GENERAL DESCRIPTION OF OPERATION

THE SPEEDPAK R-G

The Speedpak Regenerative (R-G) drive is a static, all-electric adjustable speed drive operating directly from AC plant power and providing controlled DC power to a drive motor, as directed by feedback elements, to maintain a precise speed, torque, or other controlled variable. The Speedpak R-G drive with a single set of armature rectifying elements is capable of contactorless reversing of the drive motor as well as full regenerative braking for overhauling loads.

The Speedpak R-G drive power unit for each drive motor consists of:

1. The armature rectifier package consisting of six (6) silicon controlled rectifiers (SCR's) to provide controlled DC power to the DC drive motor.

2. The regulator assembly controls the armature and field voltage and current for the drive motor. This regulator consists of etched circuit boards interconnected by means of industrial captive screw-type terminals and barrier-type terminal boards. The use of the module type of construction makes it possible to tailor the Speedpak R-G drive for the widest possible types of application. The etched boards slide into locating slides in an open frame of the regulator rack assembly. All interconnecting wiring is done at the front of this regulator panel. A built-in meter is provided, with an integral selector switch so that as many as 11 voltages can be measured within the regulator to facilitate set up and maintenance.

3. The motor field is supplied by an AC-to-DC push-pull SCR power unit.

4. The motor armature rectifying package, regulator and field supply is mounted on a subpanel together with the DC loop contactor and other necessary devices.

This entire power unit assembly is furnished in a NEMA 1A floor-mounted enclosure, arranged with filtered air louvers, to minimize environmental difficulties.

The power unit is suitable for installation in most factory areas where industrial equipment is installed. It should, however, be located in areas reasonably well ventilated and not subject to ambient temperatures above 104°F. If higher ambient temperatures are expected, check with the factory for specific instructions. These units should not be located in hazardous or explosive areas.

THE SPEEDPAK R-G (CONT.)

Each power unit is furnished with an isolation transformer to protect against inadvertent grounding of the customer's plant AC power due to any insulation breakdown or other failures that might possibly occur in the armature circuit. These transformers also provide electrical isolation between individual power units.

Isolation transformers are usually supplied in separate NEMA 1 enclosures. They can be mounted in any convenient location, either immediately adjacent to the power unit cabinets, or in remote areas such as balconies, building walls or other control rooms.

Isolation transformers used with power units for 5 H.P. or less may be furnished inside the power unit cabinet if space and conditions permit.

BASIC OPERATION

A typical Speedpak R-G drive is shown in Figure 1, which illustrates the circuits that make up the regulating system. The drive motor armature is connected to the armature rectifying package. The field of the drive motor is connected to the bi-directional field rectifier. The direction of rotation, the speed, and/or torque of the drive motor is controlled by the combined operation of the armature and field power regulators.

Connected mechanically to the DC drive motor is a DC tachometer generator. This tachometer generator produces an output voltage of a polarity dependent on the direction of the drive motor rotation, and the magnitude of which is proportional to the drive motor speed. The armature rectifying package provides a controlled DC voltage to the DC drive motor. The magnitude of this output voltage is dependent upon the input signal which the firing circuit receives from the current limit and logic module or Regenerative Drive Control board.

The current limit and logic module is a special controlling circuit which receives an input signal from the input operational amplifier and a feedback signal from the drive motor armature current.

The motor field amplifier and field firing board has a feedback signal proportional to the motor field current.

The system is a three-loop regulating system. The two inner loops are current regulators - one controlling motor armature current, the other controlling motor field current. These current controlled regulators provide the function of extremely accurate current limit and inherent stable operation from no load to maximum load.

GENERAL DESCRIPTION OF OPERATION

THE SPEEDPAK R-G (CONT.)

The outer loop is the speed regulating system which adjusts the reference to the inner current loops as necessary to maintain any preset speed within the torque capabilities set by the current limitation of the DC drive motor.

When the tachometer feedback signal becomes greater than the reference signal as the input to the first operational amplifier, as the case will be with overhauling loads, the output of the operational amplifier supplied to the armature current limit and logic module and the field regulator and firing modules causes the motor field current to reverse, which reverses the drive motor armature voltage.

The second operational amplifier (armature current amplifier) receives a reference input from the current limit pot plus an armature current feedback input. Inverting and amplifying their difference, this amplifier regulates the input to the armature firing circuit. Due to the nature of the SCR firing circuits, this output must be negative if armature current is to flow. A positive output from this amplifier causes the SCR's to turn off.

The armature firing circuit produces and synchronizes firing pulses which fire the SCR's of the armature power unit. For a 3-phase drive, the firing pulses are 60 electrical degrees apart and are synchronized to the line by a 3 phase-isolated synchronizing transformer. The pulses are delivered to the SCR power unit through a diode logic circuit which is designed to fire two SCR's simultaneously and in the proper sequence so that a controlled DC voltage is delivered across the motor armature.

If the reference signal to the first operational amplifier is reversed, such as might be done to reverse motor rotation, the drive motor will regeneratively brake to rest, and re-accelerate to the same running speed in the opposite direction with the polarity of the tachometer feedback signal reversed. Removing the reference signal or reducing it to zero will cause the drive motor to regeneratively brake to zero speed.

As a result, when the load conditions are such that more or less motor torque is required, the tachometer coupled to the motor shaft will sense the minute speed change and, by means of feedback to the speed regulating outer loop, will provide a reference signal calling for the required increase or decrease in armature and field current. Thus, the motor torque required to maintain the precise speed, no-load to full-load motoring or regenerating, is provided by this regulating system. This feature of combined armature and field current regulation is unique and makes the operation of the Speedpak R-G drive superior in both speed and torque control.

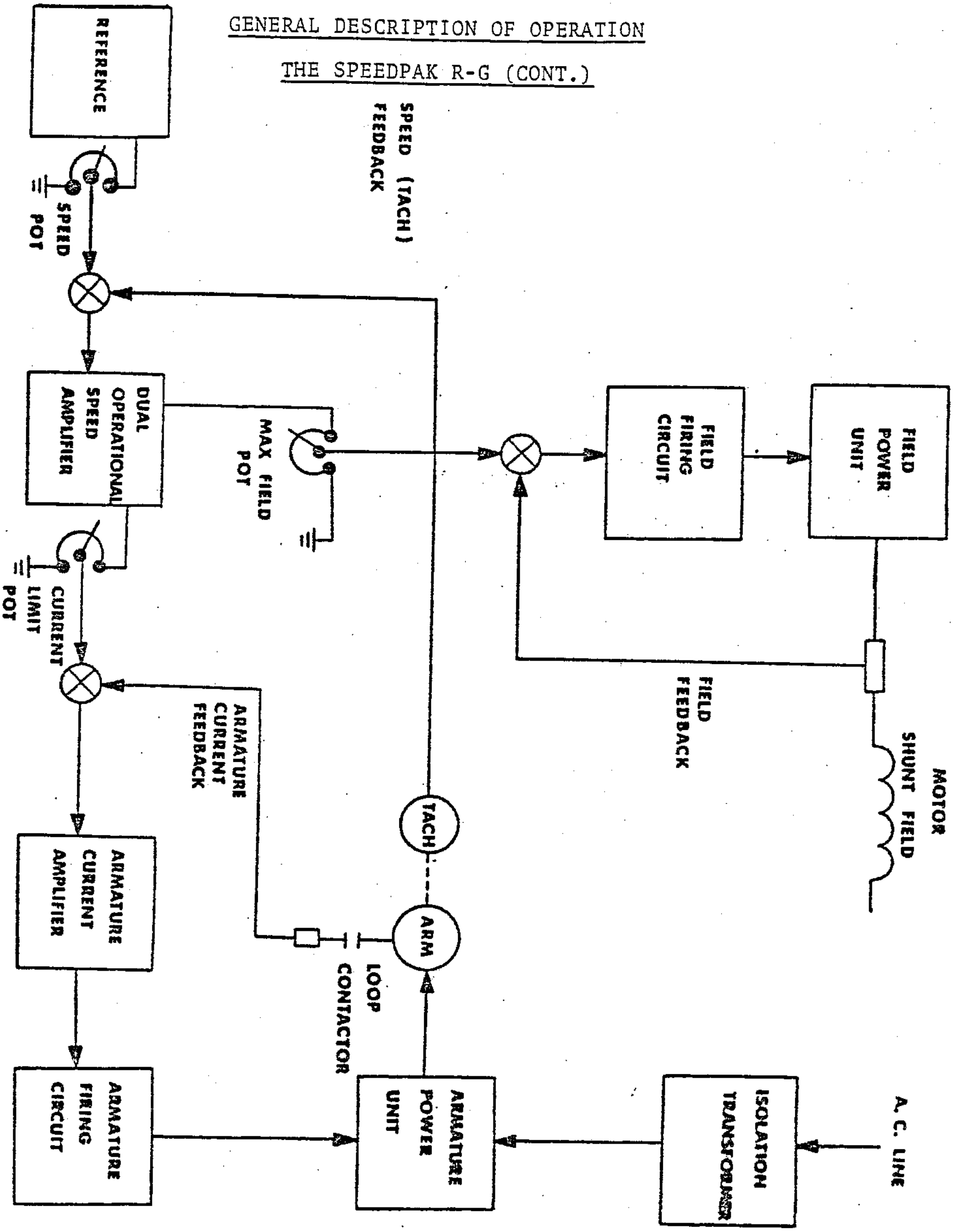
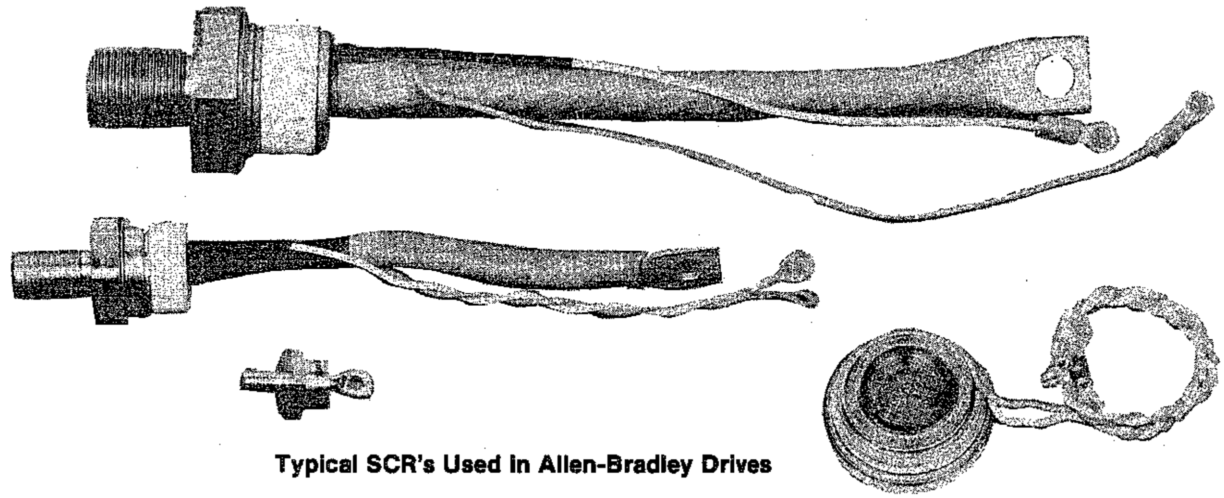


Figure 1. Typical Regenerative Drive System

SILICON CONTROLLED RECTIFIER (SCR) DESCRIPTION



Typical SCR's Used In Allen-Bradley Drives

FUNCTION

An SCR (or Thyristor) is a solid-state-device for controlled rectification of AC to DC. When used either singly or in various bridge circuits, the SCR can precisely control large amounts of power with only small control signals; hence it can be thought of as a power amplifier.

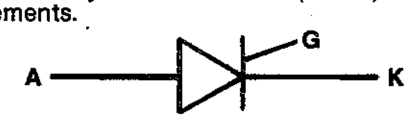
The advantages of SCR's in comparison with other devices are as follows: (1) conduct large currents at high voltages; (2) switch in microseconds; (3) small size and low weight; (4) long life, reliable, maintenance-free; and (5) require only small control currents.

CONSTRUCTION

The SCR consists physically of three elements:

1. An anode (symbol A, + connection)
2. A cathode (symbol K, - connection)
3. A gate (symbol G, control operation)

The schematic symbol for an SCR (below) shows these three elements.



In the three SCR's on the left-hand side of the photograph, the threaded stud is connected to the anode, and the heavy long lead in the bottom two is connected to the cathode. In the top two units the shorter (white) wire is the gate lead and the other small wire (red) is the gate circuit return (to the cathode).

In the disc-type unit in the lower right-hand side of the photo (often called a "hockey puck SCR") the top flat surface is the anode, an identical flat surface on the bottom is the cathode, and the two wires protruding from the right are the gate and gate return leads (a symbol on the rim edge of the SCR identifies which surface is the anode and which is the cathode).

In order to safely conduct the large maximum currents for which they are rated, SCR's are mounted in heat sinks, which range from simple finned structures (into which the SCR stud is screwed) that dissipate heat by radiation into the surrounding ambient, to larger fan-cooled, water-cooled, or heat exchanger assemblies. The amount of torque applied when screwing down the SCR into the heat sink, and the use of thermal-conducting grease between SCR and heat sink is critical for some SCR's.

Disc-type SCR's are mounted in a clamping type heat sink that also applies a controlled and evenly distributed pressure to the two discs, which is necessary for their operation since the elements are physically separated inside the device until such pressure is applied.

OPERATION

An SCR that has voltage applied to its anode and cathode is in one of three possible states:

1. Blocking forward (+ to -) current
2. Blocking reverse (- to +) current
3. Conducting forward current but blocking reverse current

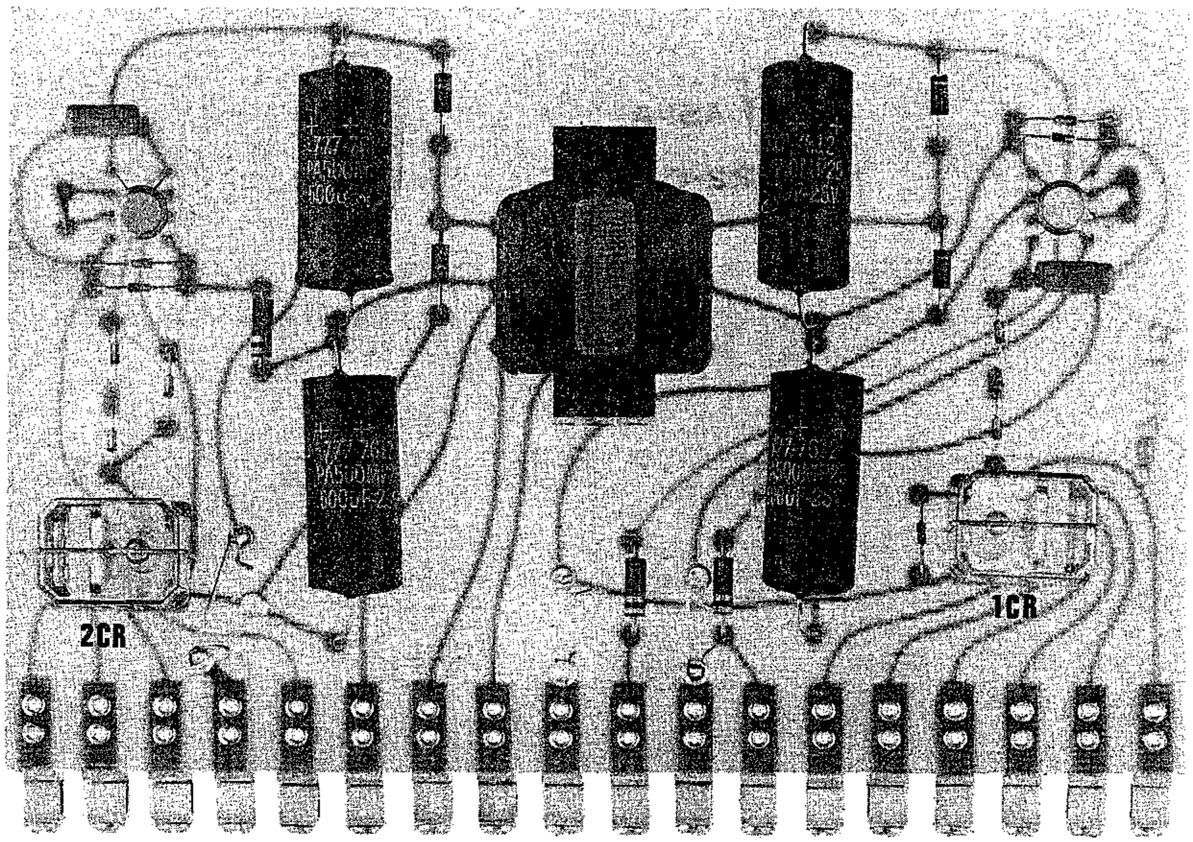
The latter state is, of course, the normal state of an ordinary diode, and permits either a diode or SCR to rectify AC — current will flow through the device during the positive half of the AC wave but will be blocked during the negative half cycle. The advantage of the SCR is that it can be rapidly switched into this forward-conducting state at will, but will not conduct (in either direction) until switching occurs.

The SCR is switched into its forward-conducting state by **momentarily** applying a + voltage to its gate (+ with respect to its cathode). The switching voltage, or gating signal, need be applied for only a very short time (in the order of 5 microseconds) in order to switch the SCR into conduction; once turned on, the SCR continues to conduct after removal of the gate signal.

Internally the SCR is constructed of two layers each of P-type silicon and N-type silicon which are alternately arranged (P-N-P-N). The region where a P and N layer are joined forms a P-N junction, and in the SCR there are three such junctions (the transistor has two P-N junctions and the diode has one). A P-N junction conducts current only when it is forward biased, which means that a + voltage must be applied to its P-type side and a - voltage to its N-type side (the opposite case is called reverse biased). When no gate signal is applied to an SCR, at least one of its P-N junctions is reverse biased and no current can flow. When a gate signal is applied, however, all three P-N junctions are forward biased and current flows (in the forward direction only).

TRANSISTORIZED RELAY

Part Number 12M3-00022-02



FUNCTION

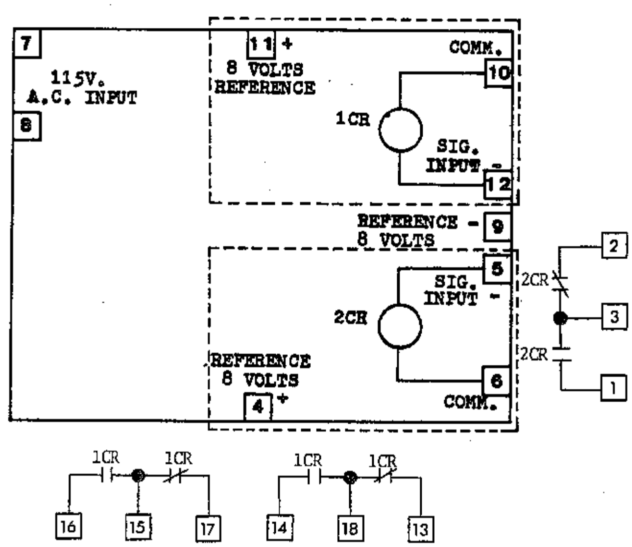
This printed circuit board contains two transistorized relay circuits, with individual low-voltage power supplies, each of which can be mechanized as a zero speed sensor (PICK-UP circuit), overspeed sensor, tachometer loss detector, field loss protection relay, etc.

A current of only 10 microamps is required to actuate these relays. Normally they are activated when a signal of negative polarity is applied to their signal input terminal, but they can be energized with a positive polarity signal with appropriate biasing.

Note that the 1CR and 2CR relays, and their respective power supplies, are completely isolated from each other, as indicated by the dashed lines in the block diagram.

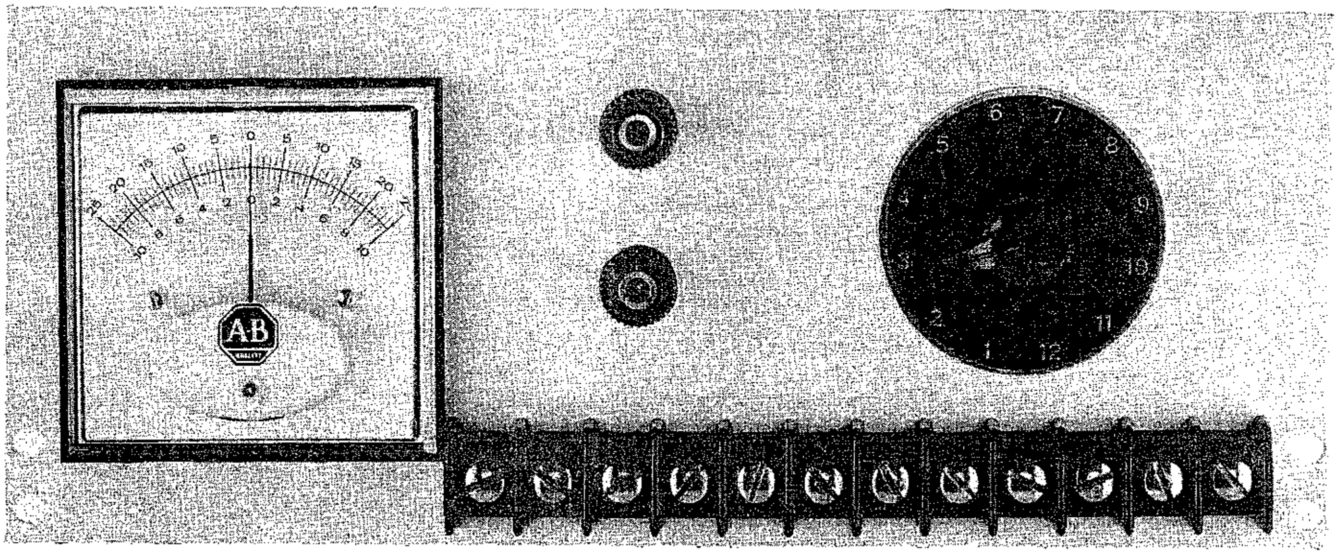
As shown, 1CR has 2 N.O. contacts and 2 N.C. contacts, while 2CR has only 1 set of N.O. and 1 set of N.C. contacts. In addition to the relay functions provided by the board, terminals 4 and 9 (or 11 and 9) can be used as a low current (4 ma) source of +8V DC.

TERMINAL CONNECTIONS



CIRCUIT CHECKER ASSEMBLY

Part Number 12M3-00028-00



FUNCTION

The purpose of the Circuit Checker is to provide convenient monitoring of up to 11 drive signals (plus drive common). A multi-range, zero-center meter is connected to the appropriate scaling resistors and connection points in the drive via a 12-position selector switch.

Rotating the selector to any of the 12 positions connects the meter to the corresponding test point in the drive. The test points are indicated on the drive schematic diagrams as small hexagons with the test point number within the hexagon. The schematic also has a Circuit Checker table showing Test Point Number, Full-Scale Voltage (of the meter), and Maximum Voltage to be expected at that test point.

METER SCALES

The meter needle deflects to the left for negative polarity signals and to the right for positive polarity signals. The bottom scale of the meter is read for signals up to +10 volts, and the top scale indicates +2.5, +25, or +250 volts (whichever Full-Scale Voltage is shown in the Circuit Checker table).

If a Circuit Checker is supplied, Test Points 3 through 8 are usually "standard," and monitor the following:

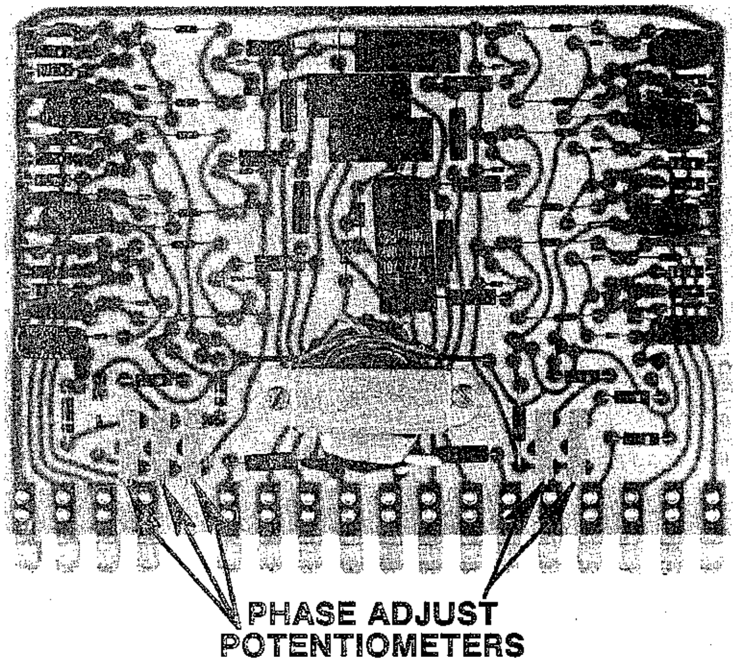
Test Point	Signal
3	Armature counter-emf voltage feedback (VR drives), or tachometer feedback voltage (SR drives)
4	Output of Speed or Torque Amplifier
5	Inversion of Test Point 4
6	Field current feedback voltage
7	Armature current regulating amplifier output
8	Armature current feedback voltage

The remaining test points are unique to each individual drive. Typically, Test Points 1 and 2 are used to monitor the output of the reference voltage source or speed potentiometers and the output of the linear acceleration/deceleration circuit, while Test Point 9 is frequently the output of the Crossover Circuit.

Use of the Circuit Checker in troubleshooting enables rapid isolation of faults to one or two possible circuit boards. 5-way binding posts on the Checker are connected in parallel with the meter for connecting an oscilloscope or other test equipment.

SIX-PULSE FIRING CIRCUIT

Part Number 12M3-00063-00



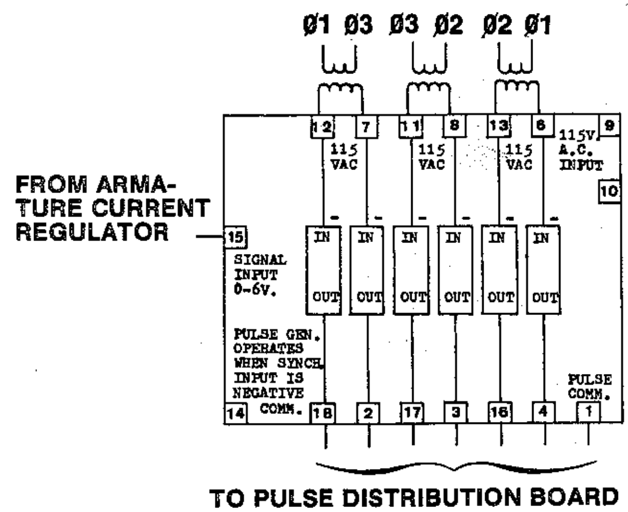
FUNCTION

The Six-Pulse Firing Board generates SCR gating pulses to control the firing angle (time of conduction) of the armature power circuit SCR's. Six sets of pulses are generated, 60 electrical degrees apart, and are synchronized with the three-phase power line by a transformer connected across each phase of the line, the secondary of which is connected to terminals 12 and 7, 11 and 8, or 13 and 6. The outputs of the board at terminals 2, 3, 4, 16, 17, 18, and common terminal 1 are connected to corresponding inputs on the Pulse Distribution Board and result in full-wave rectified, three-phase armature voltage that is controlled in magnitude by the output of the Armature Current Regulator.

OPERATION

The input to the board (at terminal 15) is the output of the armature current regulator, which varies from 0 to -6.8V DC. The point during each phase of the AC cycle at which pulse generators will fire is dependent upon the magnitude of this input voltage: a low voltage causes the generators to fire late in the cycle (small conduction angle, little armature voltage produced), while a larger voltage causes the generators to fire earlier in the cycle (large conduction angle, higher armature voltage).

Synchronization of firing pulses is accomplished as follows. As shown in the block diagram, the pulse generators are connected in pairs to the secondaries of the synchronizing transformers. The pulse generator of each pair that is connected to a negative voltage will fire. Hence, if the left side of the Ø1 transformer is -, the pulse generator connected to terminal 12 will fire and the generator at terminal 7 will not fire since the side of the transformer connected to it is then +. A half cycle later, the transformer reverses polarity and the pulse generator at terminal 7 fires and the one at terminal 12 shuts off. The same action occurs with the other pairs of pulse generators (connected to the Ø2 and Ø3 transformer secondaries), but the outputs of each pair of pulse generators is displaced 120 electrical degrees with respect to each other pair.



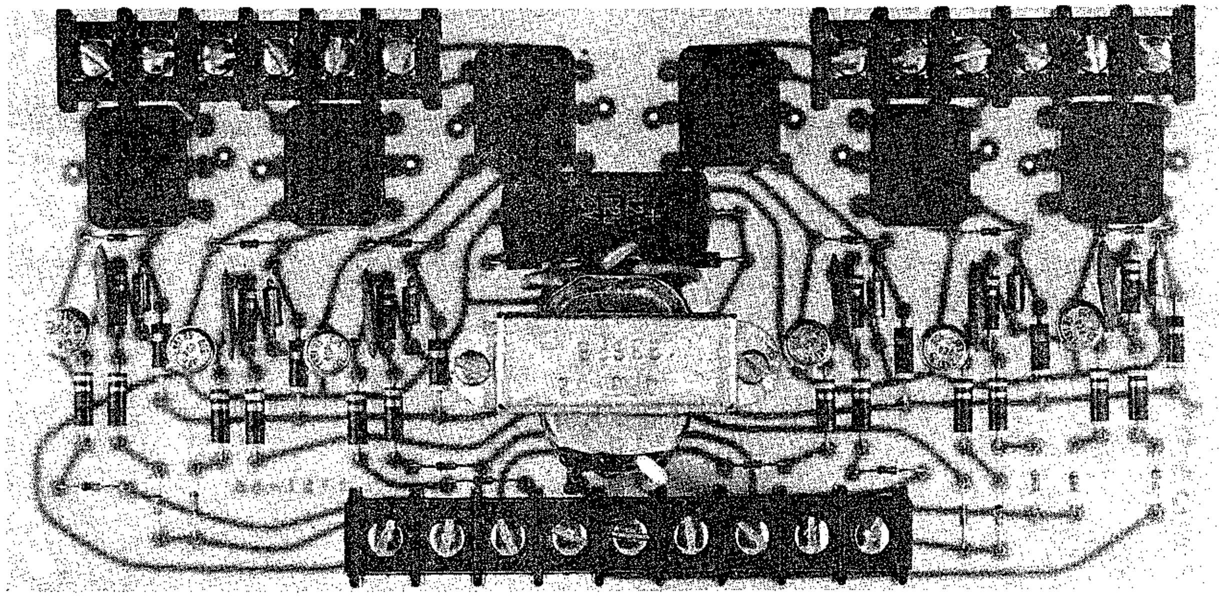
The table below summarizes this situation.

Output Pulse at Terminal	Synchronizing Voltage to Fire Pulse Generator
2	12 positive with respect to 7
18	7 positive with respect to 12
3	11 positive with respect to 8
17	8 positive with respect to 11
4	13 positive with respect to 6
16	6 positive with respect to 13

The five potentiometers shown in the photograph permit adjusting the phase relationship of each pulse generator output with respect to the sixth, non-adjustable output pulse (this is done by connecting armature voltage to an oscilloscope and observing the height of the 6 SCR outputs while adjusting the pots; see Six-Pulse Firing Board Adjustment Procedure).

PULSE DISTRIBUTION AND AMPLIFIER BOARD

Part Number 12M3-00064-00



FUNCTION

The Pulse Distribution and Amplifier Board provides SCR gating pulses that are synchronized to the incoming three-phase line to produce controlled full-wave DC voltage for the motor armature. It consists of diode steering logic to fire pairs of SCR's appropriate to each phase, and six transistor amplifiers whose outputs are transformer-coupled to the SCR gate-cathode circuits. The output voltage varies from 2 to 12 volts, depending upon the gate impedances of the SCR's used.

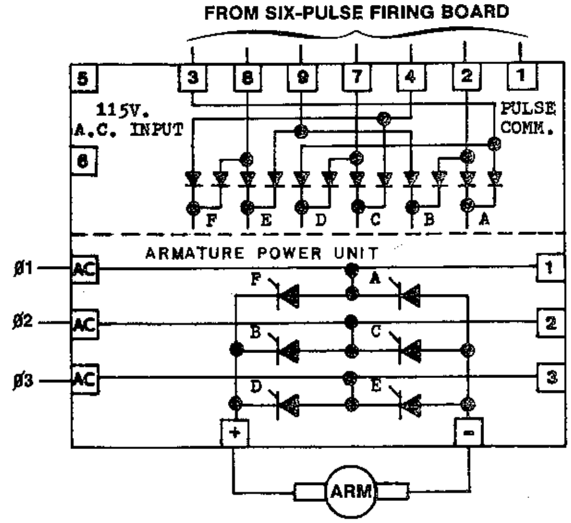
Pulse input terminals 2, 3, 4, 7, 8, 9, and common terminal 1 are connected directly to the corresponding output terminals of the Six-Pulse Firing Board. Each pair of pulse amplifier output terminals (10 through 21) is connected to the gate-cathode circuit of an SCR in the Armature Power Unit.

OPERATION

Referring to the block diagram, the relationship of input pulses to the SCR's that are gated is as follows:

Input Pulse at Terminal	SCR's Fired
2	A and B
3	A and D
4	C and F
7	C and D
8	E and F
9	E and B

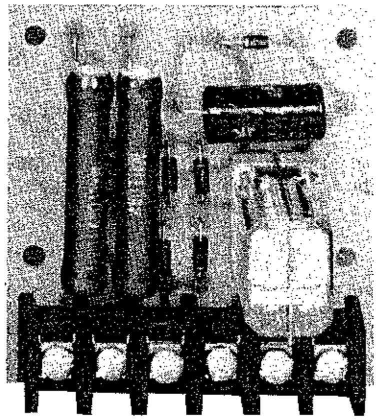
As mentioned above, the firing pulses are synchronized to the incoming three-phase line (Ø1, Ø2, and Ø3, in the diagram). To illustrate this, assume a firing pulse at terminal 4, and that at that instant Ø1 is positive with respect to Ø2. Then (assuming conventional current flow) power will flow from the Ø1 line, through SCR F, to the + terminal of the Armature Power Unit, through the motor armature, back to the - terminal of the Armature



Power Unit, through SCR C, and to the Ø2 line. During the second half of the AC cycle, there will be a firing pulse at terminal 2 (since the pulse generators on the Six-Pulse Firing Board that are connected to terminals 4 and 2 of the Pulse Distribution Board are activated by opposite ends of a synchronizing transformer secondary). The Ø2 line will be positive with respect to Ø1 at this time, and power will flow from the Ø2 line, through SCR B, through the + terminal of the Armature Power Unit and through the motor armature, back to the - terminal of the Armature Power Unit, and through SCR A to the Ø1 line. The same action takes place with input pulses at terminals 7 and 9 during the Ø2-Ø3 cycle, and for pulses at terminals 3 and 8 during the Ø1-Ø3 cycle, with the three cycles displaced from each other by 120 electrical degrees.

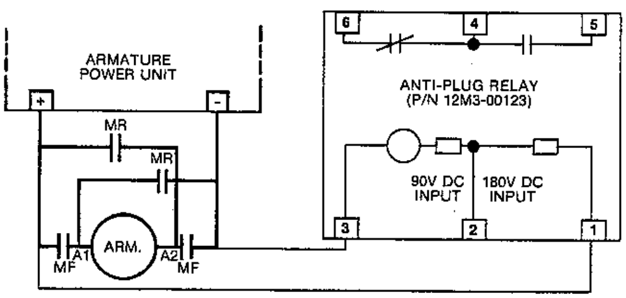
ANTI-PLUG RELAY BOARD

Part Number 12M3-00123-00



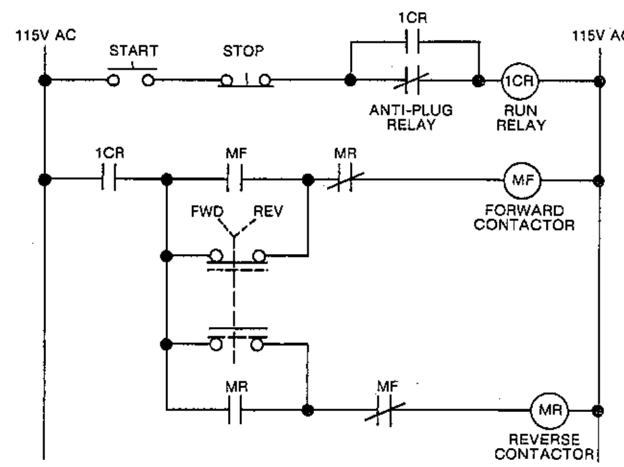
FUNCTION

The purpose of this small board (3" x 3") is to prevent "plugging" the armature of a motor that changes rotational direction by means of contactor reversing, as shown and described below. The application of reverse polarity voltage to the armature (to change direction) while the motor is still turning (and hence has a significant C.E.M.F.) is called plugging, and must not be allowed in order to prevent damage to the contactors and/or motor armature.



OPERATION

Forward operation results when Forward Contactor MF is energized, and conventional current flow through the armature is from the + terminal of the Armature Power Unit, through one set of MF contacts, to armature lead A1, through the armature to A2, and through another set of contacts of MF to the - terminal of the Armature Power Unit. Reverse operation occurs when Reverse Contactor MR is energized, and current flows from the + terminal of the Armature Power Unit, through one set of MR contacts to armature lead A2, through the armature to A1, and through the second set of MR contacts to the - terminal of the Armature Power Unit. Either MF or MR is energized, depending upon the position the FORWARD/REVERSE selector switch.



The Anti-Plug Relay board is connected across the motor armature, as shown above, and the armature voltage is rectified on the board and dropped to a suitable level to operate the Anti-Plug Relay, which has one set of N.O. and one set of N.C. contacts. Either or both sets of these relay contacts can be used in the drive control logic to interlock the forward and reverse contactors so that polarity reversal cannot take place until the motor has slowed to nearly a stop (armature voltage drops to a low level and the Anti-Plug Relay drops out). A typical logic scheme is shown below.

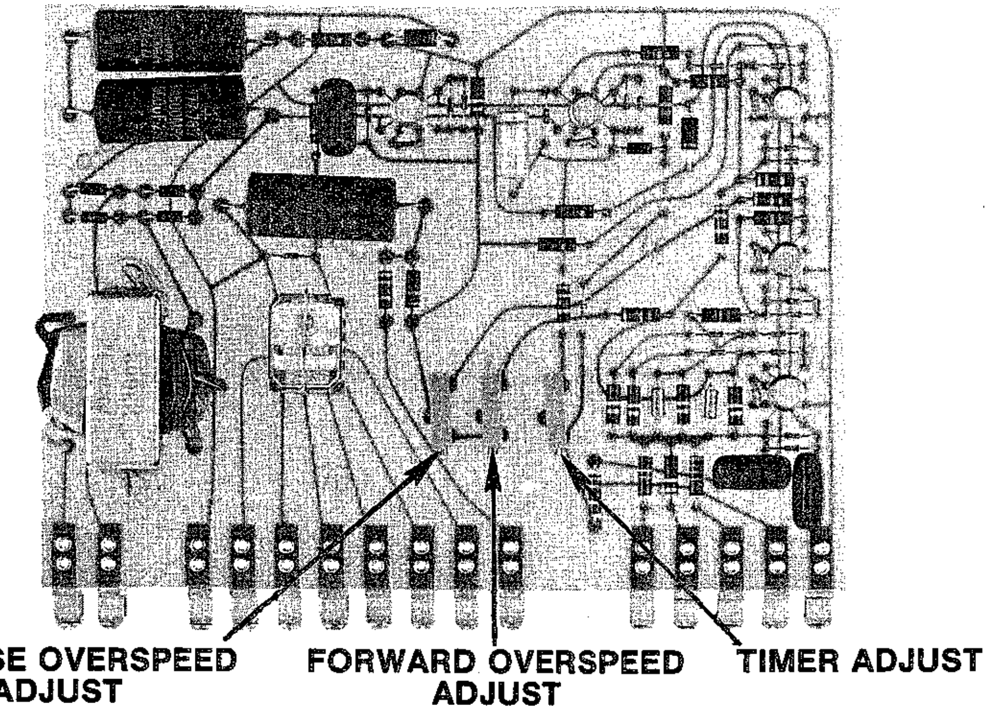
The N.C. contacts of the Anti-Plug Relay permit Run Relay 1CR to be energized only when no armature voltage is present. The Run relay seals itself in once it is picked up. A N.O. set of contacts of the Run Relay is in series with the FORWARD/REVERSE selector switch and supplies control power to it while the motor is running, but the Forward and Reverse Contactors are interlocked through N.C. contacts of each, and one contactor cannot be picked up until the other one drops out. In mechanizations without an anti-plug relay, the Run Relay could be picked up while the motor was coasting to a stop and polarity reversal (and plugging) could occur. With the above scheme, the Run Relay cannot be energized until armature voltage falls to a low level and the Anti-Plug Relay drops out.

ALLEN-BRADLEY
Cedarburg, Wisconsin 53012

Publication 5140-9.11 — August, 1977

TACH LOSS AND OVERSPEED DETECTOR

Part Number 12M3-00126-01



FUNCTION

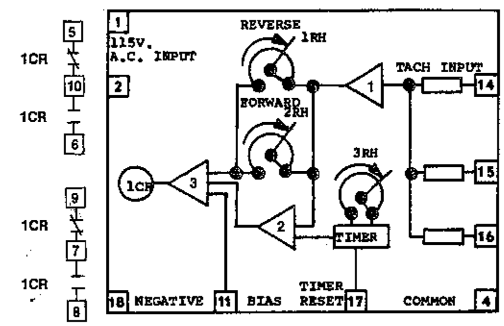
This printed circuit board can provide the following four functions:

1. Detect loss of DC Tachometer Generator feedback,
2. Detect overspeed during Inch or Jog modes,
3. Override the tach loss function for a preset timed interval (15 seconds maximum), in order to allow the drive motor to come up to speed before indicating a tach loss,
4. Override the tach loss function for 10 seconds to allow the drive motor to come to a regenerative stop without indicating a tach loss.

An absolute value circuit at the input to the board permits operation with a tachometer output of either polarity. The tach loss (or overspeed) indication and control output is the status of relay 1CR. This relay is energized whenever tach output voltage is present (or whenever the drive motor speed is below the preset overspeed for Inch or Jog mode operation). Typically one set of normally-open contacts of 1CR is included in the Drive Safeties Circuit (perhaps in series with the Run Relay), and one set of normally-closed contacts is wired in series with a "Tach Loss" indicating lamp. Hence, if tach output voltage is lost, 1CR de-energizes and the drive is shut down and the Tach Loss lamp illuminates.

OPERATION

The Tach Loss (and timer) function is obtained by connecting the tach generator ouput between Common terminal 4 and terminal 14, 15, or 16 (depending upon the output voltage level of the tachometer), connecting the Timer Reset (terminal 17) to Common through a relay contact, and connecting the board -10V DC (at terminal 18) to the Bias input (terminal 11). The output of Amplifier #1 is always positive, due to the absolute value circuit, the other two amplifiers are inverters, and the input 1CR must be a positive to energize the relay.

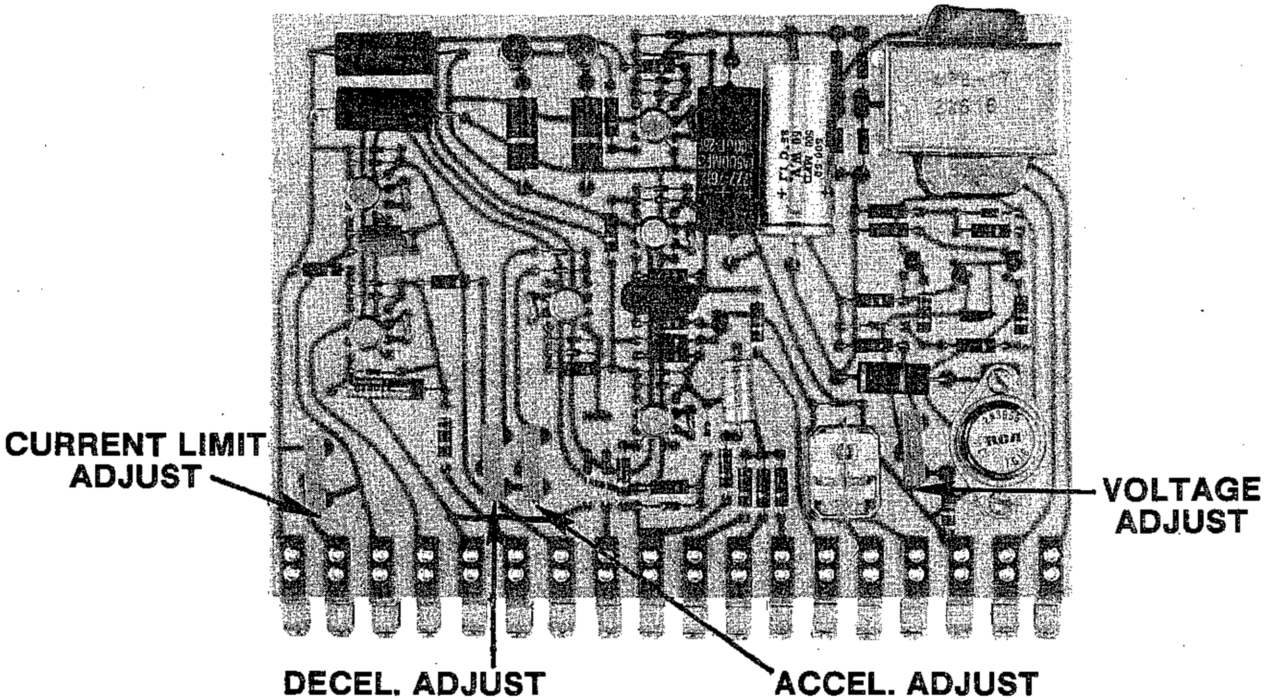


When a drive start is to be initiated, the timer is started by disconnecting it from common. The timer output is positive, which is inverted in Amplifier #2, and the negative output of this amplifier is again inverted in Amplifier #3, yielding a positive output and relay 1CR is picked up. After the timed interval, the timer output goes to zero and 1CR would drop out. But by this time the motor has come up to speed, and the tach voltage input at Amplifier #1 causes a positive output at Amplifier #1, which is applied to the input of Amplifier #2 and the relay stays energized. Amplifier #2 acts as an OR circuit, producing an output to energize 1CR if either the tach voltage (Amplifier #1) or the Timer is providing an input to it. To provide a regenerative stop from the Run mode, terminal 11 is open circuited when the stop is initiated. A built-in 10-second delay keeps 1CR held in to allow the motor to regenerate to zero speed without a tach loss indication.

To mechanize the Inch or Jog Overspeed function, terminal 11 is open circuited (by a relay contact), so that the output of Amplifier #1 controls Amplifier #3. If the tachometer speed is greater than the level set by Forward Overspeed pot 2RH or Reverse Overspeed pot 1RH, the positive input to Amplifier #3 will cause its output to go negative, dropping out 1CR to shut down the drive and signal an overspeed condition.

VR CONTROL BOARD

Part Number 12M3-00165-00

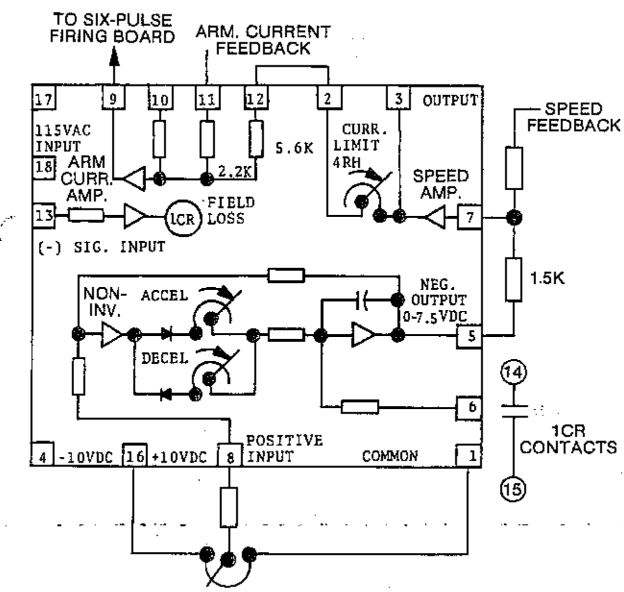


FUNCTION

The VR Control Board is a complete armature current regulator for a three-phase, non-regenerative drive. It includes an Acceleration/Deceleration circuit, a Speed Amplifier, Current Limit Pot, Armature Current Regulating Amplifier, and a Field Loss Relay. The acceleration and deceleration times (adjustable by means of the pots shown in the photo) are from 5 to approximately 70 seconds. The Speed Amplifier requires less than 0.1 microampere error signal input to produce full output, and maintains regulation of 0.1% from no load when a summing junction current of 5 milliamperes is employed. The Current Limit Potentiometer adjusts the maximum output of the armature current amplifier from 0 to -6.5V DC. This output goes to the Six-Pulse Firing Board, which controls the magnitude of armature voltage by varying the conduction angles of the armature power loop SCR's.

OPERATION

As shown in the block diagram, the positive polarity speed reference voltage input required by the accel/decel circuit (at terminal 8) is obtained from the board power supply (terminal 16). This circuit converts the step current input to a ramp voltage output (at terminal 5). The ramping output avoids abrupt changes in armature current, and results in the motor smoothly accelerating (or decelerating) to the new speed when a speed change is commanded. Terminal 5 is connected to terminal 7 through a 1.5K resistor (maximum current of 5 ma at input of Speed Amplifier). The speed feedback signal is summed with the output of the accel/decel circuit at the input of the Speed Amplifier (terminal 7). Though not shown in the diagram, there is also a rate network (Stability Pot + capacitor) between the input of this amplifier and its output (at terminal 3), and also a relay contact to clamp the output to zero when the motor comes to a stop.



The Speed Amplifier output (Armature Current Reference signal), limited by pot 4RH, is connected to the input of the Armature Current Amplifier by a jumper between terminal 2 and terminal 12. Terminal 11 accepts the (negative polarity) armature current feedback signal, which is summed with the positive Armature Current Reference. Terminal 10 is for clamping the Armature Current Amplifier output to zero after a stop. The negative polarity output of the Armature Current Amplifier (at terminal 9) is routed to the pulse generators on the Six-Pulse Firing Board, which gate appropriate SCR's in the armature power loop to regulate the magnitude of armature voltage.

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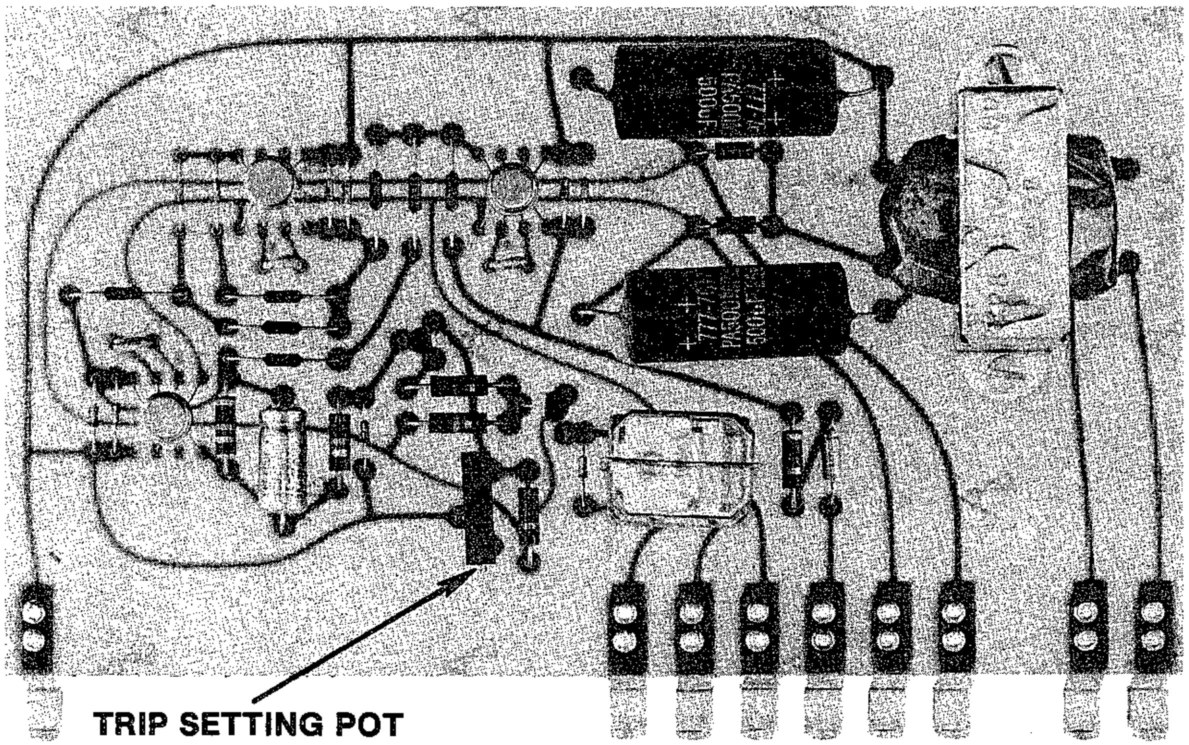
Cedarburg, Wisconsin 53012

Publication 5140-9.18 — October, 1977

AC PHASE LOSS AND CURRENT BALANCE DETECTOR

Part Number 12M3-00180-00

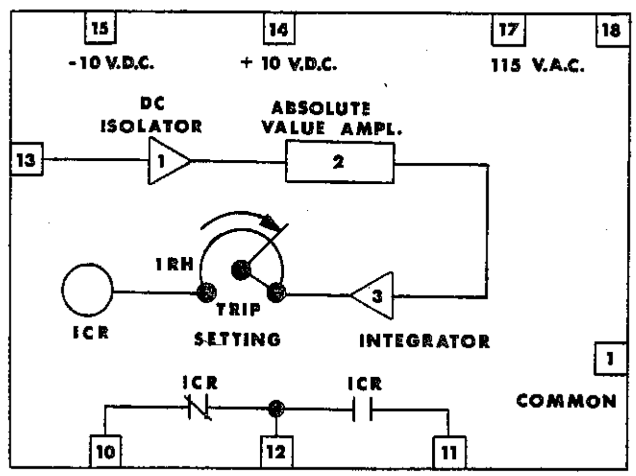


FUNCTION

The function of this board is to sense and time intergate irregularities in armature current caused by a loss of phase or missing SCR pulses, and to shut down the drive and illuminate a "Phase Loss" lamp if such a condition persists. A phase loss or sufficient current unbalance could result in motor overheating or possible damage to the isolation transformer or line chokes (which would attempt to carry the load of the missing phase). If the unbalance detected is of sufficient magnitude and persists beyond the time set by the Trip Setting potentiometer, the relay on the board will energize, effecting drive shutdown.

OPERATION

Armature current feedback voltage is applied between the input to the first amplifier (terminal 13) and board Common (terminal 1). This amplifier blocks the DC level and allows only the AC component (due to unbalances) to pass. Amplifier No. 2 converts the output of Amplifier No. 1 to a positive output (regardless of input polarity). Amplifier No. 3 time integrates the output of Amplifier No. 2, and potentiometer 1RH sets the level at which the output of Amplifier No. 3 will energize relay 1CR. Thus, both the magnitude of the unbalance and the length of time it persists determine whether or not the relay is activated. Therefore, the desired level of protection is afforded the drive, without nuissance tripping due to line transients or other short duration spikes.



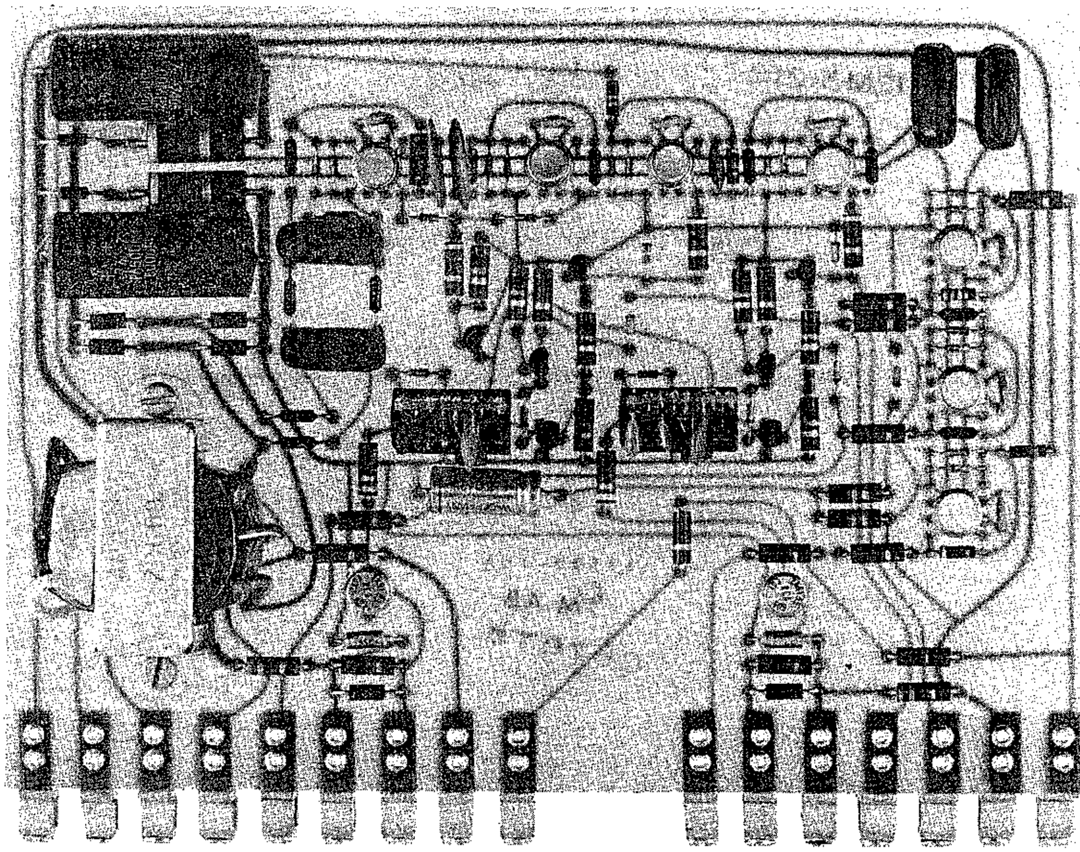
Typically, the normally closed contacts of 1CR will be included in the drive safeties circuit (perhaps in series with the Run Relay) so that the drive is shut down if the relay is energized. The normally open contacts of the relay are normally in series with a "Phase Loss" lamp, which illuminates if the fault condition is sensed and picks up the relay.

ALLEN-BRADLEY
Cedarburg, Wisconsin 53012

Publication 5140-9.20 — October, 1977

FIELD REGULATOR

Part Number 12M3-00210-00



FUNCTION

The Field Regulator P.C.B. contains a high gain inverting amplifier, an inverting amplifier and two pulse generators; each output can be used to trigger one bridge of the dual bridge SCR power unit. Also employed on this P.C.B. is a zero crossing circuit. The P.C.B. contains its own 6.8V DC zener regulated supply.

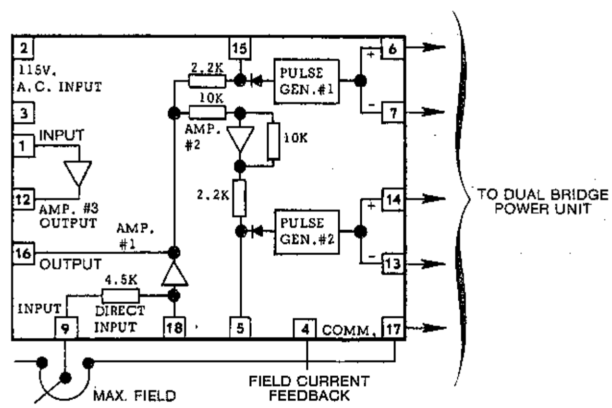
OPERATION

The field reference signal (from the Max. Field pot) is applied to terminal 9. The field current feedback signal is usually applied to terminal 4. The feedback signal produces current flow through a 2.2K ohm resistor. This is then applied to the input summing junction of the high gain amplifier (Amp #1). When a positive signal is applied to the input, terminal #9, pulse generator #1 turns on and supplies output pulses at terminals #6 and #7. When a negative signal is applied to the input (terminal #9) pulse generator #2 turns on and supplies output pulses at terminals #13 and #14.

These pulses are produced every half cycle and range from 8 to 10 volts depending on the load. The output pulses of the pulse generators are positive at terminals #6 and #14 with respect to terminals #7 and #13 respectively.

The zero crossing detector is provided to supply synchronization to the AC voltage that is applied to the SCR's and also commands the pulse generators to supply a synchronization pulse corresponding to the negative going zero crossing of the AC voltage that is applied to the field supply SCR's.

TERMINAL CONNECTIONS



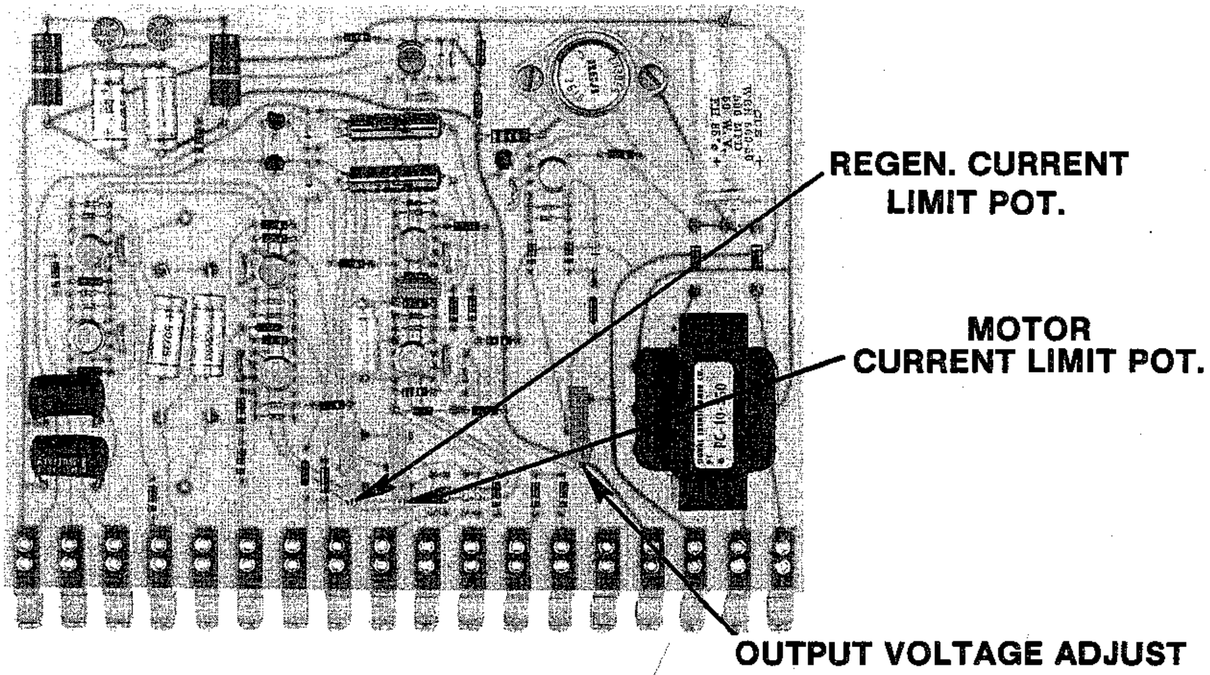
The Field Regulator P.C.B. also completely disables one pulse generator while the remaining pulse generator is triggering the field SCR's on. This feature is used to prevent crossfire that could otherwise occur between the two field supply SCR bridges.

Terminals #5 and #15 are provided for field weakening and are used in conjunction with the Crossover Circuit P.C.B.

A scaling amplifier is provided between terminals 1 and 12 to condition the input signal to the board, if required.

REGENERATIVE DRIVE CONTROL

Part Number 12M3-00211-00



FUNCTION

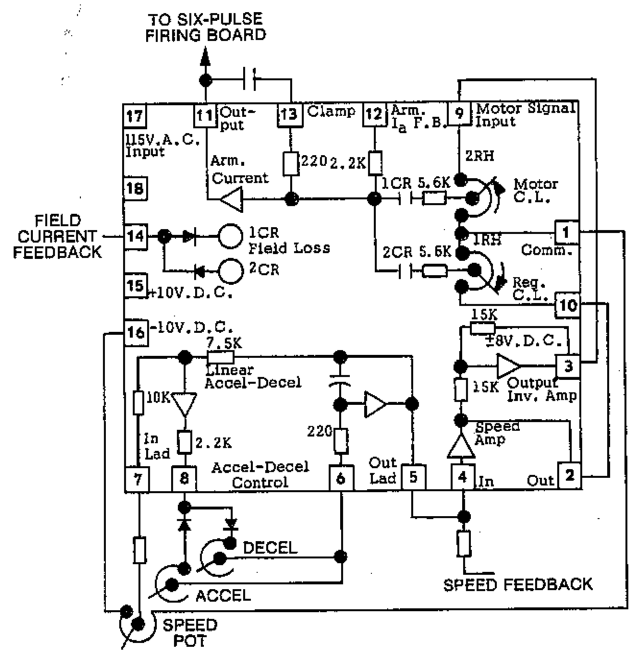
This board is a complete speed and armature current regulator for a three-phase regenerative drive. It contains a Precise Voltage Supply, Linear Acceleration/Deceleration Circuit, Speed Amplifier, Speed Amplifier Inverter, Current Limit Potentiometers for both motoring and regeneration, Armature Current Amplifier, and two field current direction sensing relays. The Precise Voltage Supply provides ±10V DC, regulated to 0.3% with permissible line voltage variations of ±15%, load variations from 0 to 100 ma., and temperature changes from 0°C to 50°C. The Accel/Decel circuit is adjustable to rates dependent upon the resistance values of the external potentiometers connected to it. The Speed Amplifier saturates (8V DC output) with error inputs as low as 70 nanoamperes; the Speed Amplifier Inverter has unity gain. The Armature Current Amplifier also accepts an armature current feedback signal (-2V DC maximum) at terminal 12. The output of this amplifier drives the Pulse Generators on the Six-Pulse Firing Board.

OPERATION

As shown in the block diagram, the Precise Voltage Supply on the board provides the speed reference, which may be applied to the accel/decel cricuit, or direct to the speed amplifier input if the accel/decel feature is not required. Although not shown, a rate network for stability is connected between the input and output of the Speed Amplifier, as is a relay contact to clamp the output to zero after a stop.

The output of the Speed Amplifier Inverter is connected to the Motoring Current Limit pot, and that of the Speed Amplifier to the Regeneration Current Limit pot. The contacts of relays 1CR and 2CR connect the output of these potentiometers to the input of the Armature Current Amplifier. If the direction of motor field current is such that the field current feedback signal is of positive polarity, relay 1CR is energized and the Motoring Current Limit pot supplies the input to the Armature Current Amplifier (2CR is de-energized). If the field current is flowing in the opposite direction, the feedback voltage polarity is negative, relay 2CR is energized, and the Regeneration Current Limit pot provides the input to the amplifier (1CR is de-energized). If neither relay is energized, no armature current is produced, thus providing field loss protection. The output of the Armature Current Amplifier is routed to the Pulse Generators on the Six-Pulse Firing Board. The magnitude of this output determines the conduction angle of the armature power unit SCR'S and hence the magnitude of armature voltage.

TERMINAL CONNECTIONS



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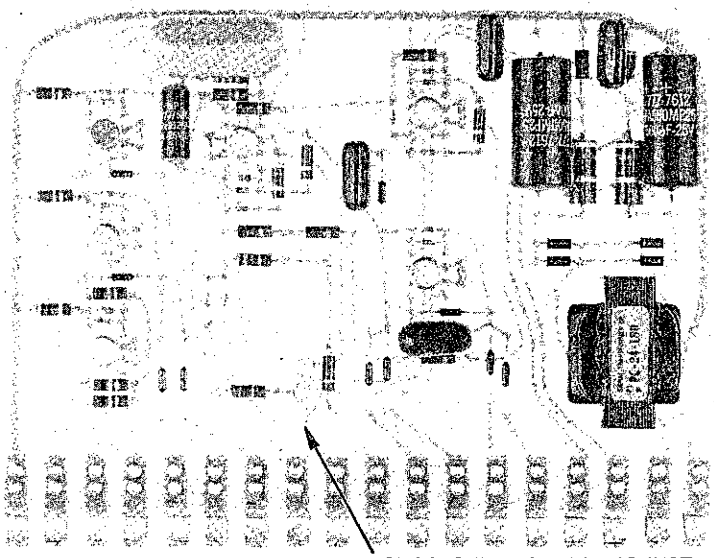
Publication 5140-9.29 — October, 1977

CROSSOVER CIRCUIT

Part Number 12M3-00221-00



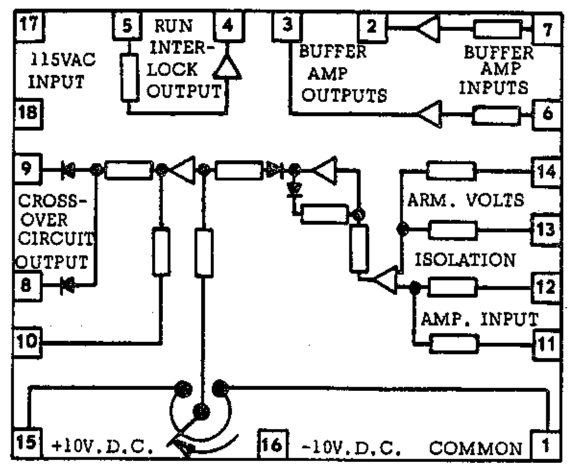
FUNCTION

The Crossover Circuit Board is used in drives where it is desired to operate the motor above base speed with constant, rated armature voltage. At or below base speed, motor speed is proportional to armature voltage. To operate above base speed, field weakening must be employed if the armature voltage is to be kept within its rated limit. The crossover point (armature voltage at which field weakening outputs are produced) is adjustable by means of a potentiometer on the board. In addition to the three amplifiers in the crossover circuit, there are three additional amplifiers on the board, and a regulated ±10V DC power supply capable of providing currents of 25 milliamperes.

OPERATION

Armature voltage is applied between terminals 14 and 11 for a motor with a 480-volt armature (terminal 13 is jumpered to terminal 14, and terminal 12 to terminal 11 for a 240-volt armature motor). The output of the first board amplifier is full-wave rectified in the second (absolute value) amplifier, and this negative output is summed with a positive bias obtained from the potentiometer connected across the positive voltage supply. The level of this adjustable bias establishes the crossover point (magnitude of armature voltage at which field weakening outputs are produced). The field weakening signals (at terminals 8 and 9) are restricted to a positive polarity by the diodes at the output of the third amplifier.

When the motor reaches base speed, its armature voltage will be at its maximum rated value, and will exceed the bias (which is adjustable) placed on the input of the third amplifier. Positive polarity field weakening signals then appear at terminals 8 and 9 — the level of these voltages being dependent upon the amount of bias set in. These positive field weakening signals are routed to the Field Firing Board, where they oppose the negative outputs of the Torque Reference Amplifiers (one for motoring and one for regeneration). The outputs of

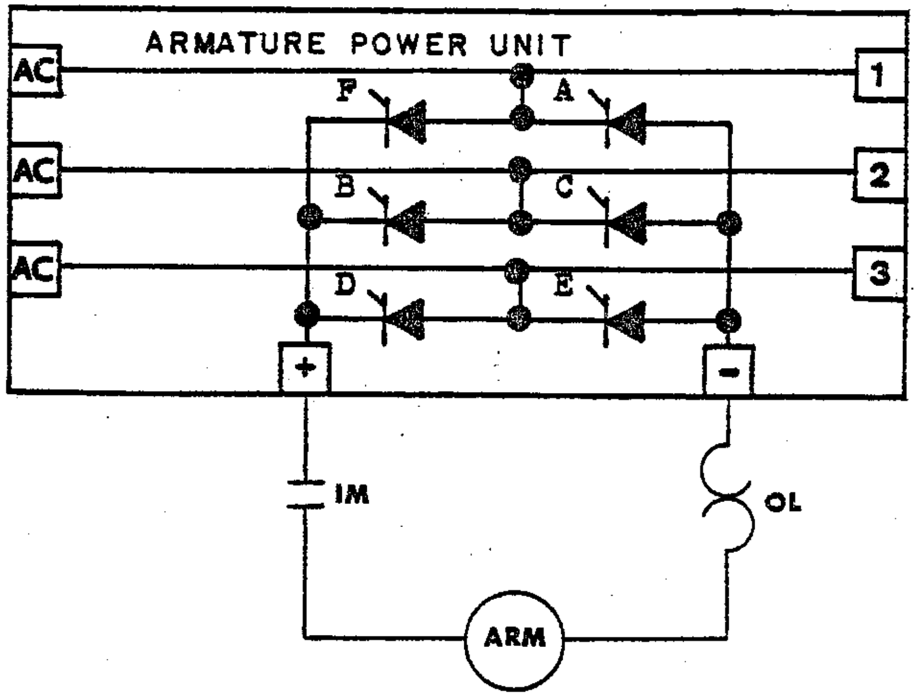


these latter amplifiers are decreased by the Crossover Circuit outputs, resulting in field weakening. Terminal 10 is normally connected to the drive Circuit Checker; if the Circuit Checker voltmeter indicates a negative polarity at this point, crossover has not been reached and the motor is operating at or below base speed. Conversely, if the meter indicates a positive polarity crossover has been reached, field weakening is occurring, and the motor is running above base speed.

Two buffer amplifiers (with input at terminals 6 and 7 and outputs at terminals 2 and 3) are included on the board to transmit the field weakening outputs to additional drives in a multi-drive system. The interlock amplifier (input at terminal 5 and ouput at terminal 4) is frequently used to drive the Torque Reference amplifiers. Its gain is made variable by relay switching an external feedback resistor, so that a drive with Inch or Jog speeds operates with a proportional field in these modes (interlock amplifier has unity gain), but the drive operates with full field in the Run mode (interlock amplifier has gain of 10).

CIRCUIT BOARD FUNCTIONAL DESCRIPTION

ARMATURE POWER UNIT
5 HP THRU 300 HP



The Armature Power Unit is the main three phase full wave SCR power bridge used to control armature voltage and current. These power units are supplied in sizes from 5 to 150 HP at 240 volt D.C. output, and 5 to 300 HP at 480 volt D.C. output. The input is connected to the secondary of a three phase Y connected isolation transformer. The output is connected thru a D.C. loop contactor, and overload relay to the armature of the motor being controlled. The SCR's are fired by the Pulse Distribution and Amplifier Board.

The Armature Power Unit is made up of six silicon controlled rectifiers (SCR's) which are factory assembled into individual heat sinks which can be considered complete separate rectifying modules. These rectifying modules are mounted within a sheet metal enclosure and are arranged for easy removal by merely loosening the four mounting screws, and removing the bus bars on the large units, or disconnecting the wires on the smaller units.

It is recommended that the customer not replace SCR's on the heat sink assemblies because of the widely varying torque requirements between the various SCR's, and the importance of proper heat transfer.

CIRCUIT BOARD FUNCTIONAL DESCRIPTION

ARMATURE POWER UNIT
5 HP THRU 300 HP

The rectifying modules are interconnected by means of oversized aluminum bus bars on 30 HP units and above. This bussing arrangement provides an extremely rigid method for mounting the protective fuses. In addition it provides a convenient means to connect the incoming AC power cables and the outgoing DC power to the armature circuit. Where required, a fan is mounted below the SCR heat sink assembly in the sheet metal enclosure. This fan is protected from external damage by the shape of the sheet metal enclosure and provides air movement over the SCR heat sinks to assure maximum life and maximum safety factor for the controlled silicon rectifiers. An air flow switch is located in the air stream of this fan to assure that the fan is operating before the power unit can supply power to the drive motor. Included with each power unit are transient filter networks. The cover for the armature rectifying package is hinged to allow for easy access to the devices mounted inside.

The power units for 20 HP and below are similar to the larger units, except that the modules are interconnected by power cables. Pressure type terminals are provided for the A.C. input and D.C. output connections. Some of these units do not require a cooling fan, since the heat sinks are capable of proper cooling by convection alone.

50 H.P. DRIVE

FUNCTIONAL DESCRIPTIONS OF ADJUSTMENTS

CROSSOVER VOLTAGE POT

The Crossover Voltage pot adjusts the field weakening circuit which extends the speed range above the base speed. It is located on the Crossover Circuit P.C.B.

CURRENT LIMIT

This pot provides an adjustment to limit the maximum amount of current that is applied to the armature. Current Limit is normally adjusted to 125% of the nameplate rating, with 1.8 to 2.0 volts dc armature current feedback.

FIRING PULSE ADJUSTMENT

Five potentiometers are located on the Six-Pulse Firing Board. The potentiometers provide a means of balancing the output pulses of the five pulse generators with the sixth non-adjustable one. The pulses control the firing angle or output of the armature SCR's.

NOTE

> This is a factory adjustment; however, the amplitude of the output pulses may require balancing when the drive is coupled to the motor. Refer to the Six-Pulse Firing Board Adjustment Sheet for instructions.

JOG

This pot adjusts the speed of the drive motor during the Jog mode, which is entered by depressing and holding the Jog pushbutton.

MAXIMUM FIELD

The Maximum Field pot provides an adjustment of the maximum amount of current applied to the field to deliver full torque of the motor. It is generally set to deliver the rated field current at the full output of the speed amplifier.

50 H.P. DRIVE

FUNCTIONAL DESCRIPTIONS OF ADJUSTMENTS

MAXIMUM SPEED

This pot provides an adjustment of the speed feedback signal to limit the drive speed to maximum when the speed reference is at maximum (not to exceed the rated rpm).

OVERSPEED

This pot adjusts the bias applied to a transistorized relay to set the overspeed at which this relay picks up and shuts down the drive.

PICK-UP

The Pick-Up potentiometer provides a bias adjustment for the tach feedback signal to sense zero speed. When the stop command is initiated, the transistorized relay senses zero speed and is de-energized; this in turn clamps all regulator loops to zero and opens the loop contactor.

RESISTOR 213R

This resistor adjusts the armature current feedback signal which should be 1.8 to 2.0 volts dc at current limit.

RESISTOR 205R

This resistor provides an adjustment for the field current feedback signal which should be approximately one to two volts negative at rated field current.

SPEED

This pot is the main speed control of the drive. It provides operator adjustment of the drive speed from zero to the rated motor rpm.

STABILITY

The Stability potentiometer provides an adjustment of the rate network around the speed amplifier to dampen the drive oscillation or reduce excessive settling time.

FUNCTIONAL DESCRIPTIONS OF ADJUSTMENTS

TIMER POT (3RH)

The Timer potentiometer provides a variable time delay of zero to fifteen seconds to allow the drive to start rotation before monitoring the tach feedback signal (i.e., normal adjustment is approximately three seconds). The Timer pot is the right hand pot on the Tach Loss and Overspeed Board.

TRIP SENSITIVITY

The Trip Sensitivity potentiometer sets the armature current unbalance point, where 1CR on the A. C. Phase Loss and Current Balance Detector P.C.B. energizes. When 1CR is energized, the drive magnetic control circuits are opened and the drive will stop. It is located on the A. C. Phase Loss and Current Balance Detector Board.

1300RPM PICK-UP

The 1300RPM Pick-Up potentiometer provides a bias adjustment for the tach feedback signal to sense a speed of 1300RPM. When this speed is attained the transistorized relay senses this speed and is energized; this in turn places additional current limiting resistance in both the Motoring and Regenerating Current Limit circuits to provide the desired current limit.

REGENERATING CURRENT LIMIT TAPER

This pot adjusts the minimum point at which the regenerating current limit will attain above 1300RPM.

MOTOR CURRENT LIMIT TAPER

This pot adjusts the minimum point at which the motoring current limit will attain above 1300RPM.

UNPACKING AND INSPECTION

After unpacking the material, check the item (s) received against the bill of lading to insure that the nameplate description of each item agrees with the material ordered. Inspect the Speedpak Controller and the other equipment for physical damage. As stated in the Allen-Bradley Company, Drives Division Terms and Conditions of Sale,

> "All claims for breakage and damage whether concealed or obvious must be made to the carrier by the Buyer as soon as possible after receipt of the shipment. The Company will be glad to render the Buyer reasonable assistance in the securing of adjustment for such damage claims."

Remove all packing material, wedges, or braces from within the drive controller. Operate the contactors and relays manually to assure that they operate freely. If any part of the equipment will not be installed when it is unpacked, it should be stored in a clean, dry place. The temperature must be within 15 degrees fahrenheit and 165 degrees fahrenheit in order to prevent any damage to the semi-conductor components of the controller.

INSTALLATION

The National Electric Code and all other local regulations govern the installation and wiring of this equipment. Connections should be made in accordance with the interconnection diagram packed with the Speedpak Controller, or those provided at the back of the instruction manual. Take care that shielded cables are used wherever called for on the interconnection diagram. Since most start-up difficulties are the result of incorrect wiring, every precaution should be taken to assure that the wiring is as shown on the diagram.

SPEEDPAK CONTROLLER - The Speedpak Controller should be located on a flat, solid surface. If the controller is housed in a ventilated enclosure, insure that the air louvres are provided with at least four inches of clearance for ventilation. Connections are usually made to terminal blocks located inside the enclosure. Since, the Speedpak Controllers are generally customized, the terminal block locations vary. It is necessary, therefore, for the customer to route connecting cables into the console as best fits the specific application. The Speedpak Controller should NOT be subjected to shock, excessive vibration, moisture, dust corrosive vapors or extreme heat. The ventilating openings must not be obstructed.

MOTOR - Careful attention to the proper alignment and rigid support of the motor will avoid rough operation and early failure of the motor bearings. If a belt or chain drive is used, excessive tension must be avoided to prevent unusual wear and tear on the bearings.

MOTOR (CONT.)- For more detailed installation and maintenance procedures consult the manufacturer's instructions packed with the motor, or those found in the Speedpak Instruction Manual.

Before the motor is connected, the shaft should be turned manually to assure that it turns freely, and that no obstruction is present. The brushes should be inspected to see that they are seated properly on the commutator. Connect the armature leads (A1 and A2) and the shunt field leads (F1 and F2) as indicated on the interconnection diagram. These connections result in counterclockwise shaft rotation (facing commutator end). To change the directional rotation, interchange either the A1 or A2 leads, OR the F1 and F2 leads, but not both. Do not connect the series field, if supplied, unless otherwise instructed.

PRELIMINARY START-UP PROCEDURES

After the installation has been completed, perform the following preliminary steps:

1. Set the switches & controls to the positions listed in the "Initial Switch and Control Settings" table.

2. Refer to the schematic diagram to determine the circuit board (s) that are contained in the specific drive. Circuit boards are illustrated as boxed-in circuits with the board name, part number and EA identification number printed within the box.

3. Particular board adjustments are not included in the start-up procedure; however, reference is made at the point where board adjustments are to be made. The Reference is made by board name only. The board name will correspond with the appropriate "Circuit Board Adjustment Sheet" found after the start-up procedure in the instruction manual. At the point in the start-up where the circuit board adjustment is cited, proceed to the appropriate sheet and perform the specified tasks as applied to the particular drive.

4. Proceed with the start-up procedure.

50 H.P. DRIVE

INITIAL SWITCH & CONTROL SETTINGS

SWITCH/CONTROL	BOARD LOCATION	INITIAL POSITION
Crossover Voltage Pot	Pot on 102EA Board	* Fully CW
Current Limit		
Motoring	2nd pot from left on 201EA	* Fully CCW
Regenerating	1st pot from left on 201EA	* Fully CCW
JOG	206RH on 202CA	Fully CCW 0%
MAXIMUM FIELD	201RH on 202CA	Fully CCW 0%
MAXIMUM SPEED	203RH on 202CA	● Fully CCW
OVERSPEED	209RH on 203CA	Fully CW 100%
SPEED	210RH	Fully CCW 0%
STABILITY	202RH on 202CA	70%
PICK-UP	204RH on 202CA	25%
1300RPM PICK-UP	205RH on 202CA	25%
Trip Sensitivity	Pot on 108EA Board	* Fully CW
Timer Pot	Right-hand pot on 103EA	* Fully CW 100%
REGENERATING CURRENT LIMIT TAPER	207RH on 203CA	Fully CCW 0%
MOTORING CURRENT LIMIT TAPER	208RH on 203CA	Fully CCW 0%

*20 turn pot

● 10 turn pot

Pot — potentiometer

CCW — counterclockwise

7.5 H.P. DRIVE

INITIAL SWITCH & CONTROL SETTINGS

SWITCH/CONTROL	BOARD LOCATION	INITIAL POSITION
Current Limit	1st pot from left on 101EA	* Fully CCW
JOG	102RH on 102CA	Fully CCW 0%
MAXIMUM SPEED	103RH on 102CA	• Fully CCW
SPEED	104RH	Fully CCW 0%
STABILITY	101RH on 102CA	70%
Trip Sensitivity	Pot on 105EA Board	* Fully CW
Timer Pot	Right hand pot on 104EA Bd.	* Fully CW

*20 turn pot
• 10 turn pot

Pot — potentiometer
CCW — counterclockwise

50 H.P. DRIVE

SPECIFIC DRIVE FEATURES

Overspeed Circuit

This circuit is similar to the Pick-Up circuit in that a signal proportional to drive speed is used to pick up a transistorized relay at a speed determined by an adjustable bias applied to the relay input. The rectified tach generator voltage is the speed signal that activates relay 209EA-2CR. Relay bias to set the speed at which the relay is picked up is provided by Overspeed pot 209RH. The N.C. contacts of 209EA-2CR are in series with drive Tach Loss Relay 202CR. Whenever overspeed occurs, 209EA-2CR is energized which de-energizes the Run relay, shutting down the drive and illuminating the Tach Loss Reset Lamp (2012PBL).

Tachometer Loss Clamp (via Armature Voltage)

Whenever the drive is started or reversed thru zero speed, relay 209EA-1CR is de-energized when armature voltage is approximately 110 volts or less. Whenever 209EA-1CR drops out, the Tach Loss and Overspeed P.C.B.(203EA) is reset, preventing nusiance tripping of tach loss relay at zero speed. Now, when armature voltage reaches approximately 110 volts, 209EA-1CR picks up, releasing the clamp on the Tach Loss and Overspeed P.C.B. which allows the tach loss relay to trip. This action will shut down the drive and illuminate the Tach Loss Reset Lamp (2012PBL).

Circuit Checker

The Circuit Checker is mechanized to read the voltage at 10 selected test points in the drive. Test point 11 is not used. A table referenced on sheet 2 of 2 of the Schematic Diagrams lists the selected functions, the appropriate meter scale, and the polarity and maximum voltage at each test point during forward motoring and regeneration and reverse motoring and regeneration.

Field Loss Protection

The normally open contacts of relays 1CR and 2CR (on the 201EA Board) are in series with the motoring and regenerative current limit potentiometers located on the Regenerative Drive Control Board (201EA). The input to these relays are connected to a variable resistor (205R) in series with the motor shunt field and one relay is energized whenever field current is present. Should field current be lost, 1CR and 2CR drop out, causing the signal input to the Six-Pulse Firing Board to be cut-off, thus, eliminating firing pulses to the SCR's and the drive coasts to a stop.

50 H.P. DRIVE

SPECIFIC DRIVE FEATURES

Crossover Circuit

When the motor is operating at base speed, the shunt field receives full rated field current, resulting in maximum field flux, and the armature voltage is at its maximum rated value. To operate the motor above base speed, the field flux is weakened. This is done by applying armature voltage (via wires 201A1 and 201A2) to the Crossover Circuit Board (at terminals 14 and 11). When the crossover voltage which is adjustable by the pot on this board is exceeded, positive voltages are produced at terminals #8 and #9 of the board, and are transmitted via wires 325 and 324 to terminals 5 and 15 of the Field Firing Board. These positive voltage signals oppose the negative voltage field current regulator signals, hence resulting in decreased field current and a weakening of field flux. With a weakened field, the motor runs above base speed, but the armature voltage never exceeds its rated value.

Tachometer Loss Protection

Relay 1CR on Tach Loss Board 203EA is normally held energized by the tach voltage applied at terminal #14. Should tach loss occur, relay 203EA-1CR drops out, which de-energizes the Tach Loss relay (202CR), shutting down the drive and illuminating the Tach Loss Reset Lamp (2012PBL).

Pick-Up Circuit

The Pick-Up pot 204RH places a bias on the input of transistorized relay 207EA-2CR. The relay is energized whenever the Tach voltage exceeds the Pick-Up bias. The contacts of relay 207EA-2CR are in series with the drive Reference relay 206CR which must be energized for a regenerative stop. As long as sufficient Tach voltage exists, 207EA-2CR and hence 206CR is energized. As the motor slows and armature voltage drops towards zero, 207EA-2CR and 206CR drop out, the motor comes to a stop at or near zero rpm without backing up and the contacts of 206CR clamp to zero the outputs of the Armature Current Amplifier.

AC Phase Loss and Current Balance Protection

Armature current feedback is applied to AC Phase Loss and Current Balance Detector Board 208EA. Irregularities in armature current caused by a loss of phase or loss of armature firing pulses are sensed and integrated by circuitry on the board. If the condition persists, relay 1CR on the board is energized, which de-energizes the Phase Loss Relay (201CR) to shut down the drive and illuminate the Phase Loss Reset Lamp (2011PBL).

50 H.P. DRIVE

SPECIFIC DRIVE FEATURES

1300RPM Pick-Up Circuit

The 1300RPM Pick-Up pot 205RH places a bias on the input of transistorized relay 207EA-1CR. The relay is energized whenever the Tach voltage exceeds the Pick-Up bias. The contacts of relay 207EA-1CR are in series with both the Motor Current Limit Taper pot and the Regenerating Current Limit Taper pot. The relay is energized above speeds of 1300RPM. This action places additional current limiting resistance in the circuit to provide the desired motoring and regenerating current limit above 1300RPM.

50 H.P. DRIVE

START-UP INSTRUCTIONS

SPEEDPAK BULLETIN 1373 TYPE RG DRIVE

Each Speedpak drive is functionally tested at the factory. However, many of the functional adjustments must be made to meet the specific machine's characteristics or operator preferences. Read these instructions carefully before attempting to start the drive.

> **WARNING**
>
> Exercise extreme care when performing any task in the drive enclosure, isolation transformer, or on the drive motor. Dangerous voltage and current levels may be encountered and line voltage may be present with the drive circuit breaker open.

To locate a specific printed circuit board (P.C.B.) in your drive, refer to the schematic circuit diagram. This diagram contains a representation of the P.C.B.'s and the functional blocks. For example, a P.C.B. is shown on the schematic with the number designation 2EA. This number, 2EA, will be adjacent to the actual P.C.B. in the circuit board rack. This procedure covers start-up and adjustments to be performed on the regenerative drive system.

The regulator section of the drive is comprised of the following P.C.B.'s:

Regenerative Drive Control	201EA
Crossover Circuit	202EA

The following P.C.B.'s generate and route the triggering pulses to the proper sets of armature and field D.C. loop SCR's:

Field Firing Board	204EA
Dual Bridge Power Unit	
Six-Pulse Firing Board	205EA
Pulse Distribution Board	206EA

The following P.C.B.'s provide protection and/or added functions to the Speedpak regenerative drive system:

Tach Loss & Overspeed	203EA
Transistorized Relay	207EA, 209EA
A.C. Phase Loss & Current Balance Detector	208EA