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AEROSPACE RECOMMENDED PRACTICE

SELECTION, APPLICATION, AND INSPECTION
OF
ELECTRIC OVERCURRENT PROTECTIVE DEVICES

Aerospace Recommended Practice ARP 1199A dated August 1972 has been reviewed and determined to be valid for use by the DoD in conjuction with MIL-STD-1498, Selection and Use of Circuit Breakers.

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AEROSPACE RECOMMENDED PRACTICE

ARP 1199A

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SELECTION, APPLICATION, and INSPECTION of ELECTRIC OVERCURRENT PROTECTIVE DEVICES

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ELECTRONIC DISTRIBUTION SYSTEMS

ARP 1199A

1. SCOPE: This Aerospace Recommended Practice provides technical and application information needed by the designers of aircraft electric systems and support equipment for the selection of overcurrent protective devices. It provides definitions to permit comparisons of various electric circuit protective devices. Included also are recommended procedures for periodic inspection.

2. TYPES OF OVERCURRENT PROTECTIVE DEVICES: For the purpose of this ARP, the types of overcurrent protective devices considered are circuit breakers, fuses and limiters (See 5, 6, 7.).

3. DEFINITIONS: The following definitions apply to terminology used in this ARP:

Ambient Temperature - Ambient temperature is the temperature of the medium, such as air, water, or earth into which the heat of the device is dissipated.

Arcing Time - Arcing time (as used for fuses) is the time measured from that point when element melt time ends to that point when current is interrupted and permanently becomes zero. If a mechanical indicator (not presently recommended) is utilized which incorporated a secondary element parallel to the fusible element, arcing time will commence from the point at which indicator melt time ends.

Arcing time (as used for breakers) is the time measured from that point when contacts first separate to that point when the current is interrupted and permanently becomes zero.

Automatic - Automatic means self-acting, operating by its own mechanism when actuated by some impersonal influence, as for example, a change in current strength, pressure, temperature, or mechanical configuration.

Blade (Knife Blade) - A fuse or limiter terminal having a substantially rectangular cross-section.

Branch Circuit - That portion of a wiring system extending beyond the final overcurrent device protecting the circuit.

Cascade Circuit - A circuit in which more than one protector is connected in series between the power source and the load (See coordination).

Circuit Breaker - A device designed to open and close a circuit by non-automatic means, as well as to open the circuit automatically on a predetermined overload of current without injury to itself when properly applied within its rating.

Multipole Circuit Breaker - A multipole circuit breaker has two or more poles controlled by a single-actuating member.

NonTrip-Free Circuit Breaker - A nontrip-free circuit breaker is a breaker so designed that the circuit can be maintained closed when carrying overload current that would automatically trip the breaker to the open position. (Not presently recommended.)

Push-Pull Circuit Breaker - Push-pull circuit breakers are those which may be manually actuated by a "push" to close and a "pull" to open.

Temperature Compensating Circuit Breaker - A temperature compensating circuit breaker is one in which means may be inherent or otherwise provided for partially or completely neutralizing the effect which the ambient temperature may have upon the tripping characteristics of the circuit breaker.

Toggle Circuit Breaker - A toggle circuit breaker is a circuit breaker which has a toggle actuating means.

Trip-Free Circuit Breaker - A trip-free circuit breaker is a breaker so designed that the pole(s) of the circuit breaker cannot be maintained closed when carrying overload currents that would automatically trip the breaker to the open position, and none of the circuit breaker poles would reclose while the operating mechanism is maintained in the closed position.

Common Trip - A common-trip multipole circuit breaker is one in which an overload on any pole will cause all poles to open simultaneously.

Coordination - Coordination defines the ability of the protector with the lowest rating (in a cascade arrangement) to open before protectors with higher ratings when a fault occurs downstream from the lowest rated protector (See Cascade Circuit).

Current-Limitation - The ability of a protective device to reduce the short-circuit peak current to a value less than that which would be available if no protective device were in the circuit (See Fig. 6.b).

Current Rating (Continuous) - The rated continuous current of a protective device is the nominal direct current or alternating current, in amperes, at rated frequency which it will carry continuously under defined conditions.

Current-Responsive Element (Fusible Element) - A current-responsive element is that part of the fuse or limiter which carries current and melts when the current exceeds a predetermined value.

Continuous Duty - A requirement of service that demands operation at a substantially constant load current for an indefinitely long time.

Intermittent Duty - A requirement of service that demands operation for alternate intervals of load and no load.

<u>Periodic Duty</u> - A type of intermittent duty in which the load conditions are regularly recurrent.

<u>Short Time Duty</u> - A requirement of service that demands operation at a substantially constant load for a short and definitely specified time.

<u>Varying Duty</u> - A requirement of service that demands operations at loads, and for intervals of time, both of which may be subject to wide variations.

<u>Element Melt Time</u> - The time elapsed from the moment a fusing current begins to flow to the moment the current sharply drops in value and arcing commences.

<u>Fault Current</u> - See Short-Circuit Current.

<u>Feeder</u> - A feeder is a circuit conductor originating at the power source bus from which the branch circuit loads are served.

<u>Ferrule</u> - The ferrule is a fuse or limiter terminal of a cylindrical shape which encloses the end of the fuse or limiter.

<u>Fuse</u> - A device which protects a circuit by the melting of its current responsive element when an over-current passes through it.

<u>Normal Opening Fuse (Fast-Acting)</u> - A fuse which opens the circuit without deliberate time-delay. (Fig. 6.a shows relative opening time.)

<u>Time-Delay Fuse</u> - A fuse that has its total clearing time deliberately delayed in the overload current range. (Fig. 6.a shows relative opening time.)

<u>Very Fast-Acting Fuse</u> - A fuse that opens the circuit without deliberate time-delay and whose short-circuit opening time is faster than a normal opening fuse. (Fig. 6.a shows relative opening time.)

<u>Fuse Clips</u> - The contacts of the fuseholder which support the fuse or limiter and connect their terminals with the circuit.

<u>Fuse or Limiter Holder</u> - A mounting device with contacts and terminals for the purpose of accepting fuses or limiters for easy connection within a circuit.

<u>Fuse Tube</u> - A tube of insulating material which surrounds the current-responsive element.

<u>Ground</u> - A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and airframe, or some conducting body which serves in place of the airframe.

<u>Indicator Melt Time</u> - The elapsed time from the moment element melt time ends and arcing commences is indicator melt time.

Instantaneous Trip (Opening) - "Instantaneous" indicates that delay is not purposely introduced into the action of the device.

Interrupting Capacity - The rated interrupting capacity is the maximum short-circuit current at rated voltage which a protective device is required to interrupt under the operating duty specified and with a normal frequency recovery voltage not less than rated voltage (See Rupture Capacity).

Inverse-Time - See Time-Inverse.

Let-Through Current - The current that actually passes through the protective device after initiation of a fault.

Limiter - A fuse designed specifically with a high temperature melting point to provide protection for electric power distribution systems against fault short-circuit current. A limiter is relatively insensitive to ambient temperature.

Maximum Limit of Ultimate Trip - The minimum current which will cause a circuit breaker to open under a given set of ambient conditions. Also known as the "Rated Trip Current".

Melt Time - See Element Melt Time.

Minimum Fusing Current - The smallest value of current that will melt the current responsive element at a specified ambient temperature is the minimum fusing current.

Minimum Limit of Ultimate Trip - The maximum current a circuit breaker must hold without tripping under a given set of ambient conditions. Also known as the "Rated Hold Current".

Overcurrent - Any current exceeding the rated current of the protective device (exceeding the maximum ultimate trip current for circuit breakers). This includes both overload and short-circuit currents.

Overload Current - An overcurrent in excess of the current rating. The overload range is considered to be greater than the rated current up to approximately ten times rated current.

Pass-Through Current - See Let-Through Current.

Recovery Voltage - The voltage impressed across the protective device after the circuit has been interrupted and after high frequency transients have subsided.

Rupture Capacity - Rupture capacity is applied to reuseable protective devices (See Interrupting Capacity).

Selective System - A system in which the protective device closest to the faulted circuit opens and isolates that circuit without disturbing the remainder of the system (See Coordination).

Self-Indicating Fuse or Limiter - That type of fuse or limiter that incorporates a device to visually denote severance of the fusible element as an integral part of the limiter is a self-indicating current limiter. Limiters or fuses that visually display the fusible element or incorporate a mechanical indicating device are classified as self-indicating current limiters or fuses.

Short-Circuit Current (Fault Current) - The maximum current that the system can produce at the point of application of the protective device.

Terminals - The contacts of a fuse or limiter, either blade or ferrule, for connecting the current-responsive element of a fuse or limiter to the fuse clips.

Time-Delay - A qualifying term indicating that there is purposely introduced a delayed action, which delay decreases as the magnitude of the current increases.

Time-Inverse - A time-current relationship where the protective device opening time decreases as the current increases.

Total Clearing Time - The total time measured from the beginning of the specified overcurrent condition until the interruption of the circuit. The total clearing time for a fuse or limiter is equal to the sum of the melting time and the arcing time.

Voltage Rating - The maximum alternating current and/or the direct current voltage at which the protective device is designed to operate.

4. PHILOSOPHY OF AIRCRAFT CIRCUIT PROTECTION: For reliable circuit protection, the design should provide automatic protection that will limit a fault to a single circuit and more importantly minimize the danger of smoke and fire not only to the component but also the conductors (or cables) leading to and from the component. The primary consideration should be the protection of the conductors or cables. Furthermore, the protection must be capable of isolating the fault from the power source so that non-faulted circuits can be kept functioning in a normal manner. This is an essential safety of flight requirement. These objectives may not always be achieved by a single protective device, but by a combination of devices, wire size and routing. Circuit designers must employ every means available to accomplish optimum protection. For example, correct sizing of wire and safe routing must contribute to the overall circuit protection philosophy.

4.1 Practical Overcurrent Protective Concepts: There are two basic principles currently in use for the protection of electric and electronic equipment from failures caused by current overloads:

(a) Current Sensing
(b) Combined Current and Temperature Sensing.

The current sensing principle is found typically in devices such as magnetic circuit breakers and fully ambient compensated thermal circuit breakers. Magnetic circuit breakers respond only to the magnitude of current, while temperature rises resulting from this current flow have little or no effect on operating characteristics. The fully ambient compensated thermal circuit breaker responds only to the magnitude of current since it is self-correcting for temperature rises resulting from this current flow.

When the protective device has temperature characteristics matching those of its load and is mounted in close proximity to the load, it is called "inherent protection". In most applications the practical considerations make it necessary for the protective device and component to be in entirely different ambients. It is more efficient to use an essentially ambient insensitive device and apply it on the basis of a maximum temperature rise expected at any point in that circuit.

The combined current and temperature sensing principles are employed in thermal circuit breakers, motor protectors and fuses. They not only anticipate thermal failures due to overcurrent but will also compensate for variations in the ambient temperature if they are located in the same ambient as the component and wire. These devices are designed to match the thermal characteristics of the component being protected so that increase in ambient temperature reduces the current trip level analogous to the reduction in component capacity.

4.2 Protector Selection: Proper selection must result in a protective device with the lowest rating that will not open inadvertently. It must interrupt the fault or overload current disconnecting the faulted line from the power distribution system before the wire insulation is destroyed. Circuit breakers must be trip-free.

The choice between circuit breakers, fuses, limiters, or other protection means is governed by many factors. Specification requirements, customer preferences, maintainability considerations, application physical and environmental restraints, and the requirements of each circuit all influence the selection of the protective devices.

The nameplate current rating of most protective devices is a nominal rating for device identification. The actual usable rating for a particular application may be considerably different from the nameplate rating. The device must be rated for the application, considering all the variables involved. The time-current characteristics of the protective device should be compared to the time-current characteristics (including starting or overload surges) of the equipment, component or wire.

4.2.1 Extent of Circuit Protection: Circuit protection extends to cover the following areas:

Any circuit whose wire length is greater than one foot in length from bus to load should be protected. Wire lengths less than one foot should also be considered, especially if it could act as a fuse and in fusing cause damage.

A circuit protector should be used at any point in a circuit where the conductor size is reduced unless the immediate upstream protector provides adequate protection for the smaller wire.

Equipment protection should receive separate consideration. Any protection provided by the circuit protection is incidental and must not compromise the prime intention of protecting the wire bundle.

4.2.1.1 Equipment Protection: There are many circuit components, such as transformers, rectifiers, filters, regulators and electronic circuits which have significantly different overload withstand characteristics from wire and cable characteristics. In general, these components and/or circuits require protective devices with much faster response times than is required for the protection of wire and cable.

Whereas, a transformer winding may be protected with some of the faster responsive miniature magnetic or thermal circuit breakers, or fuses; many electronic circuits and components require extremely fast clearing devices, such as very fast-acting fuses, to provide adequate protection from thermal damage.

The manufacturer of equipment for aircraft is governed by MIL-E-5400 which, in turn, specifies MIL-STD-454. Requirement 8 outlines the basic ground rules for equipment protection.

4.2.2 System Protection: The entire system including the power source, circuit protector, wire (single or bundles), switching devices and utilizing equipment must be protected against faults.

5. CIRCUIT BREAKERS: In the discussion of circuit breakers that follows, it is assumed that circuit breakers will be applied within the electrical rating, environmental conditions and other parameters as described in the applicable Military Specification, MS Sheets or Military Specification Sheets. The manufacturer should be consulted regarding the suitability of the circuit breaker when the conditions vary from those specified.

5.1 General: In its simplest form, the circuit breaker is a device designed to open and close an electric circuit by nonautomatic means and to open the circuit automatically on a predetermined overload of current without injury to itself when properly applied within its rating. Two more common types of circuit breakers are magnetic and thermal circuit breakers.

5.2 Magnetic Circuit Breakers: A magnetic circuit breaker may be classified as sealed or nonsealed. Sealed circuit breakers have an advantage in that they are less affected by adverse environments. Presently these sealed circuit breakers are made only in ratings up to 20 amperes, meeting the requirements of MIL-C-39019. Nonsealed circuit breakers provide for higher power requirements but are more restricted as to environment. Both the sealed and the unsealed types have three fundamental requirements:

(1) Provide manual switching.
(2) Open automatically under overload conditions.
(3) Carry full-rated current.

5.2.1 Magnetic Time-Delay (Typical): The magnetic time-delay circuit breaker operates on the solenoid principle where a movable core held with a spring, in a tube, and damped with a fluid, may be moved by the magnetic field of a series coil. As the core moves toward a pole piece, the reluctance of the magnetic circuit containing the armature is reduced. The armature is then attracted causing the mechanism to trip and open the contacts on an overload or fault condition.

The ultimate trip point is dependent upon the armature gap and the armature spring force. This trip point occurs after a predetermined time when the core has made its full travel in the tube. The ultimate trip point is independent of the ambient temperature in the range of the Military Specification Sheets or MS Drawings.

The instantaneous-trip* point is that value of current required to trip the circuit breaker without causing the core to move in the tube. This is possible because excess leakage flux in the magnetic circuit caused by high overloads or faults will attract the armature and trip the circuit breaker. The instantaneous-trip point is independent of the ambient temperature.

The instantaneous trip current is usually in the order of ten times the current rating of the circuit breaker. It is a ratio of the trip values of the circuit breakers with the core fully "in" and with the core fully "out".

The fluid fill of the tube retards the movement of the core, and an inverse overload time-delay results so that the trip time will be less as the percent of overload is increased. Longer time-delays result with lower ambients for a given fluid because the fluid thickens as the temperature decreases. The converse is true because the fluid gets thinner as the temperature increases. The values of ultimate-trip point are not affected by change in fluid viscosity. The ultimate-trip point, however, does require a longer time to trip at lower temperatures and less time at higher temperatures.

*MIL-C-39019 defines "instantaneous" as less than 0.015 seconds.

5.2.1 (Cont'd.):

Some variation in actual delay time will result with variation in mountings. This change is due to the effect of gravitational pull on the core; consequently, the smaller physical sized circuit breakers of MIL-C-39019 have less position sensitivity and will trip within the specification time current curves in any position, whereas the larger devices specified in MIL-C-55629 may not.

Magnetic circuit breakers are limited in their ability to coordinate unless the fault current is limited so that the "pass-through"* current is not more than the instantaneous-trip value of the lower rated circuit breaker. For example, a 10 and a 20 ampere circuit breaker in series to coordinate on a fault would require the "pass-through" to be limited to 100 amperes. If the pass-through current should reach 200 amperes, both circuit breakers would trip.

Normally, magnetic circuit breakers should be used on the type of current for which they are calibrated unless otherwise indicated on the Military Specification Sheets or MS Drawings. If there is any question of application, consult the manufacturer.

5.2.2 Instantaneous Trip: Instantaneous trip circuit breakers have no intentional time-delay and, therefore, are sensitive to current inrushes and vibration and shock; consequently, they should be used with some discretion where these factors are known to exist. There is no effect on trip point due to temperature in the range of -55 C to +71 C. Consult the manufacturer for recommendations concerning applications of usage under inrush conditions, and also vibration and shock if different from the Military Specification Sheet or MS Drawing.

5.3 Thermal Circuit Breaker Types:

5.3.1 Thermal: Thermal circuit breakers are dependent upon temperature rise in the sensing element for actuation. Normal operation is achieved by the deflection of a thermal element (e.g. bimetal) which will open a circuit when a predetermined calibration temperature is reached. Temperature rise in the sensing element is caused principally from load current I^2R heating. The thermal element will also integrate heating or cooling effects from external sources and will tend to derate or uprate from room temperature calibration with corresponding fluctuations in ambient temperatures.

The size of the thermal element, its configuration and its physical and electrical properties determine the amount of current carrying capacity of the circuit breaker. In some cases, a heater coil is placed adjacent to and electrically in series with the thermal element to augment self heating of the thermal trip element. This is especially true in ratings below five amperes.

*See 3., Definitions

5.3.2 Thermal-Magnetic Assist: In order to protect wiring, upstream components and the breaker itself from unnecessarily long thermal and mechanical stress during high fault level currents, an electro-magnet is added to the thermal breaker. This magnetic circuit usually consists of a few turns of large cross section conductor in series with the thermal element and has negligible effect on the total breaker impedance. The magnetic assist usually has a cross over point well above the normal overload calibration range which is to say that there is little effect on the normal thermal trip response time, but on high overload conditions the current level generates sufficient magnetic force to trip the breaker magnetically without waiting for the bimetal to deflect. Thus this construction results in very fast trip times on high overloads approaching instantaneous tripping times.

5.3.3 Temperature Compensated-Thermal: As discussed in 5.3.1, a simple thermal circuit breaker's trip point is affected by variations in ambient temperature. A temperature (ambient) compensated circuit breaker is a breaker in which a thermal responsive element is introduced to compensate for changes in external temperatures. The compensating element usually is electrically isolated from and is independent of the current carrying thermal trip element and acts only when a change in ambient temperature occurs.

The degree of compensation may vary from partial to full compensation. A fully compensated breaker will operate independently of its ambient temperature within the specified temperature range.

It may be generally stated that the bandwidth (i.e., minimum-maximum trip limits) of the characteristic trip curves of a compensated device is narrower than that of a corresponding thermal circuit breaker over the same temperature range.

5.3.3.1 Hot Wire Breaker: The hot wire type thermal circuit breaker employs the expansion of a high temperature wire as a means to cause the contacts to open. Because the temperature of the wire at time of trip is in the order of 800 - 900 F, changes in ambient temperature have little effect upon the calibration. Effectively, this type of breaker can be considered compensated at sea level. The effects of altitude on calibration must be evaluated before it is specified for use in uncontrolled ambients. Its trip time is faster than the bimetal breaker and the voltage drop is higher. Current ratings are available from one-half through five amperes. Attention should be given to the interrupting current rating of the hot wire breaker.

5.4 Remote Control Circuit Breakers (RCCB): RCCB's combine the basic features of a relay (contactor) and circuit breaker. This design permits them to be located adjacent to the load or power source and controlled and/or monitored from a remote location such as from a cockpit or flight deck. Control wiring can be of light gauge, thereby eliminating the need for long runs of heavy cable.

5.5 Application Considerations and Problem Areas: The following problem areas do not necessarily apply to all types of protectors and may be more serious in one device than in another. It must be assumed that the designer will be guided by the possibility that the device he selects may be affected by one or more of them.

5.5.1 Explosive Atmosphere Aeronautical Equipment: Most aircraft circuit breakers are unsealed devices which readily permit the surrounding atmosphere to enter. If circuit breakers are to be installed in an explosive atmosphere, the applicability of the conditions of the explosion-proof tests to the installed environment should be examined and proper installation precautions should be made.

5.5.2 Temperature Effect on Calibration: Circuit breaker and fuse time-current characteristics are influenced by the device temperatures resulting from ambient temperature, air flow, pressure altitude, wiring and bus bar configuration, operating load level, adjacent heat sources or sinks, packaging density, and proximity to external skin of aircraft. All of these factors must be considered in determining the actual continuous capacity and time-current protection characteristics of the circuit breaker or fuse (See Fig. 5.a.). It may become necessary to test the circuit protector panel or package simulating the above variables to obtain complete confidence.

5.5.3 Temperature Compensation: Temperature compensation provides some relief from the effect of ambient temperature but should not be interpreted to mean that no derating is necessary. Detail sheet MS 3320, for instance, gives 115% as the current the circuit breaker must carry without opening. This value is 15% above the application value to provide a tolerance for the effects of wear, vibration, etc. The same derating should be applied to the other values noted on the MS sheet. The 100% value at 121 C should be reduced to 85% in application and the 160% value at -55 C should be considered the limit of non-tripping current. From this it is evident that an MS 3320-10 has a possible non-tripping range of 8.5 amperes to 16 amperes over its temperature range at sea level but a specified usable load range of only 8.5 amperes to 10 amperes. Altitude introduces further derating factors.

5.5.4 Coordination of Cascaded Protectors: MIL-C-5809, MIL-F-5372 and MIL-F-15160 do not have a coordination requirement. MIL-C-27715 requires that, "two circuit breakers in series with a ratio of current rating of at least two to one, the breaker with the higher rating shall hold closed and the circuit breaker with the lower rating shall trip". No provision for coordination is made to consider the effects of temperature when the two breakers are in different ambients except MIL-C-27715 (See Figs. 5.b and 5.c). Coordination should be verified by appropriate testing.

It is recommended that all essential loads be fed directly from a bus to avoid unnecessary power outages.

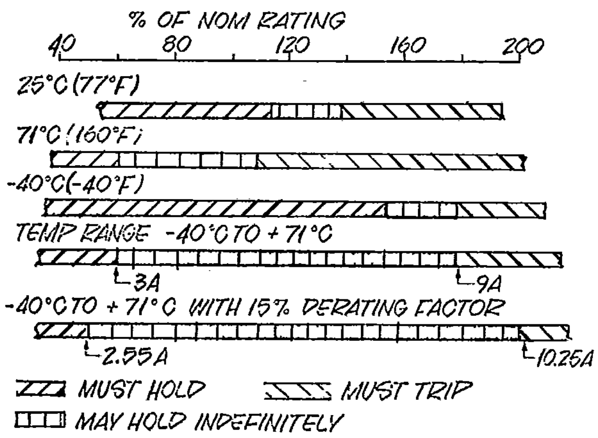

FIGURE 5.a MS25244-5 TRIP CHARACTERISTICS

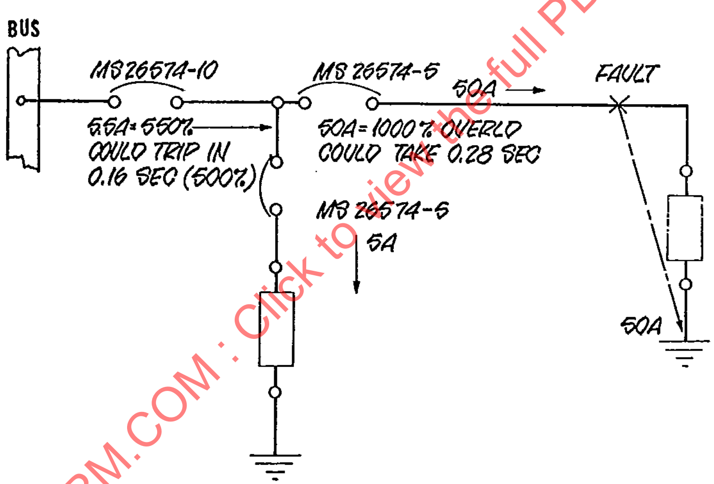

FIGURE 5.b COORDINATION MISAPPLICATION (Same Family)

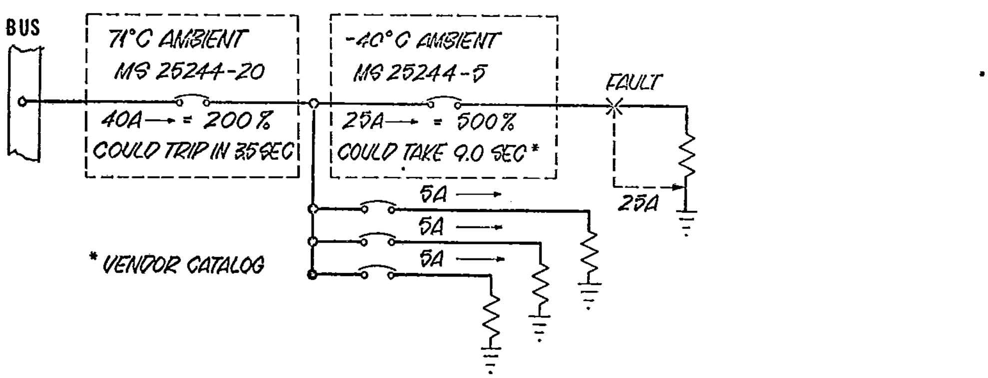

FIGURE 5.c COORDINATION MISAPPLICATION (Same Family - Different Ambient)

5.5.5 Interrupting Capacity (Rupture Capacity): In selecting the circuit protector, it is important that the available short-circuit current at the device is not in excess of that which can safely be interrupted. Failure of the protector to isolate a fault presents a definite fire hazard from overheated wiring and the possibility of arcing. The interrupting capacity of circuit breakers is established in a test laboratory. If a circuit breaker fails to meet the specification requirement, similar circuit breakers will be submitted for test. This process will be repeated until the requirements are met. Qualification status does not guarantee compliance by all breakers of that type. To determine the maximum possible short-circuit current at the input to a protector, the procedure described in Appendix A may be used.

5.5.6 Contamination: Aircraft circuit breakers which are not sealed are subject to both internal and external contamination. Voltage arc-over, current creepage, internal corrosion with its subsequent shortening of life and dry closure (i.e., mechanically latched but electrically open) are some of the end effects of contamination. The aircraft circuit breaker installations must be made with full consideration of the qualification test requirements and the installed environment.

5.5.7 Circuit Breaker Endurance: The circuit breaker "MS" detail sheets require a 5000 cycle mechanical life and a 2500 cycle inductive load life in most cases. Comparing this to the life expectancy of most switches, it is found that the circuit breaker has a life of 1/10 or less of the life of a switch. In addition, it must be recognized that circuit breakers, both push button and toggle "switch type", usually are not snap-acting devices and should not be considered as substitutes for switches. The push button or toggle may be partially actuated, causing the contacts to "make" without latching the mechanism. This means that the contacts can be "teased", drawing arcs, pitting the contacts and generating EMI.

5.5.8 Change in Circuit Breaker Trip Characteristics: The trip characteristics of a circuit breaker can change over the life of the breaker. While there are a number of factors which can cause this change, the main ones are:

- Heavy fault currents which degrade the circuit breaker current overload sensor.
- Excessive manual operation of the breaker which causes dynamic wear of the breaker latching areas and pivotal points.

Paradoxically, the trip characteristics of a breaker can change when a circuit breaker trip mechanism has been dormant for long periods of time. This phenomenon is due to the high internal spring forces which are inherent in most circuit breakers and which can cause a static type of wear to occur to the circuit breaker trip mechanism when in the closed or reset position. Test data suggests this latter condition may be prevented or deferred by periodically operating the breaker manually with no electrical load on the breaker. Manual operation of the circuit breaker should be limited, however, to two or three times yearly in order to avoid excessive dynamic wear of the trip mechanism.

5.5.8 (Cont'd.):

The amount of change in trip characteristics resulting from one of the above mentioned conditions may be significant, resulting in either nuisance tripping type problems or, in extreme cases, a circuit breaker which will not adequately protect the wire to which it is attached.

An electrical check of a circuit breaker may be justified in order to determine if a significant shift in its trip characteristics has occurred. Such a circuit breaker would be one which is known or suspected of having been subjected to one of the foregoing mentioned conditions. Electrical checks of circuit breakers should, however, be conducted in accordance with established procedures under controlled conditions such as are encountered in a test laboratory.

5.5.9 Multipole Breakers: Multipole circuit breakers should be used only when no alternative is available. Only two three-phase aircraft circuit breakers MS 21984 and MS 14154 are on the Qualified Products List. All other three-phase aircraft circuit breakers exhibit one or more of the following:

Minimum ultimate trip not consistent with single phase breakers.
Endurance - less than that of single phase breakers.
Vibration - withstand less than single breakers.
Trip-free - only the faulted phase is trip free.
Trip bar hang-up.
Voltage drop in excess of single phase breakers.
Structural integrity - poorer than single phase breakers.

In addition, size, weight and cost generally favor the use of three single phase breakers.

5.5.10 Application Analysis: The performance of individual circuit breakers in specific mounting and wiring configuration is defined in specifications and recorded during qualification tests. The designer must determine the tripping and non-tripping characteristics of the circuit breakers in the installed environment including packaging, bus bar and wiring effects. There are variables which are not rigorously identified or supported by statistical data. The designer must apply judgment to specifications, test data, and application details to arrive at a conservative usage of protective devices.

5.6 Maintenance Procedures: Circuit protectors used in circuits essential to flight should be located so that they may be reset in flight. All circuit protectors should be installed so that any protector may be inspected and replaced without disturbing other protectors or connections. Periodic inspection should be made to see that wires are tight and the mounting nut is secure.

5.7 Military Specifications Related to Circuit Breakers:

MIL-C-5809 - Circuit Breakers, Trip-Free, Aircraft, General Specification For
MIL-C-13516 - Circuit Breaker, Manual & Automatic (28 Volt)
MIL-C-27715 - Circuit Breaker, Trip-Free, High Temperature, Aircraft, General Specification For
MIL-C-39019 - Circuit Breaker, Magnetic, Low Power, Sealed, Trip-Free, General Specification
MIL-C-55629 - Circuit Breaker, Magnetic, Low-Power, Unsealed, Trip-Free, General Specification For
MIL-C-83383 - Circuit Breaker, Remote Control, Thermal, Trip-Free, General Specification For

6. FUSES: In the discussion that follows, it is assumed that fuses will be applied within the electrical rating, environmental conditions and other parameters as described in the applicable Military Specification, MS sheets or Military Specification sheets. The manufacturer should be consulted regarding the suitability of the fuse when the conditions vary from those specified.

6.1 General: A fuse is a device which protects a circuit by the melting of its current responsive element when an overcurrent passes through it. Fuses are available in a variety of characteristics to meet the requirements of the circuit designer. The scope of this ARP requires that this text cover both small dimension and power fuses.

6.2 Fuse Types: There are four basic types of fuses to consider: normal, time-delay, very fast-acting and current-limiting fuses.

6.2.1 Normal Fuses: This type of fuse is often referred to as a "normal opening" fuse and may or may not be current-limiting (See 6.2.4). Normal fuses contain single elements and possess a time-current characteristic curve which is essentially a smooth curve with no discontinuities (See Fig. 6.a.).

6.2.2 Time-Delay Fuses: Time-delay fuses also may or may not be current-limiting. These fuses are often referred to as "dual-element" fuses in that they possess two elements; a thermal cutout with very high time-lag characteristics which handles harmless transient overloads and blows on continuous light overloads, plus a short-circuit element which blows on heavy overloads and short-circuits. The thermal cutout is designed to pass momentary surges such as motor starting transients and switching transients. The time-current characteristics of the time-delay fuse show a non-uniform curve with considerable time-lag. (See Fig. 6.a, notice the comparison of the three fuses of identical current rating.)

6.2.3 Very Fast-Acting Fuses: These fuses do not possess time-delay features as they are designed to be extremely fast under short-circuit conditions. Very fast-acting fuses are designed to protect semiconductor rectifiers because of their speed of response to overcurrents. These fuses also may or may not be current-limiting. (See Fig. 6.a for comparison.)

6.2.4 Current-Limiting Fuses: The ability of a fuse to fit into this category depends upon its short-circuit performance. Current-limitation is defined as the degree of current-limiting ability a fuse possesses under short-circuit conditions. To be current-limiting, the fuse, under specific short-circuit conditions must limit the instantaneous peak current to a value less than that which would flow if the fuse were not in the circuit and it must clear the fault within one-half cycle (See Fig. 6.b).

6.3 Performance of Fuses:

6.3.1 Ratings: Fuses are rated according to current, voltage, and interrupting capacity.

6.3.1.1 Current Rating: All types of fuses must carry 110% in free air at room ambient until thermal equilibrium is established and are required to open within one hour at 135%. Time-delay type fuses are further required by MIL-F-15160 to hold for a minimum of 12 seconds at 200%. Cartridge type time-delay fuses are available which will hold for 10 seconds at 500%. Ambient temperature will affect the current rating of all types of fuses (See 6.3.2.1).

6.3.1.2 Voltage Rating: The voltage rating is the maximum rms a-c and/or d-c voltage within which the fuse is designed to operate. At this rating the fuse can safely interrupt short-circuits up to the specified magnitude. Fuses can be used for any voltage less than the maximum rating.

6.3.1.3 Interrupting Capacity Rating: This defines the maximum current at rated voltage that the fuse can safely interrupt with a recovery voltage at least equal to the rated voltage. Fuses which fall into the small dimension, glass tube class, have interrupting ratings ranging from 50 amperes to 10,000 amperes, while cartridge type fuses have interrupting ratings exceeding 10,000 amperes.

6.3.2 Environmental: Temperature, altitude, atmospheric, shock and vibration conditions should be examined before a choice of fuse is made.

6.3.2.1 Temperature Compensation Curves: Fig. 6.c and Fig. 6.d show the effect of temperature on operating characteristics for normal and very fast-acting, and time-delay fuses, respectively. Time-delay fuses are more sensitive to temperature environment because of the thermal cutout element.

6.3.2.2 Altitude: Up to 70,000 ft (21,336 meters) the interrupting rating of a fuse is not affected. The current carrying capacity of the fuse may be affected by altitude. Consult manufacturer for derating information or see Fig. 6.c and Fig. 6.d.

6.3.2.3 Atmospheric: Most atmospheric environments do not pose any problems for fuses. In a corrosive environment, it is recommended that all contact making members, i.e., ferrules, blades, fuse-holders, fuse blocks, etc. be plated. Bright alloy and silver plating are the most common types used today.

6.3.2.4 Shock and Vibration: The vast majority of fuses will withstand shock and/or vibration conditions as covered in MIL-F-23419. (Also see MIL-STD-202 for specific tests.)

6.4 Application of Fuses: Fuses are available with exceptionally close tolerances and may find additional applications because of this accuracy. Since protection of aircraft electrical systems is distinguished from the protection of ground support electrical systems, a good deal of thought should be given to fuse performance, according to environmental conditions imposed (See 6.3).

6.4.1 Fuse Sizing - General: Normal and very fast-acting fuses should be sized to adequately protect wiring and should not be continuously loaded in excess of 80% of the fuse rating. However, the characteristics of time-delay fuses allow them to be sized closer to the current load. Circuit conditions should, however, be investigated before making such a decision (Refer to 6.3.2.1).

6.4.2 Component Protection: Most circuit components can be adequately protected from overcurrents and short-circuit by selecting the proper fuse for the application. The key to component protection is current-limitation. Since damaging thermal and magnetic energies vary with the square of the current, it is important to limit this current to as small a value as possible (See Fig. 6.b).

6.4.2.1 Wire Protection: Overload protection of conductors is available when the fuse is sized according to 6.4.1. Short-circuit protection for conductors needs further investigation.

Typical Example - One Type of Wire

Table I is a chart of the maximum time-current capabilities of one type of wire. Typical wire damage charts are available for copper and aluminum conductors under short-circuit conditions. Note that for No. 10 thermoplastic aluminum wire, the maximum amount of short-circuit current this conductor can safely withstand for one cycle is 2700 amperes. If the fault current available to this conducter were 4000 amperes, the protective device must be current-limiting and reduce the fault to something less than 2700 amperes and clear in one cycle or less. Time-delay, normal, and fast-acting current-limiting fuses are available which will protect this wire from damage. See manufacturer's literature for current-limiting curves. (An example of this chart is shown in Table II.)

6.4.2.2 Protection of High Capacity Fault Systems: Current-limiting fuses (or limiters - See 7) are often used in conjunction with circuit breakers to provide adequate system interrupting capacity. In general it is better to install current-limiting fuse protection at each circuit breaker, as shown in Fig. 6.e. This arrangement, of course, isolates the fault to that particular feeder. Fig. 6.f shows another scheme which is often used; however, a fault on any feeder would discontinue service to all feeders. The proper fuse selection depends upon the coordination requirements, the interrupting capacity of the breaker and the available short-circuit current at the breaker line side terminals. Maximum size current-limiting fuses should be selected so as to limit the let-thru current to a value not greater than the interrupting rating in rms amperes of the breaker. The minimum size is determined by plotting the breaker curve and choosing the fuse that will coordinate with this breaker in the low overload region.

6.4.2.3 Motor Protection: Due to motor starting transients, time-delay type fuses are recommended for the protection of motor circuits. Because of their inherent delay, time-delay fuses can be sized close to the full load rating of the motor, thereby preventing motor burnouts which might otherwise occur from single-phasing or other types of overloads.

Recommended practices indicate that dual-element time-delay fuses for motor protection should be sized at 125% or less of the full load rating of the motor.* (Refer to "Overcurrent Protection Data Book", pg. 27 of this text.)

NOTE: Aircraft motors are designed for specific duty and environmental requirements. They require individual analysis of each application to assure compatibility with protective devices.

6.4.2.4 Rectifiers, Semiconductors: Very fast-acting, current-limiting fuses are recommended for protection of rectifiers and solid state components in that the available fault current must be limited to a value which the component can safely withstand. The withstandability of a diode, for example, is usually represented by I^2t (ampere-squared-seconds), a term representing energy and I_p, the peak half-cycle current withstand. Knowing the I^2t and I_p withstand of a component, the proper current-limiting fuse can be selected to assure protection.

6.4.3 Selective Coordination of Fuses: Isolation of a faulted circuit to the point of origin is a desirable requirement of any power system. Aircraft systems cannot tolerate nuisance outages, especially on essential circuits.

Properly selected fuses will coordinate with one another throughout the realm of possible overcurrent conditions (overload to short-circuit currents). Fig. 6.g shows a typical protective device coordination

*"Overcurrent Protection For Motors and Controllers", Actual Specifying Engineer, October, 1966, Article X.

problem. Fuses A and B will coordinate with one another if, and only if, the total clearing energy of the downstream fuse (B) is less than the melting energy of the upstream fuse (A). The relationship of total clearing energy, arcing energy and melting energy is shown in Fig. 6.h.

A coordination study can be made by plotting time-current characteristic curves on log-log paper. Further information is available from manufacturers in the form of a minimum coordination ratio chart, as seen in Table III. Note in Table III that FRN to FRS fuses have a coordination ratio of 2:1 which means that, referring to Fig. 6.g, fuse A must have a current rating of at least twice that of fuse B, to insure coordination. This ratio chart is valid throughout the realm of possible overcurrents and may be used in lieu of plotting fuse curves on log-log paper.

6.4.4 Interrupting Capacity: Referring to 6.3.1.3, the maximum available fault current that the protective device is required to interrupt should be determined. The available fault current may be calculated by using the short-circuit calculation method presented in Appendix A.

From an application standpoint, fault current at various points in an electrical power system should be known so that proper engineering design can be accomplished as prescribed in the preceding sections.

6.5 Maintenance Procedures: Periodic inspection of the fuseholding device is recommended to insure proper pressure on the contact making members. Present day fuse characteristics do not change with age; hence, no maintenance is required for those fuses in storage.

6.6 Military Specifications Available for Fuses and Fuseholders:

MIL-F-15160 - Fuses; Instrument, Power and Telephone.

Covers non-renewable instrument, power and telephone fuses designed for the protection of electrical and electronic equipment. It covers small dimensions through 600 ampere and 250 volt fuses. This specification does not have environmental requirements. Three characteristics are covered:

Relative Blowing Time

A - Normal (normal interrupting capacity)
B - Time-Lag
C - Normal (very high interrupting capacity)

MIL-F-23419 - Fuses, Instrument Type.

Covers instrument type fuses designed for electrical, electronic and communication equipment on AC and DC circuits up to 400 hertz. All military environmental conditions are imposed.

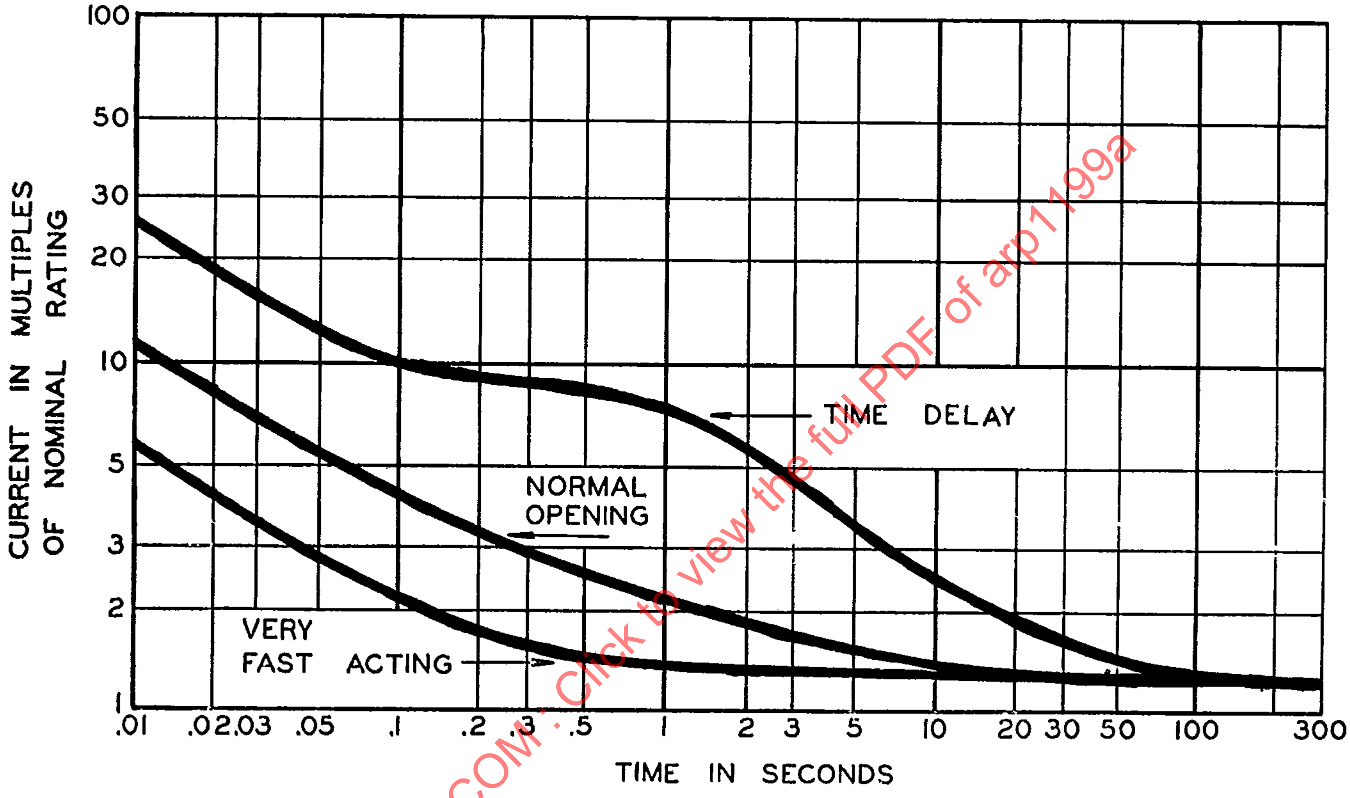

FIGURE 6.a COMPARISON OF VERY FAST-ACTING, TIME-DELAY, AND NORMAL OPENING TYPE FUSES OF IDENTICAL CURRENT RATING

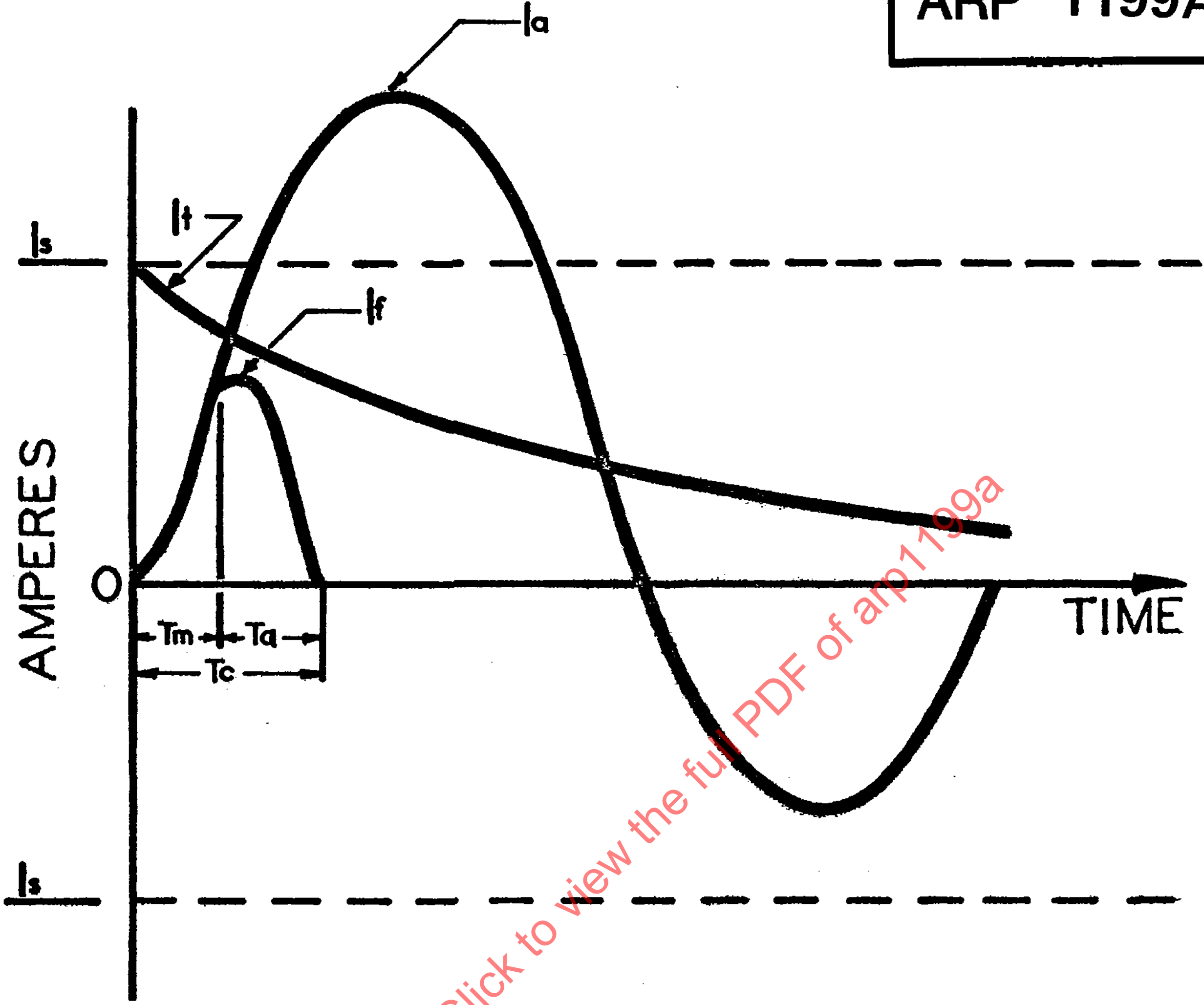

FIGURE 6.b TYPICAL CURRENT-LIMITING FUSE LET-THRU CURRENT CURVE AND PROSPECTIVE FAULT CURRENT CURVE.

I_s - Peak $\pm$ values of steady-state a-c fault current

I_t - Transient d-c component of fault current.

I_a - Total available current if not interrupted (a-c plus d-c components)

I_f - Let-thru current permitted by current-limiting fuse

T_m - Melting Time

T_a - Arcing Time

T_c - Total Clearing Time

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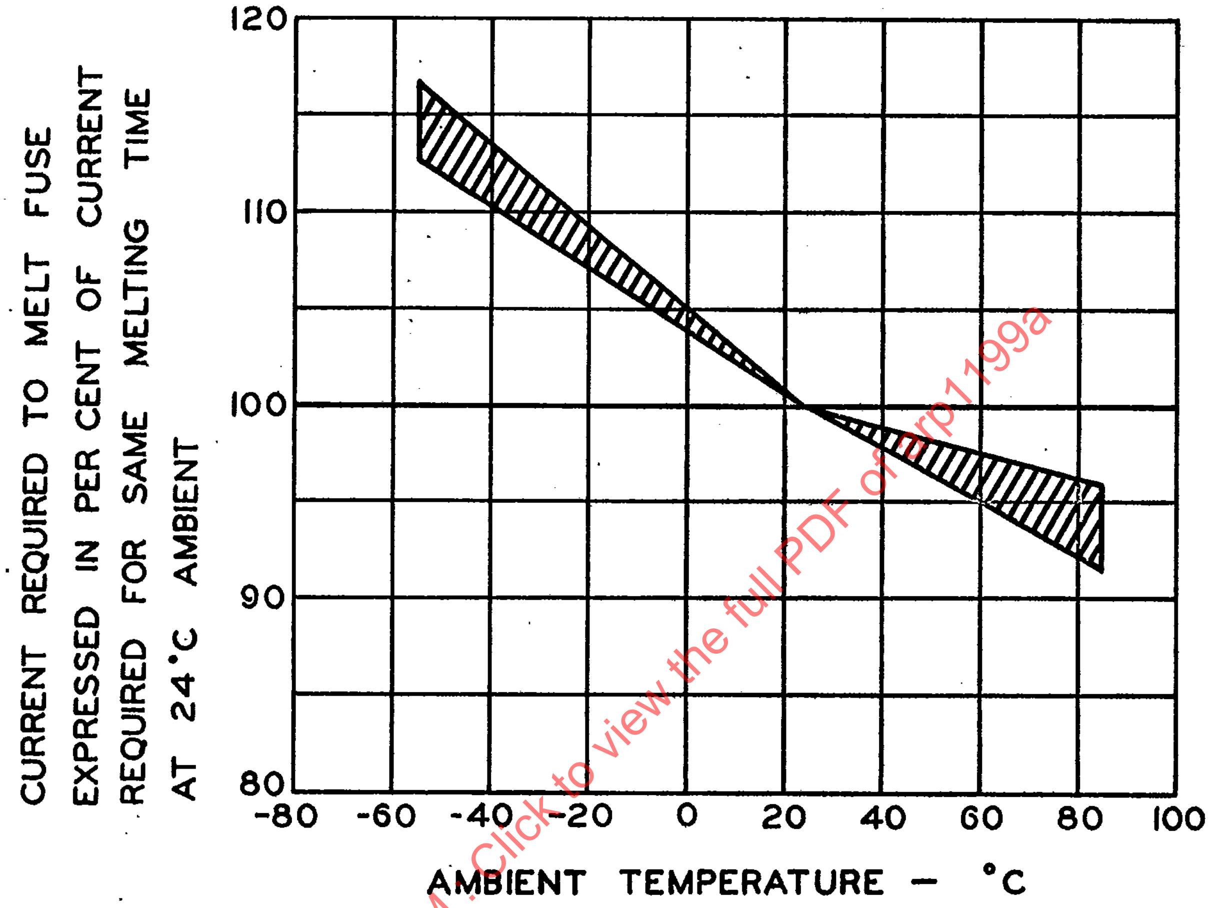


FIGURE 6.c EFFECT OF TEMPERATURE ON VERY FAST-ACTING AND NORMAL OPENING FUSE OPERATING CHARACTERISTICS

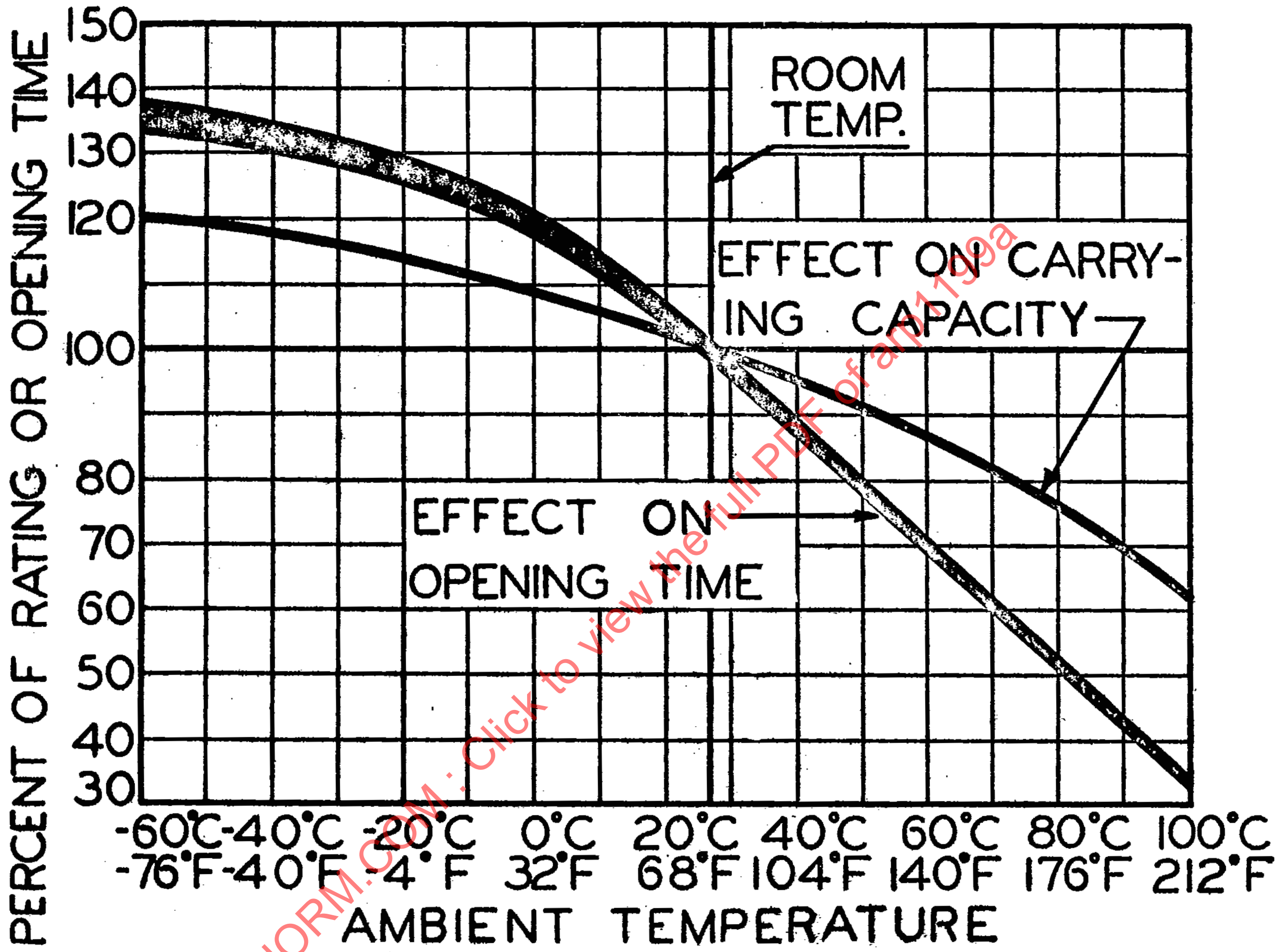


FIGURE 6.d EFFECT OF TEMPERATURE ON TIME-DELAY, DUAL-ELEMENT FUSE OPERATING CHARACTERISTICS

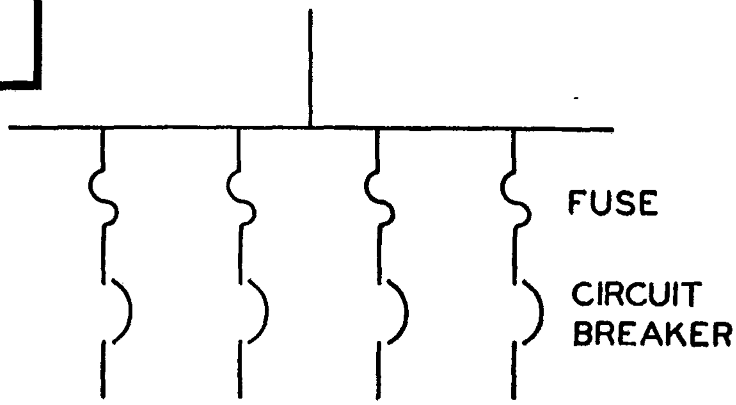


FIGURE 6.e A method of protecting inadequate interrupting rated circuit breakers with fuses.

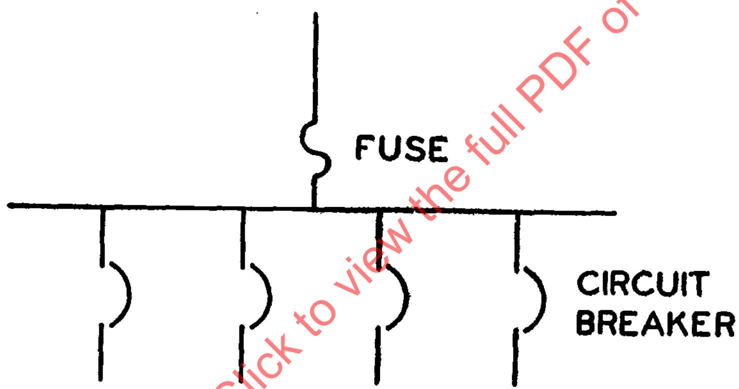


FIGURE 6.f Another method of protecting inadequate interrupting rated circuit breakers with fuses.

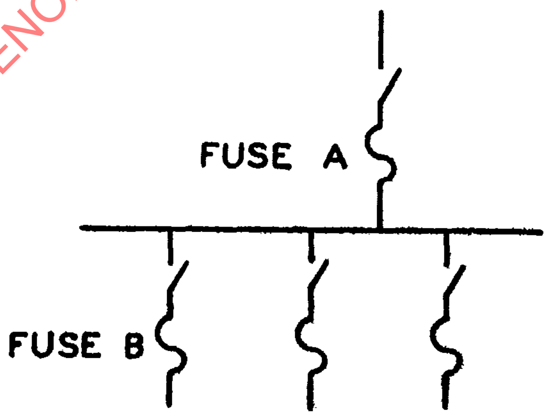
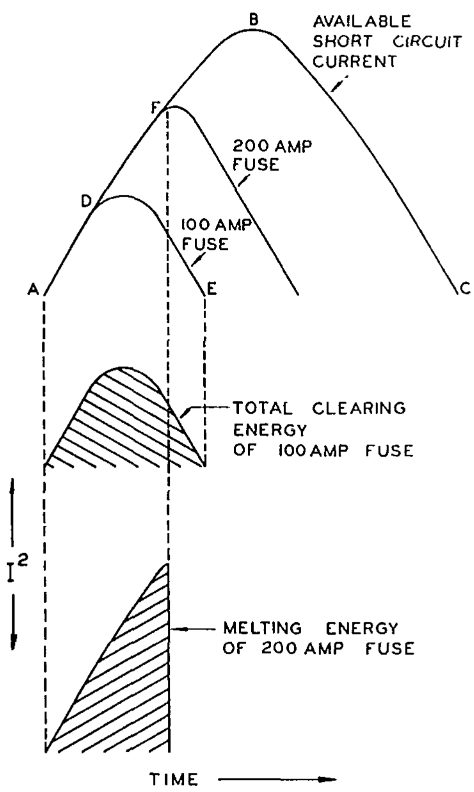


FIGURE 6.g Coordination of fuses A & B. A fault on the load side of fuse B will be isolated by fuse B without disturbing fuse A.



The phenomenon involved displays the blowing of a 100 ampere fuse in series with a 200 ampere fuse. If these two fuses were placed in a circuit set to deliver a short-circuit current as shown by A B C, the same fault current would flow through both fuses. Since it would take less energy to melt the smaller fuse, one would expect the smaller fuse to melt first and then clear. With the fault initiated at point A, the current rises to point D where the 100 ampere fuse melts, an arc is struck within the fuse and quenched at E. The cross-hatched area shows this melting plus arcing phenomenon as a given amount of energy. This total clearing energy of the smaller fuse (melting plus arcing) should be less than the energy to just melt the larger fuse. Under this condition only the smaller one will blow. It can be noted that it would take a longer time to melt out the 200 ampere fuse than the 100 ampere size. This is shown by the current being required to rise from A to point F in order to melt the 200 ampere fuse. At the bottom, the melting energy of the 200 ampere fuse is shown. In this particular case, coordination existed as the total clearing energy of the 100 ampere fuse was less than the melting energy of the 200 ampere fuse and in this case, a 2:1 ratio in fuse sizes would produce coordination.

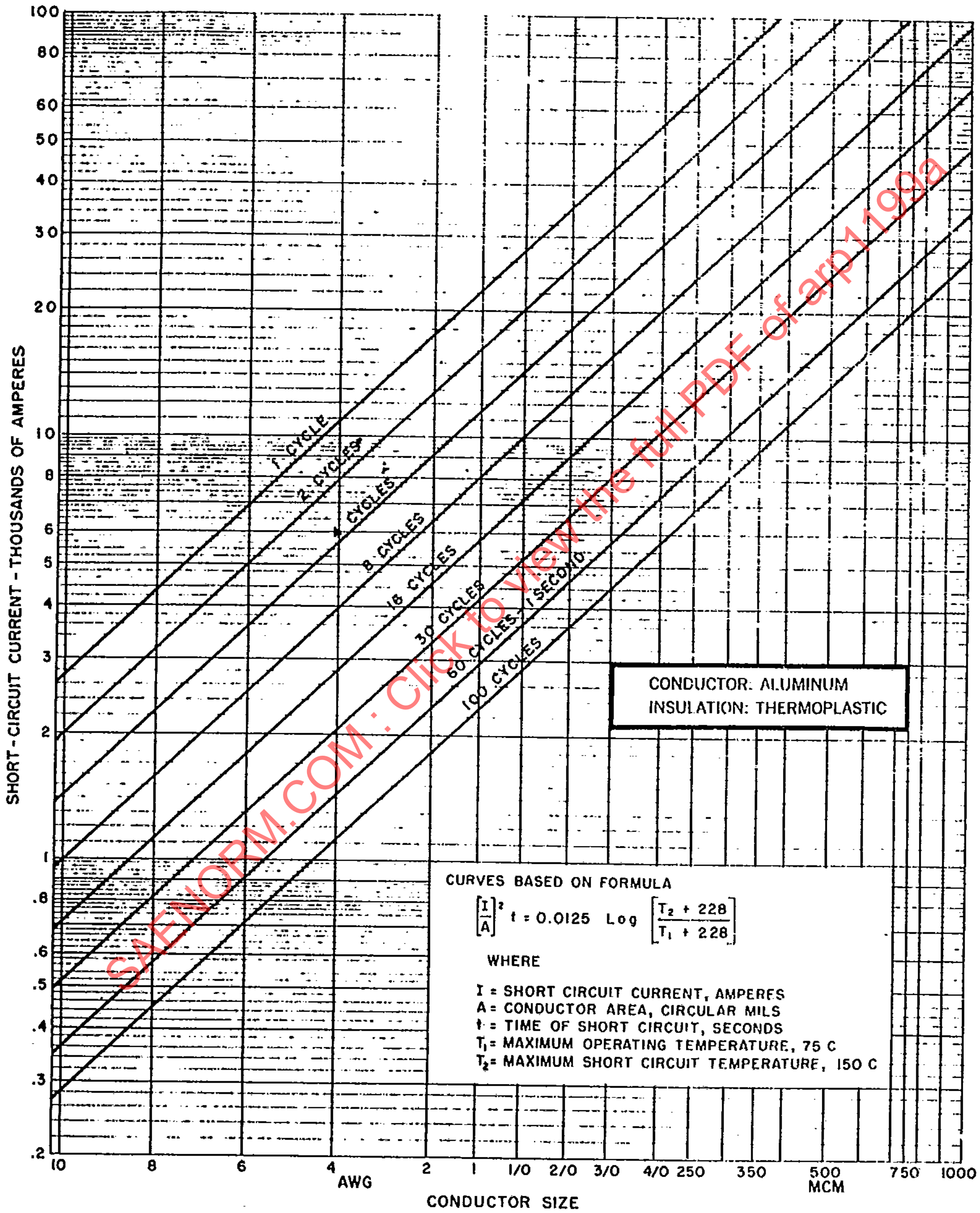
FIGURE 6.h MELTING AND TOTAL-CLEARING ENERGY RELATIONSHIP*

* Permission to reprint granted by Bussmann Mfg. Division of McGraw-Edison Company.

TABLE I

IPCEA WIRE DAMAGE CHARTS

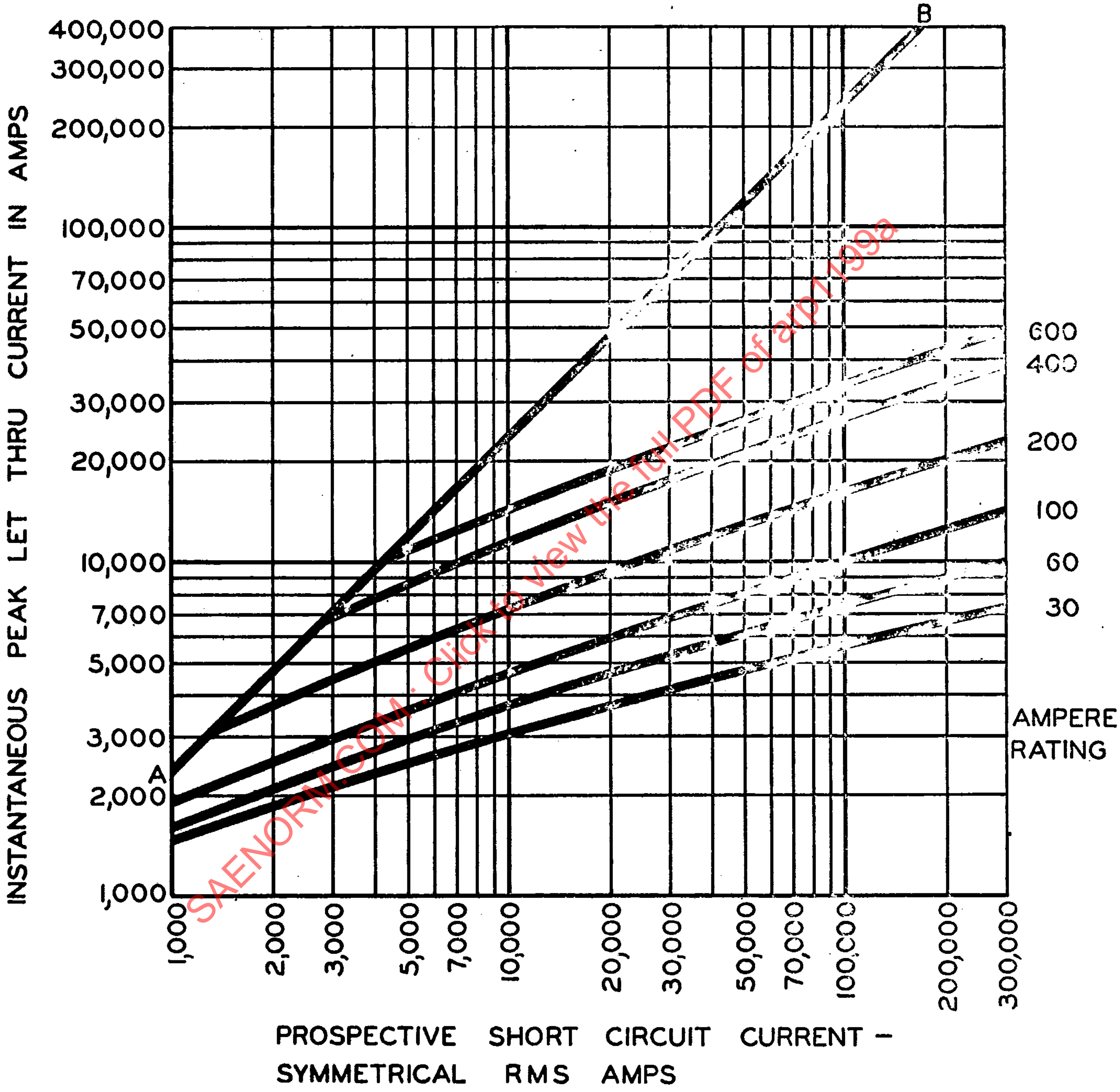
SHORT-CIRCUIT CURRENTS FOR INSULATED CABLES



NOTE: This Chart is based on 60 Hz data. Consult wire manufacturer for 400 Hz data.

TABLE II

TYPICAL CURRENT LIMITING CURVES
FOR CURRENT LIMITING FUSES



NOTE: This Table is based on 60 Hz data. Consult fuse manufacturer for 400 Hz data.

TABLE III

TYPICAL COORDINATION RATIO CHART FOR FUSES*

LINE SIDE	LOAD SIDE: KTN, KTS Limitron Fuse 0-600	JKS Limitron Fuse Class J 0-600	FRN, FRS Fusetron Fuse 0-600	LPN, LPS Low-Peak Fuse 0-600	JHC Hi-Cap Fuse (Class J Dim) 15-600
KTN, KTS Limitron Fuse 0-600	3:1	3:1	8:1	4:1	4:1
JKS Limitron Fuse Class J 0-600	3:1	3:1	8:1	4:1	4:1
FRN, FRS Fusetron FUSE 0-600	1.5:1	1.5:1	2:1	1.5:1	1.5:1
LPN, LPS Low Peak Fuse 0-600	1.5:1	1.5:1	4:1	2:1	2:1
JHC Hi-Cap Fuse (Class J Dim.) 15-600	1.5:1	1.5:1	4:1	2:1	2:1

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OVERCURRENT PROTECTION DATA BOOK

(Recommended procedures for protecting motors and motor circuits - applicable to 60 Hz equipment. Reprinted by permission from Actual SPECIFYING ENGINEER, Vol. 16, No. 4, Copyright 1966, Medalist Publications, Inc.)

This data book provides a ready reference for the solution of overcurrent protection design problems. This section is a continuation of the index starting on page 7 of the July 1966 issue and covers fuse and time delay protection for different kinds of motors.

INDEX

VI-A HOW TO USE MOTOR PROTECTION TABLES

(References are to 1965 National Electrical Code)

Size and class of motor (Column 1)

Motors are listed by horsepower size and ampere rating. Ampere ratings shown are the usual full-load currents for DC motors and AC induction motors having normal torque characteristics and running at usual speeds (Tables 430-147 to 150).

Two and three-phase AC motors are further listed as Class 1, 2, 3 or 4 as shown below, based on Code Letter marking of the motor and characteristics of the control equipment. The rating of branch circuit protection and the size of fused switch may vary for different classes of motors of the same hp rating.

Classification of Motors Based on Type or Code Marking

For selecting the correct size time delay fuse for branch circuit and running protection. (Classes correspond with columns 4 to 7 of table 430-146.)

TABLE 1

Class	Motors WITH Code letter marking (430-152)
1	F to V full voltage start or resistor or reactor start.
2	F to V with auto transformer start. B to E full voltage start or resistor or reactor start.
3	B to E with auto transformer start.
4	A—

Class	Motors WITHOUT Code letter marking, such as ordinary squirrel cage, synchronous, high-reactance squirrel cage or wound rotor motors (430-153)
1	Ordinary squirrel cage or synchronous with full voltage start or resistor or reactor start.
2	Ordinary squirrel cage or synchronous with auto-transformer start 30 amperes or less. High-reactance squirrel cage 30 amperes or less.
3	Ordinary squirrel cage or synchronous with auto-transformer start more than 30 amperes. High-reactance squirrel cage more than 30 amperes. Sealed (Hermetic-type) Refrigeration Compressor—400 KVA locked-rotor or less.
4	Wound rotor or slip ring motor.

TABLE 2 1-φ

(1) Size of MOTOR		(2) Branch-Circuit Protection These do not give motor-running protection		(3) Motor-Running Protection On NORMAL installations Also give branch-circuit protection: Time Delay Fuse Size				(4) Size of Fused Switch or Fuseholder		(5) Minimum Size of Starter
H.P.	AMP.	A	B	Ordinary service	Heavy service	Max. Size 40° C. Motor	Max. Size Other Motors	C	D	NEMA Size
115 Volt										
1/6	4.4	15	7	4 1/2	5	5 6/10	5 6/10	30	30	00
1/4	5.8	20	10	5 6/10	6 1/4	8	7			
1/3	7.2	25	12	7	8	9	9			
1/2	9.8	30	17 1/2	10	12	12	12	30	30	0
3/4	13.8	45	25	15	17 1/2	17 1/2	17 1/2	60	30	0
1	16	50	30	17 1/2	20	20	20	60	30	
1 1/2	20	60	30	20	25	25	25	60	30	1
2	24.0	80	40	25	30	30	30	100	60	
230 Volt										
1/6	2.2	15	3 1/2	2 1/4	2 1/2	2 8/10	2 8/10	30	30	00
1/4	2.9	15	5	2 8/10	3 2/10	4	3 1/2			
1/3	3.6	15	6	3 1/2	4	4 1/2	4 1/2			
1/2	4.9	15	8	5	5 6/10	6 1/4	6 1/4	30	30	00
3/4	6.9	25	12	7	8	9	8			
1	8	25	15	8	9	10	10			
1 1/2	10	30	17 1/2	10	12	12	12	30	30	0
2	12	40	20	12	15	15	15	60	30	
3	17	60	25	17 1/2	20	20	20	60	30	1
5	28	90	45	30	35	35	35	100	60	2
7 1/2	40	125	60	40	45	50	50	200	60	2
10	50	150	80	50	60	70	60	200	100	3

A—Maximum size fuse permitted by the Code
B—Time delay fuse that can be used
C—Maximum size switch that can be used
D—Size that can be used with time delay fuses

Branch-circuit protection (Column 2)

If ordinary fuses are used, the size must be as shown in column headed "Maximum size—" even though the ampere rating of the fuse may be quite different for different classes of motors of the same hp rating (430 Part D).

If two ampere ratings are shown on motor, make sure for what voltage motor is connected. Horse power of motor gives no definite indication of size time delay fuse to be used as amperage of AC motors of the same size varies a great deal.

The size shown for time delay fuses can, on normal installations, be still smaller as shown under column headed "Motor-Running Protection".

Motor-running Protection (Column 3)

The rating of the time delay fuse must be based on the **Actual** ampere rating of the motor (430 Part C). If the ampere rating differs from what is shown in the table, see tables . . . for correct size to use. (Table 7a and 7b of this article-Ed.)

For highest degree of protection use size shown in first column which is headed "Ordinary Service". The sizes shown in the third and fourth columns are in accordance with the Code which specifies that time delay fuses for motor-running protection can be 125% of the rating of motors marked to have a temperature rise not over 40° C., 115% on all other motors (430-32al) and which further specifies (430-34) that when such figure does not correspond to a standard size of time delay fuse, the next larger size can be used but must not be more than 140% of the motor rating, on motors rated at 40° C. temperature rise, or 130% of rating on all other motors.

If two ampere ratings are shown on motor, make sure for what voltage motor is connected. Horse power of motor gives no definite indication of size time delay fuse to be used as amperage of AC motors of the same size varies a great deal.

Sizes shown can be used for motor-running protection of **Normal** installations which represent at least 99% of all cases.

Abnormal Installations

These include such cases:

Where the protective time delay fuses are located in places where high ambient temperatures prevail.

Where the motor is started frequently or reversed quickly.

Where the motors are direct connected or chain drive to machines that cannot be brought up to full speed quickly due to the delay in getting extra heavy revolving part up to full speed, such as:

Centrifugal machines like extractors, pulverizes, etc.,

Large fans.

Machines having large fly wheels such as large punch presses, bulldozers, etc.

TABLE 3 3φ-208V.

Size and Class of MOTOR (1)			Branch-Circuit Protection — These do not give motor-running protection (2)		Motor-Running Protection — On NORMAL installations Also give branch-circuit protection (3)				Size of Fused Switch or Fuseholder (4)		Minimum Size of Starter (5)
					Time Delay Fuse Size		Max. size				
H.P.	AMP.	Class	A	B	Ordinary service	Heavy service	40° C Motor	All other Motors	C	D	NEMA Size
½	2.1	Any	15	5	2¼	2½	2 8/10	2½			
¾	3	"	15	8	3 2/10	3½	4	3½			
1	3.7	"	15	8	4	4½	5	4½	30	30	00
1½	5.3	"	15	10	5 6/10	6¼	7	6¼			
2	6.9	1	25	12	7	8	9	8			
		2	20	12	"	"	"	"	30	30	0
		3-4	15	12	"	"	"	"			
3	9.5	1	30	15	10	12	12	12			
		2	25	15	"	"	"	"			
		3	20	15	"	"	"	"	30	30	0
		4	15	15	"	"	"	"			
5	15.9	1	50	25	17½	20	20	20	60	30	
		2	40	25	"	"	"	"	60	30	
		3	35	25	"	"	"	"	60	30	1
		4	25	25	"	"	"	"	30	30	
7½	23.3	1	80	35	25	30	30	30	100	60	
		2	60	35	"	"	"	"	60	60	
		3	50	35	"	"	"	"	60	60	1
		4	40	35	"	"	"	"	60	60	
10	28.6	1	90	45	30	35	40	35	100	60	
		2	70	45	"	"	"	"	100	60	
		3	60	45	"	"	"	"	60	60	2
		4	45	45	"	"	"	"	60	60	
15	42.3	1	125	60	45	50	50	50	200	60	
		2	110	60	"	"	"	"	200	60	
		3	90	60	"	"	"	"	100	60	2
		4	70	60	"	"	"	"	100	60	
20	55	1	175	90	60	70	70	70	200	100	
		2	150	90	"	"	"	"	200	100	
		3	110	90	"	"	"	"	200	100	3
		4	90	90	"	"	"	"	100	100	
25	68	1	225	100	70	80	90	80	400	100	
		2	175	100	"	"	"	"	200	100	
		3	150	100	"	"	"	"	200	100	3
		4	110	100	"	"	"	"	200	100	
30	83	1	250	125	90	100	110	100	400	200	
		2	225	125	"	"	"	"	400	200	
		3	175	125	"	"	"	"	200	200	3
		4	125	125	"	"	"	"	200	200	
40	110	1	350	175	110	125	150	150	400	200	
		2	300	175	"	"	"	"	400	200	
		3	225	175	"	"	"	"	400	200	4
		4	175	175	"	"	"	"	200	200	
50	132	1	400	200	150	175	175	175	400	200	
		2	350	200	"	"	"	"	400	200	
		3	300	200	"	"	"	"	400	200	4
		4	200	200	"	"	"	"	200	200	
60	159	1	500	250	175	200	200	200	600	400	
		2	400	250	"	"	"	"	400	400	
		3	350	250	"	"	"	"	400	400	5
		4	250	250	"	"	"	"	400	400	
75	196	1	600	300	200	225	250	250	600	400	
		2	500	300	"	"	"	"	600	400	
		3	400	300	"	"	"	"	400	400	5
		4	300	300	"	"	"	"	400	400	
100	260	1		400	250	300	350	300		400	
		2		400	"	"	"	"		400	
		3	600	400	"	"	"	"	600	400	5
		4	400	400	"	"	"	"	400	400	
125	328	1-2-3		500	350	400	450	400		600	
		4	500	500	"	"	"	"	600	600	6
150	381	1-2-3		600	400	450	500	450		600	
		4	600	600	"	"	"	"	600	600	6

A—Maximum size fuse permitted by the Code
B—Time delay fuse that can be used
C—Maximum size switch that can be used
D—Size that can be used with time delay fuses

6.6 (Cont'd.):

MIL-F-19207 - Fuseholders, Extractor Post Type. Blown Fuse Indicating and Non-indicating.

Covers enclosed, panel mounted, extractor post type fuseholders.

MIL-F-21346 - Fuseholders, Block and Plug Type, and Associated Electrical Clips.

Covers open block and plug type fuseholders as well as fuseclips.

MIL-F-5372 - Fuse, Current-Limiter Type, Aircraft. (Refer to 7.)

Covers limiters for 400 cycle aircraft distribution of power.

MIL-F-5373 - Fuseholders, Block Type, Aircraft.

Fuseblocks for MIL-F-5372 limiters. (Refer to 7.)

7. LIMITERS: In the discussion of aircraft limiters that follows, it is assumed that the limiters will be applied within the electrical rating, environmental condition and other parameters, as described in the applicable Military Specification, MS Sheets or Military Specification Sheets. The manufacturer should be consulted regarding the suitability of the limiter when conditions vary from those specified.

7.1 General: A limiter is a device which responds only to high values of overcurrent (See 7.3.1.2) and should be applied with this criteria in mind. A limiter is designed specifically with a high temperature melting point to provide protection for electric power distribution systems against short-circuit currents.

7.2 Limiter Types: There are two basic types of aircraft limiters which are used in aircraft electrical power systems. The most widely used limiter is of the knife blade style and gives visual indication of a blown limiter by a spring activated pin that extends from the limiter body. The other type of limiter is the bolt-on type with an insulating window covering the link for visual inspection.

7.3 Performance of Limiters:

7.3.1 Ratings: Limiters are rated according to voltage, current and interrupting capability.

7.3.1.1 Voltage Rating: Knife-blade type limiters carry a 120/208 volt, 400 hertz AC or 125 volt DC voltage rating. Bolt-on type limiters may be applied in circuits up to 41 volts AC or DC.

7.3.1.2 Current Rating: Knife-blade type limiters are designed to carry 200% rated current for five minutes, and open at 240% within five minutes. (See MIL-F-5372 for tolerance.) These limiters have nominal current ratings from 1 to 60 amperes. Bolt-on type limiters have current ratings from 35 to 500 amperes and follow a typical fuse melting curve within prescribed tolerances.

7.3.1.3 Interrupting Ratings: The interrupting ratings for knife-blade type limiters are 6000 amperes at 120 volts AC, 4200 amperes at 208 volts AC, and 6000 amperes at 125 volts DC. Bolt-on type limiters have interrupting ratings of 10,000 amperes at 32 volts AC or DC.

7.3.2 Environmental:

7.3.2.1 Temperature: Knife-blade type limiters, in accordance with MIL-F-5372, may be applied in temperature environments ranging from -54 C to +125 C without significant changes in operation.

7.3.2.2 Altitude: Up to 70,000 ft, the interrupting rating of the limiter is not affected.

7.3.2.3 Atmospheric: Terminals on aircraft limiters are silver plated to prevent corrosion. Limiters in accordance with MIL-F-5372 are made with a high temperature plastic body to withstand exposure to the environmental extremes, such as moisture, fungus, salt spray, sand and dust, and temperature. The color of the knife-blade limiter is red.

7.3.2.4 Shock and Vibration: Limiters will withstand shock and vibration conditions as covered in the appropriate Military Specification.

7.4 Application of Limiters: Limiters are usually applied in aircraft as back-up protection for circuit breakers and in multiple cable circuits for isolating a faulted cable.

7.4.1 General Sizing: Aircraft limiters are usually sized according to their time-current characteristics. Fig. 7.a is a graph showing current as a function of opening time for limiters.

7.4.2 Circuit Breaker Back-Up Protection: Where the available short-circuit currents exceed the interrupting rating of a circuit breaker, an aircraft limiter may be used to limit the short-circuit current to within the breaker's capability. Fig. 7.b shows the location of limiters for this application.

7.4.3 Short-Circuit Protection and Isolation of Multiple Cable Circuits: Where multiple cable runs have been designed into the system, and single cable fault isolation is required, aircraft limiters should be installed at each end of each cable. Figure 7.c illustrates the proper application of limiters in multiple cable runs.