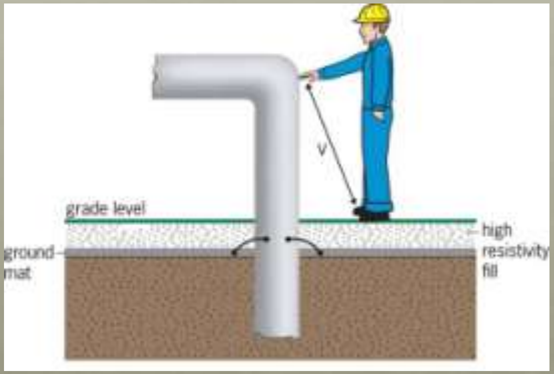
Over-Voltage Protection for CP Systems

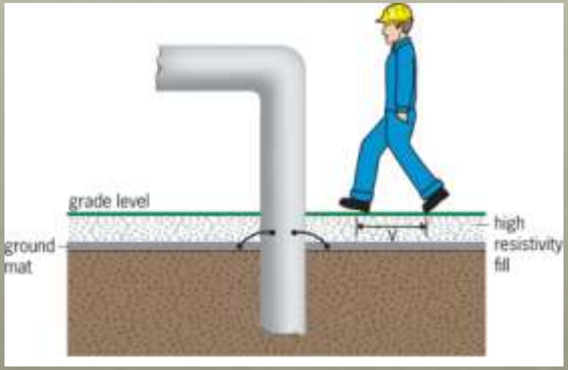
What Are We Protecting?

- Personnel (primary)
- Equipment (secondary)

Personnel Protection: Touch Potential



Personnel Protection: Step Potential



Equipment Protection

- Punctured coatings
- Breakdown of insulation
- Fuel ignition/explosion
- Equipment failure

Equipment Protection Example

From What Voltage Sources?

- Lightning (most difficult)
- AC power system faults*
- Induced voltage*
  - *If induced voltage is present, AC faults are then also of concern

Over-Voltage Protection Goal

- Minimize voltage difference between points of concern:
- Worker contact points
- Across insulated joints
- From exposed pipelines to ground
- Across electrical equipment insulation

Over-Voltage Protection Goal

- Different considerations apply for:
- Lightning
- AC faults
- Induced voltage

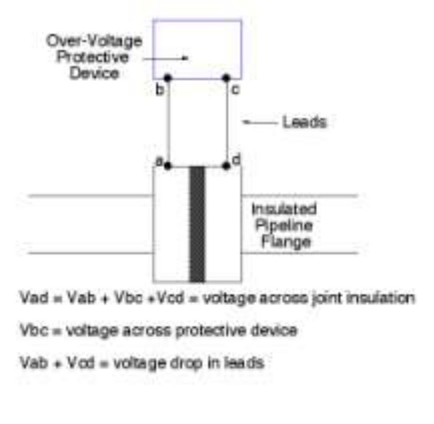
Lightning Protection: Primary Considerations

- Clamping voltage (C_{CV}) of protective device
- Voltage drop in connecting leads
  - Inductive voltage (V_{IV})
  - Resistive voltage (V_{RV})

Lightning Protection Voltage Level (V_{PV})

- $V_{PV} = V_{CV} + V_{RV\text{-lead}} + V_{IV\text{-lead}}$
- V_{CV} easily controlled by design
- $V_{RV\text{-lead}}$ easily controlled by design
- $V_{IV\text{-lead}}$ difficult to control

Voltage Across Flange Insulation Due to Lightning



Protective Device Clamping Voltage (V_{CV})

- <100V to ≈1000V typical values

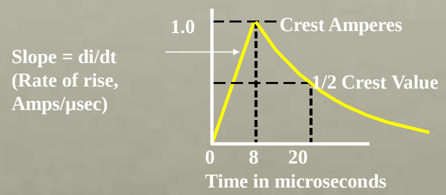
Resistive Voltage Drop (V_{RV})

- Easily made negligible relative to inductive voltage component
- Example:
  - Assume #4 copper conductor with R= 0.25milliohms/Ft.
  - Assume a 50kA peak lightning current.
  - Then IR = 12.5 V/Ft. or 41V/meter

Inductive Voltage Drop (V_{IV})

- V_{IV} = L (di/dt) where:
  - L = lead inductance, µH/ft
  - di/dt = rate of change of current, amps/microsecond

Lightning Characteristics



- Lightning has very high di/dt (rate of change of current)

Typical (V_{IV}) Parameters

- Lead inductance (L): 0.2µH/ft. typical
- Typical di/dt
  - 15,000A/µ-sec indirect lightning strike
  - 150,000A/µ-sec direct lightning strike

Protective Voltage (V_{PV}) Example

Assume:

V_{CV} = 300V

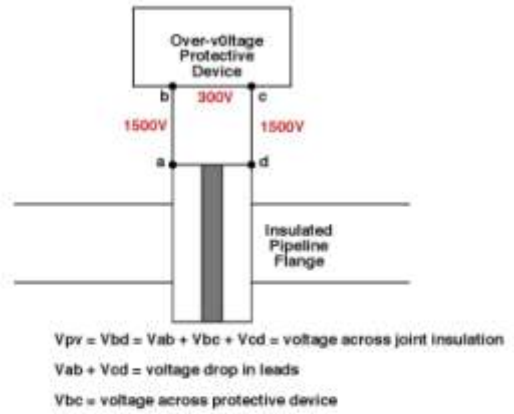
Lead inductance = 0.2µF/ft.

Total lead length = 1 ft. total

di/dt = 15,000A/µ-sec

Then V_{PV} = 300 + 0.2x15,000 = 3,300V

Voltage Across Flange Insulation Due to Lightning



For Best Protection

- Keep leads as short as possible
- Use multiple leads when feasible
- Use mounting kits furnished by mfg (minimizes inductance)

Insulated Joint Protection

Insulated Joint Protection

Insulated Joint Protection

Insulated Joint Protection

Similar Considerations Pertain To Personnel Protection From Lightning

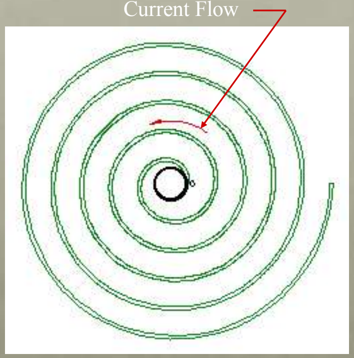
- When using gradient control mats to limit touch and step potentials
  - Mat inductance greatly affects both step and touch potentials
  - Inductance of lead connections to the mat affect touch potentials

Common Gradient Control Mat Designs

- Single conductor mat (spiral or zig-zag)
- Multi-conductor mat (grid type)

Single Conductor Spiral Mat

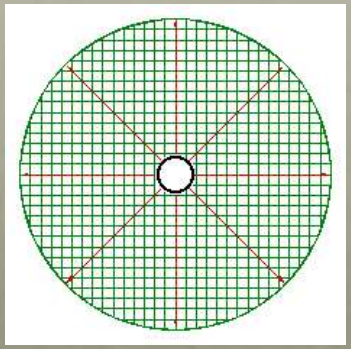
Current Flow



Pipe O.D. = 12”
Turn Spacing = 12”
Mat I.D. = 12”
Mat O.D. = 132”

Multi-Conductor Grid Mat

I (Radial Current Flow)



Pipe O.D. = 12”
Mat I.D. = 12”
Mat O.D. = 132”

Spiral Mat:

- 5 turns, 1 ft. turn separation, I.D. = 12”, O.D. = 132”
  - L = 0.2μF/ft.
  - $L_{(r=6" \text{ to } 18")} = 3.2 \times 10^{-6}$ H
  - $L_{(r=18" \text{ to } 30")} = 10.27 \times 10^{-6}$ H
  - L increases with radial distance

Grid Mat

- 2” x 2” grid, I.D. = 12”, O.D. = 132”
  - $L = 21.74 \times 10^{-9}$ H/Square
  - $L_{(r= 6" \text{ to } 18")} = 3.8 \times 10^{-9}$ H
  - $L_{(r= 18" \text{ to } 30")} = \times 1.77 \times 10^{-9}$ H
  - Decreases with radial distance

Spiral Mat Ldi/dt Values

- $L_{(r=6" \text{ to } 18")} = 3.2 \times 10^{-6}$ H
- $L(di/dt) = 3.2 \times 10^{-6} \times 1.5 \times 10^{10} = 48$kV

Or

- $L(di/dt) = 3.2 \times 10^{-6} \times 1.5 \times 10^{11} = 480$kV
- L(di/dt) *increases* with with each 12" radial increment (each turn)

Grid Mat Ldi/dt Values

- $L_{(r=6" \text{ to } 18")} = 3.8 \times 10^{-9}$ H
- $L(di/dt) = 3.8 \times 10^{-9} \times 1.5 \times 10^{10} = 57$ V

Or

- $L(di/dt) = 3.8 \times 10^{-9} \times 1.5 \times 10^{11} = 570$ V
- L(di/dt) *decreases* with each 12"radial increment

Spiral vs Grid Mat Comparison

- Touch and Step Potential Ratios
- Spiral/Grid Ratio (r = 6" to r = 18")
  - 48kV/57V = 842:1
  - Increases with each 12" increment

Spiral Mat Touch & Step Potentials (For di/dt = 1.5×10^{10} A/µ-sec)

Radial Distance (In.)	Touch Potential (kV)	Step Potential (kV/ft)	Step Potential (kV/m)
6	0	0	0
18	48.04	48.04	157.6
30	154	105.96	347.5
42	310.5	156.3	512.7
54	506.7	196.3	643.9
66	725.9	219.9	718.9

For di/dt = 1.5×10^{11}, multiply all potentials by 10

Note: Potentials in kV

Grid Mat Touch & Step Potentials (For di/dt = $1.5x10^{10}$ A/µ-sec)

Radial Distance (In.)	Touch Potential (V)	Step Potential (V/ft)	Step Potential (V/m)
6	0	0	0
18	57	57	187
30	83.4	26.4	86.6
42	101	17.6	57.7
54	114.5	13.5	44.3
66	124.3	9.8	35.2

For di/dt = $1.5x10^{11}$, multiply all potentials by 10

Note: Potentials In Volts

Ratio of Step & Potential Ratios Spiral vs Grid Mat

Radial Distance (In.)	Spiral/Grid Ratio
6	0
18	843
30	1847
42	3074
54	4425
66	5840

For di/dt = $1.5x10^{11}$, ratios remain unchanged

Over-Voltage Protection From Lightning-Key Factors

- Inductance of current flow path
- Lead inductance/length
- When over-voltage protection from lightning is provided, over-voltage protection from AC faults is also provided

Over-Voltage Protection Products

Desired characteristics:

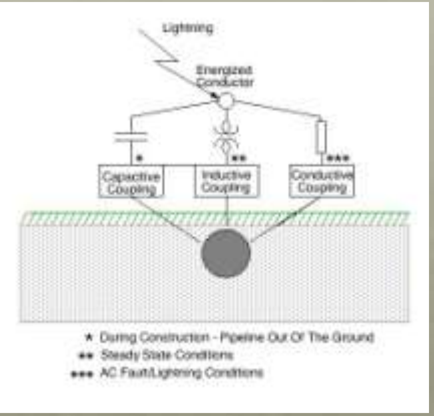
- Lowest clamping voltage feasible
- Designed for installation with minimal lead inductance & minimal lead length
- Fail-safe (fail “shorted” not “open”)
- Provide over-voltage protection for both lightning ***and*** AC faults

AC Voltage on Pipelines

AC Voltage Sources

- Capacitive, conductive, and magnetic coupling to an adjacent power line
- Lightning strike to adjacent power line or near a pipeline

AC Voltage Sources



Capacitive Coupling

- A potential shock hazard
  - Only of concern during pipeline construction when pipeline is above ground
- Ground pipeline to eliminate

Conductive Coupling

- A potential shock hazard
- Of concern when:
  - An AC fault occurs on adjacent electric power line and
  - Pipeline is located close to electric power line tower
- May damage pipe wall and coating
- Maximize distance from power line towers

Conductive Coupling

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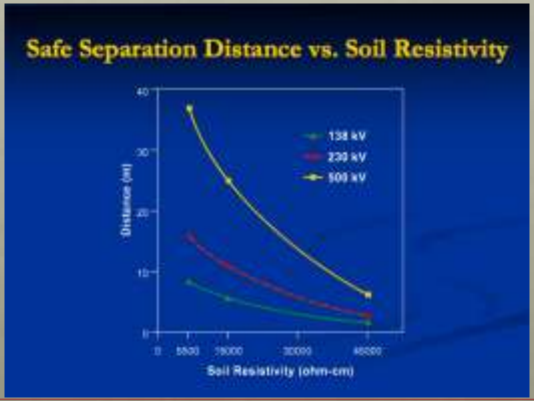

Magnetic Coupling

- Primary source of what is normally considered "induced voltage"
- A potential shock hazard
- Readily mitigated
- May also cause AC corrosion of pipeline

Lightning Strike To Power Line Adjacent to A Pipeline

- A potential shock hazard
  - Due to significant rise in earth potential transferred to adjacent pipeline
- Can readily over-stress (damage) pipeline coatings, joint insulation, etc.
- More difficult to mitigate

Magnetically Induced Voltage

- Typical voltages range from a few volts to about 100 volts
- Voltages over 15V should be mitigated (NACE)
- May be necessary to mitigate below 15V to prevent AC corrosion

Magnetically Induced Voltage

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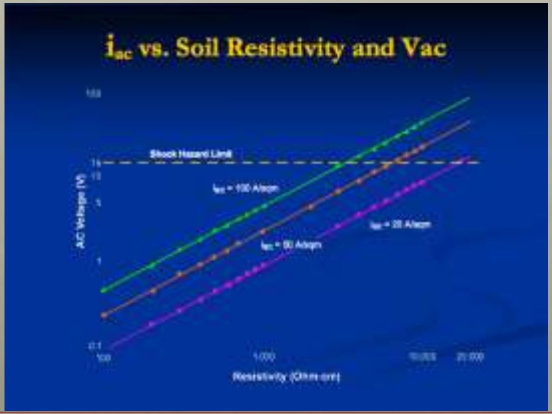

Magnetically Induced Voltage

Key Factors

- Proximity to power lines
- Power line loading (current magnitude)
- Quality of pipeline coating

Why Mitigate Induced Voltage?

- To protect personnel from electric shock
- To prevent damage to pipelines, coatings, and other pipeline equipment
- To prevent AC corrosion

Mitigation Techniques

- Spot mitigation
- Continuous mitigation
- Both approaches require a grounding system
  - Depending on grounding system material:
    - May be direct connected to pipeline

    or
    - Decoupled from pipeline

Spot Mitigation

- Used to reduce pipeline potentials at accessible locations (e.g. valve sites)
- Less costly than continuous mitigation
- Grounding system may consist of:
  - Magnesium or zinc, direct bonded or decoupled
  - Pipeline casings, copper, etc., must be decoupled
  - Gradient control mats, direct bonded or decoupled depending on material

Continuous Mitigation

- Used to reduce pipeline potentials at all locations
- Limits voltage stress on coatings to safe levels (primary advantage)
- Requires a continuous grounding system (typically zinc ribbon or copper)
- Design requires specialized software

Considerations: Direct Bonded vs Decoupled Grounding System

- Ability to take instant-off pipeline potential readings
- Decoupled-may required a “delayed-off” measurement or use of coupons
- Ability to achieve desired CP
- Stray DC current
- Mitigation costs

Mitigating Induced AC Using A Decoupler

- A commonly asked question:

  How can a decoupler with a 2V or 3V blocking voltage be used with 30Vac on a pipeline?

Example: Pipeline with Induced AC Voltage

- Open-circuit induced AC on a pipeline = 30 volts
- Short-circuit current = 10 amperes (to mitigation grounding system)
- Given the above, then the circuit impedance is 30V/10A =or 3 Ohms
- What is the effect of connecting the pipeline to the grounding system through a decoupler?

Example: Pipeline with Induced AC Voltage - continued

- Typical decoupler ac impedance Xc: Xc = 0.01 ohms
  Because the device impedance is insignificant compared to the 3 Ohm circuit impedance, the current to ground remains ≈ 10 amps
- V(pipeline-to-grounding system) = I • Xc
- I • Xc = 10 • 0.01 = 0.1 volts
- Result: Induced AC reduced from 30V to 0.1V with respect to grounding system (well below decoupler blocking level). Will be higher to adjacent earth.

Mitigating Induced AC

- Example applies to either spot or continuous mitigation
- A decoupler provides the greatest flexibility with any mitigation method

  but

- May required an alternate procedure* to determine true polarized pipe potentials

  * A delayed “off” measurement or use of coupons may be required

Mitigating Induced AC Voltage

Mitigating Induced AC Voltage

Hazardous Locations Class I, Div. 1 or Class I, Div. 2

Hazardous Locations

- Many applications described are in Hazardous Locations as defined by NEC Articles 500-505
- Pipeline Safety Regulations incorporate National Electric Code “By Reference”

Pipeline Safety Regulations Section 192.467

(e) “An insulating device [insulated joint] may not be installed where combustible atmosphere is anticipated *unless precautions are taken to prevent arcing*.”

Pipeline Safety Regulations Section 192.467, continued

(f) “Where a pipeline is located in close proximity to electric transmission tower footings

. . . it must be provided with protection against damage due to fault current or lightning, and
protective measures must be taken at insulating devices [insulated joints].”

Hazardous Locations

The products [not just enclosure] must be certified for the application and installation location

- Codes:
  - NEC Articles 250.2, 250(4)(A)(5), 250-6(E) and 500-505
  - Pipeline Safety Regulations § 192.467

Summary

Certified decouplers are available for:

- Over-voltage protection
- Voltage mitigation
- For grounding electrical equipment in compliance with electric codes
- In ordinary and hazardous locations

Conclusion

- Products are available or can be tailored for most applications
- Guidelines available for product application and model/rating selection

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