Design Principals of PILC Transition Joints

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Agenda

- Background
- Design Considerations
- Requirements
- Putting it all together
- Summary

Background

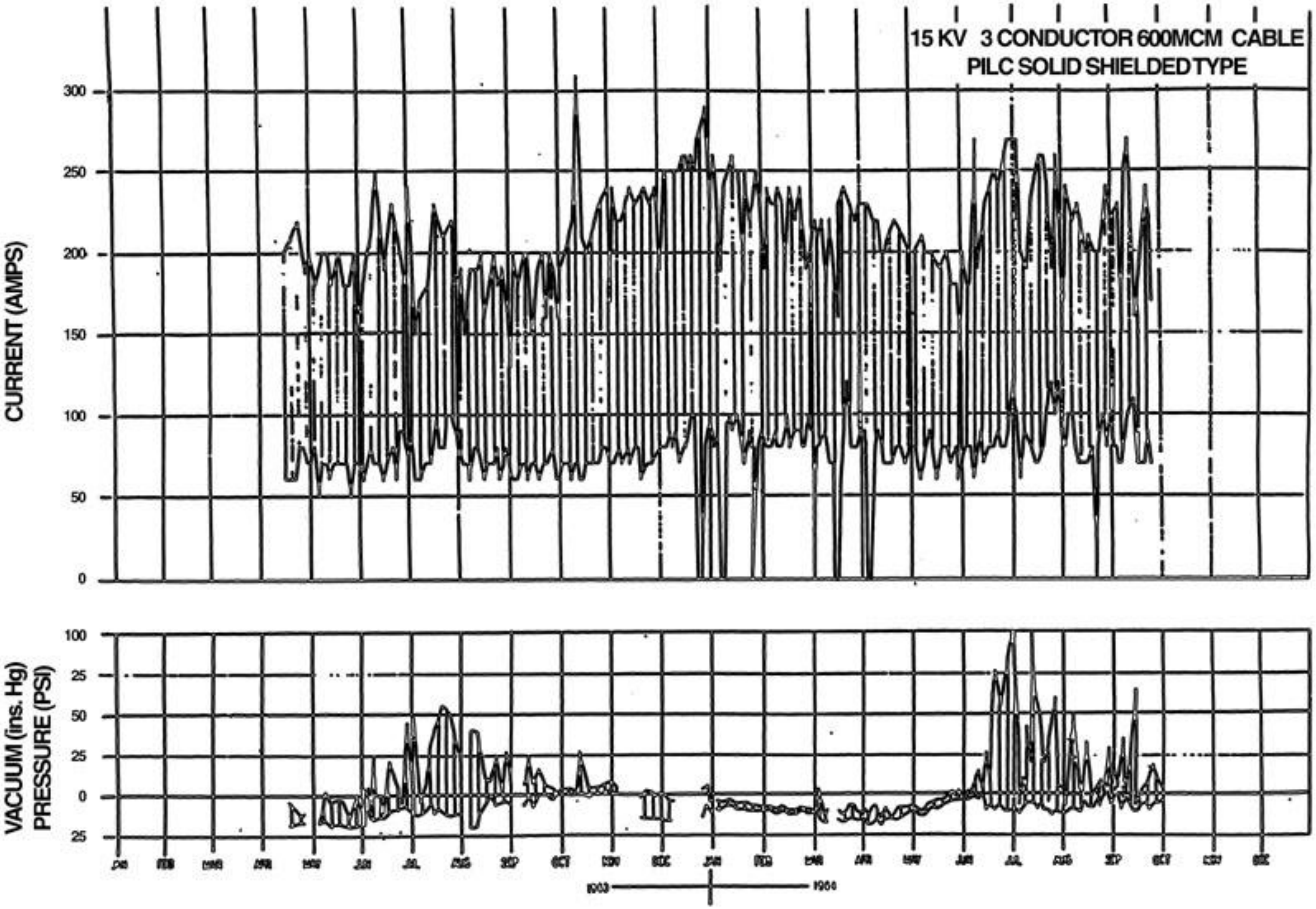
- PILC cable has been around for over 100 years
- Will address cables through 35 kV
- A lot of the cable is still in the ground, especially in large older cities
- When encountered, it is frequently jointed to extruded dielectric cables
- When installed correctly it is very reliable as some is still in service for over 90 years

Background

- Understanding PILC cable is a key to making a successful transition joint
- The oil that is used to impregnate the paper expands 6% by volume from 25ºC to 100ºC
- Expansion in a closed system can create pressure
- The pressure is relieved when the lead expands
- But when the load drops off, the oil cools and contracts and creates a vacuum in the cable

Background

- Have performed experiments in the lab which shows this performance
- Most compelling data to support this comes from Cleveland Illuminating
- Following is a graph from a 1964 IEEE transaction paper. A transducer was connected to an in-service 3/C 600 kcmil 15 kV PILC cable. The data was monitored for about 18 months



AMPERE LOAD AND INTERNAL PRESSURE ON V-58-CL-HR

FIG. 2

Background

- Conventional wisdom says that the maximum pressure in PILC cables is 15 psi
- This number may come from the specific gravity of oil and the maximum recommended elevation change in a PILC cable run
- The specific gravity yields about 0.4 psi per foot of elevation change

Background

- Typically the maximum recommended elevation change between stop joints is about 40 feet
- 40 feet X 0.4 psi/ft = 16 psi
- However, that doesn’t agree with the graph from an actual cable, so the expansion and contraction of the oil seems to contribute more than the elevation changes

Background

- There are two types of PILC cables in the US – low and high viscosity or standard and riser cable, respectively
- The manufacturing process is the same, but the oil is about six times more viscous in the riser cable than in the standard cable – see chart on next slide

Comparison of Oil Viscosities

Temperature	Low Viscosity Kinematic/ cSt	Low Viscosity Saybolt/SUS	High Viscosity Kinematic/cSt	High Viscosity Saybolt/SUS
10°C	7500	35,000	185,000	855,000
25°C	1,900	8,800	35,000	162,000
60°C	180	835	1,800	8,400
100°C	35	165	210	980

Note: Both oils thermally expand 6% by volume from 25 to 100˚C.

Background

- Manufacturing process pumps hot oil into impregnation tank when cables are dry
- Oil is then cooled and pumped out of tank and lead jacket is extruded over oil impregnated cables
- Difference between high and low viscosity oils is that high viscosity is pumped out of the tank at a higher temperature than low viscosity oil

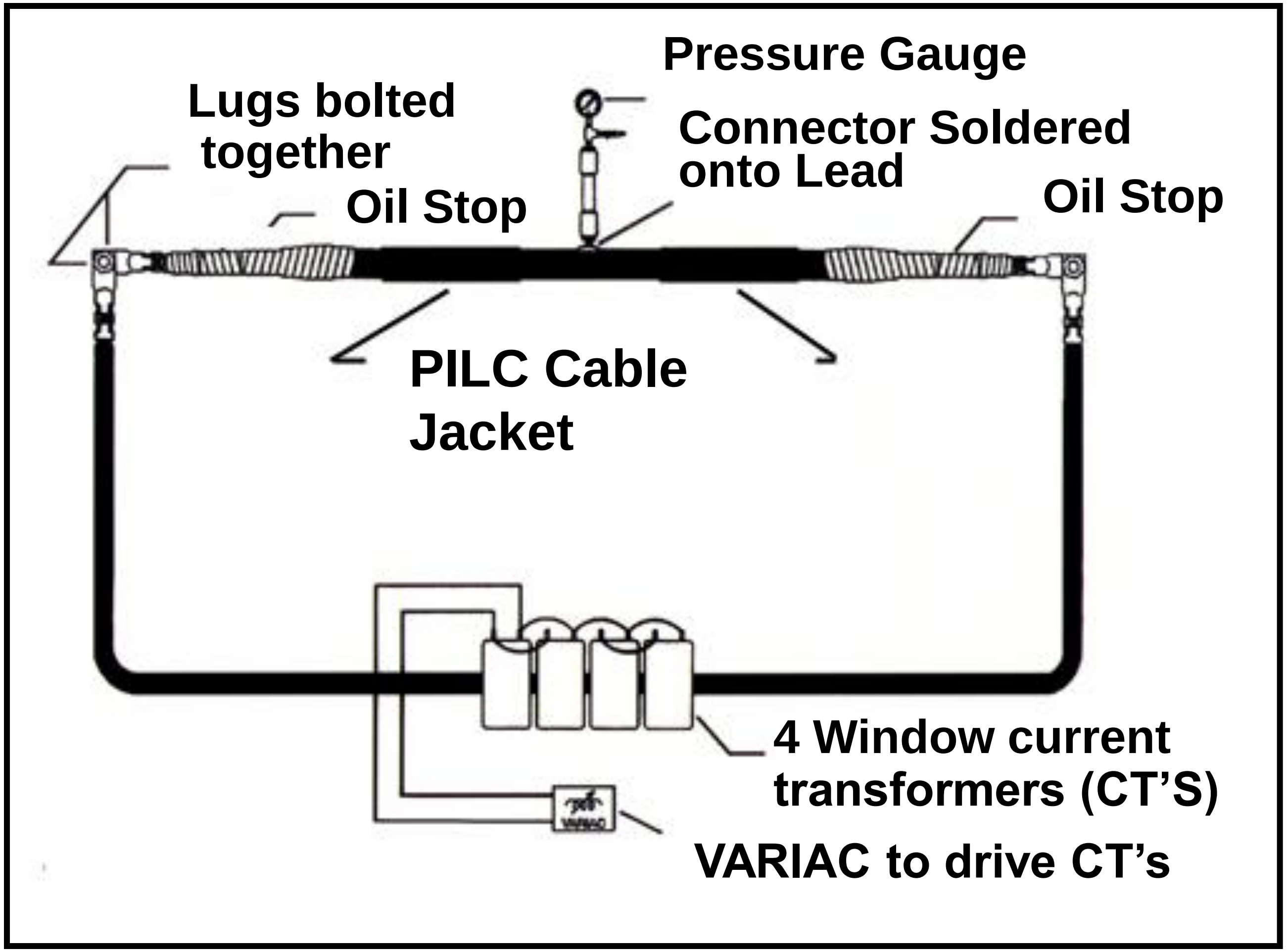
Background

- At a higher temperature, the oil is thermally expanded and therefore takes up more volume than at a lower temperature
- So, since the high viscosity oil is pumped at a higher temperature and therefore thermally expanded, it follows that there is less oil in the high viscosity oil cables than in the low viscosity oil cables
- Visual observations confirm this

Background

- With less oil in the high viscosity oil cables, there is less oil to thermally expand, and therefore less pressure created when the cables are heated up with current
- The following experimental data helps to confirm this theory
- First slide shows the configuration of the loops used to obtain the data

Typical PILC single conductor loop to measure pressure generated in cable by heat from current



Single Conductor PILC Pressure Data

Conductor Size	Voltage Rating (kV)	Type Oil	Maximum Pressure (PSI)	Maximum Vacuum (in of Hg)
2/0	25	Low Viscosity	145	N/A*
500	15	Low Viscosity	130	N/A*
500	25	Low Viscosity	115	20
1/0	35	High Viscosity	0	N/A*
2/0	15	High Viscosity	26	N/A*
500	25	High Viscosity	40	12

* These cables were only monitored with a pressure gauge without vacuum capability

Background Summary

- PILC cable is very interesting and complex
- It helps to understand how the cable works so that an accessory can be designed that will successfully perform
- There are lots of issues to consider, which we will now address

Design Considerations

- Mechanical/Environmental Requirements
  - Must be able to maintain seal to keep oil in and moisture out while encountering the pressure and vacuum conditions of the cable
  - Must provide an environmental seal and physical protection, including armor if required
  - For 3/C cables must provide containment in the breakout area so that a fault on the system doesn't cause a problem with too much bending at the breakout area. This could damage the papers and lead to a failure

Design Considerations

- Mechanical/Environmental Requirements
  - For terminations, especially 3/C, since they may be in the air and subjected to movement, due to wind, rain, snow, etc., the breakout components must take this into account.

Design Considerations

- Electrical Requirements
  - PILC cable has higher vertical dielectric strength than horizontal, because of the layers of paper and therefore requires a longer interface length than extruded cables
  - Must control the electrical stress at the PILC cable semicon (with oil resistant stress control material) or transfer the end of the cable semicon to the outside of the oil barrier

Design Considerations

- Electrical
  - The shielding system of the joint must also make good contact with the lead and carry shield currents and fault currents
  - Typical test is 10 cycles for 20 or 25 kA

Design Considerations

- Thermal
  - PILC cable cannot withstand the same temperatures as extruded cables. In North America PILC cables are typically run at an operating temperature of 90ºC with an emergency overload temperature of 110ºC. Extruded cables operate at 90ºC or 105ºC with an emergency temperature of 130ºC or 140ºC. In Europe, PILC cables are operated at 65ºC or 70ºC, with an emergency temperature of 90ºC

Design Considerations

- Chemical
  - Obviously, the layer in contact with the oil must not be adversely affected by the oil and must also not absorb the oil out of the paper. It should also be a good water vapor barrier to keep moisture out of the cable
  - Outer jacketing material may also encounter hydrocarbons and other materials in manholes and should be an adequate barrier to these chemicals

Design Considerations

- All of these mentioned considerations must be taken into account when designing an accessory so that the accessory can meet the standards as well as perform in the field

Test Standards

- IEEE-404 Provides the qualification requirements for a transition joint
- Following is the test sequence from IEEE-404 and the test values for a 15 kV joint
- The test sequence is the same for voltages through 46 kV, but different for 69 kV and higher voltages
- For the distribution voltage joints two joints are installed on two loops, one cycled in air and one in water

Qualification Test Sequence

- AC withstand test – 1 minute at 35 kV
- DC withstand test – 15 minutes at 55 kV
- Impulse at ambient temperature – 10 +/- surges at 110 kV
- Impulse at emergency overload temperature (110^{o}C) – 10+/- surges at 110 kV

Qualification Test Sequence

- Ionization test – difference between tan delta readings at 20 volts/mil and 100 volts/mil, with the insulation thickness determining the mils
- Cyclic aging in air – voltage at 2 X U_o or 17.4 kV is applied continuously and current is cycled on to obtain emergency overload temperature for a minimum of 6 hours during each 24 hour load cycle for 30 cycles
- Cyclic aging in water – same as for air

Qualification Test Sequence

- Ionization test
- High voltage time test – 6 hour AC withstand test at 35 kV
- Sectionalizer test if applicable
- Shield restoration tests – two short circuit tests with no damage to shielding components
- Jacket restoration test – 10 current cycles under water of air cycled loop and inspect moisture sensitive paper inside joint to see if leaked
- Connectors must meet ANSI C119.4 Class A current cycle and Class 2 pull out force

Additional Tests

- Material tests
  - Moisture vapor transmission rate
  - Oil absorption/compatibility
  - Dielectric properties
  - Elongation and other mechanical properties
- Other tests
  - Pressure/vacuum containment
  - Electrical AC step test and maximum impulse level

What Does It All Mean?

- PILC transition joints are very complicated
- Just testing to the standard is probably not adequate, because it doesn’t address the mechanical aspects required to make sure the joint functions properly for a long life
- Understanding the cable and how it works is critical to being able to evaluate transition joints to ensure they will perform

Summary

- To chose the best joint for your application, you must:
  - Understand how the cable works
  - Know the parameters of your system
    - Load cycling
    - Age
    - Location of stop joints
    - History, etc
  - Understand the joint design and function

Thank you for your time

Questions?