Instructions for Solid-State Brush Type Synchronous Motor Controller

I.L. 17224

SYNCHRONOUS MOTORS

Polyphase synchronous motors have stators similar to squirrel-cage induction motors and most have rotors with DC slip-ring circuits which must be energized for normal operation. They operate at constant base speeds corresponding to line frequency and number of machine poles (r/min=120 × frequency/number of poles). Synchronous motors are employed primarily to obtain high pullout torques, constant operating speeds, or generation of leading reactive kVA for system-power-factor correction. They require conventional AC polyphase power sources for their rotor fields. For normal operation, synchronous motors must be brought to near full operating speed, at which point the DC power is connected to the rotating field through slip rings. The motors are accelerated to their synchronizing speeds by means of either built-in starting windings or external auxiliary drives. Nearly all conventional synchronous motors now manufactured have built-in rotor starting windings. Such starting windings are also referred to as squirrel-cage windings, pole-face windings, damper windings, or amortisseur windings. Starting windings are actually squirrel-cage induction bars located in the faces of the DC rotor poles. They produce accelerating torque only and have relatively short time intermittent ratings (Figure 1). As starting windings, they become inoperative at synchronous speeds but serve to dampen any tendency of the rotor to oscillate in angular position with relation to the stator field.

The starting of synchronous motors involves two basic switching functions. The first is the energizing of the stator to produce breakaway torque and acceleration to synchronizing speed, and the second is the energizing of the DC rotor field at the optimum speed and rotor-stator pole relationship. For motors having built-in starting windings, the same equipment considerations are required as for full-voltage or reduced-kVA starting methods for squirrel-cage induction motors. All factors relating to stator circuits are identical.

START WINDING PROTECTION

The most critical protection for synchronous motors is that for the starting windings. These windings are short-time-rated for starting duty only and are most vulnerable at locked-rotor conditions. Optimum protection provides for stall protection while still permitting slip protection in accordance with the characteristic curve of Figure 1. Squirrel-cage protection is required on motor start-up to ensure that proper sequential synchronizing occurs and that motors will operate continuously in synchronism. The protection must detect and operate for a condition of prolonged subsynchronous operation beyond the thermal capability of the starting windings.

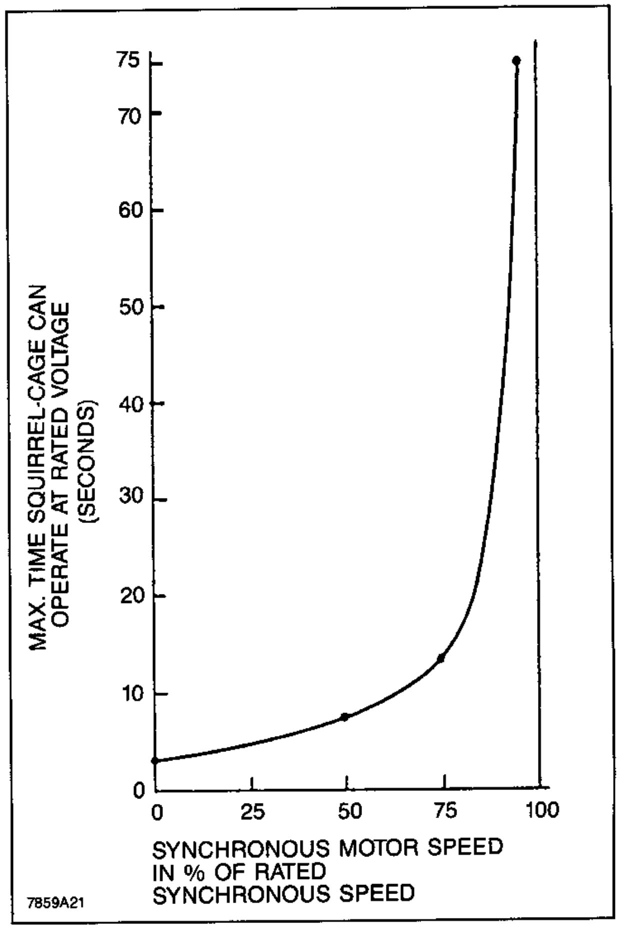

Fig. 1 Thermal Capacity of Typical Synchronous Motor Start Winding

Squirrel-cage protection is provided through a protective system which integrates subsynchronous speeds with time.

Once synchronous motors have been initially and successfully synchronized, loss of synchronism or pullout is detected by the presence of induced slip current or voltage superimposed on the DC excitation source. In brush type controllers, the same system used for field application is also employed for pullout protection where field sensing is used for both functions.

Provisions can be made for immediate shutdown or resynchronizing of synchronous motors following pullout. Because of the vulnerability of synchronous motors, the best practice is to provide for immediate shutdown on pullout except for those installations where positive protection against all combinations of operating hazards is assured.

MOTOR OPERATING HAZARDS

Some of the major operating hazards for synchronous motors are operating abuse, low line voltage, low excitation current, and excessive shaft load. The pullout-torque limitations of synchronous motors are a function of stator and field power. Supplementary protection for synchronous motors may be provided through the use of field voltage and current relays and with stator frequency relays. Extreme care must be exercised, especially with large synchronous motors, if attempts are made to reconnect motors to the line after momentary power interruption. Reconnection of line voltage which is substantially out of phase with open-circuit motor terminal voltage can result in extremely high current and torque surges capable of creating system disturbances and mechanical damage. Systems incorporating reclosing circuit breakers and resynchronizing after motor pullouts fall within this danger area.

Additional hazards for synchronous motors are jogging, too frequent starting, stalling, and excessive accelerating times. Any of these conditions are serious hazards to starting windings. Even the best protective system may not protect under such extreme operating conditions. Although protective systems follow the heating curves of the motor windings adequately, it is nearly impossible for them to follow motor cooling because of the great difference in masses between protective devices and motors. Human judgment is still important in protecting synchronous motors.

MOTOR FIELD EXCITATION

The DC power for the excitation synchronous-motor fields is typically obtained from plant buses, direct-drive DC generators, individual MG sets, or rectifiers. This I.L. describes a Field Power Supply Controller that uses an SCR power amplifier to produce the DC power. Normally, provisions are required for field-current adjustments. Usually, field currents are set to optimum values only after the motor fields have reached maximum operating temperatures. On cold start-ups, the field currents may be 20 to 40% high initially but will decrease to normal as operating temperatures are reached. The field currents are usually maintained as set during motor operation except for those applications in which reactive kVA or power factor is being controlled or regulated.

INSTALLATION

This industrial type control is designed to be installed, operated, and maintained by adequately trained workmen. These instructions do not cover all details, variations, or combinations of the equipment, its storage, delivery, installation, checkout, safe operation, or maintenance. Care must be exercised to comply with local, state, and national regulations, as well as safety practices, for this class of equipment.

Before installation, determine whether the controller is to operate (1) to resynchronize the motor or (2) to trip the line contactor on pullout. If resynchronizing after pullout is desired, be sure that the motor has sufficient torque to reaccelerate under load conditions or that a satisfactory form of automatic unloader is provided. Controllers are shipped with connections arranged to trip the line contactor on pullout. Connections may be changed for the alternate scheme of operation by reconnecting the jumpers on the panel. (See directions on controller wiring diagram.)

If an unloader is used with the driven machine, connections for its operation are shown on the controller wiring diagram. The contacts provided for this service have a current-carrying capacity of 5 amperes and an interrupting capacity of 200 volt-amperes at a maximum of 600 volts AC or DC.

Ground the positive (+) side of the output of the field power supply.

BRUSH TYPE MOTOR CONTROLLERS

Controllers for brush type (slip ring) synchronous motors consist of the basic components shown in Figure 2. Their functions are as follows:

The Line Contactor (M) operates to connect the motor to the AC line. Additional contactors are required in reduced-voltage starters to short out the reactor or to connect and disconnect the autotransformer in the circuit. The M contactor may be a medium-voltage or low-voltage device.

The Overload Relay (OL) protects the motor from damage due to overcurrent conditions such as an overload, single phase or field failure. It operates to trip the line contactor M.

The starting field discharge resistor (RES) is used to improve the motor starting torque and to limit the induced field voltage during starting or when the field excitation is removed. The resistor current and ohmic values are determined by the motor designer. The current flowing to the resistor is controlled by diode D1 and SCR Q4 (Figure 2). Voltage feedback terminal VR provides information about the induced field voltage, frequency, and phase angle. The controller is designed to operate with less than 1,500 volts rms induced in the field during starting.

The SCR power amplifier containing QA1, QB1, QC1, QA2, QB2, and QC2 supplies voltage of 125 or 250 VDC and current to the motor field. The amplifier comes in three sizes, either 50, 100, or 200 amps DC.

The printed circuit board provides gating signals for the starting and discharge circuit, the SCR power amplifier, and protective functions to the motor stator control circuit.

The field power transformers are supplied with dual 120/240 volts AC secondaries. They are sized by the formulas: KVA=.17 × amps DC @ 125 volts DC and KVA=.34 × amps DC @ 250 volts DC.

Current transformers are furnished on medium-voltage starters to supply current to the overload relay and various meters in direct ratio to the line current. On low-voltage applications current transformers are supplied as necessary.

Control power transformers are used on all medium-voltage starters and as specified on low-voltage starters to furnish a control supply. Fuses are supplied on both primary and secondary sides of control power transformers.

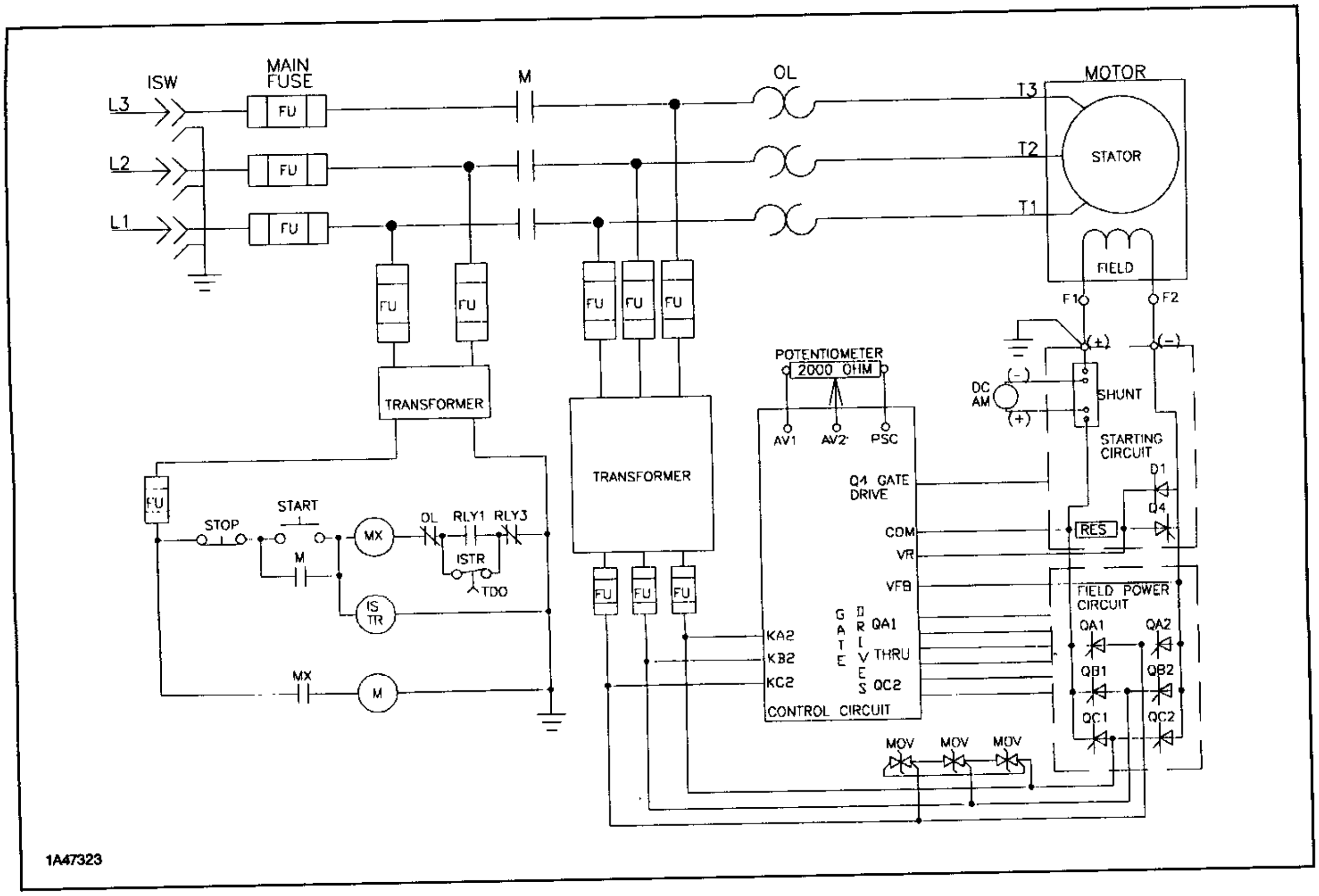

Fig. 2 Solid-State Controller Schematic

OPERATION

Figure 2 shows the field power supply controller in conjunction with the controller for the synchronous motor stator. Note that the connection to the field supply transformer is between the contactor (M) and the overload relays so that the overload relays sense motor stator current only.

The field power supply controller consists of 3 types of circuits, one each dedicated to field power, control and motor starting. The six thyristors (SCR's), QA1 through QC2 shown in Figure 2, are the main components of the field power circuit. The control circuit controls the starting circuit and the output of the field power circuit.

A motor start sequence is initiated by closing the main motor contactor (M). This results in the motor stator and the solid-state field power supply being energized. The field power supply control board becomes energized and the status relay (RLY1) closes when the proper operational status is established. Gate drives to the field power circuit thyristors are initially inhibited. The motor stator, being energized, causes the motor field to generate an output current at the instantaneous slip frequency of the motor. This current is conducted by the independently operating thyristor-controlled starting circuit. The voltage across the field starting discharge resistor (RES) is monitored during the starting sequence to determine the instantaneous slip of the motor. A motor slip condition of less than 75% must be reached within the preset time, ranging from 0 to 9 seconds, or a stalled rotor condition will be indicated by the incomplete sequence relay (RLY3) being energized.

As the motor continues to accelerate and the motor slip frequency becomes less than the level established by the setting of rotary switch SW1, the gate drives to the field power supply thyristors become activated to excite the field with positive DC voltage. The 34 or 40 second incomplete-sequence timer is disabled and a 2.5 to 3.5 second synchronizing-period timer is activated. The motor has this synchronizing period to complete synchronization during which the motor may continue to slip poles. As this occurs, the gate drives to the six field power supply thyristors (QA1 through QC2) are alternately inhibited and activated as the starting circuit thyristor (Q4) alternately conducts and blocks, respectively. Should the motor continue to slip poles after the 2.5 to 3.5 second period has elapsed, as indicated by the starting circuit thyristor (Q4) continuing to conduct, the incomplete-sequence relay (RLY3) will be energized indicating a pole slippage condition. If the motor fails to reach the expected slip frequency within 34 or 40 seconds from the beginning of the start sequence, the timeout (TO) function will operate and the incomplete-sequence relay (RLY3) will again be energized if this option is chosen (by inserting jumper TO). With motor synchronization being established, the

OPERATION (cont.)

output voltage is sensed and regulation of the field voltage is accomplished by appropriate control of the gating patterns to the field power supply thyristors.

Where this controller is used in conjunction with a reduced-voltage motor controller the external inhibit option (see **External Inhibit or Synchronizing**) must be used to ensure that the motor is running at full voltage before the DC field is energized from the field power supply. Where the external inhibit option is used without remote voltage control, a separate 115 VAC signal is withheld from terminals 115 and IN– until the motor stator has been transferred from reduced voltage to line voltage. The field power thyristors will be held OFF until the 115 VAC inhibit signal and the proper slip frequency have appeared. The 2.5 to 3.5 second synchronizing period also will not start until both these conditions are met.

On startup, three phase voltage signals are applied to terminals KA2, KB2 and KC2. The open-fuse detection circuit requires about 50 milliseconds to determine that all voltages are present. It then causes RLY1 to operate to close the circuit between terminals ST1 and ST2. The light emitting diode, LED1 is lit. If any fuse opens and voltage is lost at terminals KA2, KB2, or KC2, RLY1 will drop out to open the control circuit.

FEATURES

This solid-state field power supply controller functions without regard to the phase sequence of the three-phase power supply, which may be at either 50 or 60 hertz. The field power supply controller contains synchronizing circuitry with means to adjust the synchronizing slip-frequency from 1 to 9 percent (SW1) and the permissible stalled-rotor time from 0 to 9 seconds (SW2). It has pole slippage sensing, incomplete sequence detection, single-phase shutdown and low-voltage shutdown.

The minimum output voltage can be adjusted from 50% to 70% of nominal voltage (125 or 250 VDC) with a potentiometer (P1) on the printed wiring board. See Figure 6. Full voltage control is achieved by the addition of a user-furnished potentiometer, typically mounted on the front panel of the power supply cabinet. The range of local voltage control adjustment is coordinated with the minimum output voltage adjustment (P1) to produce the desired minimum and maximum output voltages at the minimum and maximum settings of the local voltage adjustment potentiometer.

OPTIONS

Each of the six variations rated by output current and voltage (50, 100 or 200 amperes at either 125 or 250 VDC) will perform with any combination of user selected options as determined by jumpers inserted into terminals on the synchronous control board. See Figure 3 and Table I.

110/120 VAC Operation

The supply frequency (50 or 60 hertz) mentioned above is chosen by adding or removing jumpers from the printed wiring board. To operate from a 110 VAC, 50 hertz supply, move the jumper from the 60 HZ position to the 50 HZ position on the four-pin terminal located above SW1 and SW2. Also remove the three jumpers from the six-pin terminal located to the right of RLY1. These three jumpers must be installed for 60 hertz operation. See Figure 6.

220/240 VAC Operation

When the input voltage is 220 or 240 VAC (for a 250 VDC output) install a jumper on the two pins marked 240 V in the four-pin terminal marked 240V, TO to the right of RLY3. Remove the two jumpers marked 120V from the four-pin terminal to the right of and slightly below the 240V, TO terminal. Insert one jumper over the two center pins of each four-pin terminal located above each of the three transformers at the top of the printed wiring board. See Figure 6.

Remote (Automatic) Voltage Control

Where the synchronous motor is used to generate a leading power factor to offset a lagging power factor present in the same plant, control of the field supply output voltage can be automatic rather than manual. To control the output remotely and make it responsive to the plant power factor, move the jumper from the LV pins to the adjacent RV pins on the four-pin terminal to the upper right of RLY3 and move the jumper from the L pins to the adjacent R pins on the four-pin terminal between RLY1 and RLY3. Install two jumpers on the four-pin terminal marked RV, RV. Set P1 to its lowest output position (turn counterclockwise) and apply the external (remote) voltage control signal to terminals IN + and IN –. This remote voltage control signal must be a pulse-width modulated (PWM) AC current signal at 1 kHz. The amplitude of the current signal during the ON time is between 15 and 20 milliamperes and zero during the OFF time of each cycle. Adjust the ON time of each cycle to between 1 percent and 99 percent to achieve regulated output voltage from 50 percent to 100 percent of the rated DC voltage. When no PWM signal is received, the thyristors are turned OFF. Hence the

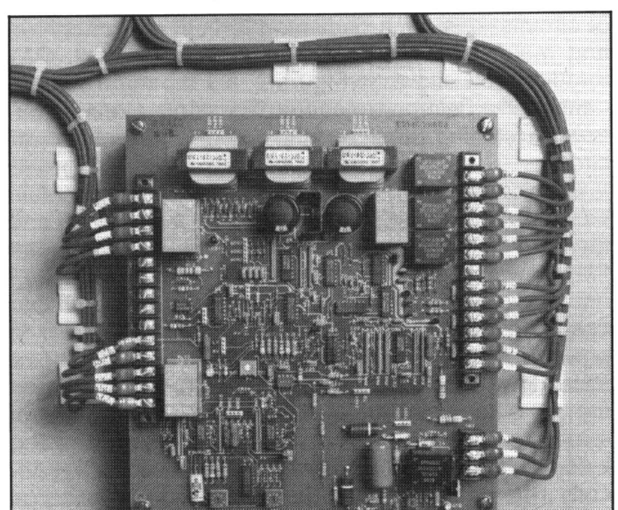

Fig. 3 Synchronous Control Board

TABLE I — JUMPER INSTALLATION FOR OPTIONS

Function	Terminal Marking	Put Jumpers at Terminals: To Activate	Put Jumpers at Terminals: To Deactivate	Jumpers Needed To Activate
Use a 50 Hertz Supply	50 HZ, 60 HZ	50 HZ	60 HZ	1
	60 HZ, 60 HZ, 60 HZ	None	60 HZ, 60 HZ, 60 HZ	0
Use a 60 Hertz Supply	50 HZ, 60 HZ	60 HZ	50 HZ	1
	60 HZ, 60 HZ, 60 HZ	60 HZ, 60 HZ, 60 HZ	None	3
Use a 110 or 120 VAC Supply	240 V, TO	None	240 V	0
	120 V, 120 V	120 V, 120 V	None	2
	(3) 120 V, 240 V, 120 V	(3) 120 V, 120 V	(3) 240 V	6
Use a 220 or 240 VAC Supply	240 V, TO	240 V	None	1
	120 V, 120 V	None	120 V, 120 V	0
	(3) 120 V, 240 V, 120 V	(3) 240 V	(3) 120 V, 120 V	3
Local (Manual) Voltage Control	LV, RV	LV	RV	1
	R, L	L	R	1
	RV, RV	None	RV, RV	0
Remote (Automatic) Voltage Control	LV, RV	RV	LV	1
	R, L	R	L	1
	RV, RV	RV, RV	None	2
Time-Out Shutdown	240 V, TO	TO	None	1
External Synchronizing†	R, L	R	L	1
External Inhibit†	R, L	R	L	1

† Use Remote Voltage Control and provide an additional 115 VAC input signal at the 115 and IN – terminals of TB1. See text.

absence of the PWM signal can be used as an external inhibit control. Note that a continuous PWM signal will also turn the DC output OFF. A PWM signal generator designed for the application can be ordered as Catalog Number PWM-1, requiring a 110-120 VAC, 50/60 Hz supply.

Local (Manual) Voltage Control

For manual control of power factor or of the power supply DC output, use the external 2000 ohm potentiometer shown in Figure 2 and remove the jumpers from the RV and R positions. Place jumpers in the LV and L positions. See Figure 6.

Incomplete Sequence — Time Out Shutdown

To utilize the timeout (TO) option which will automatically reduce the motor field supply to zero and energize control relay RLY3 which should be used to deenergize the coil of the contactor controlling the power supplied to the motor stator, place a jumper onto the two pins marked TO in the four-pin terminal marked 240V, TO located to the right of RLY3 on the printed wiring board. With the TO jumper in place, RLY3 is energized whenever the motor slip frequency fails to decrease to the synchronizing slip frequency set by SW1 within a period of 34 seconds when operating at 60 hertz or 40 seconds when operating at 50 hertz.

External Inhibit or Synchronizing

This field power supply controller can be used to control or inhibit synchronizing of the motor by applying or withholding DC output to the motor field. When external inhibit or external synchronizing is used in conjunction with remote voltage control, the PWM remote voltage signal can be withheld or applied to achieve external ON/OFF control of the field supply. See **Remote Voltage Control** above. When local voltage control is used, external inhibit or synchronizing can be obtained by removing or applying a 115 VAC signal between terminals 115 and IN –, with the jumper on the four-pin terminal marked R, L in the R position. Generally, SW1 will be set at 9% (slip) for this option. DC output is supplied to the motor field when both the 9% slip condition is satisfied and the 115 VAC signal is applied. See Figure 6.

If the controller contains an autotransformer for reduced-voltage starting, voltage should not be applied until after transition to full voltage. Synchronization is blocked by withholding 115 VAC from terminals 115 and IN –. A jumper must be in the R position. When voltage is applied to the motor field, the motor will go into the synchronizing mode.

TABLE II — RELAY RATINGS			
Printed Wiring Board Relay	Control Circuit * Ratings at 120 VAC (C150)		
	Cont.	Make	Break
RLY1, RLY3	2.5A	1800VA	180VA

* Inductive loads such as contactor coils

System Protection

This controller includes circuits that provide a means of shutting down in the event of a stalled rotor, excessive start time (timeout period exceeded) or pole slippage after synchronization. Where the protection system consists of contacts in a control circuit, use the normally-closed (NC) contacts of RLY3 to open the circuit. These contacts are available at terminals SQ1 and SQ2 of Terminal Board 1 (TB1). See Figure 4. When the protection system is based on signals, use the single-ended 15 volt square wave signal available at terminals B + and ST on Terminal Board 1 (TB1) at power line frequency (50 or 60 hertz). This is a 50 percent duty cycle signal that appears when RLY3 operates. The loading on this output signal is limited to 20 milliamperes.

RLY1 (see Figure 4) becomes energized about 50 milliseconds after power is delivered to the printed wiring board and proper operational status of the controller is established. RLY1 and its associated Light Emitting Diode (LED 1) remain energized as long as the built-in + 15 VDC voltage source remains above a prescribed level and three-phase power to the controller is present. The normally-open (NO) contacts of RLY1 should be used in series with the control circuit. Thus loss of control power will result in shutdown of the motor.

Rotary Switch Settings

Rotary Switch 1 (SW1) is a ten-position selector switch which determines the percent slip (1 to 9%) at which the controller is to apply DC power to the synchronous motor field to begin synchronization. Unless experience with a particular motor suggests otherwise, set SW1 at 5%.

Rotary Switch 2 (SW2) is a ten-position selector switch which determines the period (0 to 9 seconds) during which the motor must accelerate to a slip condition of 75% or less. If the motor does not accelerate to the 75% slip or less within the set time period, a stalled rotor condition is presumed to exist and the incomplete sequence relay (RLY3) will be energized. Unless experience with a particular motor and its load suggests otherwise set SW2 at 5 seconds.

FIELD POWER SUPPLY PANEL

Figure 5 shows the solid-state field power supply panel designed to control the application of either 125 VDC or 250 VDC to the field of a synchronous motor. The panel consists of a printed wiring board with low energy components in place, protective fuses, and an assembly of power thyristors (silicon controlled rectifiers, SCR's) arranged to convert 120 or 240 VAC, three-phase, to 125 or 250 VDC, respectively. The direct current (DC) is supplied directly to the field of the synchronous motor. The positive (+) side of the field power supply output must be grounded.

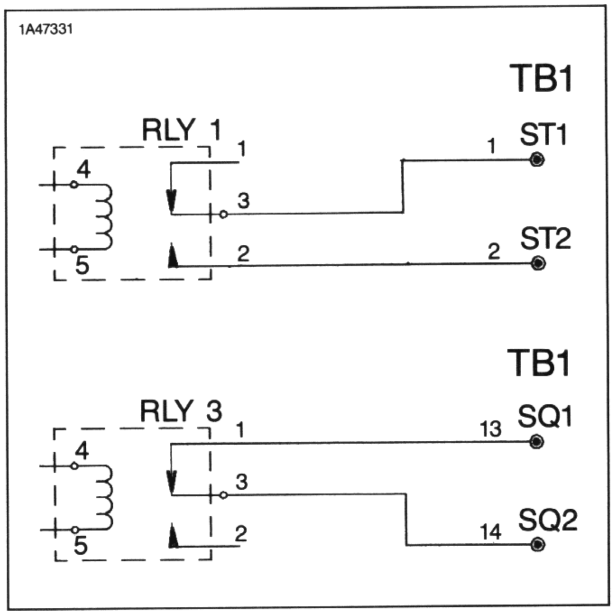

Fig. 4 Control Relay Terminals

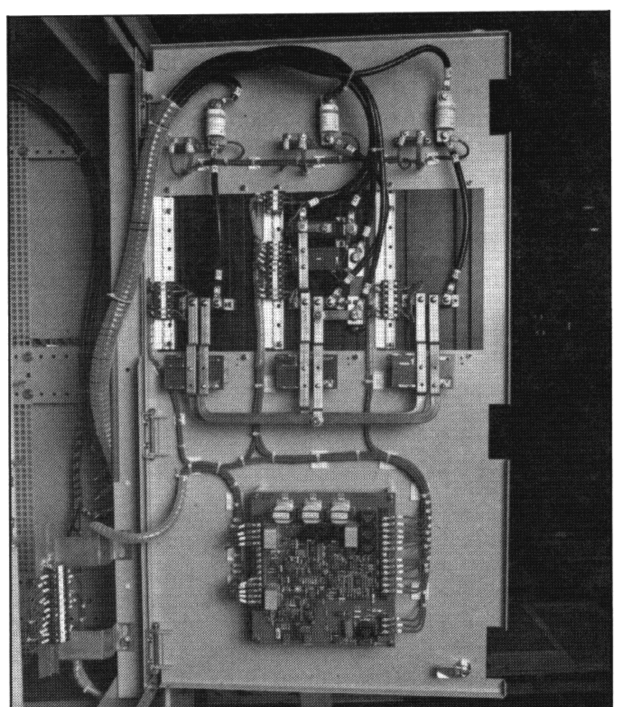
Fig. 5 Field Power Supply Panel

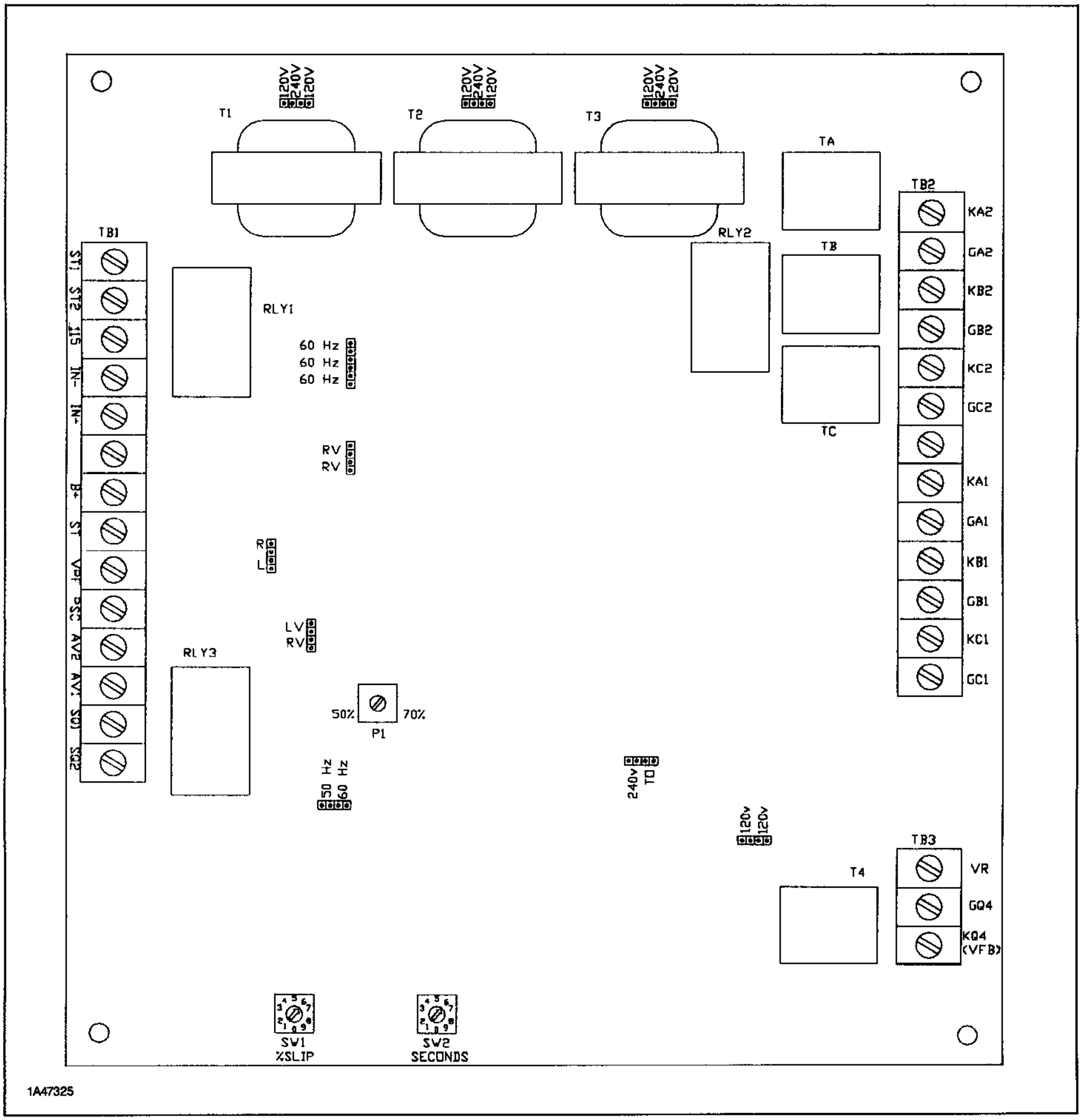

Fig. 6 Synchronous Control Board Layout

SUMMARY OF CHARACTERISTICS

Each controller has a maximum DC current capability (50, 100, or 200 amperes), a rated field supply voltage of 125 or 250 VDC, and the ability to withstand a field output (induced) voltage of up to 1500 volts during the time that the motor is coming up to rated speed, i.e., the field has not yet been energized by the power supply.

The controller protective functions include:

1. Locked rotor protection
2. Incomplete sequence protection
3. Failure-to-synchronize protection
4. Loss-of-synchronization (pull-out) protection
5. Open-phase protection

By jumper insertion on the synchronous control board, a user may choose to:

1. Use a transformer with a 110 V, 50 Hz, or a 120 V, 60 Hz, secondary to supply a 125 VDC field.
2. Use a transformer with a 220 V, 50 Hz, or a 240 V, 60 Hz, secondary to supply a 250 VDC field.
3. Control the motor power factor either manually or automatically.
4. Inhibit synchronizing, during a reduced-voltage start, for example.
5. Control the time allowed for the motor to reach a selected synchronizing slip frequency.

REPAIRS

For renewal parts consult RPD 10-120 or the Westinghouse factory shown below.

Westinghouse Electric Corporation
Construction Equipment Division
Asheville, NC 28813

Printed in USA