Advancements in 200-amp Injection Elbows

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***Abstract*: Injection elbows have been in use for over two decades with the unsustained pressure rejuvenation paradigm. Recent advancements make injection elbows safer to use and provide higher post-injection cable reliability.**

BACKGROUND

Injection elbows, designed and tested to IEEE™ 386, IEEE 592, and ANSI C119.4, utilized to supply fluid under low, unsustained pressure have evolved slowly over the last two decades. The very first injection elbows were created by Bertini and an associate at Dow Corning in 1986. These first injection elbows were crude tools, which were modifications of standard capacitive test point elbows. A hole was drilled and tapped through the capacitive test point and a nylon interface was threaded into the hole. When the injection period was complete, typically about 60-120 days after it was begun, the injection elbow was removed and a standard, unmodified elbow was permanently installed. The injection-elbow-as-a-tool approach suffered from the economic penalty of having to switch the cable out and ground it when the injection was complete. Except for this economic shortcoming, the elbow worked without failure.

The author and his colleagues worked with a first elbow manufacturer to improve this earliest elbow concept with what would be recognized today as an injectable elbow. This new elbow, the '393 elbow, is described in detail in [1] along with its injection cap in [2]. Like its predecessor, the '393 elbow had no provision to prevent fluid from entering and flooding the bushing. Fluid in the bushing did not cause a significant problem until the introduction of a new generation of fluid (XL fluid) in about 1992 as described in [3]. According to the supplier's materials safety data sheet (MSDS) at [4], XL fluid is more flammable than jet fuel A.

Figure 1. Cut-away of a typical injection elbow shows the placement of an O-ring just above the nose of the bushing.

Figure 2. Double D-ring seal located on the probe mates with brass probe-positioning-cup, providing a superior seal to a single O-ring design. The design is less likely to be affected by molding flash and more robust when the probe pin experiences a moment.

It wasn't long after the introduction of the flammable XL fluid that fires occurred when switching bushings, which were filled with fluid. As a response to this nascent safety issue, an O-ring groove and an O-ring were added to the probe pin to seal the fluid into the elbow and keep fluid out of the bushing. As illustrated in Figure 1, the fluoro-elastomer of the O-ring seated against the EPDM rubber of the elbow did not provide a perfectly reliable seal. A probe support, which was at first metallic and later a filled resin, was added to the elbow throat to provide a stiff surface to engage the O-ring. This improvement stopped most, but not all of the fluid leaks into the bushing. After some more unfortunate experiences, another modification was made to the elbow. Because of manufacturing imperfections around the probe support, EPDM flashing occasionally intrudes onto the inside face of the probe support and can cause seal failure. As a result of this persistent issue with the probe O-ring/probe-support design, the manufacturer manually inspects and pressure tests the O-ring/probe-support interface. Leaks, so identified, are corrected before supplying the parts to the rejuvenation technology supplier (RTS).

In 1998 a second elbow manufacturer introduced an improved probe seal as shown in Figure 2. The improved seal involved two D–rings and a cup-shaped brass probe support. The double D-ring seal better tolerates a moment applied to the probe and the large cup-shaped brass probe support all but eliminates flashing issues suffered by the earlier design. Unfortunately this improved design is available only for 35kV large interface elbows.

These two ring and probe support combinations represented the state-of-the-art until 2008, when the authors introduced optional improvements to the injection elbow.

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IMPROVED SEAL & ACCESS INTERFACE

In addition to the inherently unreliable probe seal, there are other issues with traditional injection elbows. In [5] and [6] it was demonstrated that the unsustained pressure method does not allow a sufficient quantity of first generation rejuvenation fluid to be injected in most URD cables. In [7] it was shown that 10% or more of the fluid injected through conventional injection elbows is lost to undesirable permeation through the elbow. At temperatures greater than 50°C over a prolonged period, the elbow can fail from excessive swell.

The authors have introduced an improved sealing system to:

1. Mitigate the amount of fluid that is lost to the EPDM elbow.
2. Create a more robust seal, which
   a. does not require the elbow manufacturer to test and rework molded parts to eliminate flashing from seal interfaces, and
   b. is less sensitive to installation craftsmanship.

Figure 3 shows the improved sealing system. In addition to the seal on the probe, which is subject to deflection when an elbow is operated, a second seal has been added to the compression connector. Besides mitigating the effects of some deflecting forces on the seal, the new seal location reduces the surface area available for permeation of treatment fluid into the elbow. The relocation of the primary seal reduces the surface area exposed to fluid and the exudation rate. The post-injection reliability is improved a like amount. The new seal location is free of molding flash issues, which hampered the older design. There are no component part interfaces near the new seal location.

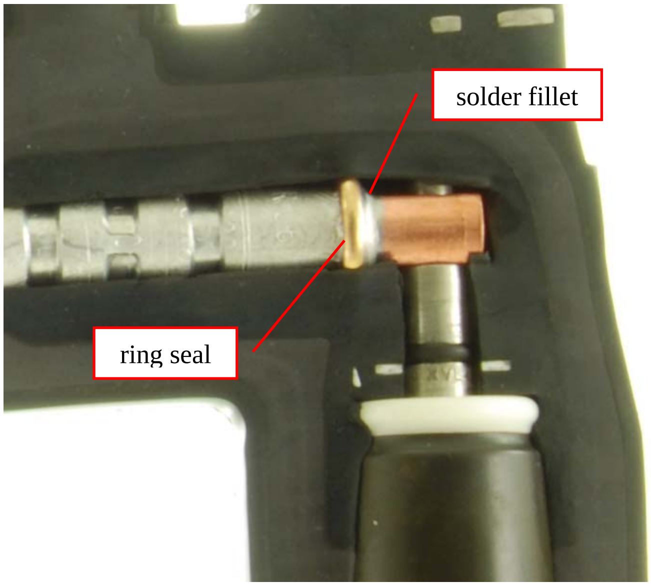


Figure 3. The improved sealing system eliminates the need for a manufacturing seal test, because there is no flashing to interfere with the seal. 100% field testing is performed.

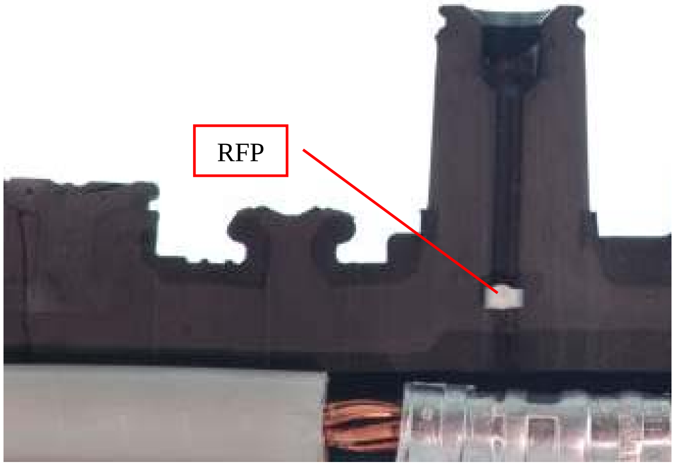


Figure 4. Direct access injection elbow used for unsustained pressure injection. The reticular flash preventer (RFP) is absent from older injection methods.

A close inspection of Figure 3 reveals an improved seal design. At the low pressure employed by unsustained pressure rejuvenation, the legacy O-ring seals on its inner circumference against the probe pin and its outer circumference against the support. The new seal is an all metal component soldered to a standard ANSI C119.4 certified compression connector. Because the inner circumference is sealed with solder, there is a 50% reduction in possible leak paths. And while the elastomeric O-ring of the legacy design may be scratched during installation, the advanced metallic ring seal is much more robust. The metallic ring outwardly deflects the inside circumference of the EPDM elbow providing a robust and static metal-to-rubber seal with a high tolerance for deviations in geometry.

A second and independent design change to the injection elbows addresses a nagging safety issue associated with the legacy elbow and cap design. The safety and operational issues are described in [8] and [9] in considerable detail. In short, the direct access injection port, shown in cross section in Figure 4, provides for direct access from the conductor to the outside and ground potential. This direct access must be exposed to swap non-permanent injection caps and permanent shielded caps. The access port is vulnerable to flash over during that swap as illustrated in Figure 5 and discussed later.

The proprietary reticular flash preventer (RFP) introduced in [10] and shown in Figure 4, is an innovation not utilized in the legacy approach. On 35 kV systems, the flash-over problem is so acute when an RFP is not present that the caps cannot be removed when the system is energized. While de-energizing the cable eliminates the potential for electrical flashover, cost and customer service penalties must be borne by the circuit owner. The RFP device is designed to take advantage of capillary forces to hold dielectric fluid in place against the pull of gravity and slight pressure differentials. At the same time the RFP does not impede the flow of fluid into or out of the cable when an access port interface is attached.

Figure 5. The relatively short distance of 3.5" from [14] for this 15kV injection elbow (4.7” for the 35kV large interface injection elbow of Figure 2) from the energized conductor to the nearest ground plane creates a flash hazard when the device does not have an RFP installed and the caps are swapped on an energized elbow. This laboratory photograph shows the initial current path.

Figure 6 presents a photograph of an access interface (AI) used to safely deliver fluid to and from the cable strands with conventional direct access elbows for unsustained pressure injection. There are no design modifications to the two-decade old elbow itself. The elbow body is precisely the same elbow designed and manufactured to the IEEE 386, IEEE 592 and ANSI C119.4 standards.

There are no provisions in IEEE 386 or the other standards to directly address fluid injection. Component manufactures have done some design testing reported in [11], [12], and [13] on the elbows, primarily to confirm that the injection ports do not interfere with the elbow integrity vis-à-vis the standards. For example in [11] and [12] the following tests were run:

Table 1. IEEE 386 testing summary.

Test	IEEE 386 Section
A. Corona voltage level	**7.4**
B. AC withstand voltage	**7.5.1**
C. DC withstand voltage	**7.5.2**
D. Impulse withstand voltage	**7.5.3**
E. Switching current	**7.7**
F. Fault-close current	**7.8**
G. Accelerated sealing life	7.12

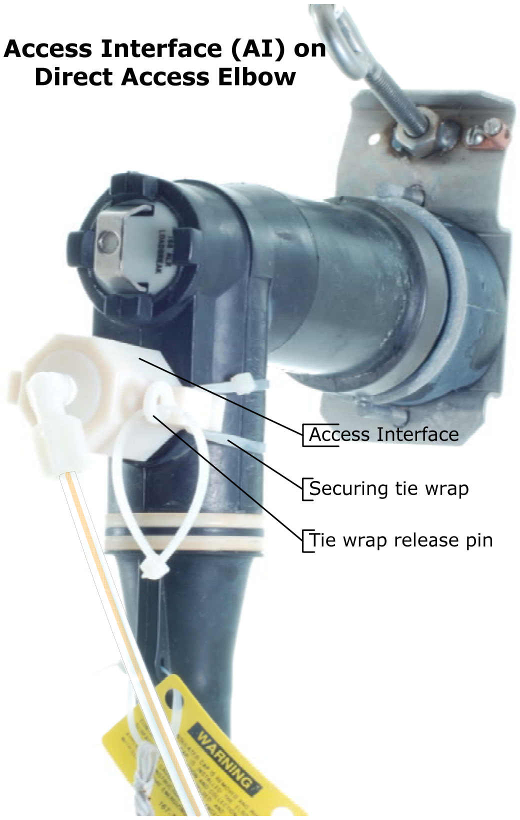
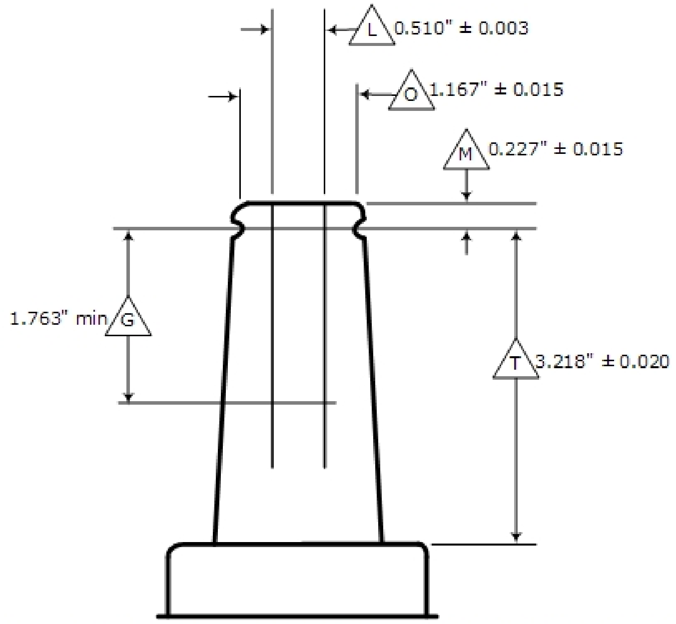


Figure 6. Access Interface (AI) used on dead-front elbows allows unsustained pressure injection on URD systems.

Of the seven tests, only the “switching current” and “fault-close current” tests introduced rejuvenation fluid into the test. The fluid used was a 50/50 mixture of water and Dow Corning cable restoration fluid (X2-2614). X2-2614 is 99.8% phenylmethyldimethoxysilane (PMDMS). Formulations, which are predominantly PMDMS, are available from both rejuvenation technology suppliers. At the time these tests were executed in 1989 and 1990 there were no sealing o-rings to exclude fluid from entering the bushing. The two tests were designed to determine if the bushing and elbow probe interface worked as required when flooded with the mixture of water and PMDMS. The flooded interface met the requirements of sections 7.7 and 7.8 of IEEE 386 in [11] and [13]. The o-ring was introduced about two years later when the X2-2614 fluid was supplanted by a new mixture of PMDMS and a second volatile silane, trimethylmethoxysilane (TMMS). As shown in [4], this new fluid has a flash point less than that of jet fuel A and was easily ignited when a flooded bushing was switched. Once a sealed system was commercialized in about 1992, the switching current and fault-close current tests of Table 1 were moot..

While IEEE 386 does not directly address an access port it does suggest the appropriate minimum uninsulated distance between live contacts and the ground shield for safe and reliable operation. Figure 7 provides a simplified view from [14] of a 15kV elbow-bushing interface.



From IEEE 386-2006 Figure 5 – 200 A loadbreak interface, 8.3 kV and 8.3 kV/14.4 kV

Figure 7. Uninterrupted distance between energized subcomponent and ground on a 15kV bushing is T + 2M + (O-L)/2 + G or 5.705” with worst case tolerances.

The minimum distance between an energized subcomponent of the device to a ground is 5.705 inches with no elbow present and 3.730 inches when a probe is moving in or out of the bushing. The later condition persists for only a fraction of a second during normal operations. Table 2 summarizes these two values for three IEEE 386 elbow/bushing classes and compares them to the access port values.

In [15] the manufacturer of the IEEE 386-2006 Figure 8, 35kV large interface elbow (pictured above in Figure 2) warns the end user:

> “**Warning:** Do not pull plug out of injection port while elbow is energized. De-energize circuit before operating plug.”

Table 2. Free path dimensions from [13], Figures 5, 7, and 8 for various standard elbow/bushing designs. The 35 kV class is sometimes referred to as large interface and is illustrated in Figure 2.

Interface	**IEEE 386 Designation**		
	Fig. 5 15 kV	**Fig. 7 25/35 kV**	**Fig. 8 35 kV**
Bushing (in)	5.705	8.270	9.718
Bushing/elbow (in)	3.730	4.350	6.218
Access cap			
Flash path (in)	3.5	3.5	4.7
Relative to bushing	61%	42%	48%
Relative to bushing/elbow	94%	80%	76%

Table 3. Materially identical; cosmetically different.

Feature	Identical?	Difference
Access port	Yes	
Permanent cap	Yes	
Probe O-ring	Yes	
Probe support	Yes	
SS hose clamp	Yes	
Tags & Markings	No	“D”/“A”; tags swapped
Factory P-test	No	RTS performs instead

This warning is entirely appropriate, because the flash over path is only 76% of that on an analogous bushing. Unlike the elbow/bushing interface, where the operator is at least partially shielded by the elbow design from an arc-flash, nothing substantive stands between the hot-stick operator and the arc-flash when an access plug is operated.

An access port may experience some of the same things that a bushing elbow interface may encounter when being operated. There may be a vacuum or pressure released. There may be contaminants such as water, which are expelled from the port when its permanent cap is removed. There is not the inevitable arc when a load is broken. The other designs encompassed by IEEE Figures 5 and 7 enjoy only marginally greater separation at 84% and 90% respectively, but are routinely operated while energized even though those separations fall below the analogous IEEE 386 requirements. The RFP device introduced above and shown in Figure 4 interrupts the path between the energized and grounded portions of the injection elbow and allow all injection ports to be operated while energized with a larger margin of safety and truly within the guidelines suggested by IEEE 386.

DISTINCTION WITHOUT DIFFERENCE

The discussions in this paper regarding the ‘393 elbow access ports have been limited in scope to injection applications. The injection ports have been used as described in [1] for other applications including direct voltage testing. The component manufacturer has suggested in its advertising literature and in private announcements that a distinction exists within a series of functionally equivalent access elbows. The distinction is suggested by the designation of “A” for “access” or “D” for “direct test.” Table 3 is a compilation of a detailed comparison of a 168AELR elbow manufactured in November 2005 (An “A” elbow) with a 168DELR elbow manufactured in December 2008 (A “D” elbow). The detailed comparison demonstrates that the intended distinction makes no material difference. The “A” and “D” elbows are materially identical. The cosmetic difference in the tags can be remedied by a rejuvenation technology supplier (RTS) with an inexpensive tag swap. The factory pressure test can be replaced with a similar test by the RTS. The only remaining difference is the integrally molded part number, which is entirely cosmetic. The interchangeability of the "A" and "D" elbows provides circuit owners with more than a single RTS to foster a competitive marketplace when unsustained pressure rejuvenation is desired.

SUMMARY

A family of improved IEEE 386, IEEE 592 and ANSI C119.4 conforming injection elbows and an improved fluid injection access interface (AI) with flash prevention provides the following benefits:

- Eliminates the risk of injection port flashover with a proprietary reticular flash preventer (RFP). Injection elbows which do not include an RFP are not compliant with the spirit of IEEE 386.
- Reduces the risk of fluid leaks with a more robust seal design incorporating a redundant or backup seal lowering the probability of transformer fires.
- Eliminates the needs for post-manufacture air pressure testing to identify flashing from molding defects.
- Improves post-injection reliability by reducing the exudation of treatment fluid from the elbow by about 30% during and after injection. Exudation may compromise the reliability of the elbow under hot conditions, and always lowers the post-injection reliability of the cable.

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AUTHORS

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