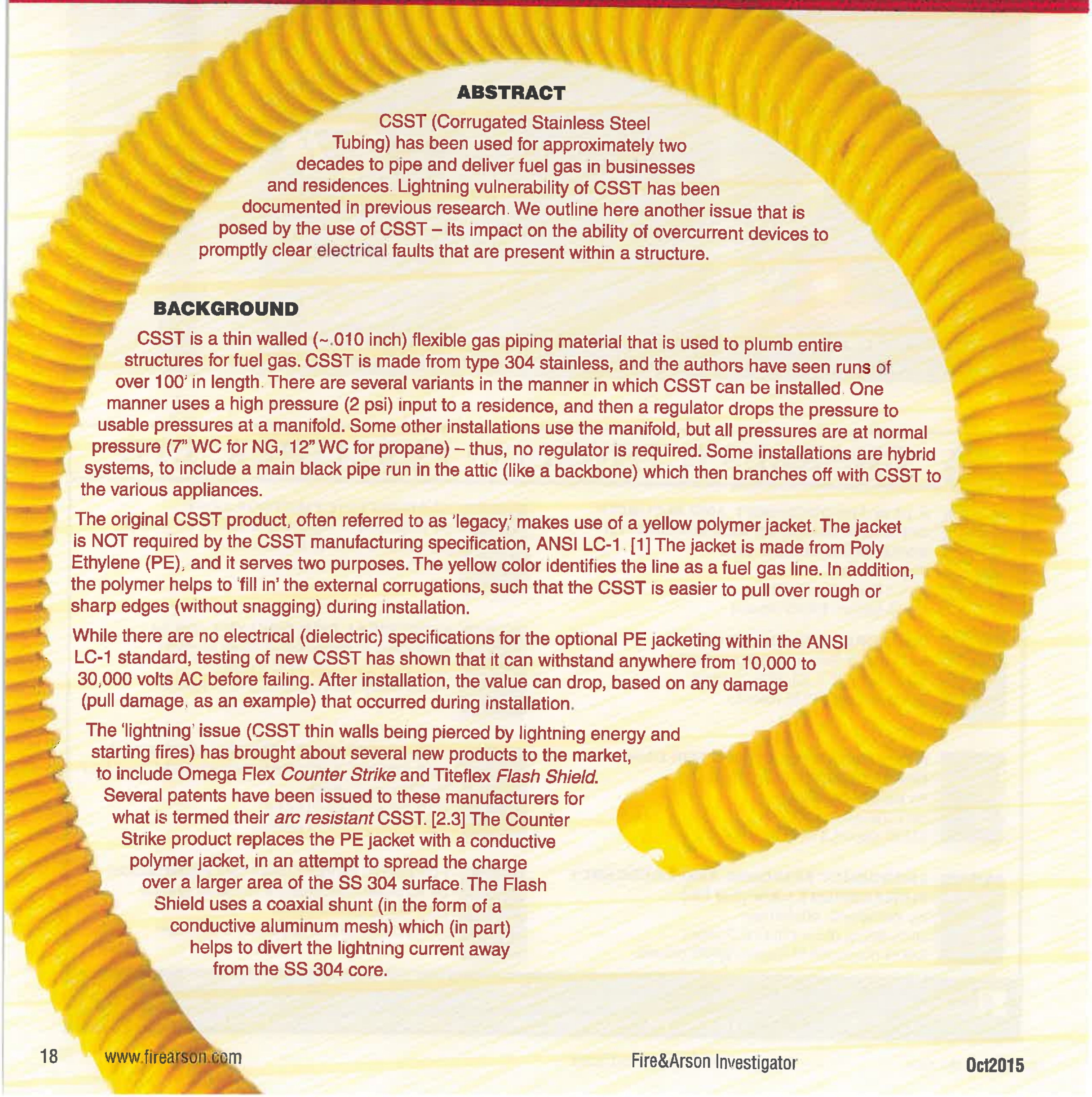
A HIDDEN CS



ABSTRACT

CSST (Corrugated Stainless Steel Tubing) has been used for approximately two decades to pipe and deliver fuel gas in businesses and residences. Lightning vulnerability of CSST has been documented in previous research. We outline here another issue that is posed by the use of CSST – its impact on the ability of overcurrent devices to promptly clear electrical faults that are present within a structure.

BACKGROUND

CSST is a thin walled (~.010 inch) flexible gas piping material that is used to plumb entire structures for fuel gas. CSST is made from type 304 stainless, and the authors have seen runs of over 100' in length. There are several variants in the manner in which CSST can be installed. One manner uses a high pressure (2 psi) input to a residence, and then a regulator drops the pressure to usable pressures at a manifold. Some other installations use the manifold, but all pressures are at normal pressure (7" WC for NG, 12" WC for propane) – thus, no regulator is required. Some installations are hybrid systems, to include a main black pipe run in the attic (like a backbone) which then branches off with CSST to the various appliances.

The original CSST product, often referred to as 'legacy,' makes use of a yellow polymer jacket. The jacket is NOT required by the CSST manufacturing specification, ANSI LC-1. [1] The jacket is made from Poly Ethylene (PE), and it serves two purposes. The yellow color identifies the line as a fuel gas line. In addition, the polymer helps to 'fill in' the external corrugations, such that the CSST is easier to pull over rough or sharp edges (without snagging) during installation.

While there are no electrical (dielectric) specifications for the optional PE jacketing within the ANSI LC-1 standard, testing of new CSST has shown that it can withstand anywhere from 10,000 to 30,000 volts AC before failing. After installation, the value can drop, based on any damage (pull damage, as an example) that occurred during installation.

The 'lightning' issue (CSST thin walls being pierced by lightning energy and starting fires) has brought about several new products to the market, to include Omega Flex *Counter Strike* and Titeflex *Flash Shield*. Several patents have been issued to these manufacturers for what is termed their *arc resistant* CSST. [2,3] The Counter Strike product replaces the PE jacket with a conductive polymer jacket, in an attempt to spread the charge over a larger area of the SS 304 surface. The Flash Shield uses a coaxial shunt (in the form of a conductive aluminum mesh) which (in part) helps to divert the lightning current away from the SS 304 core.

ST ELECTRICAL DANGER

Mark Goodson PE
Lee Green PE

BONDING and GROUNDING

There has been much discussion regarding the bonding and grounding of CSST. The manufacturers believe that their instructions pointed the installer to so-called *direct* bonding, but their instructions also warned the user to follow the NEC. The NEC, which is intended for equipment and personnel protection (as opposed to lightning protection), issued a *Formal Interpretation* (FI) that specifically stated that the grounding of a gas fired electrical appliance was an acceptable way of bonding the gas system. [4] In other words, when a gas stove or gas fired furnace is connected to the power system by plugging it into a grounded outlet, the gas system is bonded to ground. In 2009, the *National Fuel Gas Code* (NFPA 54) was changed so that *direct bonding* of CSST was required, in addition to NEC compliance. [5] Attempts at integrating this extra bonding in the NEC have repeatedly been rebuffed, as CMP 5 (Code Making Panel 5, *Grounding*) notes that the NEC is *not* a place to try and deal with lightning problems. [6] Rather, NFPA 780 (*Standard for the Installation of Lightning Protection Systems*) is the appropriate standard to use when trying to harness electrical energy from lightning. [7]

The CSST industry has maintained that direct bonding and grounding will help prevent CSST from receiving lightning damage. The industry was challenged on this point, and contracted with GTI (Gas Technology Institute) to conduct a study of the effectiveness (if any) on CSST lightning resistance when direct bonding was used. [8] That report was released in 2013.

The Hidden Danger

The GTI report first set out to characterize CSST in terms of its bulk LCR parameters. Of particular note is Table 3, which outlines these parameters. The DC resistance of CSST is given in milliohms / meter (by GTI), with the following data reported by GTI:

Mfr	CSST Diameter (Inches)	DC Resistance milliohm/ m	DC Resistance, milliohms / ft (Derived by authors from SI units)
A	.5	7.13	2.17
	1	4.33	1.32
B	.5	19.91	6.06
	1	4.75	1.45
C	.5	7.29	2.22
	1	4.72	1.44
D	.5	7.35	2.23
	1	4.35	1.32

Excerpted from GTI Report, Table 3) (Except Column 4)

With the exception of the .5" product from manufacture B, the numbers are all very similar. The GTI report explains the reason for the B reading, which was out of bounds and not representative of the bulk of the samples. (Note: the manufacturers were not identified by name, but by letter only.)

The above resistance measurements were by the authors converted into ohms per foot, in accordance with the units of measure listed in Table VI of ANSI LC 1b-2011. [9] In general, the average DC resistance for ½" CSST is ~ 2.21 milliohms per foot (using GTI data, neglecting ½" CSST from manufacturer B). For 1" CSST, the average resistance is ~ 1.38 milliohms per foot.

Per Table VI of the ANSI CSST Spec (LC 1b-2011), maximum allowable resistances for CSST are 150 milliohms per foot for ½" nominal tubing, and 120 milliohms per foot for 1" nominal CSST. In other words, when LC-1 allows 150 milliohms per foot, the product was only 2.21 milliohms per foot – well within specification.

The hidden danger that arises from the use of CSST starts when one realizes that the above GTI numbers are incorrect. More particularly, they are off by a nominal factor of 10. Better said, the true resistance of CSST is much closer to 22.1 milliohms per foot for ½" CSST and 13.8 milliohms per foot for 1" nominal tubing.

... continued on page 20

A HIDDEN CSST ELECTRICAL DANGER *continued*

An exemplar set of data was obtained using a 25' length of 3/8" CSST. We tested without the brass connectors, and injected .5 amperes, end to end. We obtained the following:

I	**.500 amperes**
V (end to end)	**.3550 volts**

Ergo, the resistance (total) is 710 milliohms, or 28.4 milliohms per foot.

Using a 25' length of ½" nominal CSST, we obtained the following data:

I	**.500 amperes**
V (end to end)	**.3105 volts**

The resistance (total) is 621 milliohms, or 24.8 milliohms per foot.

The following table (Table1) illustrates different CSST measurements that we have made, using two different techniques.

Technique 1 (.500 amperes) made use of a HP 33120A power supply, feeding current end to end through a length of CSST. Current was monitored by an inline Agilent 34401A meter, and voltage drop (end to end) was made using a Fluke 187. The 33120A power supply was operated in a current limited mode.

Technique 2 (10 amperes) used a Sorenson DC 8-125 supply operating in a current limiting mode. The current ran through a Yokogawa 50 amp shunt (1 mV = 1.00 amps) and the shunt voltage was measured by an Agilent 34401A DMM. End to end voltage on the CSST was measured by a Fluke 187 DMM. The shunt was placed in series with the CSST.

TABLE 1 – DC resistance per foot (as measured by authors)

Mfr	Size (Nom),"	Jacketing	Test Current, Amps (Nominal)	milliohms/ foot (DC)
Pro Flex	3/8"	PE	0.5	28.4
	3/8"	PE	10	28
Pro Flex	½"	PE	0.5	24.8
	½"	PE	10	24.2
Titeflex	½"	PE	0.5	19.7
	½"	PE	10	19.9
Titeflex	½"	Flash Shield(1)	0.5	20.4
	½"	Flash Shield(1)	10	20.5
Titeflex	½"	Flash Shield(2)	0.5	4.24
	½"	Flash Shield(2)	10	4.37
Tracpipe	¾"	PE	0.5	15.7
	¾"	PE	10	15.8
Tracpipe	½"	Counter Strike	0.5	20.7
	½"	Counter Strike	10	21
Ward	½"	PE	0.5	26.2
	½"	PE	10	26.4

Notes: (1) Flash Shield was tested without tube to aluminum mesh continuity at the ends, and (2) with tubing to aluminum mesh continuity at the ends. In actual usage, the use of the factory brass connectors at both ends will insure that only data set (2) is representative.

The hidden danger in the use of CSST is an electrical issue. By way of example, let us assume that a small gas water heater (30,000 BTU / hr) is fed by a 100' run of 3/8" CSST. (See Diagram 1) A further assumption is that the water piping to the water heater is nonconductive. For whatever reason, a loose #10 wire (energized at 120 volts) makes contact with the water heater. The current flow to ground (we are assuming that the CSST is bonded to ground at the manifold) is found as follows:

100' x 28.4 milliohms / foot, 2.84 ohms for 100' of 3/8" CSST

V= I R 120 = I x 2.84 = 42.3 amps.

(We have neglected bond wire resistance)

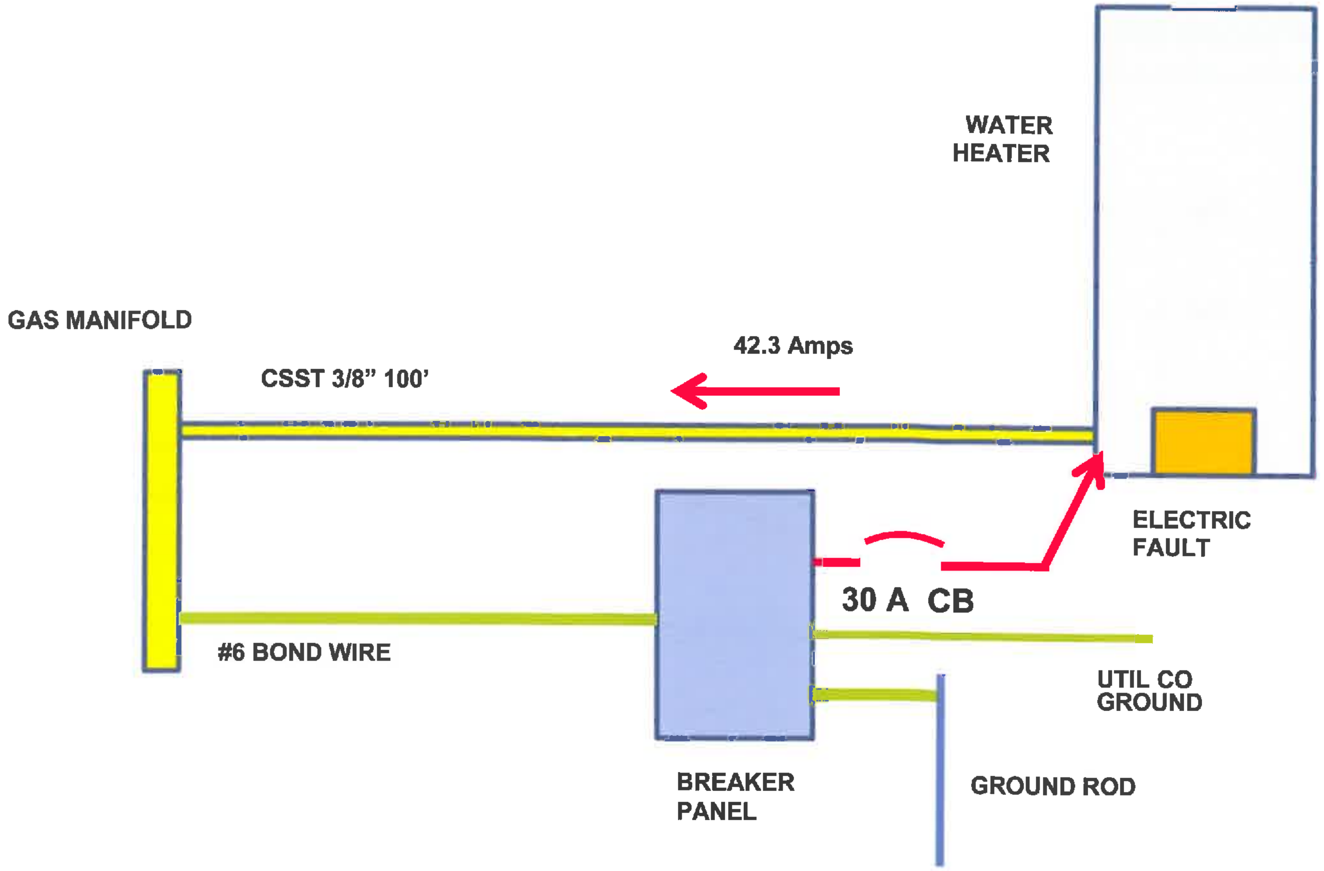


DIAGRAM 1 - #10 Wire Faulting to Water Heater

Under NEMA AB-1 requirements, a MCCB (Molded Case Circuit Breaker) must trip at 135 % of rating within 1 hour. [10] For a 30 ampere breaker, the trip time at 40.5 amperes is 1 hour or less. With the 2.84 ohm resistance of the CSST, the current flow will be about 42.3 amps, as calculated above. Thus, we have a direct short to the gas water heater with an energized 120 volt source, and the breaker will not trip timely. During this time, the #10 wire will NOT be dangerously overloaded. The CSST, however, will overheat, with power dissipation of I^2R, or or 46.5 watts per foot heat dissipation.

(We have assumed a manifold system with the manifold bonded to ground with a #6 AWG Cu conductor)

By way of comparison, #10 AWG copper has a resistance of ~ .001 ohms / ft., giving a power dissipation of 1.6 watts per foot.

We ran simulated fault currents through consecutive lengths of 2' sections of CSST, per the enclosed Diagram 2.

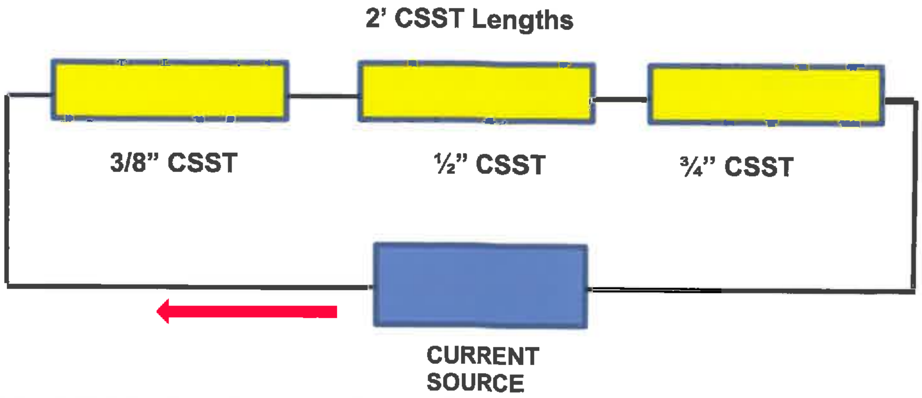


DIAGRAM 2 – Steady State Temperature Measurement

... continued on page 22

A current- temperature graph (Diagram 3) shows the steady state temperatures reached mid-span on the CSST lengths at various current levels.

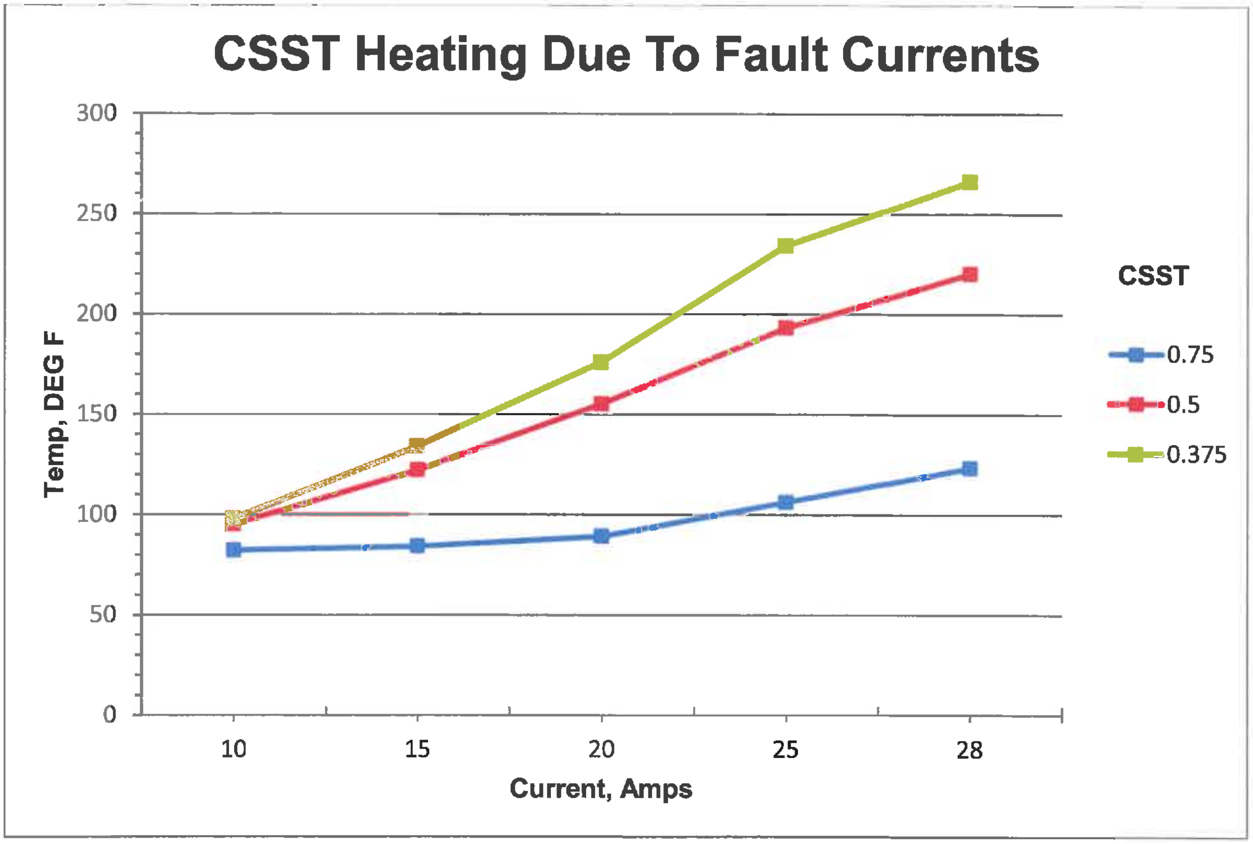


DIAGRAM 3 – Steady State Temperature Results

At the high end of our testing, the PE coating began to sag and smoke (3/8" OD, only). In the field, this is of course due to resistance heating, which is a function of current level, CSST diameter, and length of the CSST (which determines resistance and thus fault current). If the CSST is thermally insulated (IE, covered by blown in cellulose, as an example) much higher temperatures will be expected, to include ignition of the cellulose.

Related to the carrying of fault current is the presence of exposed piping and the inability to clear a fault. We refer to the following text from the 2008 *National Electrical Code Handbook*, page 198:

250.2 DEFINITIONS

Effective Ground-Fault Current Path *An intentionally constructed low-impedance electrically conductive path designed and intended to carry current under ground-fault conditions from the point of a ground-fault on a wiring system to the electrical supply source and that facilitates the operation of a overcurrent protection device or ground-fault detectors on high-impedance grounded systems.*

Ground Fault *An unintentional, electrically conducting connection between an ungrounded connector of an electrical circuit and the normally non-current carrying conductor metallic enclosures, metallic raceways, metallic equipment, or earth.*

***Ground-Fault Current Path** An electrically conductive path from the point of a ground-fault on a wiring system through normally non-current carrying conductors, equipment, or the earth to the electrical supply source.*

> *FPN: Examples of ground-fault current paths that could consist of any combination of equipment grounding conductors, metallic raceways, metallic cable sheaths, electrical equipment, and any other electrically conductive material such as metal water and* ***gas piping****, steel framing members, stucco mesh, metal ducting, reinforcing steel, shields of communications cables, and the earth itself.* **(Emphasis added)**

250.4A(4) ***Bonding of Electrically Conductive Materials and Other Equipment*** *Normally non-current carrying conductive materials that are likely to become energized shall be connected together and to the electrical supply source in a manner that establishes an effective ground-fault current path.*

250.4A(5) ***Effective Ground-Fault Current Path*** *Electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a low impedance circuit facilitating the operation of the overcurrent device or ground detector for high-impedance grounded systems. It shall be capable of* ***safely*** *carrying the maximum ground fault current likely to be imposed on it from any point on the wring system where a ground faulty may occur to the electrical supply source. The earth shall not be considered as an effective ground path. [11]* **(Emphasis added)**

Depending on the lengths of CSST, their diameters, the sizes of overcurrent devices, and the presence of EGCs (Equipment Grounding Conductors) and their sizes, ground faults causing current to flow on CSST may or may not cause a fault to be timely cleared. This is in contrast to electrical insults to BIP (Black Iron Pipe) which has resistance levels of approximately 2 magnitudes lower than CSST.

Our work has also shown that the PE jacketing (legacy or 'yellow jacketed' CSST) cannot necessarily be relied upon to serve as an electrical insulator. Installation damage can affect the integrity of the dielectric qualities, as can the thermal insult of tubing carrying fault currents. In some cases the jacketing will be intact, and in other cases anyone who touches the energized tubing can be shocked.

The question similarly arises with the use of the black jacketed (arc resistant) CSST. Testing of Flash Shield shows that the aluminum conductive mesh serves as a shunt to the higher resistance tubing, and that this shunt lowers resistance levels to a point that is compatible with bringing about overcurrent device response.

Testing of Counter Strike brought about different results. The jacketing of Counter Strike is conductive, but the tubing still has a relatively high resistance per foot, given that it does not benefit from the parallel shunt path that Flash Shield has. Moreover, the conductive outer jacket means that one can touch the jacketing and receive an electrical shock. The testing carried out was per Diagram 4, below. A 500 ohm resistor was placed in series with the 120 volt source to mimic a human body. [12] Current measured through the resistor was ~ 202 mA.

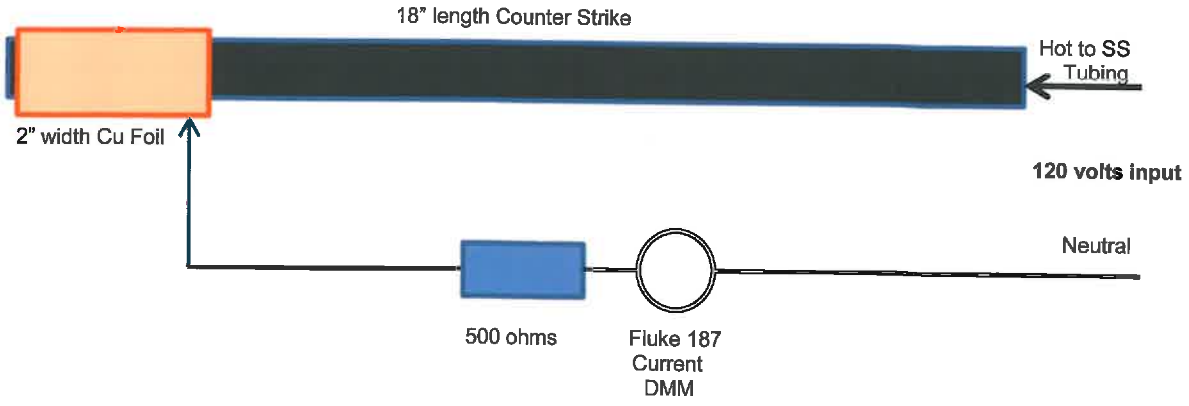


DIAGRAM 4 – Counter Strike Testing

As a further test, the 500 ohm resistor (from the previous diagram) was bypassed and power applied. Current started out at about 1.4 amperes, and started climbing rapidly, exceeding the scale of the Fluke 187. Smoke began emanating from the Counter Strike CSST, and then a brief period of flame, after which the flame extinguished when the lab circuit breaker opened.

... continued on page 24

A HIDDEN CSST ELECTRICAL DANGER *continued*

Discussion

One of the authors (MEG) has commented about the lack of electrical engineering input that was received during the design of CSST. We feel that we have shown that there indeed are more hidden dangers that allow CSST to have a negative impact on electrical safety where CSST is installed. Considering the safety of building materials is important to all facets of protecting life and property within a structure. Understanding dangers and threats posed to safety by building products is of paramount concern then when considering the use of any particular product.

As to how CSST will react in a given situation, this is simply a matter of Ohm's Law, coupled with breaker sizes, trip curves, presence (or absence) of Equipment Grounding Conductors (EGCs), and CSST sizes and lengths. These are routine calculations for a sophomore electrical engineering student. In some situations, the CSST will have no noticeable effect. In other situations, the CSST will severely degrade fault clearance. The difficulty is that the installer is given no guidance on these issues in the D&I guides. Moreover, it is folly to think that a plumber can adequately lay out a system such that electrical fault clearance characteristics are adequately considered. And we would further note that plugging a grounded gas appliance in or out of the wall receptacle (as an example) will also bring about changes in system performance.

We gave a hypothetical situation earlier where a 100' length of CSST (3/8") fed gas to an electrically charged (120 volt fault) water heater. In the example, the water plumbing was made of synthetic materials. If the water piping were instead copper, the system would react entirely different. Similarly, if there was a recirculating pump at the water heater, an EGC would increase the fault current that was flowing, making the overcurrent device trip faster. To further express this point, if the distance were cut in half (50'), maximum fault current would substantially double and the overcurrent device would once again trip faster. And finally, if the offending wire was of #6 AWG Cu construction, protected by a 60 ampere breaker, the CSST would have to be decreased to about 35 feet before 120 amperes (200%) would be available to trip the breaker. (We have ignored the TCR (Thermal Coefficient of Resistance) in these calculations.)

While we have examined the issue from an electrical fault clearing aspect (electrical shock and fire), there are also other concerns that come to mind. Is it possible that differential expansion between the SS 304 tubing and brass fittings is such that a gas leak could develop? Could fittings lose some of their torque? These are areas that will require further delving into.

The recent GTI report discussed the relative safety of CSST when certain installation techniques were used when faced with electrical arc faults. Data used by GTI to support the report's conclusions are based upon bulk CSST characteristics. The underlying resistance calculations in this GTI report misstate the resistance of CSST by a factor of 10. It is important to understand that the flaw in the data can affect any conclusions that can be drawn by the report. It is important to note here that GTI disclaimed the accuracy of its findings in a lengthy disclaimer that introduces the report.

We have not discussed the impact that the raw (and incorrect) numbers have on lightning situations. We do know that the CSST industry has advocated a number 6 bond wire (low impedance direct bond) to improve lightning performance. One would assume that having piping systems with higher resistances would negatively impact equipotential bonding. GTI used a SPICE *(Simulation Program with Integrated Circuit Emphasis)* model to help answer this question. But without seeing the model and the underlying assumptions, the writers cannot state what effect(s) the wrong input data will have on that model's outcome relative to developing an equipotential bonding so as to discourage arcing from one surface to another.

The NEC has had in its text for years a citation known as 110.3(b). This section of the NEC basically requires that all electrical components be used according to their listing and instructions. As an example, if a breaker is rated at 22 KA interrupting capacity, it is incorrect to use this breaker in a circuit where it is necessary to interrupt 40 KA.

MCCBs typically have the ability to respond to both overloads and faults. As an example, a 20 ampere wire carrying 40 amperes is considered an overload. The 20 amp breaker will trip in 120 seconds or less, long before the overload can bring about thermal damage to the insulation. Should a ground fault occur that suddenly draws 400 amperes on the same 20 ampere breaker and circuit, the *instant* (magnetic) portion of the breaker reacts, sensing the short circuit. This clearing of the fault will take place in several cycles or less, so that someone touching the piping will receive minimal shock injury. However, a fault to CSST may well be different – its high impedance can prevent the breaker from sensing a true ground fault, and instead the event is treated as an overload, calling into place the thermal (overload) portion of the breaker. This thermal response will be somewhat tardy, and is very dependent on CSST length, diameter, and even the temperature of the MCCB. Certainly, the MCCB is not being used as it was designed to be used. And as we have demonstrated earlier, there are certain ground fault conditions for which the MCCB will never respond.

Lastly, we look at the data in Table VI of the ANSI LC-1b Addendum. For ½", the spec allows 150 milliohms per foot. If we have a 40' run of ½" CSST, and it indeed has 150 milliohms per foot resistance, the resistance will be 6 ohms. A fault at 120 volts will have about 20 amperes flowing, which will never trip a 20 amp breaker, and marginally trip a 15 amp breaker. (We are assuming the fault current traverses the entire CSST length). The *real* question is – what manufacturing technique results in this type of resistance? The resistivity of SS 304 is a constant – 72 micro-ohm-cm. [13] Given a fixed length for resistance (milliohms per foot is the unit of measure), a constant resistivity, and a relatively constant diameter, one has to wonder where this specification came from? How was it derived? Indeed, we can specify a length of CSST that will have about 150 milliohms per foot resistance. This is accomplished by decreasing the wall thickness, increasing the number of furrows, or some combination of both – not at all realistic. This all fits with earlier comments – electrical engineering input has been absent during the design process.

Summation

Here, we have studied the actual resistance of various CSST products and report the findings to better understand what dangers may be present as a result of the relatively high electrical resistance of CSST piping. We believe that there are certain CSST installations that will be negatively affected in terms of their abilities to clear an electrical fault. This results in both fire and electrocution hazards. These characteristics have not been reported before. These kinds of situations are those which the NEC works to prevent, and are brought about by using a piping system that has very poor electrical conductivity, relative to black pipe.

REFERENCES

[1] ANSI LC1-2005, Fuel Gas Piping Systems Using Corrugated Stainless Steel Tubing (CSST)

[2] USPTO, Patent 7044167, Conductive jacket for tubing

[3] USPTO, Patent 8399767, Sealing devices and methods of installing energy dissipative tubing

[4] NFPA, Formal Interpretation No. 54-99-1.

[5] NFPA, National Fuel Gas Code NFPA 54, 2009

[6] NFPA, TIA70-2008. TIA Log 941

[7] NFPA, Standard for the Installation of Lightning Protection Systems, NFPA 780.

[8] Gas Technology Institute, Validation of Installation Methods for CSST Gas Piping to Mitigate Indirect Lightning Related Damage, 2013.

[9] ANSI, Fuel Gas Piping Systems Using Corrugated Stainless Steel Tubing (CSST), ANSI LC-1a-2009, Addenda.

[10] NEMA, Molded-Case Circuit Breakers, Molded Case Switches, and Circuit Breaker Enclosures.

[11] NFPA, National Electrical Code NFPA 70, 2008.

[12] UL, Standard for Safety, Ground-Fault Circuit Interrupters, UL 943.

[13] Elert, Glenn, Physics Factbook.

ABOUT THE AUTHORS

Mark Goodson

Mr. Goodson is the founder and principal engineer of Goodson Engineering in Denton, Texas, where he leads a team of professional engineers with specialties in electrical, mechanical, and fire protection engineering. Mr. Goodson is a consultant for public sector agencies, including police departments, DA's offices, morgues, prisons and crime labs. He is experienced in electrical death and injury analysis, carbon monoxide death analysis, and fire causation. His work has been published in numerous industry journals, and he has written over 30 papers on fire investigation. He was the first engineer to serve on the State of Texas Electrical Board. He is a peer reviewer for the *Fire & Arson Investigator* Journal, and is the engineer serving on the Texas Fire Marshal's Science Advisory Workgroup, where fire-related criminal convictions are being reviewed for accuracy of scientific evidence. In 2014, he was appointed to the NIST panel on forensic sciences (NIST–OSAC). Mr. Goodson holds a BSEE from Texas A&M, and attended UT Southwestern where he studied forensics medicine. He is a licensed engineer in 15 states and holds four patents on fire safety, with several more pending. Mr. Goodson was recently appointed as the independent inventor on the Public Patent Advisory Committee for the USPTO.

Lee Green

Mr. Green has a BSME from Oklahoma State, and two MS degrees in engineering from SMU. He is a licensed engineer in 10 states, and has been employed by Goodson Engineering for 5 years, where he oversees the firm's mechanical practice. Mr. Green was formerly a design engineer for PACCAR / Peterbilt. Mr. Green is active in SAE and ASME.