TESCO's Research on Hot Socket Arcing and Identifying Dangerous Field Conditions

THE EASTERN SPECIALTY COMPANY

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PART 1: Introduction

"A compelling need for early detection devices and inspection processes to identify dangerous field conditions prior to catastrophic failure was quickly identified"

PART 2: Observations from the Field

"The damage on the meters produced by controlled arcing was indistinguishable from the damage on most hot socket meters returned from the field."

PART 3: Conditions for Arcing

"…our minimum vibration threshold capable of producing arcing can be obtained quite easily and often if meter boxes are placed near highways, near washers or dryers, or even near a frequently traversed walking area."

PART 4: Characteristics of Socket Jaws

"…when preheated to 700 degrees Fahrenheit (about 370 Celsius), we repeatedly observed a rapid decay to zero pounds insertion force, within the first two or three insertions"

PART 5: Hot Socket Gap Indicator (HSGI)

"Field technicians using the tool reported that egregious faults such as blackened or pried jaws were easily recognized without the tool; however several jaws that appeared normal to a visual inspection failed the HSGI test and upon further inspection were deemed unusually weak."

PART 6: Socket Safety Clip

"We offer this tool as a temporary safe guard a meter technician can put on questionable jaws to leave them safer than when they were discovered. The two unattractive alternatives to using the socket safety clip are to either disconnect the customer immediately until the dangerous situation can be remedied or leave the dangerous situation active and hope that the customer will correct the situation before there is a fire."

PART 7: Conclusion

"The tools we developed are in the first line of defense, along with operators who have an understanding of what to look for to identify hot sockets"

PART 1: Introduction

The deployment of new AMI meters has resulted in an increase in the occurrence of fires reported at the meter box. Initial concerns are whether these fires were caused by meters or meter sockets or something else. Our laboratory investigation could find no indication of fires being caused by the meter. No fires or unsafe temperature conditions could be created in our Hot Socket Lab using only the meter, powered by a non-compromised socket. Empirical investigation revealed a variety of sources in the meter box including loose or broken connections, bad or missing insulation, or other electrical hazards. The most common cause and the symptom most commonly supported by the evidence was heat generated at the meter socket jaw to meter blade interface. The necessary ingredient to create this heat is a worn meter socket jaw. Under the same test conditions, high temperatures could not be created using a new or a less than severely worn meter jaw (more than 5 pounds of holding force). A compelling need for early detection devices and inspection processes to identify dangerous field conditions prior to catastrophic failure was quickly recognized.

Several potential causes for temperature rise were considered and tested including conditions like contact resistance, worn jaws, and debris. Energy dissipated as heat due to contact resistance seemed likely; however our research showed that the temperature rise generated by contact resistance is not sufficient to cause the significant meter deformation observed in the field. Instead, electric arcing across small gaps between meter blades and compromised socket jaws was found to be the source of the elevated temperatures and eventual destruction of meters which failed catastrophically. Compromised jaws were further defined through lab experiments to be jaws whose required insertion force (of the meter blade) is significantly less than that of a standard socket jaw. An insertion force of 10 pounds per jaw was found to be the threshold between safe and questionable conditions. Forces less than 5 pounds or less were identified as dangerous.

Conditions required to create these situations are not unusual in typical residential meter installations, once a meter has been inserted into a box that has a compromised socket jaw. Elevated temperatures can be created under typical, residential power consumption levels with a compromised jaw. Arc temperatures can approach 11,000 degrees Fahrenheit (about 6,100 degrees Celsius), allowing for a relatively fast heat transfer from the arcing location (meter jaw/blade interface) to internal components of the meter. We were able to repeatedly simulate these conditions and results in our lab, on a variety of meters. We then observed and tested a variety of socket jaws, and determined that insertion force is a measurable parameter that differentiates good jaws from jaws that create hot socket conditions. Some compromised meter socket jaws were readily identified by visual inspection while others were not. A go/no-go tool was designed based on the lab data to determine if a particular meter socket jaw was compromised or not. A preventative tool that temporarily increases the holding force of a weak jaw while the customer has time to get a replacement socket was also developed.

This paper aims to:

1) Support the theory that most meters damaged by heat were likely exposed to arcing at the socket jaws.

2) Demonstrate conditions that facilitate arcing in meter sockets

3) Suggest characteristics of socket jaws that can be used as indicators of conditions that facilitate arcing and the destruction of meters.

4) Explain the tool we developed that indicates a potentially dangerous socket jaw.

5) Discuss what can be done to leave the installation safer after a dangerous socket jaw has been found.

PART 2: Observations from the Field

Some of our research was funded by large investor-owned utilities and some was funded by meter manufacturers. This paper is based solely on data from the research performed in conjunction with the meter manufacturers. No Utility data is used as part of this report.

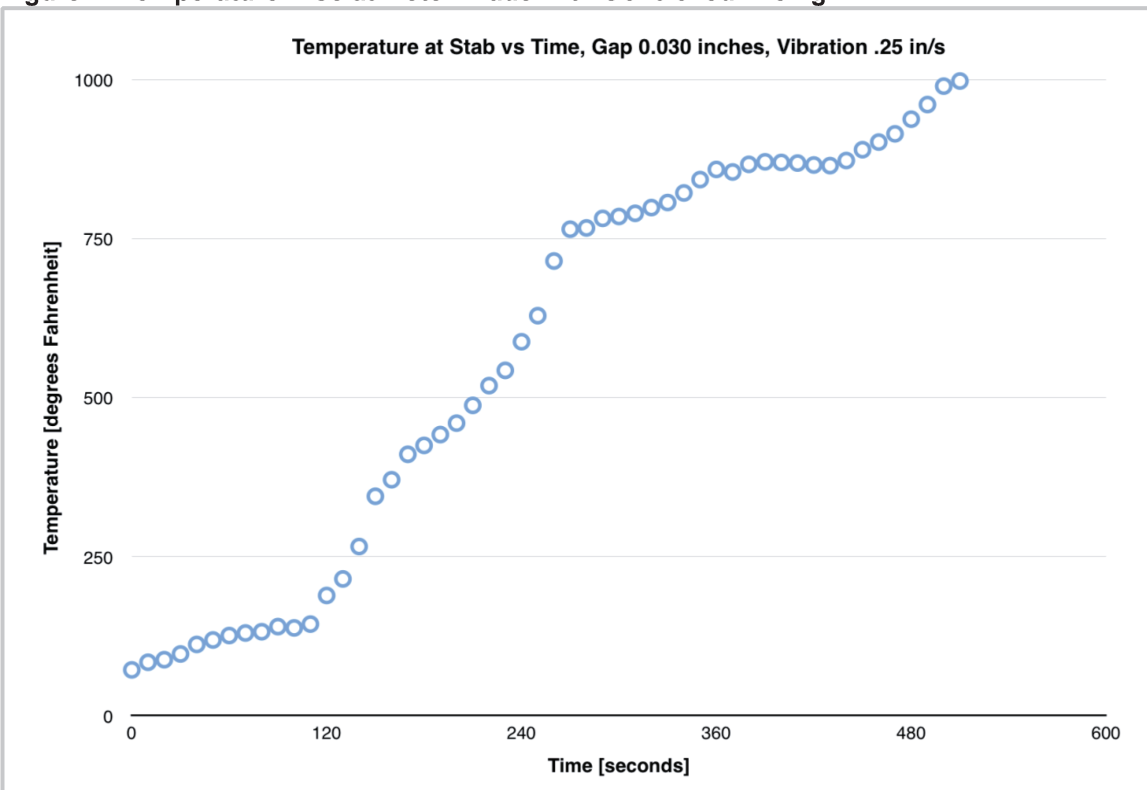
Through our own meter shop we have access to tens of thousands of returned AMR and pre-AMR meters that have been scrapped. Heat damaged meters were sorted and cataloged for similarities and to help identify patterns. Initially we did not have access to many meter sockets as utilities typically don't have ownership and control of the sockets; in most cases sockets belong to the customer. We have been able to secure a supply of used meter boxes from the field so this problem has been minimized. Our socket supply is regional in nature though so a cross section of sockets installed over the past sixty (60) years throughout North America was not available for this study. We are assuming that our sample is representative in nature.

A common characteristic of the heat damaged meters was a roughening of the surface of the meter blade (or blades) that were exposed to the most heat, shown in Figure 1. The roughening was pitting and carbon deposits, the result of an electrical arc contacting the surface.

Figure 1. Pitting and Discoloration of a Hot Socket Meter Blade Returned from the Field

Laboratory experiments simulating anything other than micro-arcing (e.g. contact resistance, small blades, water in the meter, contamination in the meter) failed to provide the elevated temperatures required for catastrophic failure of the meter. We set up experiments that aimed to correlate an increase in measured resistance at the contact to an increase in surface temperature under load. In the most extreme case with a high resistance tungsten pad representing a poorly conducting surface, the temperature rise over a full day was less than 100 degrees Fahrenheit (less than 38 degrees Celsius). In contrast, when we were able to control the arcing at the jaw-blade connection, we observed temperature rises of over 1000 degrees Fahrenheit (over 537 degrees Celsius) in less than ten minutes, shown in Figure 2. These experiments were conducted under a 25 amp load. This load was chosen as representative of a nominal but high load drawn by a typical residential user. The damage on the meters produced by controlled arcing was indistinguishable from the damage on most burnt meters returned from the field. The hypothesis was set forth that this simulation represented conditions in the field that cause most burned meters. Further testing supported this hypothesis as no other simulation produced these characteristics and every variation of this simulation produced similar physical results. Anecdotal evidence from the field showed that the same pitting and roughening of the corresponding meter jaw socket could also be seen. Our study of collected sockets is covered in Part 4.

Figure 2. Temperature Rise at Meter Blade with Controlled Arcing



PART 3: Conditions for Arcing

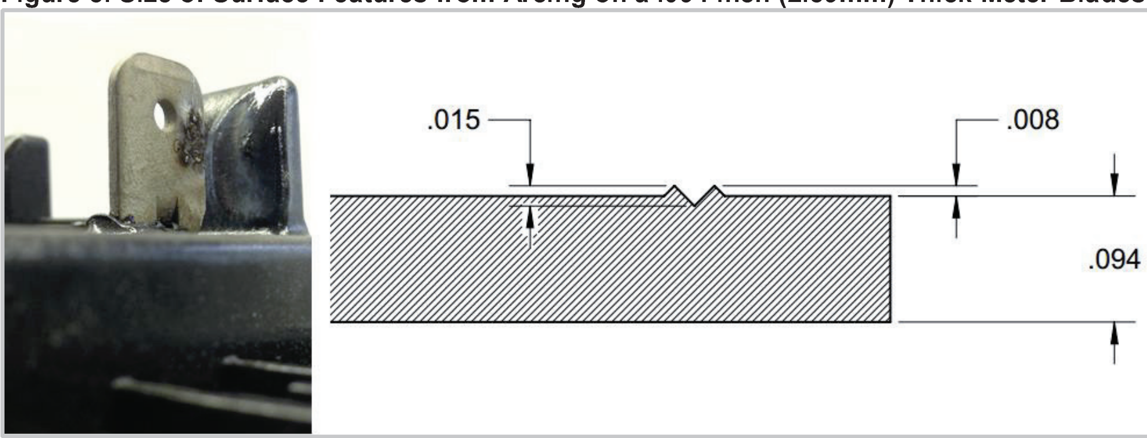
Paschen's Law suggests arcing will occur at certain gap sizes between two plates at different voltage potentials. Based on research conducted by German physicist Friedrich Paschen, the breakdown voltage necessary to create an electric arc between two electrodes is a function of air pressure and gap distance. A gap capable of facilitating arcing can be present in loose jaws, jaws with compromised contact surfaces, or ones with obstructing debris.

Applying this theory, we were quickly able to produce arcing between jaws and meter blades under realistic power levels. All experiments were at 240 Volts, and the nominal current was found to be more than 10 mA (the approximate amount of energy required to power the electronics in most meters from the line side of the service) and 0.25 amps (the lowest current tested other than just the electronics on the meter). Even at heavier loads, still within normal household use such as 20 Amps, the arc was difficult to sustain to create significant temperature rises over time without a catalyst. This is because the gaps were so small that minute changes in the surface resulting from the arc (pitting or expansion) would create conductive features that the current could pass through, rather than passing through plasma.

Our research then focused on catalysts that would start the micro-arcing. Several were identified as possibly being present in the field, but the catalyst that is commonly found in the field and readily acted as a catalyst for the micro-arcing was vibration. A moderate level of vibration quickly created significant temperature rises in dangerously, weakened meter socket jaws.

Vibration would allow the gap to open and close repeatedly, sustaining a frequency of arcing. Often this would create surfaces capable of facilitating an aggressive arc even after the vibration ceased, resulting in our most dramatic temperature rises (a rise of over 1000 degrees Fahrenheit, about 538 degrees Celsius, in less than ten minutes). With controlled arcing we began to produce damaged meters in our lab that appeared very much like the meters removed from hot sockets in the field, specifically the appearance of the pitting on the surface of the blades. Our minimum vibration threshold capable of producing arcing can be obtained quite easily and often if meters are installed near highways, near washers or dryers, or even near a frequently traversed walking area in frame construction homes.

Figure 3. Size of Surface Features from Arcing on a .094 inch (2.39mm) Thick Meter Blades

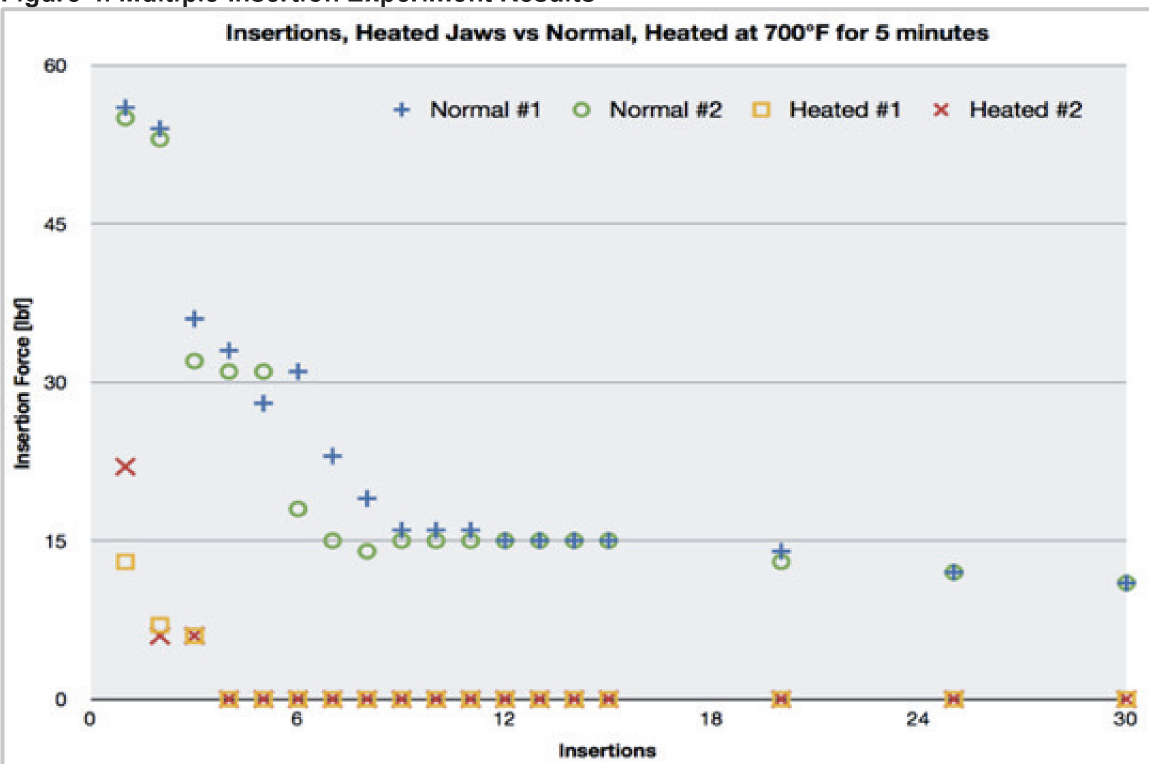


PART 4: Characteristics of Socket Jaws

At this point we were satisfied that we had found a way to create and observe a mode of failure that agreed with field observations, and the hypothesis of others working to understand this problem. Although we identified other sources of heat and fire in meter enclosures, the vibration and socket meter jaw gap created incendiary meters that matched the meters found in our meter shop that had been exposed to high heat. Our research on arcing was handed off to utilities and meter manufacturers who have the ability to continue the study on a much larger scale, and develop alarm protocols for early detection of hot sockets by AMI systems as well as design a new generation of AMI meter which can withstand a hot socket better than earlier generations of AMI meters. Our concern shifted to finding a way to flag potentially problematic jaws in the field during AMI installations or at any other time where the utility has an opportunity to inspect the meter enclosure.

We noted that visual observations of the mating surfaces and potential gaps could be subjective. We focused on finding features which could be measured and then researched these features to see if we could identify a danger threshold that could be inspected for. Our understanding of mechanical fatigue and creep led to a test where the insertion force into a jaw was measured and recorded on multiple insertions into the same jaw. This data showed exponential decay of the insertion force with each meter removal and insertion. Initially high insertion forces above 40lb quickly dropped and stabilized around 15lb after the first five to ten insertions. When the jaws were heated to the maximum allowable temperature (as per ANSI C12.1; C12.10 and C12.7) under heavy load conditions before the test (400 degrees Fahrenheit, about 204 Celsius), the decay on average stabilized at 15lb in slightly fewer insertions then in cold tests. This was still nothing indicative of a problem as the conditions were still normal for what the jaws were designed to withstand. Finally when preheated to 700 degrees Fahrenheit (about 371 Celsius), we repeatedly observed a rapid decay to zero pounds insertion force, within the first two or three insertions. This temperature level, 700 degrees Fahrenheit, was quickly reached at the jaw in our arcing tests. At this temperature the damage created to the meter and the meter socket jaw was visually consistent with "hot socket" damage to meters and meter boxes in the field (e.g. plastic melting on the meter around the blade, pitting on the meter blade and the socket jaws). The difference in holding force between normal and heated jaws is illustrated in Figure 4. We drew a threshold line under 15lb at 10lb, and developed a tool that simulated a blade being pushed into a socket jaw with 10lb force (using 10lb of spring force). We distributed the tool for testing in the field.

Figure 4. Multiple Insertion Experiment Results

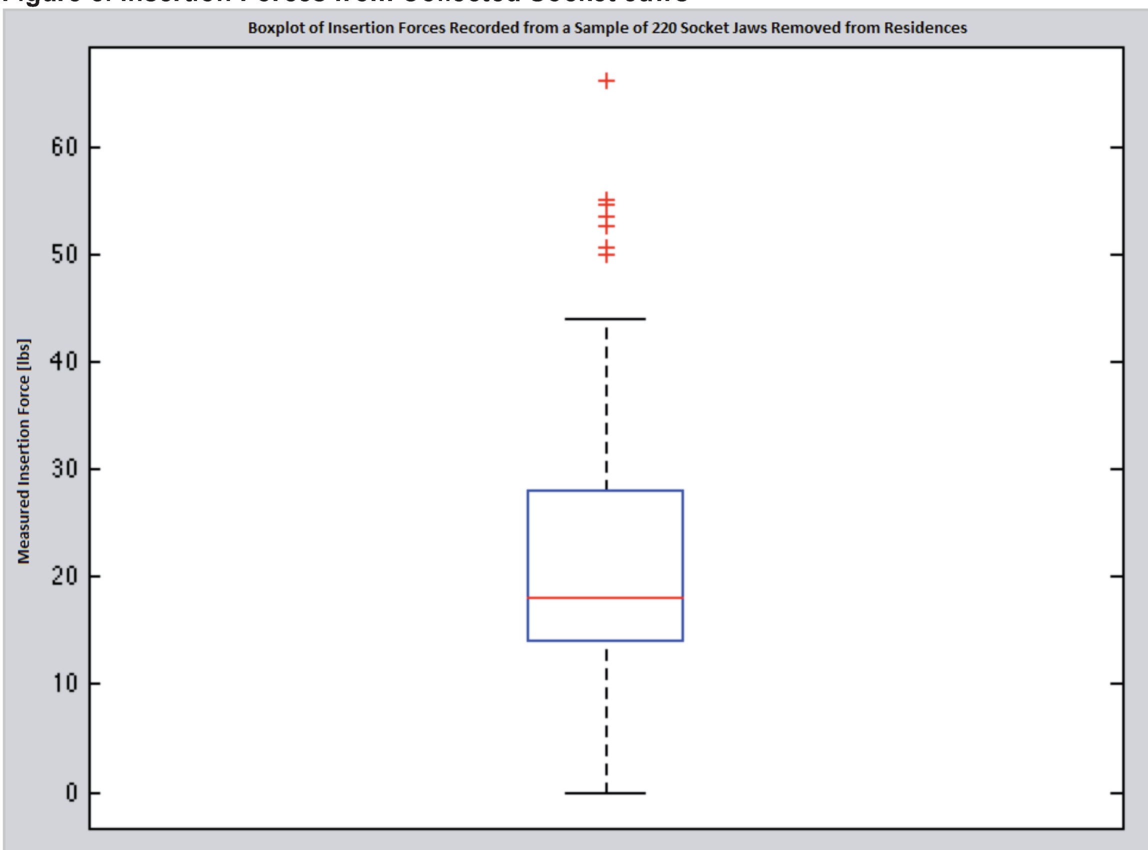


A well-defined minimum holding force for meter socket jaws has not been specified by ANSI or UL. ANSI C12.7 defines the outer dimensions of the jaw, but doesn't specify gap size or holding force. UL 414 focuses on maximum insertion forces to keep the operator safe and prevent damage to the socket and meter in sections 5 and 19, but also doesn't define a specific minimum holding force. UL 414 section 14 comes closer to defining a holding force by requiring a meter in a socket with no supplementary insertion force cannot move over 1/16th of an inch out of the socket by its own weight. As modern plastic meters have become much lighter than their mechanical counterparts, this would mean a very light holding force would be acceptable; what may be sufficient to hold one meter may fail to hold a heavier meter in the same socket.

As we had been conducting our experiments and tests, we had meanwhile collected a sample of sockets pulled from homes by local contractors. Approximately 1% of the jaws inspected had evident signs of abnormal temperature elevation; pitting, a gap, and discoloration. These jaws had a measured insertion force of zero lb. The insertion data we collected from all the collected jaws is shown in Figure 5.

Based on our observations of the range of holding forces in jaws from the field, we conducted a series of vibration experiments to see if we could induce arcing on jaws with strong holding forces, and jaws with weaker holding forces. We were unable to generate temperature rises in jaws that still had holding force above 5lb, but below 5lb we observed minor temperature rises. Though the level of vibration we experimented with is not likely to be found in the field (1in/s), the statistically significant number of jaws with holding force under 5lb was a cause for concern. Holding forces above 5lb (but below 10lb) are considered a safety range for the tools' operation. Sockets in this range are still recommended for a more rigorous inspection and replacement.

Figure 5. Insertion Forces from Collected Socket Jaws



PART 5: Hot Socket Gap Indicator (HSGI)

The hot socket gap indicator (HSGI) was developed to search out meter sockets with holding forces below the ten pound threshold, indicating the jaw was likely exposed to elevated temperatures higher than the jaw was intended to see, and/or the holding force of the jaw is in the questionable range. The blade on the initial HSGI is .050 inches wide (1.27mm); narrower than a standard meter blade that is specified at .094 inches (2.39mm) wide. The narrower blade on the HSGI fails any jaw with a gap wider than .050 inches, indicating the jaw has been deformed from the original preloaded (no gap) design.

A second HSGI was introduced with a blade holding the same dimensions as a meter blade, .094 Inches nominal (2.39mm). This tool was introduced to handle two situations found during the field testing of the original tool. The first is the use of meter man's grease in some meter installations. This grease helps the meter technicians insert meters into tough sockets. With the thin blade HSGI, grease reduced the surface friction of the jaw, allowing the tool's blade to slip into some jaws that were otherwise good. This was only the case when the grease was fresh and acting as a lubricant. The wider (.094 Inch) blade requires slightly more force to be pushed in (overcoming the larger frictional force of the thicker blade) and was not similarly affected by the grease (no false positives). The second situation discovered in field testing is a socket design manufactured with an intentional gap between two parallel jaw sides. This design is to allow maximum blade to socket area contact when a meter is inserted in the meter jaw. The narrower blade thickness of the first design flagged this meter socket as a result of this gap, regardless of holding force. The wider blade thickness eliminated this issue and correctly passed good versions of this meter socket type and failed fatigued socket jaws.

The HSGI has been designed to be simple, durable, and easy to use. The blade is attached to a red block that acts against a 10lbf spring. In the initial state the indicator always shows red, when the blade is pressed against a good jaw the red is pushed back and hidden with the operator exercising roughly ten to twelve pounds of force on the tool. When the tool is pressed against a bad jaw, the blade slips into the jaw and the red stays visible. The spring is rated for over one million compression cycles by the spring manufacturer. After assembly each HSGI is inspected for spring force within tolerance (plus or minus one pound) and cosmetic defects. A five year calibration/inspection date was set on the tool to allow the factory to visually inspect and mechanically test each unit after five years of use (and ostensibly far less than one million cycles). The unit can be re-certified, repaired or replaced. The design has been drop tested in a range of usable temperatures (20F to 120F), and has been tested for electrical insulation up to 3,000V. The HSGI should still be used with Personal Protective Equipment (PPE). The beveled edges on the blade allow the tool to work consistently on the full range of jaw designs we've acquired, eliminating misreading due to angle of insertion. The nominal force required to use the tool on a "good" jaw (blade does not enter the jaw) ensures that the tool can be used all day long without fatiguing the operator as would a tool that operates by being inserted into every jaw, good or bad.

Upon receiving feedback from the utilities who field tested the unit, we learned the original tool is preferred by utilities that didn't find many factory gap sockets and who do not use grease on their meter socket jaws. Both tools are valid based on the same design criteria and data, and both offer a large margin of safety beyond the zero to 5lb holding force danger zone. The second design handles more field situations, passing most jaw designs with holding force in the 7lb to 10lb range (and above), due to the greater force required to insert the full width blade into a meter socket jaw. The first design (thinner blade) fails most jaws once they drop below 10 pounds. Field technicians using the tool reported that egregious faults such as blackened or pried jaws were easily recognized without the tool; however several jaws that appeared normal to a visual inspection failed the HSGI test and upon further inspection were deemed unusually weak. We stress that the tool is a diagnostic assistant; the operator should have an understanding of the latest hot socket research and use the tool in conjunction with other observations the utility has assigned as hot socket indicators.

Hot sockets can also be created by broken wires, loose wires, damaged insulation, tampering, and foreign objects, but none of these conditions damage the meters in the same way that the weakened jaws damage the meters. The HSGI should always be used in conjunction with a thorough physical examination of the entire meter socket and enclosure.

PART 6: Socket Safety Clips

Once potentially dangerous jaws were identified, we considered what could be done by the utility to prevent a hot socket fire without disconnecting the customer's power. One way this has been handled in the past is with a metal clip that widens the meter blade so when the meter is reinserted the blade is theoretically making better contact with the surfaces of the jaw. The concern with this design is that if the jaw has no holding force left, a wider mater blade could deform the blade further without making better contact. Our solution was a plastic clip with roughly 20lb holding force, squeezing the questionable jaw around the meter blade. Plastic allowed for a safer installation, without the risk of inserting conductive metal parts into a live socket. We experimented with high temperature plastics, focusing on the glass transition temperature of the polymer; the temperature at which the clip would begin to mechanically deform and begin losing holding force. We were successful in finding a plastic that was not conductive and not brittle, and could maintain nearly 20lb of holding force even under the most demanding power draw where the jaw could see temperatures in excess of 350 degrees Fahrenheit (just over 176 degrees Celsius). We experimented with geometries that made the clip easy to install without compromising their holding force and while wearing appropriate Personal Protective Equipment (PPE).

We offer this tool as a temporary safe guard a meter technician can put on questionable jaws to leave them safer than when they were discovered. The two unattractive alternatives to using the socket safety clip are to either disconnect the customer immediately until the dangerous situation can be remedied or leave the dangerous situation active and hope that the customer will correct the situation before there is a fire. Some socket conditions may be so bad that a simple Socket Safety clip will not alleviate all the dangerous conditions identified in the box. Qualified Meter technicians should perform a thorough visual inspection of the socket and enclosure in addition to using the HSGI and potentially the Socket Safety Clip.

PART 7: Conclusion

TESCO's Hot Socket Gap Indicator is a simple and reliable diagnostic assistant for flagging potential hot sockets. The jaws that indicate as failed should be further inspected for signs of unusually weak holding force, discoloration, debris, and pitting from arcing. If these signs are present, the jaw or socket should be replaced to prevent overheating of the meter and the possibility of fire. To give the customer time to replace their socket without an immediate risk of a hot socket, a Socket Safety Clip may be used if the technician has performed a thorough inspection of the socket to ensure there are no other dangerous conditions present. This clip will apply roughly 20lbs of holding force, allowing the customer time to replace the dangerously weakened socket jaw.

AMI deployments have made hot sockets a front page issue, as removing a meter from an old socket and forcing a new one in can take a marginal meter socket and create a dangerous meter socket without proper inspection prior to the installation of the new meter. However, these deployments are also an opportunity to observe and flag sockets that are potentially dangerous. We at TESCO designed the HSGI and Socket Safety Clip after a successful effort of replicating in our lab a common mode of failure observed in the field; overheating due to arcing. Our goal was to develop tools that can help reduce the number of meter fires. The tools we developed are in the first line of defense, along with operators who have an understanding of what to look for to identify hot sockets and other dangerous conditions. We hope that through sharing what we learn, the industry will develop knowledge and diagnostic methods to prevent catastrophic situations going forward.