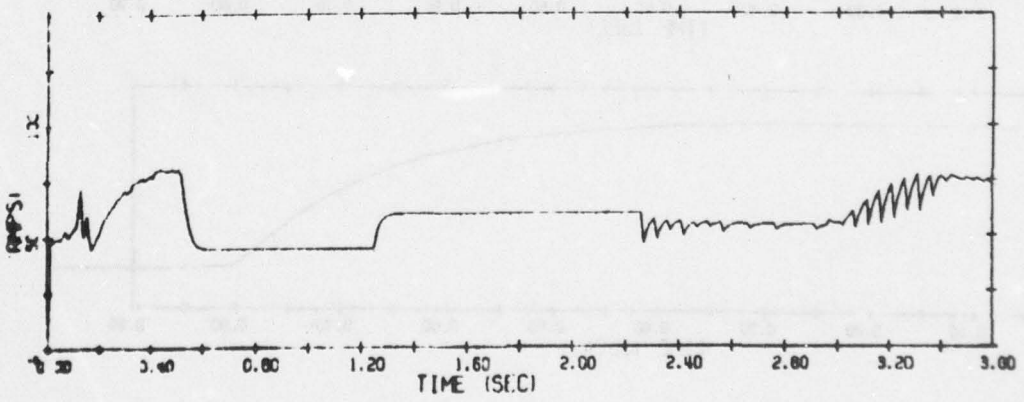


ILIMIT = 50 TO 100 AMPS

11/8/77 INCREMENT SCHOLD (50ms DELAY)

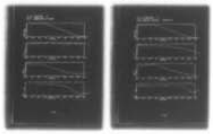






AD-A052 055 CHARLES STARK DRAPER LAB INC CAMBRIDGE MA F/G 9/5
A MICROPROCESSOR CONTROLLED MOTOR CONTROLLER FEASIBILITY STUDY.(U)
MAR 78 A L GULOVSEN N00014-77-C-0352
UNCLASSIFIED R-1147 NL

2 OF 2
AD
A052 055



END
DATE
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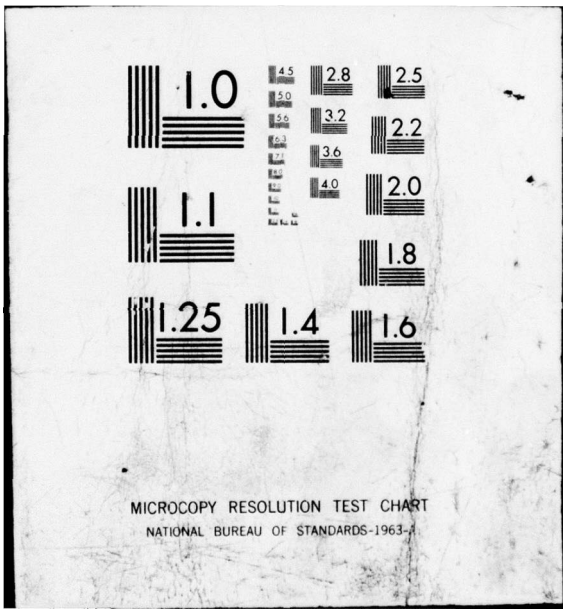
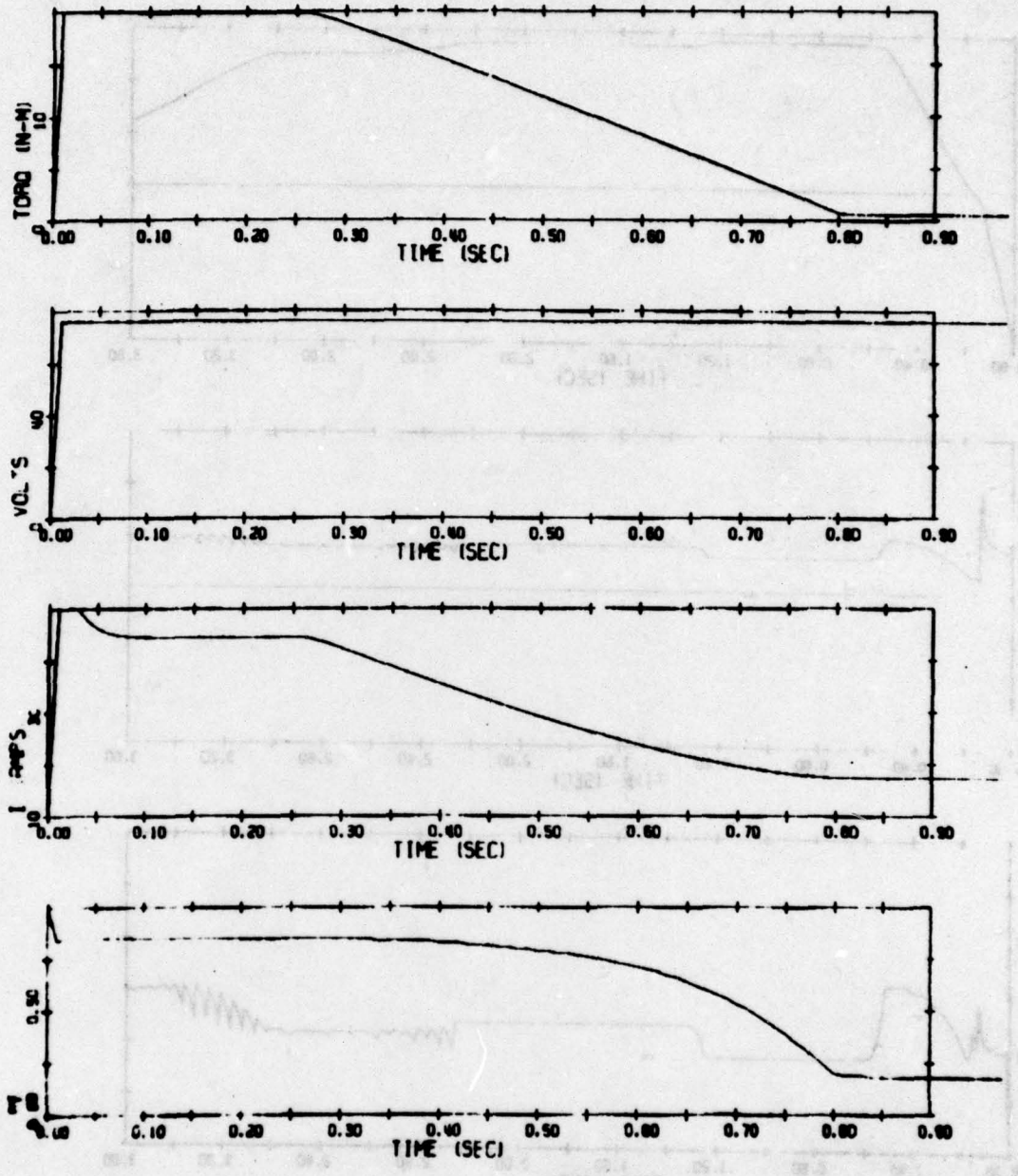
5-78
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SLIP CONTROL .F.

11/8/77 INCREMENT/DELAY SLIP CONTROL



SLIP CONTROL .T.

11/8/77 SIDEAL=5HZ (INC4DELAY) (30ms DELAY)