

Gradient Control Mats in Pipeline Applications



Introduction

Gradient control mats are installed around above ground pipeline structures to protect workers from potentially hazardous voltages that can be present on cathodically protected pipelines. Pipeline voltages can result from the following:

- When a pipeline is in an AC electric power line corridor, current flow in the power line can induce an AC voltage on the pipeline due to magnetic coupling. More notably, a phase-to-ground fault in the power line or a lightning strike to the power line can cause a significant rise in the earth potential around the base of the power line support tower and transfer this voltage to the pipeline.
- An AC fault in improperly grounded electric equipment that is an integral part of a pipeline can raise the pipe potential to unsafe levels.
- A lightning strike directly to or adjacent to a pipeline can transfer an unsafe potential to the pipeline.

These voltage sources can be divided into two categories; namely, voltages that occur at the power frequency (i.e., 50 or 60 Hz) and voltages due to lightning or power system transients. Reducing power frequency voltages to safe levels is easily accomplished whereas limiting voltage due to lightning is considerably more difficult, but achievable at no additional cost with a properly designed and installed gradient control mat.

The effectiveness of any gradient control mat is determined by the step potential and the touch potential that it allows for the two categories of voltage sources described. IEEE 80 is the standard most commonly used to define allowable step and touch potentials due to power frequencies. Very often, gradient control mats

are only designed to meet the IEEE 80 criteria and the effects of lightning are ignored, yet any pipeline subject to induced voltage is also subject to the effects of lightning and switching transients. For DC and higher frequency voltage sources, which include lightning, an International Electrotechnical Commission (IEC) Publication 479-2, entitled “Effects of Current Passing Through the Human Body” deals with alternating current with frequencies above 100Hz, for special waveforms of current, and for unidirectional single impulse currents of short duration. Any gradient control mat that is designed and installed to limit lightning induced voltages to safe levels will inherently limit power frequency voltages to safe levels provided the connections to the mat and the mat itself can carry the fault current that may be shunted to ground through the mat.

In conducting an analytical study of commercially available gradient control mat designs several factors became apparent; (1) No known manufacturer of gradient control mats provided any technical information on the effectiveness of their mat in limiting step and touch potentials to safe levels for any voltage source, and (2) single conductor mats, such as the spiral configuration mat, were found completely ineffective in limiting step and touch potentials from lightning to safe levels. To fill this void, DEI has introduced a gradient control mat that addresses all key issues. For an analytical review of the difference in performance of common gradient control mat designs, see NACE 2005 Paper #05617 available on DEI’s website, www.dairyland.com. Following is a comparison of the 3” x 3” grid type mat offered by DEI and a single conductor spiral mat with a 12” radial separation between turns.

Table 1

Touch and Step Potentials vs. Radial Distance from Pipe Centerline For the Grid Type Gradient Control Mat With 3" x 3" Grid, 0.135" Wire Diameter

Radial Distance Inches (mm)	Touch Potential, V di/dt = 1.5 x 10 ¹⁰ A/sec	Step Potential Volts/ft (V/m)	Touch Potential, V di/dt = 1.5 x 10 ¹¹ A/sec	Step Potential Volts/ft. (V/m)
6 (152mm)	0	0	0	0
18 (457mm)	78	78 (256)	780	780 (2560)
30 (762mm)	114	36 (118)	1140	360 (1180)
42 (1066mm)	138	24 (79)	1380	240 (790)
54 (1372mm)	155	17 (56)	1550	170 (560)
66 (1676mm)	170	15 (49)	1700	150 (490)

The di/dt value in column two is representative of an indirect lightning strike and the di/dt value in column four is representative of a direct lightning strike to a pipeline. Note that the units are in volts. Each touch potential value shown will be increased by the inductive voltage drop in the leads used to connect the mat to the pipeline (hence, these leads must be kept as short as possible), but all step potentials remain the same.

Table 2

Touch and Step Potentials vs. Radial Distance From Pipe Centerline For the Spiral Type Gradient Control Mat With 12" Turn Separation

Radial Distance Inches (mm)	Touch Potential, kV (di/dt = 1.5 x 10 ¹⁰ A/sec)	Step Potential Volts/ft (kV/m)	Touch Potential, kV (di/dt = 1.5 x 10 ¹¹ A/sec)	Step Potential Volts/ft. (kV/m)
6 (152mm)	0	0	0	0
18 (457mm)	48.04	48.04 (158)	480.4	480.4 (1576)
30 (762mm)	154.0	105.9 (348)	1540	1059 (3475)
42 (1066mm)	310.5	156.3 (513)	3105	1563 (5127)
54 (1372mm)	506.7	196.3 (644)	5067	1961 (6439)
66 (1676mm)	725.9	219.2 (719)	7259	2191 (7189)

The di/dt value in column two is representative of an indirect lightning strike and the di/dt value in column four is representative of a direct lightning strike to a pipeline. Note that the units in Table 2 are in kV, not volts as in Table 1. In reality, voltages of these magnitudes would not be supported turn-to-turn, and arcing would take place before these levels were reached.

Table 3

Ratio of Touch and Step Potentials for the Spiral versus Grid Type Gradient Control Mat

Radial Distance inches (mm)	Spiral/Grid Ratio for di/dt = 1.5 x 10 ¹⁰ A/sec	Spiral/Grid Ratio for di/dt = 1.5x10 ¹¹ A/sec
6 (152mm)	0	0
18 (457mm)	616	616
30 (762mm)	1351	1351
42 (1066mm)	2250	2250
54 (1372mm)	3269	3269
66 (1676mm)	4270	4270

Note that the di/dt ratio does not affect the performance difference between mats. Table 3 shows how many times greater the touch or step potentials are for a spiral mat than a 3" x 3" grid mat at a given radial distance from the centerline of the pipe. Similar results will be obtained for any single conductor type mat because the inductance in the current flow path (and hence, the voltage gradient) will always be orders of magnitude greater than for a grid type mat.

Physiological Effects

The physiological effects of short duration voltage and current pulses on humans are documented in Reilly, J. P., Electrical Stimulation and Electropathology, Cambridge University Press, New York, N.Y., pp 48, 442 and 445. For short duration (several microsecond) inductive voltage spikes expected on the mats, the currents required for fibrillation are on the order of 100 amperes. Measured impedances of humans place their typical impedance at about 300 ohms, with some impedances as low as 20 ohms. At 20 ohms, the 100 ampere limit would place the allowable surge voltage at 2kV. In an actual installation, considering that the mat will be covered with crushed limestone (assuming recommended installation procedures are followed) and considering that a worker will be wearing footwear, the impedance will be considerably greater than 20 ohms value, thereby increasing the allowable peak voltage.

DEI's analysis indicates that a grid type mat with a 4" x 4" grid spacing or less and connected with very short leads to the pipeline will limit step and touch potentials to safe levels for workers for the vast majority of

voltages that may be imposed on a pipeline.

Decoupling

While the mat may be directly connected to the pipeline or decoupled, it is recommended that the mat be connected to the pipeline through a new, low cost Solid-State Decoupler (SSD) developed by DEI for this purpose. See the DEI literature on the SSD for models available. Decoupling offers a number of distinct advantages; namely, the galvanic potential of the mat material becomes irrelevant, pipeline CP readings can be taken in the vicinity of the mat, any interaction with the pipeline CP system is eliminated, and the life of the anodes used to protect the mat is significantly increased.

Conductor Length Issues

As described in other DEI documents, conductor (or lead) length plays a significant role in determining the touch potential between any two connected points, in this case between a pipe and gradient control mat. Lead lengths must be kept very short in order to achieve acceptable touch potentials - on the order of inches. This is due to the inductance added with increasing lead length, which can be controlled by shortening the length, and by adding an additional conductor in parallel. As an additional conductor may be needed in parallel for ampacity reasons anyway, this has a side benefit of lowering the inductance. Note that only touch potentials are affected by lead length, and step potentials remain unaffected, as this relates to properties of the mat alone. Contact DEI if additional information is needed.

Conclusion

DEI's analysis indicates that a grid type mat with a 4" x 4" grid spacing or less and connected with very short leads to the pipeline will limit step and touch potentials to safe levels for workers for the vast majority of voltages that may be imposed on a pipeline, whether due to power frequency voltages or lightning.