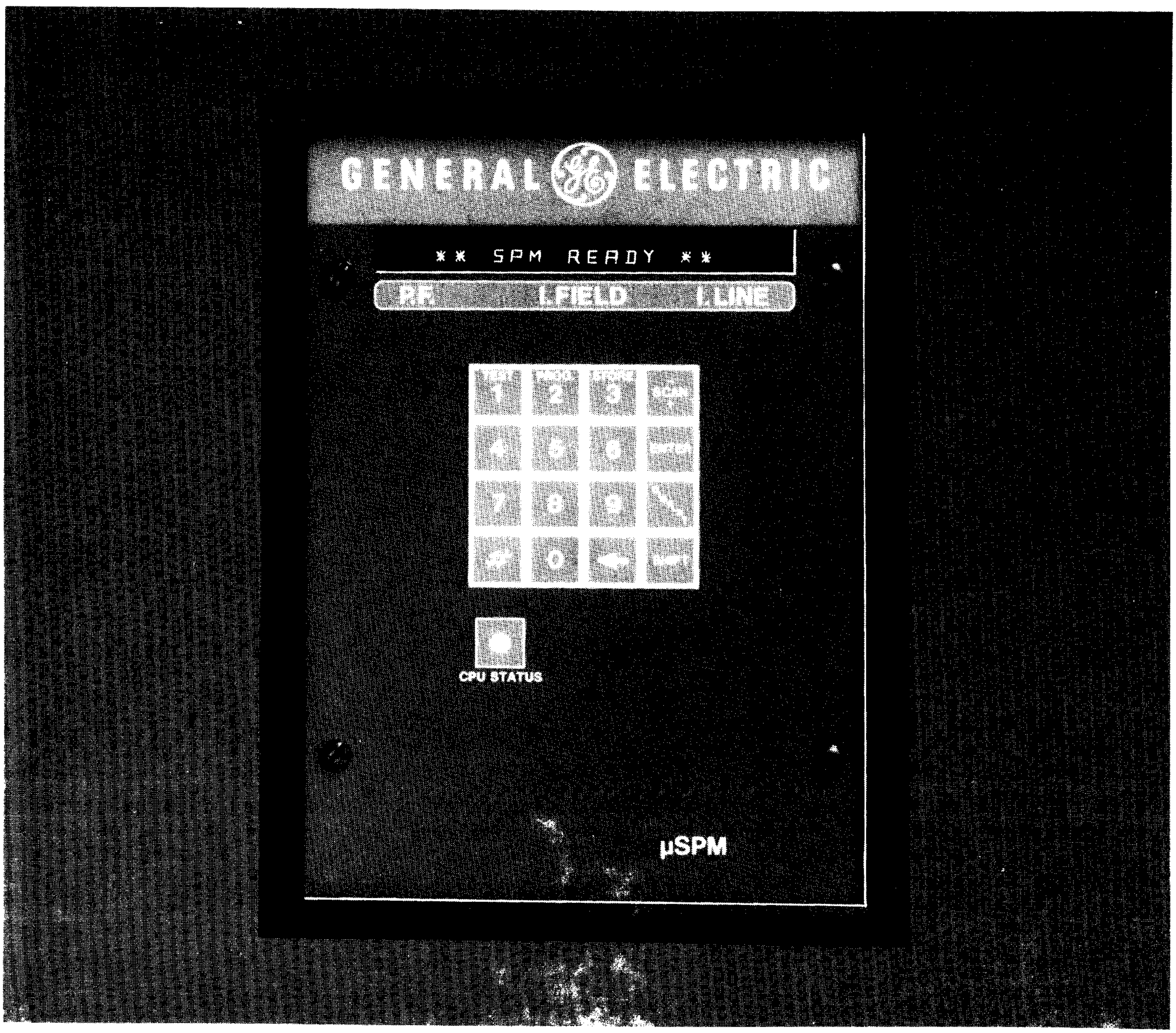
Synchronous-Motor Control

with CR192 Microprocessor-based Starting and Protection Module



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These instructions do not purport to cover all details or variations in equipment nor to provide for every possible contingency to be met in connection with installation, operation or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the Purchaser's purposes, the matter should be referred to the nearest General Electric Sales Office.

SECTION 1 — Introduction

1.1 General

These application notes and instructions apply to General Electric Synchronous-motor Controllers and field panels that employ a CR192 Microprocessor-based, Synchronous-motor, Starting and Protection Module (μSPM). These instructions also apply to the CR192 μSPM when it is supplied as a separate component. If the complete controller is not supplied, the purchaser is requested to interpret these instructions for applicability to his particular assembly by referring to the diagrams shown in Figures 10 and 23 to develop his diagrams for his particular equipment.

Brushless synchronous motors can also be controlled by the proper CR192 μSPM. See Section 9 for discussion of the Brushless Synchronous-motor Control.

SECTION 2 — Starting Synchronous Motors

2.1 General

The most attractive and widely applied method of starting a synchronous motor is to utilize squirrel cage windings in the pole faces of the synchronous motor rotor. The presence of these windings allows for a reaction (or acceleration) torque to be developed in the rotor as the ac excited stator windings induce current into the squirrel cage windings. Thus, the synchronous motor starts as an induction motor. These rotor windings are frequently referred to as damper or amortisseur windings. The other major function of these windings is to dampen power angle oscillations after the motor has synchronized. Unlike induction motors, no continuous squirrel cage torque is developed at normal running speeds. See Figure 1.

When the motor accelerates to near synchronizing speed (approximately 95 percent synchronous speed), dc current is introduced into the field windings in the rotor. This dc current creates constant-polarity poles in the rotor which cause the motor to operate at synchronous speed as the rotor poles "lock" onto the rotating ac stator poles.

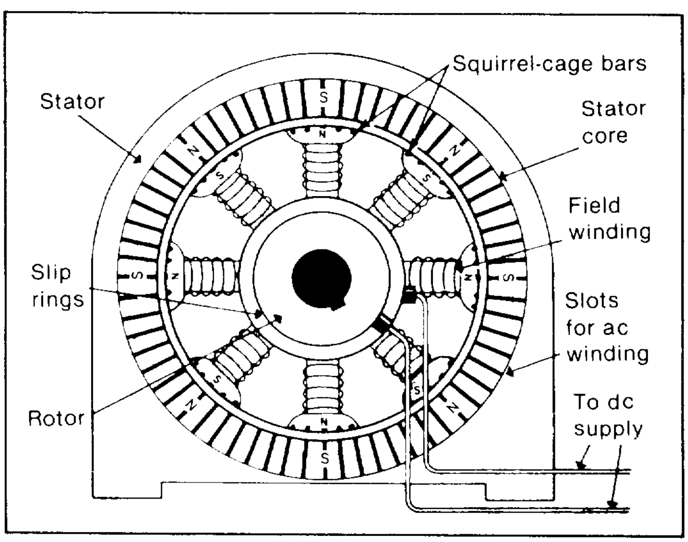


Figure 1. Salient-pole synchronous motor

Torque at synchronous speed is derived from the magnetic field produced by the dc field coils on the rotor linking the rotating field produced by the ac currents in the armature windings on the stator.

Magnetic polarization of the rotor iron is due to physical shape and arrangement of the rotor plus constant potential direct current in coils looped around the circumference of the rotor.

Synchronous motors possess two general categories of torque characteristics. One characteristic is determined by the squirrel-cage design, which produces a torque in relation to "slip" (some speed other than synchronous speed), and only in relation to slip since it can develop no torque unless there is slip. The other characteristic is determined by the flux in the salient field poles on the rotor as it runs at synchronous speed. The first characteristic is **starting torque,** while the second characteristic is usually referred to as **synchronous torque**.

In the starting mode, the synchronous-motor salient poles are not excited by their external dc source. If the poles were excited there would be no useful torque developed by them. The reason for this is that the average torque due to field excitation during slip would be a negative or braking torque that would result in reducing the total amount of acceleration torque. In addition, there is a very large oscillating component of torque at slip frequency produced by field excitation which could result in damage to the motor if the full field current was applied during the whole starting sequence. Therefore, application of direct current (dc) to the field is usually delayed until the motor reaches a speed from which it can be pulled into synchronism without slip.

At synchronous speed, the ferro-magnetic rotor poles become magnetized, resulting in a small torque (reluctance torque) which enables the motor to run at

SECTION 2 — Starting Synchronous Motors

very-light loads in synchronism without external excitation. Reluctance torque can also pull the motor into step if it is lightly loaded and coupled to low inertia.

It is convenient to make an analogy of a synchronous motor to a current transformer for the purpose of demonstrating angular relationship of field current and flux with rotor position.

If I_1* is an equivalent current in the stator causing the transformer action, then I_1 will be about 180 degrees from I_2 (or I_{FD}), and the flux will be 90 degrees behind I_{FD}. Very significantly, then, the point of maximum-induced flux (Ø) occurs as the induced field current I_{FD} passes through zero going from negative to positive; maximum rate of change of current. See Figure 2.

The rotor angle at which I_1 and I_2 go through zero will depend upon the ratio of reactance to resistance in the field circuit. A very high value of reactance to resistance will shift the angle toward minus 90 degrees (-90°). Reactance is high at low speed (high frequency). At high speed (low slip, low frequency), reactance decreases and the angle will shift toward 0 if the circuit includes a high value of resistance. As the stator goes beyond minus 45 degrees (-45°), the torque increases (essen-

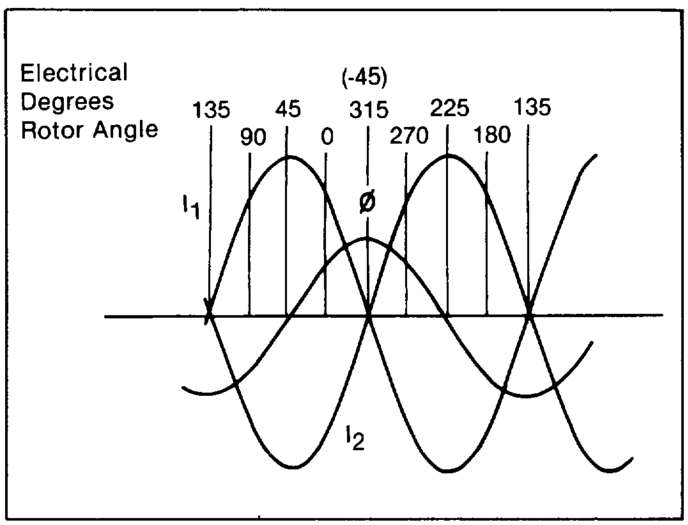


Figure 2. Transformer action of rotor flux and current (constant slip) for a typical motor

tially due to increased stator flux). At this point I_{FD} yields a very convenient indicator of maximum flux and increasing torque from which excitation is applied for maximum effectiveness.

If the field discharge loop is opened at the point of maximum flux, this flux is "trapped." Applying external amperes to the current path in correct polarity to increase this trapped flux at this instant makes maximum use of its existence. At this point

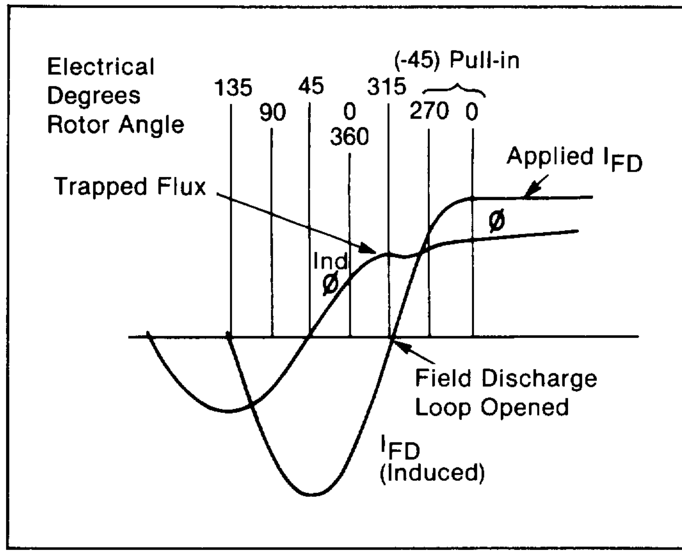
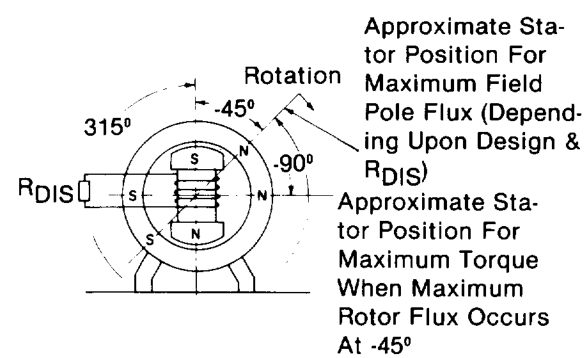


Figure 3. Rotor flux and current at pull-in (typical design)

the stator pole has just moved by and is in position to pull the rotor forward into synchronous alignment. See Figure 3.



Note: Angular displacement of rotor with respect to stator is given a negative sign to indicate the motoring condition.

Figure 4. Angular displacement of rotor

It has been established that salient-pole torque near synchronous speed is a function of both slip and field-discharge resistance. Figure 6 shows the combined effects of cage torque and salient pole torque for a typical motor. Figure 5 shows the effect of a higher value of discharge resistance on a medium-torque motor. Obviously, without salient-pole torque the motor would cease to accelerate certain loads at some point on the speed axis.

*I_1 is not an actual current. The transformer action is due to stator flux (not shown) cutting the rotor winding.

SECTION 2 — Starting Synchronous Motors

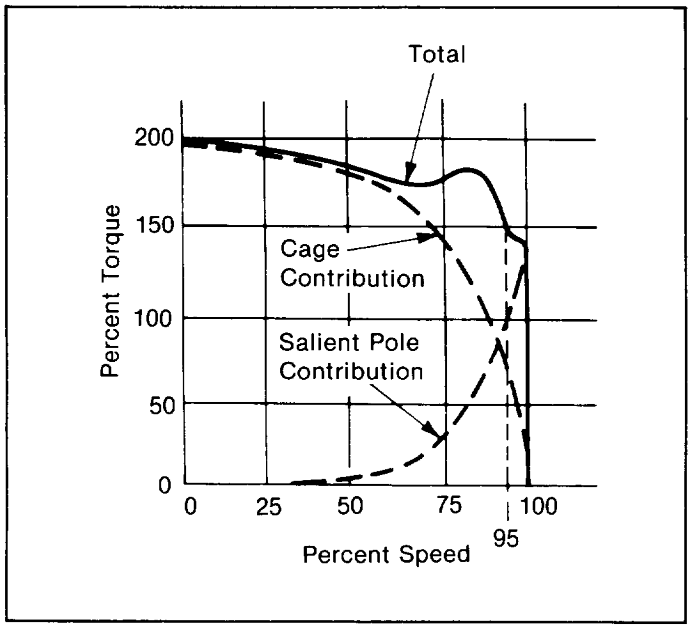


Figure 5. High-starting-torque motor

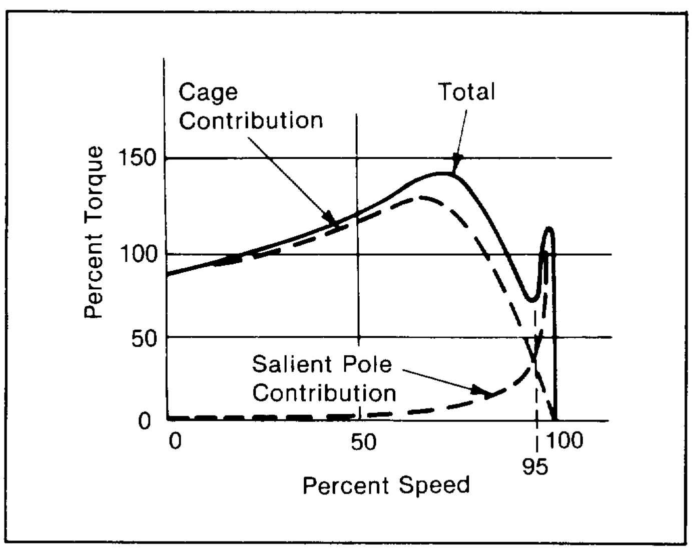


Figure 6. Medium-starting-torque motor

A high value of FDRS is not used every time, because of the other function of the resistor, which is reducing field voltage to safe levels during starting. As the FDRS value increases so does the induced voltage, and at some point this voltage would be damaging to insulation or other components in the field circuit. Solid-state excitation and control components in the field circuit have had the effect of making the value of FDRS and its voltage effect more significant. There is a greater sensitivity to field voltage tolerance levels with solid-state components.

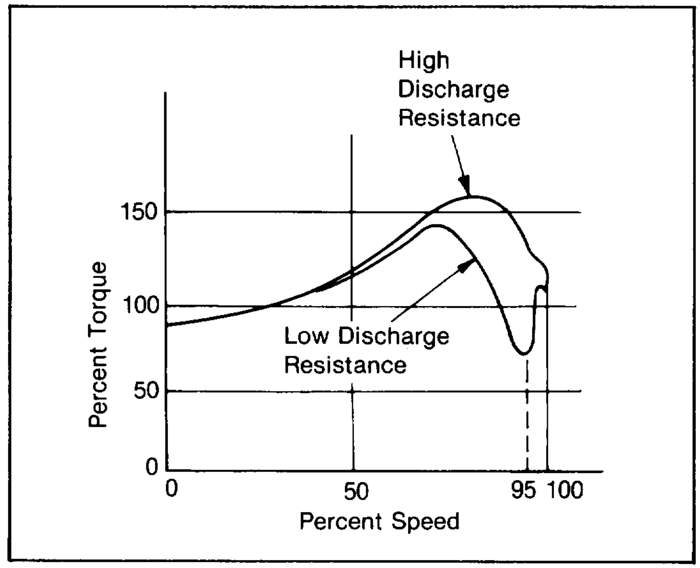


Figure 7. Medium-starting-torque motor with two values of field discharge resistance

Selection of the value of the field discharge resistance is a decision that may require judicious application of several factors present on a particular drive, such as torque, excitation systems, and control components.

The importance of speed for applying field cannot be overemphasized. Rotor and load masses cannot be accelerated fast enough to allow synchronization, if slip is in excess of ten percent.

Synchronous-motor controllers which can accurately apply field at an optimum speed and a favorable angle permit matching the motor to the load with a greater degree of precision than might otherwise be possible. The increase in load which can be pulled in due to precision application of field will vary from one motor design to another along with system inertia.

Applying excitation at the point of zero induced current (favorable angle) takes advantage of motor capability in two ways. (1) It catches ("traps") salient-pole flux at significant magnitude (provided there is a field discharge resistor of adequate value) and uses it for torque during a 180 degree (180°) acceleration period. (2) It catches the rotor in correct angular position to be pulled forward into step.

In addition to permitting closer matching of motor to load, optimum application of excitation also reduces power system disturbance which occurs when the motor goes through a complete slip cycle with the field energized. If the motor is large relative to the power system, surges transmitted to the system will be at a minimum if field is applied to prevent slip at pull-in.

SECTION 3 — Description of Synchronous-motor Controllers

3.1 General

Synchronous-motor Control equipment can be supplied either as a complete controller (including an ac power switching device for the motor starter) or as a field panel (ac power switching supplied by others).

3.2 Elements of a complete synchronous-motor controller

The complete Synchronous-motor Controller has the ability to switch the motor on to and off of the power system and protect the motor from damage that can occur if the motor is running in an abnormal condition, such as out-of-synchronism.

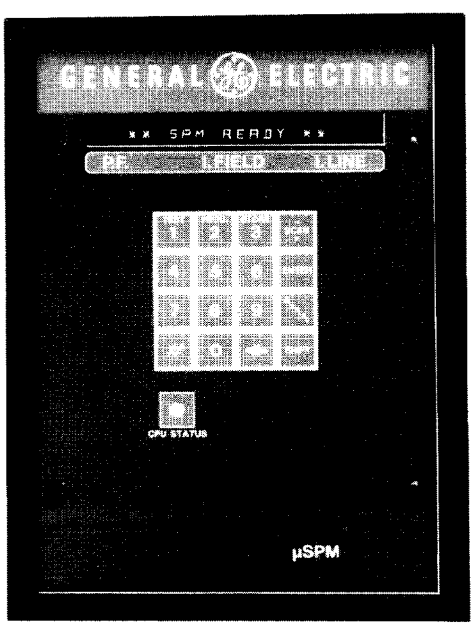


Figure 8. Front view of CR192 μSPM

The complete Synchronous-motor Controller consists of the Motor-starter, Switching device (typically a contactor) which controls the main power to the motor. In addition, protective relaying is provided (such as overload relays) and control for starting and stopping the motor (start-stop pushbuttons). Indicating devices such as line ammeters are supplied. All of these features are common with motor controllers of all types.

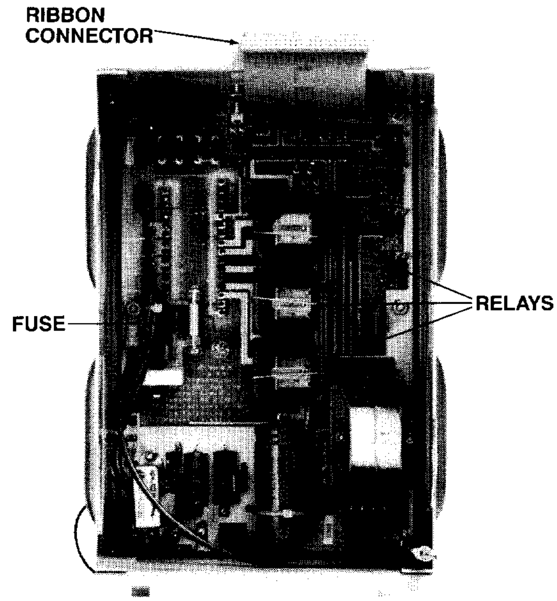


Figure 9. Backbase view of CR192 μSPM

In addition to full voltage starting, synchronous motors may be started by either reduced inrush methods, such as primary reactor, auto-transformer or part-winding control.

The following elements are unique to synchronous controllers.

3.2.1 The CR192 micro-starting and protection module

This electronic, microprocessor-based module provides the computation and monitoring functions necessary to synchronize and protect the synchronous motor from stall, prolonged acceleration, or pull-out conditions. This device is discussed in more detail starting in Section 4.

3.2.2 Field contactor

This low-voltage contactor applies and removes dc power to the synchronous motor field and switches the field discharge resistor. This device may be either solid state or electro-mechanical.

3.2.3 Field discharge resistor

This resistor bank (sometimes shipped as a separate item) is used to discharge the magnetic energy of the field during shutdown and absorb induced field energy during start-up.

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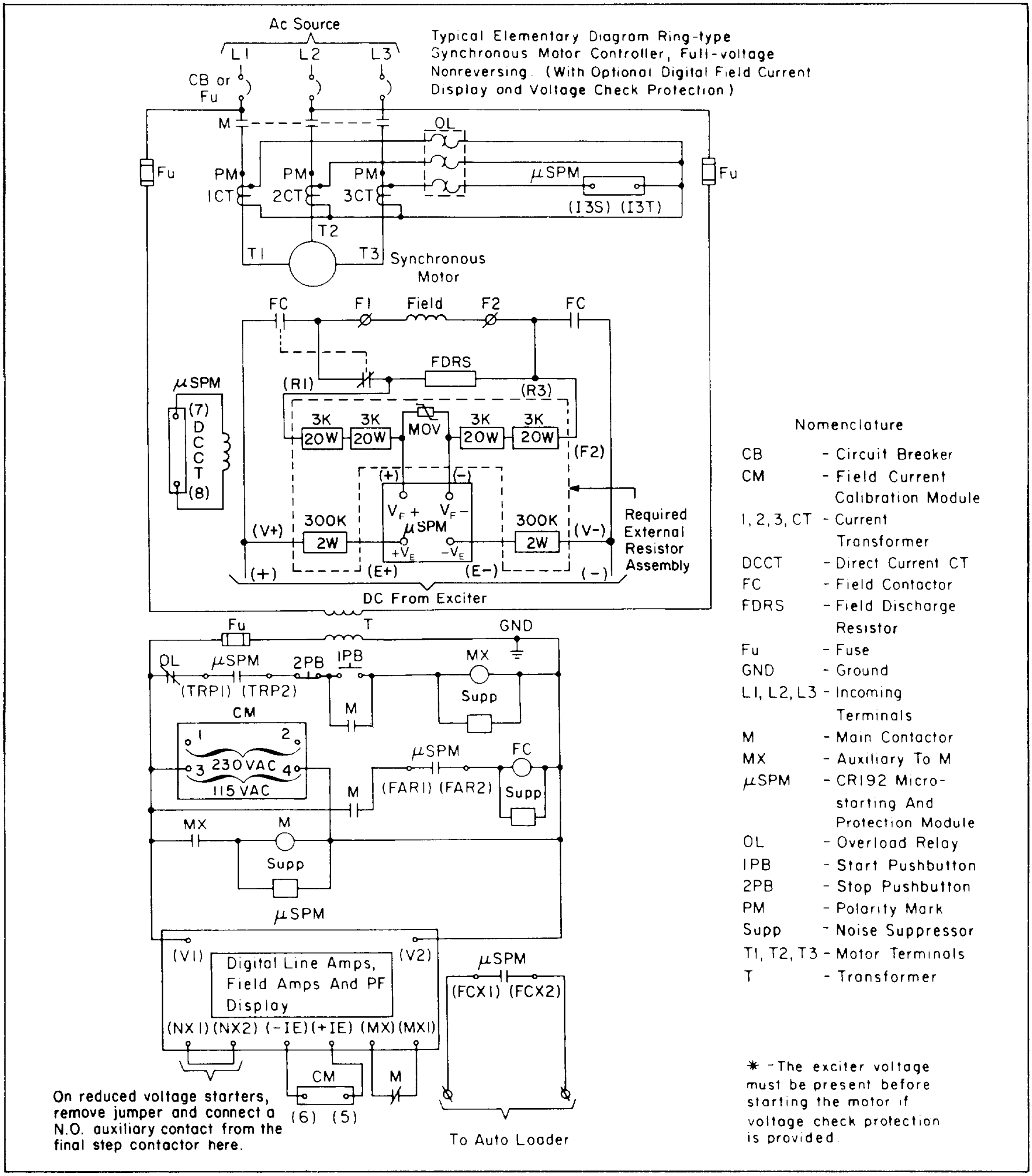

Figure 10. Typical ring-type, synchronous motor controller elementary diagram

SECTION 3 — Description of Synchronous-motor Controllers

3.2.4 Solid-state field exciter

General Electric Synchronous-motor Controllers may be supplied with either; (1) diode-rectifier/tapped transformer field exciter or (2) Silicon Controlled Rectifier exciter. Of course, provisions can be made for remotely supplied dc field power. These two exciter types are described as follows:

1. The diode-rectifier/tapped-transformer exciter utilizes a full wave bridge rectifier (either single or three phase) to obtain the required dc field supply. A tapped transformer provides a wide range of available secondary voltages so that the desired field current may be obtained by proper choice of the transformer tap. The motor must be shut down before the transformer tap can be changed.

2. The Silicon Controlled Rectifier (SCR) Exciter is available when any one of the following features is required.

   A. ON LINE FIELD ADJUSTMENT. A lockable control knob is provided either on the door or base mounted inside the enclosure. Adjustment of the knob increases or decreases the field current conveniently while motor is running.

   B. FIELD CURRENT REGULATOR. As a synchronous-motor field heats up while running, its resistance increases causing the field current to drop. This condition causes the power factor to vary, resulting in undesirable voltage fluctuations or nuisance tripping from synchronous motor pull-out. A field current regulator senses the field current and causes the SCR to either increase or decrease its output in order to maintain a constant field current regardless of field winding temperature.

   C. POWER FACTOR REGULATOR. Power factor regulation is useful in those applications where motors are subjected to high-level transient impact loads (such as chipper drives). The PF regulator senses the power factor dip that occurs when the motor is loaded and causes the SCR Exciter to respond with a boosted output. As a result, the pull-out torque of the synchronous motor is increased for the duration of the transient load. After the load subsides, the regulator senses an excessive leading power factor and causes the SCR to reduce its output. This automatic boosting of field current to avoid pull-out is called field forcing. The Power Factor regulator thus provides automatic boosting when field forcing is required and economical low field operation when the motor is idling.

   Another application of the power factor regulator is to control power factor swings that result from various levels of loading so as not to cause fluctuations in the plant system voltage.

   The μSPM provides the control signal to the SCR exciter when PF regulation is required. See Section 5.7.

3.3 Synchronous-motor field panel

The Synchronous-motor Field Panel contains at least the features listed in the previous section that are unique to the Synchronous-motor Controller. Additionally, the Synchronous-motor Field Panel may include stator protective relaying and start-stop control as well. However, the field panel will not switch or handle any of the line power to the synchronous motor stator windings.

Hence, the field panel becomes a piece of control equipment that can interconnect with either a separate contactor or circuit breaker to form a complete Synchronous-motor Controller or feeder.

Field panels may be supplied with solid-state field exciters. See Section 3.2.4.

SECTION 4 — Description of the CR192 Micro-starting and Protection Module

4.1 Description of operation

4.1.1 Starting and synchronizing

Control functions for starting the synchronous motor include the following.

1. Applying power to the stator; at full voltage or at reduced voltage.
2. Shunting the field with a discharge resistor. (FDRS)
3. Sensing rotor speed.
4. Sensing rotor angle.
5. Applying excitation at optimum speed and angle.
6. Reluctance torque synchronizing.

The first step in starting a synchronous motor is to apply power to the stator by means of a magnetic contactor or circuit breaker.

Shunting a resistor around the motor field during starting is accomplished by a field contactor. Optimum application of excitation (that is, closing the field contactor) requires accurate sensing of motor speed and rotor angle. This function is pro-vided by the CR192 μSPM. Optimum speed for pull-in will vary somewhat from one motor design to the next, and with the value of the field discharge resistor. Adjustment of the control to apply field at various values of motor speed is important. Correct rotor angle for field application does not vary, and is always the point where induced field current passes through zero going from negative to positive; the point of maximum flux in the rotor. See Figure 3. Maximum utilization of motor pull-in capability will depend upon the degree to which the control can accurately sense speed and rotor angle.

Rotor frequency is the most positive electrical parameter available for indicating speed, and can be sensed by detecting frequency of the voltage across FDRS. Voltage across FDRS is not actually "induced field voltage," but is the voltage which is essentially in time phase relation to the current through the resistor. That is, the current goes through zero at the same time the voltage goes through zero.

Figure 11 is included to illustrate the electronic circuits of the CR192 μSPM which detect the proper rotor speed (PRS) and rotor angle (PRA) signal.

Outputs from the PRS and the circuits are fed into a Central Processor Unit (CPU) to determine the proper time to close the Field Application Relay (FAR). When the proper rotor speed and the proper rotor angle conditions are met as determined by the microprocessor (CPU), the CPU delivers a signal to the FAR Relay so it can close its contact FAR1-FAR2. FAR picks up field contactor FC to apply excitation to the motor field and to open the field discharge resistor loop. See Figure 10.

Speed at which the motor is to synchronize (PRS) can be programmed over the range of 90 to 99.5 percent speed. (See Programming Instruction, Section 8.)

4.1.1.1 Reluctance torque synchronizing

A synchronous motor that is lightly loaded and connected to low inertia load may pull in to synchronism before the rotor poles are externally magnetized. This is commonly known as reluctance torque synchronizing. This magnetization can result in sufficient torque to hold the salient poles in direct alignment with corresponding stator poles and run the motor at synchronous speed. When load is applied, however, the rotor will begin to slip since the torque developed is only a fraction of rated torque under separate excitation. Furthermore, the rotor is polarized by the stator flux under this condition and can therefore be polarized in any direct axis alignment; occuring each 180 degrees. External excitation forces pole-to-pole alignment in only one orientation of the direct axis.

Should the rotor pull in to synchronism 180 degrees away from the normal running alignment, external excitation will build up flux in the rotor in opposition to the stator flux. As the external excitation builds up, correct alignment of rotor to stator will occur by slipping one pole and the motor will then run in normal synchronism.

The Field Application Control must respond in such a way as to proceed with proper application of excitation in the event the motor does synchronize on reluctance torque. Figures 12 and 13 show how the μSPM automatically responds to reluctance torque synchronizing.

4.1.2 Starting protection

The amortisseur, or cage winding of a synchronous motor, is probably the element most susceptible to thermal damage. Its function is essentially operative only during starting, and there are limitations on space available for its construction onto the rotor. Hence, it is usually made of lighter material than the cage winding of an induction motor. The cage is also vulnerable to overheating should the motor be allowed to run out of synchronism with no excitation. In this case, it runs as an induction motor at some value of slip which will produce cage current that develops running torque. However, the cage of a synchronous motor is not designed for continuous operation. Therefore, an important protective function of the controller is to prevent overheating of the cage winding both during starting and running out of synchronism.

Monitoring the starting condition of a synchronous motor can be accomplished by looking at the frequency of induced field current, the same procedure used to accomplish synchronizing. Motor designers always place a limit on the time a particular motor can be allowed to remain stalled ("allowable stall time"*). An accelerated schedule can then be established.

* "Allowable stall time" is important for the induction motor also, but the time is usually shorter for the synchronous motor and varies from one design to another in terms of greater spread.

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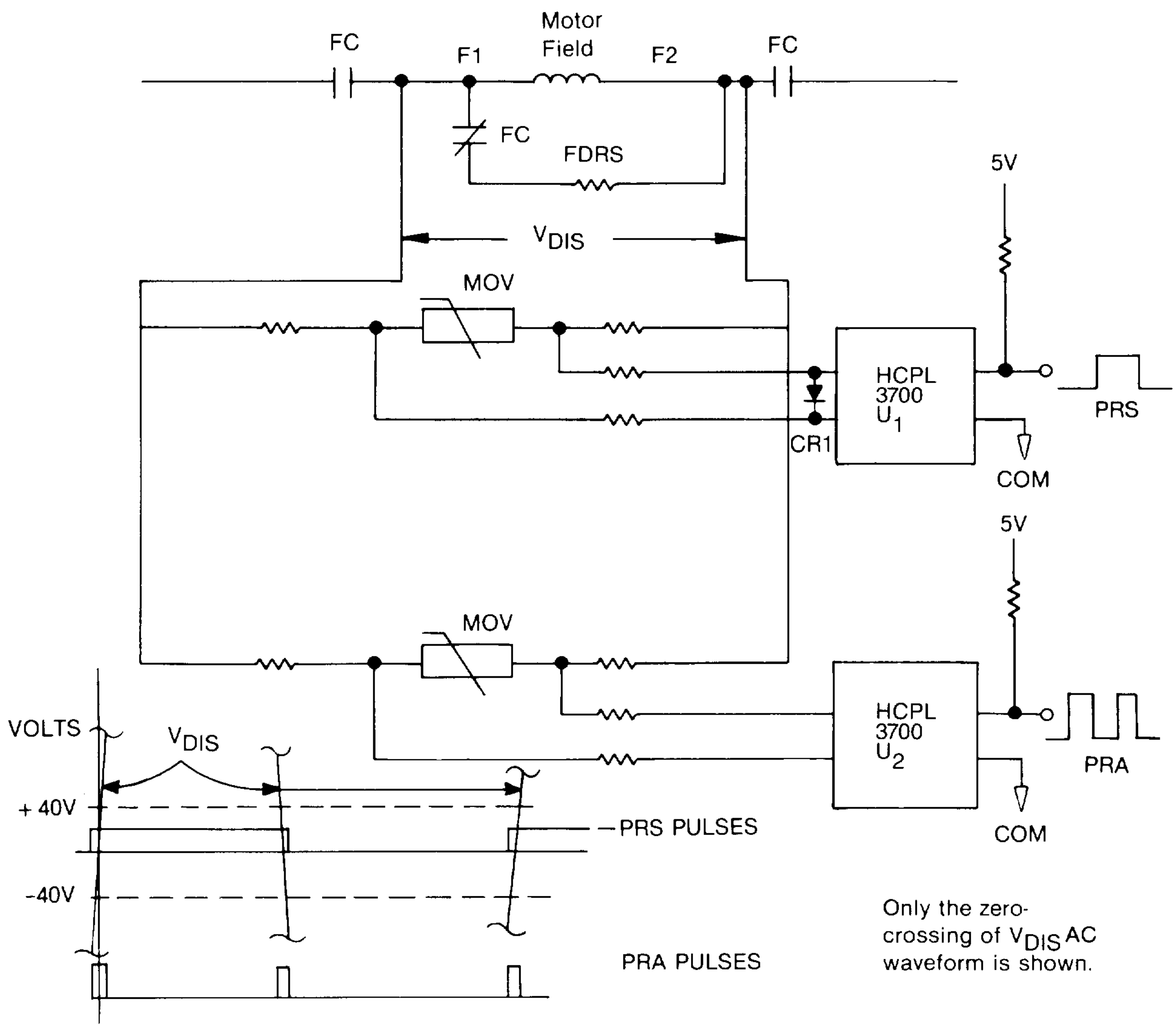

Figure 11

Positive half cycles of V_{DIS} are clamped by CR1, thus allowing U1 to stop conducting. PRS signal then goes to 5V. Negative half cycles (more negative than -40V) causes U1 to conduct pulling PRS to ground. Results are a square wave representative of V_{DIS} offset by -40V.

$\pm$ V_{DIS} causes U2 to conduct anytime it is greater than $\pm$40 volts causing PRA to be pulled to ground. When V_{DIS} is less than 40V, U2 stops conducting and allows PRA to go to 5V. Results are a 5V pulse indicating when V_{DIS} is crossing zero. The CPU senses PRS and PRA, determines when proper synchronization speed is reached, and closes the field contactor at the proper electrical angle.

Figure 11. Determining proper synchronization speed

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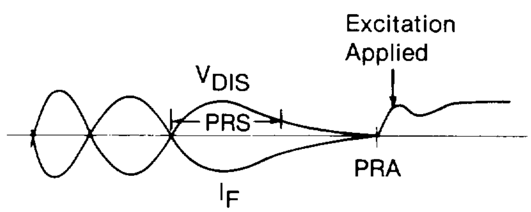
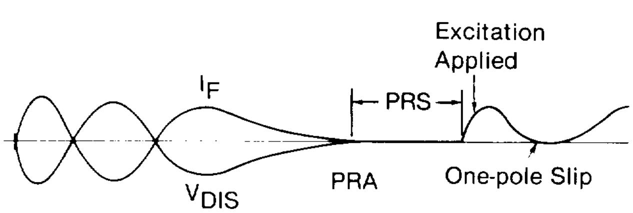


Operation

For correct orientation of the reluctance-torque rotor magnetization. PRS times out first and the PRS flag is set. PRA flag is set when V_{DIS} falls below ±40V. Since both PRA and PRS flags are set simultaneously, the field is applied.

Figure 12. Correct orientation of the reluctance-torque-rotor magnetization



Operation

For 180 degree dis-orientation of the reluctance-torque rotor magnetization, PRA flag is set when V_{DIS} falls within the range of ±40V. At this point, PRS starts timing. When PRS times out, the PRS flag is set. PRA and PRS flags now appear simultaneously and the field is applied.

Figure 13. Motor synchronizes on reluctance torque-rotor disoriented 180 degrees

for the motor in terms of running time at any speed less than synchronous as a percent of allowable stall time. Increased air circulation from the rotor fan reduces heating rate as the motor accelerates. Frequency can be measured directly as an indication of speed, and the designer's curves for speed versus time can be used for protection by software that integrates the time-speed function. Figure 14 shows the typical cage heating protection characteristics during acceleration.

The time-speed function shown in Figure 14 is accomplished internally by the μSPM software. The μSPM determines the motor speed from the induced field voltage frequency. The programmed values for maximum allowable stall time and 50 percent speed run time determines which particular characteristic of protection is needed from the family of curves shown in Figure 14.

4.1.2.1 Reduced-voltage starting

Many synchronous motor starting applications involve either reduced voltage (starting reactor or auto-transformer) or part-winding starting methods. When these methods are used, the available torque for acceleration is reduced from the torque that would result from a full-voltage start. Also, the allowable stall time of a motor is extended during a reduced-voltage start due to the reduced heating-rate resulting from lower inrush currents.

The CR192 μSPM has the ability to take advantage of the motor's extended stall time so that the motor and load can accelerate to synchronous speed in a time period longer than would be allowed with a full voltage start. The acceleration torque is reduced as the square of the ratio of reduced voltage to full voltage, and the motor-heating rate is proportional to the square of the starting current. Since the motor inrush current is reduced proportionally with the voltage reduction (due to the constant impedance of the synchronous motor at stall) the following allowable stall time factor applies:

$$(I_{PLR}/I_{MLR})^2$$

I_{PLR} = Programmed full voltage locked rotor current.

I_{MLR} = Measured inrush current.

This ratio can be used as a factor for increasing the stall time above the full voltage allowable stall time for any given speed. See Figure 15.

The μSPM calculates the ratio, squares it, and factors this value into the stall time algorithm approximately one-tenth of a second after motor starts. When the final step contactor closes and applies full voltage to the motor windings, a N.O. interlock from this contactor is wired to the μSPM to signal that the motor is now at full voltage. The correction factor for reduced voltage starts then immediately becomes unity.

If, for any reason, it is not desirable to have this ratio correction factored in, a jumper may be placed across inputs NX1 and NX2. Conversely, if the motor is started from a weak system, and significant voltage dips are expected during starting, the factory jumper from NX1 to NX2 may be removed. The μSPM will automatically extend the stall and accelerating time per the reduced voltage factor.

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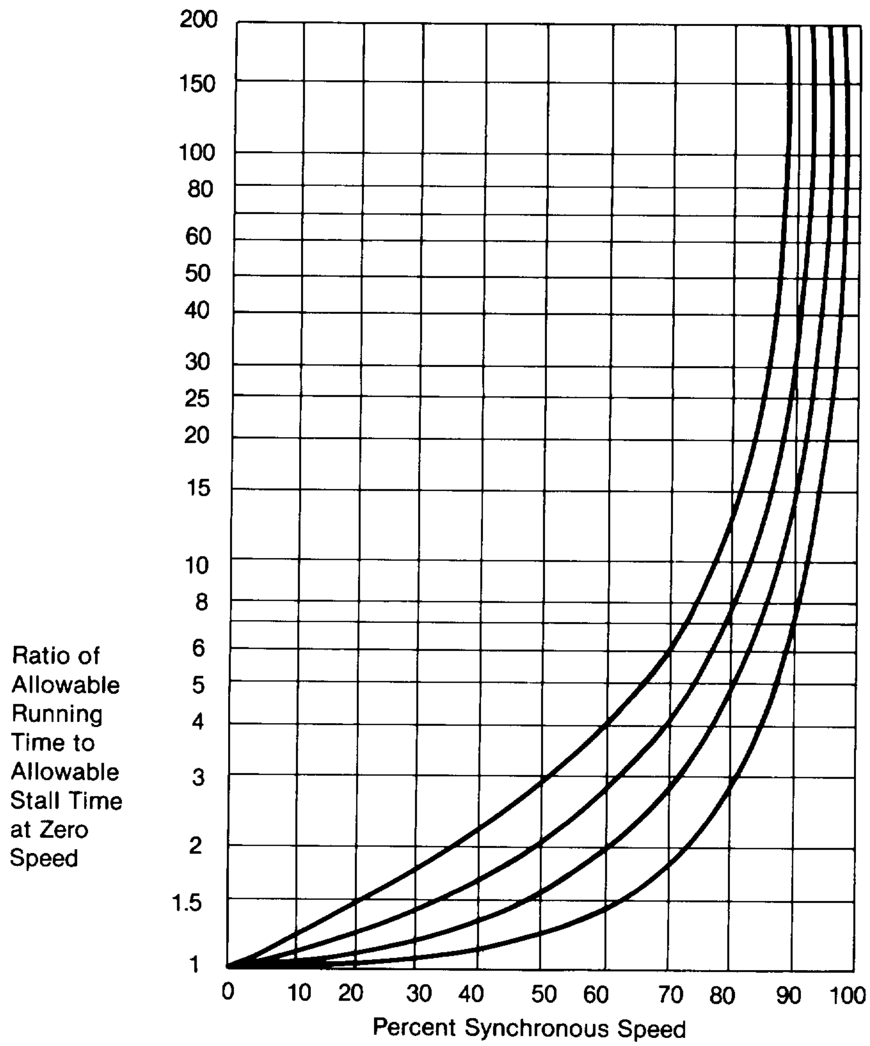

Figure 14

NOTE:

To find the protective characteristic used, plot the programmed value for 50 percent run time and draw in the complete curve through the plotted point using the above curves as a guide.

Figure 14. Amortisseur winding (squirrel cage) protective for stall and acceleration at full voltage

4.1.3 Power factor (pull-out) protection

Synchronous motors are designed to run at constant speed and drive shaft loads from torque derived from the magnetic poles on their rotors magnetically linking opposite stator poles. Whenever the rotor turns at a speed less than that of stator rotating field, the motor is said to be slipping poles. Slip can occur with the field poles magnetized while running in synchronism from the following four major causes.

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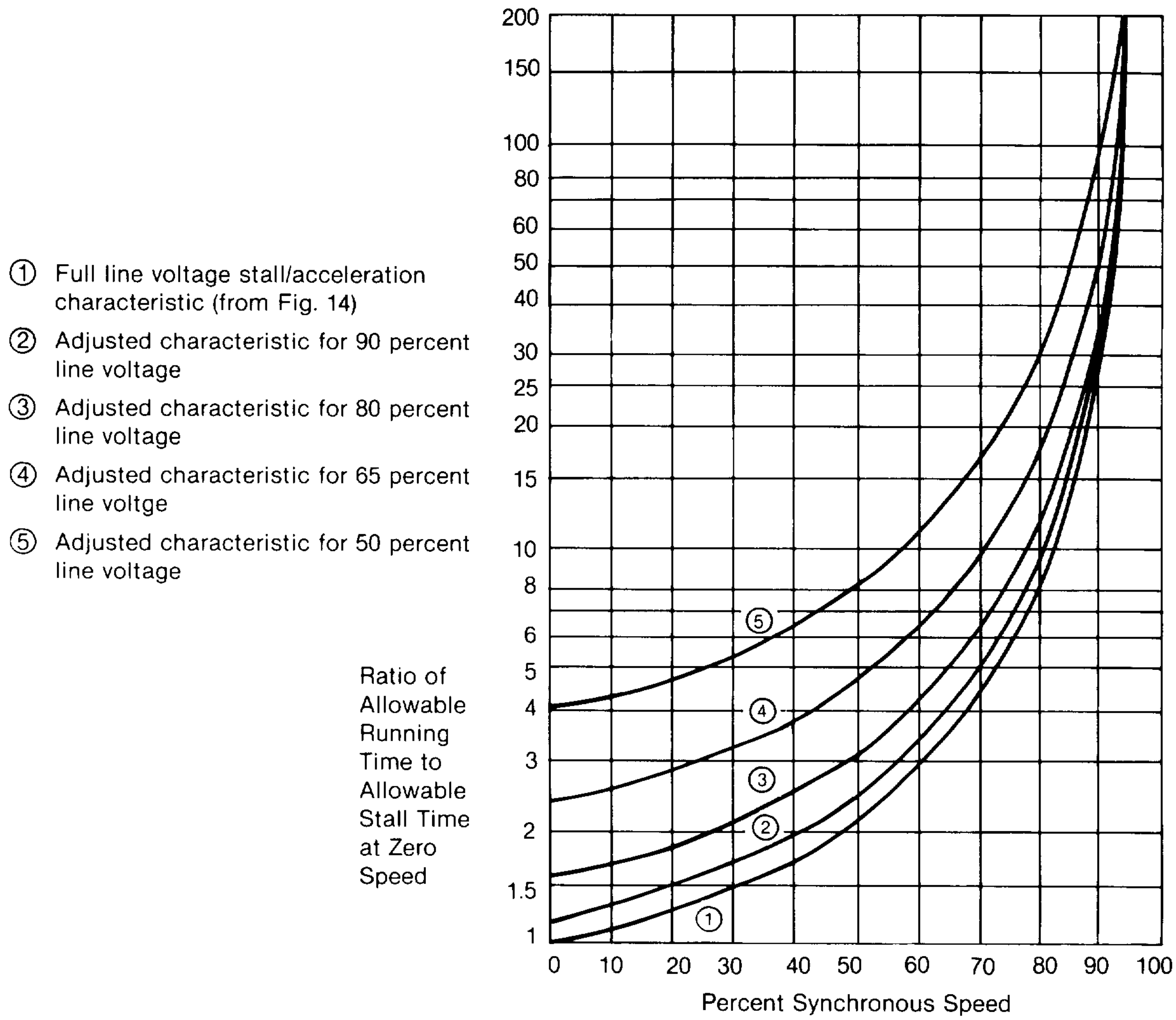


NOTE:

These curves show how the trip characteristic of the amortisseur winding protection is adjusted for reduced voltage starts. For this example, curve 1 is taken from one of the family of curves in Fig. 14.

Figure 15. Adjustment of stall/acceleration times for reduced voltage starts

1. A gradual increase in load beyond the pull-out capabilities of the motor.
2. A slow decrease in field current.
3. A sudden large impact load.
4. A system fault or voltage dip lasting long enough to cause pull-out.

Loss of synchronism with field applied will create intense pulsations in torque at the motor shaft each time a stator pole

SECTION 4 — Description of the CR192 Micro-starting and Protection Module

passes a rotor pole. Corresponding pulsations occur in line current. Both types of pulsations can be damaging. Torque pulsations can break a shaft, coupling, or other mechanical elements, and current pulsations can interfere with smooth power system operation. Slipping poles with field applied is always unacceptable for a synchronous motor, therefore some means must be provided to prevent this condition from occurring.

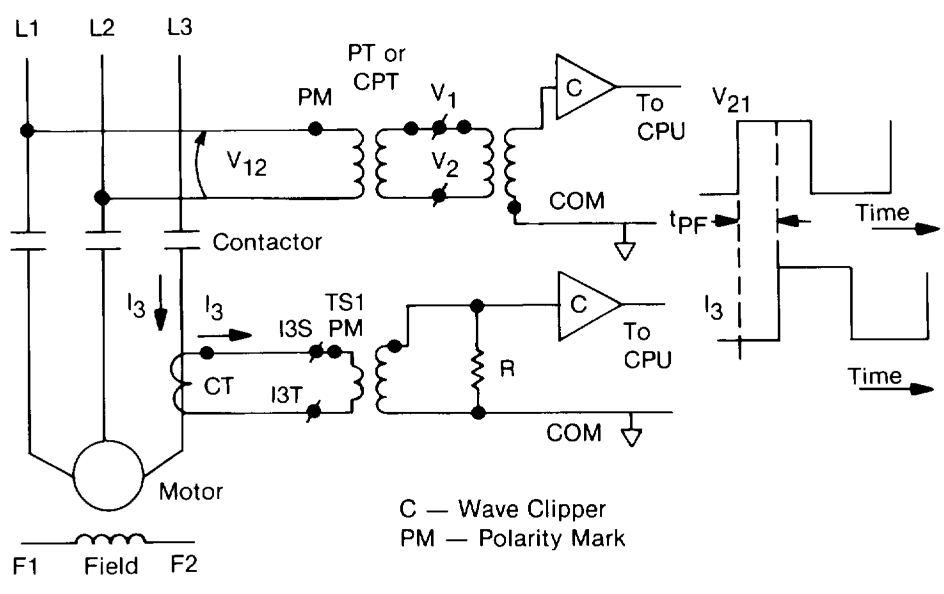
One of the most reliable indicators of synchronous and asynchronous (out-of-step) operation is the motor power factor. Power factor is related to the phase angle between voltage and current. Synchronous motors seldom, if ever, operate continuously at lagging power factor. Synchronous motors run at either unity or some value of leading power factor. Lagging power factor appears when the motor load angle increases beyond rated, becoming almost fully lagging (90 degrees) as the motor slips out-of-step. Therefore, lagging power factor can be utilized to initiate action to prevent slipping.

Torque and power pulsations during slip can be reduced by removing field current to the rotor poles. The motor will then run essentially as an induction motor on its amortisseur winding. Slip with the field current removed is tolerable to the load and power system but intolerable for any length of time to the motor amortisseur winding itself, since the winding is designed with limited thermal capability and for short-time operation. Motor Power Factor during induction motor operation (that is with field removed) is always lagging. However, the degree to which the current lags the voltage is less than at pull-out when field poles are excited. Lagging power factor can again be utilized as an indicator of "slip" during induction motor operation.

For synchronous motors, power-factor monitoring can be employed to guard against pull-out or loss of field conditions.

4.1.3.1 Power factor operation

Motor pull-out protection is provided by a circuit which monitors power factor and has a built-in time delay to prevent inadvertent tripping on transients. The μSPM senses power factor by monitoring the voltage across motor Phases One and Two and the current in Phase Three. See Figure 16. Figure 17 is



NOTE:

Square waves are generated internal to the μSPM that are in sync with zero-crossings of I_3 and V_{21}. The CPU detects the positive transition of V_{21} and measures the time (t_{PF}) to the next positive transition of I_3. This time is used in calculating power factor.

Figure 16. μSPM power factor sensing

SECTION 4 — Description of the CR192 Micro-starting and Protection Module

a phasor diagram depicting the relationship of voltage and current for various power factors.

The CR192 automatically suppresses power factor until the programmed set-point "FCX" times out. The CR192 can be programmed to suppress power factor trip action if the line current is less than 50 percent activate the PF Protection. A value of "2" in Parameter 10 gives the above feature with the "Ride Thru" mode. A value of "3" in Parameter 10 provides the above described feature with "Resync" mode operation. The normal "Ride Thru" modes (0 in Parameter 10) and "Resync" mode (1 in Parameter 10) are described in Section 4.1.3.2.

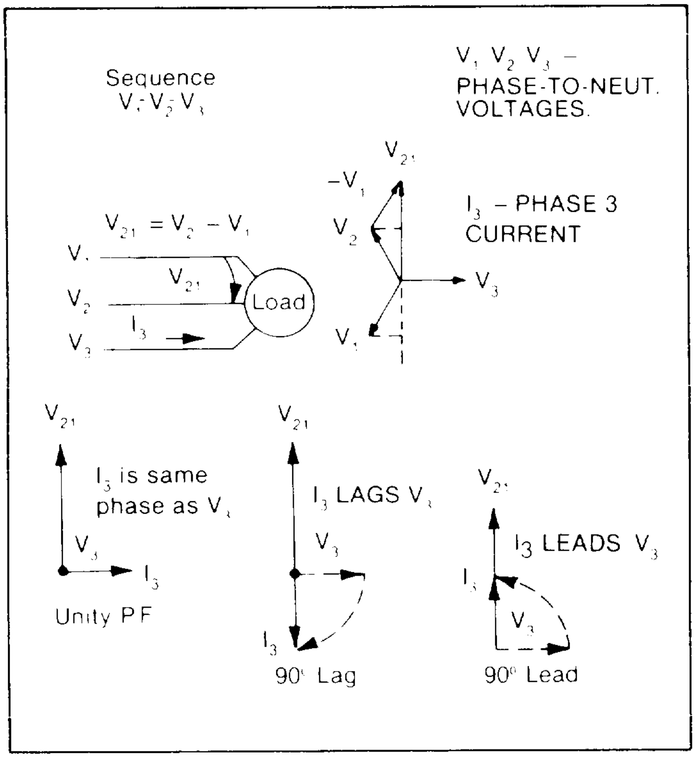


Figure 17. Phasor diagram description of power factor sensing from voltage across two phases and current in third phase

4.1.3.2 Controller action during pull-out

If excessive mechanical load is applied to the motor shaft during normal running of the motor in synchronism, the resulting lagging power factor and/or line current surge will be detected by the μSPM. Two forms of pull-out protection are available. They are as follows.

1. **Resync mode.** Resync mode operation will cause the μSPM Field Application Relay, FAR, to act to remove the motor-field excitation. Action will occur from either lagging power factor below the programmed set-point, or a line current surge above approximately four times motor full-load current. See Figure 20A.

Relay FCX drops out at the same time as FAR. Load is removed if an automatic loader is connected.

The motor will continue to run with field removed for the programmed power factor delay time, and if resynchronization does not occur within this time, the TRIP relay will operate and the motor will stop.

The display will indicate "PF TRIP."

2. **Ride-thru Mode.** If the alternate "ride-thru" mode is selected, the field is not removed immediately as in the resync mode.

Instead, if the power factor dips below the trip point and persists for the PF time delay, the TRIP relay will operate and the motor will stop. Also, a line current surge greater than approximately four times motor full load will cause TRIP operation if the PF time delay is exceeded. Power factor trips are indicated by "PF TRIP" in the display. Line current surges greater than four times rated line current are indicated by "PULL-OUT TRIP."

4.1.3.3 Effect of voltage dips on motor power factor

Solid-state excitation systems have an effect on the way motor power factor responds to line voltage dips. The effect may be to cause a power-factor relay to operate inadvertently. This causes the motor to trip on lagging power factor caused by a transient condition which is not an actual pull-out condition.

A solid-state exciter differs from a rotating exciter in the way it responds to voltage dips. The rotating inertia of a Motor-Generator set may maintain excitation voltage relatively constant for several seconds, but a solid-state exciter has practically no built-in delay in the way it responds to line voltage. Therefore, any delay in change of motor-rotor flux following an excitation voltage change is determined by the time constant of the rotor field poles themselves. This is usually 0.5 to 1.0 seconds.

The sequence of events transpiring during a voltage dip with a solid-state exciter is depicted in Figure 18. Assuming the condition of a line voltage decrease of 15 percent with the motor initially at unity power factor, the power factor will swing leading momentarily because the generated EMF does not change until the rotor flux decreases (determined by field time constant) and the motor will tend to maintain constant horsepower by slightly increasing line current. As the field flux decreases, generated EMF also decreases, and the power factor will move back towards unity, and there will be a load angle increase to permit motor torque to be restored to that required to drive the load. During both of these sequences the motor power factor has not become significantly lagging, so the power-factor relay does not operate.

Finally, when line voltage comes back to normal, the power factor will momentarily swing over to lagging and the power factor protection relay will trip because the rotor flux does not respond as rapidly to change as the stator, and generated EMF

SECTION 4 — Description of the CR192 Micro-starting and Protection Module

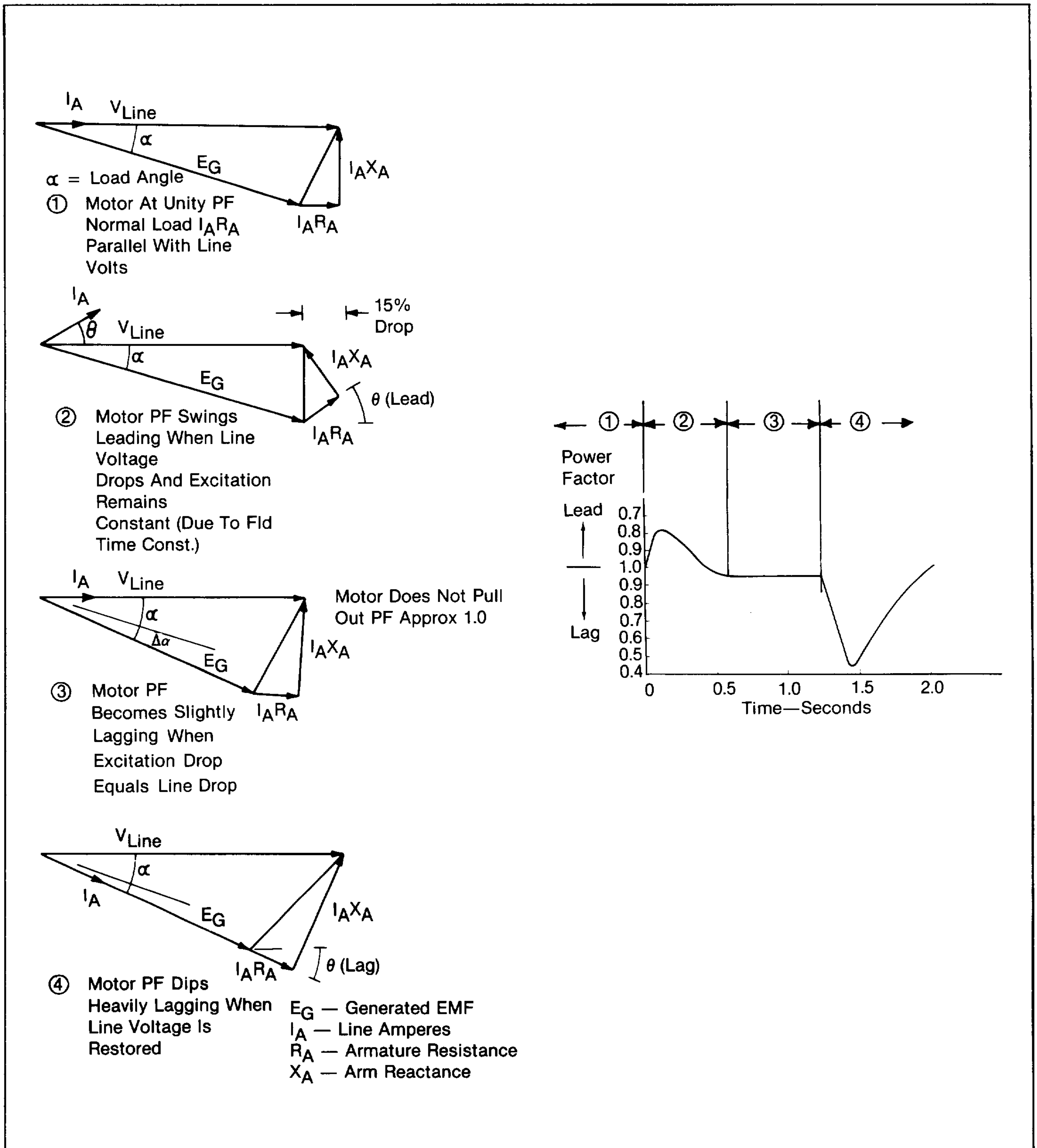


Figure 18. Motor power factor response to line voltage variances

is low relative to line volts for a time period long enough to operate the relay.

A power-factor device with a 1.0-second built-in time delay should remain unaffected by these changes.

4.1.3.4 Power factor detection and indication when motor is driven by over-hauling load (generating)

Many synchronous motor applications require that the motor operate with an overhauling load (in generating mode). The power factor protection must be able to provide pull-out protection during overhauling load conditions.

The CR192 μSPM provides pull-out protection for the synchronous motor operating in both the generating and the motoring mode. However, conventional power-factor detection and indication for motors and generators are opposite. Simply, the convention is that a motor has a leading power factor when it is **overexcited** (producing reactive power). A generator, by convention, is leading power factor when it is **underexcited** (consuming reactive power). In order to understand this difference, it is necessary to recognize that the definition of a motor voltage reference phasor is 180 degrees displaced from its corresponding conventional generator voltage reference phasor. Therefore, a given line current that leads the conventional generator voltage phasor will lag the corresponding conventional motor phasor. Figure 19 shows that I_A is lagging V_{AB} (conventional motor phasor) while it is leading V_{BA} (conventional generator phasor).

This confusion can be eliminated by defining **one** terminal voltage phasor for both generating and motoring modes. Simply, if V_{AB} is used as the reference phasor, then the leading power factor is always when the synchronous machine is producing reactive power and lagging power factor when it is consuming reactive power.

This is the approach that is taken with the PF display for the CR192 μSPM. When the motor/generator is producing reactive kVA the sign of the power factor is displayed plus (+), indicating leading power factor, regardless of the operating mode. When it is consuming reactive kVA the sign of the power factor is displayed negative (-).

Therefore, whether the machine is motoring or generating, pull-out protection is provided by limiting the degree of **lagging** power factor (under excitation) as detected by the μSPM.

The power-factor regulation option also performs to force the field in advance of a pull-out condition regardless of whether the machine is operating as a motor or a generator.

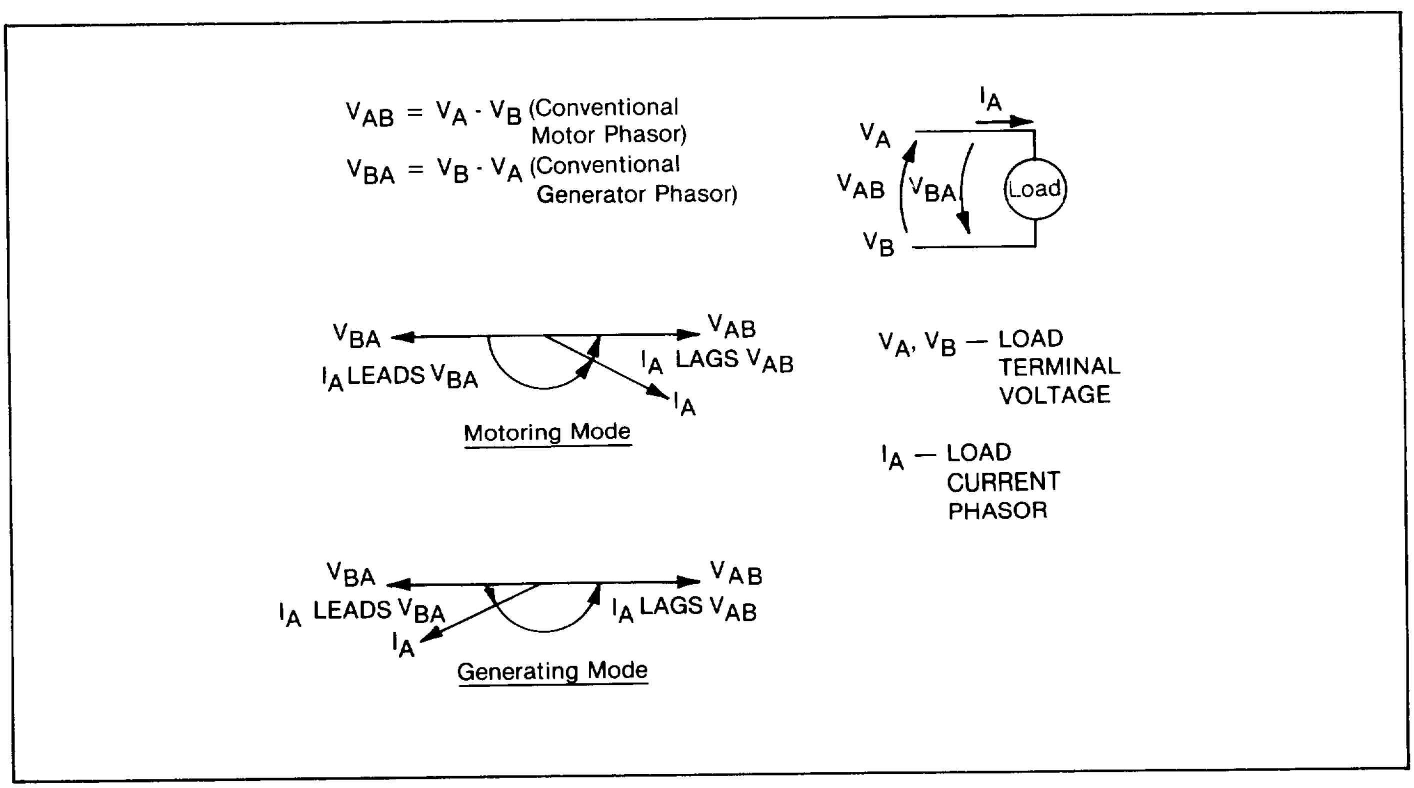


Figure 19. Power factor sensing — motor mode versus generator mode

SECTION 4 — Description of the CR192 Micro-starting and Protection Module

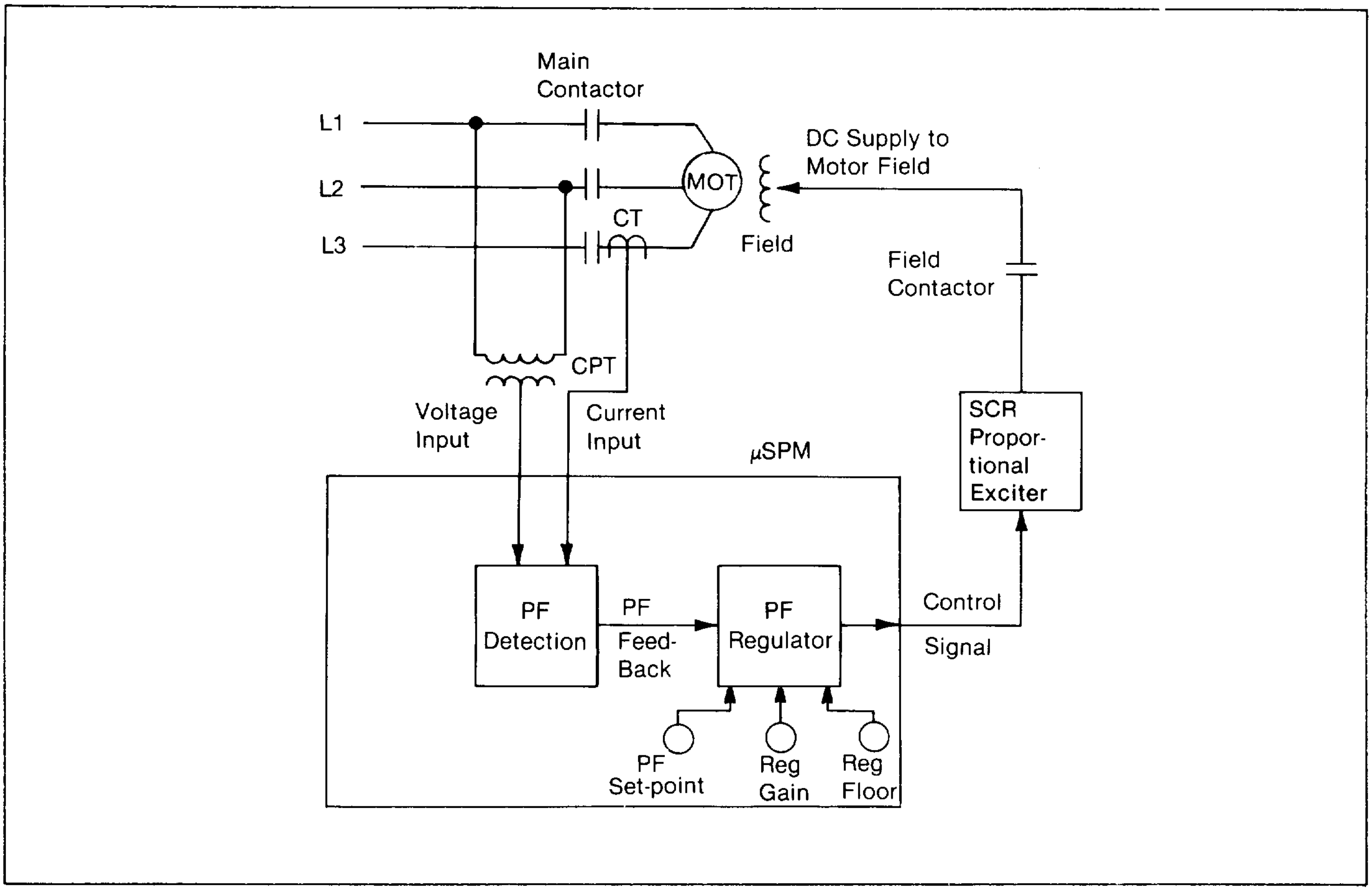


Figure 20. Power factor regulator — functional block diagram

4.2 Specifications

4.2.1 Operating temperature

Operating temperature range: 0 to 55 C (-40 C to 70 C storage). Relative humidity zero to ninety (0-90) percent (non-condensing).

4.2.2 Power source

The control voltage range of operation on the standard unit is +15% to –35% rated voltage, and 50 or 60 hertz ±3 hertz, 25 VA.

Range for 115 VAC is 75 V min. to 132 V max.
Range for 230 VAC is 150 V min. to 265 V max.

These voltage ranges should **not** be exceeded or erratic operation may result.

NOTE: *Since the potential input for the power factor detection is derived from the control power input (V_1 and V_2), it is imperative that the voltage input be taken from the two proper motor phases. See Typical Elementary Diagram (Figure 10) to determine proper phases.*

4.2.3 Relay outputs

The three relay outputs (TRP, FAR, and FCX) have the following contact ratings:

	Continuous	Interrupt
120 VAC	7A	7A
240 VAC	7A	7A

4.2.3.1. Relay output description

The following is a description of the relay outputs.

1. **TRP — Trip Relay.** This relay is normally energized and drops out on loss of power or when the module senses an abnormal condition.

2. **FAR — Field Application Relay.** This relay picks up at the proper time to apply dc to the motor field.

SECTION 4 — Description of the CR192 Micro-starting and Protection Module

3. FCX — Loading Relay. This relay picks up when the motor is fully-synchronized and ready to be loaded. It is controlled by the "FCX DELAY" programmable set-point.

4.2.4 Current transformer input

The μSPM is designed to work from a five (5) ampere Current Transformer (C.T.) secondary. The Current Transformer must be connected in the proper motor phase. (See Typical Elementary Diagram on Figure 10 to determine proper phase.) μSPM for brushless applications require inputs from two motor phases. See Figure 22.

4.2.5 Power factor analog signal output

This output is a zero to ten volts dc signal corresponding to motor power factor. Zero volts is zero lagging power factor. Five volts is unity power factor, and ten volts in zero leading power factor. Calibration: one (1) volt change corresponds to a phase shift of eighteen (18) degrees. (Not available with power factor regulation.). Do not connect less than 10 kilo-ohms to this output.

4.2.6 Optional inputs/outputs

The following are the optional inputs/outputs.

1. DC Field Current Input. DC field input must be sensed from a separately supplied D.C.C.T. (Direct Current, Current Transformer) and C.M. (Calibration Module). These devices are supplied automatically when field loss protection and/or the field current display option is furnished.

2. Exciter Voltage Output Monitor. The output of the field exciter must be connected to the μSPM through a separate resistor when exciter voltage failure protection and/or exciter voltage display is furnished.

3. Power Factor Regulation Output. This optional output consists of a dc control signal which is used to control an SCR Variable Exciter output to obtain motor power factor regulation. This pre-empts the power factor analog signal described in Paragraph 4.2.5.

NOTE: *The following paragraph applies to the CR192 -E, and -F versions only.*

If control voltage excursions occur outside the ranges listed in paragraph 4.2.2., a provision is available that will allow the user to connect an external stabilizing transformer for operation with severe control power voltage dips. The CR192 -E and -F versions have separate inputs for control power and power factor reference voltage. This allows connection for control power from a stabilized voltage source of 115 VAC (CR192E), or 230 VAC (CR192F). Both of these versions require a 6-7 VAC nominal input (unstabilized) for the power factor reference voltage. Terminal points "V1 EXT" and "GND" have been added to accommodate the separate PF reference voltage. See Figure 31.

4.3 The CPU status light

The CPU status light is a bicolor type device. It should normally glow green. If it is red continously, a problem exists with the microprocessor or with a peripheral device. If the

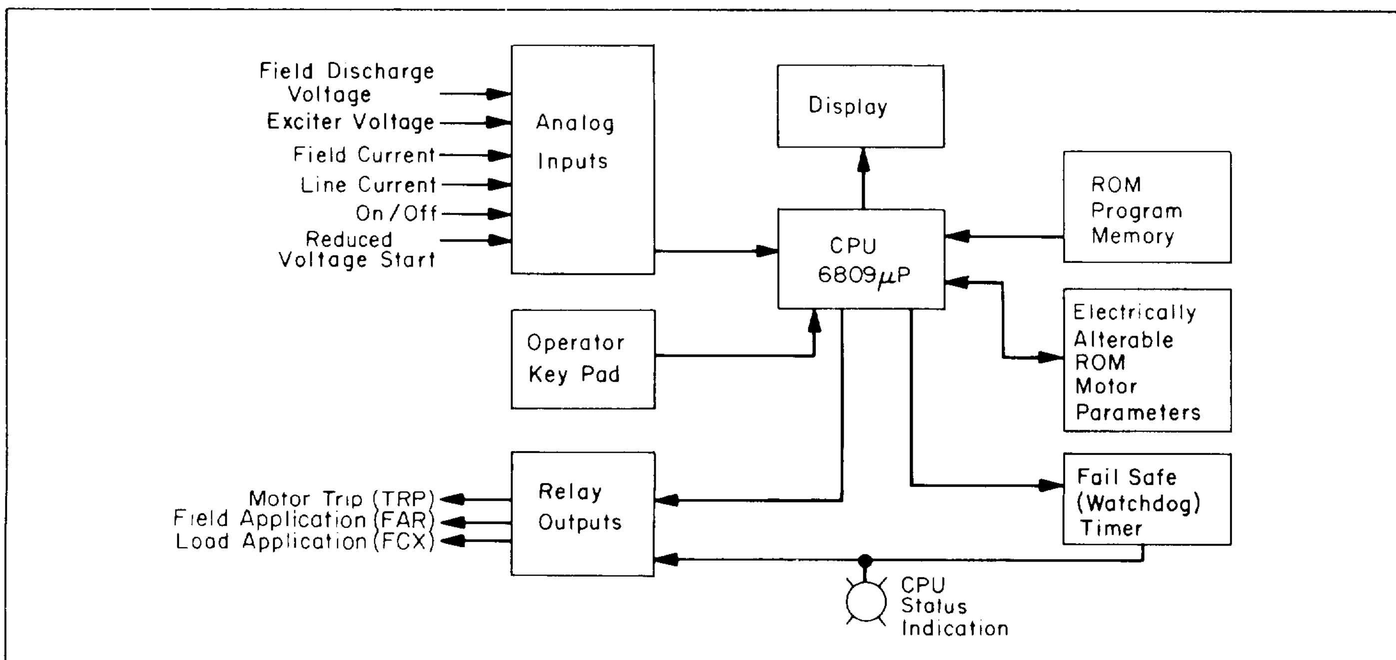


Figure 20A. CR192 μSPM block diagram

SECTION 4 — Description of the CR192 Micro-starting and Protection Module

light cannot be reset to green by depressing the recessed pushbutton on top of the case, then the unit should be replaced. Momentary flashes of red, particularly during power up initialization, are normal and should be ignored.

4.4 Non-volatile, set-point memory

The CR192 μSPM contains an electronically-alterable, read-only-memory (EAROM) to retain set-point parameters through periods of power outage without the use of a battery storage. Also if the μSPM is stored or left idle for long periods of time, its set-points do not have to be re-entered prior to placing the unit back in service.

4.5 Readout of module temperature

The CR192 can display its internal temperature in degrees Celsius. To display the internal temperature press "SHIFT" then the "4" key. The internal temperature of the μSPM will be displayed. Press any key to return the display to normal. The temperature may be displayed while the motor is running or stopped.

4.6 Circuit board conformal coating

All of the printed circuit boards are now conformally coated to help protect the board, the components, and the soldered connections from moisture, dust, and common atmospheric contaminants.

SECTION 5 — Optional Features

5.1 General

The CR192 μSPM may be supplied with several options as described below. If required, these options MUST BE SPECIFIED when ordering. See Section 7 for ordering options.

5.2 Exciter voltage check protection

Connecting the exciter output to μSPM Terminals +VE and -VE through a separate resistor assembly will provide exciter voltage check protection when that option is supplied. (Figure 25.) This will not allow the motor to be started if exciter voltage is not up, but the μSPM will not require a reset. If exciter voltage is lost while the motor is running, the μSPM will trip the motor and will require a reset before motor can be restarted. "CHECK EXCITER" will be displayed until reset. See Section 8 for programming the set-points.

This function is supplied for equipment that has exciters energized prior to starting the motor. If the exciter is designed to be energized with motor starting, as with shaft-connected rotating exciters, either order field current loss protection described in Section 5.4 below, or a separate voltage relay for voltage check protection.

5.3 Exciter voltage display

By addressing the exciter voltage display function, the exciter voltage will be flashed digitally onto the display. To display exciter voltage press "SHIFT" then "7" key. To go back to normal display, press any key. Input is required to Terminals +VE and -VE per Section 5.2

NOTE: *Exciter voltage cannot be displayed unless this option is supplied. Return to normal display by pressing any key.*

5.4 Field current loss protection

Field current loss protection is available when this option is supplied and when the separately supplied current sensor (D.C.C.T.) and Calibration Module (C.M.) assemblies are connected. This protection trips the motor if the field current drops below the programmed set-point after the motor has synchronized. If trip occurs, "FIELD-CURRENT LOSS" is displayed. See Section 8 for programming instructions.

5.5 Field current display

Field current may be displayed digitally if this option is ordered. It becomes the third normally displayed value (along with power factor and line current). The same separate components used in the field current loss protection option (Section 5.4) are required.

5.6 Incomplete sequence protection

If the motor does not synchronize within the time programmed in the incomplete sequence set-point, the motor will trip and "INCOMPLETE SEQUENCE TRIP" will be displayed. The μSPM must be manually reset before the motor can be restarted. This can be accomplished by pressing any key on the keypad.

5.7 Power factor regulation option

The applications requiring power factor regulation are discussed in Section 3.2.4. The CR192 μSPM outputs a control signal to an external proportional SCR exciter. The regulator has three adjustable set-points that can be changed while the motor is running to facilitate regulator tune-up. See Figure 20. These are the only three parameters that can be changed while the motor is running. The three parameters are as follows:

1. **Regulator Set-point.** The desired power factor set-point for regulation is adjustable over the range of leading power factors.

2. **Regulator Gain.** This adjustment is provided to allow optimum regulator response without instability.

3. **Regulator Floor.** A floor adjustment is provided that overrides the regulator if the regulator causes the field current to dip too low.

Certain conditions of operation require a floor so that the motor power factor will not become unstable if the field current is drastically reduced.

When the floor overrides the regulator, the power factor moves in a more leading condition than the regulator set-point. As the load and/or system force the motor power factor toward the lagging condition such that the power factor falls below the regulator set-point, the regulator will once again take control and boost the field above the floor so that the power factor will not dip **below** the set-point.

5.7.1 Regulator tune-up Instructions

Following these instructions will permit tune-up of the regulator during the initial start-up of the motor.

SECTION 5 — Optional Features

NOTE: *Perform all start-up instructions in Section 6.2 before proceeding.*

Enter the following initial values into the μSPM:

REG PF = 2.0

REG GAIN = 10

FLOOR = 5.0

NOTE: *See Section 8 for programming these set-points.*

The 2.0 value for regulator PF set-point places "FLOOR" in control of the motor field. The power factor regulator is disabled.

The 5.0 value for the FLOOR is sufficiently high so that the motor will not trip due to underexcitation when it is started.

After the above values are stored in memory, and with the display reading **SPM READY**, start the motor (unloaded if possible) and allow it to synchronize. The display should indicate a leading (+) power factor.

The three power factor regulator parameters can be changed while the motor is running so that regulator tune-up is facilitated. These are the only parameters that can be changed while the motor is running.

To get in the program mode while the motor is running, press "SHIFT" followed by "0."

The display now reads

REGULATOR ADJ. Λ

Press the "SCAN" key until the "FLOOR = " parameter is displayed. Adjust the motor field current for a desired minimum (typically between 80 to 100 percent of rated field current.) Change the floor value by first pressing the "#" key followed by a new value either above or below the initial value of 5.0, depending on whether more or less field current is desired. The value entered in the floor parameter is the output voltage across the PF regulator output terminals +N and −N. To enter the new value of floor voltage, first press the "ENTER" then "DISPLAY" keys.

NOTE: *This method of parameter entry can only be employed while the motor is running and only for the three power factor regulator parameters.*

Once the desired minimum motor field current is obtained, press the "SCAN" key until the "PF REG = " appears in the display. Now program the desired set-point of power factor (typically between 0.8 and 1.0 PF) by pressing the "#" key followed by the desired set-points. Enter the new value by pressing the "ENTER" and "DISPLAY" key. The control of the motor field current should now be in control of the Closed-loop Power Factor regulator.

The gain set-point can probably be left at 10. However, should instability (hunting) occur or if more optimum response is desired, the gain may be increased or decreased as desired. Press "SCAN" until "REG GAIN =" appears in the display and enter new set-points (Range 1-100) using the same procedure as for the FLOOR and REG PF set-points. Optimum gain would be the highest possible gain setting without power factor instability which is detectable by a fluctuating exciter output and power factor. These parameters are automatically stored in the EAROM, when the motor is shut down.

NOTE: *Do not attempt to regulate 1.0 power factor with an unloaded or lightly loaded machine. A synchronous machine running unloaded at or near unity power factor is inherently unstable and will probably be tripped from power factor protection. Adjust the FLOOR set-point high enough to override the regulator and avoid the instability; while allowing the PF to move near zero lead power factor.*

SECTION 6 — Installation and Start-up

6.1 Receiving and installation

When the equipment is received, follow the directions for unpacking and handling as directed in instructions attached to the equipment. Be sure to keep equipment in an upright position, unless measures have been taken to lay equipment down.

The field discharge resistor assembly is probably shipped separately for field installation on top of the equipment. The resistor assembly is identified by a catalog number coinciding with that of the section on which it is to be mounted. Report any equipment damage to the carrier immediately.

CAUTION: *DE-ENERGIZE ALL EXISTING EQUIPMENT BEFORE INSTALLING NEW EQUIPMENT.*

6.1.1 Installing complete controller equipment

Follow instructions provided with the equipment for placement of the enclosure. Refer to the outline drawings, details for incoming conduit and cable locations, and floor bolt holes.

CAUTION: *SEPARATELY SHIPPED FIELD DISCHARGE RESISTOR MUST BE MOUNTED AND WIRED TO CONTROLLER BEFORE ENERGIZING CONTROLLER.*

Refer to elementary diagrams and outline drawings for identification and location of incoming power cable, motor cable, field wire and control wire connections. After installation is complete refer to the start-up procedure (6.2) in Section 6 prior to energizing the equipment.

6.1.2 Installing field panels

For installing field panels, refer to Section 4.1.2 entitled "Starting Protection." Also check that the interconnecting wiring between the field panel and the ac power switching device (contactor or circuit breaker) is wired per the elementary diagram for the field panel equipment. In case of trouble, it is mandatory that this wiring be correct so that the field panel can trip the motor off line by means of the ac power switching device. Review the start-up procedure before energizing the equipment.

6.1.3 Component CR192 μSPM

When the μSPM is shipped separately, carefully unpack the module and report any observable damage to the carrier.

Mounting the CR192 μSPM requires careful attention to the following instructions.

1. Remove the face-plate assembly by loosening the four (4) screws on the front of the μSPM. The screws do not need to be completely removed.

2. **Carefully** disconnect the ribbon cable from the face-plate assembly. Disconnect the cable at the face-plate assembly. A small screwdriver can be used to gently pry the disconnect apart from tabs on each end of the disconnect. Use the ejector tabs to disconnect the cable.

3. **Carefully** unstab the ground wire from the face-plate assembly.

4. Mount the cable to the rear of the panel over the cutout prepared for the μSPM. See Figure 26.

5. **Carefully** re-connect the ribbon cable and the ground wire to the face-plate assembly. Make sure the ejectors close over the connector properly.

NOTE: ***DO NOT*** *shift or skew the ribbon connector.*

6. Re-mount the face-plate assembly to the case from the front panel. (It may be necessary to further loosen the screws before re-mounting.) Be certain all four screw latches engage the μSPM box. These can be inspected from the rear of the unit.

NOTE: ***DO NOT*** *let the face-plate assembly dangle from the connecting wires.*

Wire the μSPM using either Figure 10 (ring type) or Figure 23 (brushless) as a guide. Pay particular attention to the connection of the C.T. and C.P.T. inputs to the μSPM. These inputs must be connected per Figures 10 and 23 for proper power factor protection.

7. **Field and exciter voltage inputs.** The field voltage inputs (V_F+ and V_F-) and exciter voltage inputs (+V_E and -V_E) must be connected to a separately supplied external resistor assembly. Resistor assembly Cat. No. for field voltage input only is 55B529836G3. Resistor assembly for field and exciter voltage inputs is 55B529836G4 (used when EXCITER VOLTAGE CHECK PROTECTION and EXCITER VOLTAGE DISPLAY options are supplied). These assemblies are supplied automatically with the new CR192 μSPM units. See Figure 10.

WARNING: *DO NOT ATTEMPT TO START THE MOTOR WITHOUT THE EXTERNAL RESISTOR ASSEMBLY WIRED IN WHEN USING -C THROUGH -F VERSIONS. SEVERE DAMAGE TO THE CR192 μSPM WILL RESULT IF THE EXTERNAL RESISTOR ASSEMBLY IS NOT PROPERLY CONNECTED.*

NOTE: *The following paragraph applies to the CR192 -E and -F versions only:*

8. If voltage excursions occur outside the above ranges, a provision is available that will allow the user to connect an external stabilizing transformer for operation with severe control power voltage dips. The CR192 -E, and -F versions have separate inputs for control power and power factor reference

SECTION 6 — Installation and Start-up

voltage. This allows connection for control power from a stabilized voltage source of 115 VAC (CR192E), or 230 VAC (CR192F). Both of these versions require a 6-7 VAC nominal input (unstablized) for the power factor reference voltage. Terminal points "V1 EXT" and "GND" have been added to accommodate the separate PF reference voltage. See Figure 31.

Be sure to follow the step-by-step start-up procedure before energizing the module on the equipment in which it is mounted.

6.2 Start-up procedure

6.2.1 Inspection

Inspect all wiring and verify that the connections are clean, tight, and there is adequate clearance for all devices.

All external wiring from the controller must be made in strict accordance with the Main Connection Diagram supplied with the controller.

While referring to 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).

While performing the inspection of the field contactor, manually pick up the contactor and confirm that the normally-closed contactor pole opens after the two normally-open poles close. It is important that all three poles are closed momentarily (overlap) during contactor pick-up and drop out (closed transition contacts).

Later versions of the CR192 contain a disconnect type terminal board to facilitate field change out of units. Check to see that terminal board halves are fully engaged and that the removable part is not shifted up or down on the non-removable part. The two halves must mate flush at the top and bottom of the terminal board halves.

To clean the face of the CR192 μSPM, wipe with a damp cloth and mild detergent.

6.2.2 Grounding

Equipment should be grounded to a suitable system ground. The ac control power circuit is grounded, unless the Customer's specification requests an ungrounded circuit.

6.2.3 Test checks for CR192 μSPM

After the wiring check is complete, the equipment may be energized but **DO NOT START MOTOR**.

> **CAUTION:** *DO NOT TOUCH ANY CONNECTION POINT AT THE REAR OF THE μSPM. POTENTIALS UP TO 1000 VOLTS MAY BE PRESENT ACROSS INPUTS VF+ AND VF-.*

With control power on, carefully follow the following procedure:

1. **Standby Mode**

   Apply control power ONLY (do NOT start the motor).

   The display should come up **SPM READY**.

At this point obtain a listing of the factory-programmed set-points. (Nameplate on back of μSPM contains factory-programmed parameters.) Now press the SCAN button on the keyboard and compare each of the display set-points with the factory-supplied listing. Each time the SCAN button is depressed the next set-point item is displayed. To view the previous set-point item, press the SHIFT key just prior to the SCAN key.

The CPU STATUS light should be green. If the light is red, then a problem exists with the microprocessor or peripheral device.

2. **Test Mode**

The μSPM has built-in test diagnostics which are provided to indicate that the unit is operational prior to start-up.

Place the μSPM in the "test mode" by pressing the SHIFT key and then the TEST key. The μSPM will respond with the message "TEST NUMBER?," and relay TRP will open.

NOW PRESS 0—FOR SYNCHRONIZING/P.F. TRIP TEST
OR PRESS 1—FOR SQUIRREL CAGE PROTECTION TEST.
OR PRESS 2—FOR INTERNAL TEST.

If the test mode was entered by mistake, the operator may exit by pressing the nine (9) key instead of the 0, 1 or 2 key.

A. **Synchronizing Test** — The synchronizing test proceeds as follows after initiation.

   First the μSPM generates an internal "slip frequency" into the synchronizing circuitry. This frequency slowly glides downward (simulating an accelerating motor). When this frequency matches the set-point "SYNCHRONIZING SLIP," the display flashes "FIELD IS APPLIED" and relay FAR picks up followed by FCX after the "FCX DELAY" time set-point. See Figure 20A.

B. **Power Factor Test** — Next, the μSPM **automatically** tests the power-factor circuitry by internally generating a test power factor signal. No operator interface is required to go from the synchronizing test to the power factor test. This signal slowly decreases in value until it dips just below the set-point, power-factor, trip level. After the "PF DELAY" set-point time, the display reads "PF TRIP." Press any key to reset. If μSPM is in the RESYNC mode, the μSPM may attempt to resynchronize. If it does, "FIELD IS APPLIED" will be displayed momentarily, before PF TRIP occurs.

C. **Squirrel Cage Protection Test** — The third test is the Squirrel Cage Test and it is initiated by pressing SHIFT key followed by the TEST key followed by the ONE (1) key.

The μSPM generates an internal SCP test frequency into the SCP program. After a time delay, corresponding to the 'STALL TIME" set-point parameter, the display reads "SQ. CAGE PROT TRIP." Press any key to reset.

D. If the TWO (2) key is pressed the μSPM will perform a complete system test on the internal memory, input-output devices, timers and other system functions. As the test progresses the results are displayed. If a particular part of the μSPM fails, the test sequence will report the failure. If a failure persists after two or three attempts, the unit should be replaced. If the test fails, the μSPM must be reset. See the caution note on Page 25.

WARNING: *THE SYSTEM TEST PERFORMS A COMPLETE REINITIALIZATION OF THE μSPM. ANY SQUIRREL CAGE PROTECTION TIMER VALUE WILL BE LOST. DO NOT RESTART A HOT MOTOR AFTER PERFORMING A μSPM SYSTEM TEST. ALLOW THE MOTOR TO COOL BEFORE A RESTART IS ATTEMPTED.*

3. **Phase Sequence**

Normal phase sequence is L1-L2-L3. Start the motor and observe whether a "+" or a "-" appears in the PF display prior to field application. Before field application the PF sign should always be "-". If this is the case, phase sequence is correct. After field application the normal sign will be "+", indicating motor is operating in leading power factor. If "FIELD IS APPLIED" message appears before the PF sign, motor probably accelerates too quickly and there is insufficient time to display PF during acceleration.

If "FIELD IS APPLIED" message appears before the PF sign, shut down motor and temporarily lift the wire on μSPM terminal FAR2. Now restart motor, note PF sign, and immediately shut down motor. **Do not allow motor to run more than three seconds after "FIELD IS APPLIED" message appears.** If a "-" sign appeared in the PF display PF polarity is correct. if a "+" sign appeared, polarity is reversed. Reverse wires on μSPM terminals V1 and V2 ("V1EXT" and "GND" on CR192 -E and -F versions) to correct for reverse phase sequence. Reconnect wire to FAR2 and proceed with start-up.

WARNING: *BE SURE TO STOP MOTOR **AND** DE-ENERGIZE ALL POWER BEFORE CHANGING ANY LEADS.*

6.3 Start-up description

Closing the feeder to the controller unit provides power to the control circuits and to the Micro-starting and Protection Module (μSPM). Energizing the μSPM causes the TRIP relay contacts (TRP1-TRP2) to close and the μSPM display to read "**SPM READY**." See Figure 10 or Figure 23.

Pressing the START button will pick up relay MX which, in turn, energizes the coil of Main Contactor M. When M closes and applies ac power to the motor, induced field current flows in the discharge resistor FDRS and its voltage drop appears at the μSPM terminals VF+ and VF-. The frequency of this induced field voltage decreases as the motor speed increases, and the speed sensing circuits of the μSPM cause the relay FAR to close as the motor reaches the programmed slip value. When the FAR Relay Contacts (FAR1-FAR2) close, the Field Contactor (FC) picks up and applies excitation to the motor from the exciter.

After the programmed FCX delay, relay FCX picks up and closes its contacts, allowing the customer's automatic loading circuits to be activated.

6.4 μSPM displays

The μSPM contains an alpha-numeric display for (1.) programming prompts (See Section 8), (2.) reason for μSPM trip operation, and (3.) readout of the desired motor running parameters. The parameters are as follows.

Before start, display screen reads **SPM READY**.

When the field contactor closes, FIELD IS APPLIED is displayed momentarily, followed by the normal running display of line amperes, field amperes (if this option is furnished) and motor power factor. The (+) or (−) indicates whether the motor is leading or lagging power factor. "+" indicates leading power factor (motor generating reactive power) while "−" indicates lagging power factor (motor consuming reactive power). Unity (1.0) power factor display may have a "+" or "−" sign indicating that power factor is just slightly leading or lagging.

Display exciter volts using the following procedure.

Depress "SHIFT" key, then depress "7" key to display exciter volts. To return to normal display parameters, depress any key. Field volts will be displayed only if this option is furnished with the CR192 μSPM. See Section 7 for ordering.

The μSPM can display its internal temperature in degrees celsius. Press "SHIFT" and "4" to display the temperature. Press any key to return to normal display.

6.5 μSPM messages

The μSPM has a number of built-in messages that may appear during normal operation of the μSPM or if an error is detected. Errors may occur because of an improper operator entry or if the CPU detects a problem internal to the μSPM. The following discussion explains these messages in detail. Each message will be shown and the explanation will follow.

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FIELD IS APPLIED. This message appears when the μSPM has closed the field contactor. The message is displayed briefly and is a normal μSPM function.

P.F. TRIP. If the μSPM has determined that the motor has been operating below the power factor set-point for too long, the μSPM will trip and display "P.F. TRIP."

REDST ERR. This message indicates that the CPU has detected an error in a calculation performed as part of the squirrel cage protection algorithm during a reduced-voltage start. If this error persists after several attempts to start the motor, the μSPM may have an internal fault.

CHECK EXCITER. If the "CHECK EXCITER" message appears the μSPM has determined that the field voltage is below the minimum that has been entered in the field voltage set-point. The exciter should be checked to determine that the exciter is functioning properly. Also, the set-point should be examined to see if it is too high for the normal exciter output.

FIELD LOSS. The "FIELD LOSS" message indicates that the field current is less than the field current set-point. The exciter should be checked for proper output and the field current set-point should be checked.

EAROM ERROR. After the μSPM writes information to its non-volatile memory (EAROM) the CPU immediately reads back the last value and compares it with what should have been written. If the two values are not equal the μSPM will display the "EAROM ERROR" message. This generally indicates that a problem exists with the CPU Board and the μSPM should be replaced.

MISSING VOLTAGE. This message indicates that the μSPM is **NOT** receiving a power factor-reference voltage input to terminals "V1 Ext" and "GND" on Models CR192 "-E" and "-F". This message may also mean that the V1-2 jumper on the power-supply board is connected at Postion J-4 (internal) for Models CR192 -C and -D; or position J5 (external) for Models CR 192 "-E" and "-F".

SCP TRIP. The "SCP TRIP" message indicates that the μSPM has tripped the motor off-line due to a squirrel cage protection trip. The motor should be allowed to cool at least twenty (20) minutes before a restart attempt is made.

ISCP ERR. This message is an internal CPU message that indicates that the incomplete sequence counter was improperly initialized. If the message persists, the μSPM should be replaced.

BELOW CURVE D and ABOVE CURVE A. These messages indicate that the parameters stored in the stall time and run time set-points are not compatible with each other. Those two set-points should be checked and changed if necessary.

RUN TIME ERROR. This message indicates that the CPU has calculated an allowable run time for the motor that is too large.

2 DEC PTS. This message indicates that a set-point was entered that had more than one decimal point. The set-points should be checked and re-entered, if necessary.

INV DIGIT. This an internal CPU error and indicates that a digit in the data memory was not in the proper form. The μSPM should be re-initialized and checked again. If the problem persists, replace the μSPM.

PULL OUT TRIP. This message appears after a trip that is caused by motor line current exceeding 4 times longer than the P.F. delay time.

INV BCD. This message indicates that an invalid character was found in the data memory. The μSPM should be re-initialized and if the problem persists, replace the μSPM.

PARAM TOO LARGE. If a parameter entered is outside the valid range this message will appear. It usually indicates that the last parameter entered from the keyboard needs to be re-examined and corrected.

INC SEQ TRIP. This message indicates that the μSPM has tripped the motor due to an incomplete sequence fault. The source of the fault should be located before the motor is started again.

RESYNC ERROR. This message indicates that an unusually long period of time has elapsed while the μSPM was attempting to resynchronize the motor.

CHECKSUM ERROR. This message indicates an EAROM READ error. To correct this error, enter the Program Mode and change at least one set-point and then store the set-point. At this time the μSPM recalculates the MEMORY CHECKSUM and the problem should correct itself. If the problem persists, replace the μSPM.

The μSPM also has several messages that appear at the end of the programming process when the operator enters a value outside the valid range of the set-point. These messages are listed below and, although most are self explanatory, some are not and need definition. Refer to the valid set-point ranges described in Section 8 to determine the proper range for each set-point.

MESSAGE	EXPLANATION
INVLD PF TRIP	INVALID POWER FACTOR TRIP SET-POINT
INVLD PF DELAY	INVALID POWER FACTOR DELAY SET-POINT
INVLD STALL	INVALID STALL TIME SET-POINT
INVLD RUN TIME	INVALID RUN TIME SET-POINT
INVLD FLC	INVALID FULL LOAD CURRENT SET-POINT
INVLD LRC	INVALID LOCKED ROTOR CURRENT SET-POINT
INVLD % SLIP	INVALID PERCENT SLIP SET-POINT
INVLD FAR DELAY	INVALID FAR DELAY TIME SET-POINT
INVLD LFREQ	INVALID LINE FREQUENCY SET-POINT

MESSAGE	EXPLANATION
INVLD CT RATIO	INVALID CURRENT TRANSFORMER SET-POINT
INVLD REPLY	INVALID ENTRY FOR THE RESYNC SET-POINT
INVLD FCX DELAY	INVALID FCX DELAY SET-POINT
INVLD FLD V	INVALID FIELD VOLTAGE SET-POINT
INVLD FLD I	INVALID FIELD CURRENT SET-POINT
INVLD FIELD CT	INVALID FIELD CURRENT TRANSFORMER SET-POINT
INVLD PF REG	INVALID POWER FACTOR REGULATOR SET-POINT
INVLD GAIN	INVALID GAIN SET-POINT
INVLD FLOOR	INVALID FLOOR SET-POINT
INVLD INC SEQ	INVALID INCOMPLETE SEQUENCE SET-POINT

NOTE: *To clear a trip message such as* ***PF TRIP*** *or* ***SCP TRIP, press any key*** *on the keypad.*

CAUTION: *DO* ***NOT*** *DEFEAT THE MOTOR RESTART PROTECTION PROVIDED BY THE μSPM BY SWITCHING THE CONTROL POWER ON AND OFF, OR BY DEPRESSING THE SMALL, RECESSED RESET PUSHBUTTON AT THE TOP REAR OF THE MODULE CASE. EITHER ONE OF THE ABOVE ACTIONS RESETS THE STALL TIME COUNTERS WHICH DEFEATS MOTOR PROTECTION FROM FREQUENT RESTARTS.*

6.6 Interchangeability with earlier CR192 models

The CR192 -C and -D μSPM modules are physically interchangeable with the -A and -B models. However, if an -A or -B model is substituted for a -C or -D model, it will be necessary to install jumpers across the external resistor assembly as follows:

Install	Between resistor assembly terminals
JUMPER #1	(R1) and (+)
JUMPER #2	(F2) and (-)
JUMPER #3	(V+) and (E+)
JUMPER #4	(V-) and (E-)

Also remove the V130L20 MOV from the resistor assembly.

WARNING: *REMOVE THE ABOVE JUMPERS AND RECONNECT THE MOV, IF THE CR192 -C OR -D MODEL IS RE-INSTALLED IN PLACE OF THE -A OR -B VERSION.*

We recommend that prominent tags be attached to each of the above jumpers with wording such as:

WARNING: *REMOVE THIS JUMPER IF THE CR192 -C OR -D μSPM IS RE-INSTALLED IN PLACE OF THE -A OR -B VERSION.*

SECTION 7 — Ordering the CR192 μSPM

7.1 General

The CR192 μSPM can be ordered by assembling a suffix to the basic number to select the desired options. The arrangement and nomenclature of the eight-digit suffix is described in Table 1.

> **NOTE 1:** *A separate D.C.C.T. and the calibration module are required (supplied automatically) when either field current loss trip and/or field amps display option is ordered. The standard D.C.C.T. can be used with motor fields up to a rating of 154 amps dc. Contact the factory for ratings greater than 154 amps dc.*

> **NOTE 2:** *Power factor regulation* **NOT** *recommended for brushless motor applications.*

> **NOTE 3:** *A special SCR exciter and rectifier transformer is required in addition to the CR192 μSPM (with regulation option). Contact factory for details.*

> **NOTE 4:** *A separate resistor assembly is required (supplied automatically) when ring-type, exciter-voltage check protection is ordered. Connect to the* μSPM per Figure 10 (or Figure 23 for brushless version).

Table 1 Ordering arrangement and nomenclature

Suffix	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Catalog No.								
CR192	(C)	1	1	1	1	1	1	1

Suffix Nomenclature

(1) C-115VAC

D-230VAC CONTROL

E-115VAC CONTROL PLUS SEPARATE PF SUPPLY VOLTAGE

F-230VAC CONTROL PLUS SEPARATE PF SUPPLY VOLTAGE

(2) 0 = BRUSHLESS TYPE
1 = COLLECTOR RING[4] TYPE

(3) FIELD CURRENT LOSS TRIP[1]
0 = NO
1 = YES

(4) EXCITER VOLTAGE CHECK PROTECTION[4]
0 = NO
1 = YES

(5) FILED AMPS DISPLAY[1]
0 = NO
1 = YES

(6) EXCITER VOLTS DISPLAY[4]
0 = NO
1 = YES

(7) INCOMPLETE SEQUENCE PROTECTION
0 = NO
1 = YES

(8) POWER FACTOR REGULATION[2,3]
0 = NO
1 = YES

SECTION 8 — CR192 μSPM Programming Instructions

8.1 Programming procedure

The μSPM is a user programmable device with a wide range of set-points that enable operation with a wide variety of ring-type and brushless synchronous motors. This section deals with programming the μSPM for a ring-type motor. The set-points will be explained and a practical example will be given. The example may be followed step by step by the operator as a guide to program his μSPM for his motor.

In order to program set-points the μSPM must be placed in the PROGRAM MODE. This can only be done when the motor is not running. Any attempt to place the μSPM in the PROGRAM MODE while the motor is running will be ignored. To enter the PROGRAM MODE the following keystrokes must be entered:

SHIFT — PROGRAM

The μSPM responds with:

ACCESS CODE?

The operator must now enter the proper access code to enable the PROGRAM MODE. If no response is given or an incorrect access code is entered the μSPM will display:

INCORRECT CODE

and then return to the ready state. The correct access code is **192** and it must be entered before a built-in time delay expires.

When the correct access code is properly entered the μSPM will display:

PARAMETER *?Λ

The small up arrow indicates that the μSPM is in the PROGRAM MODE and the arrow will remain in the display as long as the μSPM is in the PROGRAM MODE. This serves as a reminder that the motor will not start until the PROGRAM MODE is exited.

The μSPM is now prompting for the parameter number that the operator wishes to change. Following is a table of the set-points that may be programmed by the operator. Each set-point has a parameter number which the μSPM is asking for in the display above. The operator may enter the number of the particular set-point he wishes to change or, if desired, the ENTER key may be pressed and the μSPM defaults to the first set-point. Table 2 gives a detailed explanation of each set-point and information about the Front-panel Keyboard. Finally, a programming example is given.

Once the parameter number is entered, press ENTER. Display now shows current value of that parameter. Now press #. The parameter value is shifted to the left and a cursor (*) is indicating that the μSPM is waiting for new value. Enter new parameter, then press ENTER. The new parameter will now be displayed. Press SCAN to proceed to the next parameter to be changed and again follow the above procedure.

Once all the desired parameters are changed, store the new values by pressing:

SHIFT-STORE

if all parameters were correctly entered, display should flash:

STORED-VERIFIED

followed by:

** SPM READY**

8.2 μSPM Programmable Parameters

Table 2 Programmable parameters

Type	Parameter Number	Title	Valid Range
Standard Parameters	1	PF Trip	−0.6 (lagging) to unity Power Factor
	2	PF Delay	0.1 to 10 seconds
	3	Stall Time	1 to 40 seconds
	4	Run Time	1.05 to 3 times stall time
	5	Full Load Current	See Table 3
	6	Locked Rotor Current	2 to 12 times F.L.C.
	7	Synchronizing Slip	10 to 0.5 percent
	8	Line Frequency	25, 50, 60-Hertz
	9	C.T. Ratio	5:5 to 999*:5 (Enter primary amperes only)
	10	Resync	0, 1, 2, 3
	11	FCX Delay	1 to 6 seconds
Option Parameters	12	Field Voltage Trip	20 to 200-volts
	13	Field Current Trip	0.00 to 1000-amperes
	15	Field C.T. Rating	10 to 1000-amperes (Enter primary amperes only)
	16	Incomplete Sequence	1 to 100 seconds
	17	Regulator PF	1.0 to 0.00 leading Power Factor
	18	Regulator Gain	1 to 100
	19	Floor Voltage	0 to 10-volts

*For motor full-load currents greater than 999 Amperes, contact the factory.

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8.3 Explanation of standard set-points

Each set-point has a specific purpose and care must be taken when programming each one. The μSPM checks each entry to make sure that the value entered lies within the range shown in Table 2; however, the μSPM **cannot** detect if a particular set-point is safe for use with a particular motor.

NOTE: *It is the operator's responsibility to insure that the set-points are correct for the operator's motor. Improper entry of any set-point parameter may cause faulty motor protection.*

Table 3 Standard set-points

Parameter Number	Parameter	Function
1	TRIP PF	The trip power factor set-point is the value of lagging power factor that will cause a trip or a resynchronizing attempt during motor operation. For example: if the trip power factor is set at 0.85 lagging, the μSPM will trip if the power factor falls below 0.85 for a time longer than the PF delay set-point. (Always enter three digits plus decimal point.)
2	PF DELAY	The power factor delay set-point is the time delay that will elapse before the μSPM will operate during a power factor trip condition. If the PF delay is set for three seconds the μSPM will allow the motor to continue to operate for three seconds before tripping. (Two digit entry, plus decimal.)
3	STALL TIME	This set-point determines the allowable time that power may be applied to the motor during locked rotor conditions. This information may normally be found on the motor control data sheet. (Three digit entry, plus decimal.)
4	RUN TIME	Run time is the time that the motor may run at 50 percent speed and is expressed as a multiple of the allowable motor stall time. For example: if the motor stall time is 10 seconds and the run time set-point is programmed at 3, then the motor can run for 30 seconds at 50 percent speed. (Three digit entry, plus decimal.)
5	FULL LOAD CURRENT	This set-point is the motor-nameplate, full-load current. It is related to the C.T. ratio (number 09) listed in this table. Depending on the value of the C.T. ratio, the set-point that is entered here may cause an invalid full-load current error until the C.T. ratio is changed. The proper range of currents may be determined by dividing the value of the entry by the C.T. ratio and if the result is within the range of two to five amperes, the value entered will be accepted. Always enter full load current (no decimal).
6	LOCKED ROTOR CURRENT	The value of locked-rotor current is expressed as a multiple of the motor full-load current. For example, if the motor full load current is 100 amperes and the locked rotor current is 550 amperes, then the locked rotor current should be entered as 5.5 (550/100 = 5.50). (Enter three digits, plus decimal.)
7	SYNCHRONOUS SLIP	The value stored here is the slip at which the μSPM will close the field contactor. It is expressed as percent slip. For example, if 5.5 is entered as the set-point, the μSPM will close the field contactor when the motor reaches 94.5 percent of synchronous speed. (100 percent Speed − 94.5 percent Speed = 5.5 percent SLIP). (Enter two digits, plus decimal.)
8	LINE FREQUENCY	This set-point is simply the value of the local power frequency and can be 25-*, 50- or 60-Hertz.
9	C.T. RATIO†	The ratio of the current transformers supplied with the starter should always be entered in this set-point. The value entered here affects the valid range of motor full-load current, that may be entered in set-point number 05 above. Enter only primary amperes. Secondary of 5 amperes is assumed.
10	RESYNC/PF TRIP SUPPRESSION	0 = Ride thru mode. 1 = Resync (field removal) mode. 2 = Ride-thru plus PF Trip suppression below 50 percent rated line current. 3 = Resync Mode plus PF Trip suppression below 50 percent rated line current.
11	FCX DELAY	**Set time to enable Power Factor Protection and Relay FCX Operation, timing begins with Relay FAR Operation. Set between 1 and 6 seconds (one digit only).**

† Do NOT try to store new full-load current before new C.T. Ratio is entered, or vice versa.

* Contact factory for 25-Hertz applications.

SECTION 8 — CR192 μSPM Programming Instructions

8.4 Explanation of option set-points

The following are option set-points that are only available if certain options are ordered with the μSPM. If a particular set-point is requested from the keyboard that is associated with an unavailable option the μSPM will briefly display "OPTION DISABLED" and prompt for another parameter number.

Table 4 Option set-points

Parameter Number	Parameter	Function
12	FIELD VOLTAGE TRIP	The minimum value of the field voltage may be entered here. This parameter determines the value of field voltage that will cause a "check exciter" fault. For example, if the exciter normally provides at least 100-volts to the field circuit, and this set-point is programmed for 100-volts, then the μSPM will trip and display CHECK EXCITER if the field voltage falls below the set value. The μSPM checks the exciter voltage before allowing the motor to start, and also displays "CHECK EXCITER" anytime the μSPM is energized and the field voltage is below the set-point. (Enter three digits, no decimal.)
13	FIELD CURRENT TRIP	The value programmed here will determine the minimum permissible field current that the μSPM will recognize as valid. If the field current falls below the set-point the μSPM will trip and display a field-loss fault. (Three digit entry, plus decimal.)
15	FIELD C.T. RATING	The rating stamped on the Current Transformer (C.T.) is entered here if one turn is passed through the C.T. window. If more than one turn is used, divide the C.T. rating by the number of turns and enter this number here. (Four digit entry including decimal.)
16	INCOMPLETE SEQUENCE	If the starter does not properly complete its starting sequence in a preset time then the μSPM will trip and display an incomplete sequence fault. The time setting may be set to any value between 1 and 100 seconds. (Three digit entry, no decimal.)
NOTE: *Settings 17, 18 and 19 may be programmed while the motor is running. See Section 5.7 entitled "Regulator Tune-up Instructions."*		
17	POWER FACTOR REGULATOR	The μSPM is capable of providing a Closed-loop Power Factor Regulator with a very fast response. The regulator may be set up to regulate motor power factor in a range between 1.0 (unity) to 0.0 leading power factor. This set-point determines at what power factor the regulator will operate. The regulator may be disabled in order to output the floor value (See Parameter 19) by entering a set-point of 2.0. This enables the operator to set up base-field amperes, then the regulator power factor may be returned to its normal setting and the regulator will function normally. (Enter three digits, plus decimal point.)
18	REGULATOR GAIN	The gain setting of the regulator is adjustable by changing this set-point. The gain should be set so that the response of the regulator is satisfactory and the regulator is stable. This setting may be subject to some experimentation before a satisfactory setting may be found. (Three digit entry, no decimal.)
19	REGULATOR FLOOR	The floor value is the minimum output voltage that will be sent to the field-rectifier equipment when the regulator loop calls for little or no output. This will occur if the motor jumps to a power factor considerably more leading than the set-point. If the floor is set to zero the field could be completely removed from the machine and this is an undesirable condition. The value programmed here is the exact output voltage from the μSPM. For example, if the floor is programmed at 1.5 the μSPM will output 1.5-volts minimum. (Three digit entry, plus decimal.)

8.5 The μSPM keypad

The μSPM keypad has several keys that serve a dual purpose. This was made possible by making one of the keys a "shift" key and marking several of the other keys with two labels. Without exception the top level marking on each key equipped with this feature is accessible by first pressing the shift key. The shift key itself functions in a similar manner to a shift key on a typewriter except the key does not need to be held

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down. In fact, if the shift key is held continuously, the μSPM will not recognize any other keypress. The shift key also has a built-in timer function so that if the operator presses it and does not press another key within a few seconds, the shift function is automatically cancelled. Therefore, the operator should press the shift key and then press another key within three or four seconds.

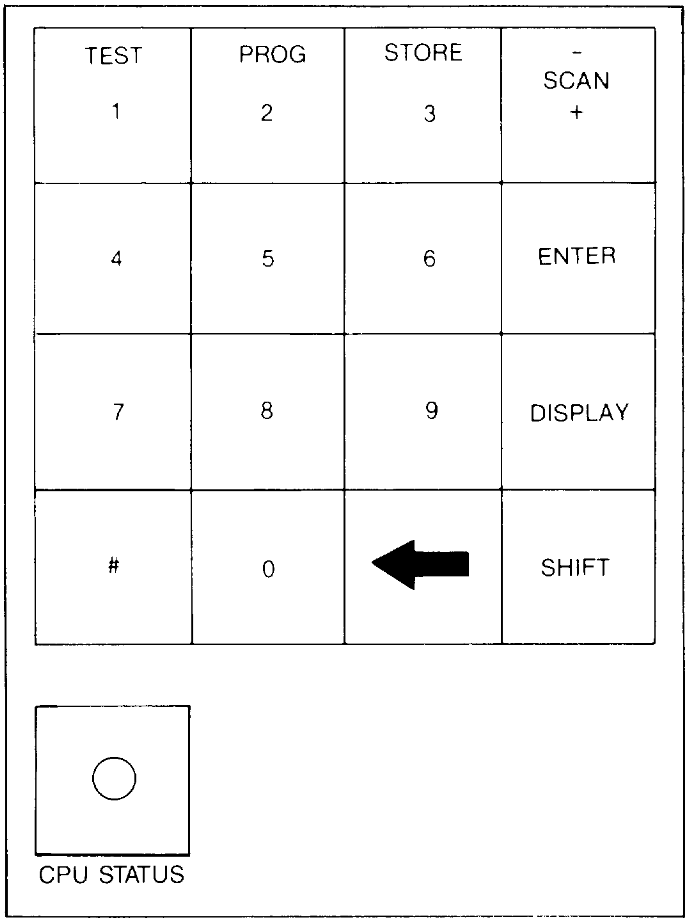

Figure 21. Keypad arrangement

The following keys have a shift function associated with them and each will be described in some detail.

One/Test Key/. This key will place the μSPM in the test mode. The μSPM has three tests available. When this key is pressed the display shows:

TEST NUMBER*? Λ

Either 0, 1 or 2 may be entered. The test mode is described in Section 6.2.3.

Two/Program Key/. This key is used to enter the program mode. The μSPM will prompt for an access code as described above.

Three/Store Key/. This key is used to exit the program mode. When the operator has completed the necessary programming operations the SHIFT key and then the THREE key are depressed. If no changes have been made the μSPM briefly displays:

NO CHANGES MADE

and then returns to the ready mode. If changes have been made, the μSPM will display:

STORED-VERIFIED

and then return to the ready mode. During the short delay between the keypress and the "verified" message, the μSPM has evaluated all of the set-points to see if they are in their proper range and if so, stored them in the μSPM nonvolatile memory. If a mistake was found, the μSPM will remain in the program mode and will display a message pointing to the offending parameter. If there was more than one invalid parameter, the μSPM will flag the first bad one. After the first parameter is changed and another attempt to exit the program mode is made, the second bad parameter will be flagged and so on. For example, if the trip power factor was set to 0.40, the μSPM would respond with:

INVLD PF

The operator is required to enter a value that is in range before the program mode may be exited. If an attempt is made to exit the program mode in an unusual manner, such as removing power, the μSPM does not store the bad set of parameters and on power-up the previous parameter values will be recalled.

SCAN + /SCAN − Key. This key is utilized to scan through the set-points one at a time. The SCAN + key moves the display forward and the SCAN − key moves the display backward. The SHIFT key is pressed first if a backward scan is desired. If any of the optional functions are omitted in a particular μSPM, the scan function automatically skips the set-points associated with the disabled option.

THE # KEY

Before proceeding with the programming example, a brief explanation of the # key is required. The # key is used as a means to request the change mode while the μSPM is in the PROGRAM MODE. After the change mode has been entered, the # key is used as a decimal point key. For example, after the PROGRAM MODE has been entered and a set-point is showing in the display, it is necessary to tell the μSPM that the set-point needs to be changed. This is done when the # key is depressed as follows:

DISPLAY SHOWS: TRIP P.F. = 0.80 Λ
OPERATOR PRESSES # KEY
DISPLAY SHOWS: 80*Λ
μSPM IS NOW IN THE CHANGE MODE

In the change mode the old set-point is moved to the left of the display and a cursor appears on the right side of the display. The set-point may now be changed by typing the desired value into the display. The value on the left of the display also indicates the number of digits that must be entered by the operator.

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NOTE: *Replacements for all of the digits must be entered or the old set-point may affect the value of the new. The decimal point counts as a digit.*

The # key will now act as a decimal point key. Some parameters do not need decimal points and this will be demonstrated in the following paragraphs. There is no need to enter numbers any more accurately than one decimal point since the μSPM truncates any extra decimal positions. The backarrow key [←] is used to correct any mistakes made when entering a set-point. Simply press the backarrow key to clear the right-side of the display and re-type the entry.

Parameter	Desired Value	Parameter Number
PF TRIP	0.85 LAG	1
PF DELAY	0.2 Second	2
STALL TIME	7.0 Second	3
RUN TIME	1.6	4
FULL LOAD CURRENT	58 Amperes	5
LOCKED ROTOR CURRENT	3.9	6
SYNCHRONIZING SLIP	4 Percent	7
LINE FREQUENCY	60 Hertz	8
C.T. RATIO	100/5	9
RESYNC	1	10
FCX DELAY	3.0 Seconds	11
FIELD VOLTAGE TRIP	125 Volts	12
FIELD CURRENT TRIP	45 Amperes	13
FIELD CT RATING	100	15
INCOMPLETE SEQUENCE	15 Seconds	16
REGULATOR PF	0.85	17
REGULATOR GAIN	10	18
FLOOR VOLTAGE	1.0	19

8.6 Programming Example

The following example uses the following motor data and should be referred to as the example progresses. The data is for a 400-HP, 4000-volt, ring-type motor. We will assume that all of the optional features available with the μSPM have been installed. Table 5 shows the keypresses made by the operator, the μSPM display response and comments concerning the programming operation. At the beginning of the operation the μSPM should be displaying the **SPM READY** message.

Motor — 400-HP, P.F.-0.8, RPM-720, Volts-4000. Induced field current 0% SPD, 30-amps; 95% SPD, 17-amps. Recommended field-discharge resistance is 21 ohms; Allowable stall time — 7 seconds; 50 percent run time — 11 seconds.

NOTE: *The induced field voltage (product of induced field in amperes and discharge resistance in ohms) must fall between 200-volts and 1000-volts at both zero and 95 percent speed. For this example:*

21 OHMS × 30 AMPERES =
630-VOLTS (ZERO SPEED CHECK)
21 OHMS and × 17 AMPERES =
357-VOLTS (95 PERCENT SPEED CHECK)
The criterion is thus met for this example.

NOTE: *If induced field voltage is greater than 1000-volts, contact the factory.*

Section 9 should be studied before using a brushless controller equipped with the CR192 μSPM.

Table 5 Programming example

Keypress	Display Shows		Comments
SHIFT-PROGRAM	ACCESS CODE ?		Request program mode
192	PARAMETER *?	Λ	Access code accepted
ENTER	TRIP P.F. = 0.65	Λ	First parameter displayed
#	0.65 *	Λ	# key enables change mode
0#85	0.65 0.85*	Λ	New value has been selected
ENTER	TRIP P.F. = 0.85	Λ	New value has been entered
SCAN +	P.F. DELAY = 5.0	Λ	Next set-point is displayed
#	5.0 *	Λ	Change mode
0#2	5.0 0.2*	Λ	Note # key is decimal point
ENTER	P.F. DELAY = 0.2	Λ	New value has been entered
SCAN +	STALL TIME = 35.0	Λ	Next set-point
#	35.0 *	Λ	Change mode
07#0	35.0 07.0	Λ	7 second stall time
ENTER	STALL TIME = 07.0	Λ	New value has been entered
SCAN +	RUN TIME = 4.00	Λ	Next set-point
#	4.0 *	Λ	Change mode
1#60	4.0 01.6*	Λ	11 second run time (1.6 × 7 second)
ENTER	RUN TIME = 1.6	Λ	New value has been entered
SCAN +	F.L.C. = 100.	Λ	Next set-point

* = Cursor   Λ Up Arrow indicates μSPM is in the Program Mode

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Table 5 Programming example (cont'd)

Keypress	Display Shows	Comments
#	100 * Λ	Change mode
058	100 58* Λ	58 amperes F.L.C.
ENTER	F.L.C. = 58* Λ	New value has been entered
SCAN +	L.R.C. = 06.0 Λ	Next set-point
#	06.0 * Λ	Change mode
03#9	06.0 03.9* Λ	393 percent times F.L.C.
ENTER	L.R.C. = 03.9 Λ	New value has been entered
SCAN +	SYNC SLIP = 7.5 Λ	Next set-point
#	7.5 * Λ	Change mode
4#0	7.5 4.0* Λ	New sync slip is 4 percent
ENTER	SYNC SLIP = 4.0 Λ	New value has been entered
SCAN +	LINE FREQ = 60 Λ	This value is correct
SCAN +	CT RATIO = 5:0100 Λ	This value is correct
SCAN +	RESYNC 0 Λ	We want resynchronizing
#	0 * Λ	Change mode
1	0 1* Λ	Now it will be resync mode
ENTER	RESYNC 1 Λ	New value is entered
SCAN +	FCX DELAY = 3.0 Λ	This value is correct
SCAN +	FIELD V = 150 Λ	Next set-point
#	150 * Λ	Change mode
125	150 125* Λ	Change to 125-volts
ENTER	FIELD V = 125 Λ	New value is entered
SCAN +	FIELD I = 35.5 Λ	Next set-point
#	35.5 * Λ	Change mode
45#0	35.5 45.0 Λ	Change rated field I to 45 amperes
ENTER	FIELD I = 45.0 Λ	New value is entered
SCAN +	FIELD CT = 0100 Λ	This value is correct
SCAN +	INCOMP SEQ = 025 Λ	Next set-point
#	0.25 * Λ	Change mode
15#	0.25 15.* Λ	Change to 15 seconds
ENTER	INCOMP SEQ = 15. Λ	New value is entered
SCAN +	REG PF = +0.60 Λ	Next set-point
#	0.60 * Λ	Change mode
0#85	0.60 0.85 Λ	Change to 0.85 leading PF
ENTER	REG PF = +0.85 Λ	New value is stored
SCAN +	REG GAIN = 010 Λ	This value is correct
SCAN +	FLOOR = 1.00 Λ	Change to 11.5
#	1.00 * Λ	Change mode
11#5	1.00 11.5* Λ	Change floor to 11.5
ENTER	FLOOR = 11.5 Λ	New value is entered
SHIFT-STORE	INVLD FLOOR	Attempt to store values, OOPS! invalid floor message
#	11.5 * Λ	Back to change mode
3#50	11.5 3.50* Λ	Change to corrected value of 3.50
ENTER	FLOOR = 3.50 Λ	Corrected value is entered
SHIFT-STORE	(Flash) STORED-VERIFIED (Followed by) **SPM READY**	All parameters are stored, μSPM ready for operation

SECTION 9 — Brushless Motor Control

9.1 Description of brushless controller

A brushless controller must provide the functions peculiar to starting and protecting a brushless synchronous motor. To understand the functional requirements, it is necessary to review the construction of a brushless motor.

9.1.1 Brushless motor review

A brushless motor is like a conventional slip-ring motor in that it has rotor mounted field poles which must have dc supplied to their windings so that the rotor poles can "lock" onto the rotating stator field and run in synchronism. Also, like the slip ring motor, amortisseur windings are built into the tips of the rotor poles to provide acceleration and damping torques during starting and normal operation. During start, the motor accelerates to near synchronous speed. When the rotor is close enough to synchronous speed for the field poles to pull the rotor into

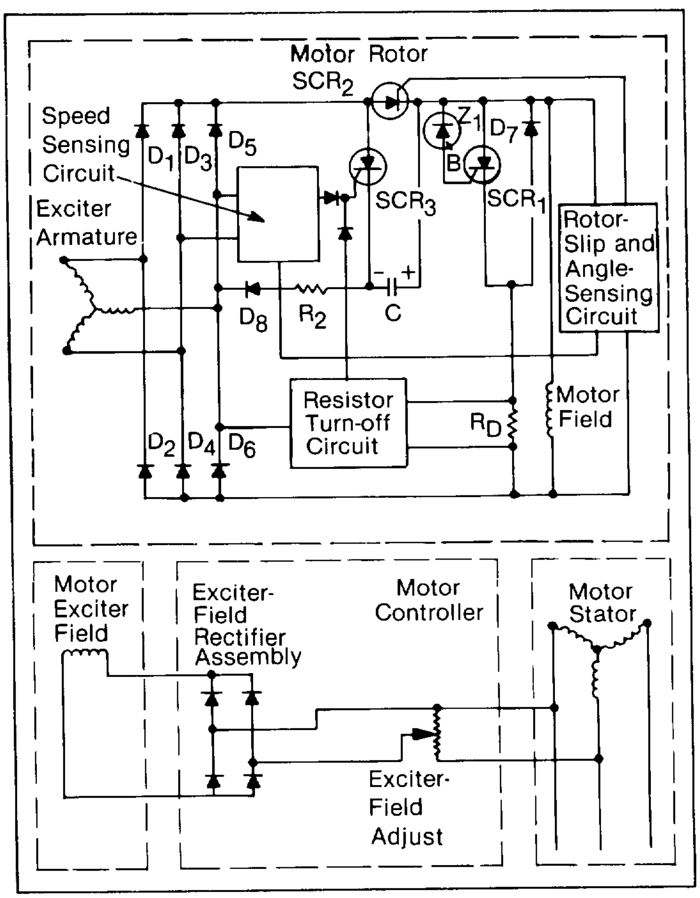


Figure 22. Typical rotating rectifier exciter schematic diagram with synchronous motor

synchronism, dc is applied to the main field and the rotor then pulls into step, and normally operates at some power factor equal to or more leading than unity.

The brushless motor has, as its name implies, no brushes or slip rings. Instead, it contains a rotating exciter with stator mounted dc windings and the armature winding on the rotor. A rotor-mounted, solid-state rectifier converts the ac from the exciter to dc for the main-field poles. The Silicon Controlled Rectifiers (SCR) and control circuitry are rotor mounted, along with the field discharge resistor, to control the application of dc to the main field at proper rotor speed and angle. From Figure 22, it is seen that the actual field control is provided with the motor and is **not** part of the motor controller.

9.2 Starting the brushless motor

The brushless motor is started by first applying power to the stator windings followed by application of dc to the exciter field. See Figure 23.

There are two basic timing functions a brushless controller must provide during start.

1. Apply dc to exciter (not main) field a given pre-set time after stator windings are energized.

2. Enable the power-factor, pull-out protection and provide a contact for signalling external automatic motor loading devices for motor loading. This is determined by a second given pre-set time delay that allows sufficient time after the application of the exciter field for the motor to synchronize and stabilize.

Both of these times can be entered as set-point parameters in the CR192 μSPM. (See brushless programming, Section 9.6.)

9.3 Protecting the Brushless Motor

The brushless motor is like the conventional synchronous motor in that it requires special start protection and power factor pull out protection. These two functions are provided in the CR192 μSPM.

9.3.1 Stall protection

Stall protection is derived from stator current inputs from two lines feeding the motor. The protection characteristic is shown in Figure 24. After the motor synchronizes, the CR192

SECTION 9 — Brushless Motor Control

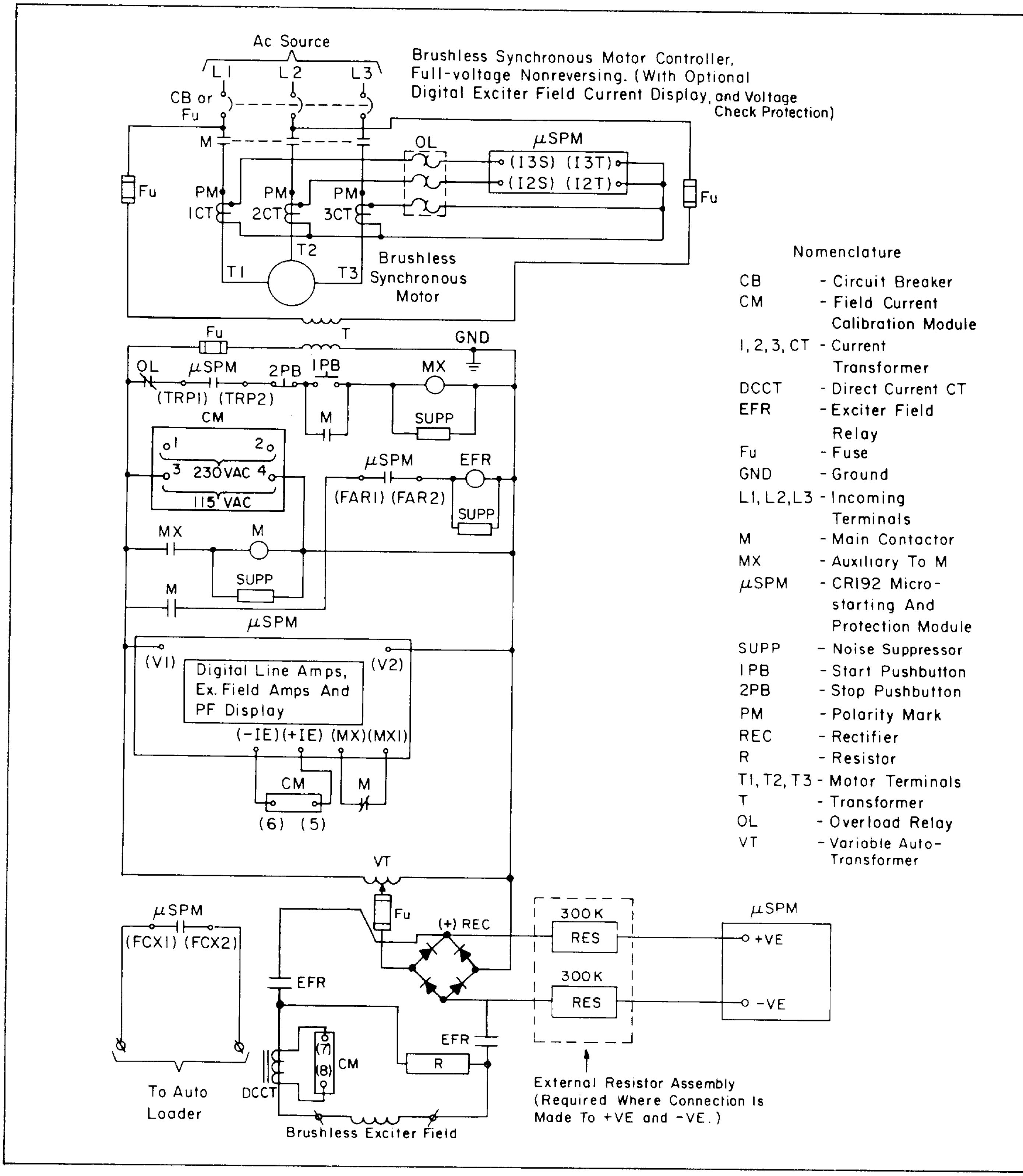


Figure 23. Typical brushless elementary diagram

SECTION 9 — Brushless Motor Control

The curves at right depict trip characteristics for three cases of programmed set-points as follows:

A Stall Time — 30 Sec
   Locked Rotor — 6XFLC

B Stall Time — 10 Sec
   Locked Rotor — 6XFLC

C Stall Time — 2 Sec
   Locked Rotor — 6XFLC

This protection is enabled when motor is started and disabled when power factor protection is enabled (concurrent with FCX Relay pickup).

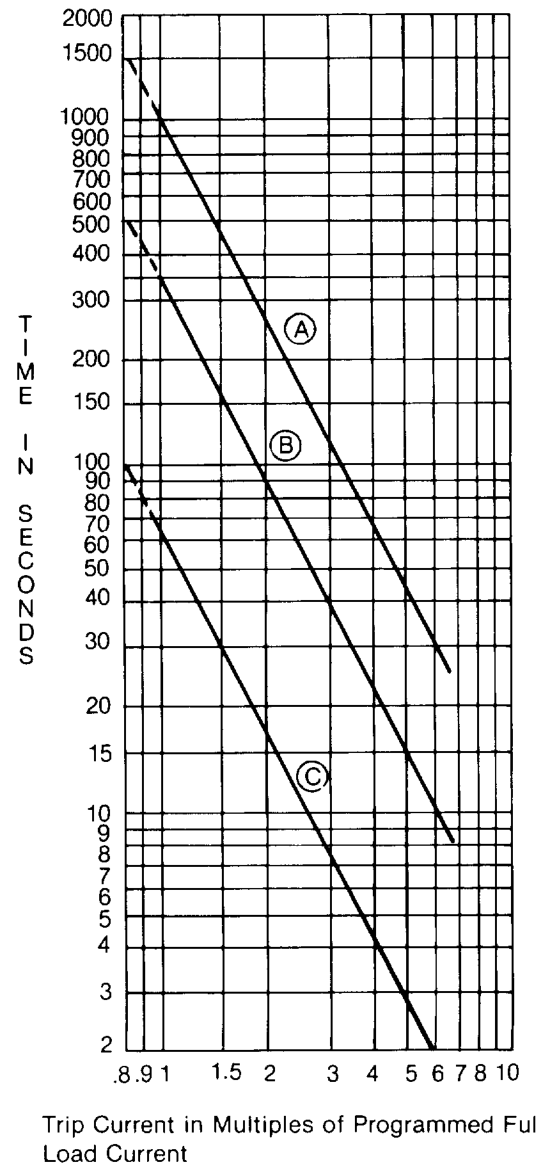


Figure 24. Brushless stall/acceleration protection characteristic

μSPM starts tracking motor cool down at approximately a 15-minute time constant rate so that protection is provided against abusing the motor from too frequent starting. Wait at least 15 minutes before attempting a restart on a motor that has been shutdown from a stall protective operation, or one in which two or more rapidly successive start/stop operations have been performed.

9.3.2 Power factor (pull-out) protection

The power factor protection for brushless control operates as power factor protection for collector ring motors described in Section 4.1.3. However, current I_3 is derived internally to the CR192 μSPM by algebraically summing currents I_1 and I_2 inputs.

SECTION 9 — Brushless Motor Control

NOTE: *It is important to connect current inputs for I_1 and I_2 as shown in Figure 23 for brushless machines.*

Only the ride-thru mode is available for brushless machines. If an attempt to resynchronize is desirable, set the "PF trip delay" parameter for one or two seconds. If the motor slips pole in this condition, the rotor-mounted, control device will remove the field instantaneously. When, and if, the motor recovers from the disturbance, the main field will be applied. If it does not recover within the "PF trip time delay" the motor will trip.

If no attempt to resync is desirable, set the "PF trip time delay" parameter to 0.1 second. This time will be too short for the power factor to recover following a slipped pole condition and the motor will trip on lagging power factor.

9.4 Options for brushless control

All of the options listed in Section 5 are available for brushless applications except power factor regulation. Power factor regulation is not available on brushless machines due to instability problems arising from the long time constant of the rotating exciter field.

If incomplete sequence protection is supplied, its set time must be greater than the time setting of the sum of the FAR and FCX time delay set-points to avoid nuisance trips.

An external resistor assembly of two 300K ohm resistors is required to be connected as shown in Figure 23 when either the "EXCITER VOLTAGE CHECK" opotion or the "FIELD VOLTS DISPLAY" option is supplied. Connect these resistors to the "$+V_E$" and "$-V_E$" inputs.

Since no input is ever required to the "V_F+" and "V_F-" inputs on brushless machines, resistor assemblies that normally connect to these points are not required.

9.5 Ordering the brushless μSPM

Refer to Section 7 for CR192 μSPM ordering.

9.6 Programming the brushless μSPM

9.6.1 Procedure

The programming procedure for the brushless μSPM is the same as for the collector ring μSPM except that some programmable parameters are different. Follow the programming procedure in Section 8 for entering set-points.

The brushless μSPM programmable table (Table 6) is listed below:

Table 6 Brushless μSPM programmable parameters

Parameter Number	Title	Valid Range
01	PF TRIP	0.6 lagging to unity
02	PF DELAY	1 to 3 seconds
03	STALL TIME	1 to 40 seconds
05	FULL LOAD CURRENT	See Table 3
06	LOCKED ROTOR CURRENT	2 to 12 times F.L.C.
08	LINE FREQUENCY	25-, 50-, 60-Hertz
09	C.T. RATIO	5:5 to 999:5
10	RESYNC	0 or 1
Option Parameters 11	FCX DELAY	1 to 90.0 seconds
Option Parameters 12	FIELD VOLTAGE TRIP	0.0 to 200 volts
Option Parameters 13	FIELD CURRENT TRIP	0.00 to 1000 amperes
Option Parameters 15	FIELD C.T. RATING	10 to 1000 amperes
Option Parameters 16	INCOMPLETE SEQUENCE	1 to 100 seconds
20	FAR DELAY	0 to 90 seconds

NOTE: ***All of the parameters listed in Table 6 except 11 and 20 are described in Section 8.3. Parameters 11 and 20 are described below:***

Parameter Number 11 FCX Delay. This value is the delay between the time the FAR relay picks up and the time when the power factor protection is enabled. This time also determines when the loading relay (FCX) picks up.

Parameter Number 20 FAR Delay. This value is the time between the initial application of power to the motor to the energization of FAR (application of exciter field).

9.6.2 Programming example

The following is a programming example.

MOTOR: 1000HP, PF 1.0, RPM-400, VOLTS-2300

Parameter	Desired Value	Parameter Number
PF TRIP	0.8 lag	01
PF DELAY	0.5 seconds	02
STALL TIME	5.0 seconds	03
FULL LOAD CURRENT	195 amperes	05
LOCKED ROTOR CURRENT	415	06
LINE FREQUENCY	60	08
C.T. RATIO	300/5	09
RESYNC	0	10
FCX DELAY	10 seconds	11
FIELD VOLTAGE TRIP	125	12
FIELD CURRENT TRIP	3.2	13
FIELD C.T. RATING	10.0	15
INCOMPLETE SEQUENCE	15 seconds	16
FAR DELAY	0 seconds	20

Follow the procedure of Section 8.2 and 8.5 to enter parameters into the μSPM.

SECTION 10 — Trouble Shooting

TABLE 7 Trouble-shooting chart

Type of Trouble	Cause	Recommended Solution
I. Do not get **SPM READY** display when μSPM is powered up. (Motor not running.)	1. Blown control power fuse.	1. Check control fuses in sychronous controller (on primary and secondary of control power secondary).
	2. μSPM power supply fuse blown.	2. Remove keyboard plate from μSPM and replace fuse with the same size fuse.
	3. Wrong voltage is applied to terminals V_1-V_2 of μSPM.	3. Be sure proper control voltage is applied to the μSPM. For CR192C module, voltage must be 110-120VAC. For CR192D, voltage must be 220-240VAC.
	4. CPU status light is Red.	4. Drop power momentarily to μSPM and reapply. If "CPU FAULT" light is still Red, replace μSPM with a new unit.
	5. Missing or improper motor-on, motor-off input to μSPM.	5. Add or correct the isolated normally closed interlock from the main contactor or relay that is operated with the main contactor. Interlock is to be placed across MX to MX1 interlocks. **NOTE:** *This interlock must be open when the motor is energized.*
	6. CR 192 μSPM not programmed properly.	6. Call each program address and check set-point data against the desired set-points (usually listed in the controller elementary).
	7. If exciter voltage check option is supplied, exciter may not be energized.	7. Correct operation of dc field exciter so that it outputs dc.
	8. Relay in tripped condition.	8. Press any keyboard button to RESET.
	9. Internal connector cable loose.	9. Remove front panel of μSPM and check ribbon cable connectors for tightness. Be sure connectors are not skewed or partially connected to card pins.
	10. Disconnect Terminal Strip on rear of module box is partially or totally disconnected.	10. Secure the removable half of the terminal strip to the stationary half by pressing the removable half so it is fully engaged with the removable half.
II. Motor starts but will not synchronize. (FC does not close.)	1. Synchronizing slip set too low. Motor cannot accelerate to set slip level.	1. Refer to programming Section 8 and program a higher value of "percent slip."
	2. Relay FAR does not pick up. (Display flashes "FIELD IS APPLIED" but contactor does not close.)	2. Check FAR Contact circuit wiring. Make sure relays are properly seated in the sockets on power supply board.
	3. Field discharge resistor (sometimes shipped separately) is not connected or incorrectly installed.	3. Check connection of field discharge resistor and correct if necessary.
	4. Motor trying to accelerate excessive load.	4. Unload or reduce load on motor shaft until relay FCX picks up.
	5. A motor restart is aborted by SCP operation ("SCP trip" appears on display.)	5. Wait a minimum of 10 minutes before attempting restart to allow motor to cool down. More time would be allowed for restart if 20 minutes elapsed before restart.
	6. Disconnect Terminal Strip on rear of module box is partially or totally disconnected.	6. Secure the removable half of the terminal strip to the stationary half by pressing the removable half so it is fully engaged with the removable half.
III. Motor starts and sychronizes but shuts down immediately upon application of excitation.	1. Trip PF setting programmed too high.	1. Reduce trip PF value (address 01) to no higher than 0.8.
	2. Motor "FCX delay" setting too low.	2. "FCX delay" setting (addresses 11) is not long enough. Increase to 3 seconds minimum.
	3. Input polarity incorrect for power inputs V_1—V_2.	3. Reverse power leads to V_1 and V_2. PF display must have a "-" sign prior to field application.

SECTION 10 — Trouble Shooting

TABLE 7 Trouble-shooting chart (cont'd)

Type of Trouble	Cause	Recommended Solution
III. Continued	4. No excitation voltage. 5. No excitation current, open circuit at motor field, brushes or leads. 6. Electronic noise signals enter electronic circuits from unsuppressed relays or contactors. 7. Disconnect Terminal Strip on rear of module box is partially or totally disconnected.	4. Check for available dc excitation voltage. If a rotating exciter is used that is driven by the motor shaft, the exciter field should be forced (rheostat is shorted out) during acceleration to cause exciter to build up its output as quickly as possible. 5. Correct discontinuity in field circuit. 6. Add resistor capacitor (R-C) suppression around all relays and contactors that are controlled by the μSPM. 7. Secure the removable half of the terminal strip to the stationary half by pressing the removable half so it is fully engaged with the removable half.
IV. Shutdown occurs during normal running (after successful synchronization).	1. Motor has pulled out of step from excessive overload. (PF TRIP or PULL-OUT TRIP is displayed). 2. Loss of excitation. 3. Transient power factor change occuring during power system disturbance. 4. Motor is unloaded and power factor regulator reference set-point setting at or near unity resulting in instability. 5. Disconnect Terminal Strip on rear of module box is partially or totally disconnected.	1. Check condition of load bearing and other mechanical situations at the drives. Push any key to reset μSPM and restart. 2. Check exciter, exciter fuse and connections to field. 3. Increase "PF delay" setting. 4. Increase "REGULATOR FLOOR" set-point to override regulator to maintain stability during light-load condition. 5. Secure the removable half of the terminal strip to the stationary half by pressing the removable half so it is fully engaged with the removable half.
V. Motor Starts, applies dc to field and then immediately removes dc from field.	1. Exciter voltage too low, causing μSPM to remove field and attempt to resynchronize. 2. Field contactor is closing too soon. Motor cannot pull-in to step because slip too high. 3. Excessive shaft load is greater than the motor's capability to pull into step. 4. Disconnect Terminal Strip on rear of module box is partially or totally disconnected.	1. Adjust exciter transformer tap or field rheostat to obtain higher exciter-voltage output. 2. Reset "SYNCHRONIZING SLIP" for lower value of synchronzing slip. 3. Reduce load or unload motor during start. Apply load after motor has synchronized and stabilized. 4. Secure the removable half of the terminal strip to the stationary half by pressing the removable half so it is fully engaged with the removable half.
VI. Display Garbled or Incorrect.	1. Loose electrical connections or spurious noise disrupts display.	1. Depress recessed pushbutton (with pencil point) located at top rear of μSPM to reset CPU and display. 2. Check ribbon connector between the faceplate assembly and power supply board in the rear of the box. It must not be loose, shifted or skewed.

*Relay FCX interlocks may be used for automatic loading if required.

SECTION 11 — Renewal Parts

11.1 List of Renewal Parts

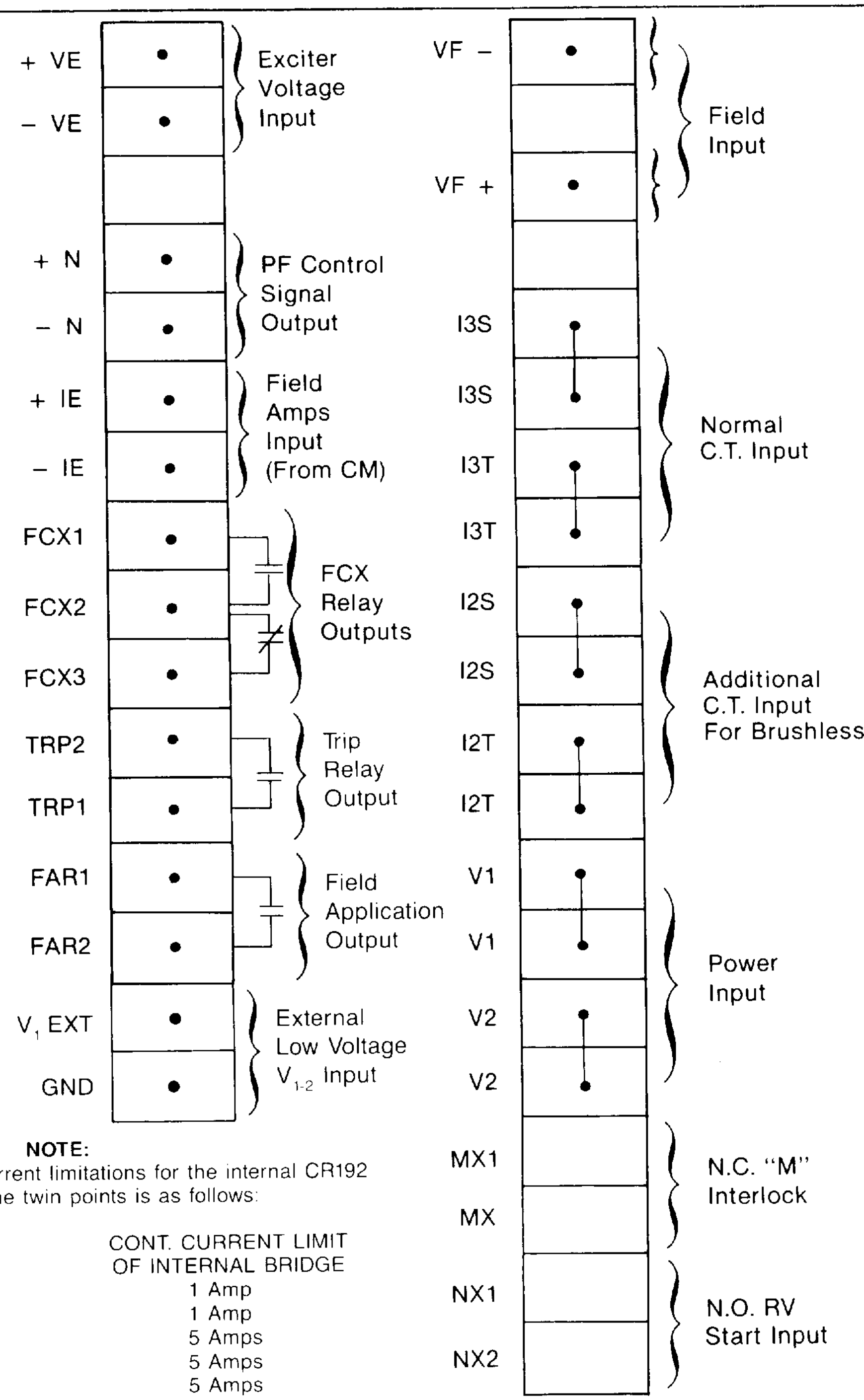
Renewal Parts are offered for the CR192 µSPM in Table 8.

TABLE 8 Renewal parts list (See Figure 9 for location of parts)

Part	Catalog Number	Number Required
Output Relay	4000N13P034	3
Fuse	0.4 Amp (Buss MDL-4/10) 120V 0.2 Amp (Buss MDL-2/10) 240V	1 1
Complete Replacement CR192	*	*

*See Section 7 for ordering instructions

SECTION 12 — Terminal Point Layout



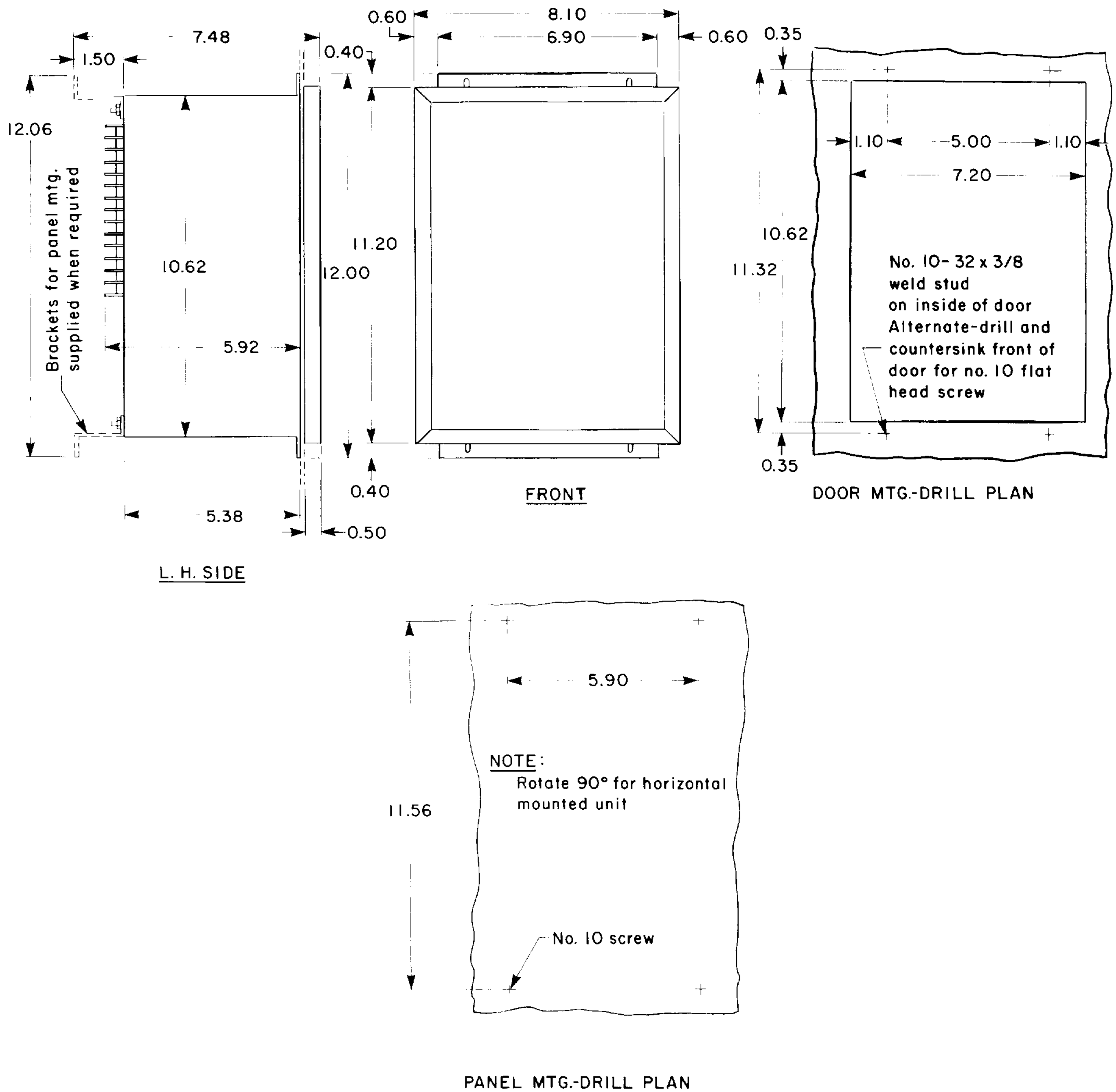
NOTE:
The following continuous current limitations for the internal CR192 bridge conductor between the twin points is as follows:

TERMINAL TWIN	CONT. CURRENT LIMIT OF INTERNAL BRIDGE
V1	1 Amp
V2	1 Amp
I2S	5 Amps
I2T	5 Amps
I3S	5 Amps
I3T	5 Amps

Please be careful, when routing wiring, to avoid passing more than the above current limits through the twin internal bridge conductors. *Note particularly the one ampere limitation between the V1 and V2 Twin Terminals.*

Figure 25. Arrangement of terminal points

SECTION 13 — Outline Dimensions



NOTE: Dimensions are in inches.

Figure 26. CR192 μSPM outline

SECTION 13 — Outline Dimensions

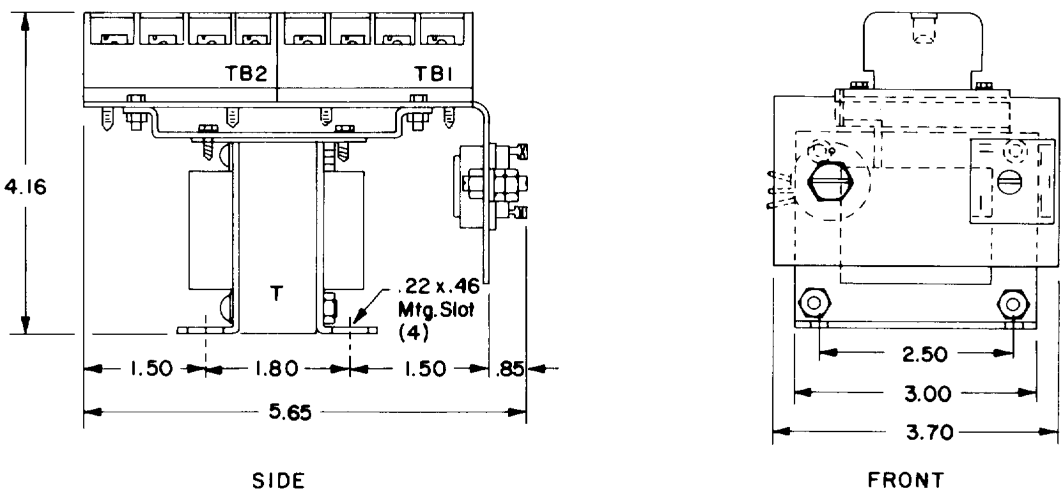
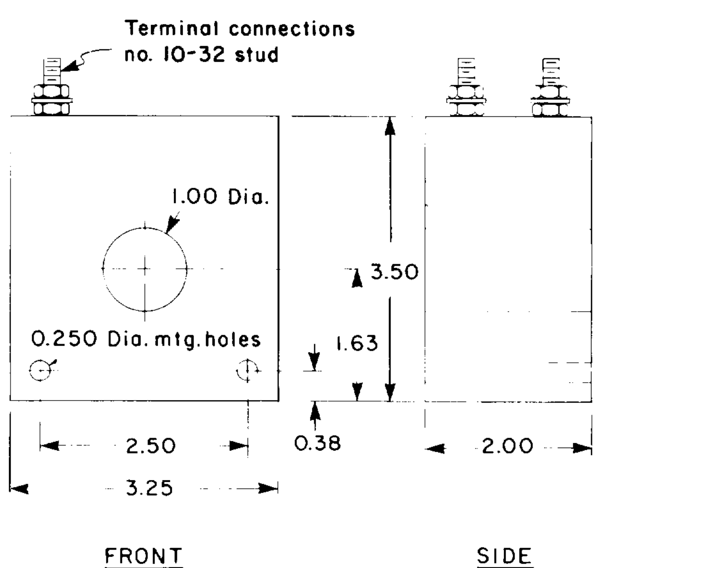


Figure 27. Field current calibration module — outline



RATINGS: 200A-CAT. NO. MAG # DCCT-2

NOTES: 1–Dimensions are in inches.
2–Apply to rated field currents up to 154A maximum.

Figure 28. DC current transformer — outline

SECTION 13 — Outline Dimensions

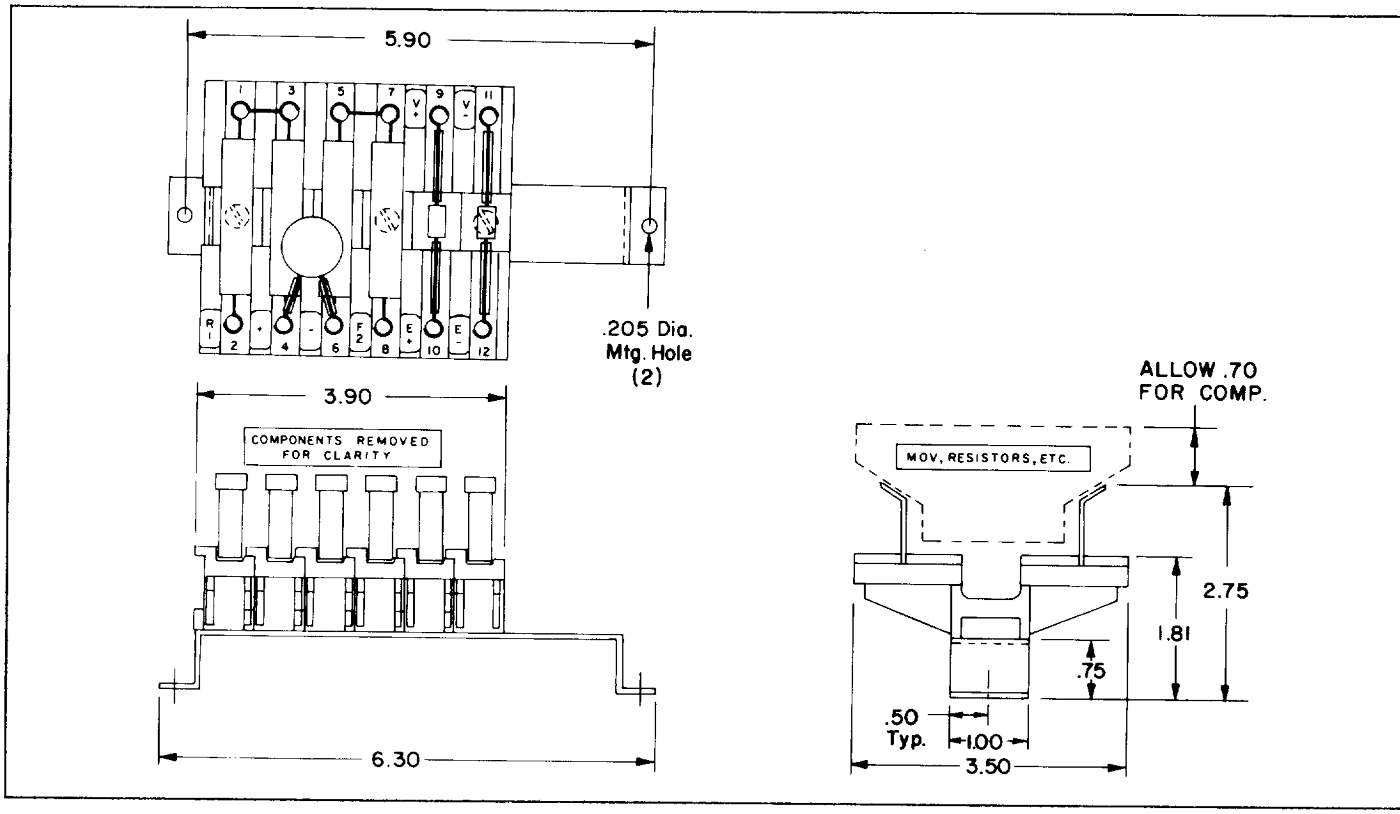


Figure 29. Separate resistor assembly outline. Cat. No. 55B529836G1, G2, G3, and G4

SECTION 14 — Calibration Module — Elementary Diagrams

14.1 General

The Calibration Module provides the proper ac excitation voltage to the DCCT and provides a calibration adjustment to obtain proper field amperes reading into the [SPM. This calibration is performed by means of Potentiometer "R" and is made in the factory prior to shipment. This adjustment may be used to recheck calibration in the field, but readjustment will not normally be required. Calibration Module Cat. No. 169C6351AWG1 to be used with DCCT Cat. No. MAG#DCCT-2.

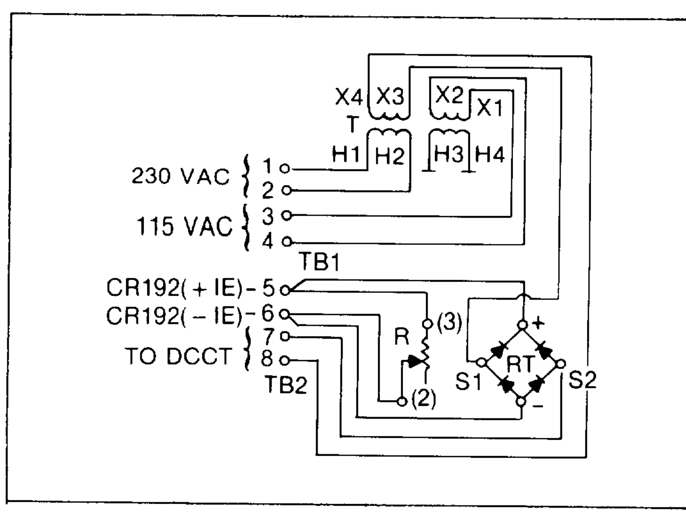


Figure 30. Calibration module-elementary diagrams

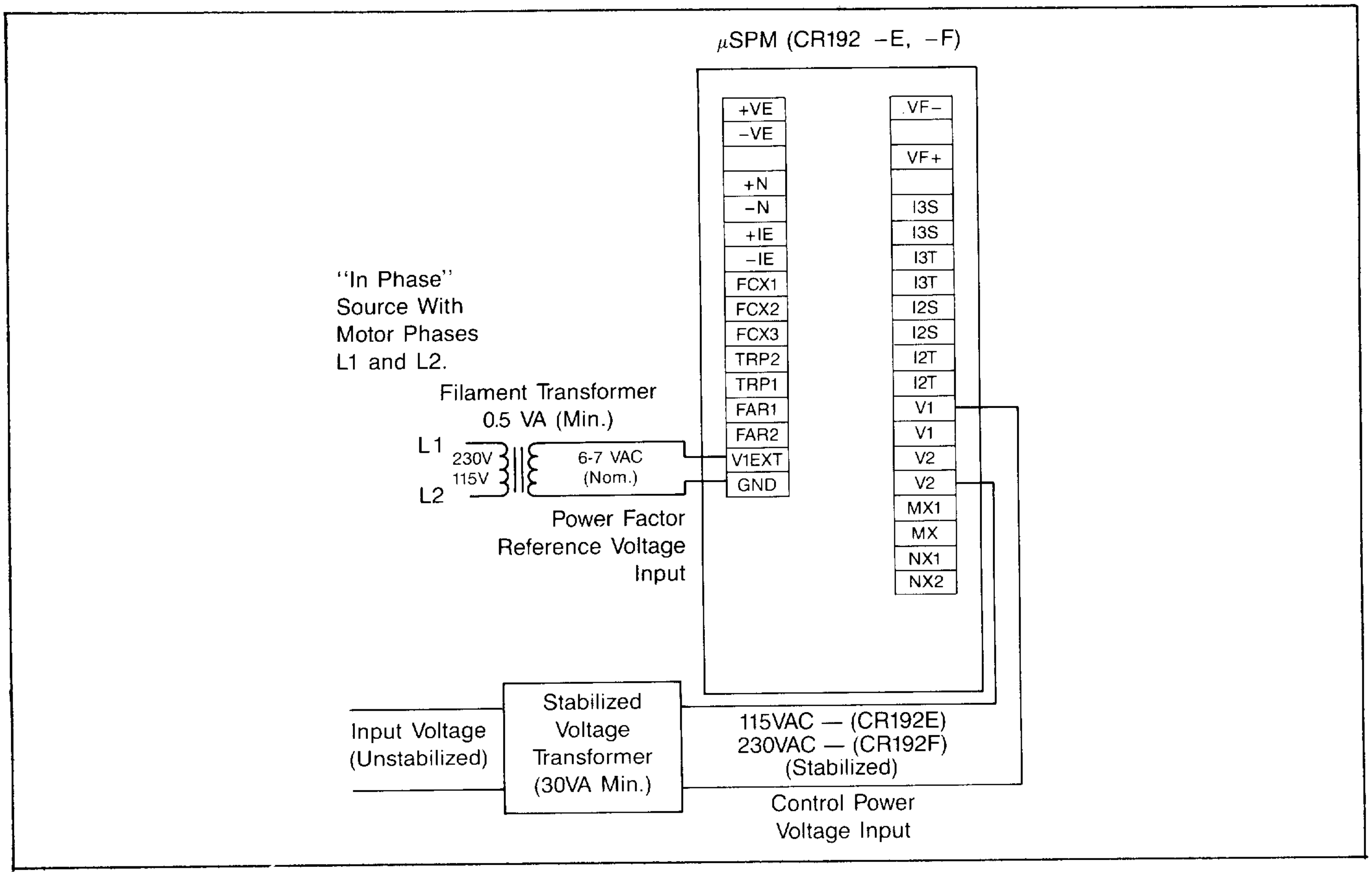


Figure 31. Connections for separate stabilized control power voltage and power factor reference voltage inputs. Use only with CR192 -E and -F versions.

The Customer May Use This Space to List the μSPM Set-points

USER VERIFY SETTINGS BEFORE ENERGIZING MOTOR SEE GEH-5201				
DRIVE				
CR192				
FUNCTION			SETTINGS	
01	TRIP P.F.	POWER FACTOR		
02	P.F. DELAY	SECONDS		
03	STALL TIME	SECONDS		
04	RUN TIME	X STALL		
05	F.L.C.	AMPERES		
06	L.R.C.	X FLC		
07	SYNC. SLIP	PERCENT (%)		
08	LINE FREQUENCY	HERTZ		
09	C.T. RATIO	5:		
10	RESYNC.	0 = NO		
11	FCX RELAY	SECONDS		
12	FIELD VOLTAGE	VOLTS		
13	FIELD CURRENT	AMPERES		
15	FIELD C/T	AMPERES		
16	INCOMP. SEQ.	SECONDS		
17	REG. PF	POWER FACTOR		
18	REG. GAIN	X		
19	FLOOR	VOLTS		
20	FAR DELAY	SECONDS		

USER VERIFY SETTINGS BEFORE ENERGIZING MOTOR SEE GEH-5201				
DRIVE				
CR192				
FUNCTION			SETTINGS	
01	TRIP P.F.	POWER FACTOR		
02	P.F. DELAY	SECONDS		
03	STALL TIME	SECONDS		
04	RUN TIME	X STALL		
05	F.L.C.	AMPERES		
06	L.R.C.	X FLC		
07	SYNC. SLIP	PERCENT (%)		
08	LINE FREQUENCY	HERTZ		
09	C.T. RATIO	5:		
10	RESYNC.	0 = NO		
11	FCX RELAY	SECONDS		
12	FIELD VOLTAGE	VOLTS		
13	FIELD CURRENT	AMPERES		
15	FIELD C/T	AMPERES		
16	INCOMP. SEQ.	SECONDS		
17	REG. PF	POWER FACTOR		
18	REG. GAIN	X		
19	FLOOR	VOLTS		
20	FAR DELAY	SECONDS		

These instructions do not purport to cover all details or variations in equipment nor to provide for every possible contingency to be met in connection with installation operation or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the purchaser's purposes, the matter should be referred to the GE Company.

GE Electrical Distribution & Control

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GEH-5201C 1093 BLA