Instructions For Ampgard® Mark V Solid-State, Brush-Type, Synchronous Motor Controllers

DANGER

HAZARDOUS VOLTAGE.

READ AND UNDERSTAND THIS BOOKLET AND ITS RELATED INSTRUCTION MATERIAL FOR FULL-VOLTAGE CONTROLLERS IN THEIR ENTIRETY BEFORE INSTALLING OR OPERATING THE CONTROLLER. SEE TABLE 1.

INSTALLATION, ADJUSTMENT, REPAIR AND MAINTENANCE OF THIS TYPE OF EQUIPMENT MUST BE PERFORMED BY QUALIFIED PERSONNEL. A QUALIFIED PERSON IS ONE WHO IS FAMILIAR WITH THE CONSTRUCTION AND OPERATION OF THIS EQUIPMENT AND THE HAZARDS INVOLVED.

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. The controller described in this booklet is for a synchronous motor with slip rings and brushes.

Synchronous motors operate at constant base speeds corresponding to line frequency and the number of machine poles (revolutions/min = 120 x frequency/number of poles). They are employed primarily to obtain high pullout torques, constant operating speeds, or generation of leading reactive VA (VAR) for system power-factor correction. They require conventional AC polyphase power sources for their stators and suitable DC 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 brushes and slip rings. The motors are accelerated to their synchronizing speeds by means of either built-in start 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. Start windings are actually squirrel-cage induction bars located in the faces

TABLE I. REFERENCE MATERIAL

Contactor Type	Ampere Rating	Instruction I.L. or I.B.
Type SJA	360A	I.B. 48002
Type SJA	720A	I.B. 48005
Type SJD	360A	I.B. 48004
Type SJO	360A	I.L. 16-200-33
Type SJO	720A	I.L. 17047
Type SJS	360A	I.B. 48003

of the DC rotor poles. They produce accelerating torque only and have short-time intermittent duty ratings. As start 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 near synchronous speed, the second is the energizing of the DC rotor field at the optimum speed and rotor-stator pole relationship. For motors having built-in start windings, the same equipment considerations are required as for full-voltage or reduced-voltage starting methods used for squirrel-cage induction motors. All factors relating to the stator circuits are identical.

Synchronous motors have two torque characteristics, starting torque and running or synchronous torque. The first is determined by the squirrel-cage design and the "slip" as the motor accelerates from zero to near synchronous speed. "Slip" is expressed as a percent fraction where the numerator is the difference between the synchronous speed and the non-synchronous speed, and the denominator is the base speed, all speeds expressed in revolution per minute (rpm). The running torque characteristic (at synchronous speed) is produced by the magnetic fields created by the DC field coils in the rotor which link with the rotating fields produced by the AC current in the stator windings. See Figure 1.

The DC field coils are energized via two slip rings and brushes. The DC voltage applied to the field coils can be varied to produce the desired level of direct current which in turn produces a magnetic field through each pole which can be varied. Once at synchronous speed,

SYNCHRONOUS MOTORS (Continued)

changing the field current can change the power factor at which the synchronous motor runs or the reactive current drawn from the AC line.

A synchronous motor cannot start with its DC pole windings excited. Voltage is applied to the DC winding only after the motor has been accelerated to a speed which is over 90 percent of synchronous speed. With a slip of less than ten percent, the DC poles will jump to synchronous speed when DC voltage is applied and will lock onto the rotating magnetic field produced by the three-phase alternating current in the stator.

Applying DC at the most advantageous time is the job of the motor controller which uses feedback signals to optimize the transition and thereby minimize the disturbance to the power system at the time of synchronization.

MOTOR FIELD EXCITATION

In this controller, the DC power for the excitation of a synchronous motor field is obtained from a solid-state power supply (exciter). Provisions are made for field current adjustments. Usually, field current is set to optimum values only after the motor field has reached maximum operating temperatures. On cold start-ups, the field current may be 20 to 40% high initially but will decrease to normal as operating temperatures are reached. The field current is usually maintained as set during motor operation except where the field current regulator option is included for those applications in which VAR, power factor, or the field current itself is being automatically adjusted.

THE MOTOR CONTROLLER

As explained in the companion instruction material, each Ampgard® full-voltage motor starter (controller) consists of one nonload-break isolating switch, one contactor, current-limiting fuses, a set of current transformers, and some form of overload protection. A reduced-voltage starter includes all of the components of a full-voltage starter plus one or two additional contactors and related control components. A synchronous motor controller is either a full-voltage starter or a reduced-voltage starter which includes a source of DC and the additional controls needed to start a synchronous motor, operate it at synchronous speed, and protect it.

THE MARK V CONTROLLER

The Mark V is a field power supply and controller that blocks the field voltage during subsynchronous operation and applies the field voltage during synchronous operation. The field voltage is adjusted by a potentiometer during operation.

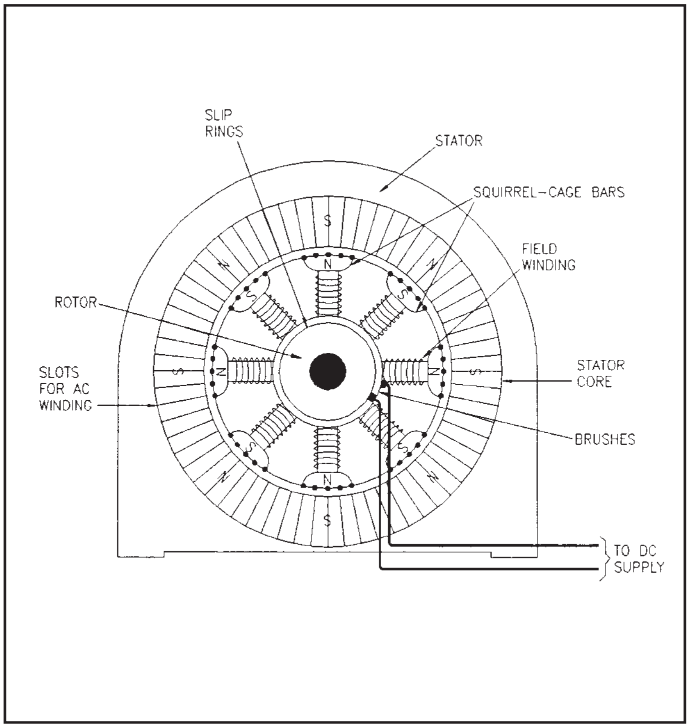

Fig. 1 Synchronous Motor Components

This solid-state field power source 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 and 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 and shutdown in the case of exciter low voltage or phase loss.

Figure 2 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 circuit board (synchronizing control board), 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 synchronizing control board shown in the lower portion of Figure 2 appears enlarged in Figure 3.

Characteristics

Each Mark V 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 DC power supply, or the converse, the motor coasting to a stop with the field deenergized.

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
6. DC loss (field loss) protection

Automatic power factor regulation is not included with the standard unit, but is available as an option.

Functions

Mark V controllers for synchronous motors consist of the basic components shown in Figure 4. 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 overload protection relay (e.g., IQ1000-II) protects the motor from damage by overcurrent conditions, single phasing, or other abnormal conditions such as phase reversal or ground fault. It operates to trip the line contactor M.

The starting and field-discharge resistor (S/D 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 motor controller is designed to operate motors with less than 1,500 volts rms in the field during starting. The current flowing to the resistor is controlled by diode D1 and SCR Q4 (Fig. 4). Voltage feedback (VR on the synchronizing control board) provides information about the induced field voltage, frequency, and phase angle.

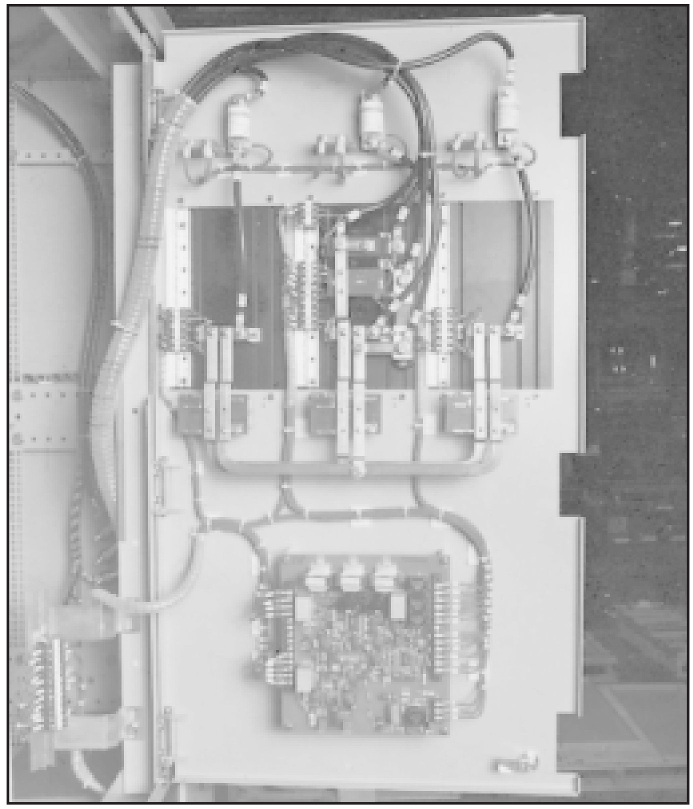

Fig. 2 Mark V Field Power Supply Panel

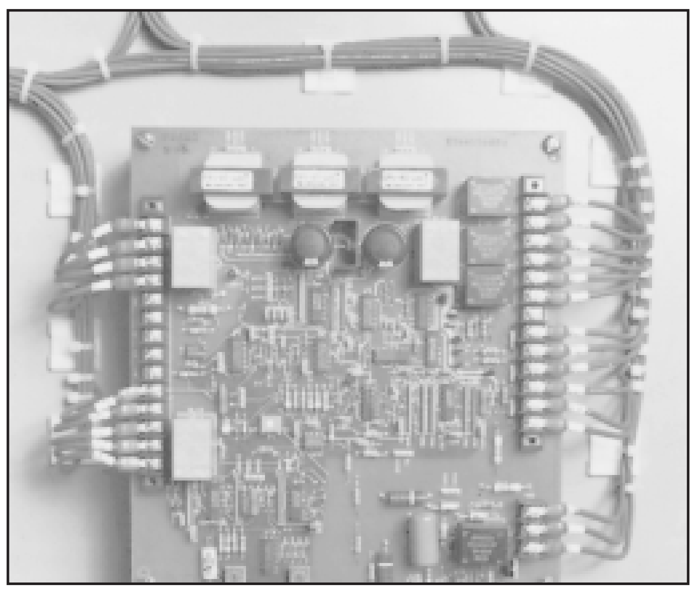

Fig. 3 Synchronizing Control Board

Mark V Controller Functions (Cont.)

The SCR field power supply QA1, QB1, QC1, QA2, QB2, and QC2 supplies voltage (125 or 250 VDC) and current to the motor field. The power supply comes in three sizes, 50, 100, or 200 amperes DC.

The printed circuit board provides gating signals for the starting and discharge circuit and protective functions as well as the SCR power supply.

The field power transformer must have either a 120 or 240 volt three-phase AC secondary. A 120 volt AC secondary is required for the 125 VDC system. A supply of 240 volts AC is required for the 250 VDC system. It may be connected wye or delta. Do not ground the system. The transformer is sized KVA = .17 x rated amps DC @ 125 volts DC or KVA = .34 x rated amps DC @ 250 volts DC.

Current transformers are furnished in the motor starter (controller) to supply current to protective relays and various meters in direct proportion to the line current.

CONTROLLER OPERATION

Figure 4 shows the field power supply controller in conjunction with the motor controller for a synchronous motor starter. Note that the connection to the field supply transformer is between the contactor (M) and the IQ component so that the current transformers sense motor stator current only.

The field power supply controller consists of three types of circuits, one each dedicated to (1) field power, (2) control, and (3) motor starting. The six thyristors (SCR's), QA1 through QC2, 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 line contactor (M). This results in the motor stator and the solid-state field power supply being energized.

On start-up, three-phase voltage signals are supplied to terminals KA2, KB2, and KC2. The open-fuse detection circuit requires about 100 milliseconds to determine that all voltages are present. It then causes RLY1 to close the circuit between terminals ST1 and ST2 on TB1 (Figure 5). 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.

RLY1 and RLY3 may pulse open and closed during certain types of faults causing the interposing relay "MX" to drop out, insuring that the "M" contactor has dropped out. SYTR remains energized until "M" drops out.

The motor starter, being energized, causes the motor field to generate an output voltage at the instantaneous slip frequency of the motor. This voltage is controlled by the independently operating thyristor-controlled starting circuit D1-Q4.

The voltage across the field starting and discharge resistor (S/D RES) is monitored during the starting sequence to determine the instantaneous slip of the motor. A motor slip condition of less than 75% (more than 25% speed) must be reached within the preset time (rotary switch SW2), 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 (0-9%), the gate drives to the field power supply thyristors activate and the soft turn-on circuit begins to apply DC voltage to the motor field. If the motor does not synchronize, Q4 is gated on. At the same time gating to QA1 - QC2 is inhibited until Q4 stops conducting.

Once again QA1-QC2 is gated on, applying voltage to the motor field. This process is repeated until the motor synchronizes or until a fixed time in the range of 2.5 to 3.5 seconds elapses.

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 failure to synchronize.

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). See **OPTIONS** on Page 6.

When motor synchronization is being established, the 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 QA1-QC2.

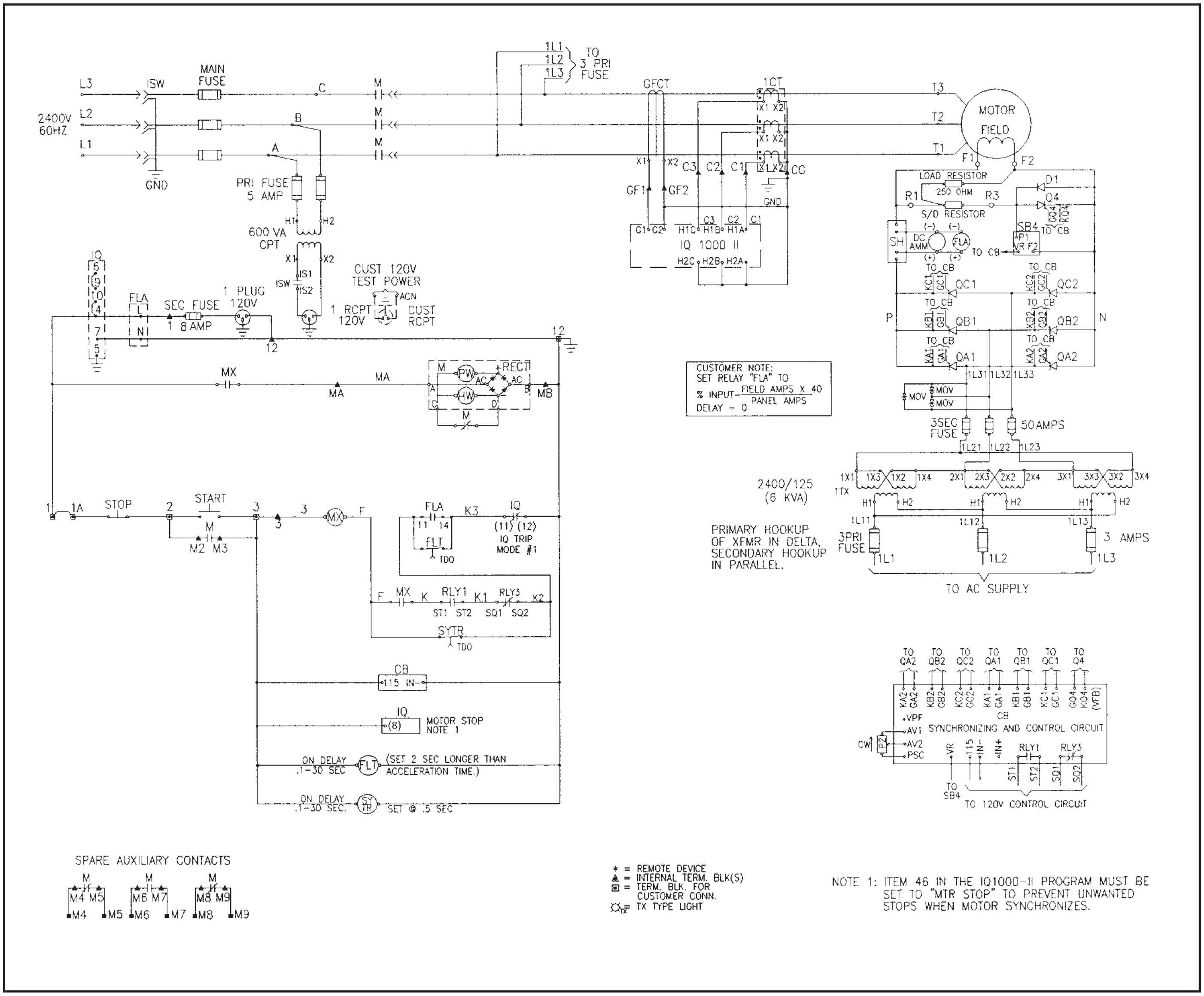

Fig. 4 Mark V Controller Schematic

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 circuit board. See Figure 5. Full voltage control is achieved by the addition of a potentiometer (P2), 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.

When the motor is running at rated speed and the line contactor (M) opens, the gating must be inhibited to SCRs QA1 to QC2. To do this, voltage is removed from terminal 115 and IN-.

If gating is not inhibited, the <u>motor</u> will continue to supply excitation voltage until it slows to about 50% speed.

OPTIONS

Each of the six variations rated by field supply 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 5 and Table II.

Supply Frequency

The synchronizing and control circuit board may be operated from either a 50 or 60 hertz power supply. To operate from a 60 hertz power supply add three jumpers to the 60 hertz terminals located near RLY1 and one jumper to the 60 hertz terminal located near RLY3. See Figure 5 and Table II.

To operate from a 50 hertz supply remove all four jumpers from the 60 hertz terminals and add a single jumper to the 50 hertz terminal located near RLY3. See Figure 5 and Table II.

110/120 VAC Operation

To operate the synchronizing and control circuit board from a 110 or 120 VAC supply, add six jumpers to the120V terminals located above T1, T2, and T3 and two jumpers to the 120V terminals located near T4. Remove the jumper from the 240V terminal located with TO terminal near T4. See Figure 5 and Table II. (Jumpers are factory installed, when supplied as part of a complete motor starter.)

220/240 VAC Operation

To operate the synchronizing and control circuit board from a 220 or 240 VAC supply, add three jumpers to the 240V terminals above T1, T2, and T3 and one terminal to the 240V terminal located with the TO terminal near T4. Remove jumpers from the two 120V terminals located near T4. See Figure 5 and Table II.

ADJUSTING THE MOTOR FIELD VOLTAGE

To adjust the motor field voltage, use the external 2000 ohm potentiometer (P2) shown in Figure 4.

POWER FACTOR, VAR OR DC FIELD CURRENT CONTROL (OPTION)

When this option is included, a two-position selector switch marked AUTO-MAN (SS1) is furnished. On initial startup, place SS1 in the MAN (manual) position. I.B. 48009 explains the automatic operation and the connection of this additional control panel to terminals VPF and PSC on the synchronous control board (Figure 5).

INCOMPLETE SEQUENCE – TIME-OUT SHUTDOWN

To utilize the time-out (TO) option which will energize control relay RLY3, 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 circuit 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.

TABLE II — JUMPER INSTALLATION FOR OPTIONS

FUNCTION	TERMINAL MARKING	PUT JUMPER AT TERMINALS	JUMPERS NEEDED TO ACTIVATE
Use a 50 Hertz Supply	50 HZ, 60 HZ	50 HZ	1
	60 HZ, 60 HZ, 60 HZ	None	0
Use a 60 Hertz Supply	50 HZ, 60 HZ	60 HZ	1
	60 HZ, 60 HZ, 60 HZ	60 HZ, 60 HZ, 60 HZ	3
Use a 110 or 120 VAC Supply	240V, TO	None	0
	120 V, 120V	120 V, 120 V	2
	(3) 120 V, 240 V, 120 V	(3) 120 V, 120 V	6
Use a 220 or 240 VAC Supply	240 V, TO	240 V	1
	120 V, 120 V	None	0
	(3) 120 V, 240 V, 120 V	(3) 240 V	3
Time-Out Shutdown	240 V, TO	TO	1

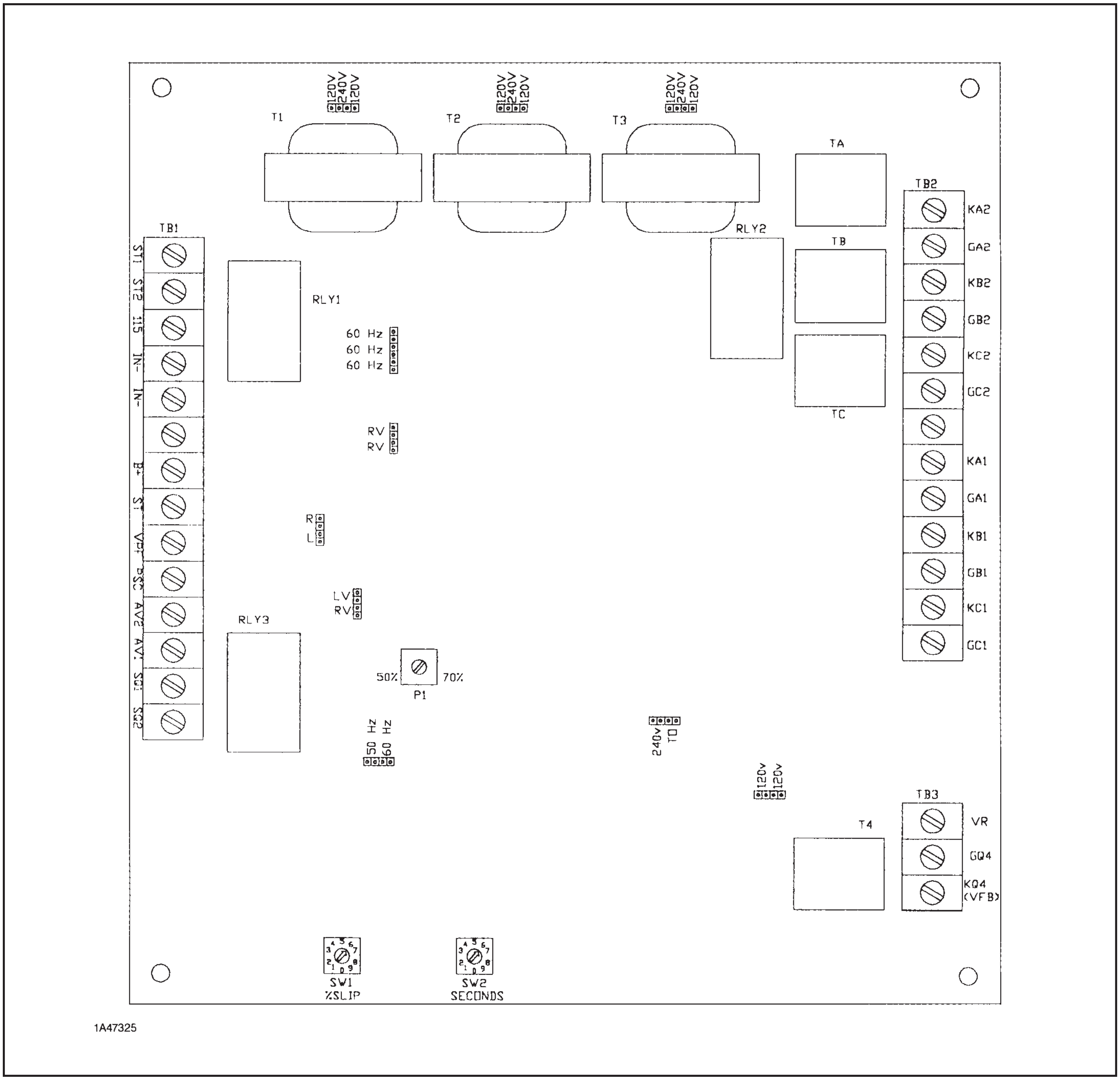

Fig. 5 Synchronous Control Board Layout

EXTERNAL INHIBIT

If the controller contains an autotransformer for reduced-voltage starting, DC voltage will not be applied until after transition to full voltage. Synchronization is blocked by withholding 115 VAC from terminals 115 and IN-. When voltage is applied to terminals 115 and IN-, the Mark V will go into the synchronizing mode.

SYSTEM PROTECTION

This controller includes circuits that provide a means of shutting down in the event of a stalled motor, excessive start time (time-out 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

SYSTEM PROTECTION (Continued)

circuit. These contacts are available at terminals SQ1 and SQ2 of Terminal Board 1 (TB1). See Figure 6.

RLY1 (see Figure 6) becomes energized about 50 milliseconds after power is delivered to the printed circuit board and proper operational status of the controller is established. RLY1 and its associated Light Emitting Diode (LED1) 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.

START WINDING PROTECTION

The most critical protection for synchronous motors is that for the windings used to start the motors. These windings are short-time rated for starting duty only and are most vulnerable under locked-rotor conditions. Optimum protection provides for stall protection while still permitting slip protection. Squirrel-cage bar protection is required on motor start-up while ensuring that proper sequential synchronizing occurs and that motors will operate continuously in synchronism. The protection system must detect and operate for a condition of prolonged subsynchronous operation beyond the thermal capability of the starting windings. See Figure 7.

Once synchronous motors have been initially and successfully synchronized, loss of synchronism or pullout is detected by the presence of induced slip current or AC 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.

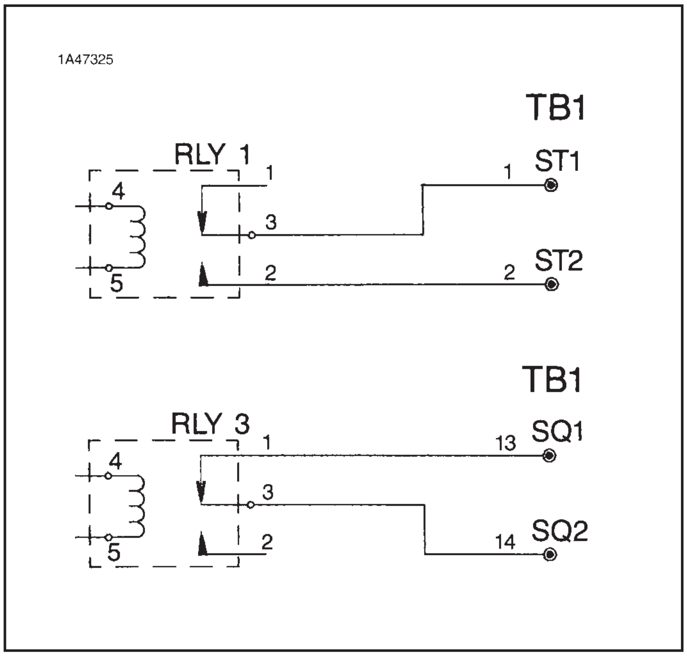

Fig. 6 Control Relay Terminals

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 capabilities 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 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 that 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.

Additional hazards for synchronous motors are jogging, too frequent starting, stalling and excessive accelerating times. Any of these conditions are serious hazards to start windings. Even the best protective system may not protect under such extreme operating conditions.

AUTOTRANSFORMER STARTER OPERATION

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. When the controller is used in conjunction with a reduced-voltage motor controller, the gating is inhibited until full voltage is applied to the motor. This is done by not applying 115 volts to terminal 115 and IN- on the circuit board, until motor is at full voltage.

The field excitation must not be applied until an autotransformer starter has been sequenced to full voltage. If the field is applied before the starter has transitioned to full voltage, a high current will result from the voltage unbalance condition, and may cause physical damage.

START-UP PROCEDURE FOR AMPGARD LINE-UP

Prior to start-up, verify a proper line-up installation, one that is undamaged, free of skids, eyebolts, lifting angles, debris, and all foreign material, one that is level and securely mounted and properly wired. Confirm each starter compatability with motor voltage, HP, and FLA. Check the torque tightness of all connections. Study all applicable instruction material and diagrams. Have available the schematic and connection diagrams furnished with the following equipment:

1. Dielectric (Hi-pot) tester capable of delivering 40 milliamps at 16 kVAC or 23 kVDC.
2. Multimeter to measure ohms and DC volts.
3. Meg-ohm meter (Megger) capable of producing 2500 volts.

Safety Check

Verify that the primary (medium-voltage) sources of power to the Ampgard bus system are disconnected and locked out.

Fuse and Contactor Check

1. Remove power circuit fuses and contactor from each enclosure.
2. Remove control transformer primary fuses from each contactor.
3. Use ohmmeter to verify continuity of fuses.
4. Check contactor and Hi-pot 16 kVAC or 23 kVDC across each bottle for 1 minute. 5ma leakage is failure.

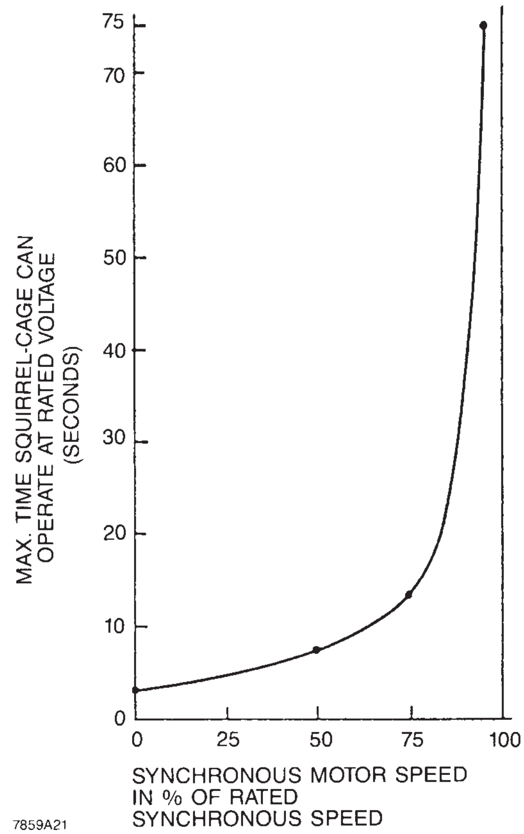

Fig. 7 Thermal Capacity of a Typical Synchronous Motor Start Winding

Bus System Check

With the contactors and power circuit fuses removed, prepare the line-up for a megger test:

1. Close each isolating switch.
2. Disconnect metering taps, capacitors, arrestors and any other equipment connected to the bus bar system.
3. Then measure and record the megohm resistance between phases of the bus bar system and between each phase and ground. Track down and correct any source of a low reading.

Synchronous Motor Check

Each Mark V synchronous motor controller has a terminal strip consisting of seven studs on standoff insulators mounted on a subpanel and labeled as shown in Figure 8. Disconnect leads from these stabs as necessary to conduct the following tests:

1. With the motor slip rings clean and brushes down (in operating position) measure and record the cold motor field resistance between F1 and F2. Calculate the field resistance by dividing the nameplate field voltage by the nameplate field current. The measured ohms should be between 70 and 80 percent of calculated ohms. If the measured resistance at the terminal strip (F1 and F2) is more than 80 percent of calculated resistance measure the field resistance at the motor slip rings. This latter reading should be less than the previous reading. If resistance readings are still high determine cause.
2. With the motor field disconnected verify that the resistance between F1 and F2 on the terminal strip is 250 ohms, $\pm$ 15 ohms.
3. Measure the resistance of the starting and discharge resistor (S/D RES on schematic diagram, Figure 4) at terminals R1 to R3 on the terminal strip (Figure 8). The measured value should be as shown on the diagram accompanying the order. Measure the resistance between terminals VR and KA1 on the synchronous control board (CB). The reading should be 50 ohms + R1-R3 value.
4. Reconnect all leads.

Controller Check

1. Verify that the jumpers required for the installation are properly installed. See Table II.
2. Read the ampere ratings of the three fuses supplied on the secondary side of the transformers providing power to the solid-state controller.

   These fuse ratings are equal to the ampere rating of the field power supply.
3. Verify the dial setting of the FLA relay located adjacent to the synchronous control board (Fig. 3). This dial setting should equal 40% of the motor nameplate field current divided by the ampere rating of the field power supply.

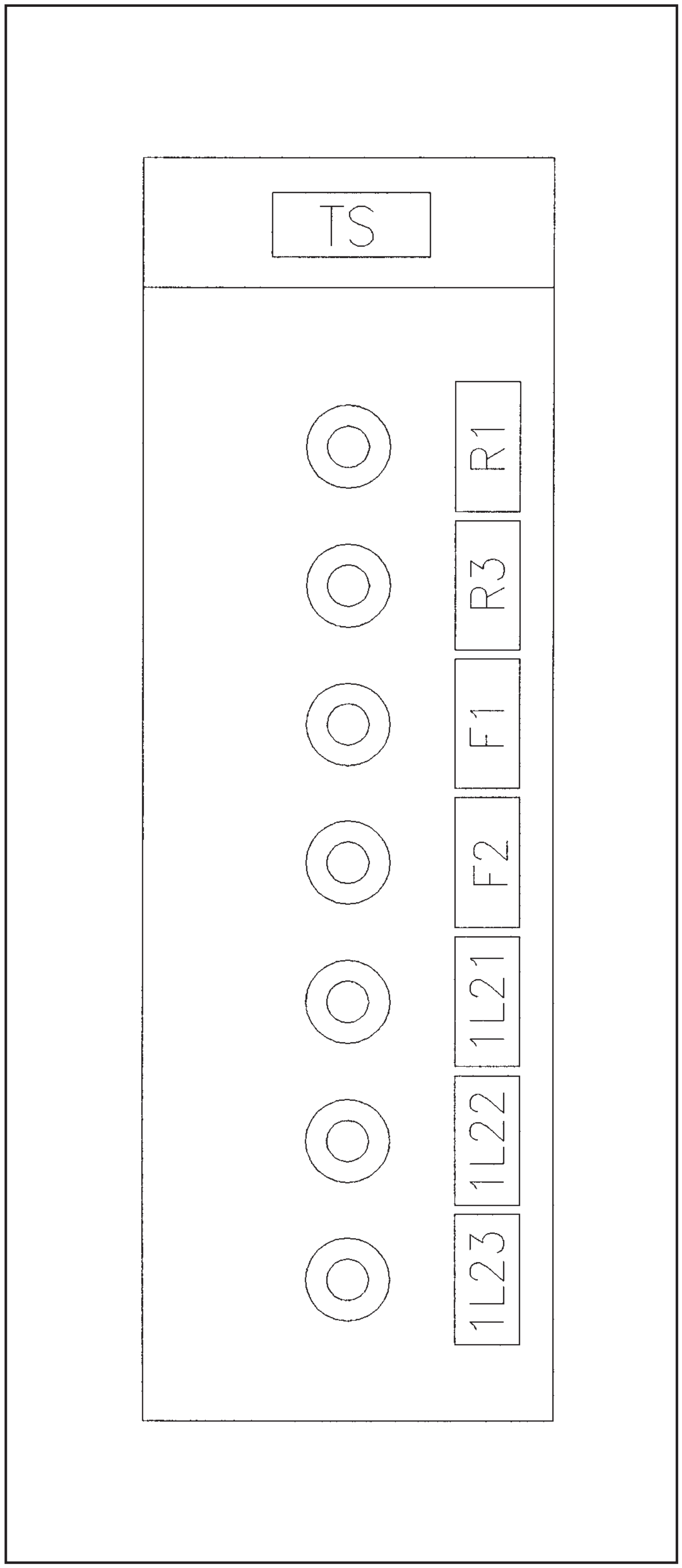

Fig. 8 Cubicle Terminal Strip

Static Field Test

Verify the field supply output without energizing the motor as follows:

1. Install contactor and all fuses.
2. Connect the motor field leads to terminals F1 and F2.
3. Disconnect the motor stator leads from the starter load terminals and isolate them from ground, each other, and any live parts.
4. Close and latch all enclosure doors except that necessary to monitor voltage at F1 to F2, have access to potentiometer P1 on CB (See Figure 6) and read field current on the panel ammeter provided.
5. Notify personnel that the motor field is about to be energized.
6. With power available on the Ampgard bus system, close the controller isolating switch and close the line contactor (M).
7. **Plan to keep the motor field energized with the motor still for not more than two minutes! Motor field windings may be damaged if energized for more than two minutes with motor not rotating.**
8. Since there is no induced AC voltage on the motor rotor a DC field voltage will appear at terminals F1-F2 as the motor field is energized. With potentiometer P2 at full counter clockwise (CCW) position, adjust potentiometer P1 to give 50% of nameplate field voltage as measured at F1-F2. With P1 set, adjust P2 to obtain full-load field current as read on the panel meter.

Full Operation

1. Open isolating switch.
2. Reconnect motor leads.
3. Close and latch all doors.
4. Close isolating switch.
5. Start motor.

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Cutler-Hammer
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Arden, NC 28704

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