MOD 80
MOTOR FIELD BUS VOLTAGE REGULATOR SYSTEM

INTRODUCTION

The following discussion provides a detailed circuit description as well as start-up procedures for a motor field bus voltage regulator. The regulator system diagram is shown on sheet 2 and either sheet 3 (for an M5B system) or sheet 4 (for an F80 system).

CIRCUIT DESCRIPTION

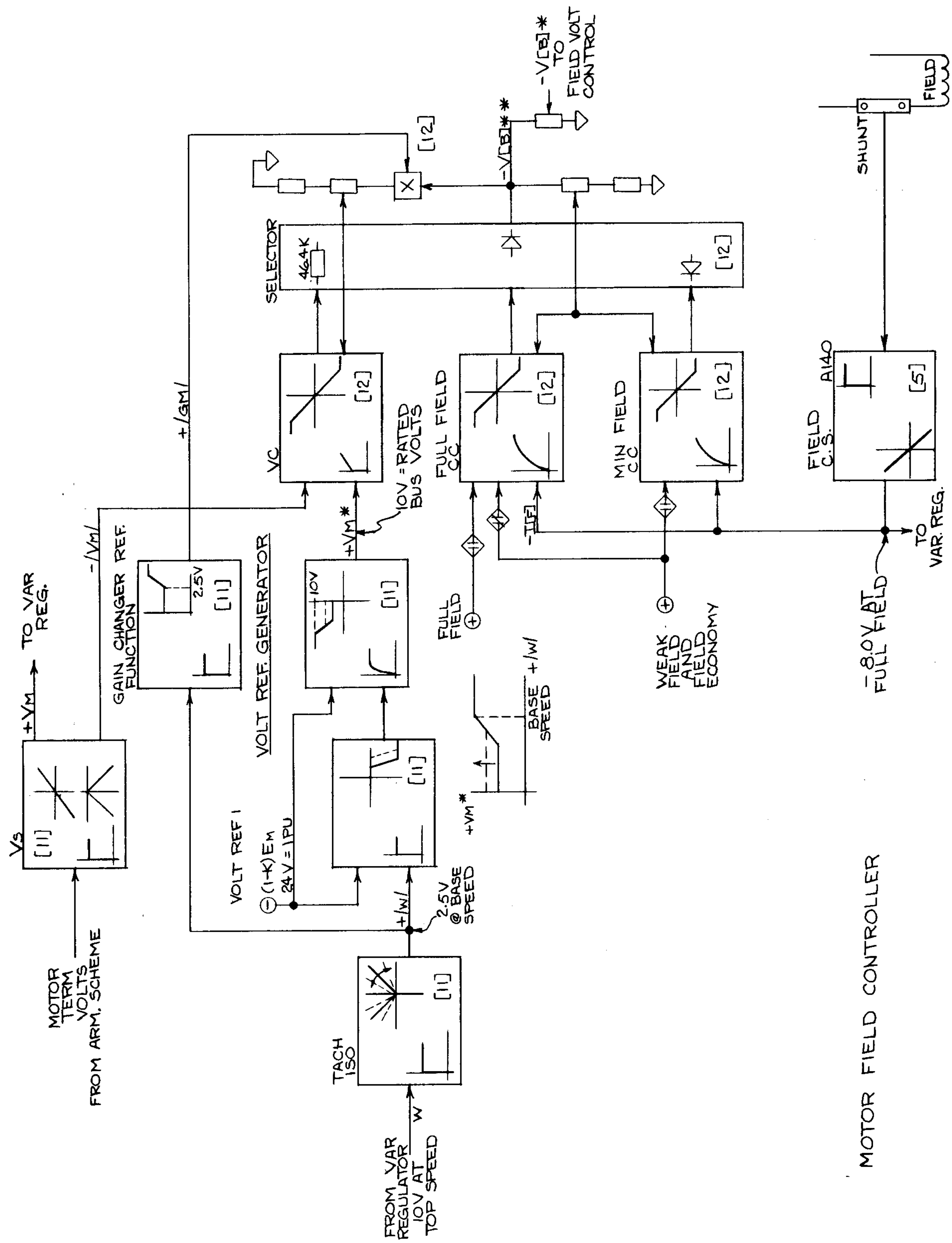
The field regulating system is a multi-loop control system with an inner loop that regulates for field terminal voltage and an outer loop parallel controller that regulates for either field current or for motor terminal voltage depending upon motor speed. The block diagram on sheet 3 shows the M5B regulating system for field terminal voltage. Also shown on sheet 3 is a function which monitors field current and generates an overexcitation signal if the field current exceeds a preset level. The block diagram on sheet 4 shows the F80 regulating system for field terminal voltage. In either case, the input reference to the loop is -V(B)* and the regulating loop forces the field terminal voltage to follow this reference. The block diagram on sheet 2 shows the parallel outer loop regulating system as well as various conditioning functions which are required for proper interfacing with external signals.

System regulation is provided by the motor field controller card (sheet 6) which is a plug-in card. This card contains three operational amplifiers connected in parallel. Amplifier 1-OA regulates for motor terminal voltage. Amplifier 2-OA regulates for full field current when in the run mode (1CR energized) and regulates for weak or economy field when not in the run mode (1CR de-energized). Amplifier 3-OA regulates for weak field in the run mode. This function may be disabled by removing the wire between pins 27 and 59.

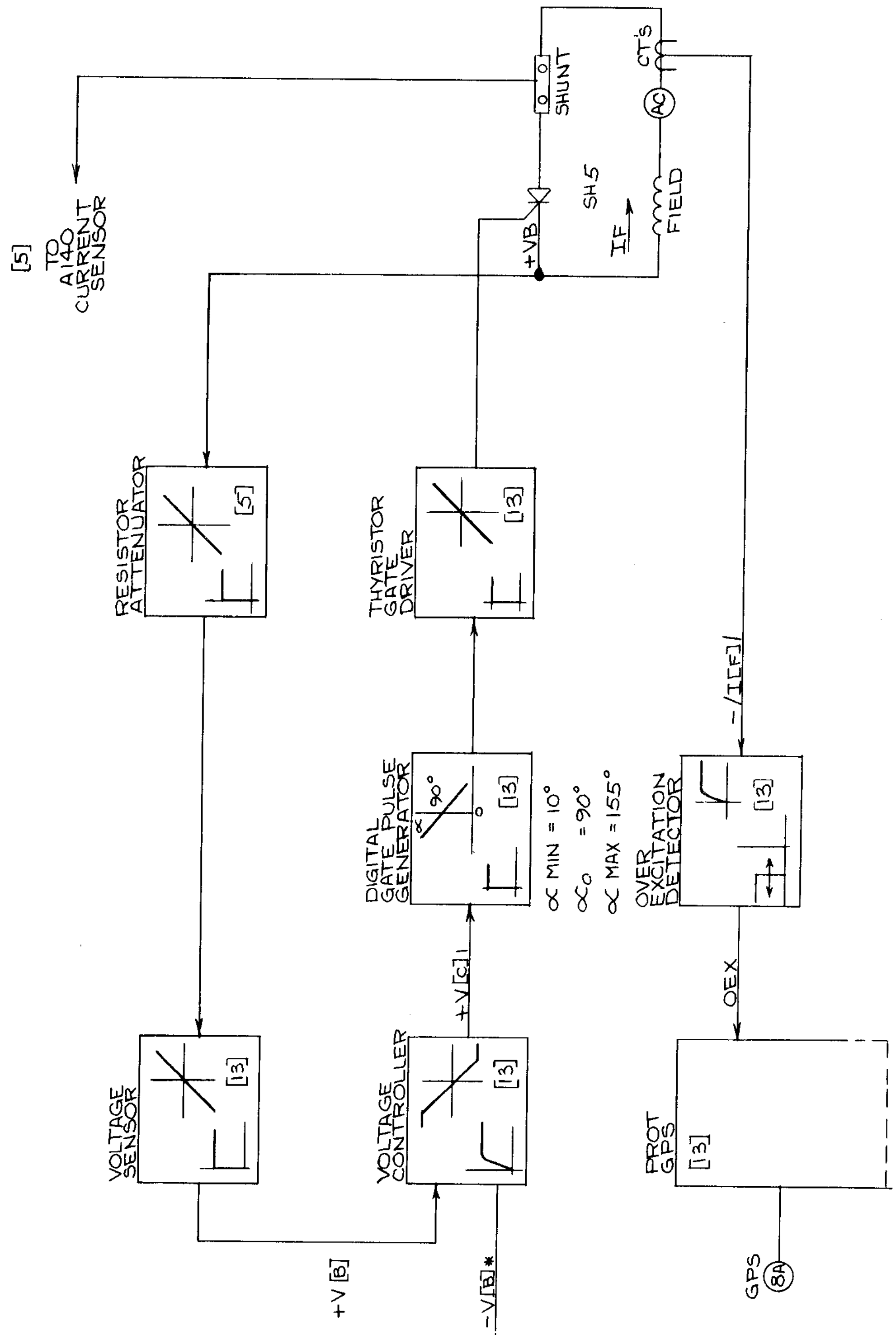
The operation of a parallel type controller will be discussed with reference to Figure 1 and the waveforms of Figure 2. Because of parallel operation, only one of the controllers can be operable; that is, controlling its own variable. The other parameter is uncontrolled and its regulating amplifier must be in limit.

Assume that the parameter being controlled is $-V_2$. This would be the case of time interval A to B as shown in Figure 2. In this instance 2-OA is controlling, 1-OA is in negative limit and the output $-V_3^*$ is the same as V_{02} (except for a diode drop). 1-OA is in limit because $+V_1^* > |-V_1|$. 2-OA regulates so that $|-V_2| = +V_2^*$.

Assume that at time interval B something in the system causes the feedback signal $-V_1$ to increase. At time C the feedback signal $-V_1$ starts to exceed the reference level V_1^* and 1-OA will come out of limit to force $|-V_1| = +V_1^*$. At time interval C, 2-OA will go into negative limit because it is assumed that, when 1-OA causes regulation of $-V_1$, $+ V_2^* > |-V_2|$. In the time interval B-C it is

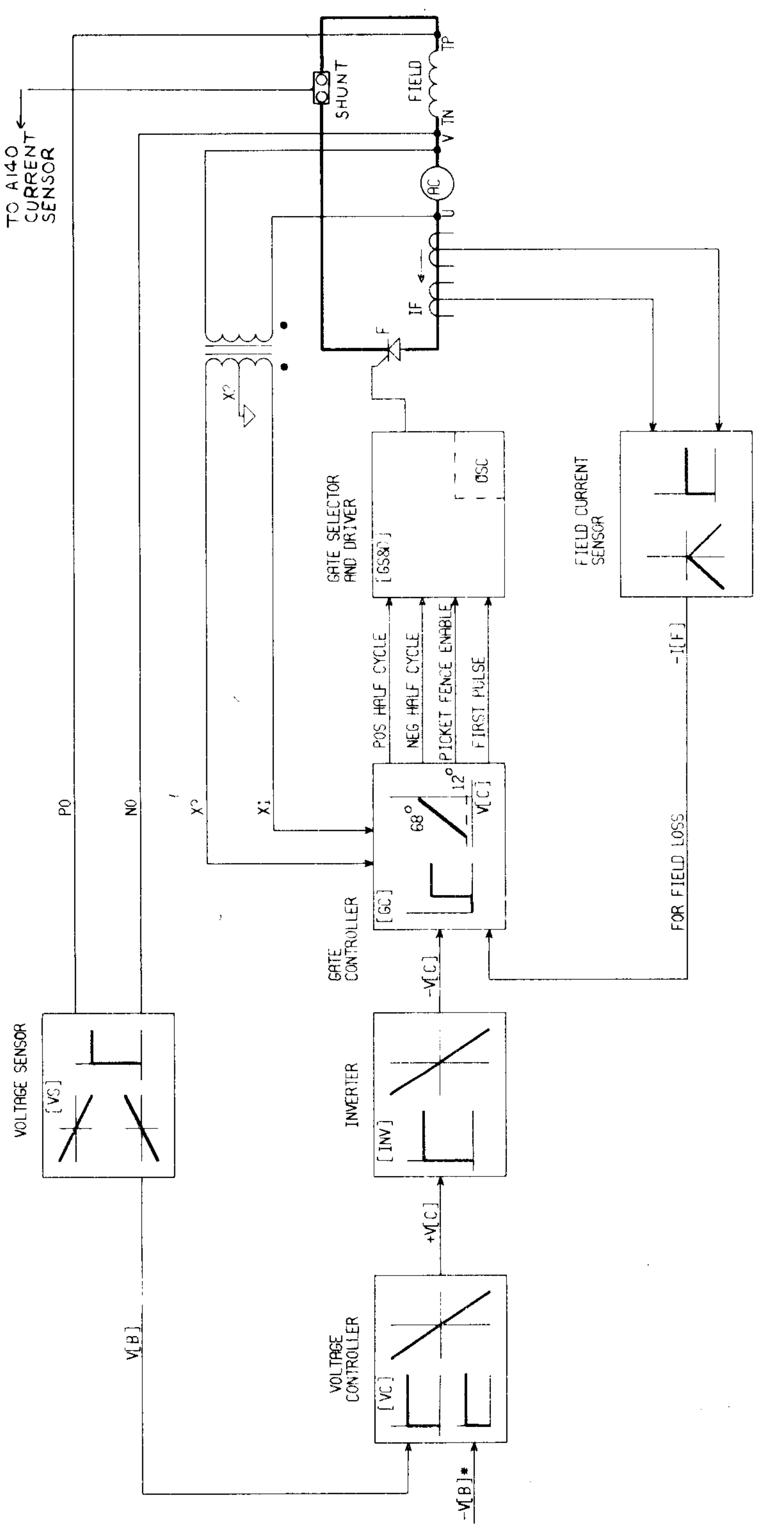


MOTOR FIELD CONTROLLER

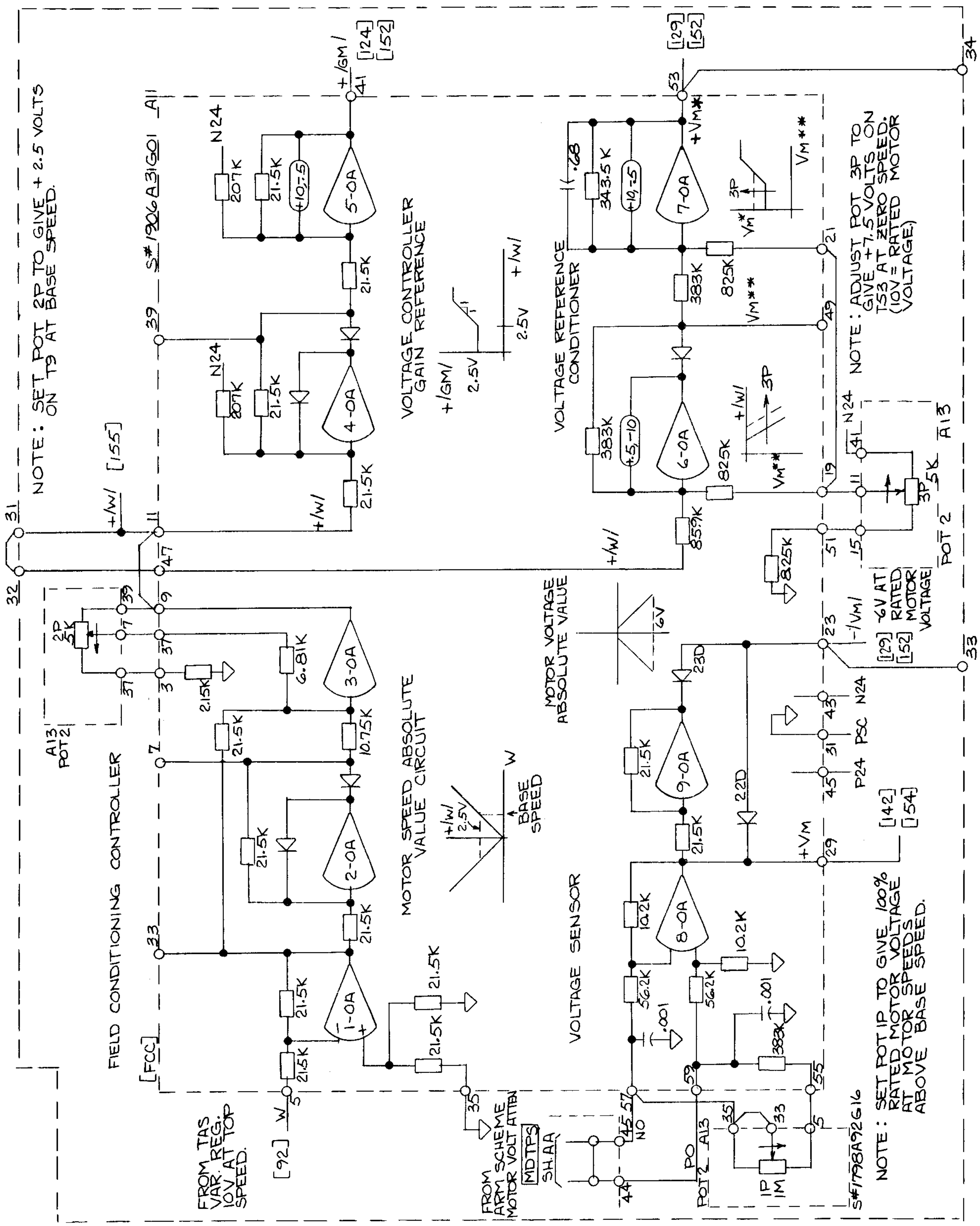


M5B FIELD VOLTAGE CONTROLLER

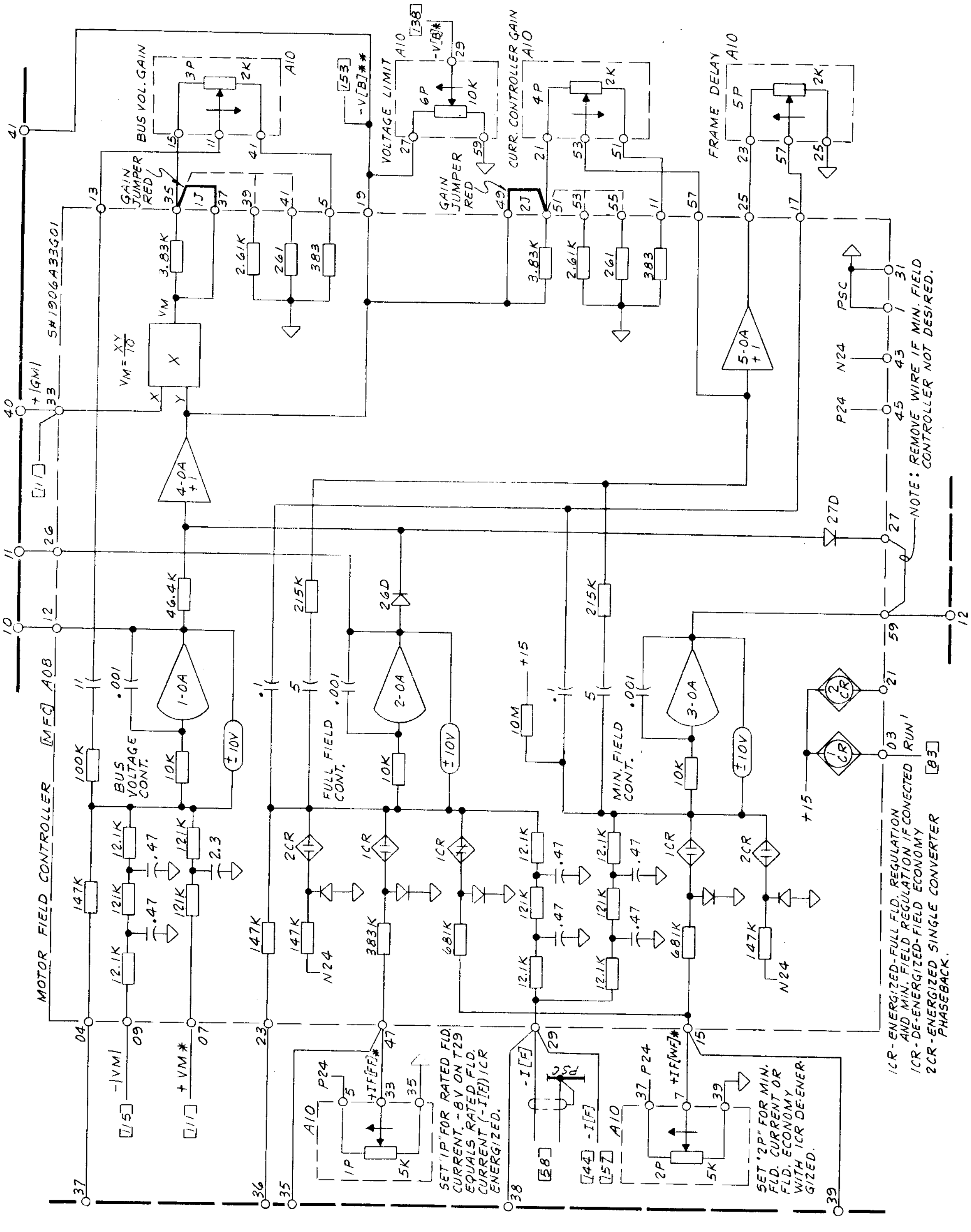
BLOCK DIAGRAM



F80 FIELD VOLTAGE LOOP

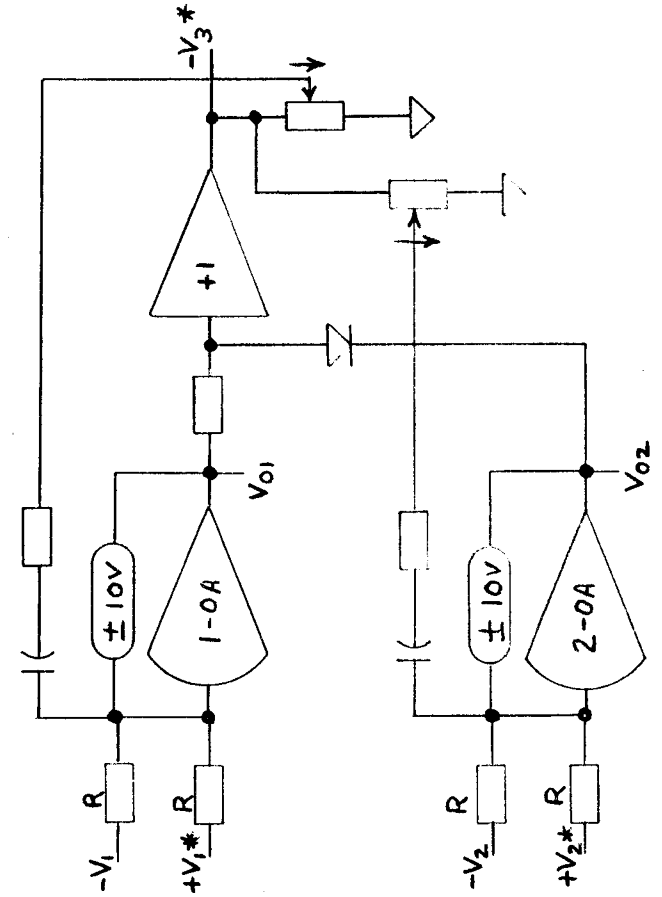


MOD 80 FIELD CONDITIONING CONTROLLER



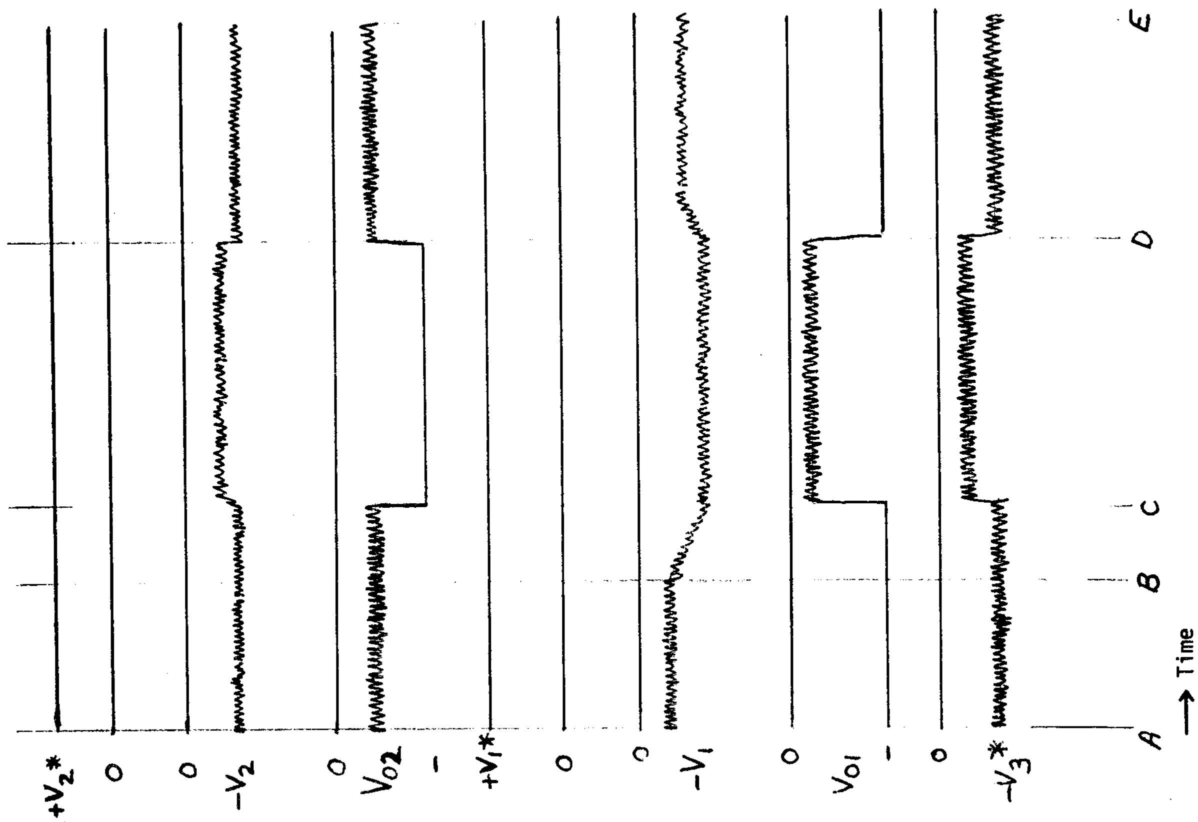
MOD 80 MOTOR FIELD CONTROLLER

Westinghouse Electric Corporation



SIMPLIFIED PARALLEL CONTROLLER

FIGURE 1



TYPICAL WAVEFORMS FOR FIGURE 1

FIGURE 2

the result of changes in the system reflected in the feedback signal that have caused the control to switch from 2-0A to 1-0A. In interval C-D, the output $-V_3$* is shown being at a level less than that shown during the interval A-B. The output level $-V_3$* is determined by the system requirements only. In the interval C-D the output $-V_3$* is the same as V_{01}. At time interval D, system changes cause $-V_1$ to decrease. Because $-V_1$ has decreased, 1-0A will no longer be able to regulate and will go into negative limit as $+V_1^* > | -V_1 |$. As a result of 1-0A going into limit 2-0A will come out of limit to regulate the parameter $-V_2$.

In an armature control system where the motor is operated above base speed and the motor terminal voltage is controlled by field weakening, the intervals A-C and D-E correspond to operation at less than base speed where the parameter being regulated is field current. The interval C-D corresponds to operation above base speed where the parameter being regulated is motor terminal voltage.

The operation of the motor field controller card as a parallel type controller will be discussed with reference to Figure 3. In the normal run mode assume 1P is set for a full field reference, 2P is set for a weak field reference and the bus voltage reference signal +VM* is set for rated motor terminal voltage.

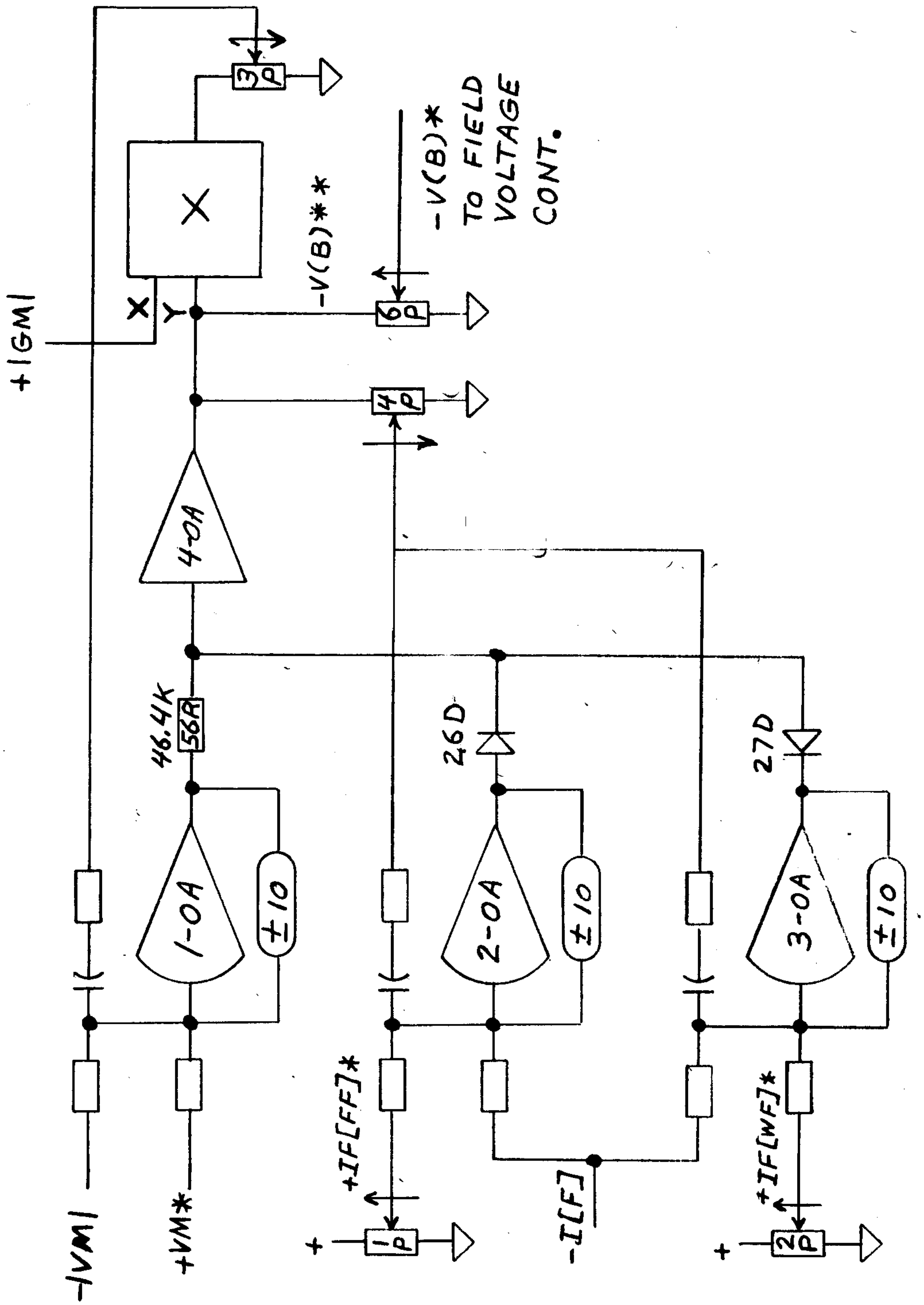
When the motor is operating at less than rated terminal voltage, 1-0A will be in negative limit because $+VM^* > |VM|$. Amplifier 2-0A will regulate for the full field current as determined by the setting of 1P. In this instance diode 26D is conducting and resistor 56R provides isolation to allow amplifier 1-0A to be in negative limit.

When the bus voltage controller output reduces (comes out of limit) in an attempt to regulate the motor terminal voltage, diode 26D will be reverse biased and amplifier 2-0A will be in negative limit. The bus voltage controller (1-0A) will then regulate the bus voltage to a level set by the reference signal +VM*. This condition would exist when the motor is operating at weak field above base speed. In the weak field mode, amplifier 3-0A provides a minimum limit on the field weakening range. In the field weakening range, if the bus voltage controller attempts to reduce the signal -V(B)** to a voltage level below that required for the minimum field current setting, amplifier 3-0A comes out of positive limit. Diode 27D conducts and 3-0A regulates for the minimum field current level as determined by 2P. In this mode 1-0A would be in positive limit and resistor 56R would provide isolation. Amplifier 3-0A would go back into positive limit (27D reverse biased) when the bus voltage requirements caused the signal -V(B)** to increase above that required for the minimum field current level.

Refer to sheet 6 for the following discussion.

The reference input to 2-0A is from potentiometer 1P (cage position 10). This potentiometer is adjusted to provide an input reference which calls for full field current when the motor is operating at less than rated terminal voltage. Potentiometer 2P (cage position 10) is adjusted to provide an input reference to both 2-0A and 3-0A which calls for weak or economy field. This potentiometer can be set with the field regulator in the non-run mode.

The field current controllers consist of summing operational amplifiers (2-0A and 3-0A) with PIV response. The lead time constant which is fixed at one second effectively cancels the delay of the motor field and the time delay determined by potentiometer 5P (cage position 10) compensates for the



PARALLEL VOLTAGE/CURRENT CONTROLLER

FIGURE 3

motor frame delay (result of motor frame eddy currents). The frame delay can vary from 0.2% to 10% of the motor field delay depending on whether the motor frame is laminated or non-laminated. The integrating time constant of the field current controller determines the crossover frequency of the field current loop and is adjustable by means of gain potentiometer 4P (cage position 10) and backplane jumper 2J (cage position 08). The field current feedback signal -I(F) (terminal 29 of the MFC card) is provided by the field current sensor which has a gain adjustment to calibrate the signal -I(F) = -8.0 volts at rated field current.

Static relays 1CR and 2CR on the MFC card are used for field current reference switching. These two relays are controlled by external command signals. In the non-run mode relay 1CR is de-energized. 2P (cage position 10) provides an input reference to 2OA to regulate for economy field. When relay 1CR is energized 1P (cage position 10) provides a full field current reference to amplifier 2-OA and 2P (cage position 10) provides a minimum field current reference to 3-OA which is effective only when the backplane wire (terminal 59 to terminal 27) is connected. In single converter systems where the field current is reversed by contactor switching, relay 2CR can be used to force the field current to zero prior to contactor switching.

The motor bus voltage controller consists of a summing operational amplifier (1-OA) with a PI response. The lead time constant effectively cancels the delay of the motor field, and the integrating time constant determines the crossover frequency of the bus voltage loop. The lead time constant is fixed at 1 second, while the integrating time constant is adjustable by means of potentiometer 3P (cage position 10) and backplane jumper 1J (cage position 08). The bus voltage feedback signal to pin 9 of the Bus Voltage Controller is determined by the motor terminal voltage sensor on the FCC card and potentiometer 1P (cage position 13) which are shown on sheet 5. This feedback signal - |VM| is always negative.

MOTOR FIELD CONTROLLER MULTIPLIER (Sheet 6)

The bus voltage controller (sheet 6) has provision for changing controller gain as a function of motor speed. The gain in the "fixed plant" (motor) of the voltage feedback loop increases as motor speed increases since:

Motor CEMF = Motor Speed X Motor Field Flux

In order to maintain the same bus voltage feedback loop gain regardless of motor operating speed, bus voltage controller gain should decrease as motor speed increases as was done in this regulator. If this feature is not provided, the gain of this voltage loop would have to be adjusted so that the voltage loop was stable at top speed (when gain was maximum) and slow at base speed (gain was reduced by field weakening ratio). At base speed, a fast voltage loop is required to prevent motor overvoltage when the motor is accelerating through base speed. The static multiplier, used to accomplish this adaptive gain feature as a function of motor speed, is connected between the voltage controller operational amplifier output (Y) and its gain pot (Z) as shown below.

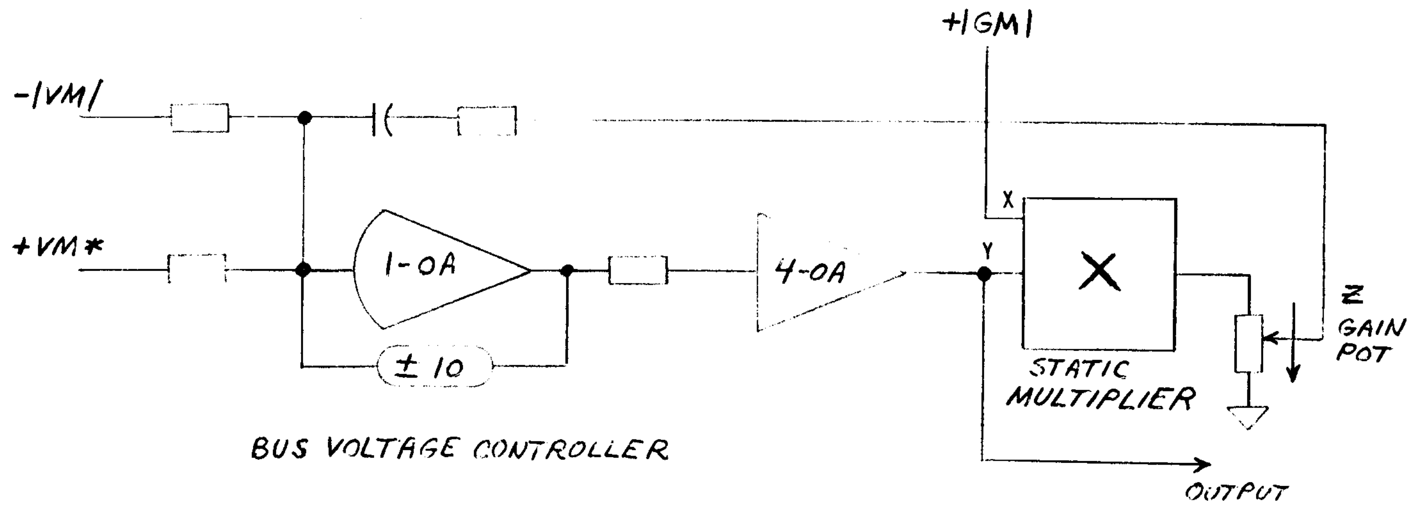


FIGURE 4

The other input (X) to the static multiplier varies as a function of motor speed and has a minimum constant value (+2.5V) at motor speeds below rated motor speed and a maximum voltage at maximum motor speed thus permitting a reduction in bus voltage controller gain to compensate for a gain increase in the "fixed plant". The transfer function of the voltage controller is given below:

$$\text{Voltage Cont. T. F.} = \frac{KX\ (1 + T5S)}{TXS} \times \frac{1}{Z}$$

where:

Z = 1 @ Motor Speed < Rated Speed
Z = P.U. Motor Speed @ Motor Speed > Rated Speed
KX = is a normalizing constant
T5 = is a lead time constant which compensates for the motor field time delay; sec.
TX = is controller integrating time constant, sec.
S = Laplace operator, 1/sec.

MOTOR ARMATURE CURRENT LOOP

The motor armature current loop should be made as fast as possible without affecting the stability of the motor speed regulator system. The faster the armature current loop, the faster the bus voltage loop can be made. Interaction between the bus voltage regulator operating on the motor field and speed regulator operating on the motor armature limits the response of the bus voltage loop to approximately 1/10 the response of the armature current loop.

Refer to Sheet 5 for the following discussion.

The Bus Voltage Reference signal +VM* and the Bus Voltage Feedback signal -|VM| are generated by the Field Conditioning Controller (FCC) plug-in card (Sheet 5).

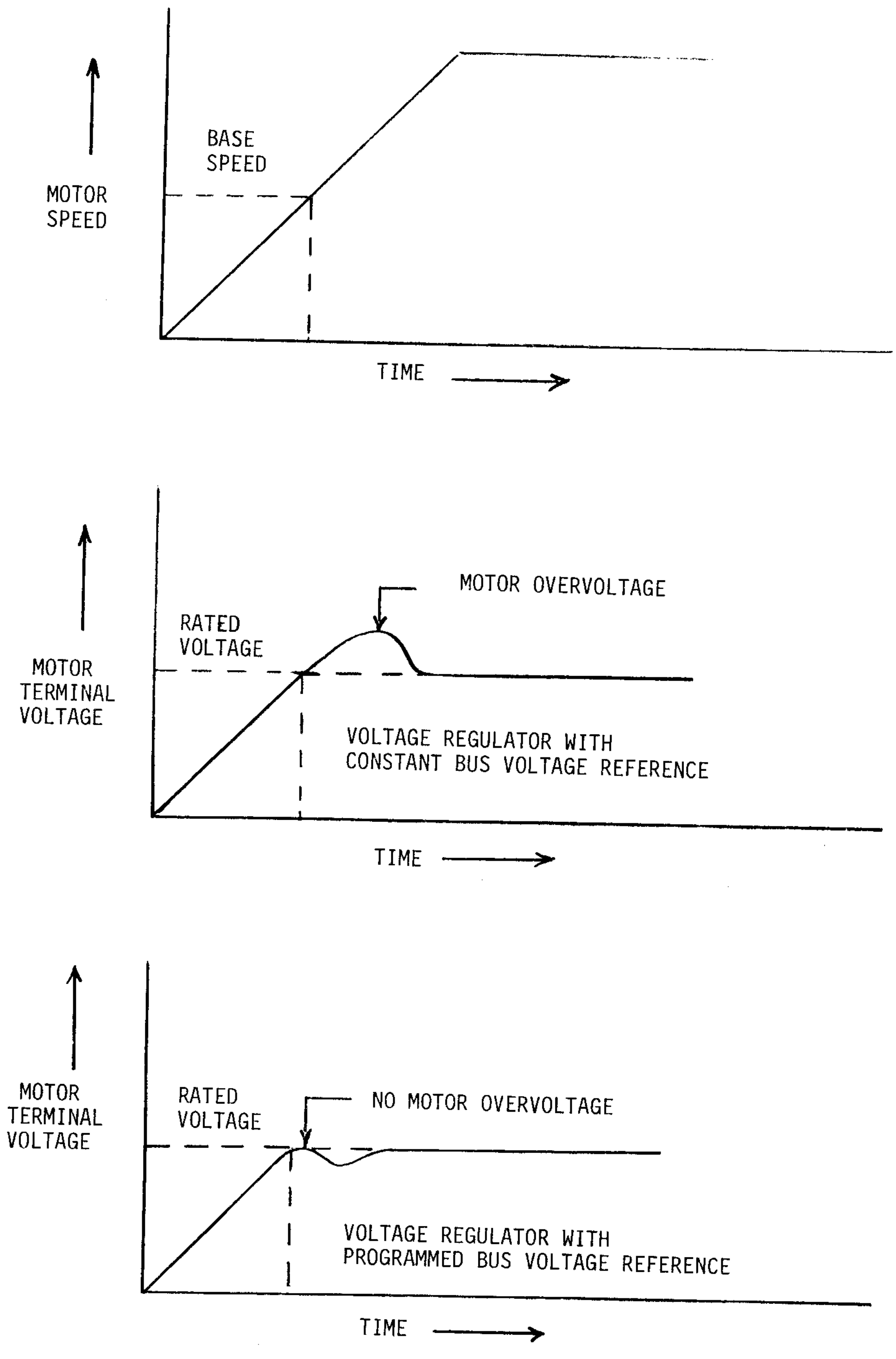
BUS VOLTAGE FEEDBACK (Sheet 5)

The bus voltage (motor terminal voltage, $-V_m$) feedback signal is generated by amplifiers 8-OA and 9-OA. 8-OA is a differential input amplifier. The input to this amplifier comes from an external attenuator board which is provided with taps to match standard bus voltages from 240 to 800 volts. Amplifier 9-OA is an inverter. Diodes 22D and 23D are used to keep the feedback signal negative. At rated motor terminal voltage the bus voltage feedback signal -|VM| on terminal 23 of the FCC card is adjusted by potentiometer 1P (cage position 13) to be -6.00 volts.

BUS VOLTAGE REFERENCE SIGNAL (Sheet 5)

In this motor field regulator, the bus voltage reference to the motor field controller card is programmed as a function of motor speed. This feature permits the bus voltage regulator to start regulating bus voltage before the motor gets to rated speed. Using this feature, the transient bus voltage overshoot has occurred at a motor terminal voltage less than rated terminal voltage: therefore, any voltage overshoot peak is less than the motor rated terminal voltage. If the bus voltage reference was constant at a value corresponding to rated motor voltage when the bus voltage started to regulate, transient voltage overshoots would overvoltage the motor. Typical bus voltage transient voltage peaks when the drive motor is accelerating on a fast ramp through base speed are compared in Figure 5 for this bus voltage regulator and for bus voltage regulators with constant bus voltage reference:

Operational amplifiers 6-OA and 7-OA generate the bus voltage reference signal +VM*. Potentiometer 3P (cage position 13) biases both amplifiers. 3P biases 7-OA to generate a minimum positive output on terminal 53. With 3P max. CW, the output voltage will be +10.0 volts. With 3P max. CCW, the output voltage will be +6.22 volts. +10 volts on terminal 53 corresponds to 100% motor terminal voltage. 3P also biases 6-OA. When 3P is max. CW the bias into 6-OA corresponds to +2.5 volts on terminal 47: the speed feedback signal at base speed. With 3P max. CCW, the bias into 6-OA corresponds to 62.2% of the base speed signal. The bias on 6-OA from 3P is such that no output from 6-OA is generated for 7-OA (terminal 49) until the speed signal exceeds the setting of potentiometer 3P. As 3P is adjusted CCW, the voltage on terminal 53 is reduced. When the speed signal exceeds the bias, the bus voltage reference is increased by the signal generated by 6-OA. Circuit gains are such that when the motor speed exceeds the bias of 3P, an incremental reference is added to the



TYPICAL VOLTAGE REGULATOR RESPONSES ILLUSTRATING DIFFERENCES BETWEEN CONSTANT AND PROGRAMMED BUS VOLTAGE REFERENCE

FIGURE 5

initial voltage on terminal 53. When the motor is at base speed, the output voltage on terminal 53 will be at +10 volts. Amplifier 7-0A is limited to a maximum output of +10 volts. The incremental reference change produced by 6-0A is time delayed by the feedback circuitry on 7-0A and by an input filter on the motor field controller card to slow up reference changes into the bus voltage loop.

As an example, the bus voltage reference could be 75% rated motor voltage and when the motor terminal voltage gets to 75% rated voltage (k = .75 P.U.) the bus voltage regulator overrides the field current regulator and starts to regulate for bus voltage. A 25% rated motor voltage overshoot could occur and the motor terminal voltage would still not be exceeded. Bus voltage reference is then increased as a function of motor speed until motor speed is at rated speed or higher, at which time, the bus voltage reference is clamped at motor rated terminal voltage. To give some time for the bus voltage regulator transients to die out, the incremental increase in bus voltage reference as a result of an increase in motor speed is delayed (typically 0.5 sec.). If the motor should stop at a speed somewhere between 75% rated speed and 100% rated speed, the bus voltage reference would correspond to that speed and the motor field current would still be rated field current. Sheet 2 illustrates the functional block diagram for this bus voltage reference circuit. The equation below illustrates the transfer function for the bus voltage reference as a function of motor speed if k = .75 P.U.

1) Bus Voltage Ref. = 0.75 (rated Voltage); Motor Speed < 0.75 Rated Speed.

2) Bus Voltage Ref. = $\left(0.75 + |\text{P. U. Motor Speed} - 0.75| \times \left(\frac{1}{1 + 0.5S}\right)\right)$ (Rated Voltage)
0.75 (Rated Speed)< Motor Speed < Rated Speed; S = Laplace Operator

3) Bus Voltage Ref. = Rated Voltage; Motor Speed >Rated Speed.

The novel features of this bus voltage motor field regulator are:

1) That the bus voltage reference is programmed as a function of motor speed such that all transient motor terminal voltage overshoots occur below motor rated voltage and therefore do not overvoltage the motor.

2) That the bus voltage feedback loop gain is constant (does not vary as a function of motor speed).

These features permit a bus voltage regulator to be applied on drive motors operating on a fast reversing duty cycle such as a slab or plate mill and no motor terminal voltage overshoot will occur.

ABSOLUTE VALUE & GAIN CALIBRATION (Sheet 5)

Amplifiers 1-0A, 2-0A and 3-0A on the FCC card generate the positive absolute value of the tachometer signal. The input tach signal comes from the armature variable regulator and should already be calibrated to +10.0 volts at top speed. Potentiometer 2P (cage position 13) is used to calibrate the tach signal to +2.5 volts on terminal 9 of the FCC card at motor base speed.

VOLTAGE CONTROLLER GAIN REFERENCE (Sheet 5)

Amplifiers 4-0A and 5-0A produce the second input to the multiplier on the MFC card which is used to adjust the gain of the bus voltage loop as a function of motor speed. The input signal to this circuit is the positive absolute value of the tach signal. The output signal +|GM| is maintained at +2.5 volts until the tach signal goes above base speed (+2.5 volts). Above the base speed level +|GM| = +|W|.

As +|GM| increases above base speed, the gain of the bus voltage loop is reduced by the multiplier function. The 10V limit on amplifier 5-0A limits the use of this card to systems with a change of 4 to 1 or less in the speed range above base speed.

Amplifier 5-0A is biased for a minimum output of +2.5 volts on terminal 41. An identical bias into 4-0A holds the output from 4-0A on terminal 39 at zero volts until the input speed signal is above base speed (+2.5 volts). Above base speed, the signal on terminal 41 is the same as the input signal on terminal 11.

START-UP

CAUTION - It is presumed that the power and control system, including the TPM Assembly, has been thoroughly checked in accordance with instructions in the associated TPS I.L. before any attempt is made to start-up the regulator system using the following procedure.

The start-up instructions have been written with regard to the diagrams included in this instruction leaflet. A set of job schematics for the particular job being started should be checked to insure that the proper correspondence still exists.

1. Field Voltage Loop

With the motor at rest (disconnected if possible from its TPS) set 1P (cage position 10) 100% clockwise. Set 6P (cage position 10) 0% CW. Relay 1CR on the Motor Field Controller card and relay 1CR on the Field Volt. Cont. Card (M5B System only) must be energized at this time. The MFC output on terminal 19 of the MFC card (cage terminal 41) should be in limit at -10 volts.

For AN M5B Basic Regulator

Set 5P (cage position 13) 0% CW. Adjust 6P (cage position 10) until the field current is 1.15 X rated value. Adjust 5P (cage position 13) until the system trips due to the overexcitation signal.

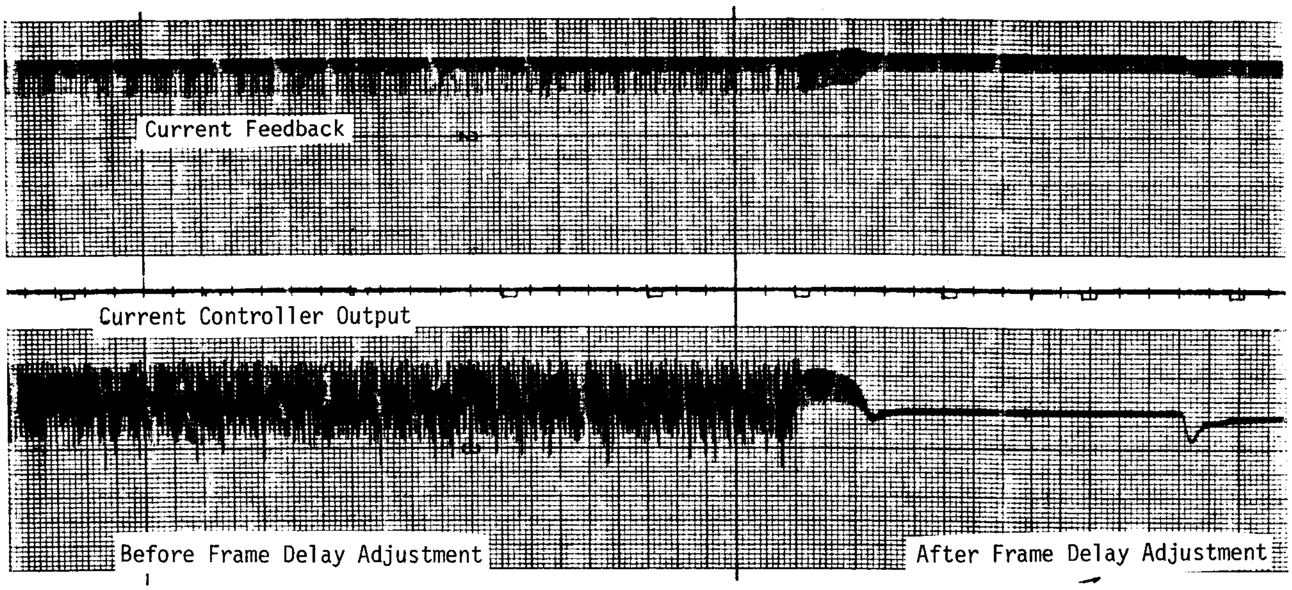
Both Regulators

With the field exciter shut down, disconnect the motor field. Re-energize the field package and with the 1CR relays as mentioned above energized adjust 6P (cage position 10) until the field terminal voltage is equal to the rated output of the TPS.

2. Field Current Loop (Sheet 6)

The field current loop is to be adjusted while the motor is at rest (disconnected if possible from the TAS). Set 1P (cage position 10) 25% clockwise. Set 2P (cage position 10) 25% clockwise. Set 3P cage position 13) 100% clockwise. On the A140 set the gain pot max. clockwise. Remove the appropriate thyristor pulse amplifier card: TGD card on the M5B system or the GS&D card on the F80 system. With the card removed (no thyristor pulses) set the balance pot on the Current Sensor so that CFB to PSC on the Current Sensor is 0.00 volts. With the pulse amplifier card re-inserted, set 1P (cage position 10) so that the wiper output (cage terminal 35) is +8.00 volts. Start the field supply and reduce the gain of the Current Sensor until the field current is at rated value.

De-energize 1CR on the MFC card. Adjust 2P (cage position 10) so that the field current is at the desired minimum or economy field level. Set the current controller gain pot 4P (cage position 10) 0% CW, the backplane gain jumper 2J (cage position 08) connecting terminal 49 to terminal 51. (Increasing gain jumper positions are in sequence T49 to T51, T49 to T53, T49 to T55). Set the frame delay pot 5P (cage position 10) 0% CW. Connect a test battery source to terminal 23 of the MFC card (cage terminal 36). Reduce the setting of 1P (cage position 10) (Cage terminal 35) until it is 0.5 volts above the setting of 2P (cage position 10) (cage terminal 39). 1CR on the MFC card must be energized. Connect the brush recorder to field current signal (cage terminal 38), small step field current reference (cage terminal 36), Full Field Cont. output (cage terminal 11), Bus Volt. Cont. output (cage terminal 10) and Min. Field Cont. output (cage terminal 12). Using the test battery apply a small step field current reference signal to the field current controller and record the signals on the brush recorder. Adjust the gain pot 4P (cage position 10) and the gain jumper 2J (cage position 08) to obtain the best response. Observe the brush recorder signals Full Field Controller output and Current feedback. If these signals show any indication of jittering, adjust the frame delay pot 5P (cage position 10) to eliminate the jitter on both signals without adversely affecting response time. Gain jumper 2J changes must be made with the TPS field exciter de-energized. The small test step field current reference setting should be small enough such that the full field current controller (2-OA) does not limit. Also, the Bus Voltage Controller and the Min. Field Current Controller outputs should be in limit during these tests. Figure 6 shows a brush chart recording displaying the affects of the frame delay pot.



FRAME DELAY AFFECTS IN CURRENT LOOP ADJUSTMENTS

FIGURE 6

Increase the field current reference pot 1P (cage position 10) in four steps to rated field current and repeat the above dynamic tests readjusting the field current controller dynamic pot settings 4P and 5P (cage position 10) if necessary. If these pot settings are changed at any field current level, recheck the field current load step response at the other field current levels.

The last pot adjustment to be made on the field current controller is to adjust the field current reference card pot 1P (cage position 10) to give rated motor field current.

3. Bus Voltage Loop

The bus voltage loop dynamics are to be adjusted at top motor speed where the gain in the fixed plant (drive motor) of the bus voltage loop is maximum. It is assumed that the drive armature dynamics have already been established.

a. Initial Bus Voltage Loop Adjustments

Disconnect the jumper on cage terminals 31 and 32. Set 2P (cage position 13) 0% CW. Set 1P (cage position 13) 0% CW. Set 3P (cage position 13) so that the bus voltage reference (cage terminal 34) is +9.0 volts. Set the Bus Voltage Gain pot 3P (cage position 10) 0% CW. Set the backplane gain jumper 1J (cage position 08) connecting terminal 35 to terminal 37. Increasing gain jumper positions are in sequence T35 to T37, T35 to T39, T35 to T41. Connect a test battery to test input terminal 04 (cage terminal 37) of the MFC card. Connect a brush recorder to bus voltage feedback (cage terminal 33), bus voltage reference (cage terminal 34), field current feedback (cage terminal 38), bus voltage controller output (cage terminal 41), bus voltage controller speed compensation (cage terminal 40) and motor tach speed feedback (cage terminal 31).

b. Bus Voltage Feedback & Tach Calibrations

In this adjustment it is assumed that the tach signal from the TAS variable regulator has already been calibrated to 10.0V at top speed. Slowly increase drive speed to base speed. With the bus voltage controller regulating motor terminal voltage, adjust pot 1P (cage position 13) so that the motor terminal (bus) voltage is 90% rated motor bus voltage. With the drive operating at base speed, adjust pot 2P (cage position 13) so that the tach signal (cage terminal 31) is +2.50 volts.

c. Bus Voltage Controller Dynamic Adjustments

Slowly accelerate the drive to top speed. The motor terminal voltage should still be 90% rated terminal voltage. Adjust the test battery voltage to +0.20 volts and apply a step change in motor terminal voltage reference with the test battery switch with the brush recorder at a brush speed of 25mm/second. Reduce the small step bus voltage reference setting if the bus voltage controller saturates (10.0 volts output). Adjust the bus voltage controller gain pot 3P (cage position 10) to give the fastest bus voltage response possible with less than 10% bus voltage overshot. If the gain jumper 1J (cage position 08) has to be changed, this must be done with the drive stopped and with the field TPS exciter de-energized. Take similar small test step voltage reference responses at motor base speed.

d. Controller Adjustments For Fast Accelerating Ramp

Reconnect the jumper between cage terminals 31 and 32. Set 3P (cage position 13) so that the bus voltage reference (cage terminal 34) is +7.50 volts at zero speed. With the speed reference set at 75% of top speed, accelerate the drive on its fast ramp observing the motor terminal voltage on the brush recorder when the motor drive speed goes through base speed. If for some reason the motor terminal voltage overshoots its rated value, adjust 3P (cage position 13) counterclockwise to initiate a lower breakover point.