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Direct Lightning Withstand of Corrugated Stainless Steel Tubing for Gas

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***Abstract*—Corrugated stainless steel tubing (CSST) is used in many countries throughout the world as a practical way to distribute gas within houses and other installations. CSST has become very popular in some countries as it is a very thin and thus flexible tube that allows for easy installation in crawl spaces, inside walls, and in the attic. A link between lightning activity and fires involving CSST piping has been reported in the United States as early as 2003. Damages documented to CSST generally result in one or more holes in the wall of the pipe leading to a release of gas into the structure with no fire to fire with minimal damage and in some cases complete destruction of the structure. Many experts have studied this subject and many scenarios have been established to explain the failure modes. A few reports exist and are summarized in the paper. This paper will then mainly concentrate on case studies and on test results for one scenario that has been almost ignored: partial lightning current flowing**

Keywords-CSST;gas, corrugated; lightning; field experience; fire; tests

I. INTRODUCTION

Corrugated stainless steel tubing (CSST) is used in many countries throughout the world as a practical way to distribute gas within houses and other installations. The length of CSST may be short, connecting a fixed metal pipe to appliances, or may be long if it is used as the primary gas distribution method inside a house. In the latter case, the transition between metallic pipe on the supply side of the service entry and CSST piping could occur at the regulator/meter or at a manifold where CSST piping distributes gas to individual points of utilization. Where CSST is utilized between the service entry point and the first manifold, the CSST piping can be tens of meters in length.

CSST has become very popular in some countries [1],[2],[3] as it is a very thin and thus flexible tube that allows for easy installation in crawl spaces, inside walls, and in the attic. The use of CSST allows for inexpensive installation of gas utilization devices at any location throughout the structure. CSST is protected by an insulating jacket and for some products by a proprietary jacket designed for the purpose of a better behavior in a lightning environment.

Figure 1. Location of CSST Damage Near a Strap Connected through a Concrete Footing

A link between lightning activity and fires involving CSST piping has been reported in the United States as early as 2003. Damages documented to CSST generally result in one or more holes in the wall of the pipe leading to a release of gas into the structure with no fire, to fire with minimal damage, and in some cases complete destruction of the structure.

II. CASE STUDIES

We first present possible explanations from various authors that have studied this phenomenon (theoretical studies, laboratory studies or forensic evaluations of sites experiencing some type of damage to CSST piping) [4],[5],[6],[7],[8],[9],[10],[11],[12],[13],[14]. We then present two case studies by the authors that will illustrate the problem. In Case 1, we will discuss an incident occurring as a result of a direct strike to an unprotected structure. In Case 2 we will discuss damages to a structure protected by a UL Master Label lightning protection system which experienced two lightning events in an 8 month period. It should be understood that many have studied lightning damage to CSST but little has been published so far; mainly due to the fact that much data is proprietary information or related to litigation.

A. *Possible explanations*

Many experts in the USA have studied the link between lightning and CSST damage and have confirmed lightning occurrence in the vicinity of the damaged installation through the use of national lightning location networks or eyewitness reports. For all the observed damages for which a thorough analysis has been reported, one or more holes have been observed in the wall of the CSST. There have been many scenarios discussed to explain this type of damage. Some of these scenarios are discussed below. One such explanation for scenarios where the CSST supplies gas utilization devices providing grounding through the electrical service is that induced surges occurring on power lines allow a sparkover between the internal power lines and a nearby grounded CSST pipe. The overvoltage should then be high enough to puncture the insulating jacket. The power follow current from the power source then flows through this arc to ground allowing the AC current to create the resulting hole and ignite the gas leaking from the hole. Another scenario is that a surge current occurs on the CSST piping through the gas supply and the sparkover occurs between the CSST and a metallic grounded element (frame of structure, chimney etc.). The charge associated with the surge current could be large enough to create the hole and ignite the gas. One expert has discussed the fact that the corrugated shape of CSST may have a high frequency behavior that may create a sparkover between two ridges when lightning surge occurs. This, in conjunction with a minimum bend radius could explain the presence of adjacent holes observed for some CSST damages.

An additional scenario for damages could be a direct strike to houses (with or without lightning protection system) and sparkover to CSST with enough charge due to the direct lightning event to create a hole or numerous holes and ignite the gas.

Figure 2. View of damaged CSST near two insulated vertical pipes below horizontal electrical cables and metallic water pipe

B. *Case Study N°1*

In this case, the structure was located in a densely populated development in a suburban community in the southeastern United States. The structure is a 3-story wood-framed single family dwelling with municipal gas service. All utilities entered the structure underground. There is a significant amount of CSST piping throughout the structure with the transition from iron pipe coming from the regulator to CSST immediately upon entry in the crawl space below the home. There are multiple manifolds in the crawl space with CSST runs to the kitchen, a gas fireplace, and significant distances to a gas grill on the patio and gas furnace, water heater and clothes dryer on the 3rd floor.

The family was home at the time of the incident, sitting on the screened back porch watching a storm move into the area, estimating its distance using the flash-to-bang technique. They experienced what they determined to be a direct strike to the home and immediately entered the home to look for any indication of damage. As he reached the top floor of the structure, the homeowner noted a small fire in the vicinity of the water heater and began to try to extinguish it while other family members notified the fire service. Upon reducing the intensity of the initial fire, additional fires were noticed in the wall leading to the room containing the clothes dryer and in a utility room on the other side of the water heater which contained the gas furnace.

A review of the evidence indicated there were numerous holes in each of two CSST pipes in the proximity of the origin of the fire. Evidence supported by data from the National Lightning Detection Network (NLDN) suggests that there was a -12.3 kA lightning strike to the vent pipe shown in Figure 3 which was attached to the water heater. The water heater had no electrical service but was provided with copper water lines. There was evidence of arcing at the screws attaching the vent pipe to the water heater and from the feet of the water heater to the metal catch pan on which it was installed.

The gas supply to the water heater was provided by a T-connection with one side coming from the utility room and the other continuing into the laundry room. It is surmised that the CSST piping on both sides of the water heater experienced a significant portion of the lightning current through the piping and finding the path to ground through the electrical service provided to the clothes dryer and the furnance and it is this partial strike current that that caused numerous holes in both sections of CSST pipe.

Figure 3. View of vent pipe on roof which served as the strike attachment point

C. Case Study N°2

This case involved a 4-story seaside structure in a resort area which experienced lightning-related damage twice within an 8 month period. Gas service was provided through the use of a buried metallic tank with transition from iron pipe to CSST in a utility room at the point of entry to the structure. All utilities entered the structure underground. The structure was provided with an Underwriters Laboratories Master Label lightning protection system (LPS) prior to both of the events. There were conflicts between the LPS installer and the local codes enforcement authority because the local authority would not allow the bonding of the gas piping entering the structure as required by UL 96A [15] and NFPA 780 [16]. However, the bonding of the gas piping on the customer side of the regulator was installed as shown in Figure 4 at the time of both of the events. The ability to provide a detailed evaluation of the CSST installation was not available but access was provided to the location where damage was located.

The first incident was identified by workers in the area to be a direct strike to the structure by this could not be confirmed by forensic evidence. However, strike location data from NLDN indicate a -57.3 kA strike with a confidence ellipse that overlaps the structure. Significant losses to audio-visual equipment and other electrical hardware inside the structure were reported and there was a hole in CSST piping which ignited resulting in fire damage in the garage area. The damage was repaired prior to the author's visit but the replaced CSST section was available for review. A survey of the site of the fire did not reveal any obvious sideflash probabilities other than small floating metal surfaces such as nails, screws, and nailing plates. Other items in the ductwork area where the fire originated had foam insulation and there was not reported to be any evidence of arcing through the foam. The incoming gas piping was grounded just prior to entry to the utility room where it transitioned to CSST and the location of the breach of the CSST was within 10 meters of the transition.

The second event did not have an eyewitness and no conclusive evidence of a direct strike but the NLDN also showed a confidence ellipse that overlaps the structure

Figure 4. Bonding of incoming gas piping to LPS using main-sized conductor

. The peak current in the this event was -21.4 kA with reported damage to satellite receivers, DVRs and other electronic hardware but the extent of the damage was less than the first event. There was no damage to the CSST piping in the second incident.

III. DIRECT LIGHTNING TESTS

It is likely from the cases studies reviewed that there is not a single mode of damage. However, most of the present studies concentrate on induced lightning combined with power follow current and direct strike behavior is almost ignored; although cases have been investigated and varying damages have been noted.

The threat due to a direct strike to a structure is a reasonable probability and therefore must be addressed. The purpose of this action is two fold. First, it is necessary to determine necessary rules for adequate grounding and bonding of CSST when a lightning protection system (including natural LPS) is installed. Second, it is necessary to establish the possible behavior of standard CSST products, as well as CSST with improved jackets, when subjected to high frequency lightning currents. This data must be gathered with the CSST in a straight configuration, in a configuration with a minimum bend radius, and with the CSST jacket damaged such as that associated with bad handling on site.

A. Test layout

A 10/350 current generator designed for testing of SPDs and Lightning Protection Components was used in the testing of the CSST. The test procedure was developed in accordance with the methodologies identified in IEC 62561-1 [17] for Lightning Protection Components and in IEC 61643-11 [18] standard for SPD.

The challenge in the testing comes both from the size of the sample (1 m straight for most of the test and the other times bent) and the high resistance of stainless steel limiting somewhat the current delivered the generator. However the generator used allowed us to by-pass these problems because it was powerful enough (maximum discharge current of 200 kA) to deliver the maximum current we wanted to in the sample (50 kA) and it also allowed the sample to exceed the normal testing area thanks toby using a hole originally dedicated to a high speed camera.

We decided to test 3 types of new commercially available samples to avoid any bias in tests results. Half inch and 3/4 inch samples of standard CSST piping and a 1/2 inch diameter sample with claimed enhanced lightning current withstand capability was used in the testing.

We tested the samples under 2 typical currents values: 10 kA 10/350 and 50 kA 10/350. 50 kA is supposed to represent a 200 kA direct lightning strike to the structure for which 50% is flowing through the lighting earthing system and the remaining 50% shares equally between the connected services i.e. a power line and a CSST pipe. 10kA is typical of a direct strike to the power line or gas pipe flowing through CSST pipe due to the bonding at a building entrance [19].

The CSST sample was terminated on both ends by a threaded steel tube that adjusts to the CSST fittings as it would in a normal installation. The steel tube and CSST fitting is shown in Figure 5.

The CSST samples were tested straight or with the recommended bending radius of 3 mm; as well as some tests configured using the minimum bending radius of 1 mm allowed by the manufacturer in its technical data sheet.

To be able to make some comparisons, especially to compute the high frequency effect on CSST, we measured both the resistance and inductance of the CSST samples with an impedance meter. Resistance of the sample was 55,2 mΩ for 1/2 inch samples and 64,6 mΩ for 3/4 inch samples. Inductance was found to be 0,5 µH (measured at 16 kHz) for all samples.

During the tests the waveshape was typically 15 µs/425 µs.

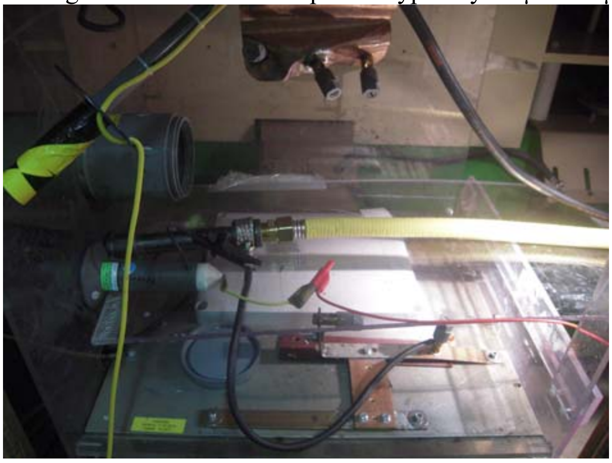

Figure 5. The 10/350 direct lightning experiment

B. *Test results*

Tests results are presented in Table 1.

As can been seen from this table, it was not possible to damage the steel part of the CSST sample, even with a 50 kA current. At 10 kA no visible evidence of damage could be noted. The samples were filled with pressured air and no holes were found in these samples. At 50 kA only the jacket was damaged. Once again, there was no puncture of the steel tubing but the jacket was partially destroyed. Surprisingly, the product with a jacket designed to better withstand the lightning stress had more jacket damage than the standard version.

This can probably be explained by the fact that this jacket is not developed to withstand such high currents and the lower longitudinal resistance will result in greater current flow through it, leading to thermal and mechanical effects on the jacket.

This damaging mode of the CSST jacket is consistent with some of the damages observed in the field after CSST failed and fire occurred. It is difficult to be conclusive of the fact that this is the result of the lightning stress and not the result of the fire that occurred.

Figure 6. Example of test results - test 10

If this damaging mode of CSST can be a candidate for explaining a few CSST damages observed in field during lightning, this cannot explained all damages. A potential scenario could be that a first return stroke damages the jacket and a second stroke creates a flashover between CSST and a metal grounded part through this opened jacket; leading to hole in the CSST wall. A resulting gas release could be ignited by the hot spot resulting in a fire.

The bent samples, even with the minimum bending radius allowed by the manufacture, were found to behave the same as the straight ones during this testing.

Even when in direct contact with a metal plate, the samples behaved well. This configuration was supposed to simulate one of the possible scenarios: CSST near a metal grounded part and when a surge occurs, the jacket insulation is damaged and the steel tube could be damaged as well. However, the generator voltage (below 2,5 kV) was probably not high enough to puncture the jacket. The purpose of our testing was to check the effect of current flowing through CSST and not to observe sparkover of the CSST insulation. Additional test hardware would be required to address such a scenario.

An additional test configuration was developed to address the scenario where the CSST jacket is damaged during the installation due to rough handling or transportation: By rolling gently rolling a metal tube over the CSST samples, we were able to partially damage the insulation.

Figure 7. Example of test results - test 6

TABLE I. TESTS RESULTS.

N° Test	Shape	1/2	3/4	Special 1/2	Ipeak	C	W/R	Results
					(kA)	(C)	(ksA²)	
1	straight		X		8,8	4,88	24,1	No flashover
2	bent R 3 inches		X		8,8	4,85	21,1	No flashover
3	straight	X			8,63	4,86	20,37	No flashover
4	bent R 3 inches	X			8,647	4,84	20,38	No flashover
5	straight on a grounded metal plate	X			8,6			No flashover
6	Idem but pre-failed	X			8,6			Flashover on metal plate. 2 marks
7	straight			X	8,613	4,96	20,4	No flashover
8	bent R 3 inches			X	8,62	4,97	20,4	No flashover
9	bent R 3 inches			X	42	23,6	436	No flashover but special jacket damaged
10	bent R 3 inches	X			42,2			No flashover: yellow jacket less damaged than special jacket
11	Idem but pre-failed	X			42,26			No flashover
12	pre-failed straight on a grounded metal plate		X		46,7	19,77	557	3 holes
13	bent R min 1 inch		X		43	24,8	487	No flashover
14	bent, 2 parts in direct contact and contact with grounded metal plate		X		43,26	24,7	491	No flashover

Once again, we obtained no damage (test 11) when the CSST was tested alone but when in contact with a metal plate near the location where the jacket was pre-failed, we obtained 2 marks at 10 kA (test 6) and 3 holes at 50 kA (test 12).

In these two cases, it was demonstrated by air pressure testing that the sample was leaking. In addition, when the measured voltage obtained during tests is compared with a simulated value taking in consideration the magnitude of current, waveshape, and impedance (both resistance and inductance) measured by an impedance meter, we found that results were on average comparable within 4%.

Figure 8. Example of test results - test 12

C. Conclusions from tests

As a preliminary conclusion from these tests we can try to better define the possible failure modes related to direct lightning.

Apparently, there is no obvious effect due to the corrugated shape of CSST. Even when bending of CSST in severe conditions we were not able to create the damage noted in some field obserbations when a mild to high current flow was developed through CSST.

High lightning currents (>> 10 kA) can damage the CSST jacket. This can be a preliminary step to a CSST puncture. To avoid this, it is necessary to bond CSST to ground at the building entrance and to protect the building by a Lightning Protection System.

Another possible scenario damage to CSST occurring during handling. This can occur when CSST is handled during transportation or during the installation in a structure. In such a case, a 10 kA lightning current can damage CSST if the voltage is high enough. Both failures modes (marks at 10 kA and holes at 50 kA) are consistent with what is observed in many cases. To avoid this, global equipotential bonding is needed as well as surge protection devices on power systems at the service entrance in the building.

IV. Conclusions

One of the possible causes of failure of CSST is direct lightning current flowing along the CSST. There has been little investigation into this cause with minimal confirmation of how the CSST will react to such a stress. Tests have been performed using limited to high current levels from a 10/350 lightning impulse waveform to examine how CSST will perform under partial direct lightning conditions. The test procedure and test results are presented and comments are provided on their significance.

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