# Development of an Enhanced Connector Testing Protocol for MV Cable Joints

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# Background

- IEEE 48 (Terminations) and 404 (Joints) evaluate the connector as part of a system
- Each is a one time qualification test
- Each looks at a specific joint or termination design
- A limited number of connectors for use in a given housing (min, max, and middle for MV systems)

# Background

Limitations of the "Classical" Test Procedures

- Typically test only a single connector size with a given conductor size and housing combination
- The test results are assumed to qualify a broader range of connectors and housings that are based on the same design criteria

# Background

- Other standards
  - UL 486B "Wire Connectors for Use with Aluminum Conductors"
  - UL 486D "Insulated Wire Connectors for Use with Underground Conductors"
  - ANSI C119.1 "Insulated Low Voltage Connectors"
  - ANSI C119.4 "Overhead Connectors"
  - IEC 61238-1 "Connectors"

# Heat Dissipation in a Joint

- Conduction
  - Housing materials
  - Can help or hinder heat dissipation
  - Affects connector performance
  - There is a critical diameter where heat dissipation is maximized
- Convection (air flow) – minimal impact
- Radiation (from surface) – even less impact
- Mass of connection (thermal capacitance)

# Heat Generation in a Joint

- Load current magnitude
- Connection resistance
  - Point contact conduction
  - Oxide layer interferes
- Contact between connector and conductor surface is important
- Contact between strands within the conductor is important

# Designing a Connection System

What's Important

For a joint:

- Contact between connector surface and joint body
  - Heat dissipation
  - Electrical continuity
- Elongation of the connector upon installation (push outside of conductor shield)

# Designing a Connection System

For a Joint:

- Inside and Outside Diameters
- Selection of connection method (bolted, compressed, welded, etc.)
  - Retention of mechanical strength
  - Quality of electrical connection
  - Material properties of connector (hardness)
  - Surface finish/condition after installation

# Designing a Connection System

For Joints:

- Barriers to fluids and gases
- Exposure to environmental conditions during installation
  - Rain, salt spray, oxidizing atmospheres
- Continuity of neutral
  - Additional heat source

# Trends

- Utilities are pushing the limits of systems more and more
- Economic incentives to get all you can
- Application variety is increasing
  - New designs and concepts—Heat-shrink, Cold-shrink, premolded
  - Types—Compression, bolted, port-hole, welded, pin and socket, other
  - New Materials—EPDM, silicone, other

# Trends

- Less experienced installers
- Experienced people are retiring
- Quality of training may be an issue (do you wire brush the conductor?)
- Knowledge gained by experience is not always recorded and passed along

# History

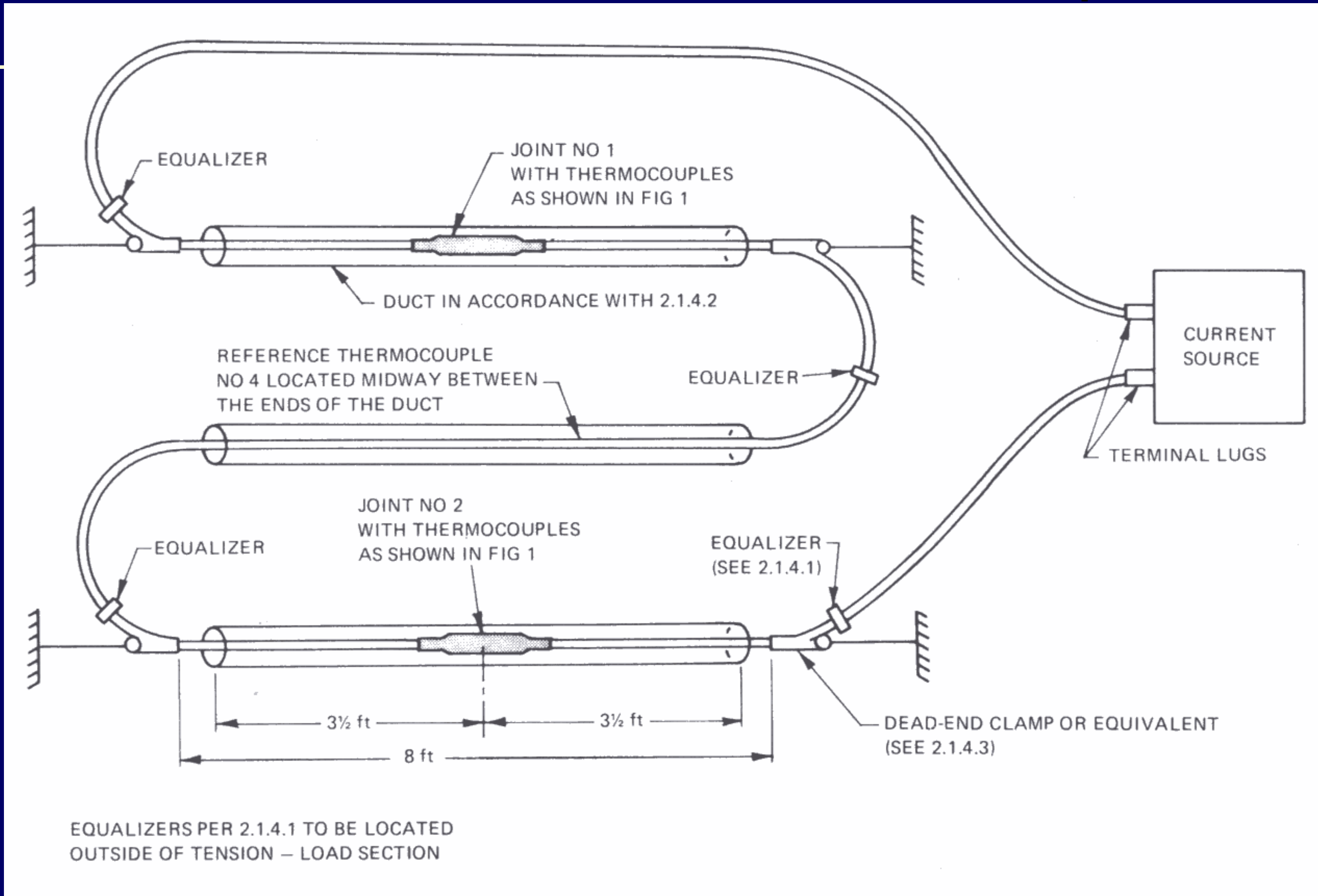
- Connector applications on insulated cables has been an issue at ICC for many years
- Earlier efforts have met mixed success
- IEEE 972 “Trial Use Standard for Connections of Insulated Aluminum Conductors” – Issued in March 1986

# IEEE 972

- Covered 601 V thru 46 kV
- Connectors with Field Coverings
- Goal of Standard
  - Demonstrate with reasonable assurance that connectors meeting the standard will perform in a satisfactory manner

# IEEE 972

- Test Setup



# IEEE 972

## Test Protocol

- Heat cycle to achieve 130 °C on reference conductor
- 100 cycle aging
- 4/0 AWG and smaller conductor
  - 3 hr ON, 3 hr OFF
- 250 kcmil and larger conductor
  - 6 hr ON, 6 hr OFF

# IEEE 972

## Monitored Parameters

(similar to ANSI C119.4)

- Temperatures monitored
  - On connector in joints
  - On reference conductor
- Resistance monitored
  - Between equalizers on connectors
  - Between equalizers on reference conductor

# IEEE 972

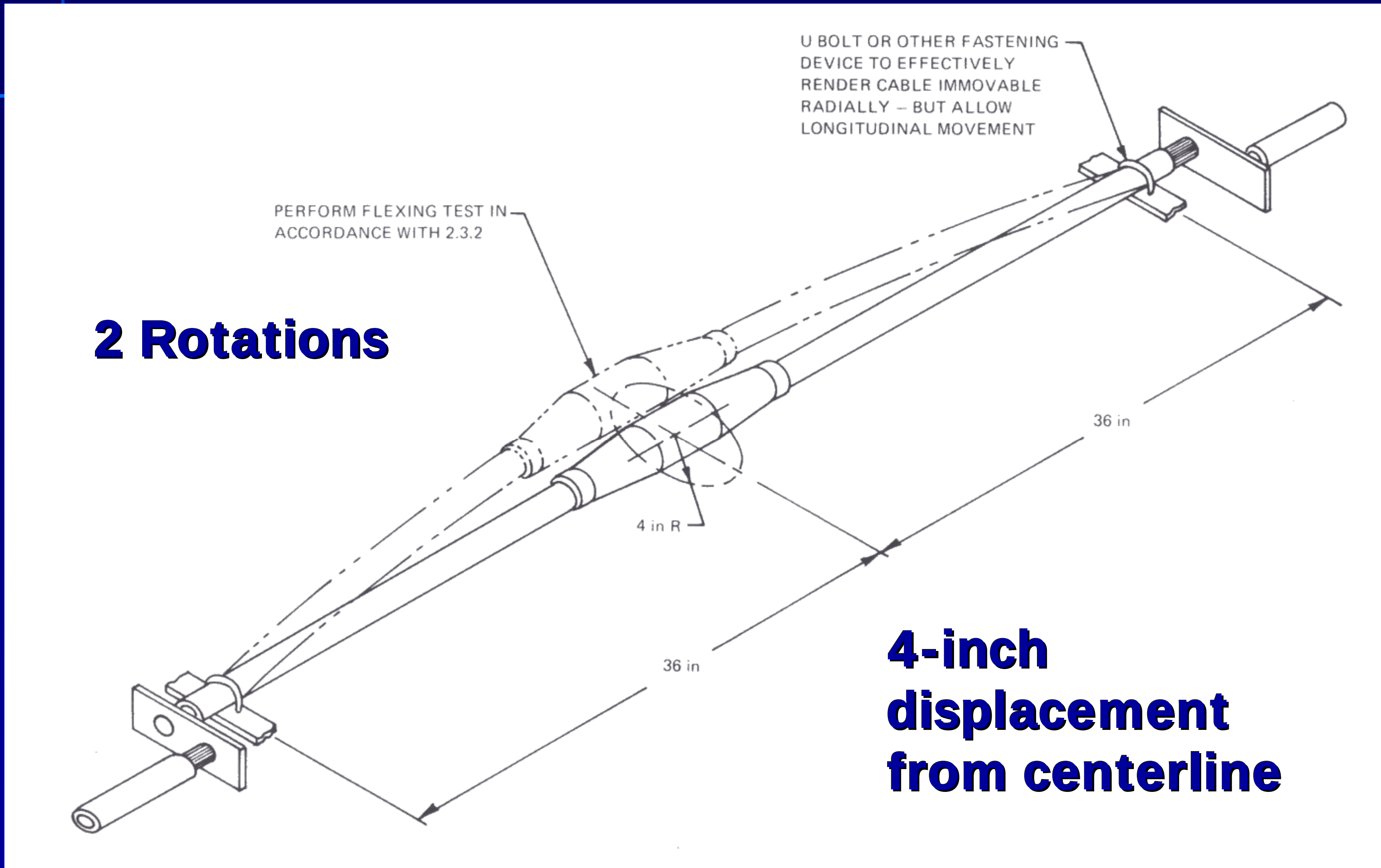
## Test Protocol

- Tension applied to conductors
  - 200 lbs. minimum
  - 10% of conductor RBS (rated breaking strength)
  - Measured at ambient temperature
- Joint aged inside conduit

# IEEE 972

- Flexure of Joints on selected thermal cycles
  - 28th, 56th, and 84th cycles
  - Conduits removed
  - Cable ends loosely clamped
  - Rotate around axis in loop

# IEEE 972


U BOLT OR OTHER FASTENING DEVICE TO EFFECTIVELY RENDER CABLE IMMOVABLE RADIALLY – BUT ALLOW LONGITUDINAL MOVEMENT
PERFORM FLEXING TEST IN ACCORDANCE WITH 2.3.2
2 Rotations
36 in
4 in R
36 in
4-inch displacement from centerline

# IEEE 972

- Evaluation criteria
  - Based on ANSI C119.4
  - Connector 10 °C cooler than reference conductor
  - Connector resistance remains stable–variation of not more than 5% from the average of the measured values

# IEEE 972

- What happened?
- Draft standard never became a full standard and was withdrawn
- Cost of doing test was high
- Setup was difficult
- All connector and housing combinations had to be tested

# Where do we go from here?

- Interest within ICC seems to be in some sort of compromise or meshing of requirement between ANSI and IEC
- What's needed is data on which to make a decision
- But! What type of data? There are a multitude of approaches to the problem

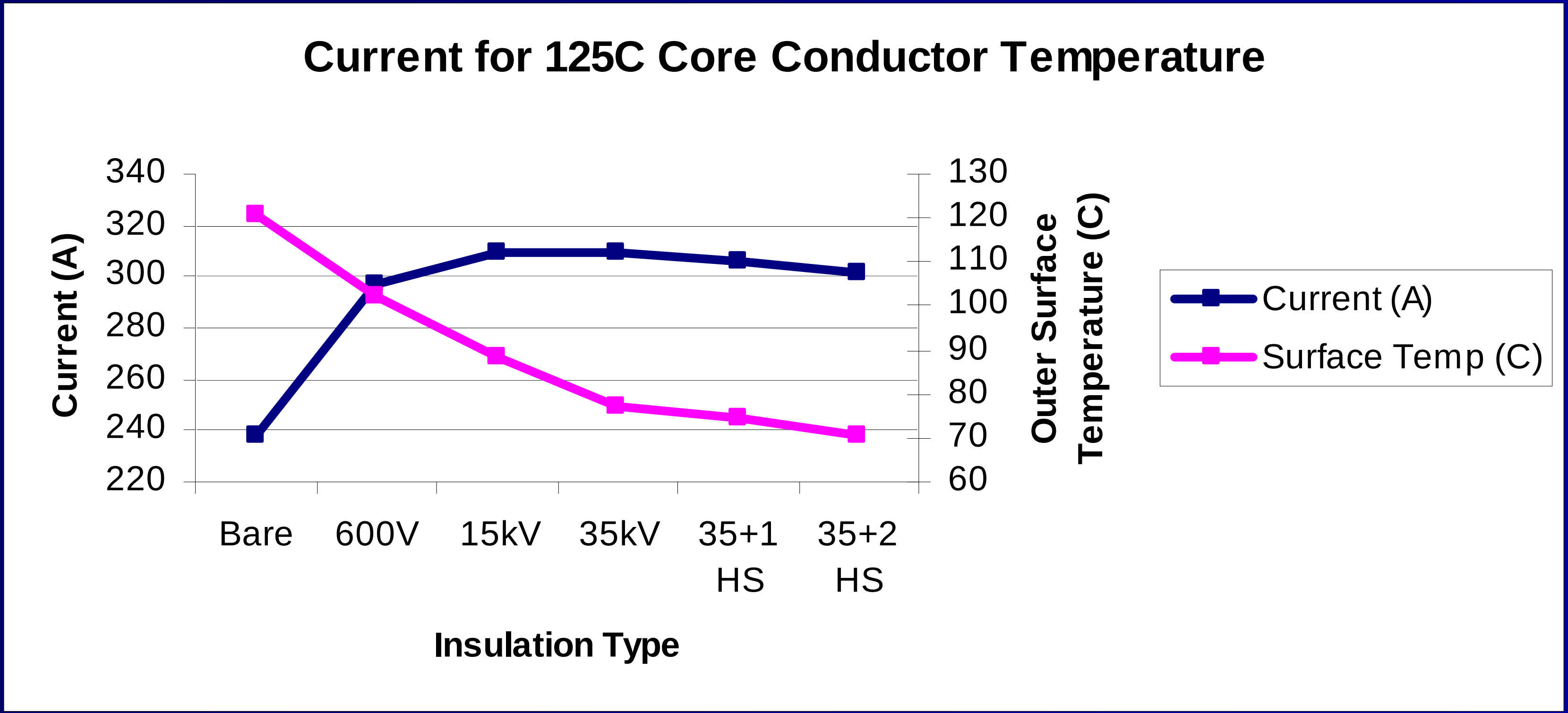
# Some Experimental Data

- Effect of conductor size and insulation thickness on ampacity/temperature
- 1/0 AWG Class B stranded aluminum
- Target temperature – 125 °C at conductor core
- 12 foot conductor lengths
- Various insulation thicknesses

# Some Experimental Data

| Cable Voltage Rating | Insulation Type | Outside Diameter (Inches) | Surface Temp (°C) | Current (A) |
|---|---|---|---|---|
| | Bare | 0.365 | 120.5 | 238 |
| 600V | LLPE | 0.520 | 102.2 | 297 |
| 15 kV | XLPE | 0.845 | 88.2 | 309 |
| 35 kV | XLPE | 1.171 | 77.1 | 310 |
| 35 kV | XLPE+1 HS Tube | 1.359 | 74.3 | 306 |
| 35 kV | XLPE+2 HS Tubes | 1.504 | 70.7 | 301 |

# Some Experimental Data



# Some Experimental Data

- Results show that changing the insulation thickness will change the heat dissipation from the connector or cable
- Adding insulation can increase the ability to dissipate heat
- A peak in heat dissipation occurs at a particular insulation thickness, called the critical radius for each conductor diameter

# What Happens When:

You test a bare connector on an insulated conductor?

Using ANSI C119.4 Procedures:

- 1/0 AWG, Class B stranded bare conductor
- Industry accepted connector for 1/0 AWG conductor

# What Happens When:

| Cond. Insulation | Conn. Insul. | Current (A) | Cond. Temp (°C) | Result |
|---|---|---|---|---|
| Bare | Bare | 240 | 125 | ANSI C119 **PASS** |
| 15kV (175 mils) | Bare | 290 | 125 | ANSI C119 **FAIL** |

# What Happens When:

- Failure early in test sequence
- Temperature exceeded reference conductor
- Resistance increased steadily

Why?

- Connector temperature too high
- Creep in metal becomes a factor

# What's Needed for a Meaningful Test Program

- Account for difference in heat transfer between insulated and bare components
- Evaluation of all connector/cable/cable accessory combinations is not practical
- Some assurance of extension to other components produced based on use of the same design principles

# Test Protocol Development

- Use the information gained on the effect on insulation addition on temperature and effect of temperature on the connector
- Aluminum is the important case
  - Effect of creep with temperature
  - Sets a maximum limit for connector temperature

# Test Protocol Development

- Common factors
  - Combination of bare and insulated conductors
  - Addition of short-circuit application
  - Start with a common connector known to meet ANSI C119.4
  - 1/0 AWG, Class B, ¾ Hard, strand filled conductor

# Test Protocol Development

- Vary the quality of the connector installation
  - Properly installed—3 compressions/side
  - Improperly installed—2 compressions/side
- Distinguish a “good” versus a “marginal” connector installation

# Test Protocol Development

- Common factors
  - 4 properly installed and 4 improperly insulated connectors in each test loop
  - 6 Short circuits applied at 100 cycles
  - Raised conductor temperature to between 250 and 270 °C, cool to ambient between shots
  - 60 cycle ± 20 cycles/short circuit
- Push the envelop slightly
- 4 possible protocols considered

# Test Protocol Development

**ABBREVIATIONS:**

**CR = critical radius**

**Amb = Ambient**

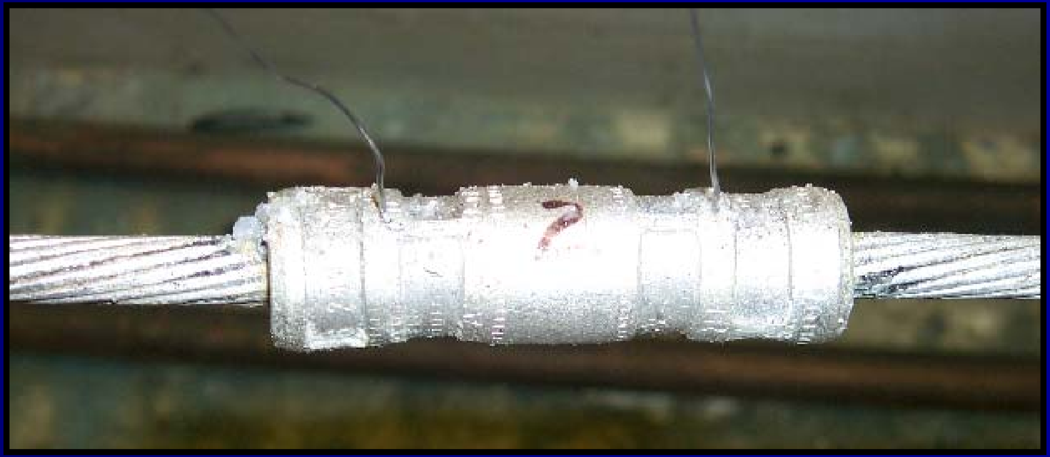
- 4 Protocol Combinations Tried

| Proto-col | Ref. Cond. | Loop Cond. | Conn. | Ref. Temp. | Cycles |
|---|---|---|---|---|---|
| 1 | Bare | Bare | Bare | Amb+ 100°C | 200 |
| 2A | Insulated @ CR | Insulated @ CR | Bare | Amb+ 100°C | 200 |
| 2B | Insulated | Bare | Bare | Amb+ 100°C | 200 |
| 3 | Bare | Bare | Bare | 140°C | 300 |

# Connector Installation

Properly Installed ⇐

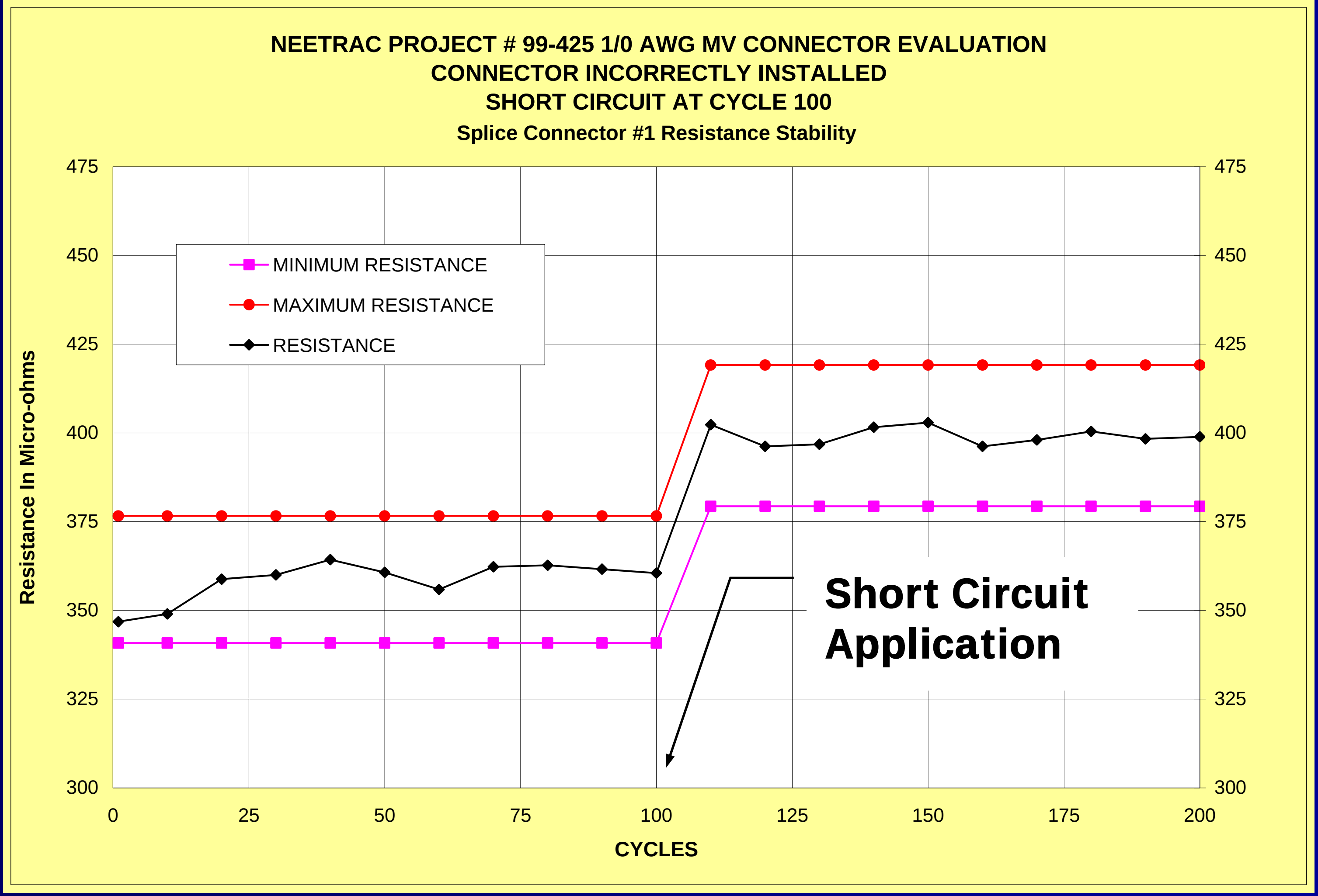
Improperly Installed ⇒



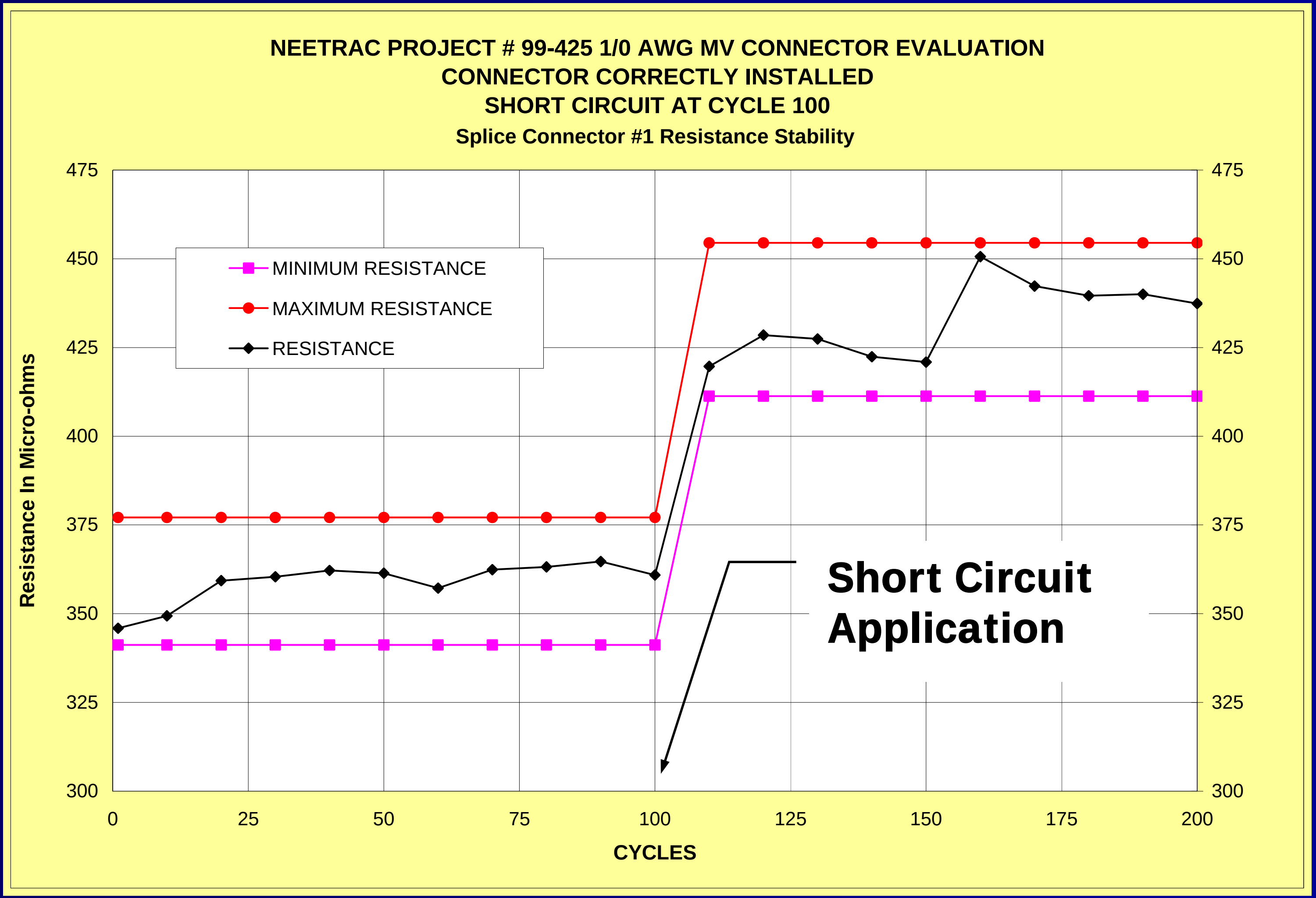
# Test Method

ANSI C119.4 Current Cycle Submersion Test

# Typical Test Results



# Typical Test Results



# Test Protocol Development

ABBREVIATIONS:

ICI = Incorrectly installed

CI = Correctly installed

- Results

| Proto-col | Ref. Cond. | Loop Cond. | Conn. | Results |
|---|---|---|---|---|
| 1 | Bare | Bare | Bare | PASS |
| 2A | Insul. @ CR | Insul. @ CR | Bare | Equalizer failures |
| 2B | Insu-lated | Bare | Bare | ICI failures at 22 cycles<br>CI failures after short circuit |
| 3 | Bare | Bare | Bare | Results depend on evaluation criteria—See following Table |

# Test Protocol Development

- Results of Protocol 3

| Connector | ANSI Temp. Stability | ANSI Resis. Stability | IEC Resis. Stability |
|---|---|---|---|
| Correct 1 | **PASS** | **FAIL** | **FAIL** |
| Correct 2 | **PASS** | **PASS** | **PASS** |
| Correct 3 | **PASS** | **PASS** | **PASS** |
| Correct 4 | **PASS** | **PASS** | **PASS** |
| Incorrect 1 | **PASS** | **FAIL** | **FAIL** |
| Incorrect 2 | **FAIL** | **FAIL** | **FAIL** |
| Incorrect 3 | **FAIL** | **FAIL** | **FAIL** |
| Incorrect 4 | **PASS** | **PASS** | **FAIL** |

# Recommendations

- Use ANSI C119.4 CCST procedures
- Apply 6 short circuits at 100 cycles
- Use IEC 61238-1, 250 - 270 °C on Reference Conductor, cool between shots
- Run 300 cycles (instead of 100 cycles)

# Recommendations

- Don't use ambient + 100 °C on reference conductor
- Use 140 °C reference conductor temperature
- Use ANSI C119.4 temperature and resistance stability analysis
- Use IEC 61238-1 resistance analysis

# Recommendations

- Other test protocols are possible
- Consider results of testing
- Consider the physical aspects of what leads to connector deterioration
- Recognize the limitations of the materials involved in setting test parameters