Background

Up until now, 14 AWG was the smallest branch-circuit conductor allowed for general building systems use in the NEC®. 2008 NEC® added requirements for overcurrent protection of 16 and 18 AWG CU insulated conductors for power circuits in 240.4(D). This action in itself does not permit the use of these smaller conductors; it provides the criteria for the proper overcurrent protection if other articles of the NEC® permit these smaller conductors for the circuits/equipment covered by a given article.

Requirement

240.4(D) Small Conductors. Unless specifically permitted in 240.4(E) or (G), the overcurrent protection shall not exceed that required by (D)(1) through (D)(7) after any correction factors for ambient temperature and number of conductors have been applied.

(1) 18 AWG Copper. 7 amperes, provided all the following conditions are met:

1. Continuous loads do not exceed 5.6 amperes
2. Overcurrent protection is provided by one of the following:
   a. Branch-circuit rated circuit breakers listed and marked for use with 18 AWG copper wire
   b. Branch-circuit rated fuses listed and marked for use with 18 AWG copper wire
   c. Class CC, Class J, or Class T fuses

(2) 16 AWG Copper. 10 amperes, provided all the following conditions are met:

1. Continuous loads do not exceed 8 amperes
2. Overcurrent protection is provided by one of the following:
   a. Branch-circuit rated circuit breakers listed and marked for use with 16 AWG copper wire
   b. Branch-circuit rated fuses listed and marked for use with 16 AWG copper wire
   c. Class CC, Class J, or Class T fuses

(3) 14 AWG Copper. 15 amperes
(4) 12 AWG Aluminum and Copper-Clad Aluminum. 15 amperes
(5) 12 AWG Copper. 20 amperes
(6) 10 AWG Aluminum and Copper-Clad Aluminum. 25 amperes
(7) 10 AWG Copper. 30 amperes

In future, if permitted in another Article

Either fuses or circuit breaker must have maximum ampacity of 7A for 18 AWG and 10A for 16 AWG. In addition, Class CC, J or T fuses can be used without any marking requirements. However, for other fuse classes or circuit breakers the devices must be marked “for use with 16 AWG” (or 18 AWG) to ensure adequate conductor protection.

In future, if permitted in Article 430

For motor branch-circuit short-circuit and ground-fault protection, either fuses or circuit breaker amperage ratings based on the sizing provisions of 430 for motor circuits. Class CC, J or T fuses can be used without any marking requirements. However, for other fuse classes or circuit breakers the devices must be marked “for use with 16 AWG” (or 18 AWG) to ensure adequate conductor short-circuit protection. Overload protection must comply with 430 and 240.4(D).

Why

Short-circuit currents can quickly damage insulated conductors. The level of damage can vary from slight insulation damage, to annealing of the copper, to vaporization of the copper. Under short circuit conditions the level of damage sustained is a factor of a specific insulated conductor’s withstand capability, the level of short-circuit current, and the time the short-circuit current is permitted to flow. Smaller conductors such as 16 AWG and 18 AWG have very low short circuit current withstands and in many instances, the generally acceptable overcurrent protective devices do not have the operating characteristics to provide adequate protection as required in 110.10.
**Small Wire Report**

In August, 2001 there was an investigation by the Small Wire Working Group of the NFPA 79 Electrical Standard for Industrial Machinery. The investigation focused on the protection of 16 and 18 AWG CU conductors for use in Industrial Machinery applications and resulted in similar requirements as 240.4(D). The basis of this study compared the conductor short-circuit current withstand to the overcurrent device let-through energy under short-circuit conditions. The Small Wire Working Group studied the critical application considerations for small conductors, proposed the requirements and conducted UL witnessed tests to prove the proposed requirements are acceptable. After considering several damage criteria, the group decided to use the ICEA damage levels because they were the most conservative. All other methods allowed certain levels of damage. A testing program with insulation damage evaluation criteria was conducted to prove the engineering analysis as valid. This study determined that small conductors could be sufficiently protected by certain overcurrent protective devices, but not all the standard commercially available overcurrent protective devices provided acceptable levels of protection.

In this study, Class CC, J and T fuses, 30A and smaller, were found to provide short-circuit protection for these conductors. The very current limiting characteristics of these fuses provide the necessary level of protection under short-circuit conditions. For Class CC, J, or T fuses, the maximum short-circuit current energy permitted by UL for the 30A or less ampere ratings is below the ICEA thermal energy damage criteria. In the testing, special fuse limiters that purposely exceed the short-circuit current I’t umbrella limits for the applicable class fuses from UL 248 Fuse Standard were tested with 16 and 18 AWG CU insulated conductors. After the tests, the insulated conductors were evaluated by a set criteria including dielectric testing. The conclusion was that Class CC, J and T 30A or less fuses protect 16 and 18 AWG CU insulated conductors simply by complying with UL 248 performance required for listing and follow-up testing. The

**240.4(D) Protection of Small Conductors**

UL 248 30A or less Class CC, J, and T fuse let-thru energy limits are less than the 16 or 18 AWG CU insulated conductor ICEA withstands. See Table Below.

<table>
<thead>
<tr>
<th>ICEA I’t Withstand Limit CU Conductor Thermoplastic Insulation (75ºC)</th>
<th>UL 248 I’t Let-Thru Limits for 30A Class CC, J, Fuses</th>
</tr>
</thead>
<tbody>
<tr>
<td>CU Wire Size</td>
<td>Short-Circuit I’t Withstand</td>
</tr>
<tr>
<td>16 AWG</td>
<td>7,344 A’s</td>
</tr>
<tr>
<td>18 AWG</td>
<td>18,657 A’s</td>
</tr>
</tbody>
</table>

**Conclusion:** All commercially available fuses of 30A or less of these fuse types will provide short-circuit protection for 16 and 18 AWG CU insulated conductors.

Note to Table: all commercially available UL Class CC, J, and T 30A or less fuses can protect these conductors from short-circuit currents. However, the actual maximum ampere rating permitted for a given application is restricted by the applicable NEC® requirements.

As important, the study confirmed that many other overcurrent protective devices do not provide the necessary level of protection. Therefore, fuses, other than Class CC, J, or T fuses, and circuit breakers are required to be marked “for use with 16AWG” or “for use with 18AWG”. In essence, this means other fuses and all circuit breakers are required to be tested under a specific criteria for small wire and if pass, then listed and marked as such. UL issued a Special Service Investigation, An Investigation of the use of 16 and 18 AWG Conductors for Power Branch Circuits in Industrial Machinery Applications, file number E4273 to verify the test results. The analysis, test program and results can also be viewed in an IEEE paper presented at the 2002 IEEE Industrial and Commercial Power Systems Technical Conference titled, An Investigation of the Use of 16 and 18 AWG Conductors for Branch-Circuits in Industrial Machinery Built to NFPA 79 2002. The report and paper can be found on www.cooper-bussmann.com.
An Investigation of the Use of 16 and 18 AWG Conductors for Branch Circuits in Industrial Machinery Built to NFPA79 2002

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Abstract – It has been a long-standing requirement that conductors smaller that 14 AWG shall not be used in branch circuits. The industrial machinery industry has expressed a need to use smaller conductors, similar to those allowed by the International Electrotechnical Commission (IEC). This paper presents the engineering analysis and the experimental results of testing performed to verify the acceptability of 16 and 18 AWG conductors for branch circuits in industrial machinery built to NFPA 79 2002.

Index terms – conductor protection, overcurrent protection, insulation damage, industrial machinery, NFPA 79.

I. INTRODUCTION

In order to remain competitive within the global marketplace, United States industrial machinery manufacturers on the committee for NFPA79 (Electrical Standard for Industrial Machinery) expressed the need to be able to utilize circuit conductors that are smaller than 14 AWG, the existing minimum allowed for branch circuits in the United States. Several proposals were written and submitted for NFPA79 adoption. However, a study was requested to confirm the theoretical engineering analysis utilized for the substantiation of the proposals.

The existing requirements, 2002 edition of the National Electrical Code® (NEC®) [1] and the 1997 edition of NFPA79 [2], do not allow conductors smaller than 14 AWG to be utilized for branch circuits (per NEC® 210.19(A)(4) and 310.5, and NFPA 79 subclause 15.3).

The industrial machinery industry has recognized the need to utilize 16 and 18 AWG conductors for both motor and non-motor loads to remain competitive in the global market. Wire sizes of 0.75 mm² and 1 mm² are commonly applied where the load currents are very small in applications based upon IEC 60204-1 [3] (Safety of Machinery – Electrical Equipment of Machines). Wire sizes of 0.75 mm² and 1 mm² have an ampacity similar to 18 AWG and 16 AWG wire respectively.

An engineering-based analysis was completed on the properties of 16 and 18 AWG conductors. This analysis, developed by the NFPA 79 Small Wire Working Group was designed to cover typical “worst case” overcurrent conditions that could occur in various types of electrical distribution systems, and will be discussed in this paper. A Special Service Investigation was performed by UL to verify the premise and the testing results. This investigation was submitted to the full NFPA 79 committee to substantiate the inclusion of 16 and 18 AWG conductors for branch circuits in the 2002 edition.

II. ENGINEERING ANALYSIS

A. Withstand Capabilities

The first step was to determine the withstand capabilities of the 16 and 18 AWG conductors. Withstand capabilities of insulated cable pertains to the level of short-circuit current an insulated conductor can handle for a certain amount of time before there is damage to the insulation, or the conductor itself. Insulated conductors are considered to be components of an electrical system and are therefore required to be protected against “excessive damage” per the NEC® in Section 110.10 and NFPA 79 subclause 8.1.2.

Research of available literature was conducted on the effects of short-circuit currents on insulated conductors. The findings of four different methods were analyzed to determine the most appropriate method to use for this analysis. The four different methods included:

- Insulated Cable Engineers Association Standard P-32-382 [4]
- “Grounding Electrical Systems for Safety,” Eustice Soares [8]
- Onderdonk melting point.

The Insulated Cable Engineers Association (ICEA) standard P-32-382 provides a standard physics formula for determining the most appropriate method to use for this analysis. The four different methods included:

- Insulated Cable Engineers Association Standard P-32-382 [4]
- “Grounding Electrical Systems for Safety,” Eustice Soares [8]
- Onderdonk melting point.

The Insulated Cable Engineers Association (ICEA) standard P-32-382 provides a standard physics formula for determining the short-circuit withstand of insulated copper conductors. The formula is as follows:

\[
\frac{I}{A} \cdot \frac{t}{T_1} = 0.0297 \log \left( \frac{T_2 + 234}{T_1 + 234} \right)
\]

I = Short-circuit Current – Amperes
A = Conductor Area – Circular Mils
t = Time of Short-circuit - Seconds
T₁ = Maximum Operating Temperature
T₂ = Maximum Short-circuit Temperature
This physics formula for determining the heat rise for a specific cross sectional area of copper was used to create a worst-case condition for the wire. The formula utilized by ICEA was based upon an adiabatic process where all the heat is contained within the wire. ICEA then determined maximum short-circuit temperatures for conductors with various types of insulation as shown:

- Thermoplastic (150 °C)
- rubber, paper, varnished cloth (200 °C)
- Crosslinked Polyethylene & Ethylene Propylene Rubber (250 °C)

The temperatures specified above designate the start of insulation damage. Thermoplastic insulation (150°C) has the lowest temperature to reach its damage point, therefore was used to simulate a worst-case situation. Inserting 150 °C for T₂ into physics equation 1, would generate I²t values as shown in Table I.

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>Short-circuit Withstand I²t</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 AWG</td>
<td>47,000 A²s</td>
</tr>
<tr>
<td>12 AWG</td>
<td>120,000 A²s</td>
</tr>
</tbody>
</table>

Studies conducted by William H. Middendorf of the University of Cincinnati explored the effects of short-circuit currents on insulated conductors. The studies were conducted to evaluate the damage levels referenced in the ICEA standard P-32-382. The purpose was to evaluate the accuracy of the ICEA damage levels. As a result, Middendorf derived withstand limits different from the levels achieved by ICEA. The withstand levels derived from this research were based upon the amount of I²t that would cause the dielectric strength of the insulation to be decreased to half that of its original value. As expected, the I²t levels required to reduce the dielectric strength of the wire were greater than those for which there was no insulation damage allowed (ICEA). The I²t values resulting from this research are shown in Table II.

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>Short-circuit Withstand I²t</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 AWG</td>
<td>150,000 A²s</td>
</tr>
<tr>
<td>12 AWG</td>
<td>450,000 A²s</td>
</tr>
</tbody>
</table>

Soares I²t Withstand Limits for Copper Conductor, (Conductor Becomes Loose Under Lug)

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>Short-circuit Withstand I²t</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 AWG</td>
<td>94,000 A²s</td>
</tr>
<tr>
<td>12 AWG</td>
<td>238,000 A²s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>Short-circuit Withstand I²t</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 AWG</td>
<td>320,000 A²s</td>
</tr>
<tr>
<td>12 AWG</td>
<td>804,000 A²s</td>
</tr>
</tbody>
</table>

After thoroughly reviewing these four methods it was decided that the most conservative approach would be utilized to represent the worst-case scenario. The ICEA formula in physics equation I had the lowest withstand ratings as can be seen by the data in Tables I-IV. It is also the most common method used to determine conductor withstand ratings in the industry recommended by IEEE in the following standards:

- ANSI/IEEE 141-1993 (Red Book) [9] sections 5.6.2 and 12.4.6
- ANSI/IEEE 241-1990 (Gray Book) [10] sections 8.5.6 and 9.8.7.1
- ANSI/IEEE 1015-1997 (Blue Book) [12] section 4.11.1.2

It is also referenced in the Canadian Electrical Code, C22.1-98 [13] Appendix B. Therefore this was the method chosen to evaluate the 16 and 18 AWG conductors.
equation 1 was used to calculate the withstand $I_2t$ values for 16 and 18 AWG conductors in Table V.

**TABLE V**

| ICEA $I_2t$ Short-Circuit Withstand Limits Copper Conductor, Thermoplastic Insulation (75°C) |
|---|---|
| Wire Size | Short-circuit Withstand $I_2t$ |
| 18 AWG | 7,355 A²s |
| 16 AWG | 18,657 A²s |

These values reflect the short-circuit withstand ratings of the conductor, but the overload capabilities of the conductors must be explored as well. Again using physics equation I, we determined specific over current damage points for a given period of time. These are shown in Table VI.

**TABLE VI**

<table>
<thead>
<tr>
<th>Duration</th>
<th>16 AWG Withstand Current</th>
<th>18 AWG Withstand Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 sec</td>
<td>137</td>
<td>86</td>
</tr>
<tr>
<td>5 sec</td>
<td>61</td>
<td>38</td>
</tr>
<tr>
<td>10 sec</td>
<td>43</td>
<td>27</td>
</tr>
</tbody>
</table>

### B. Overcurrent Protective Devices

Once the withstand limits were determined it was necessary to select the proper overcurrent protective devices to prevent damage to the 16 and 18 AWG conductors. Devices must be selected based on their ability to carry the rated current and protect the conductor against overcurrents.

In order to provide protection against short-circuit currents, the protective device must be able to limit the energy let-through. The $I_2t$ let-through of the device must be lower than the short-circuit withstand levels determined in Table V. The NFPA 79 small wire group chose to investigate the use of current limiting fuses listed to UL/CSA/ANCE 248 [14] to provide short-circuit protection. These devices were chosen because they have published standards with maximum clearing $I_2t$ let-through limits. It was not the intention of this investigation to exclude other types of devices. Other devices may be suitable for use, but standards with published let-through values were not readily available. These devices must be individually evaluated for their suitability for use with 16 and 18 AWG conductors.

Any fuse that is listed to the UL/CSA/ANCE 248 standard must have a clearing $I_2t$ let-through lower than the umbrella limit that is set by the standard. These umbrella limits can be found in the UL White Book [15], General Information for Electrical Equipment Directory. These limits were evaluated, and the fuses that had umbrella limits lower than the determined withstand levels were selected for this study. The overcurrent protective devices that met these criteria were Class CC, J and T fuses. The umbrella limits for these devices are shown in Table VII.

The overcurrent protective device must also interrupt low level overloads before overheating causes insulation damage. The two major types of branch circuit loads considered in this analysis were motor loads, and non-motor loads. The circuits with non-motor loads will only have one overcurrent protective device; therefore this device must protect the conductors from both overloads and short-circuits. The Class CC, J and T fuses are designed to provide overload and short-circuit protection when sized to match conductor ampacity. For circuits with motor loads, the fuses are only intended to provide short-circuit protection when sized per NEC® and NFPA 79 requirements. These circuits have an overload relay as part of a motor starter to provide protection against overload currents. UL508 [16] is the standard pertaining to motor starters. The overload relays are classified according to their opening time at 600% of their current rating per UL508. A Class 10 overload relay will open a 600% overcurrent in ten seconds, and a Class 20 relay will open a 600% overcurrent in twenty seconds. The Class 10 and 20 overload relays were investigated in this testing due to the popularity of these types of devices in the industry.

### III. METHODS

A testing program was developed to provide data to support the engineering analysis. Tests were set up with three major principles in mind:

1. Create tests using a conservative approach to represent the worst case.
   - “Bus bar” testing from UL489 [17]
   - UL248 Umbrella fuses for short-circuit testing
   - 1’, 4’, 100’ lengths of wire
2. Create tests to simulate the various types of electrical systems and grounding schemes
   - Full voltage, high current testing on each phase
3. Check validity of wire insulation using dielectric testing
   - UL 83 [18], Thermoplastic Insulated Wire and Cable, section 27

**TABLE VII**

<table>
<thead>
<tr>
<th>UL Class of Fuse</th>
<th>Current Rating</th>
<th>Between Threshold and 50KA</th>
<th>At 100 KA</th>
<th>At 200KA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$I_p$ (A)</td>
<td>$I_2t$ (A²s)</td>
<td>$I_p$ (A)</td>
</tr>
<tr>
<td>Class CC</td>
<td>30</td>
<td>6,000</td>
<td>7,000</td>
<td>7,500</td>
</tr>
<tr>
<td>Class J</td>
<td>30</td>
<td>6,000</td>
<td>7,000</td>
<td>7,500</td>
</tr>
<tr>
<td>Class T (600V)</td>
<td>30</td>
<td>6,000</td>
<td>7,000</td>
<td>7,500</td>
</tr>
</tbody>
</table>
The test setups were created around these principles and used for the investigation. UL standards 248, 489, and 508 were used as the basis for testing. The test program to determine the suitability of the use of 16 and 18 AWG conductors for branch circuits was divided into two major categories: verification of overload protection, and verification of short-circuit protection. Following each test, the conductor was visually inspected, then subjected to dielectric testing per UL83, section 27.

A. Verification of Short-Circuit Protection

Testing was performed to investigate the short-circuit protection of 16 and 18 AWG conductors. Development of the test setups was based upon creating tests that would cover the majority of the applications for which the wire would be installed. A conservative approach using “worst case” test situations was used for this development.

The first step was to determine the test configuration for the short-circuit testing. In order to cover the variety of installations that could exist, it was determined that, initially, 1 foot, 4 feet and 100 feet lengths of conductor would be used in the testing, see Figs 1 through 3. The 1 foot and 4 feet lengths would investigate the thermal and magnetic withstands of short runs of conductor inside a cabinet. The 100 feet test setup investigated the thermal and magnetic withstands of long runs of conductor.

Three phase bolted fault conditions were used following testing configurations in UL248, UL489, and UL508 to simulate the worst case three phase short-circuit condition. The fault was created at the end of the conductor run. The circuit was connected to the test lab terminals following UL489 “bus bar” high fault circuit test configuration. This configuration calls for 4 feet of 1 AWG feeding the line lugs of the overcurrent protective device and 10 inches of rated wire for the load side. The tests were conducted with 1 foot of conductor on the load side for simplicity. For all of the short-circuit testing, special “umbrella” fuses were used that had clearing $I^2t$ let-through values above the UL published limits. This insures that all commercially available Class CC, J and T fuses will have clearing $I^2t$ values less than the “umbrella” fuses used in the test program.

Three short-circuit current levels, 50,000 amps, 10,000 amps and 5,000 amps were used to cover a variance in installations and available fault current levels in the industry. The 50kA level was chosen based on the UL248 fuse testing. The Class CC, J, and T each have the same $I^2t$ limit for 50kA, 100kA, and 200kA. The 50kA level was determined to represent the high short-circuit current testing. The 10kA level was chosen because of its commonality in various UL standards for low level short-circuit current testing. And finally the 5kA level was chosen to represent the lower end of short-circuit currents. The 5kA testing was only used on the 1 foot, three phase bolted fault test setups.
All of these tests were performed at 480V, three phase. Conditional tests at a full 600V were performed on only the 18 AWG with the branch-circuit, short-circuit devices that passed all the 480V 1 foot testing, see Fig. 1 for setup. This test sequence was conducted for the 5, 10, and 50kA tests.

Additional test configurations were utilized to investigate various commonly used grounding schemes. The test configurations were used to verify the suitability of the conductors where the maximum possible $I^2t$, instantaneous peak current, and voltage would be imposed on the conductor pertaining to the various systems. The four types of systems investigated are shown in Fig.4 through Fig. 7.

The three phase bolted fault test configuration described previously covered the solidly grounded wye system. Additional test configurations were used to investigate the remainder of the systems. A fault was created across one pole of the branch-circuit, short-circuit devices using line-to-line voltage. This would simulate a situation that could exist in these grounding schemes where single or multiple line to ground faults could impose full rated line-to-line voltage across one pole of the device (test setup is shown in Fig. 8). Consequently, a single pole of the three phase branch circuit overcurrent protection (set of three fuses, or a single three pole circuit breaker) would be required to interrupt the fault current at the full rated line-to-line voltage [19].

The single pole test setup used to simulate fault conditions for corner grounded delta, resistance grounded wye and ungrounded systems was performed with 1 foot of rated wire. These tests were conducted at 480V at the 50kA and 10kA fault levels.

![Fig. 4 Solidly Grounded Wye](image1)

![Fig. 5 Corner Grounded Delta](image2)

![Fig. 6 Resistance Grounded Wye](image3)

![Fig. 7 Ungrounded Systems](image4)
B. Verification of Overload Protection

To investigate overload protection of 16 and 18 AWG conductors, testing was performed to explore overcurrent protection for two different types of loads: motor loads and non-motor loads.

To investigate motor branch circuits, motor starters were used in conjunction with branch-circuit short-circuit protective devices that they were listed with. The motor controller characteristics had to be explored. Based upon the information proved in UL508, test points were compared to the time current curve to evaluate the performance of the overload device under long term heating conditions. The criteria for determining the full load ampacity was based on the maximum current value the conductor can handle for the set amount of time using physics equation 1 (10 sec for Class 10, 20 sec for Class 20, etc.). Both Class 10 and Class 20 overload relays were used in the test program. Class 20 overload relays are more common, but as shown below, the use of Class 10 overload could lead to a larger permissible load current because it will operate faster during overload conditions. Limitations were placed on the load current for 16 and 18 AWG conductors depending on the class of overload relay used. These current levels are shown in Table VIII.

Two current levels were investigated on each test setup:
- 15 Amps
- 600% Maximum Full Load Ampacity

The first level was selected to link the overload testing with a common branch circuit current level recognized in the industry. The second level was selected to coincide with UL508 testing for the overload relays and to simulate a locked rotor condition on a motor. The overload relay was sized according to the maximum permissible load current during the overload testing. Opening time was recorded for each test. Visual inspection and dielectric testing of the wire was conducted.

Testing for non-motor loads consisted of a single branch circuit overcurrent protective device sized at the ampacity of the conductor. Two current levels were investigated on each test setup:
- 135% of the Overcurrent Protective Device Rating
- 600% of Maximum Full Load Ampacity

The first level was selected based upon a common overload test level conducted on branch circuit overcurrent protective devices. The second was selected to simulate a higher-level overload condition that might exist.

C. Acceptability of Results

To verify if a conductor passes the overload and short-circuit testing, a two-step investigation was implemented. Immediately following the tests, a visual inspection was performed on the conductor and observations were noted. Visual damage to the insulated wire including insulation damage, wire pulled out of terminal, or vaporization of the wire would result in a failure for the test. If a failure of the visual test resulted, the dielectric test was not conducted. The second step in the wire acceptance testing was a dielectric withstand test. It was determined that the dielectric withstand test in UL83, *Thermoplastic Insulated Wire and Cable*, section 27 would be used.

Dielectric Voltage-Withstand Test as specified in UL83 section 27.
- Immers as much of the insulation of the wire as possible in room temperature tap water for a period of not less than 6 hours.
- With wire still immersed in the tap water, attach one lead of a dielectric voltage tester to the bare ends of the wire. Attach the other lead to a conducting material that is immersed in the water.
- Apply 2000V to the wire under test for 60 seconds. If the wire were not able to withstand the applied voltage without breakdown for the specified amount of time it would result in a failure.

<table>
<thead>
<tr>
<th>Overload Relay</th>
<th>16 AWG Maximum FLA</th>
<th>18 AWG Maximum FLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 10</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Class 20</td>
<td>5.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>
IV. RESULTS

The maximum I<sub>t</sub> let-through was measured for each short-circuit test. The opening time was recorded for each overload test. Tables IX and X summarize the testing sequences for the overload and short-circuit testing respectively. The resulting data is also found in these tables.

<table>
<thead>
<tr>
<th>Overload Test</th>
<th>Volts</th>
<th>Phase</th>
<th>Current (Amps)</th>
<th>Overcurrent Protective Device(s)</th>
<th>Wire Size</th>
<th>Conductor Withstand (Amps² sec)</th>
<th>Opening Time</th>
<th>Visual Inspection Observation</th>
<th>Dielectric Testing Results (Pass/Fail)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>15</td>
<td>20A Class CC Fuse &amp; Class 10 Relay</td>
<td>16</td>
<td>18,657</td>
<td>Relay opened, 5 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>48</td>
<td>20A Class CC Fuse &amp; Class 10 Relay</td>
<td>16</td>
<td>18,657</td>
<td>Relay opened, 2 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>15</td>
<td>20A Class CC Fuse &amp; Class 20 Relay</td>
<td>16</td>
<td>18,657</td>
<td>Relay opened, 4.9 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>33</td>
<td>20A Class CC Fuse &amp; Class 20 Relay</td>
<td>16</td>
<td>18,657</td>
<td>Relay opened, 3.1 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Non-Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>11</td>
<td>10A Class CC Fuse</td>
<td>16</td>
<td>18,657</td>
<td>5 min. 48 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Non-Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>48</td>
<td>10A Class CC Fuse</td>
<td>16</td>
<td>18,657</td>
<td>4.6 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>15</td>
<td>15A Class CC Fuse &amp; Class 10 Relay</td>
<td>18</td>
<td>7,355</td>
<td>Relay opened, 6 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>30</td>
<td>15A Class CC Fuse &amp; Class 10 Relay</td>
<td>18</td>
<td>7,355</td>
<td>Relay opened, 3 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>15</td>
<td>15A Class CC Fuse &amp; Class 10 Relay</td>
<td>18</td>
<td>7,355</td>
<td>Relay opened, 5.8 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>21</td>
<td>15A Class CC Fuse &amp; Class 10 Relay</td>
<td>18</td>
<td>7,355</td>
<td>Relay opened, 3.8 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Non-Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>8</td>
<td>7A Class CC Fuse &amp; Class 10 Relay</td>
<td>18</td>
<td>7,355</td>
<td>35 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Non-Motor Overload</td>
<td>LV</td>
<td>1</td>
<td>34</td>
<td>7A Class CC Fuse &amp; Class 10 Relay</td>
<td>18</td>
<td>7,355</td>
<td>5.4 sec.</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
</tbody>
</table>
V. CONCLUSION

The tests performed support the engineering analysis. The devices that were used for the testing had lower I²t let-through values than the withstand ratings of the 16 and 18 AWG conductors. As expected all of the conductors passed both a visual inspection and the dielectric withstand test. These results were witnessed by UL and the Special Service Investigation, An Investigation of the use of 16 and 18 AWG Conductors for Power Branch Circuits in Industrial Machinery Applications, file number E4273 [20] was issued. Based on these findings, the following comment was sent to the NFPA 79 for the ROC meeting for inclusion in the 2002 edition of the standard:

13.6.1 Conductors shall not be smaller than 14 AWG for power circuits unless otherwise permitted in (a) or (b).

(a) 16 AWG shall be permitted, if part of a jacketed multiconductor cable assembly or flexible cord, or individual conductors used in a cabinet or enclosure, under the following conditions:

1. Non-motor power circuits of 8 amperes or less provided all the following conditions are met:
   (a) Circuit is protected in accordance with Clause 7
   (b) Overcurrent protection does not exceed 10 amperes
   (c) Overcurrent protection is provided by one of the following:
   (1) A branch circuit rated circuit breakers listed and marked for use with 16 AWG wire
   (2) Branch circuit rated fuses listed and marked for use with 16 AWG wire
   (3) Class CC, Class J, or Class T fuses

2. Motor power circuits with a full load ampacity of 8 amperes or less provided all the following are met:
   (a) Circuit is protected in accordance with Clause 7
   (b) Circuit is provided with Class 10 overload protection
   (c) Overcurrent protection is provided by:
      (1) A branch circuit rated circuit breakers listed and marked for use with 16 AWG wire
      (2) Branch circuit rated fuses listed and marked for use with 16 AWG wire
      (3) Class CC, Class J, or Class T fuses

3. Motor power circuits with a full load ampacity of 5.5 amperes or less provided all the following are met:
   (a) Circuit is protected in accordance with Clause 7
   (b) Circuit is provided with Class 20 overload protection
   (c) Overcurrent protection is provided by:
      (1) A branch circuit rated circuit breakers listed and marked for use with 16 AWG wire
      (2) Branch circuit rated fuses listed and marked for use with 16 AWG wire
      (3) Class CC, Class J, or Class T fuses

(b) 18 AWG, shall be permitted if part of a jacketed multiconductor cable assembly or flexible cord, or
individual conductors used in a cabinet or enclosure, under the following conditions:

(1) Non-motor power circuits of 5.6 amperes or less provided all the following conditions are met:
   (a) Circuit is protected in accordance with Clause 7
   (b) Overcurrent protection does not exceed 7 amperes
   (c) Overcurrent protection is provided by one of the following:
       (1) A branch circuit rated circuit breakers listed and marked for use with 18 AWG wire
       (2) Branch circuit rated fuses listed and marked for use with 18 AWG wire
       (3) Class CC, Class J, or Class T fuses

(2) Motor power circuits with a full load ampacity of 5 amperes or less provided all the following conditions are met:
   (a) Circuit is protected in accordance with Clause 7
   (b) Circuit is provided with Class 10 overload protection
   (c) Overcurrent protection is provided by:
       (1) A branch circuit rated circuit breakers listed and marked for use with 18 AWG wire
       (2) Branch circuit rated fuses listed and marked for use with 18 AWG wire
       (3) Class CC, Class J, or Class T fuses

(3) Motor power circuits with a full load ampacity of 5.5 amperes or less provided all the following are met:
   (a) Circuit is protected in accordance with Clause 7
   (b) Circuit is provided with Class 20 overload protection
   (c) Overcurrent protection is provided by:
       (1) A branch circuit rated circuit breakers listed and marked for use with 18 AWG wire
       (2) Branch circuit rated fuses listed and marked for use with 18 AWG wire
       (3) Class CC, Class J, or Class T fuses

This comment was accepted at the December NFPA 79 ROC meeting.

REFERENCES

[4] Insulated Cable Engineers Association, Inc. “Short Circuit Characteristics of Insulated Cable” Insulated Cable Engineers Association Publication P-32-382 , 1969
[20] Underwriters Laboratories Special Service Investigation, An Investigation of the Use of 16 and 18 AWG Conductors for Power Branch Circuits in Industrial Machinery Applications. UL, Northbrook, IL, August 10, 2001