

1. **Scope**

This SAE Standard defines the test conditions, procedures, and performance requirements for circuit breakers in ratings from 50 to 200 A. This document covers automatic reset, modified reset and manual reset types of circuit breakers for low voltage DC systems (12 V and 24 V).

NOTE—It is technically feasible for circuit breakers in this general class to be provided in amperage ratings below 50 A. In those instances, the procedures as detailed herein may be used provided compensation is made for test currents, test leads, and power supply requirements. Additional guidance may be obtained from SAE J553 – Circuit Breakers.

1.1 Operational requirements for 42V vehicular electrical systems are under development as of this revision. The electrical environment is not completely defined, particularly as it relates to other components that would influence circuit breaker function (such as storage battery technology, charging system design and operational characteristics). The test and evaluation requirements of this standard are sufficient to determine relative performance concerning current carrying capability, environmental durability, and general requirements regardless of maximum voltage rating. It is anticipated that a separate technical document will be created to capture requirements unique to 42V electrical system architecture and load characteristics.

2. **References**

2.1 **Applicable Publications**

The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

SAENORM.COM : Click to view the full PDF of J1625-2013

2.1.1 SAE PUBLICATIONS

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J537—Storage Batteries

SAE J1127—Battery Cable

SAE J1128—Low Tension Primary Cable

SAE J1171—External Ignition Protection of Marine Electrical Devices

SAE J1211—Recommended Environmental Practices for Electronic Equipment Design

SAE J1428—Marine Circuit Breakers

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 SAE PUBLICATIONS

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J258—Circuit Breaker—Internal Mounted—Automatic Reset

SAE J554—Electric Fuses (Cartridge Type)

SAE J1284—Blade Type Electric Fuses

SAE J1888—High Current Time Lag Electric Fuses

SAE TSB 002—Preparation of SAE Technical Reports

2.2.2 CSA PUBLICATIONS

Available from CSA Sales Department, 178 Rexdale Boulevard, Etobicoke, Ontario, M9W 1R3.

CSA C22.2 No. 14-M1987—Industrial Control Equipment

CSA C22.2 No. 235-M89—Supplementary Protectors

2.2.3 U.S. GOVERNMENT PUBLICATIONS

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-202F—Test Methods for Electronic and Electrical Component Parts

2.2.4 UNDERWRITERS LABORATORIES PUBLICATIONS

Available from Underwriter Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062.

U.L. 1077—Standard for Supplementary Protectors for use in Electrical Equipment

2.2.5 APPENDICES

Appendix A Circuit Protection Application Guidelines

Appendix B Glossary of Document Terminology

3. Definitions

3.1 Circuit Breakers – are overcurrent protective devices, responsive to electric current and to temperature.

NOTE—There are no implied restrictions on circuit breaker design as to component form or ornamental housing designs provided the circuit breaker exhibits performance characteristics within the scope of this standard. This standard has been developed for use by the ground transportation industry, however other users of DC circuit protection may find the test and performance requirements of benefit.

3.2 Externally Mounted Circuit Breakers – are defined as self-contained devices, which are mounted individually or in assemblies via brackets, bus bars, electrical centers, compatible fuse holders, or mechanically in or through panels.

3.3 Internally Mounted Circuit Breakers – are defined as protection sub-assemblies that are most often integrated with other electrical devices, such as part of a switch with circuit breaker function or in a motor housing to provide overload protection to the motor windings.

3.4 There are three general classes of breaker, defined as follows:

3.4.1 Type 1 – Automatic reset – is defined as cycling or continuously self-resetting unit, which is opened by overcurrent. The terms “cycling” and “continuously self-resetting” refer to the functional characteristic in which the reset feature is not dependent upon any deliberate action or intervention by the user or user’s application system to initiate the reset of the tripped circuit breaker. These terms do not imply that the trip and reset function can continue unabated without consequence to either the life of the circuit breaker or potentially adverse effects to an electrical system wiring and/or components, if a fault condition persists undetected and uncorrected.

NOTE—Type 1 automatic reset circuit breakers are best utilized in applications that provide for other self-limiting or non-resettable means (such as after a main fuse, main manual reset circuit breaker, or momentary switch). Intermittent electrical short circuit operation, which may be observed during a cycling event on a Type 1 automatic reset circuit breaker after overload or short, could be misinterpreted as loose connections by operators if self-limiting means are not in place, which in turn may lead to delayed service of a fault.

3.4.2 Type 2 – Modified Reset – is defined as a device that is opened by overcurrent and remains open as long as a minimum voltage and current is available to the affected circuit (as established in this standard). A sequence of trip and reset cycles may occur prior to achieving the steady-state open condition as defined in the test and performance requirements.

NOTE—As of this revision, there are no commercially available Type 2 heavy-duty circuit breakers. There are no specified tests or requirements in this standard. Type 2 tests and requirements are published in SAE J553, which may be relied upon as a general guideline for evaluation until such time that specifications would be included in this document.

3.4.3 Type 3 – Manual Reset – is defined as a non-cycling unit that is opened by overcurrent. A manual reset circuit breaker, once opened by overcurrent requires manual actuation of a reset mechanism in order to re-establish continuity.

NOTE—Trip free designation on manual reset circuit breakers as it applies to this standard - indicates a manual reset circuit breaker in which any forced restriction of the reset mechanism in the operating mode does not prevent cycling under fault current, or causes the circuit breaker to keep passing electrical current in lieu of any form of trip function.

3.4.3.1 Type 3 – Manual Reset with Switchable Feature - Functions as a conventional manual reset circuit breaker as defined in 3.4.3, but also has a mechanism, which when exercised at the discretion of the user, permits opening of the breaker's internal circuit to stop current flow. The breaker is reset to its normal operating condition by the manual reset function, whether tripped unattended by a real fault condition or by the user.

3.4.3.2 Type 3 – Manual Reset/Switch – an integrated switch design that provides both switching function for on-off activations and includes a circuit breaker feature to “toggle” the switch to an off position in the event of overcurrent or short circuit. Reset function is likely to be incorporated into the on/off activating mechanism, permitting reset of the circuit breaker portion of the device. Circuit breakers of this type could be considered externally or internally mounted units as defined in paragraphs 3.2 and 3.3. Additional or alternate test requirements may be noted elsewhere in this standard.

4. Test Requirements

4.1 Test Equipment, Instrumentation, and Conditions

4.1.1 POWER SUPPLIES

4.1.1.1 A current and voltage regulated DC power supply shall be used for all tests except 4.2.6 Interrupt Test.

The power supply shall be capable of delivering 14.0 VDC during open circuit portion of tests and have sufficient current output capacity to meet highest load requirements. Voltage and current settings shall be accurate to within $\pm 1\%$ of set point or better. Power transient response shall be such that when a 30% step increase in power is demanded by the load, the transient in the regulation output shall typically recover to within 3% of the final value within 100 ms or better. The power supply shall be operated with controlling circuitry to achieve all necessary test conditions.

NOTE—DC power supplies used for testing could have large storage capacitors in the DC output section. Load switching may induce current spikes, which while brief in duration, may be significant enough to bias test results or affect reset and re-trip activity of circuit breakers (especially more vulnerable lower amperage rated devices). For this reason, it is necessary to buffer the output by placing low resistance power resistors (generally one ohm or less) in series with the DC power supply output as part of the overall circuit breaker test circuit. See Figure 1 Current Rating Test Circuit.

- 4.1.1.2 Storage batteries specified in Table 1 shall be used as the power supply for 4.2.6 Interrupt Test. Open circuit voltage as specified shall be maintained by a battery charger or power supply with voltage regulated per Table 1 and charging current output restricted to 100 A or less.

TABLE 1—STORAGE BATTERIES

Voltage Rating	Cold Cranking Amperage (CCA)	Open Circuit Voltage
12 V	1100 - 1200 A	14.0 ± 0.5V DC

4.1.2 VOLTMETER

0 to 30 VDC maximum range, accuracy $\pm 1/2\%$.

NOTE—A digital meter having at least 3-1/2 digits readout with an accuracy of $\pm 1\%$ plus 1 digit is recommended for millivolt readings.

4.1.3 AMMETER

Capable of displaying full load current with an accuracy of $\pm 1\%$. A calibrated shunt shall be used in series with the test circuit to minimize circuit resistance (use of an inductive ammeter is permissible in lieu of an ammeter/shunt set-up, provided accuracy and stability of load current reading is assured).

NOTE—A digital meter having at least a 3-1/2 digit readout with an accuracy of $\pm 1\%$ plus 1 digit is recommended for amperage readings when used in conjunction with a millivolt output calibrated shunt.

4.1.4 HIGH-VOLTAGE BREAKDOWN TESTER

Capable of providing 500 VAC RMS - 60 Hz, accuracy $\pm 5\%$, with 5 mA leakage.

4.1.5 THERMOCOUPLE AND METER

0 to 200 °C minimum range, accuracy $\pm 2\%$, maximum thermocouple wire size - 0.22 mm² (#24 gage); J or K style.

NOTE—A digital thermometer with thermocouple input is recommended, with an accuracy of ± 1 °C.

- 4.1.5.1 Two ambient observations are necessary during test cycles: ambient of test room and ambient of test chamber containing breakers under test.

- 4.1.5.2 Delta heat rise of terminations shall be calculated during 4.2.2.1 testing (at the tester's discretion).

4.1.6 OVEN

Variable controlled temperature oven shall be able to vary temperature at a rate of 1 °C per minute and control temperature ± 1 °C of set point accurate to ± 2 °C.

4.1.7 TEST LOAD

Any combination of fixed and/or variable resistor(s) capable of varying circuit load to specified test requirements in conjunction with a power supply. A test circuit by-pass may be employed to verify current settings.

4.1.8 TEST LEADS

Circuit breakers shall be tested using copper stranded wire sizes listed in Table 2 that conform to wire specifications as found in SAE J1127. The wire length shall be 1.22 m (48.0 in) for all voltages tested and insulation shall be rated 105 °C, or better.

TABLE 2—TEST LEAD SIZES

Rated Current	SAE Wire Size No.	ISO Cable Size mm ²
50A to 60A	# 6	13mm ²
>60A to 90A	# 4	19 mm ²
>90A to 120A	# 2	32 mm ²
>120A to 150A	# 0	50 mm ²
>150A to 200A	# 00	62 mm ²

NOTE—ISO metric cable sizes are not exact equivalents to the SAE wire sizes. Tests and requirements in this Standard are based on SAE wire. Use of ISO metric cable may require shortening of the test leads from 1.22 m in length for SAE to 1.0 m in length for resistive and thermal compensation.

4.1.8.1 Termination of Test Leads

All test leads shall use standard commercially available terminals suitable for the range of wire gages and threaded circuit breaker terminations. To avoid secondary heat generation and/or adverse millivolt drop, it is recommended that test lead terminals be crimped and soldered when practical; also, connections to breakers must be repeatable and uniform. Terminals shall be attached to breakers with screw threads to a specified torque value that is generally recommended for the particular thread size. For custom terminations, consult the circuit breaker manufacturer.

4.1.9 TEST ENCLOSURE

Provide for a draft and convection air current free test chamber with volume of approximately 7.08 x 10⁴ cm³ (2.5 ft³). Chamber must allow for test lead access, internal chamber temperature monitoring, and indirect venting if needed to ensure requirements of 4.2.1 are met.

4.1.10 AMBIENT CONDITIONS

Environmental conditions have been selected for this document to help assure satisfactory operation under general customer use conditions. Circuit breakers shall be tested in still air at the temperatures indicated and allowed a 30 min soak without electrical load before testing (and repeated 30 min soaks for individual breakers that are involved in more than one test condition). Equipment listed in 4.1.9 fulfills the still air requirement. If not otherwise specified, all tests shall be performed at room temperature (23 ± 3) °C (68 – 79 °F) at a relative humidity (RH) of 45 % to 75 % (standard condition). If room ambient is unstable or unregulated and an environmental chamber is employed, breakers under test must be isolated from chamber forced air currents. Paragraph 4.1.9 test enclosure shall be used within the chamber compartment and temperatures monitored per 4.1.5.1.

NOTE—Breakers stored in environments below 15 °C (59 °F) or above 35 °C (95 °F) shall be allowed a minimum of 1 h soak at the specified test temperature prior to initiation of any testing.

4.1.10.1 Test leads and terminations subject to thermal rise from test operations shall be allowed to re-stabilize to ambient conditions before starting a new test. Alternating between multiple sets of leads is suggested.

4.2 Test Procedures

4.2.1 CURRENT RATING TEST PROCEDURE

The circuit breaker shall be electrically connected with a pair of test leads described in 4.1.8 in series with the power supply as described in 4.1.1.1, a voltmeter as described in 4.1.2, a shunt with ammeter as described in 4.1.3, and an appropriate test load as described in 4.1.7 to provide the required current pass through the circuit breaker. Refer to Figure 1 for all tests except 4.2.5 and 4.2.6. Refer to Figure 2 for 4.2.5 and 4.2.6 only.

4.2.1.1 *Maximum Voltage Drop Test Procedure*

With the circuit breaker connected as described in 4.2.1, the voltage drop across the circuit breaker shall be measured while the breaker is passing full rated current and has achieved equilibrium (typically after 15 to 20 min of continuous operation at 100% of rated current, exhibited by no appreciable increase in voltage drop). Continue operation at 100% of rated current until 1 h elapses. If after 30 minutes of continuous operation at 100% of rated current, equilibrium has not been attained, continue testing until equilibrium has been attained and voltage drop is within acceptable limits, or, unit exceeds voltage drop limits and/or trips out.

NOTE—For applications sensitive to heat-rise at the circuit breaker terminations, thermocouple leads may be affixed to the terminations. General practice is to place the thermocouple lead on that portion of the terminal that is likely to come in contact with the wire lead insulation. Benchmark maximum values for delta heat rise (observed thermocouple temperature minus ambient temperature) at 65 °C delta for factory wired terminations and 50 °C delta for field wired terminations, which is based on 90°C rated wire insulation. Test temperature readings should be compared with the rating of application wire. Results of this testing will assist the user with circuit design and proximity considerations for breaker installation.

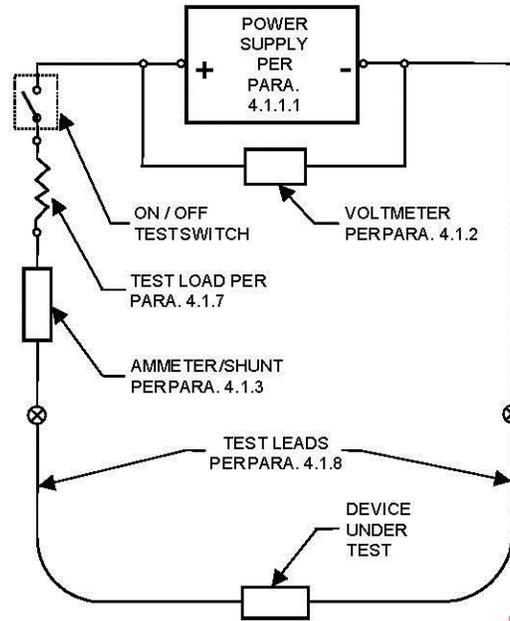


FIGURE 1—CURRENT RATING TEST CIRCUIT

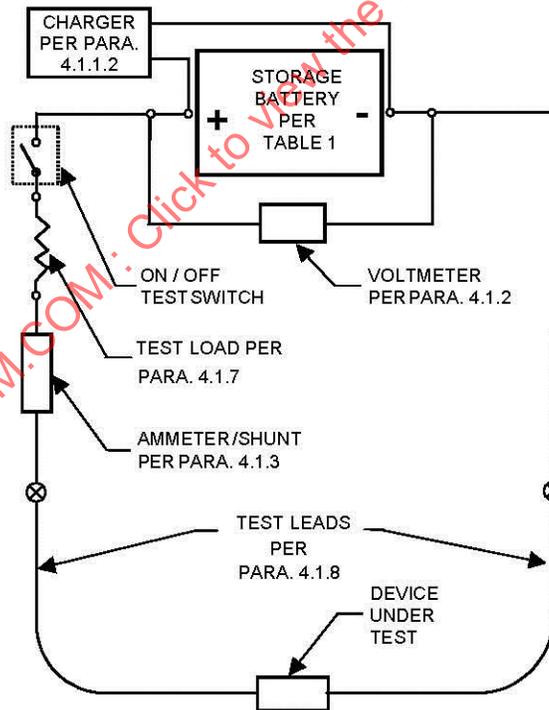


FIGURE 2—INTERRUPT CYCLING TEST CIRCUIT

4.2.2 OVERLOAD TRIP RATING TEST PROCEDURE

After a 30 min soak, reconnect the breaker as described in 4.2.1. Operate at 135% of rated current and record the elapsed time in seconds for the breaker to trip. If breaker has not opened after 1 h, discontinue the test. Repeat 30 min soak, operate at 200% of rated current and record elapsed time for the breaker to trip. If breaker has not opened after 2 min, discontinue the test.

4.2.3 VOLTAGE BREAKDOWN TEST PROCEDURE

4.2.3.1 With the circuit breaker connected as described in 4.2.1, adjust the current to 400% of the circuit breaker rating and allow the breaker to cycle. At the end of 10 min, check the continuity at 500 VAC between each terminal of the circuit breaker individually and the cover of the breaker (if cover is metallic) with the breaker in both an open and closed circuit condition.

4.2.4 HIGH AMBIENT DE-RATING TEST

4.2.4.1 With the circuit breaker connected as described in 4.2.1, place the circuit breaker in a temperature controlled environmental chamber heated to $85\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ with 30.5 cm (1 ft) of each lead inside the chamber along with the breaker. Apply 70% of rated current continuously for 1 h. End the test when 1 h is attained or if the breaker opens.

4.2.5 ENDURANCE (OVERLOAD) TEST PROCEDURE

4.2.5.1 *Type 1 circuit breakers.*

4.2.5.1.1 With the circuit breaker connected as described in 4.2.1, Type 1 externally mounted circuit breakers shall be cycled for 1h at 600% of rated current. Following the 1h of cycling at 600% of rated current, perform a millivolt drop test in accordance with paragraph 4.2.1.1, at 80% of rated current.

4.2.5.1.2 Using the circuit breaker from 4.2.5.1.1 (unless 4.2.5.1.1 requirements were not met), reconnect as described in 4.2.1 and cycle Type 1 circuit breaker at 600% of rated current for an additional 6 h, after which terminate the test.

4.2.5.2 *Type 3 circuit breakers.*

4.2.5.2.1 With the circuit breaker connected as described in 4.2.1, Type 3 circuit breakers shall be cycled for 100 on-off cycles at 600% of rated current utilizing the trip indicating/reset mechanism of the breaker. Cycle time shall be adjusted to accommodate the reset characteristics of the circuit breaker and to facilitate actuation of the reset mechanism for initiation of repetitive cycles. Following the 100 on-off cycles, perform a millivolt drop test in accordance with paragraph 4.2.1.1, at 80% of rated current.

4.2.5.2.2 Cycling Endurance Test for Switchable Type 3 Circuit Breakers (as defined by 3.4.3.1). At the option of the tester, a cycling endurance test shall be performed as is described herein. With the circuit breaker connected as described in 4.2.1, apply a current cycling waveform as shown in Figure 3 through the breaker for 1000 cycles at 80% of rated current. Upon start of test, a pre-conditioning cycle of 60s is applied followed by initiation of the repetitive cycle pattern.

NOTE—Construction of an electromechanical apparatus to facilitate consistent cycling action is recommended. Precautions should be taken to avoid applying damaging or excessive force to the circuit breaker mechanisms.

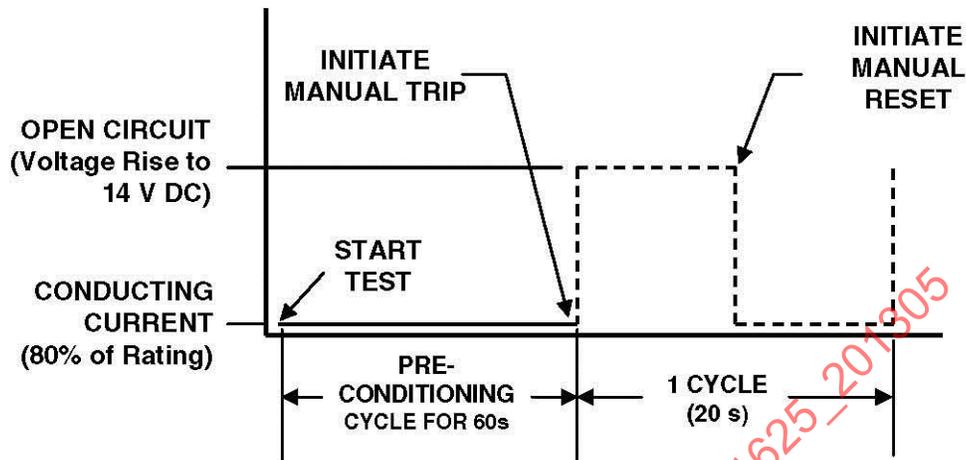


FIGURE 3—CYCLING ENDURANCE TEST CYCLE PROFILE

4.2.6 INTERRUPT TEST PROCEDURE

4.2.6.1 *Type 1 circuit breakers.*

4.2.6.1.1 With the circuit breaker connected as described in 4.2.1 (utilizing 4.1.1.2 power source), Type 1 circuit breakers shall be subjected to 1-1/2 cycles of interrupt current at the level specified by Table 3 and in the pattern shown by Figure 4. Following the interrupt cycles, perform a millivolt drop test in accordance with paragraph 4.2.1.1, at 80% of rated current.

4.2.6.1.2 Using the circuit breaker from 4.2.6.1.1 (assuming 4.2.6.1.1 requirements were met), reconnect as described in 4.2.1 and cycle Type 1 breaker until failure as described in paragraph 5.7.1.2.1.

4.2.6.2 *Type 3 circuit breakers*

4.2.6.2.1 With the circuit breaker connected as described in 4.2.1 (utilizing 4.1.1.2 power source), Type 3 circuit breakers shall be subjected to 1-1/2 cycles of interrupt current. Procedure shall be to apply fault current for first 1/2 cycle. The next 1/2 cycle shall consist of allowing the unit to come into the "ready to reset" mode. As soon as reset capability is enabled, the reset mechanism shall be activated to restore the circuit, at which time the last 1/2 cycle of interrupt current will be present. Following interrupt test, perform a millivolt drop test in accordance with paragraph 4.2.1.1, at 80% of rated current.

TABLE 3—INTERRUPT TEST CURRENT REQUIREMENTS

Rated Current	12 V DC Amps
50A to 70 A	900
<70 A to 90 A	1200
<90 A to 110 A	1500
<110 A to 130 A	1800
<130 A to 150 A	2100
<150 A to 175 A	2500
<175 A to 200 A	3000

NOTE—The instantaneous fault current required and delivered from the storage battery is not the same value represented by cold cranking amps (CCA) as indicated in Table 1. It is the result of the overall test circuit impedance and general condition of the battery being used.

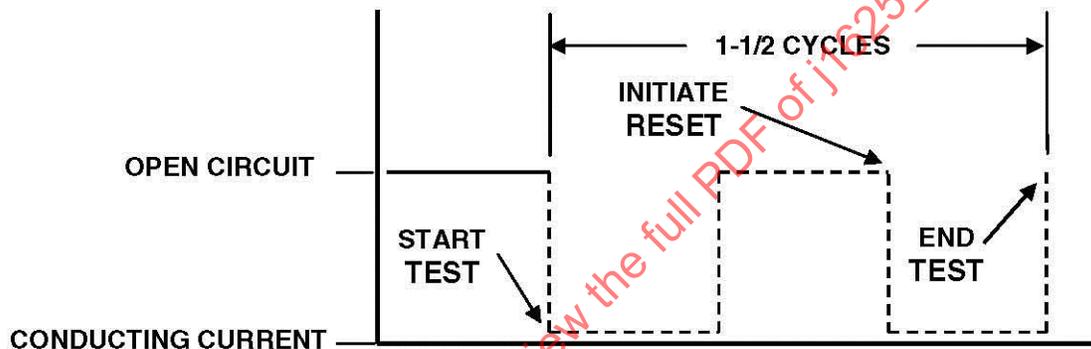


FIGURE 4—INTERRUPT CYCLE DEFINITION

4.2.7 ENVIRONMENTAL TESTS

4.2.7.1 Since end use applications may differ, the following tests are recommended, but not mandatory to determine general suitability of components. All tests shall follow the guidelines as set forth in SAE J1455 unless otherwise specified.

4.2.7.1.1 Temperature Test

Perform per SAE J1455. Test as described for temperature cycling, thermal shock, and thermal stress at the specified test temperatures and according to the temperature transition charts.

4.2.7.1.2 Humidity Test

Perform per SAE J1455 according to recommended test procedures and environmental conditions.

4.2.7.1.3 Salt Fog Test

Perform per SAE J1455. Time duration may vary, from 24 to 96 h, depending on anticipated location of breaker and potential for exposure to saline solutions.

4.2.7.1.4 Immersion and Splash Test

For general guidelines refer to SAE J1455.

NOTE 1—Immersion testing shall apply only to devices that are stated as being 'waterproof,' 'sealed,' 'watertight,' etc. Test procedures per SAE J1171 may be followed for basic test requirements.

NOTE 2—Splash testing shall apply only to devices that are stated as being 'splash-proof,' 'water resistant,' 'weatherproof,' etc. Test procedure in SAE J1428 may be used. Devices passing immersion testing do not require splash testing.

NOTE 3—Chemicals used for testing shall be restricted to tap water for immersion and splash. Evaluation of external identification marking shall be conducted by splash testing using commonly encountered chemicals that shall include: engine oil, power steering fluid, windshield washer solvent, gasoline, diesel fuel, anti-freeze, steam, and salt water.

4.2.7.1.5 Mechanical Vibration Test

Perform per SAE J1455 (Random Vibration). Test shall be for 1 h in each of three mutually perpendicular primary axes using the suggested current practice per SAE J1455.

4.2.7.1.6 Drop Test

Perform per SAE J1455.

5. Performance Requirements

5.1 Current Rating

With the circuit breaker connected as described in 4.2.1, all circuit breakers shall pass 100%±1.5%, of rated current continuously for a minimum of 1 h, shall open at 135% ±1.5% maximum of rated current within 1 h, and shall open at 200% ±1.5% of rated current within 2 min.

5.2 Maximum Voltage Drop

Using the procedure described in 4.2.1.1, the maximum voltage drop across the circuit breaker shall be within the limits provided by the manufacturer.

5.3 Voltage Breakdown

Using the test procedure described in 4.2.3, there shall be no continuity between either terminal of the circuit breaker and the cover.

5.4 High Ambient De-rating Test

Using the procedure described in 4.2.4, all circuit breakers shall pass 70% of rated current for 1 h without opening.

NOTE—Recognizing device design variations, it is recommended that manufacturers' temperature de-rating curves be consulted for application considerations. Consequently, the test procedure of 4.2.4 and performance requirements of 5.4 may, at the tester's discretion, be omitted from the test program.

5.5 Endurance Test

5.5.1 Type 1 externally mounted circuit breakers shall be tested as described in 4.2.5.1.1 and then shall continuously pass $80\% \pm 1.5\%$ of rated current for 1 h. After re-connecting and cycling the circuit breakers for 6 hours as described in paragraph 4.2.5.1.2, the preferred condition is continued cycling function, however an open circuit condition may occur dependent upon design characteristics, which is acceptable as well.

5.5.2 Type 3 externally mounted circuit breakers shall be tested as described in 4.2.5.2.1. The breaker shall trip and reset without failure. There shall be no measurable current passing through the breaker while in the tripped position for the 100 cycles. It shall then continuously pass $80\% \pm 1.5\%$ of rated current for 1 h and the voltage drop at 80% of rated current shall be within the limits specified by the manufacturer.

5.5.3 All breakers when tested as described in 4.2.5.5.1 shall be capable of passing $80\% \pm 1.5\%$ of rated current for 1 h without opening after 1000 cycles are completed.

5.6 Interrupt Test

5.6.1 TYPE 1 CIRCUIT BREAKERS.

5.6.1.1 When tested as described in 4.2.6.1.1, the preferred performance is for the circuit breaker to demonstrate continuity and functionality by passing $80\% \pm 1.5\%$ of rated current for 1 h. Circuit breakers that clear the circuit but cease to function shall be examined according to the guidelines of 5.6.1.1.1.

5.6.1.1.1 If failure occurs with the circuit breaker tested, the ultimate failure of all circuit breakers shall result in an open circuit in the circuit breaker, and there shall be no damage to the associated wiring. Failure falls into three general categories: catastrophic failure—part of the electrical contacts and/or thermostatic material burns up and the circuit path is broken (contained with breaker housing/no external manifestations); operational fatigue—thermostatic material loses original form, no longer cycles or chatters (trip/reset excursions less than 1 s in duration), or loses contact pressure resulting in circuit discontinuity; contact failure—electrical contact material erodes or carbons to a level of non-conductance or high resistance, causing inability to pass current (which is exhibited by measured current $<1A$).

NOTE—In some circuit breaker applications instances, a high circuit resistance, and/or low current power source, may not provide enough fault current to assure that ultimate failure will always result in an open circuit breaker.

5.6.2 TYPE 3 CIRCUIT BREAKERS

5.6.2.1 When tested as described in 4.2.6.2.1, the preferred performance is for the circuit breaker to demonstrate continuity and functionality by passing $80\% \pm 1.5\%$ of rated current for 1 h. Circuit breakers that interrupt the fault current but are non-functional afterwards shall be examined according to the guidelines of 5.6.1.2.1.

5.7 Environmental Tests

5.7.1 TEMPERATURE TEST (THERMAL SHOCK)

5.7.1.1 After completion of test as described in 4.2.6.1.1, the circuit breaker shall exhibit no signs of physical damage and be capable of passing $80\% \pm 1.5\%$ of rated current for 1 h.

5.7.2 HUMIDITY TEST

5.7.2.1 After completion of test as described in 4.2.6.1.2, the circuit breaker shall perform in accordance with 5.1 and 5.2 at $80\% \pm 1.5\%$ of rated current.

5.7.3 SALT FOG TEST

5.7.3.1 After completion of test as described in 4.2.6.1.3, the circuit breaker shall perform in accordance with 5.1 and 5.2 at $80\% \pm 1.5\%$ of rated current. Physical corrosion shall not prevent proper fit and function of the breaker.

5.7.4 IMMERSION AND SPLASH TEST

5.7.4.1 Immersion Test

After completion of test as described in 4.2.6.1.4, pass/fail criteria of SAE J1171 shall apply.

5.7.4.2 Splash Test

After completion of test as described in 4.2.6.1.4, pass/fail criteria of SAE J1428 shall apply.

5.7.5 MECHANICAL VIBRATION TEST

5.7.5.1 While testing as described in 4.2.6.1.5, the circuit breaker shall continuously pass $80\% \pm 1.5\%$ of rated current during the last 1 h with no loss in continuity. Loss of continuity is defined as a resistance across the circuit breaker terminals in excess of 100 Ω , or a voltage rise across the terminals exceeding 50% of test circuit unloaded voltage for longer than 5 ms.

5.7.6 DROP TEST

5.7.6.1 After completion of test as described in 4.2.6.1.6, the circuit breaker shall not exhibit any physical damage. It shall be capable of passing $80\% \pm 1.5\%$ of rated current for 1 h minimum and comply with 5.2.

5.8 General Requirements

5.8.1 MARKING

Externally mounted circuit breakers shall be permanently and legibly marked with the current rating and voltage as well as any other identifying part numbers. Date coding is strongly recommended. Marking shall be generally resistant to common contaminants and chemicals. Evaluate suitability during 4.2.6.1.4 testing.

NOTE—Specifying of marking information, use of color codes, or custom information shall be the responsibility of the circuit breaker manufacturer. Specialized marking requirements may be developed as needed jointly between manufacturer and user.

5.8.2 APPLICATION

The specific current capacity of the circuit breaker is a function of the particular electrical system being utilized. It is recommended that actual performance be verified through testing experimentally in the proposed application. To aid in determining the actual capacity change caused by variations in circuit parameters, several factors should be considered by the application engineer.

5.8.2.1 Voltage Rating

The voltage rating marked on the externally mounted circuit breaker is the maximum value recommended (system, not charging voltage). Use at higher voltages may significantly shorten the ultimate life under overload conditions.

5.8.2.2 Current Rating

The current rating marked on externally mounted circuit breakers is the maximum value/ultimate rating but is subject to redefinition based on the application analysis. It is generally not desirable to specify circuit protection where the breaker will pass 100% of rated current during normal continuous circuit load. Electrical system engineers generally specify circuit protection such that normal continuous circuit loads are approximately 75 to 80% of the circuit breaker current rating. Paragraphs 5.8.2.3 and 5.8.2.4 explain why.

5.8.2.3 Ambient Temperature

The circuit breakers covered by this document are thermal devices. Changes in the ambient temperature will have an effect on the current carrying capacity and on the effective limitation of current during overload cycling. Therefore, the application engineer needs to consider environmental conditions to which the breaker will be subject during operation and make use of circuit breaker manufacturer's de-rating/re-rating curve information if available.

5.8.2.4 Wire and Terminations

The connecting wires and their terminations will affect the heat dissipation characteristics of the circuit breaker. Deviations from the circuit breaker application specifications may affect the current carrying capacity or the effective limitation of current during overload cycling. Heat sources associated with poor interfacing terminations that connect with the circuit breaker may be a cause of abnormal circuit resistance, excessive millivolt drop, damage to associated wiring, and ultimately, significant de-rating/re-rating.

6. Qualification Test Sequence

6.1 Test Programs

Test sequences are listed in Table 4; the basic test sequence that covers all core requirements, and the expanded test sequence, which in addition to the basic test includes additional optional tests that may be selected for further evaluations as deemed appropriate for application conditions. Sample size and sample group distributions for tests are indicated accordingly.

TABLE 4—TEST SEQUENCE CHART

Step No.	Test Description	Test Para.	Sample Group Distribution	
			Basic Test Routine	Expanded Test Routine
Electrical Tests				
1	Maximum Voltage Drop	4.2.1.1	X (9)	X (9)
2	Overload Trip Rating – 135%	4.2.1.2	X (9)	X (9)
3	Overload Trip Rating – 200%	4.2.1.2	X (9)	X (9)
4	Voltage Breakdown Test	4.2.3	Use Step 3 Samples Numbers 1 - 3	Use Step 3 Samples Numbers 1 - 3
5	Endurance Test	4.2.5	Use Step 3 Samples, Numbers 4 - 6	Use Step 3 Samples, Numbers 4 - 6
6	Cycling Endurance Test	4.2.5.4	Optional (See Expanded Tests)	Use Step 4 Samples
7	High Ambient De-rating Test	4.2.4	Optional (See Expanded Tests)	Use Step 3 Samples, Numbers 7 - 9
8	Interrupt Test	4.2.6	Use Step 3 Samples, Numbers 7 - 9	Use Step 7 Samples
Environmental Tests				
10	Temperature Test	4.2.7.1.1	Optional (See Expanded Tests)	Separate Group X (3)
11	Humidity Test	4.2.7.1.2	Optional (See Expanded Tests)	Separate Group X (3)
12	Salt Fog Test	4.2.7.1.3	Optional (See Expanded Tests)	Separate Group X (3)
13	Immersion & Splash Test	4.2.7.1.4	Optional (See Expanded Tests)	Separate Group X (3)
14	Mechanical Vibration Test	4.2.7.1.5	Optional (See Expanded Tests)	Separate Group X (3)
15	Drop Test	4.2.7.1.6	Optional (See Expanded Tests)	Separate Group X (3)

7. Notes

7.1 Marginal Indicia

The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

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APPENDIX A

CIRCUIT PROTECTION APPLICATION GUIDELINES FOR THERMAL CLASS CIRCUIT BREAKERS

A.1 Scope

Appendix A provides technical commentary regarding the use of thermal design circuit breakers in vehicular and/or motor vehicle accessory (service equipment or components) applications and certain limitations to consider. Appendix A does not set forth any tests or performance criteria. Test and evaluation specifications are found in the preceding sections of this document.

A.2 Definitions

A.2.1 Circuit breakers for purposes discussed here are overcurrent protective devices that are responsive to electric current and to temperature. As thermally classified circuit breakers, their protective action is based largely on an ability to respond predictably to temperature change induced by elevated current pass through the circuit breaker's thermally active element. The activity of the thermal circuit breaker (making or breaking continuity) is primarily a function of varying rates of heating or cooling. The source of the heating or cooling should ideally be limited to changes in electrical current passing through the thermally active element. However, other sources of heating or cooling may impact the operation of the thermal circuit breaker in conjunction with varying rates of current pass.

A.2.2 There are three general classes of thermal circuit breakers, defined as follows:

A.2.2.1 TYPE 1—AUTOMATIC RESET

Automatic reset circuit breakers are defined as cycling or continuously self-resetting units, which are opened by overcurrent. The terms "cycling" and "continuously self-resetting" refer to the functional characteristics in which the reset feature is not dependent upon any deliberate action or intervention by the user or user's application system to initiate the reset of the tripped circuit breaker. These terms do not imply that the trip and reset function can continue unabated without consequence to either the life of the circuit breaker or potentially adverse effects to an electrical system wiring and/or components, if a fault condition is not reasonably and prudently detected and corrected.

A.2.2.2 TYPE 2—MODIFIED RESET

Modified reset circuit breakers are devices that are opened by overcurrent and remain open as long as the power is on to the affected circuit or until the load is removed. A number of cycles may occur before achieving a steady-state open circuit condition.

A.2.2.3 TYPE 3—MANUAL RESET

Manual reset circuit breakers are non-cycling devices that open by overcurrent and elevated temperatures, but remain open until manually reset into a conducting state. A trip-free designated manual reset circuit breaker indicates that any forced restriction of the reset mechanism in the operating mode does not prevent cycling of the thermally active element under fault current. This means that an operator or technician cannot create a condition where the circuit breaker must pass current continuously in the presence of fault current on the protected circuit.

A.2.2.4 TYPE 3—SWITCHABLE MANUAL RESET

Functions as a conventional manual reset circuit breaker as defined in A.2.2.3, but also has a mechanism, which when exercised at the discretion of the user, permits opening of the breaker internal circuit to stop current flow. The breaker is reset to its normal operating condition by the manual reset function, whether tripped unattended by a real fault condition or by the user. A trip-free designated switchable manual reset circuit breaker indicates that any forced restriction of the reset mechanism in the operating mode does not prevent cycling of the thermally active element under fault current. This means that an operator or technician cannot create a condition where the circuit breaker must pass current continuously in the presence of fault current on the protected circuit. These types of circuit breakers have a switching capability that is incorporated for convenience, so that users may disable an electrical circuit for maintenance or tests without removing or disconnecting the circuit breaker. It is likely that they do not have switch ratings, such as high cycle life as true switches normally would. Their primary function is as a protective device with function as a switch being the secondary function.

A.2.2.5 TYPE 3 - MANUAL RESET/SWITCH

An integrated switch design that provides both switching function for on-off activations and includes a circuit breaker feature to “toggle” the switch to an off position in the event of overcurrent or short circuit. Reset function is likely to be incorporated into the on/off activating mechanism, permitting reset of the circuit breaker portion of the device. These types of devices are preferred in applications requiring active on-off switching function in the installed electrical circuit. Their primary function is as a switching device with protection as a circuit breaker being the secondary function.

A.3 Application Considerations

A.3.1 General Considerations

A.3.1.1 ELECTRICAL

A.3.1.1.1 Voltage

Thermal circuit breakers are typically rated for a standard voltage. For vehicular use, the two most frequently used ratings are 12 VDC and 24 VDC. These ratings refer to the standard system nominal voltage specification. In actual conditions, system voltages may range from 9 to 16 VDC and 18 to 32 VDC, respectively. Just as voltage fluctuations may adversely affect electronic components, abnormally low or high system voltages may adversely affect thermal circuit breakers. Examples: a Type 2 circuit breaker that uses a resistive element to create the maintained open state upon overload may not generate adequate heat due to low source voltage; a Type 1 breaker may fail prematurely under cycling conditions due to abnormally high source voltage that induces excessive arcing between the electrical contacts; and, a Type 2 heater element may be destroyed by excessively high voltage (or if a Type 2 12 VDC rated unit is installed in a 24 VDC system).

A.3.1.1.2 *Current*

The current rating on a thermal circuit breaker is the maximum value (sometimes referred to as the ultimate rating) the breaker is capable of passing without tripping, for an indefinite time. The current rating assigned is based upon performance under standardized conditions in a nominal ambient environment of 23°C. The current rating, while a specification of its maximum continuous current-pass amount is not generally considered to be the sole basis for application specification. Circuit designers must consider other thermal factors that directly or indirectly impact upon the circuit breaker's environment. The sum of these factors will determine the breaker's true rating as it applies to a specific application or installation.

A.3.1.1.3 *Wiring and Terminations*

The connecting wires and their terminations will affect the heat dissipation characteristics of the thermal circuit breaker. Terminals, whether screwed on, plugged on, welded on, soldered on, or integral to a mating interface terminal block or harness, act in some fashion as heat sinks to a thermal circuit breaker. Poor connections, whether the result of inadequate design, looseness, corrosion, or other induced elevated resistance, cause elevated voltage drop and hot spots in the presence of high current conditions. If poor connections are sufficiently adverse, de-rating/re-rating and premature tripping of the thermal circuit breaker will occur.

A.3.1.2 ENVIRONMENTAL

A.3.1.2.1 *Ambient Temperature Conditions*

The environmental temperature conditions prevalent both where circuit breakers are used (as in geographical climatic conditions) and relative to their installation (as in proximity to other sources of heat and cold), have considerable bearing on the selection of the appropriate amperage rating. In some instances, circuit design changes, relocation of circuit breaker mounting, or ventilation or insulation from other sources of ambient altering environments must occur.

A.3.1.2.1.1 Examples of potentially detrimental environmental conditions relative to temperature: mounting a breaker or multiple breaker harness near heat sources such as exhaust manifolds, coolant hoses, heater cores, or external oil reservoirs and or filtering systems; mounting a breaker or multiple breaker harness in a restricted space without even convection ventilation possible; mounting a breaker or multiple breaker harness exposed externally to wind chill effects.

A.3.1.2.2 *Other Environmental Factors*

While temperature conditions are the most significant factor affecting breaker performance, other conditions may with sufficient severity and duration of exposure negatively impact circuit performance, reliability, and longevity. Typical environmental conditions of this sort may include: thermal shock, high humidity, salt fog or spray, immersion or splash of liquids (water-based compounds and petroleum-based compounds), mechanical vibration, and sudden impact. Positioning of circuit breakers so that environmental factors are managed is crucial to ensuring dependable service.

A.3.1.2.2.1 Examples of other environmental factor negative effects: chemically induced corrosion deteriorates terminal connections causing elevated resistance, intermittent continuity, or total loss of continuity; unusually persistent or severe cyclic harmonic vibration induces momentary loss of continuity between the circuit breaker electrical contacts.

A.3.1.3 INTERFACING COMPONENT MATERIALS

A.3.1.3.1 When circuit breakers are interfaced with wiring harnesses via terminated plastic distribution modules, heat generation factors resulting from normal as well as potential abnormal circuit breaker operation must be considered when specifying the plastic materials to be used in such proximity. Low temperature index plastics that lend themselves to certain design flexibilities and reduced costs can pose performance problems if heat wicking from circuit breakers causes softening or more severe degradation from long-term exposure to elevated temperatures.

A.3.1.3.1.1 Higher performance plastics with respect to heat indices should be used for test purposes during circuit breaker performance evaluations. Radiant heat characteristics developed by circuit breakers should be thoroughly considered in the design phase of plastic-based terminal blocks intended for interface with circuit breakers.

A.3.2 Circuit Breaker Type Considerations

A.3.2.1 TYPE 1 CIRCUIT BREAKERS

A.3.2.1.1 Type 1 circuit breakers are the most basic design of the thermal circuit breaker family. As cycling or continuously resetting devices, their use is best applied protecting loads controlled by momentary switches or other self-limiting means. In select situations, they protect circuits where cycling of an overloaded circuit is preferred over complete disruption of service until the fault condition is corrected for reasons of operator safety or other compelling interest.

A.3.2.1.2 Favorable aspects of Type 1 circuit breakers are: simplicity of design; lower cost as a component; automatic resetting after a trip event, and are available for applications requiring complete waterproofing.

A.3.2.1.3 Unfavorable aspect of Type 1 circuit breakers are: cycling may not be conducive for adequate protection of sensitive equipment for repetitive fault current exposure; the cycling condition may encourage operators or technicians to unwisely delay correction of a fault; cycling may continue for extended periods and drain storage batteries below minimum cranking capacity; and extended cycling without proper attention may create conditions that lead to damage of peripheral components or wiring harnesses. It is important to note that cycle life of a thermal circuit breaker is impacted both by the operational characteristic of the circuit breaker as well as the relative magnitude and duration of overcurrents or short-circuits that the device experiences. For this reason, it is impractical to establish cycle life predictions for a Type 1 circuit breaker, as the impact of overcurrents or short-circuits upon the circuit breaker are infinitely variable within the confines of a specific electrical system. Type 1 circuit breakers will encounter the most electro-mechanical degradation under extended cycling, which in turn diminishes function and response over time.

A.3.2.2 TYPE 2 CIRCUIT BREAKERS

- A.3.2.2.1** Type 2 circuit breakers initially function with great similarity to Type 1 breakers. Upon presentation of fault current the breaker will react under the same time constraints as a Type 1 and after an initial trip may cycle (trip and reset) several times, appearing to perform as if a Type 1 design. During this initial period of reaction to the fault current, a secondary circuit within the breaker construction is creating a heat source each time the breaker has tripped. Within a relatively short time span (typically 60 s and up to 300 s) this secondary heating circuit will have developed sufficient heat radiation to maintain the breaker's thermal element in a tripped state. After the circuit breaker achieves a maintained, tripped condition, there is a reduced current value (typically 1 A or less) drawn by the heating circuit. Virtually no current is passed on through to the fault site. Type 2 circuit breakers are reset by disconnecting or switching off the power source to the protected circuit for a time period long enough to allow the breaker components to cool off and the thermal element to revert to its conducting state. This cooling off may require several minutes until a stable conducting state is achieved.
- A.3.2.2.2** Type 2 circuit breakers may be used instead of Type 1 circuit breakers where the possibility of long-term cycling during faults is not desirable or the location of the breaker prevents easy access for resetting if a Type 3 circuit breaker had been preferred over Type 1.
- A.3.2.2.3** Favorable aspects of Type 2 circuit breakers are: simpler design alternative to Type 3 breakers when Type 1 usage is undesirable; can be reset from any point in the same circuit where power switching is possible; less likely to drain storage batteries before fault is detected and corrected; and encourages timely maintenance since components affected are not functional even intermittently as with Type 1.
- A.3.2.2.4** Unfavorable aspects of the Type 2 circuit breaker are: cannot be reset without shutting circuits down; extreme low source voltage may prevent successful Type 2 function rendering the breaker into a Type 1 operation; extreme high voltage may radically shorten Type 2 function; tripped Type 2 breaker may radiate excess heat and de-rate other breakers in a confined close proximity installation; and time between initial trip and maintained open state may still be too long for the level of protection necessary to prevent further equipment damage where the fault has occurred.

A.3.2.3 TYPE 3 CIRCUIT BREAKERS

- A.3.2.3.1** Type 3 circuit breakers differ significantly from both Type 1 and Type 2 breakers in that they provide a complete interruption of circuit continuity once tripped. Continuity restoration will not occur until a conscious decision is made by a responsible party to initiate circuit breaker resetting. This is typically accomplished by inspecting the breaker for visual indication of a tripped state (a button or lever extended or moved from a normal operating location) and manually with physical force replacing the indicator to its original state.
- A.3.2.3.1.1** In the case of switchable Type 3 or manual reset/switch circuit breakers, circuit continuity can be broken by the breaker on a manual basis without the presence of fault current by the definite choice of an operator or technician.

- A.3.2.3.2 Type 3 circuit breakers are used where no cycling after a fault is desired or deemed safe and where an immediate investigation of fault causes is the most appropriate course of action.
- A.3.2.3.3 Favorable aspects of Type 3 circuit breakers are: highly unlikely to permit damage to wiring or interfaces from long-term fault exposure; brings human element of analysis into the decision to reset or not; can provide circuit interruption for maintenance or investigation (if with switchable or switching feature); and provides operators with a sense of control and awareness over electrical systems.
- A.3.2.3.4 Unfavorable aspects of Type 3 circuit breakers are: cannot be reset unattended; mounting requirements (reset mechanism access) may restrict location options; higher initial cost to install likely; and may not be practical for some circuits with shared components having requirements for quick or unattended re-initiation of electrical power.

A.4 Limitations of Performance

A.4.1 Failure Modes

A.4.1.1 GENERAL FAILURE MODES

A.4.1.1.1 All styles of simple thermal circuit breakers once exposed to varying levels of fault current begin to experience decay with regard to the integrity of their functioning components. The rate of degradation is in proportion to the severity and duration of fault current exposures. Random events of moderate intensity that are quickly detected (i.e., within minutes) and corrected are far less likely to seriously impair breaker function for future events. Specific events of moderate to severe intensity that are left unattended for extended periods (i.e., minutes to hours) are very likely to result in breaker destruction and potential collateral damage. Emphasis on operator awareness for quick fault detection and correction is essential to electrical system integrity.

A.4.1.1.2 The following describes more common reasons why circuit breakers eventually cease to function.

A.4.1.1.2.1 Catastrophic Failure

Part of the electrical contacts and/or thermostatic material burns up and the circuit path becomes discontinuous.

A.4.1.1.2.2 Operational Fatigue

The thermally active element loses its original form and stress biases, loses the ability to cycle from aging, changes occur in contact relationships, and circuit discontinuity eventually occurs.

A.4.1.1.2.3 Contact Failure

Electrical contact material erodes and/or carbonizes from long-term cycling resulting in circuit discontinuity.

A.4.1.1.2.4 Environmental Contamination

Chemical gases or liquids attack active elements and corrode or oxidize current-carrying portions resulting in circuit discontinuity.

A.4.1.1.2.5 Extreme Shocks

Radical temperature swings or violent mechanical force exposures before or after breaker installation dislodge critical alignments of components resulting in circuit discontinuity.

A.4.1.2 CIRCUIT BREAKER FAILURE MODES BY TYPE

A.4.1.2.1 *Type 1 Circuit Breakers*

A.4.1.2.1.1 As cycling or continuously resetting units, Type 1 circuit breakers are the most susceptible style concerning unpredictable or undesirable failure modes when cycled for extended time periods. During cycling under less than direct short conditions, they are most likely to fail from fatigue and/or contact erosion. Unattended long-term cycling can lead to other phenomena such as contact sticking or welding that permits excessive duration of fault current into connective conductors, leading to collateral damage.

A.4.1.2.2 *Type 2 Circuit Breakers*

A.4.1.2.2.1 Type 2 circuit breakers are vulnerable to failure at two fundamental points. When initially exposed to fault currents, they must survive the initial bursts of current to develop the maintained open circuit state. While in the maintained open circuit state for extended periods of time, the secondary heater circuit could eventually fail and the breaker would revert to Type 1 like operation, subject to Type 1 like failure modes.

A.4.1.2.3 *Type 3 Circuit Breakers*

A.4.1.2.3.1 Because of the necessity for manual resetting after a trip event, Type 3 breakers are less likely to endure the repetitive long-term fault exposure that Types 1 and 2 may encounter.

A.4.1.2.3.2 Type 3 circuit breakers may experience failure for mechanical reasons such as: insulating trip mechanism jams electrical contacts or contaminates them to where re-establishment of the current path is prevented, contact insulating mechanism fails to insulate contacts and the unit acts as if a Type 1 breaker, or reset mechanism becomes jammed or otherwise inoperative preventing the re-establishment of continuity.

A.4.2 Preventions to Safe Failures

A.4.2.1 In the 1988 revision to SAE J553 Circuit Breakers, the following advisory was first published: "In some instances, a high circuit resistance, and/or low current power source, may not provide enough fault current to ensure that ultimate failure will always result in an open circuit breaker, or prevent wiring insulation breakdown near breaker terminations."