ENGINEERING REPORT
PHASES I & II
MITIGATOR PERFORMANCE TESTS

INDUCED AC MITIGATION PERFORMANCE
ON A STEEL GAS TRANSMISSION PIPELINE

REPORT OF JANUARY 29, 2014

Table of Contents

EXECUTIVE SUMMARY

Phase I

1. Independent tests were conducted with National Grid, an electric and gas utility, to determine the performance characteristics of the MATCOR Mitigator AC mitigation system versus bare copper cable in mitigation of AC induced corrosion and shock potential.
2. Bare copper and two types of Mitigator grounding systems (one with AWG #2 copper cable and one with AWG #1/0 copper cable) installed below a 345 KV overhead AC electric transmission power line on a fully functioning 12-inch, steel gas transmission pipeline in northern New York State.
3. The MATCOR Mitigator showed a 28% improvement over the bare copper system in lowering the induced AC voltage on the steel gas transmission pipeline.
4. There was almost no difference between the Mitigator with AWG 1/0 and the Mitigator with AWG #2 in lowering induced AC voltage.

Phase II

1. The second set of independent tests with National Grid determined the performance characteristics of the MATCOR Mitigator AC mitigation system versus bare copper cable and zinc ribbon anode in mitigation of AC induced corrosion and shock potential.
2. Bare copper cable, MATCOR Mitigator and zinc ribbon anode installed below a 345 KV overhead AC electric transmission power line on a fully functioning 12-inch, steel gas transmission pipeline in northern New York State.
3. The MATCOR Mitigator showed an average of 39% improvement over the bare copper system and an average of 22% improvement over the zinc ribbon anode system in lowering the induced AC voltage on the steel gas transmission pipeline.

INTRODUCTION

Corrosion of steel by alternating current can occur as a result of electromagnetic (inductive) coupling. Voltage and current from overhead electrical lines can be electromagnetically induced on a steel pipeline, especially when the pipeline parallels the overhead electric corridor for a significant length.

Corrosion from induced AC current can cause corrosion failures of the steel pipeline(s) even if there is a functioning cathodic protection system.

The conventional methods used for the mitigation of the AC voltage are to bury a bare copper cable or a zinc ribbon anode adjacent to the steel pipeline being adversely affected by the overhead electric transmission lines. The copper line or zinc ribbon is then connected to the steel pipeline through one or more decouplers. The solid state decoupler functions as a DC isolation and AC coupling device preventing the flow of cathodic protection (CP) current up to a predetermined voltage threshold, while passing any induced AC to the Mitigator system, bare copper ground cable or the zinc ribbon anode. The decoupler permits safe passage of the AC current while maintaining the cathodic protection system for the intended pipeline.

While the copper ground cable and the zinc ribbon anode have been beneficial in reducing the induced AC voltage, newer mitigation systems have been developed that showed promise in improving the reduction of AC voltage. National Grid, in conjunction with MATCOR, Inc. conducted two test programs: Phase I to compare two versions of MATCOR's MITGATOR grounding system to the copper grounding system used on National Grid's pipelines, and Phase II to compare the Mitigator to the copper cable ground and the zinc ribbon anode used as a ground cable.

The pipeline selected is in New York State with the following characteristics:

- Pipeline installed in 1991
- 12-inch diameter high pressure transmission pipeline
- Extruded polyethylene mainline coating
- A functioning galvanic cathodic protection system was installed and maintained since the pipeline was built
- Up to 80 volts of induced AC voltage measured in the winter peak load conditions
- In 2002, the pipeline had a documented leak believed to be due to AC corrosion

- 2,500 foot length of AWG # 2/0 bare copper grounding cable connected through a solid state coupler to the pipeline installed in 2003 to mitigate the AC corrosion voltage
- Test results reported in October 2013

The acceptable AC current density of 20 amp/m^2 and step touch potential limits of 15 volts AC on the pipeline were exceeded in late 2012 due to increasing overhead electric loads. The measurements are shown below. The original existing bare copper/decoupler mitigation was no longer sufficient and required improvement. National Grid agreed to cooperative comparative testing with both the bare copper and two versions of the Mitigator grounding systems.

Test Station	**AC Potential**	**Soil Resistivity**	**Current Density**
	(volts)	(ohm-m)	(A/m^2)
North Device	2.36	344.6	1.74
South Device	**15.6**	**130.2**	**30.50**
TS #24	6.5	130.2	12.7
TS #30	1.7	842.6	0.50
TS #36	1.87	160.8	2.96
TS #89	10.5	107.2	24.9
TS #48	16.3	95.75	43.50

Notes:

1. South device was the location selected for the Mitigator tests.
2. Locations highlighted in yellow exceed the recommended current density levels of 20 amps/m^2.

TEST PROCEDURES

The test configuration is shown on Figure 1 in this paper.

The test was to compare the performance of the existing #2/0 bare copper grounding cable with two types of the MATCOR Mitigator grounding system.

The Mitigator is manufactured system that consists of a copper cable packed in a continuous flexible cloth tube filled with conductive backfill employing copper corrosion inhibitors. The final manufactured diameter of the Mitigator was approximately 1.5-inches (38 mm) for both versions of the Mitigator tested. Two sizes of Mitigator were used in the test: one with an AWG #1/0 bare copper cable and one with AWG # 2 bare copper cable. Both sizes have the same electrode to ground resistance and are manufactured the same with identical fabric and backfills. The two sizes were both tested in 1,250 ft. lengths.

The two lengths of Mitigator were placed parallel to the existing bare copper grounding cable and to the overhead power line. The Mitigator A (#1/0) and Mitigator B (#2) were placed in-line to create a 2,500 ft. long total length. Mitigators A & B were installed so that the effect of each individually, or together, could be measured. All other components such as the galvanic cathodic protection system and existing bare copper grounding were not changed and remained operating.

The Mitigator sections were installed in October 2012 and the field tests for this report were completed in December of 2012. However, ongoing monitoring continues.

Measurements taken on each section of grounding at existing test stations included:

- Induced AC voltage on the pipeline
- Current flow, in amps, through the grounding systems.

Measurements taken on the following grounding systems configurations:

- The copper grounding system alone
- The Mitigator A alone
- The Mitigator B alone
- The Mitigator A & B connected to serve as one 2,500 piece
- Mitigator A & B connected to the bare copper grounding system

A second testing goal was to determine if there was any measureable difference between the use of Mitigator A and B. If there was no significant difference between the two sizes, then a cost savings could be achieved by using Mitigator B.

Phase II Installation:

- Three sections of zinc ribbon, copper cable and Mitigator. Each section was 333 ft. long. See Figure 2 for the installation details.
- The test results were reported in December 2013

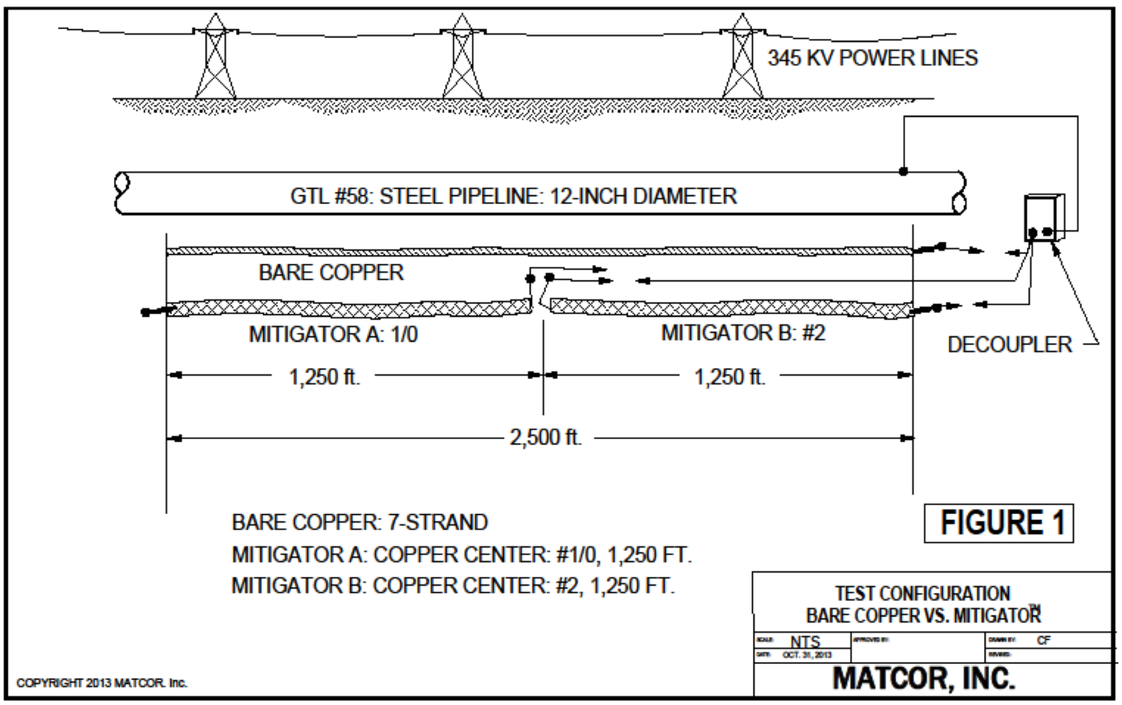
Phase II Installation and Results:

Once the results of Phase I were known and it was known that the Mitigator outperformed the bare copper cable, the next phase of the testing was done to test the Mitigator against the zinc ribbon anode as well as to continue to test against the bare copper cable.

The test site arrangement for the Phase II test is shown on Figure 2 and consisted of three sets of zinc ribbon anode, bare copper cable and the Mitigator (AWG #2 only). Each section had 333 ft. of each grounding material. Tests were conducted with just Segment 1 connected, then with Segments 1 & 2 connected and finally with segments 1, 2 & 3 connected together. Measurements were made at three locations along the pipeline. The tests were conducted on the same pipeline as in phase I.

The measurements were made with a calibrated Fluke meter. All measurements were taken by the operator's representative, a NACE qualified corrosion technician.

PHASE I TEST RESULTS



The following is a summary of the measured test results:

Connection	Length (ft.)	AC Volts	Current in Amps
No Connection-No grounding	-	52	-
Bare Copper: Existing	2,500	9.5	53.7
Mitigator A	1,250	17.5	46.3
Mitigator B	1,250	15.9	46.2
Mitigator A & B combined	2,500	6.8	63.8
Mitigator A & B and bare copper	5,000	6.4	63.8

Continuing measurements are in the above reported range.

PHASE II TEST RESULTS:

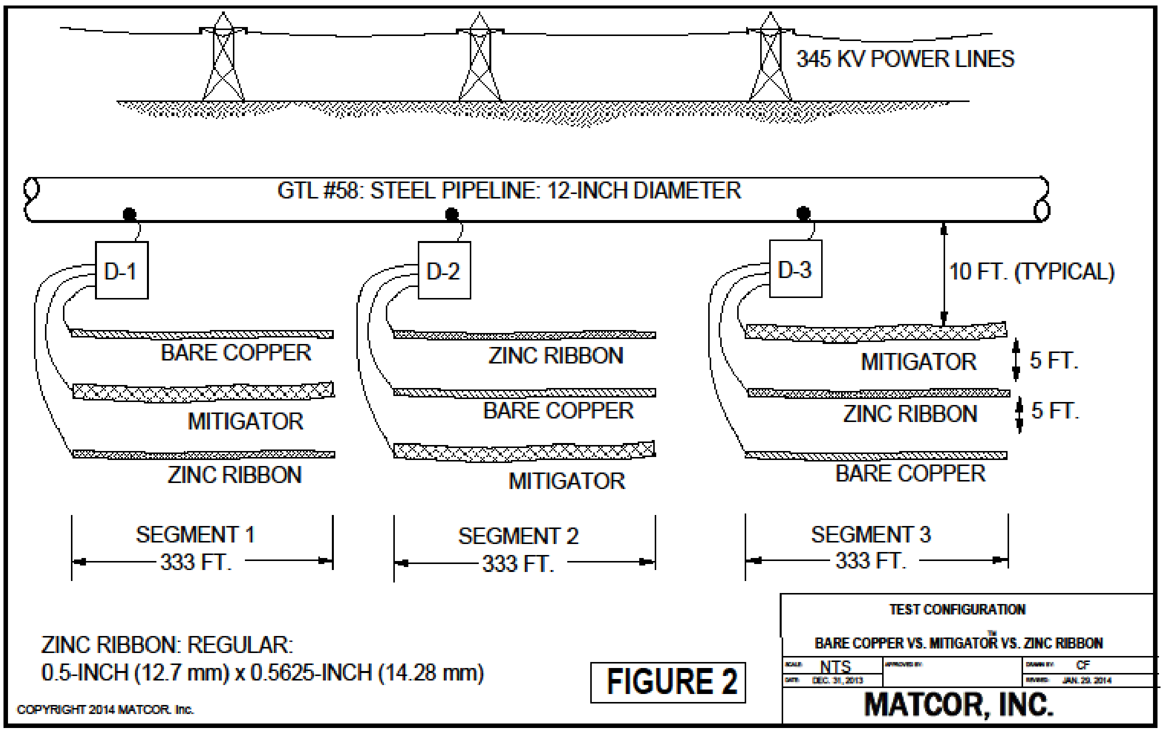


FIGURE 2

The following is the summary of the test results:

A. Pipe ungrounded: max value 38.96 VAC

B. Segment 1 connected-333 feet

COMPONENT	Location D-1		Location D-2		Location D-3	
	AC Volts		AC Volts		AC Volts	
MITIGATOR	12.03		15.46		14.67	
BARE COPPER	20.99		22.83		22.58	
ZINC RIBBON ANODE	16.36		16.94		19.83	

C. Segment 1 & 2 connected-666 feet

COMPONENT	Location D-1		Location D-2		Location D-3	
	AC Volts		AC Volts		AC Volts	
MITIGATOR	10.6		9.3		26.21	
BARE COPPER	17.99		18.6		27.78	
ZINC RIBBON ANODE	13.94		14.29		27.14	

D. Segment 1, 2 & 3 Connected-999 feet

COMPONENT	Location D-1		Location D-2		Location D-3	
	AC Volts		AC Volts		AC Volts	
MITIGATOR	8.96		8.13		8.58	
BARE COPPER	16.2		16.9		16.75	
ZINC RIBBON ANODE	12.49		9.02		14.32	

Data reported to MATCOR by National Grid.

CONCLUSIONS

Phase I:

As can be seen in the above data summary, the following conclusions are apparent:

1. The combined Mitigators or a total length of 2,500 ft. of the Mitigator showed a significant reduction in induced AC current over an equal length of bare copper. The equivalent length of Mitigator had a 28% improvement in lowering the induced AC voltage on the pipeline.
2. There was a significant improvement in current flow with the Mitigator vs. the bare copper.
3. There is no significant difference between using Mitigator A or Mitigator B. The less expensive Mitigator B can be used for most applications.
4. There was no significant improvement in performance by adding the bare copper system to the Mitigator system.

Phase II:

1. The Mitigator continued to show a significant reduction in induced AC current over the bare copper cable. The average improvement was 39% in lowering the induced AC voltage on the pipeline.
2. The Mitigator showed an average of 22% improvement in lowering the induced AC voltage on the pipeline over the bare zinc ribbon anode.

Summary:

The use of the Mitigator can greatly increase the performance of the grounding system when an equal length of Mitigator is used versus a bare copper ground cable or a zinc ribbon anode. Furthermore, shorter lengths of Mitigator can achieve the same results as longer lengths of bare copper cable or zinc ribbon. However, the model will dictate the required length of grounding system.

APPENDIX A

Investigations on the severity of AC corrosion date back to the early 1900's. Only recently was consensus reached on one important factor whose importance cannot be disputed, the effect of AC current density. AC current density for a steel pipeline is calculated for a circular coating holiday (bare spot), by combining the formula for resistance and surface area of a circular disk with ohms law:

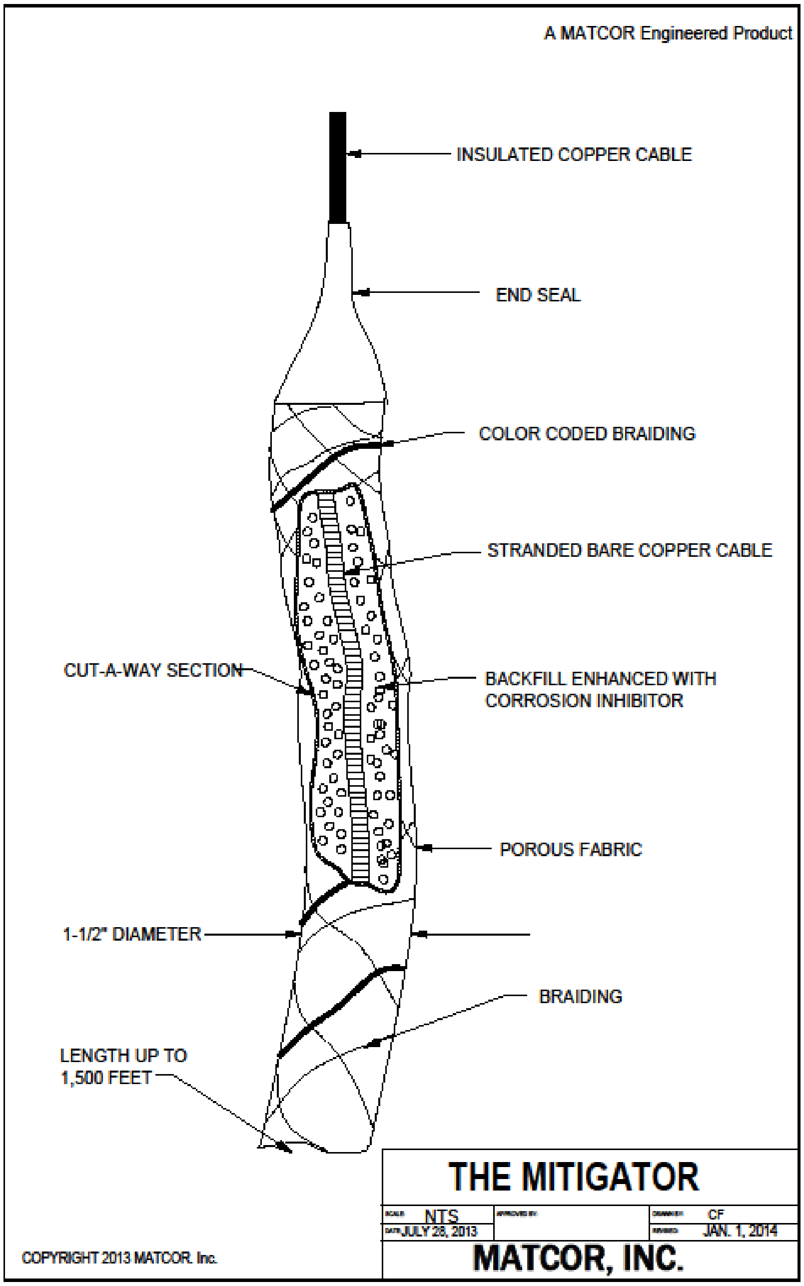
$$AC_{\gamma}\ (A/M^2) = \frac{\overset{\text{Volts}}{V_{AC}} \times 8}{\pi \times \underset{\text{Soil resistivity}}{p} \times \underset{\text{Coating holiday}}{d}}$$

- VAC represents the measured induced AC voltage on the steel pipeline
- AC current density less than 20 a/m^2 equates to no corrosion, while AC current densities above this limit will lead to unpredictable corrosion (above 100 a/m^2 corrosion is to be expected)*
- p: soil resistivity
- d: default diameter for coating holiday (0.011m)

* Per NACE published guidance

To maintain AC current density at acceptable levels, per the above equation there are only two controlling variables: the induced AC voltage on the steel pipeline and soil resistivity. Since we cannot easily alter the environment/soil that surrounds the pipeline, we elect instead to safely lower the induced AC voltage via an effective grounding system. This is accomplished by the installation of ground electrodes and decouplers.

APPENDIX B
MATCOR MITIGATOR



For additional information, see www.matcor.com