GEH-1504D

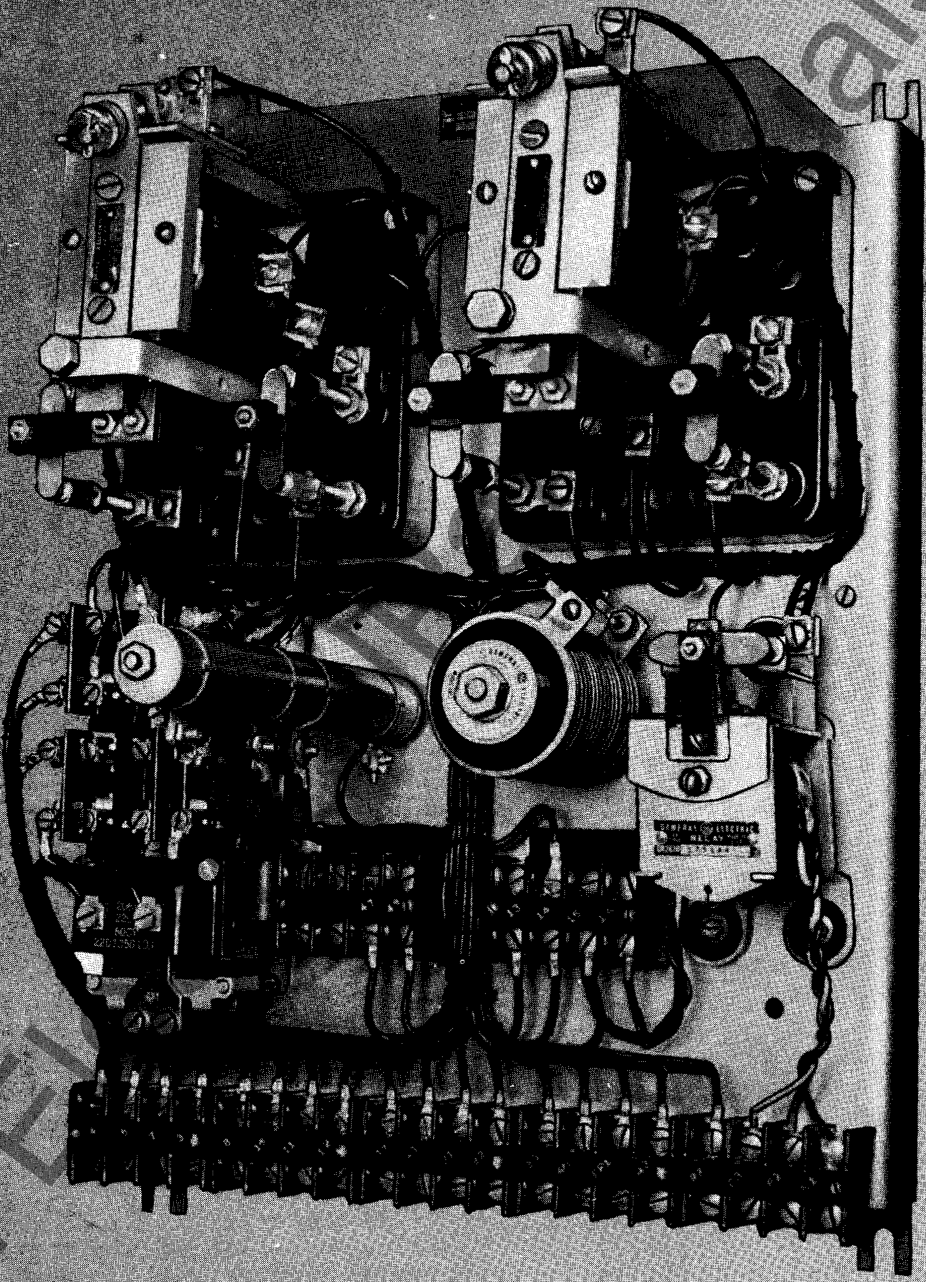
Supersedes GEH-1504C

INSTRUCTIONS

SYNCHRONOUS MOTOR CONTROL

With *IC7069-B1C Field Panel Having Slip-frequency Field Application and Power-factor Field Removal

(Also identified with prefix CR instead of IC)



GENERAL ELECTRIC

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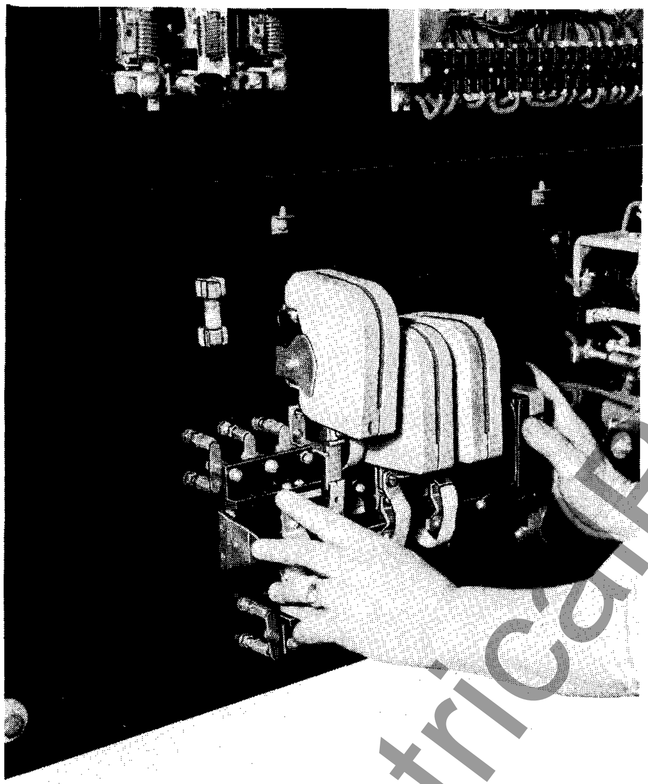


Fig. 2. Make sure that devices operate freely and contacts are properly aligned

Any separate switching means for reversing the direction of motor rotation must be connected in the circuit, between the controller and motor, for correct functioning of the field-removal relay (PFR).

As indicated on the main connection diagram supplied with the controller, inspect the wiring to determine definitely that the starting and field discharge resistor is connected in the motor-field discharge circuit through the discharge (closed) contact of the field-applying contactor (FC) and the squirrel-cage protective relay (SCR).

DO NOT APPLY power to the controller of the motor until the instructions under "Operation" have been studied.

CONTROL FUNCTIONS

A-C POWER SWITCHING TO THE MOTOR

Magnetic Full-voltage Starting

mined time interval, an adjustable-time transfer relay will operate to reconnect the motor from the starting connection to the running or full-voltage connection.

Magnetic Part-winding Starting

The sequence of operation of the a-c power switching for part-winding is equivalent to the preceding paragraph when a portion of the motor winding is first connected to the power source. After a predetermined time interval, a second portion of the motor winding is connected in parallel with the first portion; or, in effect, normal or full voltage is applied to all windings of the motor.

Part-winding starting may be accomplished in two steps or more, each step following the first in a timed sequence as above until the full winding is energized.

Semi-magnetic Starting

This method of starting is similar to magnetic starting, except that manual operation of the a-c power switching devices is required.

FIELD CONTROL

The system of field control, as included herein, provides the following features:

1. Field is applied at the proper speed and at a consistently favorable angle.
2. Removal of field within the first slip-cycle on pull-out without premature removal.
3. Wide load swings permitted before removal of field.
4. D-c voltage check relay is included.
5. Motor shutdown or field removal only on pull-out by simple jumper connections.
6. Contacts for field forcing of the exciter during starting.
7. Contacts for compressor unloader circuits.

THERMAL PROTECTION

The stator winding is protected against running overloads by an isothermic temperature overload relay. The tripping of this relay corresponds to the stator-winding heating curve. To provide adequate protection to the squirrel-cage winding, the controllers are equipped with a temperature squirrel-cage protective relay (SCR). This relay is independent of the stator temperature-overload relay, and, therefore, permits the design of the controller to be such that both the stator and the squirrel-cage windings are fully proaccurately the heating curve of the squirrel-cage winding. On all controllers, the relay heater and reactor of the squirrel-cage protective relay are designed specifically to suit the motor with which they are used.

OPERATION

STARTING AND FIELD APPLICATION

Referring to the diagram, Fig. 3, pressing the **START** button will pick up relay **FCX** and in turn the main line contactor through contacts 3-8 and 8-10. The seal circuit for **FCX** will thus be established through **M** contact 2-8, **FCX** contact 8-3 and **FC** contact 3-4; and the **M** contactor will also be sealed in so that the **START** button may be released.

The closing of relay **FCX** (8-14) will also short out a portion of resistor 1RS in series with coil **PFR**, thus increasing the voltage on relay **PFR** potential coil 15-16 to match the high starting current through **PFR** current coil 61-63 and holding open **PFR** contact 17-18 during starting.

When contactor **M** closes, relay **FR** closing coil (CC) will be energized through **M** contact 40-44, **FC** contact 44-47 and **FRX** contact 47-50. Relay **FR** will pick up at a relatively low voltage through its closing coil thus closing its contact 42-43 and opening contact 18-19 to prevent the field contactor **FC** from closing. Induced field current flowing through the rectifier, **FR** contact 42-43 and **FR** synchronizing coil R3-42, will hold the **FR** relay in. Relay **FR** contact 47-48 will close the circuit to the **FRX** coil 48-49. This device is set for a pick-up voltage high enough to synchronize the motor and when exciter voltage builds up to this value, relay **FRX** will pick up, opening its contact 47-50 and de-energizing the **FR** closing coil. Thus the field contactor cannot close until the proper d-c voltage is available to pull the machine into step. The **FR** relay is held in until the time of succeeding blocked-out half waves of induced field current equals or exceeds the time drop-out setting of **FR**. Therefore, when the proper rotor speed has been reached relay **FR** will drop out, closing its contact 18-19. The **FC** field contactor coil 19-5 will then be energized through relay **FRX** contacts 21-18 and relay **FR** contacts 18-19, d-c excitation will be applied and the motor will pull into step. Opening the **FR** relay will open its contact 47-48, de-energizing the **FRX** relay coil, but **FRX** is a time opening device and its contact 21-18 will thus hold contactor **FC** closed for a time long enough to allow the motor to settle down after synchronizing. Relay **FRX** also seals in relay **FCX** through its contact 7-4, thus **FCX** has the same drop-out time as **FRX**. At the end of this time, relay **FCX** opens, contact 22-23 closes, energizing the automatic unloader which allows the compressor to begin pumping; contact 12-14 opens inserting resistance in the **PFR** relay potential coil which calibrates this device for pull-out protection and closes contact 17-18 (if not already closed); contact 8-10 opens which transfers the seal circuit of contactor **M** to **FC** contact 8-9 and oil pressure switch **OPS** (9-10); and the contacts of relay **FCX**, which are connected across the exciter rheostat, open inserting resistance in the exciter-field circuit and reducing the exciter voltage to its normal operating value. Relay **FR** is the device which measures motor-field frequency and makes sure that field is applied to the motor at the proper speed. The time of closing of contactor **FC** is a known value and has been set at the factory for the best angle to give smooth synchronizing.

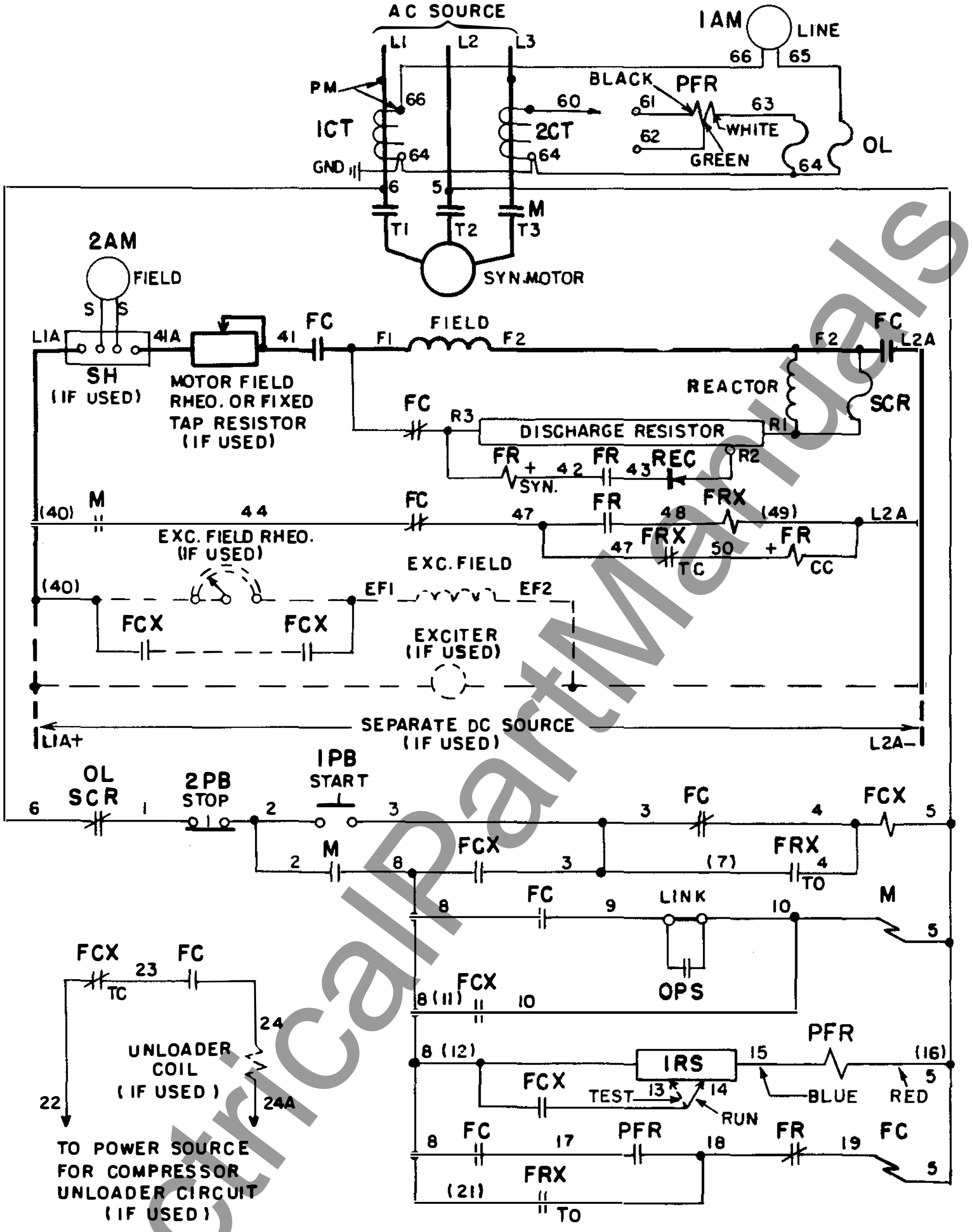
PULL-OUT PROTECTION

When the machine pulls out of step because of abnormal operating conditions, it is essential that excitation be removed as rapidly as possible.

The power-factor field-removal relay serves this purpose by accurately checking the phase relationship between the current in its current coil 61-63 and the current in its potential coil 15-16. These two coils are wound one on top of the other on the same core. Under normal running operation the relay contact 17-18 will be closed to keep the field contactor coil energized. When the machine pulls out of step, the line current increases and becomes lagging, such that the flux due to the **PFR** relay current coil opposes that of its potential coil and contact 17-18 opens, which opens the field contactor and removes d-c excitation from the motor.

When contactor **FC** opens, its contact 8-9 opens which de-energizes contactor **M** coil and removes a-c power from the stator and the motor stops. If it is desired not to shut the motor down, but merely to remove excitation (this will allow the motor to resynchronize provided the condition which caused pull-out is corrected, and the torque requirements are such that the motor can resynchronize) jumpers may be added around the **FC** contactor interlock 8-9 and the **FCX** relay contact 3-8. Refer to Note D on the connection diagram furnished with the starter.

When connected for resynchronizing as above, note that relay **PFR** is recalibrated, relays **FR** and **FCX** operate as during the original starting, the unloader circuit is de-energized, the exciter rheostat is shorted for field forcing, etc. The entire operation is automatic.



NOMENCLATURE

AM—Ammeter
CC —Closing coil
CT —Current transformer
FC —Field contactor
FCX—Auxiliary relay to FC
FR —Field-applying relay
FRX—Auxiliary relay to FR
M —Line contactor
OL —Stator thermal-overload relay—Hand reset
OPS—Oil pressure switch

PB —Control station
PFR—Power-factor field-removal relay
PM —Polarity marks
RS —Resistor
REC—Rectifier
SCR—Squirrel-cage protective relay—Hand reset
SH —Shunt
SYN—Synchronizing coil
TC —Time closing
TO —Time opening

Fig. 3. Elementary diagram of a full-voltage, low-voltage starter

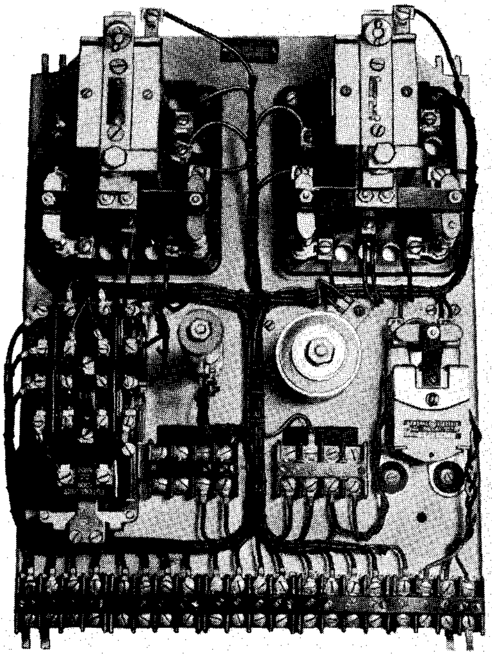


Fig. 4. IC7069-B1C field control panel

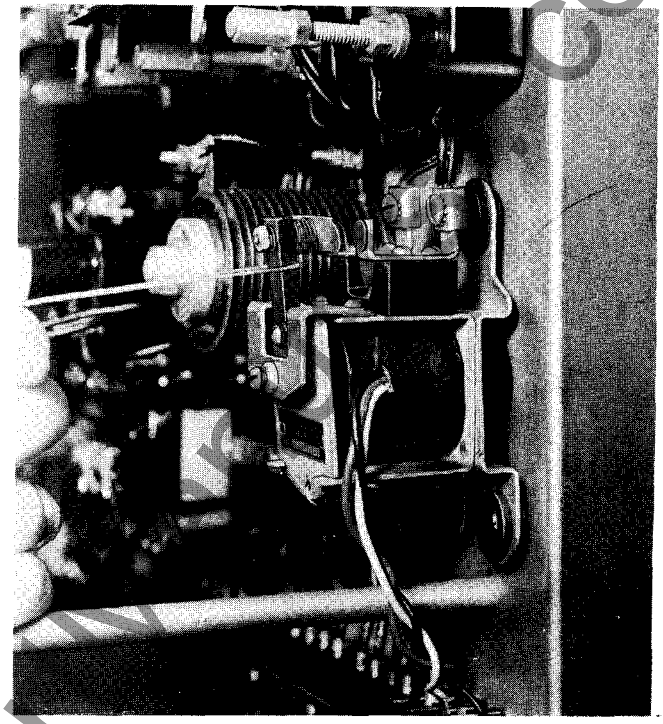


Fig. 5. To check polarity of PFR relay

TESTS AND ADJUSTMENTS

POWER-FACTOR FIELD-REMOVAL RELAY

Since this device operates on the phase relation of stator voltage and current it is essential that proper polarity and phasing connections are made, as is the case with wattmeters, watthour meters and the like. As shipped from the factory, connections will be correct if phase rotation is 1, 2, 3. It is not necessary that the actual phase rotation be known since the following test will disclose incorrect connections. Refer to the connection diagram supplied with the starter. Note that the current coil of relay **PFR** must be in one phase and the potential coil in the other phase on a two-phase system or across the other two phases of a three-phase system.

As shipped from the factory, the lead from the **FCX** relay contact is connected to test terminal No. 13 on 1RS. (See Fig. 3.) At the instant of starting, the **PFR** potential coil will be energized as soon as relay **FCX** picks up. This may be somewhat ahead of the time when current begins to flow in the **PFR** current coil, due to the time required for the line contactor to close. Therefore, during the initial installation test to determine the correctness of connections, it is necessary to manually hold relay **PFR** open momentarily at the instant of starting, as in Fig. 5. If, after release, contact 17–18 remains open during acceleration up to a motor speed of approximately half speed or above, the connections are correct. If the contact closes immediately upon release after the line contactor closes, the connections are incorrect and the potential coil leads No. 15 and No. 16 on relay **PFR** should be reversed and the test repeated.

After correct polarity has been determined, the lead from the **FCX** relay contact should be reconnected to the normal running position, terminal No. 14.

If the equipment is the type on which resistor 1RS has only one tap at the mid-point, wires No. 13 and No. 14 may be connected together at the resistor, or there may be but one wire at this point. In such case it will of course be unnecessary to reconnect for test purposes.

For further discussion of the test procedure refer to page 21

The current portion of the **PFR** coil has two sections consisting of the entire winding and a tapped portion of the winding. This tapped portion is provided to cover wide ranges of pull-out currents.

The selection of the proper connection on the PFR relay current coil is made at the factory in accordance with the following table.

MAX. CURRENT WITH NORMAL* EXCITATION (Percent of full load)	STARTING CURRENT (Percent of full load current)	CONNECT Lead No.	to	CONNECT Coil Term. No.
170 to 330	250 to 700	60 (Pt. 1 on diagram furnished with panel)		61
250 to 330 330 to 430	700 to 850 350 to 850	60 (Pt 2 on diagram)		62

* *In first slip cycle after pull-out.*

FIELD-APPLYING RELAY AND AUXILIARY

The following table gives the time drop-out settings of relay **FR** when tested from a separate d-c source, applying rated excitation to the closing coil, to synchronize from a given constant slip:

SLIP SETTING DESIRED FOR SYNCHRONIZING	RELAY FR TIME SETTING IN SECONDS 25 CYCLES	40 CYCLES	50 CYCLES	60 CYCLES
1%	2.20	1.50	1.20	1.00
2%	1.16	0.74	0.62	0.53
3%	0.76	0.52	0.44	0.37
4%	0.61	0.41	0.34	0.29
5%	0.50	0.34	0.28	0.24

Unless otherwise specified on the order, standard general purpose starters will be shipped from the factory with the **FR** relay set to apply d-c field excitation at 4½ percent slip. If, due to special operating conditions, it is found that the field should be applied at a speed other than that as set originally, the timing of the **FR** relay dropout may be changed by shifting the location of the shim. In order to obtain a setting for 1 percent slip at 25 and 40 cycles, it may be necessary to "back off" on the armature spring adjusting nut as well as shifting the shim.

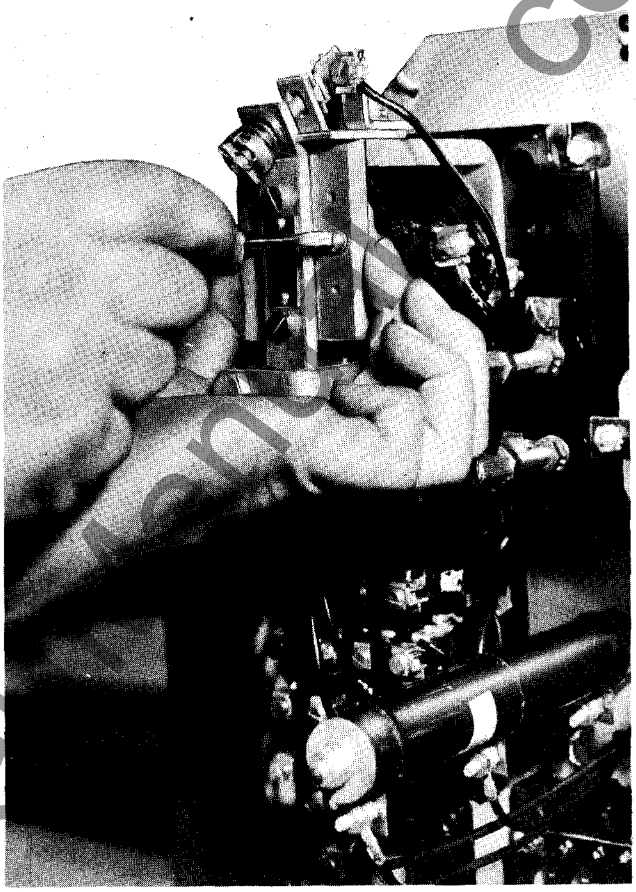


Fig. 6. Adjustment of shim for timing

To shift the position of the shim on the CR2820-1754 relay, loosen the two screws in the armature of the relay and slide the shim either up or down (as in Fig. 6) depending upon the change in time required. Sliding the shim up decreases the time required to drop out, while sliding the shim down increases the time required to drop out. After the desired time dropout is obtained, the shim should be locked in the proper position by tightening the two screws in the relay armature.

The contact gap on the **FR** relay should be ⅛-inch and the wipe 1/16-inch, while the contact gap on the **FRX** relay should be ¼-inch and the wipe 1/16-inch. The **FRX** relay should be set to drop out at 1.5 seconds. The contact gap on the **PFR** relay should be ⅛-inch or more but not exceeding ¼-inch, and the wipe 1/16-inch.

DISCHARGE RESISTOR TAP

The tap on the discharge resistor is selected so that with the machine operating as an induction motor at 95 percent speed, the voltage applied to the **FR** synchronizing coil will be in the range of 100 to 125 volts.

SQUIRREL-CAGE PROTECTIVE RELAY

If the squirrel-cage protective relay trips during starting, do NOT replace merely the heater or bimetal strip, and do NOT tamper with the bimetal calibration. These parts have been selected and adjusted at the factory to suit the particular motor with which relay SCR is to be used. The selection of components was based on calculated information supplied by the motor designer. If premature tripping occurs the following information should be referred to the General Electric Company:

1. Actual induced field current at start (a clamp-on ammeter may be used). Extreme care must be exercised since induced voltage of the field-discharge circuit may reach a high value.
2. Time of acceleration of the motor from rest to synchronous speed.
3. Actual trip time of the relay.
4. Line voltage during start.
5. Voltage at motor terminals during start (for use on reduced-voltage type of starter).
6. Heater and coil catalog numbers.
7. Complete nameplate data of starter and requisition reference or motor serial number.

TIME TRANSFER RELAY

The time setting of the transfer relay, on magnetic-reduced-voltage or part-winding starters, should be set for the average maximum time required for the motor to reach its maximum speed before full voltage is applied. An initial trial start should be made, using a temporary time setting of approximately twenty seconds and then the actual time interval required under normal loading conditions determined. The most economical practice is to use the highest voltage tap and the shortest accelerating time consistent with the limitations imposed by the line, the load, or the motor.

OTHER DEVICES

For instructions on adjustments of other devices, refer to the list on page 22.

TECHNICAL DESCRIPTION

SYNCHRONOUS MOTOR CHARACTERISTICS

STARTING

Synchronous motors differ from ordinary induction motors in that d-c field excitation is supplied while running and the usual field-armature relationships of d-c motors are reversed. They are started as squirrel-cage induction motors. Either the stator or the rotor of a synchronous motor could be made the d-c field, but the design is simpler with the field revolving and with the armature, to which the a-c line voltage is applied, stationary. This requires only two low-voltage slip rings for the field winding. On the rotor the d-c excitation coils are wound on salient poles in the faces of which are mounted squirrel-cage winding bars for starting.

A typical three-phase synchronous motor is illustrated, with the collector rings for the d-c winding, less shaft and bearings. (See Fig. 7.) As far as stationary elements are concerned, the construction features are the same as those of polyphase induction motors. Bearings, end shields, stator frames, punchings, and windings in general follow the same pattern. In fact, many of these parts can be interchanged.

Distinguishing characteristics of synchronous motors are operation at constant speed and opportunity for power-factor adjustment. Other advantages are higher efficiency for low-speed motors, and for high-speed motors of unity power factor, and lower starting current for some types and ratings. Lower starting torques and the necessity for a separate d-c power source, may be disadvantages.

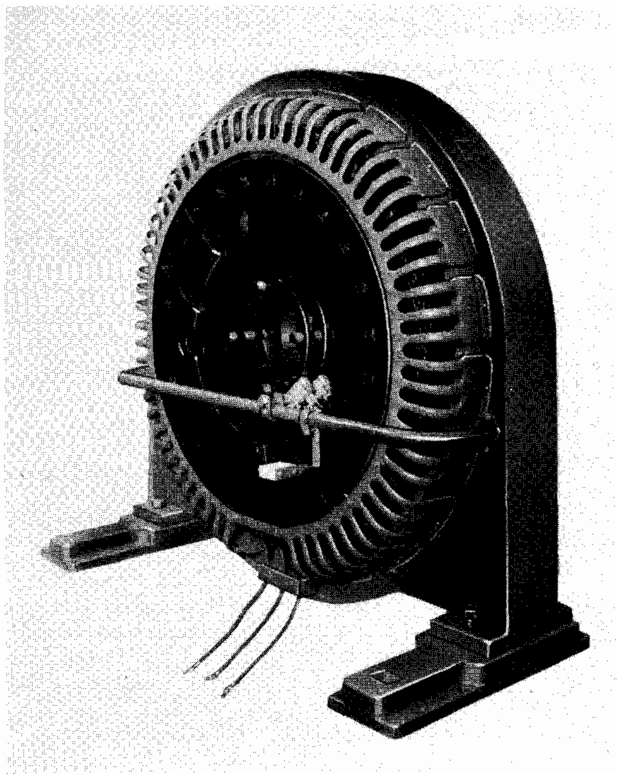


Fig. 7. Typical synchronous motor, less shaft and bearings

Typical applications are compressors, motor-generator sets, pumps, blowers and rubber-mill machinery drives.

High-speed synchronous motors are usually provided with direct-connected exciters for the d-c supply, while low-speed motors are furnished with belted or separately driven exciters. Where several motors are involved the excitation source may be a d-c bus. The d-c field winding produces a flux with poles of fixed position relative to the rotor. These poles are attracted by poles of opposite polarity in the rotating a-c field set up in the stator winding. Thus, the rotor is caused to revolve at the same speed as that of the rotating stator flux after the rotor has been accelerated nearly to that speed, in a manner to be described. The motor speed is constant and can not be changed in any given machine except by a change of frequency of the power supply. However, the basic synchronous speed may be changed by a special design which permits a regrouping of both stator and rotor poles, resulting in a 2-to-1 speed ratio. Two-speed synchronous motors find a wide application in rubber-mill service.

With a-c voltage applied to the stator and with the rotor at standstill, because of the large number of turns on the field poles, transformer action will induce a very high voltage in the field if it is open-circuited. To avoid excessive potential at starting, it is necessary to short-circuit the field winding through a resistor, or to sectionalize it into several parts, each of which is left open. With the field open, there will be no circulating current in it and hence no starting torque. If the field is shorted through a resistor, the current flowing in it produces a small torque at standstill and an appreciable component of the total torque near synchronous speed. The resistor used to short the field during starting is chosen in order to limit the voltage across the field rings to a safe value. When d-c excitation is removed, the inductive "kick" voltage must also be held to a safe value. The same resistor which is used for starting is also used as a discharge resistor.

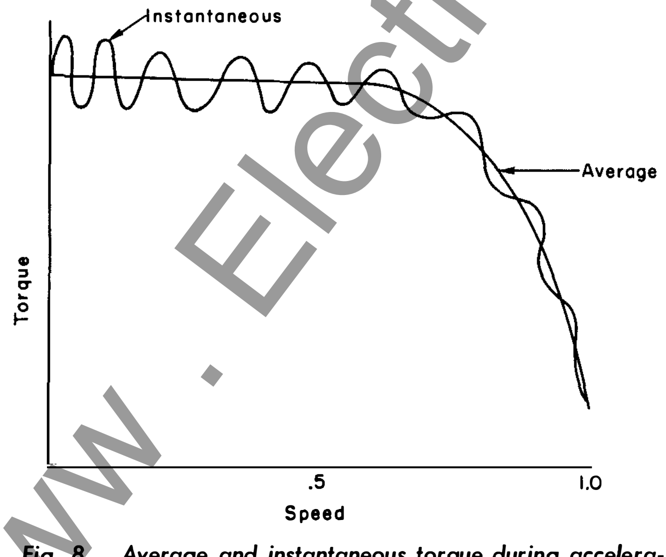


Fig. 8. Average and instantaneous torque during acceleration of a synchronous motor

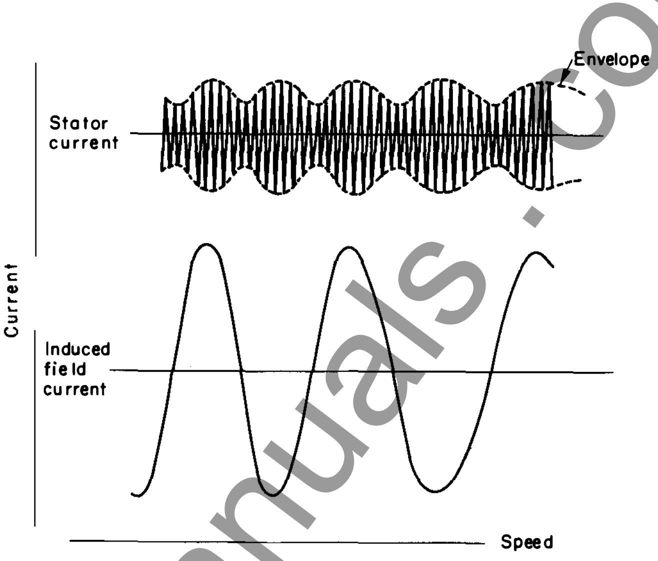


Fig. 9. Stator and field current during acceleration near synchronism, showing decreasing slip (lower frequency)

If direct current is supplied to the rotor and alternating current to the stator, the motor will develop very large oscillating torques but will be incapable of starting from rest. In order to start and accelerate the machine it is therefore necessary to add a squirrel-cage winding. These squirrel-cage bars are embedded in the pole faces of the rotor and connected to end rings. Groups of bars of adjacent poles may be left open-circuited, or the end rings may be continuous around the entire rotor periphery. Hence, the machine may be started and accelerated nearly to synchronism as a squirrel-cage induction motor, with the field disconnected from its d-c supply and usually short-circuited through its starting and discharge resistor. D-c voltage is then applied to the field and the motor synchronizes or pulls in to step and runs at synchronous speed. Thereafter the squirrel-cage serves also as a "damper" winding by modifying the instantaneous speed variations due to sudden changes of load.

Speed-torque curves for typical synchronous motors are shown in Fig. 8. The current which circulates in the short-circuited field winding follows this same general pattern. Figure 9 shows typical speed-current curves. Modulation of the stator current due to salient pole effect is indicated by the dash lines.

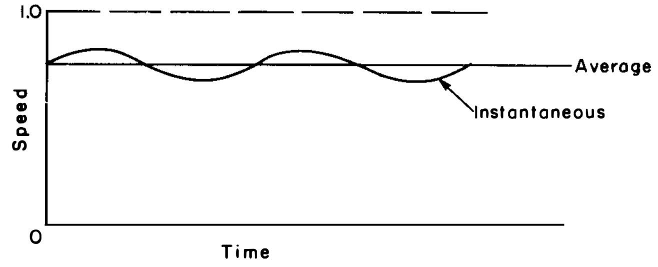


Fig. 10. Average and momentary speed at low slip

Since synchronous motors are started and accelerated as squirrel-cage induction motors, the average curves of Fig. 8 and 9 are similar to those of such machines. At zero speed the frequency of the current in the field and squirrel-cage bars is line frequency, while at synchronous speed it is zero. Under locked rotor conditions the stator current is maximum and the power factor is minimum. As the rotor accelerates from rest, the stator current decreases in magnitude and the power factor increases to a maximum value in the neighborhood of 80 to 90 percent of synchronous speed. Due to the salient pole effect, the stator current is modulated at a frequency which varies, from a maximum value of half line frequency at 25 and 75 percent speed, to zero frequency at standstill, half speed, and full synchronous speed.

Figure 10 shows a speed-time curve of a synchronous motor, operating as an induction motor at a low value of slip, and indicates the variation in instantaneous speed.

PULL-IN TORQUE AND SYNCHRONIZING

Pull-in torque is the maximum constant-load torque against which the motor will pull its connected inertia load into synchronism when d-c field excitation is applied. The higher the WK^2 of the connected load, the closer to synchronous speed the motor must accelerate as an induction motor in order to synchronize when field is applied, or the lower is the load which it will pull in from a given speed. Pull-in torque varies with the angle between the axes of rotor and stator poles at the instant field is applied. Figure 11 shows the maximum pull-in torque which a motor is capable of developing, plotted against angular displacement of the rotor. This curve will differ from one motor to another.

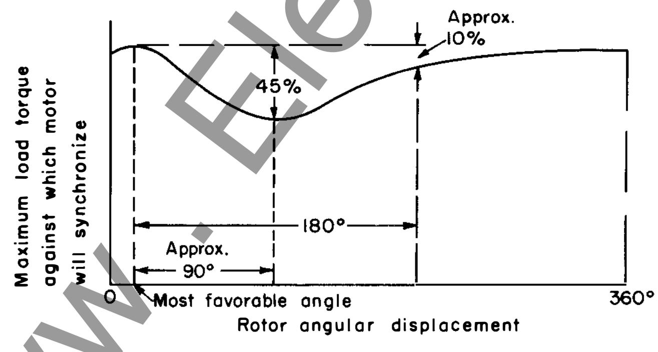


Fig. 11. Variation of synchronizing torque with angle of field application. Most favorable angle is where field current passes through zero in a positive direction

Timing for Maximum Pull-in Torque

Maximum load can be synchronized when field is applied in the region of 15 to 30 electrical degrees beyond the no-load angle. At this point, induced field current is zero and field flux linkages are maximum. If the polarity of applied field excitation is in a direction to increase the flux linkage trapped by closing the field circuit, maximum pull-in torque will be obtained. Minimum pull-in torque is developed approximately 90 electrical degrees beyond this point. There is a gain of approximately 45 percent in synchronizing torque between minimum and maximum. At 180 electrical degrees beyond the maximum point, which corresponds to applied excitation of reversed polarity, the loss in pull-in torque is approximately 10 percent.

Since synchronous motors operate at constant speed, the speed-torque curve for normal operation is a straight line from zero torque to the maximum or pull-out torque.

LOAD ANGLE, NORMAL OPERATION

With field on and the motor operating at synchronous speed, the axes of the rotor poles lag behind the axes of the stator poles by the load angle. As the load is increased, the load angle increases. When this angle becomes one-half pole pitch (90 electrical degrees), or somewhat less for salient pole machines, the torque developed is the maximum the motor can produce. Beyond this point, the magnetic lines of force which drag the rotor around are not strong enough to hold it, and the motor pulls out of step. If field is left on, the motor may stall unless the torque developed in the squirrel-cage winding is able to hold the load at some sub-synchronous speed.

PULL-OUT, OUT-OF-STEP OPERATION

On pull-out under load, if field excitation is left on, the stator current increases, the power factor becomes rapidly lagging, and there are severe current and torque pulsations which might damage the motor or the connected load.

These current pulsations will be reflected into the power system and may build up to a value sufficient

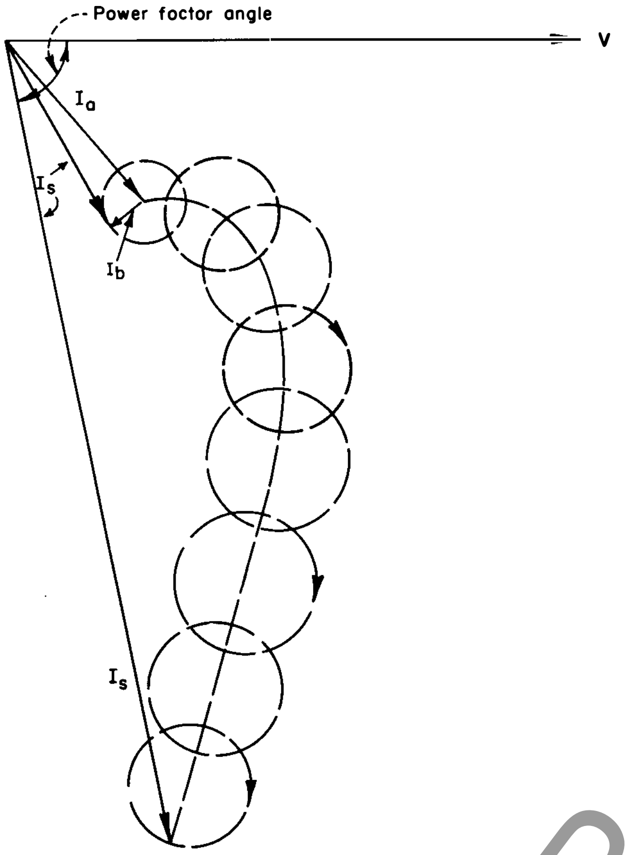
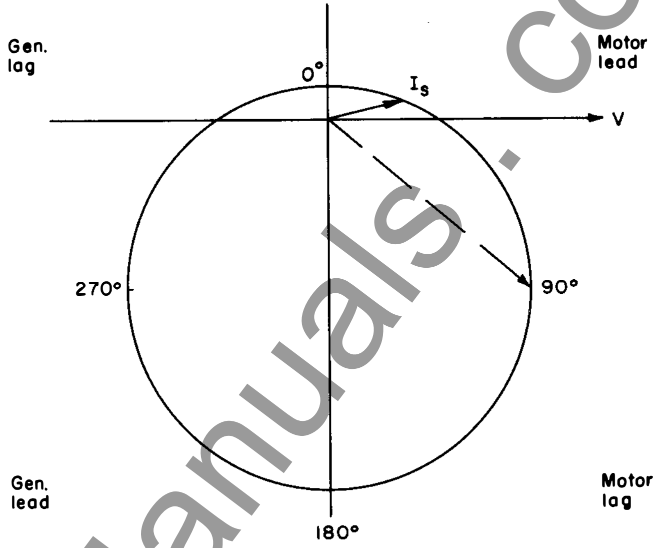


Fig. 12. Vector diagram of one phase of stator current versus power-factor angle during acceleration



(The angles shown denote the approximate load angles.)

Fig. 13. Vector diagram of one phase of stator current versus power-factor angle, with motor operating in synchronism and excitation on. Pull-out is near 90 degrees

to trip feeder breakers and thus result in costly shutdowns of other machines or processes. The magnetic stresses set up in the motor may cause vibration and shifting of the windings, damage or failure of the insulation, or loosening and shifting of the laminations and pole pieces. The torque pulsations have been known to damage motor shafts or bearings, shear off gear teeth, and break drive belts or chains, etc. The machine connected to the motor will be subjected to these severe torque pulsations also and may suffer extensive damage. The speed of the motor may decrease rapidly and the motor may even stall, depending on the torque requirements of the load and the design of the particular motor. It is therefore important that excitation be removed from the motor as rapidly as possible, but not prematurely. It will be shown how G-E control accomplishes this within the first slip cycle out of synchronism.

In Fig. 12, starting current during acceleration is represented as I_s which is made up of two components: forward component I_a and backward component I_b. Near synchronous speed, I_b rotates at twice slip frequency. The locus of the tip of the current vector is in the form of a spiral, from the instant of start to its maximum speed as an induction motor. Figure 13 is a four-quadrant vector diagram of one phase of a polyphase synchronous motor, showing the relationship of line voltage and stator current with respect to power-factor angle. Vector I_s is shown as normal full-load current for a leading power-factor machine. The synchronous characteristic circle shows the value and phase angle of vector I_s, as power factor and load angle are varied with the machine in synchronism

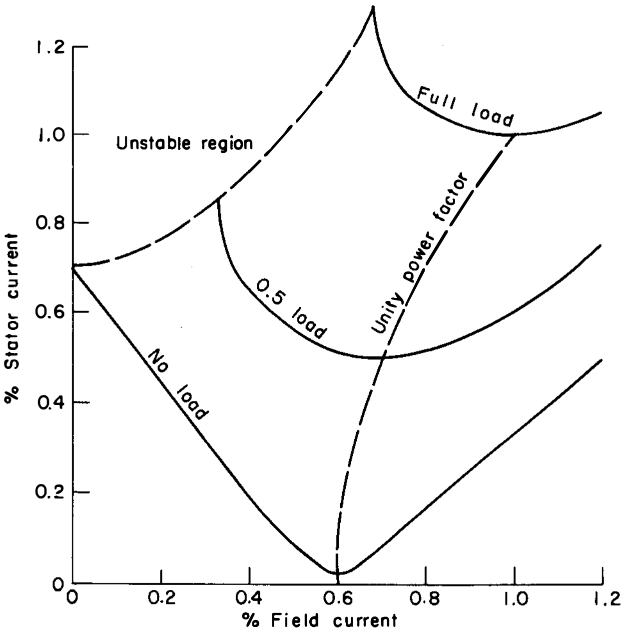


Fig. 14. Typical stator-field current V curves

and with rated excitation. Reduction of excitation reduces the radius of the circle. At an angle of approximately 90 degrees, maximum steady-state torque is developed. With oscillating loads it is possible to swing the rotor to a maximum load angle of approximately 120 degrees, yet the motor may recover and remain in step if the load is removed quickly enough.

Standard motors are usually rated on the basis of 1.0 or 0.8 power factor leading at full load, with rated excitation. Leading power-factor motors can be used to drive a mechanical load and, at the same time, provide leading reactive kva to improve the power factor of the system. The power factor and the stator current vary with the direct current supplied to the field winding. See typical V curves in Fig. 14. With a given load and a certain field current, let us assume the power factor is unity. The stator current is minimum. Now if field current is decreased, stator current increases and the power factor becomes lagging. If field current is increased, stator current increases and the power factor becomes leading.

FUNCTIONAL REQUIREMENTS OF CONTROL

Motors should be carefully selected to suit the starting and running conditions imposed by their driven loads. So also should the devices which control these machines be wisely selected to meet the electrical limitations of the power system to which they are to be connected and the mechanical limitations of the load. Before any motor can be used, means must be provided to connect it to its source of power, to control its acceleration, to stop it, and to protect its windings from damage due to thermal overload and electrical circuit faults. These functions must be performed by the control efficiently and economically without penalizing the motor by distorting its characteristics. Control for synchronous motors must provide all of these primary functions and, in addition, must also apply d-c excitation at proper speed and angle at pull-in, must remove field excitation promptly on pull-out, and protect the squirrel-cage winding against overheating under stall conditions or while operating as an induction motor at speeds below synchronism.

STARTING

The motor may be started by applying either full voltage or reduced voltage to the stator winding. Full-voltage starting requires that the motor windings be sufficiently braced and the mechanical structure of both motor and connected load be sufficiently rigid to withstand the stresses produced by the high inrush current and the sudden application of maximum starting torque. This method is the simplest and is the most economical in cost of equipment, cost of power involved in starting, and in time required to accelerate. Most modern motors meet these requirements. A typical starter of this classification is illustrated in Fig. 15. However, because of limitations of the power system or mechanical limitations of the load or of the motor, it may be necessary to reduce the current drawn from the line, or the torque applied to the load, during starting. Special motors with multiple-circuit stator windings may be started by energizing one winding and then energizing successive parallel circuits in steps, at full voltage, until the full winding is in use. This method reduces the starting current and the starting torque in various combinations depending on motor design. Figure 16 shows typical connections of one phase of a part-winding motor stator.

Any of the conventional methods of reduced-voltage starting may be used with synchronous motors. One method is by use of a voltage transformer, the most economical being an autotransformer. This is the most efficient method of reducing the motor-starting current but is usually the most expensive. Voltage applied to the motor is a reduction from the line voltage in proportion to the turn ratio of the transformer, and it is practically constant during the starting period. Standard taps provide 50, 65, and 80 percent voltage to the motor. Motor current is reduced in direct proportion to tap voltage, but current drawn from the line varies as the square of the

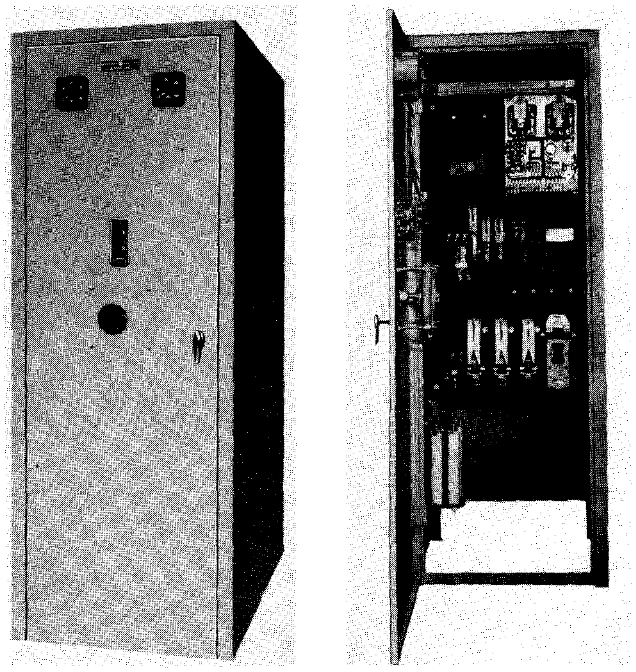


Fig. 15. Front views of full-voltage, low-voltage synchronous-motor control, with field control at upper right

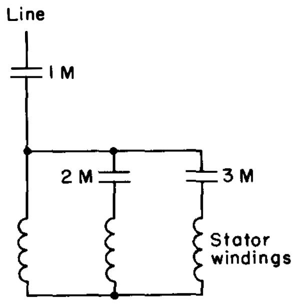


Fig. 16. Three-step, part-winding starting (one-phase shown)

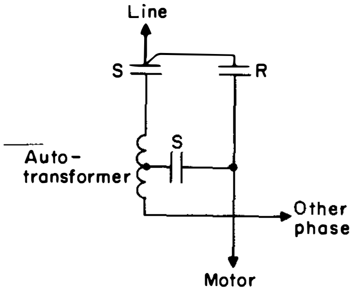


Fig. 17. Autotransformer starting with open-circuit transition

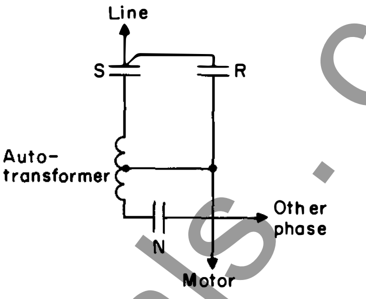


Fig. 18. Autotransformer starting with closed-circuit transition

tap voltage, if transformer magnetizing current is neglected. Starting torque is reduced in the same proportion as line current.

Figure 17 shows motor connections using an autotransformer for reducing the starting voltage. Contactor S is a 5-pole device and connects motor and line to the autotransformer. After the motor has accelerated, contactor S is opened, disconnecting the motor; and contactor R is closed, energizing the motor at full-line voltage. This arrangement provides an open-circuit transition which is required to prevent S and R from being closed at the same time and short-circuiting a portion of the autotransformer. A modification of this circuit to permit a closed-circuit transition can be accomplished as shown in Fig. 18 in which S and N are closed initially for starting. After acceleration N is opened, R is closed; then S is opened. This leaves the motor connected to the line through contactor S and a portion of the autotransformer winding, as a series reactor during the period of transition from reduced voltage to full voltage. Figure 19 illustrates a low-voltage autotransformer starter.

Another method of obtaining reduced voltage for starting is by inserting a series resistor in each phase of the line to the motor. After the machine has accelerated, these resistors are shorted out in one or more steps, depending upon power system limitations or torque requirements. Motor current is the same as current drawn from the line. Starting torque is reduced by the square of the ratio of applied motor voltage to line voltage.

A series reactor in each phase of the power supply will also reduce the voltage at the motor terminals. This reactor may be shorted out after the motor is up to speed. Impedance drop across the reactor reduces motor voltage and motor current. Starting torque varies as the square of the ratio of motor voltage to line voltage. As the motor accelerates, the drop across the reactor decreases, the power factor increases and the reactor drop swings out of phase with the motor voltage. Applied voltage to the motor thus increases during acceleration more than in resistor starting and the maximum torque is greater. Figure 20 illustrates speed-torque curves with various types of motor starting.

THERMAL PROTECTION

Stator running-overload protection is provided to prevent damage due to overheating of the stator windings when operating under mechanical overloads. Motors rated 40C rise have a 1.15 service factor while those rated 50C rise are maximum rated. These machines carry their rated loads continuously without exceeding rated temperature rise. Loads above rated value will cause overheating. These over-temperatures, if not excessive or prolonged, may not cause

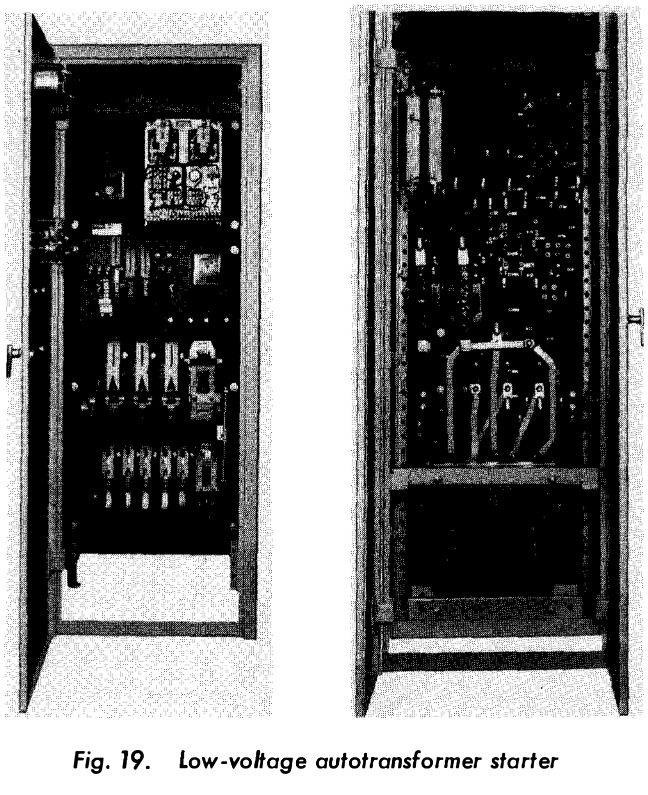


Fig. 19. Low-voltage autotransformer starter

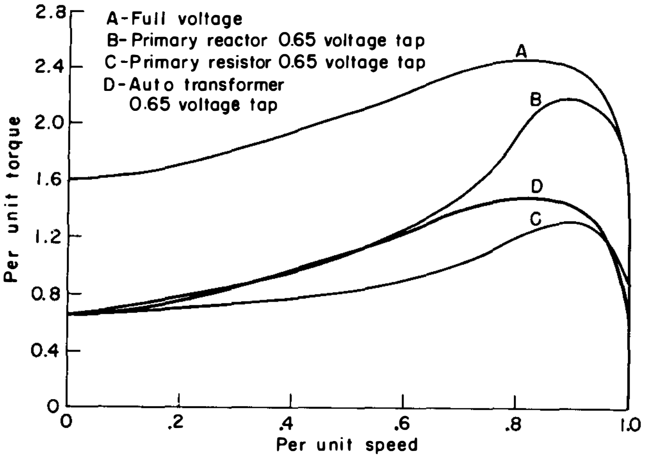


Fig. 20. Synchronous-motor speed-torque curves obtained under various methods of starting

apparent damage immediately but life of the insulation will be reduced and repeated overheatings, however slight, will in time result in failure. The problem is to have the thermal overload relay fully protect the motor. Thermal overload relays should have tripping characteristics that closely follow the motor heating curve as shown in Fig. 21. Different motors have different heating characteristics as do various types of stator overload relays. Figure 21 represents average conditions.

When the motor is running as an induction motor, a thermal overload relay is connected in the field discharge circuit to protect the squirrel-cage winding against overheating. A reactor is connected in parallel with this relay. At start, the frequency of the current through this combination is at line frequency, but decreases as speed increases. The impedance of the reactor thus varies inversely as the speed of the rotor and takes more of the current from the relay as the motor accelerates. By a proper combination of reactor impedance and relay-heater resistance, a tripping characteristic comparable to the squirrel-cage heating curve may be obtained. The individual components of this combination must not be replaced independently, since the heater, the bimetal strip and the reactor coil are calibrated ***as a unit*** to fit the particular machine.

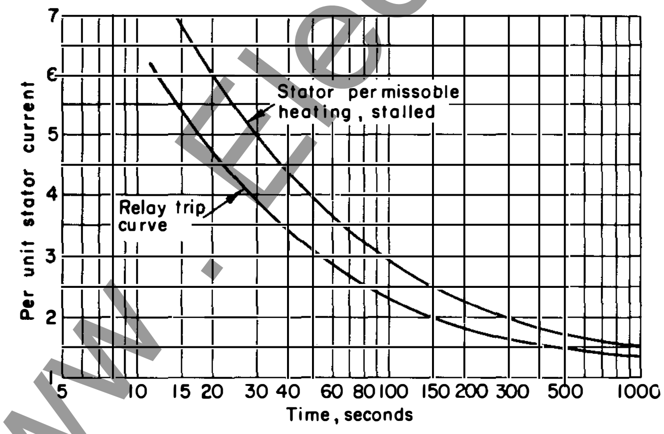


Fig. 21. Motor heating and thermal relay tripping curves should correspond for adequate protection

Since the selection and calibration of this device at the factory is based on calculated information furnished by the motor designer, any tripping of the trip element before the motor reaches synchronous speed must not be corrected by an arbitrary change of heater or by bending of the bimetal strip, for this will spoil the calibration and may result in loss of protection. The bimetal strip setting also may not necessarily correspond to the 90C ambient setting of strips used in stator overload devices. Hence, if cases of this nature are encountered, report to the Service Engineering group at the factory giving the actual measured induced-field current during starting, the actual starting voltage applied to the motor terminals, the accelerating time and the actual relay trip time. A new combination may then be selected to meet the actual service conditions under which the motor is being operated.

PROTECTION AGAINST SYSTEM FAULTS

NEMA Class A standards require that the control interrupt only ten times motor full-load current, that is, locked-rotor current. However, the use of increasingly higher voltages and "stiffer" systems, capable of producing greater short-circuit currents, makes it necessary that control equipment be built to clear faults and protect the motor and its connecting leads. A goodly portion of existing installations is wholly inadequate to properly provide fault current protection, and too often new equipment is being added to expanding power systems without proper consideration being given to this very important question. Part of the reason for this may be that users are not aware of the seriousness of the hazard of improper protection, and part probably due to the fact that this type of protection is expensive. The extent of damage incurred is determined by the energy dissipated in the fault and, therefore, it is advantageous to clear the fault as soon as possible.

The controller must interrupt the full available short-circuit current. This involves complete coordination of all current-carrying parts. Current transformers, thermal-overload relays, contactor or breaker tips and shunts, bus and bus risers, etc., must all be adequate, thermally and mechanically, to withstand the temperatures and stresses resulting from fault currents. Interrupting ability may be provided by the use of oil or air circuit breakers, by the more economical combination of fuses and contactors, or by the introduction of a reactor to limit the amount of short-circuit current to a value which may be safely interrupted by the equipment.

The use of fast-acting current-limiting fuses permits the use of contactors which by themselves could neither carry nor interrupt the high-fault currents available. The short-circuit current that a system is capable of producing requires time to build up to its maximum. Current-limiting fuses operate at values of current much below the system peak, and so rapidly that the contactor and other current-carrying parts are never subjected to the full amount the system could produce. Figure 22 shows how the characteristics of fuse melting, thermal-overload relay tripping, and contactor current-carrying and interrupting ability are co-ordinated to give complete over-all protection.

High-voltage, high-interrupting-capacity synchronous motor starters made by the General Electric Company are known as Limitamp equipment and are illustrated in Fig. 24.

FIELD APPLICATION

The earliest control devices were manually operated. The sequence of operation was left to the discretion of the operator, who by observation or by sound, attained in time no small degree of skill in determining adequate timing. The inherent electrical hazard of hand-operated devices by unskilled personnel and the manual labor involved are reasons for a change from this practice but most important is the better performance obtained from magnetic equipment, especially where timing sequence is involved.

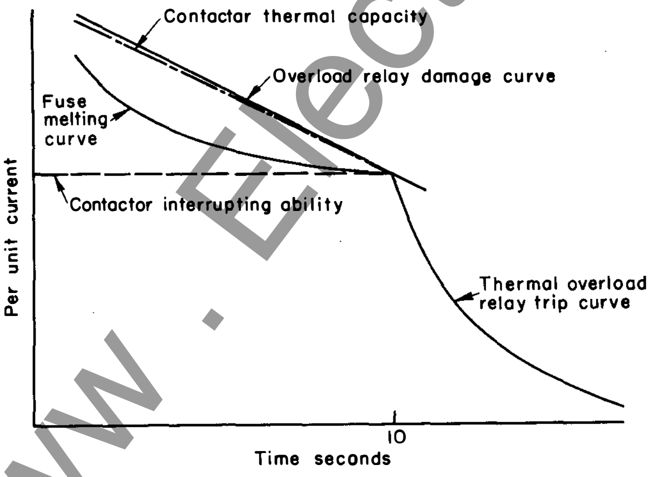


Fig. 22. Curves showing co-ordination of current-limiting fuse, contactor and thermal relay characteristics

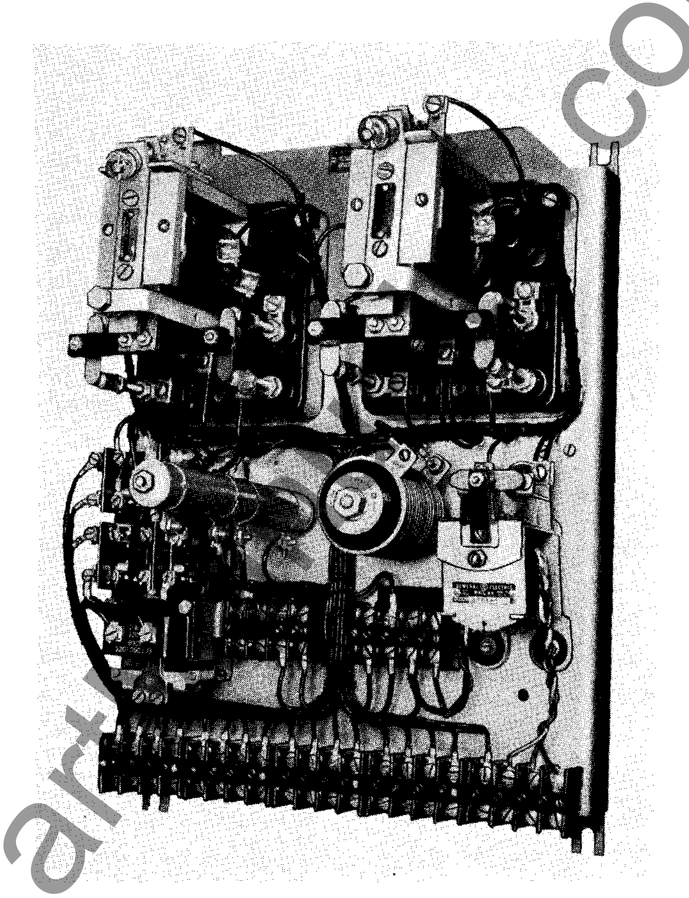


Fig. 23. Field-control panel subassembly. Field-applying relay and its auxiliary are at top; power-factor field-removal relay is below at right

For synchronous-motor control, the first attempts at automatic operation were made in the application of field excitation.

Various devices, using slip-frequency and amplitude of the induced-field current during starting, have been manufactured. Most of these rely on this signal to initiate field application, although others also make use of it for field removal.

The trend throughout has been toward entirely automatic operation under all conditions, and equipment which gives complete over-all protection. Totally enclosed equipment is being supplied to protect personnel from accidental contact with live parts, and to protect devices from dust and dirt. A line ammeter, field ammeter, and means for adjusting field current, are provided as standard equipment.

The G-E field-control system described herein provides that the control lead the motor through starting, acceleration, pull-in, running operation, and pull-out from any cause, taking full advantage of the motor's available characteristics and assuring complete over-all protection against abnormal conditions. Features of simplicity and sturdiness, ease of installation, adjustment, and maintenance have been incorporated.

This field-control system employs separate relays for field application and field removal. The field-application relay operates in response to the changing frequency of the current, induced in the field winding as the motor approaches synchronous speed. The field-removal relay operates on the change of power factor of the motor as it pulls out of step. The field control panel is illustrated in Fig. 23 and includes all devices for control of the field, except the field contactor itself, mounted on a steel base as a front-connected unit assembly.

Field-applying Relay

Refer to Fig. 25. The field-applying relay and its auxiliary relay are exactly alike except for coils. They are made front-connected and have individual molded bases for mounting on steel. Sliding bimetal shims, by which the amount of magnetic material in the air gap may be changed, provide easy adjustment of time dropout. The timings are consistent since the air gap itself remains uniform throughout the adjustment range. The field relay has two coils; the first or closing coil is a d-c coil operating on the excitation voltage; the second or synchronizing coil operates from a tap in the discharge resistor through a half-wave rectifier.

Referring to the elementary diagram, Fig. 3, of a typical full-voltage starter, it will be noted that when the START button is pressed, relay FCX picks up, followed by the main line contactor M. This energizes the closing coil of relay FR which picks up at a relatively low voltage to energize relay FRX. Relay FRX is set to pick up at a voltage high enough for synchronizing and thus provides a d-c voltage check to prevent closure of the field contactor unless or until

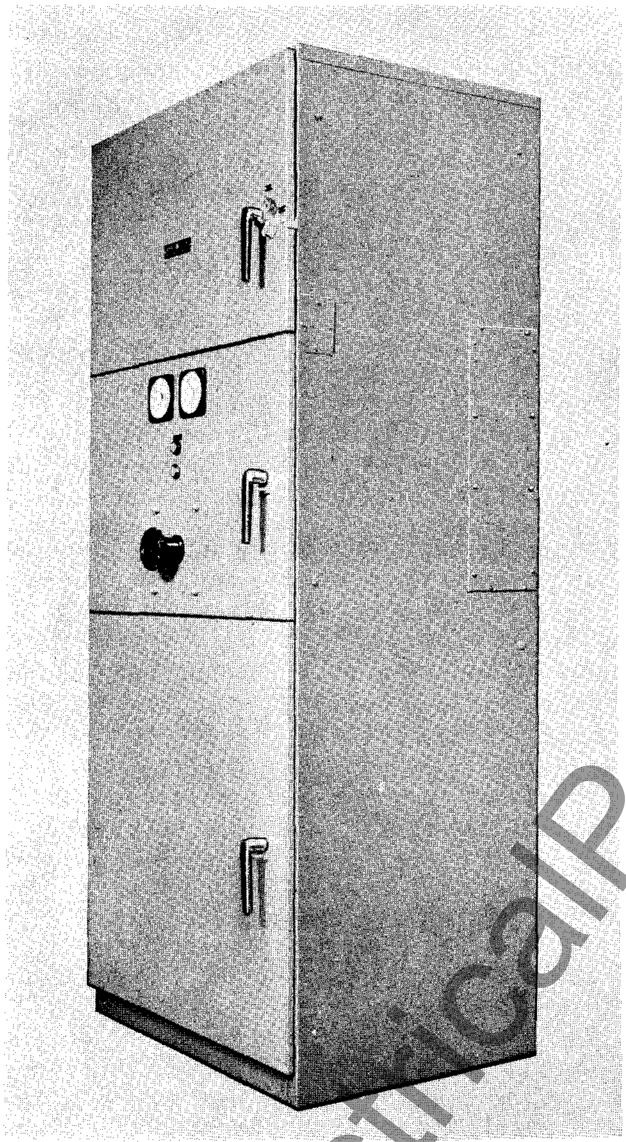


Fig. 24. Limitamp equipment

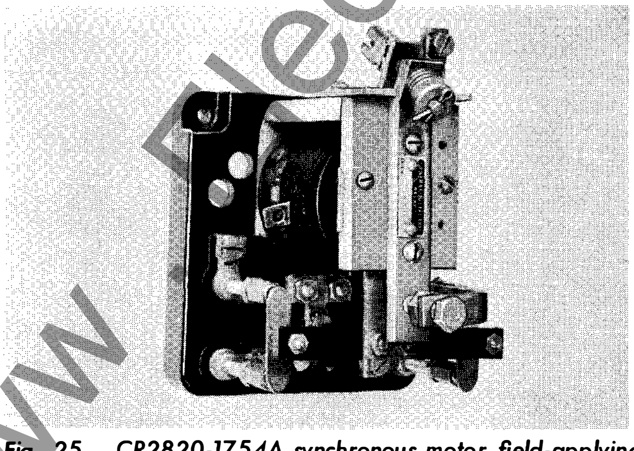


Fig. 25. CR2820-1754A synchronous-motor field-applying relay

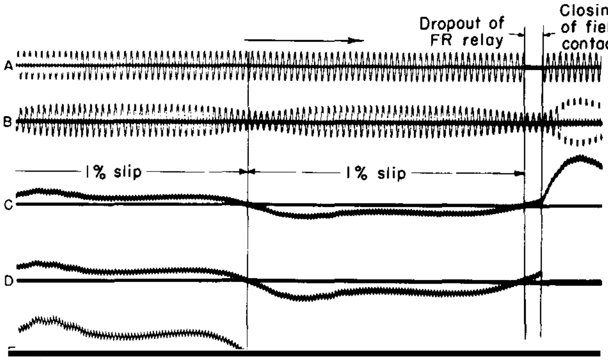


Fig. 26. Oscillogram showing d-c field application from constant slip of one percent from synchronism

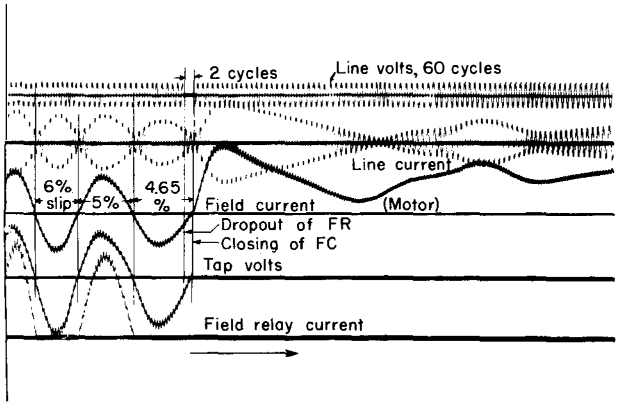


Fig. 27. Oscillogram showing d-c field application from five percent slip, with motor accelerating

sufficient d-c excitation voltage is available to pull the machine into step. When relay **FRX** picks up, relay **FR** is then held in by induced-field current. Successive half waves of induced-field current are blocked out by the half-wave rectifier. As the speed of the motor increases, the time between current pulses in the relay increases until near synchronism and at the time setting of the relay, **FR** will drop out. The field contactor **FC** is thus energized. By blocking out the proper half cycle of induced-field current, it is possible to polarize relay **FR** so that field excitation will always be applied in the proper direction. By adjustment of the time of dropout of relay **FR**, it is possible to select the proper speed at which excitation is applied to the field coils.

The oscillogram of Fig. 26 includes, from top to bottom, a 60-cycle timing wave, line current, field current, tap voltage from the discharge resistor and relay **FR** coil current. The break in the timing wave indicates the opening of relay **FR** and the closing of the field contactor. The time dropout of relay **FR** is set to correspond to the speed of the rotor at a given slip as measured by the distance between successive half cycles. At a given constant slip, relay **FR** drops out at the end of the blocked-out half cycle to close the field contactor about 1½ to 2 cycles later.

From Fig. 11 it was noted that the most favorable angle at which to apply field is at the point where induced-field current is passing through zero in the same direction as the applied field current, in order to trap maximum flux linkages. Figure 26 indicates that, at constant slip, field excitation is applied very slightly beyond this most favorable angle.

If load conditions or other factors are such that the machine is able to accelerate during the time relay **FR** is timing out, field will be applied earlier. Figure 27 illustrates that, with relay **FR** set for 5 percent slip, during the next half cycle the rotor has accelerated to 4.65 percent slip. Relay **FR** thus drops out before the zero point but contactor **FC** closes at the ideal point, with the most favorable angle, with maximum pull-in torque and least line-current surge. Since any variation in the downward speed of the rotor will not allow relay **FR** to drop out, it follows that any speed variation from the relay setting must be upward. If this occurs, the tendency will be to apply field earlier.

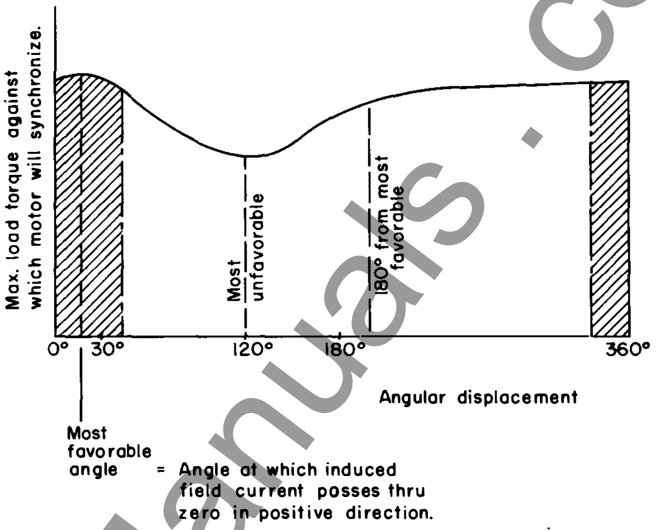


Fig. 28. Synchronizing torque curve with shaded area showing region of operation of field-applying relay

Figure 11 may then be redrawn as shown in Fig. 28 in which the shaded area indicates the operating range of relay **FR**. Any portion of this shaded area is still in a very favorable torque region, and a long way from the valley of the torque curve and the worst angle. The entire range of time setting can be obtained, with one spring setting and one gap setting of the relay, merely by adjustment of the shim position, ***except for one per cent slip on 25- or 40-cycle machines.***

The time settings for relay **FR** shown on page 8, when tested from a d-c supply, indicate times which are somewhat longer than the actual time length of one half slip cycle. The a-c wave which passes through the **FR** synchronizing coil will actually begin desaturating the relay before the zero point is reached. The difference in time between the d-c setting and the a-c setting thus takes into account this desaturating effect at various speeds, and has been carefully predetermined by actual tests. If it is necessary to measure the time dropout of relay **FR** in order to assure field application at a definite speed, energize the **FR** closing coil from its rated d-c voltage, then measure the dropout time by means of a synchronous timer after release. The following circuit may be used.

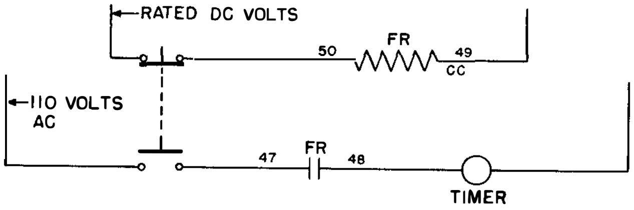


Fig. 29.

If the developed torque of the motor is not sufficient to enable the machine to accelerate to the speed for which the field-applying relay is set, the field contactor will not close, and the motor will not synchronize. The table on page 8 indicates the time drop-out settings of the **FR** relay for various synchronizing speeds. It is a very simple matter to check the actual motor speed without resorting to the use of a tachometer; provided, of course, that the motor is not accelerating, but is running at a constant speed during the time required for the following test:

Connect a high-resistance d-c voltmeter across the synchronizing coil of the **FR** relay (leads 42 and **R**3) and count the number of pulses of the meter during approximately one half minute. From the following table determine the motor speed.

PERCENT MOTOR SPEED	PERCENT SLIP	POWER SYSTEM FREQ. 60	50	40	25
		Number of pulses on meter per second			
100	0	0	0	0	0
99	1	0.6	0.5	0.4	0.25
98	2	1.2	1.0	0.8	0.50
97	3	1.8	1.5	1.2	0.75
96	4	2.4	2.0	1.6	1.00
95	5	3.0	2.5	2.0	1.25
94	6	3.6	3.0	2.4	1.50
93	7	4.2	3.5	2.8	1.75
92	8	4.8	4.0	3.2	2.00
91	9	5.4	4.5	3.6	2.25
90	10	6.0	5.0	4.0	2.50
75	25	15.0	12.5	10.0	6.25
50	50	30.0	25.0	20.0	12.50
0	100	60.0	50.0	40.0	25.00

FIELD REMOVAL ON PULL-OUT

The power-factor field-removal relay (**PFR**) is illustrated in Fig. 30 and consists of a potential coil connected across lines 1 and 2 of a three-phase system, and a current coil connected in line 3. This results in a 90-degree relation between the fluxes of the two elements with the motor operating at unity power factor. For a two-phase system, the 90-degree relation is provided by connecting one coil in each phase. The two coils are wound, one on top of the other on the same spool.

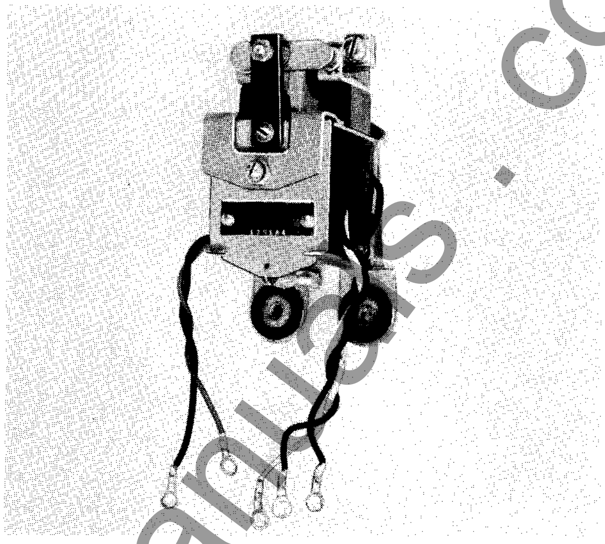
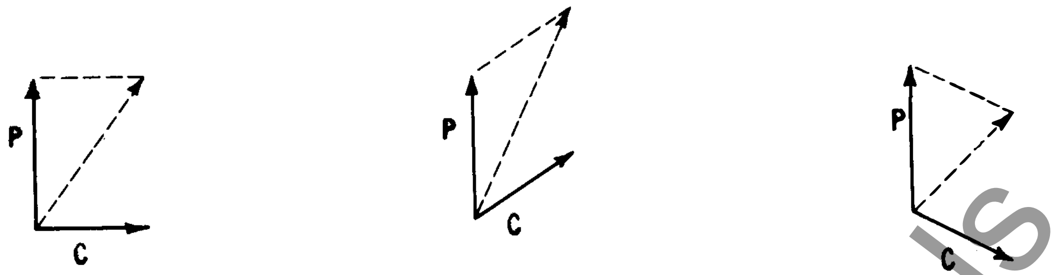


Fig. 30. CR2820-1751A power-factor field-removal relay

Figure 31a illustrates the vector relations of **PFR** coils when correctly connected, while Fig. 31b shows the effect when the current coil is reversed with respect to the potential coil. From these it will be evident that on three-phase systems, incorrect connections, due to reversed potential coil, reversed current coil or phase sequence other than as shown, can be corrected by merely reversing the potential coil connection. A terminal board is provided on the field panel so that this may be easily accomplished.

A certain value of effective ampere turns is required to pick up and hold the relay closed. Either the current coil or the potential coil will provide sufficient mmf (magneto-motive force) to do this. As mechanical load is increased to the point of pull-out, the line current increases and becomes more lagging. If properly connected, at a point slightly beyond pull-out, the current coil mmf will be sufficient to buck down the potential coil mmf to the point where the relay will drop out. This same demagnetizing action will take place whether the line current goes too far lagging due to mechanical overload, or too far leading due to pump-back loads. This is shown in Fig. 32. Any value of current which falls inside of the relay characteristic circle will open the relay contacts, since here the current coil mmf opposes that of the potential coil.

Upon the loss of d-c voltage, the machine would operate as an induction motor at a slip depending on the load. In all cases, the values of motor line current

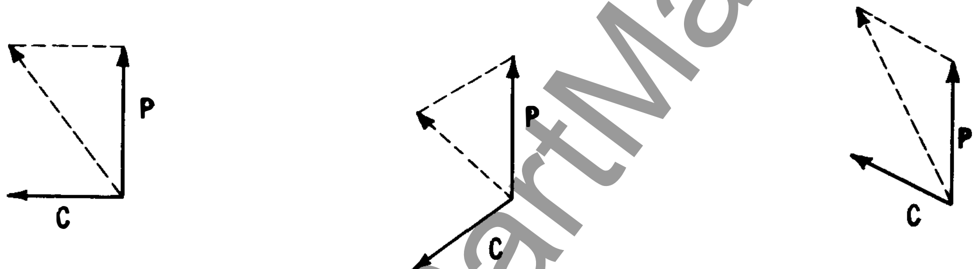


Unity P.F.
C—Coil current 90° behind P

Leading P.F.
C—Coil boosts P

Lagging P.F.
C—Coil bucks P. Relay drops out as motor approaches 90° lag after pull-out

Fig. 31a. Vector relations of coils on relay PFR when properly connected. Dotted vector represents effective ampere-turns in relay. P—potential coil, C—current coil



Unity P.F.
C—Coil current 90° ahead of P

Leading P.F.
C—Coil bucks P

Lagging P.F.
C—Coil boosts P. Relay would hold in with motor P.F. at 90° lagging after pull-out

Fig. 31b. Vector relations of coils on relay PFR when improperly connected (C—coil reversed). Dotted vector represents effective ampere-turns in relay. P—potential coil, C—current coil

and power factor will be such that its locus will fall within a sector of the **PFR** relay circle in the lower right-hand quadrant before the motor speed drops to 85 percent of full speed.

For each value of voltage on the potential coil there is a pick-up circle and a drop-out circle; the dropout being inside as shown in Fig. 32

Assuming that field removal only is desired, the field-applying relay **FR** should promptly take over after relay **PFR** opens on pull-out. The closing coil on relay **FR** is provided to make sure that relay **FR** will pick up promptly under this condition without it being necessary for motor speed to drop to the point where the **FR** synchronizing coil might otherwise close the device.

Currents outside of the pick-up circle close **PFR** contacts. Currents inside the drop-out circle open **PFR** contacts. For a combination of normal voltage and normal starting current during acceleration, the current should remain inside the pick-up circle so as not to close the contacts. The increase of a-c voltage moves both circles down from the origin. For test purposes during installation, the circles are pushed down only far enough to be certain that the relay does not pick up if properly connected. This is done by means of a tapped resistor connected in series with the **PFR** potential coil.

The current portion of the **PFR** coil has two sections consisting of the entire winding and a tapped portion of the winding. This tapped portion is provided to cover wide ranges of pull-out currents.

Selection of the proper connection on the **PFR** relay current coil is made at the factory in accordance with the following table.

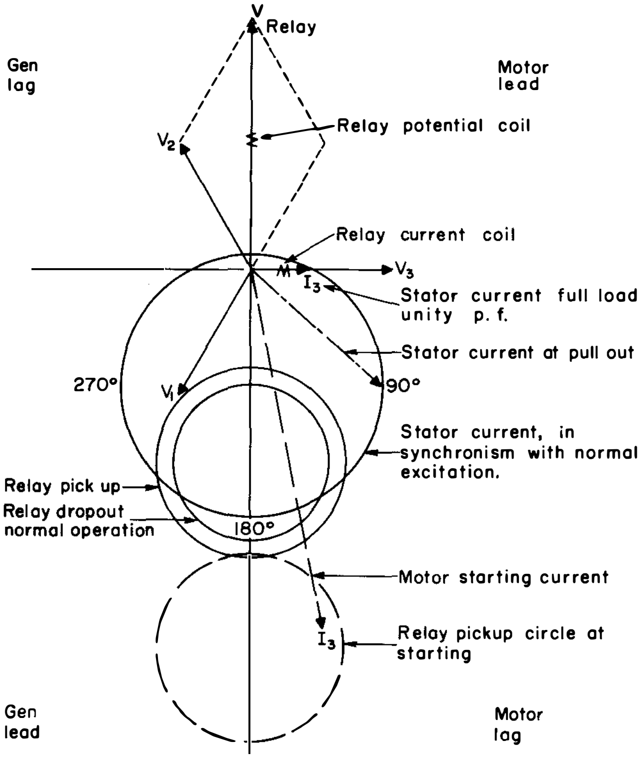


Fig. 32. Vector diagram of power-factor field-removal relay characteristics compared with motor characteristics

MAX. CURRENT WITH NORMAL* EXCITATION (Percent of full load)	STARTING CURRENT (Percent of full-load current)	CONNECT	
		Lead No. to	Coil Term. No.
170 to 330	250 to 700	60	61
		(Pt. 1 on diagram furnished with panel)	
250 to 330	700 to 850	60	62
330 to 430	350 to 850	(Pt. 2 on diagram)	

* *In first slip cycle after pull-out.*

For normal starting, the circles must be pushed down far enough to be sure that starting current gets outside of the circle near the synchronizing point to allow for low voltage, light loads, synchronizing on reluctance torque, etc., since the relay contact must close when the machine pulls into step.

The FCX relay contact 12-14 is used to short out part of the potential-coil series resistor, in order to push the relay characteristic circle outward during starting, and contact 12-13 is used during test for the same purpose.

The time delay dropout of relay **FRX** short-circuits **PFR** contact 17-18 to allow time for the machine to assume its normal load angle after synchronizing.

Figure 31 represents the four quadrants of motor and generator operation and shows voltage and current vectors of the motor and of the relay for starting, normal operation and pull-out conditions. The motor characteristics are taken from Fig. 12 and 13. Currents outside of the pick-up circle of the relay (with potential coil energized) close the relay contacts. Currents inside of the drop-out circle open the relay contacts. For starting, then, it is necessary to move the pick-up circle outward to keep the stator-starting current vector inside the circle initially but to permit this vector to fall outside of the circle, and **PFR** contacts to close, as the machine comes up to speed. The increase of a-c voltage applied to the relay will move this circle downward. Complete pull-out protection is provided (pull-out due to loss of a-c or d-c voltage or excess mechanical load) by drawing the circle inward under normal operation. This is accomplished and the relay in effect recalibrated by changing the a-c voltage applied to the relay by means of changing the amount of the resistance in series with its potential coil.

It will be noted that the relay will permit wide load swings in either the motor region or the generator region without removing field prematurely, but will definitely and positively remove field excitation within the first slip-cycle out of synchronism.

The importance of this was shown on page 11. The power-factor method has been proved to be the most effective means for obtaining rapid removal of excitation. Systems which depend upon a signal from the field circuit must wait until pole slippage occurs before the signal appears.

Relay **FCX** provides the interlocks to control the resistor which recalibrates relay **PFR**. Time delay contacts on **FRX** short out **PFR** contacts for a time sufficient for the motor to stabilize after synchronizing.

The test for polarity shown on page 7 may not be a conclusive test under exceptional conditions since it may be difficult to detect whether or not the relay contacts remain open during acceleration of the motor. Motors in certain applications, when started at full voltage with very light loads, will accelerate so rapidly that the time when the contacts would normally remain open with correct connections is extremely short. Also, when using reduced-voltage starting on motors which have very low normal full-voltage inrush currents, the motor-starting current may then fall just outside of the relay pickup circle, and the relay contacts will close even though the potential coil is connected with correct polarity. This will occur only on those equipments which were furnished with only one tap on resistor 1RS, assuming that the current transformer ratio and the current coil tap were correctly selected. For these exceptional cases, if it is necessary to resort to further tests, the following procedure will give a positive check for correct polarity. Connect a high-resistance voltmeter (such as a Simpson or Triplet circuit analyzer, with at least 5000 ohms per volt) directly across the potential coil of relay PFR (leads 15 and 16). Record the readings of this voltmeter as the motor is being started with coil leads 15 and 16 connected first in one direction, then in the other. The connection which gives the *lowest* voltage reading during starting is the *correct* connection.

Contacts are provided on relay FCX for use in automatic unloader circuits and for field forcing of exciters during starting. As shipped, the circuit also provides motor shut-down on pull-out. By adding jumpers, it is easily possible to change for field removal only on pull-out if the motor torque or load conditions permit resynchronizing after pull-out.

OTHER FEATURES

Contacts are also provided for use in automatic unloader circuits of compressor drives, and for use in field forcing of direct-connected exciters during starting.

The circuit of Fig. 3 may be easily changed by means of jumpers on the terminal board to provide either motor shutdown on pull-out, or field removal only if the motor torque or load conditions permit resynchronizing after pull-out.

High voltage starters include time-delay undervoltage protection which may be made instantaneous, if desired, by means of a simple jumper connection.

OTHER DEVICE INSTRUCTIONS

Since this is a general instruction book applying to full voltage and to reduced voltage starters, low voltage as well as high voltage, it should be understood that not all of the following devices will necessarily be supplied as a part of any one particular equipment.

Normally, the instructions required for any equipment are supplied with the starter. If for any reason additional copies are desired, order from the nearest G-E office from the following partial list:

Field contactor CR2810-1357	GEH-637
Auxiliary relay CR2811-B11	GEH-1484
Thermal relay CR2824	GEH-888
Timing relay CR2820-1740	GEH-1223
Time-delay undervoltage system	GEI-42540
Line contactors	
*CR2811R	GEH-1306
CR2811E11	GEH-1481
CR2810-1863	GEH-1293
*CR2810-1563	GEH-768
*CR2810-1573	GEH-1039
*CR2810-1251	GEH-273
*CR2810-M13	GEH-1926

RENEWAL PARTS

PRINCIPAL RENEWAL PARTS FOR IC7069-B1C FIELD PANEL

DESCRIPTION	CAT. NO.
Principal Parts List for:	
One CR2810-A11AP Contactor—	
Complete set of stationary and movable contacts, springs, and screws for one pole (8 required)	6960045G11
Coil	Order by Cat. No. Marked on Coil
One *CR2820-1754A Relay—	
Movable contact (2 required)	3667572G1
Stationary contact (4 required)	3614137G1
Contact screw (1 required)	2840219G1
Contact spring (2 required)	2411917
Armature spring (1 required)	235184
Coil	Order by Cat. No. Marked on Coil

DESCRIPTION	CAT. NO.
One *CR2820-1751A Relay—	
Movable contact (1 required)	3667572G1
Stationary contact (2 required)	9385130G1
Contact spring (1 required)	2419415
Armature spring (1 required)	2418828
Coil	Order by Cat. No. Marked on Coil

For complete Renewal Parts see Renewal Parts Bulletin GEF-3625.

For principal renewal parts lists for some of the other devices, refer to device instructions listed on this page or for complete renewal parts of any device refer to nearest General Electric sales office.

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* *Also identified with the prefix IC instead of CR.*

WHEN YOU NEED SERVICE

IF YOU NEED TO REPAIR, recondition, or rebuild any electric apparatus, a G-E service shop near you is available day and night, seven days a week, for work in the shops or on your premises. Latest factory methods and genuine G-E renewal parts are used to maintain the original performance of your G-E equipment. For full information about these services, contact the nearest service shop or sales office listed below:

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Louisville, Ky............2014 New Main St.
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Milwaukee 3, Wisc.....940 W. St. Paul Ave.
Minneapolis 12, Minn.....2025 49th Ave., N.
New York 14, N. Y..........416 W. 13th St.
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San Francisco 3, Calif......1098 Harrison St.
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Spokane 3, Wash........S. 115 Sherman St.
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Denver 2, Colo.........650 Seventeenth St.

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