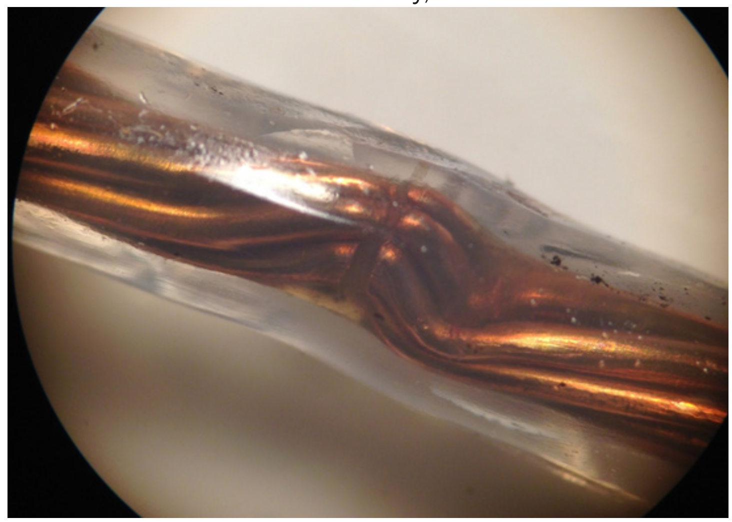
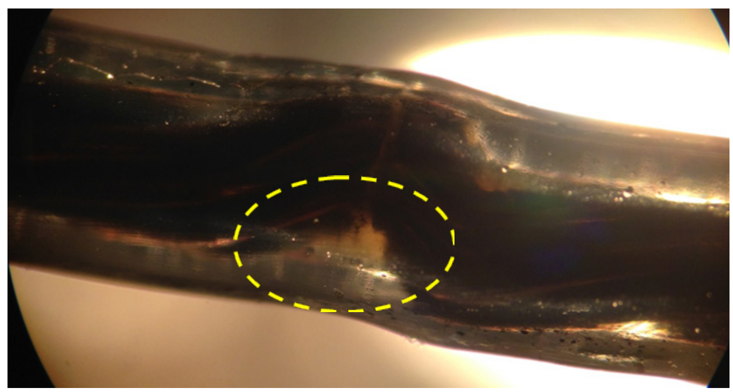
Open Circuit in an Electromechanical Cable

Forensic Analysis of Wireline Cables – Mechanical Damage

An open circuit is a condition in a cable when a conducting component of the cable, the copper conductor, physically breaks and is not able to maintain electrical continuity, but has not short circuited to the steel armor. This type of an event is rare but has occurred in the past. It is usually a result of mechanical damage which may be subtle enough to only break the copper conductor but still keep the insulation and armor intact. The reason it may not damage or burnout the insulation is it would have most likely occurred when the cable was not carrying electrical power. In the example shown below it can be seen that the center of the *z-kink*[1] in the copper conductor has parted creating an open space. It can also be seen that the conductor insulation or the water blocking agent has flowed into this space, thus, creating the open circuit in the conductor.



Z-kink in a copper conductor showing a fracture (30X)



Circle shows the flow of conductor insulation or the water blocking agent into the open gap in the conductor (30X).

Open Circuit Detection: An open circuit can be detected with use of the "continuity" function in a multi meter (e.g. Fluke 87 V). When checking for continuity between the two ends of the copper conductor, an "OL" or open line is indicated, then an open is likely present. To confirm an open, check for continuity between the conductor and armor, if "OL" is indicted then an open line condition is present. To locate an open circuit, a check of the cable capacitance is conducted. **Capacitance** is the ability of a body to store an electrical charge. Any object that can be electrically charged exhibits capacitance.

The capacitance is a function of the geometry (including their distance) of the conductors and the permittivity of the dielectric of the insulation. The two factors that affect capacitance[2] in an EM Cable are the dielectric properties of the insulation used and the distance of the conductor from the inner armor.

[1] Z-kinks will develop in cables when the load on the cable is rapidly cycled from high tension to low tension, when the cable is placed in high tension the copper is stretched past its elastic limit, a rapid release in tension will cause the stretched copper to buckle (Z-kink). The rapid cycling of tension maybe caused by shock loading (for example, pulling out of rope sockets, perforating under balance, dropping off a heavy packer, etc.). The increase and decrease in tension while trying to free stuck tools if done rapidly may also create Z-kinks. Pulls in excess of 67 per cent of breaking strength may also create Z-kinks.

[2] The SI unit of capacitance is the Farad (symbol: F). A 1 F capacitor, when charged with 1 Coulomb of electrical charge, has a potential difference of 1 Volt between its plates. Historically, a Farad was regarded as an inconveniently large unit, both electrically and physically. Its subdivisions are invariably used, namely micro Farad, nano Farad and pico Farad.

- 1 mF (milli Farad, one thousandth (10−3) of a Farad)
- 1 µF (micro Farad, one millionth (10−6) of a Farad)
- 1 nF (nano Farad, one billionth (10−9) of a Farad)
- 1 pF (pico Farad, one trillionth (10−12) of a Farad)

technical bulletin

Capacitance

Caution

To avoid possible damage to the Meter or to the equipment under test, disconnect circuit power and discharge all high-voltage capacitors before measuring capacitance.
Use the de voltage function to confirm that the capacitor is discharged.

The Meter's capacitance ranges are 10.00 nF, 100.0 nF, 1.000 μF, 10.00 μF, 100.0 μF, and 9999 μF.

To measure capacitance, set up the Meter as shown in Figure 6.

To improve the accuracy of measurements less than 1000 nF, use the relative (REL) mode to subtract the residual capacitance of the Meter and leads.

Note

If too much electrical charge is present on the capacitor being tested, the display shows "tliSC"

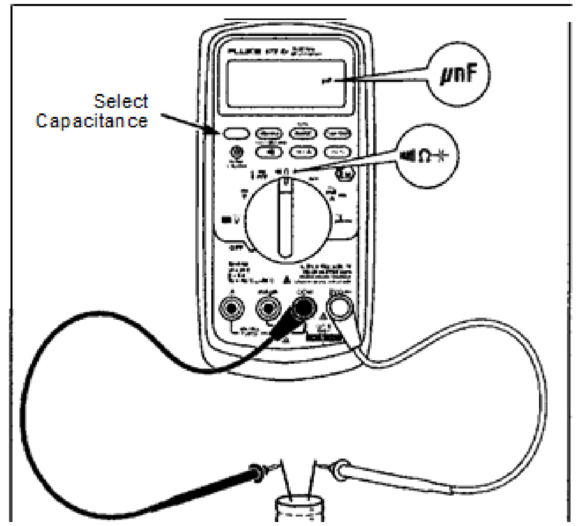


Figure 1. Measuring Capacitance

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Capacitance of Camesa cables is in the range of 26 to 70 pF per ft. The capacitance is accumulative over the length of the cable. For example, a Camesa 1N29PTZEH cable has a capacitance 56 pF/ft. This cable type 25,000 ft. long will have a total capacitance of 56 pF x 25,000 feet = 1,400,000 pF or 1400 nF or 1.4 μF.

When using a Fluke 87V meter to measures Capacitance the meter should be set up as shown in Figure 1.

Detailed Procedure
When an open in a conductor is indicated the following procedures can be followed to locate the open:

1. Prepare both ends of the cable for testing. Remove all tools and devices from the cable such as tool heads and collector rings. Peel back about 9 inches of armor from both ends of the cable. Remove the insulation from about a ½ inch length of the conductor core. Clean the ends of the cable using an electrical contact cleaner or brake cleaner. Make sure that each of the conductor ends is free and does not touch anything.

2. Setup the Fluke 87 to measure capacitance "F". Press the REL button to zero the meter.

3. At the Tool End "TE" place one lead on the copper conductor and one lead on the armor; record the reading as **Ft**, the reading will either be in μF or nF, make sure to note this.

EX: 1.12 μF or 12.31 nF.

If the reading is in μF multiply that number times 1,000,000 to get pF.
EX: 1.12 μF X 1,000,000 = 1,120,000 pF

If the reading is in nF multiply that number by 1,000 to get pF.
EX: 12.31 X 1,000 = 12,310 pF

4. From line record book get an accurate Cable Length "CL". From Camesa Final Inspection Report get pF/ft. value of the cable. The accuracy of the test will be dependent on accurate meter readings and an accurate CL.

5. Convert **Ft** reading to pF. Divide **Ft** by the pF/ft. value to obtain the distance of the open from the TE in feet.

6. At the Drum End "DE" place one lead on copper and one lead on armor, record reading as **Fd.**

7. Convert **Fd** reading to pF. Divide **Fd** by the pF/ft. value to obtain the distance of the open from the DE in feet.

8. The sum of the distances from TE and DE should be equal to the CL.

EX: The cable we will be testing is a Camesa 1N29PTZEH with a pF/FT value of 56pF/Ft. The nominal conductor resistance is 2.8Ω/kFt. Customer reports cable length of 20,339 ft. Customer believes that the conductor is open.

A continuity test shows OL; because of this we cannot get an end to end R reading and will have to use the customer furnished CL for now.

We read .570µF from the TE and .569µF from the DE
Ft = .570µF x 1,000,000 = 570,000pF
Fd = .569µF x 1,000,000 = 569000pF

Distance from TE "TEd" = Ft 570,000 / 56 = 10,178.5 feet
Distance from DE "DEd" = Fd 569000 / 56 = 10,160.7 feet

To check our work we add Ted + DEd = CL
10,178.5 feet + 10,160.7 feet = 20,339.2 feet this is our reported cable length.

As usual with an example, the numbers came out perfect. Do not expect such precise results with a real test.

Example
An example from a case study is used to illustrate the use of capacitance in locating the position of an open circuit. During investigation of a failure of Camesa cable type 7H42RTZHS when the conductors were checked for continuity, number 3 conductor indicated OL. The other conductors checked good with an average resistance of 239 Ω. In order to determine the location of the open Fluke 87V meter was set to read capacitance. A reading from the TE of the cable was,

Ft = 30 nF = 30,000 pF

DE of the cable gave a capacitance reading of,
Fd = 1.1 µF = 1,100,000 pF

To calculate the location of the open we performed the following calculations. The capacitance of 7H42RTZHS is 46 pF/ft. Therefore, the estimated open circuit location from the tool end would be, (30,000 pF)/(46 pF)=652 ft.

In a similar manner, the location of the open circuit from the drum end would be, (1,100,000 pF)/(46 pF)=23,913 ft.

Upon pulling down to 650 ft. from the tool end a very severe kink was found in the cable. The kink was cut out and the armor removed. A z-kink was found in the conductor 3. Adjacent to the z-kink, the conductor had parted which created the open condition as also seen in the pictures above. From the capacitance reading we estimated cable length at 24,565 ft. while the actual length was found to be 24,450 ft.