M5B VARIABLE REGULATOR

INDEX

I. INTRODUCTION

The variable regulator comprises the printed circuit boards and other apparatus required to regulate the process variables, such as armature or field current, bus voltage, speed and/or position of the machine. The word "variable" regulator refers to the fact that a great variety of combinations of boards is required to satisfy all of the varied industries.

Modern applications of regulated drives require not only the accurate control of the primary variable (for instance, speed), but also the control has to fulfill one or more of the following requirements.

(a) Limitation of critical variables of the drive such as armature current or voltage to protect the system.

(b) Close control of variables to avoid excessive rates of change. For example, control of the rate of rise of current to assure good commutation of the machines.

(c) Smooth transfer from one mode of control to another. For example, smooth switchover from speed control with current limit to current control with speed limit.

(d) Simple and straightforward adjustment and optimization of a control loop. This requirement shows its importance during startup and later when a malfunctioning controller has to be replaced.

The multi-loop (or cascaded) control concept is used in M5B variable regulators to fulfill the requirements as listed above. No attempt can be made to describe all possible variable regulators as it would be too extensive; rather the principles are highlighted and some regulator boards are described.

Developed specifically for M5B are four controllers which incorporate several changes and improvements over previous boards which had the same functional name (and similar functions). These new boards are:

(1) Current Controllr (CC) S#1745A21.

(2) Speed Controller (SC) S#1745A39.

(3) Voltage Reference Controller (VRC) S#1745A40.

(4) Ramp Function Generator (RFG) S#1684A62.

Even with these few controllers, a number of regulator combinations is possible. These would be simple regulators and in most cases would comprise part of a more complex regulator. Some examples are:

(5) Current regulator.

(6) Current regulator with outer voltage limit.

(7) Current regulator with outer speed limit.

(8) Voltage regulator with inner current limit.

(9) Speed regulator with inner current limit.

(10) 8 and 9 above with ramp function generator.

Sequencing of variable regulator boards will change depending on requirements of the system. However, sequencing will not be discusses in this I.L. except in its most simple form.

II. MULTI LOOP REGULATORS

Figure II-1 shows a block diagram of a multi-loop speed regulator with ramp function generator for a double converter basic regulator. It will be used to discuss variable regulator concepts used in M5B.

The most outer loop is the RFG. It would likely be required if several drives have to track speed on acceleration. In that case ramp rates would have to be slow enough so current limit is not reached for tracking accuracy to be possible. Also an absolute value ramp detector is available which would likely be used in stop sequencing following a ramp deceleration. The non inverted output of the RFG is used as the speed reference signal. This allows the same polarity of reference for speed whether an RFG is used or not.

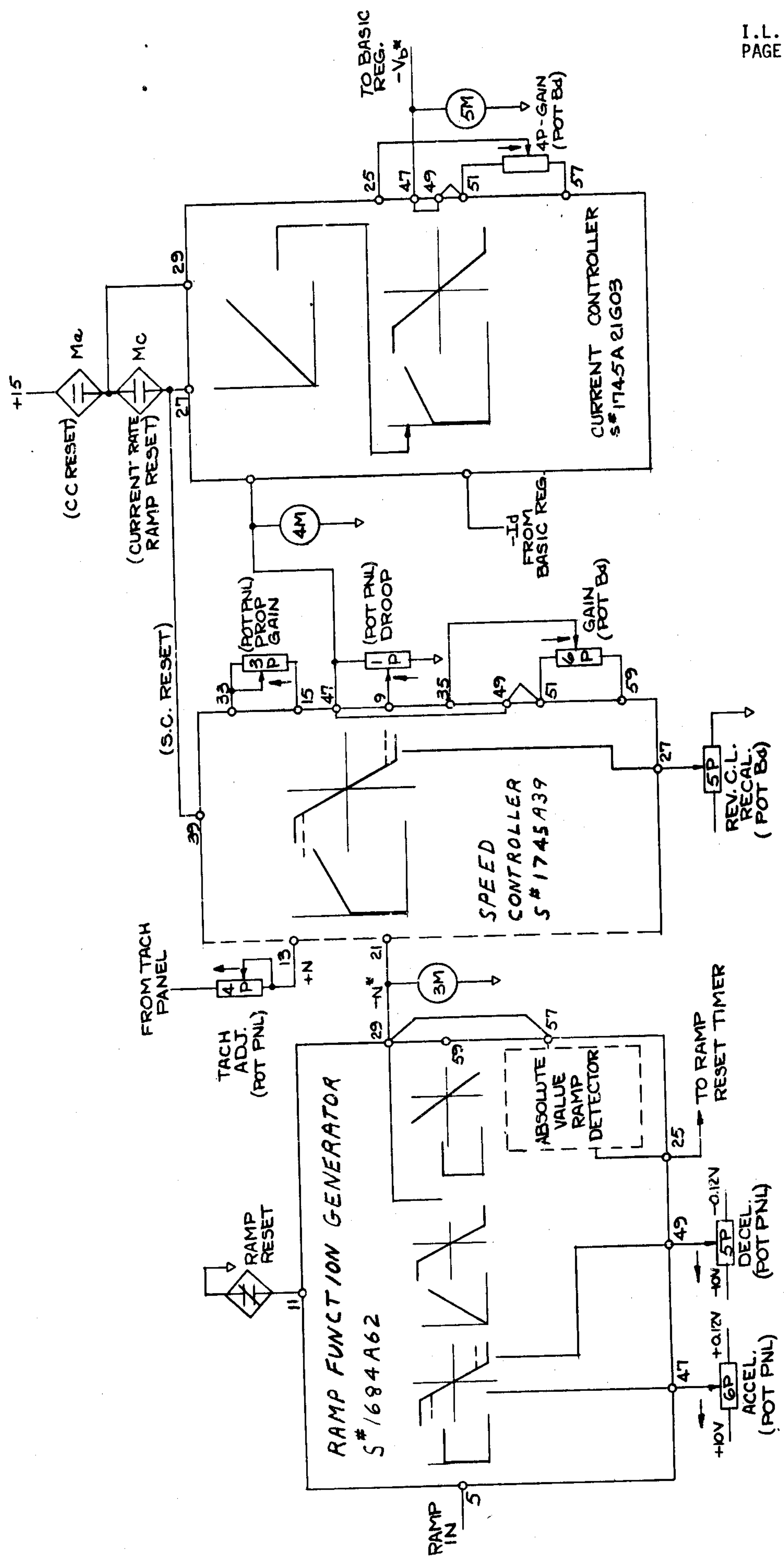

TO BASIC REG. $-V_b^*$
5M
4P-GAIN (POT Bd)
CURRENT CONTROLLER S# 1745A21G03
+15
Ma
Mc
(C C RESET)
(CURRENT RATE RAMP RESET)
4M
-Id FROM BASIC REG.
(S.C. RESET)
(POT PNL) PROP GAIN
(POT PNL) DROOP
GAIN (POT Bd)
SPEED CONTROLLER S# 1745A39
REV. C.L. RECAL. (POT Bd)
FROM TACH PANEL
TACH ADJ. (POT PNL)
+N
$-N^*$
3M
RAMP FUNCTION GENERATOR S# 1684A62
ABSOLUTE VALUE RAMP DETECTOR
TO RAMP RESET TIMER
RAMP RESET
DECEL. (POT PNL)
ACCEL. (POT PNL)
RAMP IN

FIGURE II-I

The primary variable (speed) is controlled in the next loop. Its output represents the reference for control of the secondary variable (current) in the inner loop. Therefore, it is possible by limiting the output of the outer (speed) controller to obtain any desired current limit characteristic. A constant output limit results in a vertical current limit characteristic. By limiting the output dependent on armature voltage or drive speed, a tapered current limit can be obtained. The output of the current controller, in turn represents the reference ($-V_b$*) for the basic regulator and in limit sets the maximum bus voltage V_b produced by the converter.

The outer speed loop is adjusted to be only about half as fast as the inner current loop to provide a dynamic separation of the two loops. It is possible to add more loops (other than RFG) around the outer speed loop (for instance, tension loop). In this case, the above adjustment rule applies and the next outer loop is adjusted about half as fast as the loop it is generating a reference for.

It is very easy in a multi-loop system to change the mode of control and to switch, for instance from speed control to current control. In our example with no RFG, it would require reducing the setting of the speed controller output limit to the desired current reference value and applying a reference (speed limit) step into the speed controller to saturate the SC amplifier.

M5B controllers in general are designed so that only one major time delay is in each loop, which can be readily cancelled by the lead term of the respective controllers. Startup is straightforward since the steady-state and dynamic characteristic of the control are independent of each other. The most inner loop is adjusted, then each next outer loop.

There are four possible adjustments in the SC which are essentially independent. Proportional gain adjust is the lead time constant adjustment to cancel the mechanical time constant of the machine. Gain adjust is for dynamic adjustment (crossover frequency) of the SC loop. Tach adjust is to match tach feedback to maximum reference into the S.C. for speed limit. Droop adjust is available if required. It should be noted that all gain jumpers and potentiometers are external to the controllrs. Should a controller board become defective, readjustment of gain and limits is usually not required.

The lead time constant of the CC is fixed to approximately cancel the armature time delay. Gain pot adjusts the dynamic response of the CC (crossover). A rate of current change ramp is used in the CC to assure good machine commutation of current. As a ramp is used, rather then a lead term in the current feedback loop, no additional lead term is required in the speed controller. As only one lead term is used in the SC, this regulator is less susceptible to tach noise and misalignment noise than would be a SC with two lead terms.

The multi-loop control concept has proved to be very effective and in M5B is used almost exclusively. A summary of the features of this control concept yields:

(a) Separate controllers are used for each controlled variable. This allows an optimum and straightforward adjustment for each loop.

(b) Steady-state and dynamic characteristics are independently adjustable.

(c) Smooth transfer from one control mode to another.

III. REGULATOR BOARDS

A. Current Controller

This board contains the current controller, rate current limit ramp, means of current limit adjustment in steps by an external edge connector jumper. For G01 and G03 a potentiometer is provided so that rate current limit can be adjusted to greater rates than on the fixed rate of change of current. On G01 and G02 this board contains the single converter voltage controller for inner voltage loop and reverse current simulation circuit.

The current reference ($-i_d$*) comes into terminal 35. Current limit is determined with limit voltage from the S.C. or V.R.C. and current limit jumper position. Unless reduced by external networks this limit voltage is ±10V accurate to within 2%. Reference $-i_d$* at terminal 35 only, gives a current limit of 100% rated motor (or drive) current. A jumper from terminal 35 to terminal 37, 39, 41, 5, 7, or 9 gives a current limit of 125%, 150%, 175%, 200%, 250% or 300% respectively.

The ramp or rate current limit is made up of op amps 1, 2 and 3 with associated circuitry. With a step reference change 1-OA goes to 10V. The capacitor on 2-OA will start to ramp and as 3.3V output on terminal 13 corresponds to 100% current reference the time required to change to 100% current reference for G02 and G04 is:

$$t = \frac{3.3V \times .33uf \times 464k}{10V} = .05 \text{ seconds}$$

Therefore the rate of change of current is:

$$\frac{100\%}{t} = \frac{100\%}{.05 \text{ sec.}} = 20 \text{ times rated current/sec.}$$

For G01 and G03 additional current is available into the ramp from 1P and 22R and the rate of change of current can be incrased to a maximum of 97 times rated current per second. 3-0A provides feedback to 1-0A to match $+i_d*$.

A ramp for rate current limiting has some advantages over using a lead term in the current feedback, for speed controlled systems. The ramp requires no additional lead term in the S. C. to force the C. C. This provides less high frequency gain for tachometer ripple and makes the ramp system less susceptible to sloppy current limiting caused by tach noise, ripple, etc.

4-0A and associated circuitry provides the current controller function. It is a PI controller with a fixed lead of 30ms to approximately cancel the armature time delay. 100% current reversals through the dead zone can be completed in about 40ms with about 7% overshoot. Current feedback $-i_d$ is brought in at terminal 17, and is adjusted to -2V at rated current by the current adjust pot (2P or 2P and 3P) on the pot board.

Dynamic adjustment of the current loop is provided by 4P on the pot board and a jumper between terminal 51 and terminal 49, open, 53, or 55. Terminal 51 to 49 gives the least gain, next no jumper, next 51 to 53, and greatest gain is 51 to 55. With standard adjustment procedures, a crossover response of about 200 rad/sec is expected.

A zero input at terminal 27 resets the ramp and effectively opens the reference. A one (+15V) at terminal 27 allows the ramp to operate. A zero at terminal 29 resets the current controller which is a zero voltage demand.

For single converters (G01 or G02 used) the voltage controller and reverse current simulation is provided on this board. Terminal 49 is tied to 21 ($-v_b*$). When forward current and voltage is demanded 5-0A and associated circuitry provide the same gain as the voltage controller in the double converter. Reverse current demand should be only a few per cent of rated; just enough to be sure the drive is turned off. This however would make the current controller wind up to saturation without reverse current simulation. 6-0A and associated circuitry with 58R, 27D, 28D, and 60R reduces the gain of the voltage controller and provides a simulated feedback to the current controllr when reverse current is demanded.

B. Speed Controller

This Speed Controller module can be used in either a Type I or a Type II system. It is a proportional integral controller with the lead in the controller feedback. The lead time constant can be adjusted from 0.1 seconds to 1.1 seconds by the proportional gain pot.

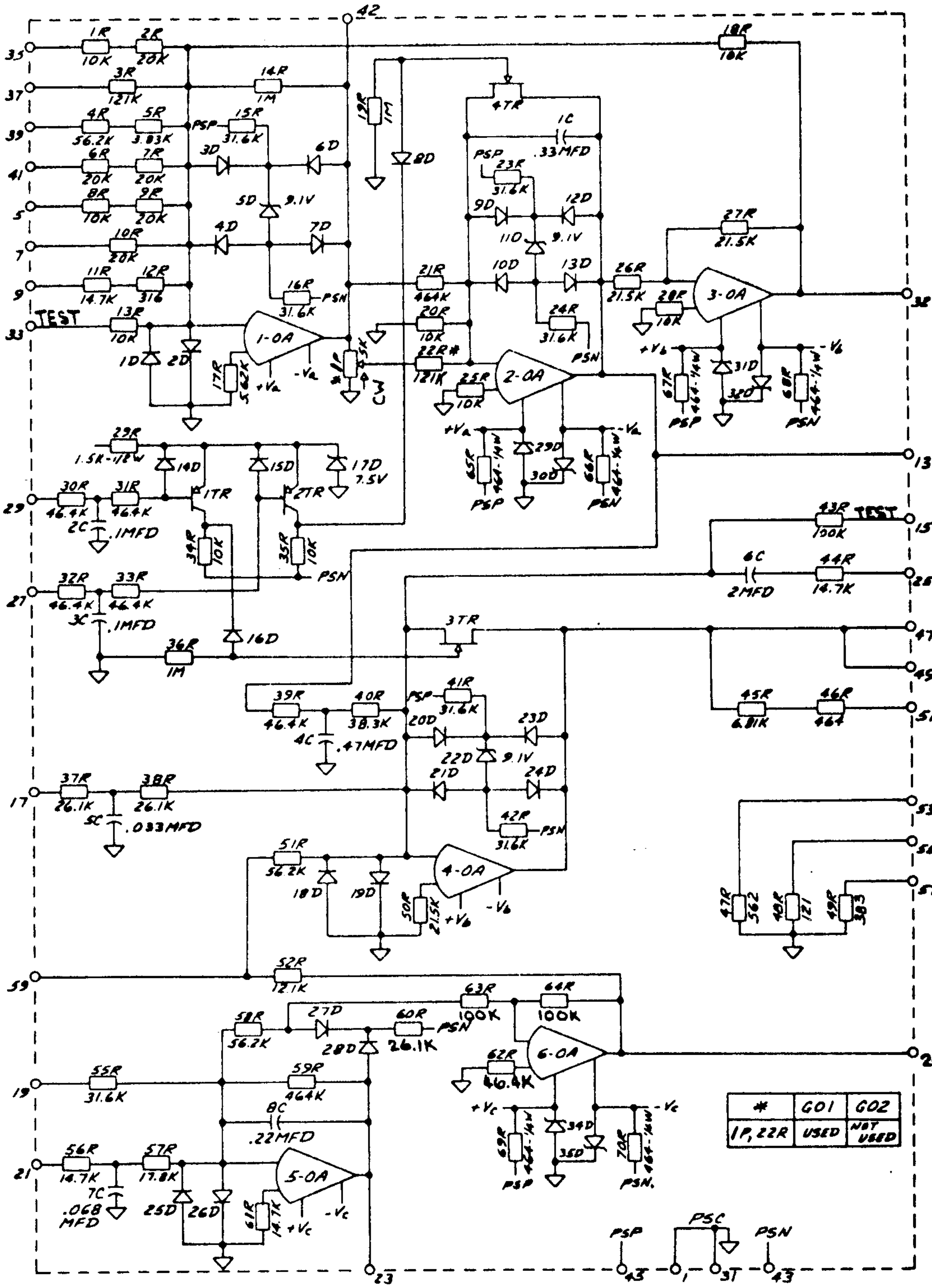
For a Type II speed controller as normally used with a RFG leave terminal 29 open. For a Type I speed controller tie terminal 29 to PSC which puts a 0.19 second delay on the reference input effectively eliminating overshoot on the speed response. Reference is brought in at terminal 21 and terminal 19 is available to make incremental speed reference changes where this change does not want to be brought through the primary reference circuit.

Tachometer feedback is brought in at terminal 13. An external tach attenuator is used on the higher tach voltage feedbacks. A tach filter is employed with a second tach filter available by tieing terminal 41 to PSC. A combination of tach voltage feedback and tach filters is available.

When opening the contactor and resetting the speed controller to demand zero current, the state at terminal 39 is changed from +15V to zero. If a zero speed is required with the contactor left closed, terminal 37 is changed from +15V to zero shorting out the integrating capacitor. This gives a zero current demand with zero reference and tach feedback, however, if the motor should start to turn for some reason a feedback is available to limit speed.

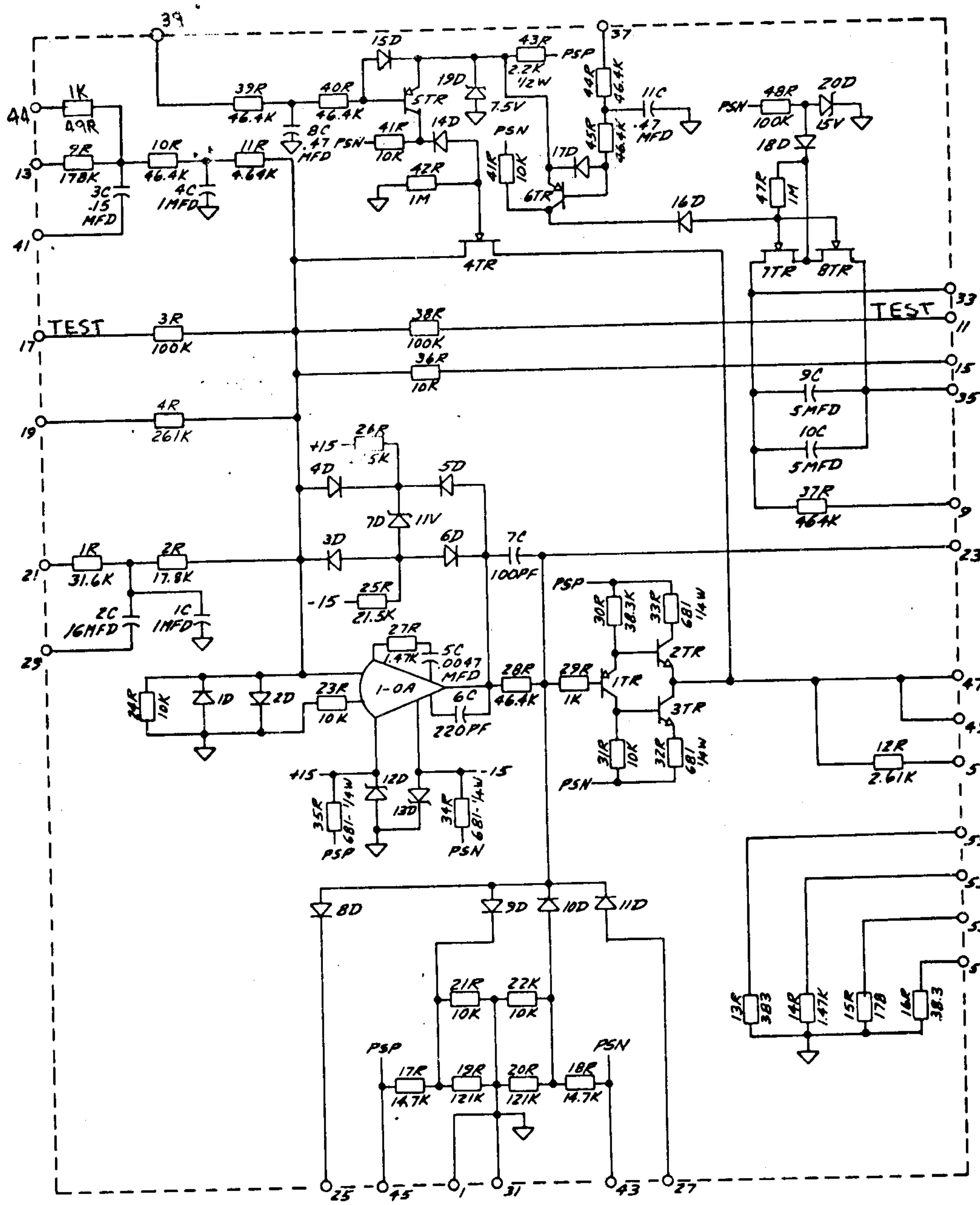
Droop is available with 1P on the meter pot panel and is brought in at terminal 9.

The vernier gain of the controller is adjusted by 6P located on the pot board. Gain range changes are made by a jumper between terminal 51 and terminal 49, 53, 55 or 57 listed in order of increasing gain.



CURRENT CONTROLLER

FIGURE III-1



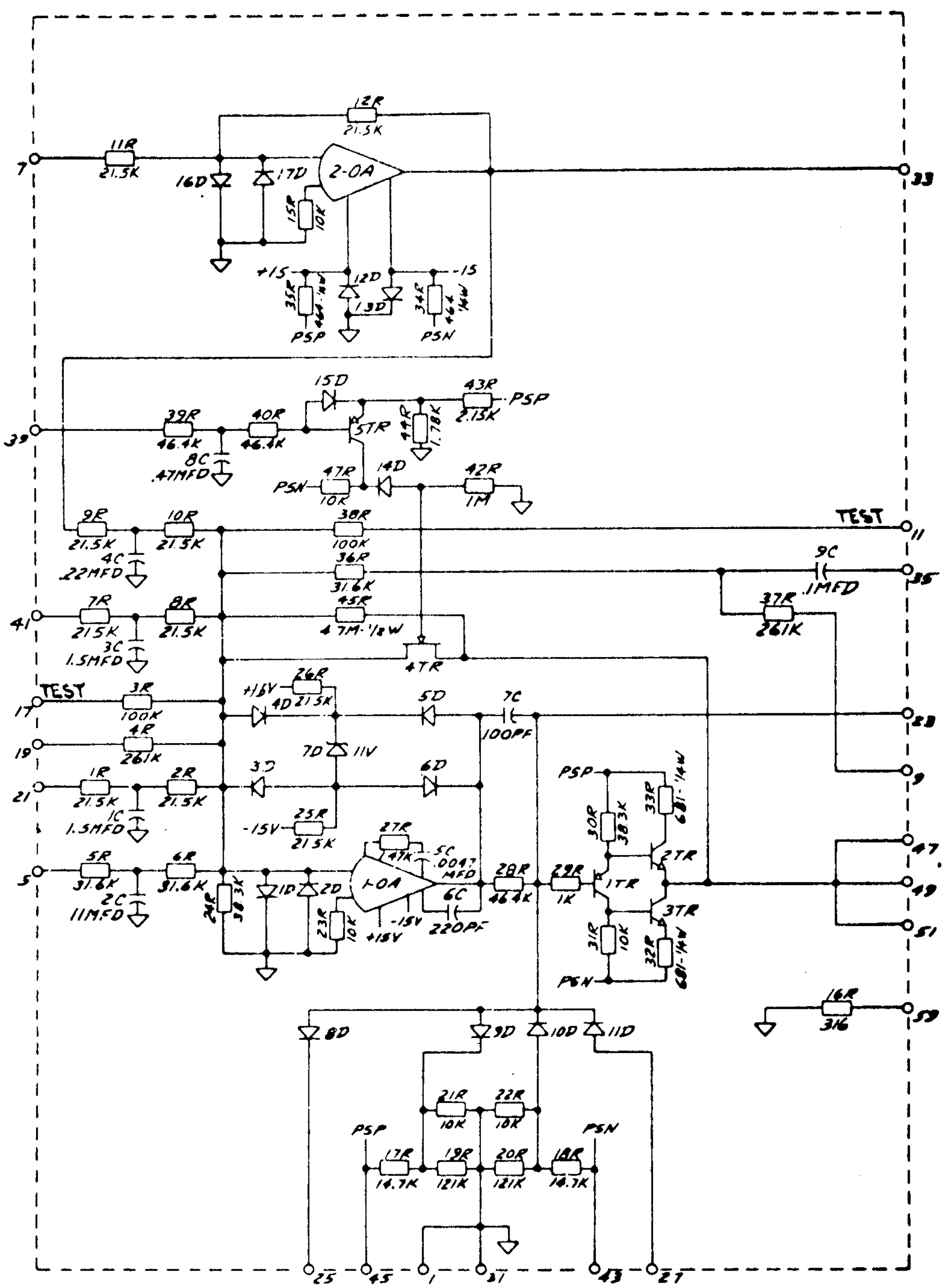
SPEED CONTROLLER

FIGURE III-2

Internal ±10V limiters accurate to within 2% are employed as the current limit signal. Reduced reverse current limit can be obtained by varying the voltage at terminal 27 from -10V toward zero. Similarly positive current limit can be reduced at term 25 with a +10V toward zero adjustment. Terminal 23 is available to connect to such as a limit controller for a variable current limit.

C. Voltage Reference Controller

The VRC module has basically a proportional response. In order to operate as a voltage controller, the input (Term. 7) is connected to the output of the current controller which is the voltage demand signal for the TPM. For M5B systems G01 is used while G02 can be used for duplex drives which have two inputs to the inverting amplifier (Term. 7 and 37).



VOLTAGE REFERENCE CONTROLLER
FIGURE III - 3

A small amount of droop is required and is brought in at Term. 9. Dynamic adjustment of the voltage loop is affected by settings of the gain potentiometer, droop potentiometer, IR comp potentiometer, as well as the gain established in the current controller which the VRC feeds and has feedback from. Usually satisfactory performance can be obtained over a wide range of potentiometer settings as long as a little droop is used.

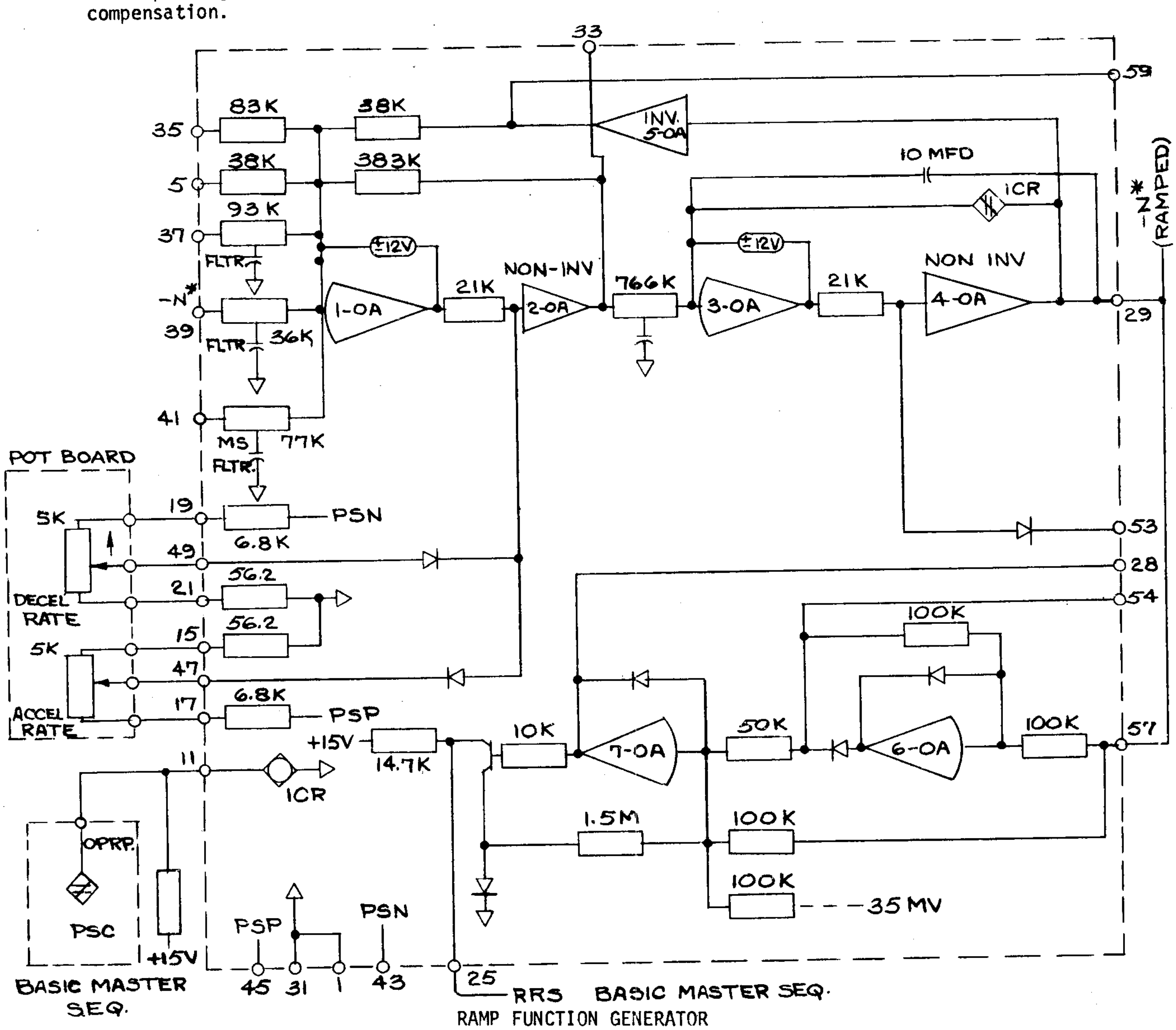
An internal ±10V limiter is used into the non inverting gain of one amplifier which is the 1TR, 2TR, 3TR circuit. Reverse current limit can be lowered below the -10V level by applying a smaller negative signal at Term. 27. Forward current limit can be reduced with a smaller positive signal at Term. 25. The non inverting amplifier input is brought directly out to Term. 23 for use with such as a limit controller.

The amplifier is released for operation by applying a +15V signal to Term. 39 which operates the FET switch circuit and removes the short from across the amplifier.

A second identical input as the input reference signal (-n* at Term. 21) is available at Term. 41.

D. Ramp Function Generator

The ramp function generator (RFG) produces a linear ramp output when the input is a step voltage. Terminals 29 and 59 provide bidirectional opposite polarity ramp signals. Terminal 33 provides an output signal representing the ramp time derivative. This signal is available for inertia compensation.



RAMP FUNCTION GENERATOR

FIGURE III - 4

Operational amplifiers 1-0A, 2-0A and rate adjust circuits brought in on terminals 47 and 49 provides the ramp adjust feature. A step at the input drives 1-0A into limit voltage (±12V) and the input to 2-0A is determined by ramp adjust pots. 1-0A stays in limit until the ramped output (5-0A) matches the input step and at this time 1-0A output goes to zero reducing to zero the input to 2-0A.

Operational amplifirs 6 and 7 with associated circuitry is a ramp detector. Detection voltage is approximately 50mV. When ramping toward zero, such as on a controlled stop, this level allows start of timing for setting the ramp (and other controllers). A "1" (+15V) at terminal 11 releases the ramp.