Personal Protective Equipment

Section 8
Chance (Hubbell Power Systems) offers a wide variety of personal protective grounding equipment. Most clamps and assemblies are rated to meet ASTM F855 requirements for both current magnitude and flow duration. Some items are designed for special applications and are not covered by a standard. Where appropriate, catalog literature indicates conformance to an ASTM grade.

In the past, protective-grounding equipment was considered to be only a chain thrown over the line and grounded. Later it became a piece of cable with a clamp on each end. While that is basically true, the selection and correct use has added more complexity. Early versions of the governing standard specified current levels that ensured the cable would not fuse during operation. There was no mention of the voltage drop across the man during the time current was flowing. This remains true today. Because this is such a key factor in protecting workers, it has been addressed more completely in other sections.

Personal protective grounding assemblies now consist of clamps, ferrules and interconnecting cable. Each component should be selected to compliment the others to achieve the desired level of protection. For example, clamps and ferrules must carry the same or higher current rating than the cable that they are used within an assembly. The cable is considered the weak link in the system because of the amount of information known about cable and its consistency of manufacture. The selection of personal protective grounding equipment rating and style is the choice of the user, important criteria being its electrical and mechanical ratings.

Equipment must be sized to provide the necessary worker protection if called upon to do so. It must be capable of carrying the full fault current for the amount of time that the fault current can flow and maintain its electrical integrity. It must have sufficient mechanical strength to resist the high level of force placed upon it caused by the magnetic forces and cable whipping action. As available fault current levels increase, the demands on the equipment increases, not proportionally, but as the square of the current. That is, if the current doubles, the mechanical force quadruples and the cable heating increases.

Clamps

Chance grounding clamps come in a variety of styles, sizes and ratings. Included are C-type clamps in Figure 8-1 rated from 21,500 to 60,000 Amperes, also Snap-On (Duckbill-type) in Figure 8-2 and Flat-Face in Figure 8-3, All-Angle in Figure 8-4, and Ball-and-Socket styles in Figure 8-5. Clamps are designed for mounting with insulated hot sticks or Grip-All clampsticks and some by hand. Others are permanently mounted onto the end of insulated sticks. A complete line of accessories such as pole mount cluster bars, fully assembled grounding sets, underground distribution transformer and switch grounding items, cutout clamps and sets for substation use complement the Chance line of clamps.

Each clamp has a preferred application. C-type clamps are typically used on round bus or stranded conductor; the Flat-Face clamp is used on flat bus or tower legs or braces; the All-Angle clamp is a popular style where different conductor approach directions are required.
A unique development by Chance was the Ball-and-Socket set. This consists of an electrical grade copper rod, threaded on one end and with a spherical ball machined on the other. The mating clamp has an opening shaped like a keyhole. The larger opening accepts the ball and the smaller opening captures the rod. Because the clamp is free to move on the ball, it minimizes stress on the cable by allowing the cable to hang in a normal position. Then, tightening the eyescrew captures the ball. A rubber cover may be used to protect the ball stud when it is not in use.
Each clamp is rated for a maximum and minimum main and tap conductor size. This provides the customers with a broad selection of equipment to specify for use by their line crews.

A variety of other clamps for special uses are available. The All-Angle Clamp provides flexibility over a wide range of cable and bus sizes and provides easy positioning with its pivoting body. The Cutout Ground Clamp provides a unique ground position while also providing a physical barrier that prevents accidental closure of the cutout fuse tube as long as the clamp is installed in the lower hinge of the cutout. The Cable Spiker Clamp was designed to ensure the complete de-energization of underground distribution cables with jacket over concentric neutral. It determines the absence of cable voltage when working mid-span before or after removing and parking end span elbows for maintenance activity.

Underground distribution ground sets are available for a wide variety of applications with URD transformers and deadfront switchgear. Chance grounding elbows are available with a fault duty rating of 10,000 amps.
ASTM[6] ratings of clamps, ferrules and assemblies are shown in Table 8-1.

Table 8-1 Protective Ground Cable, Ferrule, Clamp and Assembly Ratings for Symmetrical Current

<table>
<thead>
<tr>
<th>Grade</th>
<th>Grounding Clamp Torque Strength, min</th>
<th>Withstand Rating, Symmetrical kA RMS, 60 Hz</th>
<th>Short Circuit Properties&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Continuous Current Rating, A RMS, 60 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield&lt;sup&gt;b&lt;/sup&gt; Ultimate</td>
<td>15 cycles (250 ms) 30 cycles (500 ms) Copper Cable Size</td>
<td>15 cycles (250 ms) 30 cycles (500 ms) 60 cycles (1 s) Maximum Copper Test Cable Size</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>280 lbf-in 32 n-m 330 lbf-in 37 n-m</td>
<td>14 10 #2 18 13 9 2/0 200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>280 lbf-in 32 n-m 330 lbf-in 37 n-m</td>
<td>21 15 1/0 29 21 14 4/0 250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>280 lbf-in 32 n-m 330 lbf-in 37 n-m</td>
<td>27 20 2/0 37 26 18 4/0 300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>330 lbf-in 37 400 lbf-in 45 34 25 3/0 47 33 3 250 kcmil 350</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>330 lbf-in 37 400 lbf-in 45 43 30 4/0 59 42 29 250 kcmil 400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>330 lbf-in 37 400 lbf-in 45 54 39 250 kcmil or 2 2/0 70 49 35 350 kcmil 450</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>330 lbf-in 37 400 lbf-in 45 74 54 350 kcmil or 2 4/0 98 69 48 550 kcmil 550</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Withstand and ultimate short circuit properties are based on performance with surges not exceeding 20% asymmetry factor.

<sup>b</sup> Yield shall mean no permanent deformation such that the clamp cannot be reused throughout its entire range of application.

<sup>c</sup> Ultimate rating represents a symmetrical current which the assembly or individual components shall carry for the specified time.

<sup>d</sup> Ultimate values are based upon application of Onderdonk’s equation to 98% of nominal circular mil area allowed by Specifications B172 and B173.

The interconnecting cable is expected to be the weak link in the personal protective grounding system. Over the years, many cable tests have been conducted and a great deal is known about its electrical and mechanical properties. Cable manufacturing processes are well established and when consistent provide a reliable interconnection. The requirement on associated components is that they must now perform better than the cable.

The ultimate ratings shown in Table 8-1 were originally calculated from an equation developed by Onderdonk[6]. They are based upon the time a known current can flow causing the cable to melt and separate, much like a fuse, thereby interrupting the flow of current. The withstand rating is approximately 70% to 75% of the ultimate rating. It was included in the ASTM F855 standard to emphasize the need to include a margin of safety when developing a personal protective ground system.

The ratings used for cable are specified in ASTM B8 and are presented in Table 8-2.
**Ferrules**

It is recommended that a crimp ferrule be used to interface the cable to the clamp. While it is possible to strip the cable insulation and insert it into the compression terminal of a clamp, this is not a recommended method for long term use. While copper strands are new and shiny, tests show that such an assembly functions at the rated current. However, as time passes, individual strands exposed through the clamp compression fitting become corroded. Resistance between the exposed strands can increase substantially when this happens. Passing a high level of fault current through this increased resistance generates a substantial amount of heating. Test results have demonstrated the separation of cable and clamp due to this heating. In some cases, heat was so intense that the pressure terminal actually melted and burned away from the clamp body. This results in a complete loss of worker protection.

Ferrule size must match the conductor size. Ferrules are made both with and without a shroud. See Figure 8-7. The shroud slips over the insulation and is crimped. By covering the cable insulation, it provides protection against the entry of dirt and some contaminants. Ferrules without shrouds often are used with a short length of clear heat shrink material placed over the cable jacket and the base of the ferrule. This also helps to prevent the entry of moisture and other contaminants and provide stress relief. This provides the added benefit of allowing the user to visually inspect the cable for broken strands.

Ferrules are available in both aluminum and copper and are normally specified by the preference of the end-user. A properly crimped ferrule reduces the entry of contaminants. Contact aid is injected to reduce the corrosive effects resulting from the dissimilar metals (Al and Cu). The ferrule material is often selected based on the material used in the cast body of the ground clamp, i.e., aluminum ferrules with aluminum body clamps and copper ferrules with bronze body clamps. There are sufficient variations of clamp, ferrule and conductor sizes and styles to meet every need for personal protective grounding. Many applications and the accompanying theory are presented in later sections.

**Voltage Detectors**

Verification that a line is de-energized before attaching personal protective grounds are applied is a critical starting point. From this came the slogan “If it’s not grounded, it’s not dead.” There are several devices available to make this determination. Some involve temporary direct contact with the line to make the measurement. Non-contact models are positioned near the line and held long enough to make the reading. They make their measurements based upon the flow of capacitive leakage current between the line and the Earth or nearby grounded objects. Other devices operate similar to normal voltmeters. That is, they have two leads that can make contact with the line and a ground point to read the voltage present. Procedures for using these devices is explained further in General Installation Procedures, Section 10.

Chance offers Multi-Range Voltage Detectors (MRVD) in several measurement ranges, covering from 1 kV to 600 kV. They are available with either analog or digital meters. They are designed for mounting on an insulated universal pole of sufficient length to maintain a safe working distance for the worker. A metal probe is brought into contact with the line to take the reading. If the line is energized from a substation source, the reading is that of the system voltage. If the line being measured is opened and floating an induced voltage substantially lower or higher than the system, voltage may be present if that line shares poles or a corridor with other lines that are energized. A capacitive induced voltage falls to near zero as soon as the first grounded jumper is installed. This device is easy to read and does require some interpretation by the user, but with the guidelines supplied is easily learned and becomes a very useful tool. Adapters are available to use with underground distribution system equipment such as transformers, switches, elbows, etc.
Chance also offers the Full Range Auto Ranging Voltage Indicator (ARVI) in ranges from 600 volts to 500 kV. This is a direct-contact device that is mounted on an insulated universal pole of sufficient length to maintain a safe working distance for the worker. An audible alarm sounds if the voltage exceeds the system voltage. These are also available with adapters for use on underground distribution system components.

Another offering from Chance is the Phasing Tester. While this tool was designed for establishing the phase rotation of energized lines, it can be used to determine a de-energized line’s status. It is basically a two-probe voltmeter for high voltage applications. Each probe is insulated and of sufficient length to maintain a safe working distance for the worker. One probe is placed in contact with the line to be measured and the other to a ground or zero potential contact point. The measured voltage will again be either the system or some induced voltage as described earlier.
Ground Rods

A connection to the Earth by means of a driven ground rod consists of more than the metallic rod alone. In addition to the rod, it includes a series of concentric earthen shells around the rod. Current flowing into the rod is radiated in all directions through the entire surface area, creating a current density measured in amperes per square inch. It enters the thin earthen shell surrounding the rod. The surface area of this shell is larger than the rod. The total entering current now passes into the next earthen shell, which has still a larger surface area. The level of amperes per square inch is further reduced. The current continues entering and leaving additional shells, each with successively larger surface areas, illustrated in Figure 8-11. The resistance increases with each incremental increase in distance, but in smaller and smaller amounts because of the increasing surface area until a full hemisphere is achieved. Resistance \( R \) of any path is a function of the length \( L \) and cross section \( A \) of the current path, and of the resistivity \( \rho \) of the path.

Within the shell, the surface area increases faster than the distance from the rod. This results in a decrease in the exiting current’s level of amperes per square inch faster than the increase in distance. This is an exponential decrease and is shown in Figure 8-12.

The implication of the discussion of earthen shells and that of resistance is that as the distance becomes greater, the resistance should also substantially increase. However, the increase in distance is offset by an increase in cross section, as the current spreads throughout the earthen path. So, the result is a non-linear change in the region of the shells. Beyond the boundary of the shell (or between two remote shells shown in Fig. 8-13) the resistance tends to approach a constant value.

If the soil resistivity were constant, the resistance of the path over the entire length might be considered constant. However, soil resistivity varies substantially with its make up. Some of the causes of variations are types of soil, presence and amount of moisture, sand or rock.

The effective shell diameter equals twice that of the depth of the rod. Multiple rods used to make parallel connection paths to Earth tend to lose their parallel current carrying effectiveness if the shells substantially overlap.
29 CFR 1910.269 (n)(4)(i)(7) states that it is the utility’s responsibility to provide “protective grounding equipment” that “shall be capable of conducting the maximum fault current that could flow (underlined by the author for emphasis) at the point of grounding for the time necessary to clear the fault...” Further, 29 CFR 1910.269 (n)(4)(ii) states “Protective grounds shall have an impedance low enough to cause immediate operation of protective devices in case of accidental energizing of the lines or equipment.” These two statements imply a responsibility upon the employer. While not specified, these two statements imply a responsibility to ensure equipment is maintained for use in a safe and usable state. In the past, little attention was paid to the condition of personal protective jumpers. They often were coiled loosely and thrown into the back of a line truck by the workers whose very lives depended upon them. This type of oversight must be corrected.

Maintenance involves manual and visual inspection and electrical testing. Electrical tests are used to determine the condition of the clamp, ferrule and cable-to-ferrule interface. Convenient electrical tests have not been fully developed that will identify broken strands in the cable away from the crimp ferrules, unless a very large number of the strands are broken and not in contact with each other. Most electrical tests make resistance measurements using various levels of test current for short periods of time. If some strands are broken but still in contact with each other, held together by the outer jacket in the cable position, test current can still flow through both the broken and unbroken strands. The change in total resistance over the length of the cable due to small strand breakage usually cannot be seen.

Test currents using the maximum continuous rating of the cable for a long-term test may heat the area of the broken strands. The resulting heating may or may not be manually detected, again depending upon the amount of breakage. Infrared thermographs or thermocouples may improve the reading, but their use exceeds the definition of a convenient field test. This test may take several hours to complete. A careful manual inspection of the cable, feeling for the breaks, is the most reliable method of cable evaluation known at this time.

It may not be practical to make micro-ohm resistance measurements on aluminum clamps using a low voltage source. A coating of aluminum oxide covers bare aluminum surfaces. The coating is described in thickness of molecules, rather than inches. Aluminum oxide is an insulator for very low voltages, but it takes only a few volts to break down this layer and allow current to flow. The breakdown voltage can be as low as 5 to 10 Volts. Levels below 1 Volt may give an incorrect resistance reading.

Chance offers a microprocessor-controlled tester for personal protective grounding sets, the Chance C4033220 Tester for Protective Grounding Sets. It allows the user to input the selected level of body voltage considered safe and the cable size. The measurement made is the resistance from clamp jaw surface to clamp jaw surface. The maximum allowed withstand current as specified in ASTM F855 for the input cable size is represented to pass through the cable and is used in the calculation of the maximum voltage across the entire length of the jumper. In addition to the microvolt reading, a green or red (pass/fail) panel light will be illuminated to assist in the evaluation. These panel lights are to
be used when testing the ground set that will be connected directly in parallel with the worker.

The Chance Ground Set Tester C4033220 provides a 10V DC test voltage. This DC voltage level can easily break down any aluminum oxide on aluminum ferrules to give a reliable reading on all personal protective ground sets.

There are other ground set testers on the market today that use an AC source for testing. These test sets may not apply a test voltage to the jumper high enough to break down any aluminum oxide on ferrules, which could potentially give an incorrect reading. Possible errors are also noted in ASTM F2249-03, section 7.5.4 Note 3 and Note 4:

Note 3 - AC testing measurements of grounding jumper assemblies are susceptible to errors and inconsistent results due to induction in the cable if the cable is not laid out per the test method instructions.

Note 4 - AC testing measurements of grounding jumper assemblies are susceptible to errors if metal is laid across the cable or the cable is laid across a metal object, even if the metal object is buried, such as a reinforcing bar embedded in a concrete floor.

Other benefits of using the Chance Ground Set Tester include:

- No need to measure cable lengths up to 25 ft.
- Probing capability allows the user to locate high resistance areas within the ground set.
- Inductance of the cable or “coiling” the cable will not affect the readings.
- Grounding elbows can be tested without disassembling.
- DC voltage is easy to work with in the repair/test facility.

To ensure proper test procedures and methods are applied when testing temporary grounding jumpers, refer to ASTM F2249-03 and the manufacturer’s instructions for proper use of the ground set tester.

Ground sets that will not be connected in parallel with the body are not the subjects of body voltage measurement. For example, the requirement of a ground assembly that connects the cluster bar installed below workers feet to the Earth is only that it not melt or fuse into two parts. Its added length will have an increased resistance that may reach a voltage in excess of the selected level of body safety during the passage of a high fault current. However, this voltage is not across the worker. The micro-ohm measurement of such a cable can be compared to the expected resistance based upon standard resistance tables for a cable of the same size and length, but does not affect worker voltage.

ASTM F855 requires the resistance of a clamp to be equal or less than the same length of the largest cable that the clamp will accommodate. The resistance of a new clamp and crimp ferrule to cable value can be in the range of 100 micro-ohms. When tested after
use and extended atmospheric exposure, this value may substantially increase. Electrical testers can locate high resistance problems in the area of the clamp and ferrule on the jumper. A typical reading might be 500 micro-ohms for the clamp plus some resistance value for the length of the cable. The increase in resistances is typically the result of dirty or corroded clamp joints, loose inserts in the jaws or badly corroded cable in the ferrule crimp joint. The reading will vary with the size of the cable and type of clamp.

For example a typical test using a tester with the capability to make measurements in the micro-ohm range may be as follows. First, connect the grounding assembly to the tester and make an end-to-end reading through the clamp, ferrules and the interconnecting cable. If an unexpectedly high reading is obtained, use the probe feature to isolate the high resistance area. Using the probes, make measurements from the connection post to the clamp body. This measures the connection to the jaws. Then measure from the clamp body to the ferrule. This measures the connection between these two parts. Then measure from the ferrule to a spot on the cable 1 foot from the ferrule exit. This measures the hidden crimp joint and cable corrosion inside the ferrule. Repeat this procedure on both clamp ends.

A high resistance reading from any of these indicates a need for maintenance. Disassemble the ferrule from the clamp. Clean the clamp jaws and ferrule connection and use a wire brush to remove any corrosion. If the high reading is from the ferrule to cable connection, cut off the ferrule and crimp on a new one. The problem could be that the crimp was loosening, the cable strands were corroding or strand breakage at the ferrule edge.

If the above test does not show a high resistance, the reading will be originating from the cable itself. Make a careful manual inspection, as this is the most reliable means of evaluating the interconnecting cable at this time. Feel for broken strands, corrosion lumps under the jacket or flattened spots that may have been run over by a vehicle. If any of these are found, replace the cable.

Most ground sets can be returned to a usable condition by performing this type of inspection and maintenance on a periodic basis. Remember, the provision to supply suitable equipment is an OSHA requirement.