NATIONAL RADIO ASTRONOMY OBSERVATORY
Socorro, New Mexico

VLBA Antenna Memo Series No.90

2015 - St Croix Corrosion Report

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1.0 Executive Summary

On June 23, through June 26, 2015, the author visited the St. Croix antenna. With the help of the local VLBA site technician Greg Worrel, we performed a top to bottom corrosion inspection of the antenna structure. What was found is that the coating system is performing remarkably well on the larger structural members and plate sections of the antenna. These members have very minimal corrosion. The coating system is not performing as well on the fasteners, sharp edges and places where the structure traps water. These areas have levels of corrosion that can be described as the good, the bad and the ugly. The areas that fall in the good range will just need a wash and a brushed on coat of acrylic polysiloxane paint. The bad areas will require additional surface prep before they are coated with surface tolerant epoxy. The ugly sections will need to be completely replaced.

The budget impact of these repairs will be about $90,000. This includes $40,000 of contractor repairs that should be accomplished as soon as possible and approximately $50,000 worth of additional tiger team travel cost associated with painting and replacing corroded sections of the antenna. The tiger team would require an additional welder and 3 painters for a period of approximately 3 weeks.

2.0 Inspection Results

This section presents brief descriptions of the level of corrosion observed. Photographs of this corrosion are included in Section 4.0.

2.1 Apex

The corrosion on the upper part of the quad legs and donut structure is minimal. The bolted connections where the Quad legs attach to the donut shaped structure are showing rust staining due to corrosion of the fasteners. There is also superficial corrosion on the FRM counterweights and other locations (Figure 1).

Subreflector – The white overcoat paint on the subreflector has eroded to the point where it looks bad cosmetically but the silver layer below is still intact and functional. There is a small area on one side of the subreflector where it appears that a fiberglass patch is beginning to delaminate (Figure 2).

Quad Leg – Although the upper sections of the quad legs only show minimal corrosion (Figure 3), the lower part of one of the quad legs is corroded all the way though (Figure 4). The other quad legs have not corroded all the way through but they have sections that have corroded to the extent where they will need repair.

2.2 Backup Structure

The antenna backup structure located just below the dish was designed using bolted connections instead of welded connections which are preferred for marine environments (Figure 5). A large percentage of these bolts are showing rust staining or corrosion. The bolts have not corroded to the extent where they need to be immediately replaced but they will need to be repainted. The corrosion is worse on the windward side of the antenna.

Trusses – Figures 6, 7 and 8 show the extent of the corrosion on the backup structure trusses.

Vertex Room – Prior to the antenna painting in 2007, the bolts and nuts that attach the vertex room feed house to the structure were severely corroded. These bolts were replaced and put in from the opposite direction and were carefully painted in 2007. The new bolts are holding up quite well as evinced in figure 9.

Tanks – The access doors on the large enclosed box sections of the backup structure were opened so that the box sections could be inspected from the inside (Figure 10). In 2007, the inside of the box sections were severely corroded. This part of the structure was a pleasant surprise as the box sections only showed minimal corrosion where the drain holes (Figure 11) were previously cut and slight staining where water pools in the structure. These drain holes should be repaired by cutting out the corroded sections and then welding in a patches. These patches will then need to be painted.

Star Structure – The paint on the large surfaces like the star structure is performing well. However, the bolts in these areas are rust stained (Figure 12).

Counterweights – Some of the bolts on the counterweight and gear sector are corroded and will need attention (Figure 13).

2.3 Lower Structure

The large beam sections and I-beams that support the antenna show very little corrosion. Thus, the antenna is not in danger of a catastrophic failure. There is however, significant corrosion on the stairs and catwalks that must be addressed as soon as possible. The corroded stairs and bar grating has in places corroded to the point where it is unsafe.

Catwalks and Stairs – Since the bar grating on the catwalks and stairs is so hard to prep and paint, it was expected that it would soon need to be replaced. Surprisingly, the paint on the majority of this grating is still in great condition (Figure 14). However, in the places where the coating did become compromised, the bar grating has extensive corrosion and must be replaced (Figure 15). The site technicians have installed plywood decking over the failed bar grating as a temporary repair. The lightweight grating around the vertex room is also corroded to the point where it will soon need to be replaced (Figure 16)

There are 9 pieces of bar grating that need to be replaced. There are also 17 stair treads and nose pieces that need to be replaced (Figure 17). There are an additional 13 steps that only need the nose piece replaced (Figure 18). These repairs should be done as soon as possible.

Large Tubes and I beams - The large structural tubes and I-beams supporting the antenna show only minimal corrosion on some of the flange bolts where the tubes are connected (Figure 19).

Rail – The rail was painted with latex paint and is not corroding excessively. The splice plates and rail clips are showing some signs of corrosion and will need to be scaled and repainted (Figure 20).

Pintle Bearing – The washers under the pintle bearing nuts were replaced with galvanized washers and repainted during the 1999 maintenance visit. The new paint has performed well and there is very little corrosion in this area (Figure 21).

2.4 Ancillary Systems

Drive Systems – The corrosion on the drive motors and gearboxes is mostly superficial (Figure 22).

HVAC –The HVAC condenser platform is badly corroded and will need to be replaced (Figure 23).

3.0 Remediation

This section details the steps needed to return the structure to full strength and to moderate the effects of corrosion.

3.1 Steel Repair

The steel that has corroded to failure as described in the previous section will need to be replaced. While on the Island, I spoke with the steel fabrication contractor Lincoln Tang How of Tang How brothers, Inc. Lincoln quoted $40,500 to supply all labor, materials and equipment to complete the following tasks. These tasks should be contracted and completed as soon as possible.

1. Replace 17 stair treads and noses. Treads needing replacement marked with blue paint. Replace with hot dipped galvanized bar grating painted per specification.

2. Replace 13 additional stair noses. Marked with blue paint. Replace with hot dipped galvanized and paint per specification.

3. Replace grating marked with blue paint. Replace with hot dipped galvanized bar grating painted per specification.

4. Repair swinging platform handrail pipes.

5. Replace swinging platform stair supports.

6. Replace elevation platform extensions.

There are several areas where the corrosion repair should be completed by NRAO personnel because the extent of the repair cannot be determined without destructive testing or we have a unique capability or experience that will be required for the task. The following tasks should be accomplished during the next tiger team visit. The contractor quote to complete this work was an additional $43,200. This does not include approximately $20,000 needed for painting the antenna and the travel expense for an NRAO engineer to supervise the work.

7. Replace lightweight grating around vertex house. Use galvanized material and paint per specification.

8. Repair corroded quad legs.

9. Repair holes in tank sections

10. Replace HVAC condenser platform.

3.2 Paint System

As described previously the paint system on the antenna is showing signs of failure. This is particularly evident where the structure traps water and on the bolts and nuts that hold the structure together. Fasteners are almost always the weak link in marine environments. Traditional coatings systems tend to break down on the sharp edges of the exposed threads and in the crevices under the washers and between the nut and bolt.

At this point the most economical remedy would be to send a crew of painters on the next tiger team to repair the paint system. In areas where there is heavy rust scale, the surface will need to be surface prepped and then repainted. Areas where there is light rust staining or tightly adhered rust can be cleaned and overcoated. Overcoating rust is not a permanent solution but the barrier can eliminate the available oxygen and electrolyte and extend the surface life. This overcoat will need to be continuously maintained and will require frequent repainting. If the site technicians cannot keep up with the painting, then other resources will need to be employed.

Eventually a more permanent solution to the fastener corrosion problem will need to be addressed. The offshore oil and gas industry is continuously researching marine corrosion and developing solutions. I have included a paper on one of the newer corrosion prevention systems in the appendix of this report. The application equipment for this system starts at $20,000 and the material cost about $40/ ft^2. The advantage of this system is that it is effective even when applied over previously corroded fasteners.

4.0 Figures

Figure 1, Superficial corrosion at FRM barrel counterweights.

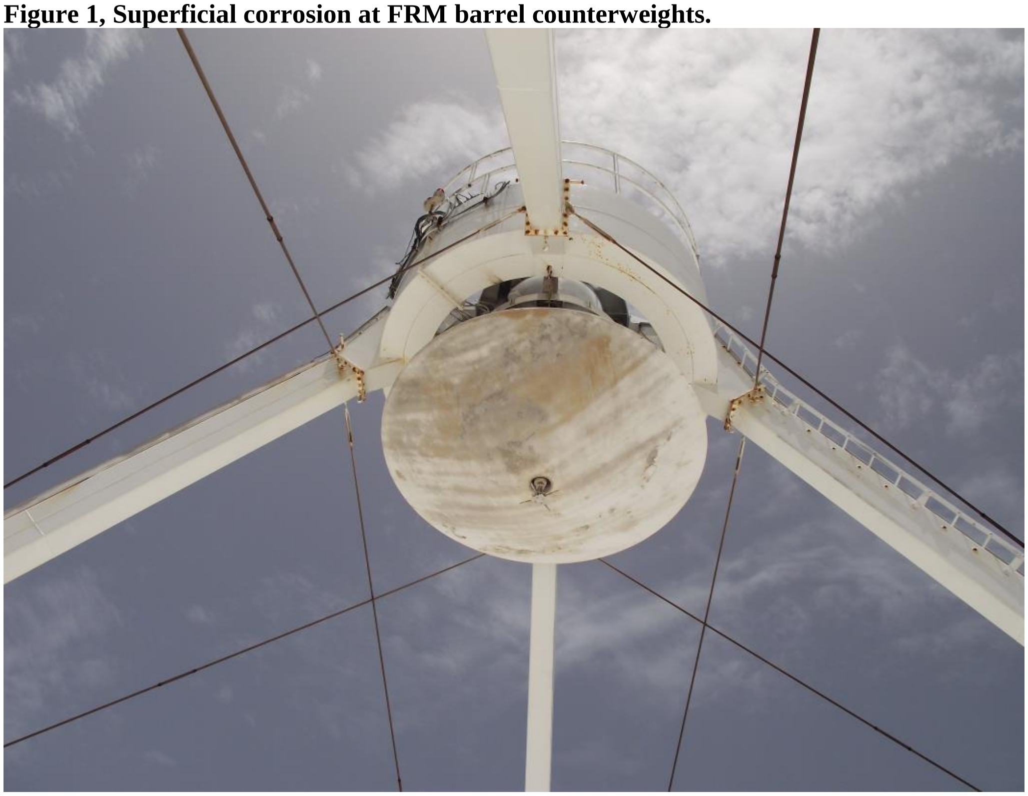

Figure 2, Rust staining on bolted connections at apex. Subreflector paint condition

Figure 1, Quad leg corrosion above the dish.

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Figure 2, Quad leg corrosion below dish

Figure 3, Welded connections vs. bolted connections in marine environment.


Figure 4, Extent of rust stained bolts.

Figure 5, Close up of typical bolted connection.

Figure 6., Minor corrosion due to paint thinning on edges.

Figure 7, Vertex room bolt corrosion.

Figure 8, Photograph of the inside of the box structure. This part of the antenna is not subject to UV radiation so it was not painted with the white topcoat.


Figure 9, Corroded drain hole that will need repair.

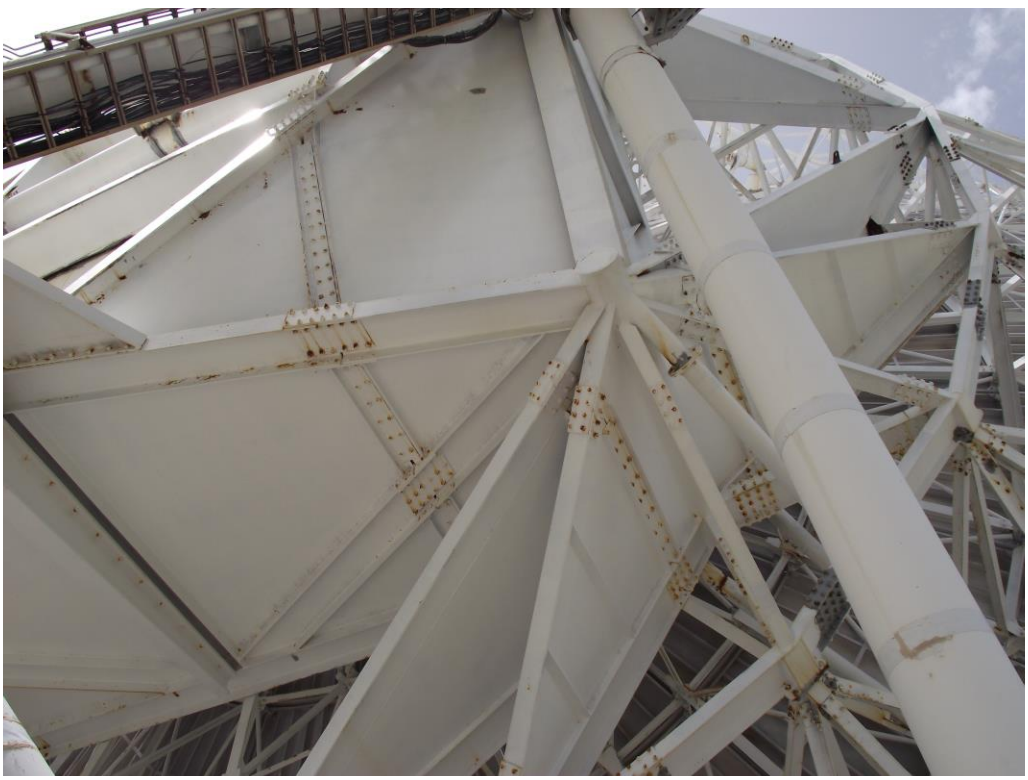
Figure 10, Star structure bolt corrosion.

Figure 11, Counterweight bolts. Corroded section on left is where the site techs needle scaled the corrosion and have not yet repainted.

Figure 12. Typical paint condition on bar grating and hand rails.


Figure 13. Example of failed bar grating.


Figure 14, Lightweight walkway grating around vertex room is failing and will need to be replaced.

Figure 15, Stair treads and noses that will require replacement

Figure 16. Stair nose that requires replacement.

Figure 17, Support structure corrosion is minimal.


Figure 18, Corrosion on rail, rail clips and splice plates.

Figure 19, Pintle bearing housing corrosion.

Figure 20, Drive wheel and gearbox assembly corrosion.


Figure 21, HVAC condenser platform.

5.0 Appendix

Long-term evaluation of bolt and infrastructure protection using corrosion-inhibiting thermoplastics.

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Abstract

The fate of a complex steel assembly may be determined by the vulnerability of its smallest and least considered component. The bolts or fasteners holding the assembly together are often the areas where corrosion first starts and where the effects of corrosion may have the most serious consequences.

Although the use of alloy bolts would considerably mitigate the galvanic effects suffered by bolted systems, the vast majority of bolts used in the offshore industry and elsewhere are carbon steel. With some bolts failing in as little as 6 months and design lifetimes of industrial infrastructure being regularly exceeded, a remedy is required which can improve on the often short-lived results achieved using standard coating systems.

Over the last ten years, a system has been developed which uses a corrosion-inhibiting thermoplastic to provide long-term active protection of vulnerable steel systems and this paper looks at the results of several years testing of the system, both in the field and in controlled conditions.

Offshore samples, exposed for more than 7 years, and onshore systems in outdoor coastal environments are examined and compared with unprotected samples in test programmes for major oil companies and national power companies - with excellent results on new substrates and on those which were already suffering from the effects of corrosion prior to application.

The paper also looks at the protective mechanisms around which the system is designed and how they contribute to its success.

Keywords: galvanic corrosion, thermoplastic, corrosion inhibitor, coating, sprayable, bolt failure, carbon steel, fasteners, bolted systems, corrosion failure, corrosion protection, assembly, pipeline, flange.

Introduction: why do bolts rust so easily?

Steel is a marvellous substance, made from abundant raw materials, strong and easy to use but, like most things, it has a downside – corrosion. Although 'stainless' steel has been widely available since the early 20th century, the majority of steel components are manufactured from carbon or low-alloy steel and, especially when combined into an assembly, these steels are liable to corrode – sometimes extremely rapidly.

The focus of this paper is the particular nature of the corrosion process in steel bolted systems, where large components are assembled into a structure and secured using relatively small fasteners – usually nuts and bolts. Such assemblies are to be found on pipelines, machinery and other infrastructure in every corner of the globe and, wherever they are found, it is in the joins, and most particularly in the fasteners, where the greatest corrosion effect is to be found.

A number of factors govern the propensity for corrosion in steel assemblies: design, material selection, stress, differences in materials, relative size, damage to coatings during assembly and crevices formed between components - to name but a few. Some of these factors are beyond the ability of any remedial coating to provide a remedy - and in all cases, design and material selection are key to minimising failure. Nevertheless, corrosion failures will occur and it is how best to address this corrosion that we are looking at today.

Background

To give the subject context we will briefly deal with some of the background:

Material Selection.

Material selection is fundamental to the prevention of corrosion. As noted, so-called 'stainless steel' or 'high alloy' steels have been available for many years and their use is widespread in safety and production critical areas. Although not without their problems, many corrosion failures could be prevented by the use of high alloy steels but, as we will see, their use can sometimes make a situation worse. See Table 1: Galvanic Series.

Galvanic Corrosion

We know that galvanic corrosion is induced whenever two dissimilar materials are coupled in an electrolyte. One metal becomes an anode and corrodes faster than it would all by itself, while the other becomes the cathode and corrodes more slowly. The severity of this effect is determined by the relative nobility of the materials involved as shown in the Galvanic Chart. Any difference will have an effect but a difference of greater than 0.2 volts would usually be considered unacceptable.

Relative Size

A small anode to cathode area ratio is highly undesirable. In this case, the galvanic current is concentrated onto a small anodic area. Rapid thickness loss of the dissolving anode tends to occur under these conditions. [1]

Now that we have established a context, let us look at the photograph (Figure 1). This is just one of a million pictures I could show you where design and construction of an assembly are creating unnecessary corrosion problems – and making remedial treatment extremely difficult. The photo shows a section of pipework constructed from a combination of low and high alloy steels, with a central section where a low-alloy steel flange is connected to a high-alloy flange using low-alloy bolts and nuts – all supported by pieces of welded angle iron. It may surprise you to learn that this structure is less than two years old.

Corrosion in the low-alloy flange is apparent where coating damage has occurred but most significant is the level of corrosion in the bolts. Here we have two of the factors we have discussed operating – relative size and corrosion potential. The bolts are of low-alloy steel, corrosion potential around 0.85, the flange is high-alloy, around 0.5 – a difference of 0.35 and well outside acceptable differences. In addition, the bolts and nuts are small relative to the structure in which they find themselves, exacerbating the corrosion effect. In some environments, such bolts may well show significant corrosion within weeks of installation.[2]

As you can see in Figure 2, small, low-alloy bolts play the same role in a bolted system as do the sacrificial anodes in a CP system.

Damage & Crevice corrosion

We have already seen that coating damage can lead to corrosion on the flange surfaces. In nuts and bolts too, assembly can cause damage and penetration of the coating leading to corrosion. Figure 3 shows a nut after only 18 months in the splash zone, its ptfe and zinc plating failing within 6 weeks of exposure.

In a salt-spray test, a zinc/nickel coating would be expected to last at least 1000 hours before 'red rust' occurs. An accelerated test such as this is designed to demonstrate the potential longevity of a coating system on the basis that the test conditions are so extreme, the lifetime of the coating should, for example, be 10 years under normal conditions if it could last 1000 hours in a salt-spray cabinet.[3]

However, 1000 hours is only 6 weeks. In the real world, the fasteners in Figure 4 have been exposed to constant salt-spray conditions for eighteen months.

Crevice corrosion under washers, fastener heads, disbonded coatings and threads also has a role to play in the litany of problems affecting bolted systems. In a report on bolt failures as part of a testing programme by DNV, it was shown that washers are more likely to fail than any other component in a bolted system. It is easy to see why this might be, as they are the smallest component, trapped in a crevice, subject to turning forces from both sides and rarely treated with any care. [4]

What remedies are available?

Essentially, three standard remedies are available when corrosion occurs in a bolted assembly:

1 - Do nothing.

Rusting infrastructure around the world is a tribute to the philosophy of putting off until tomorrow that which you should be doing today.

2 - Take everything apart, clean, recoat, replace and reassemble.

Not really practical if an entire LPG carrier, offshore platform or refinery needs refurbishment every 18 months.

3 - Clean/blast/coat the worst affected areas on a routine basis.

Common practise but, once corrosion is in a system, rarely completely successful.

Table 1: Galvanic Series

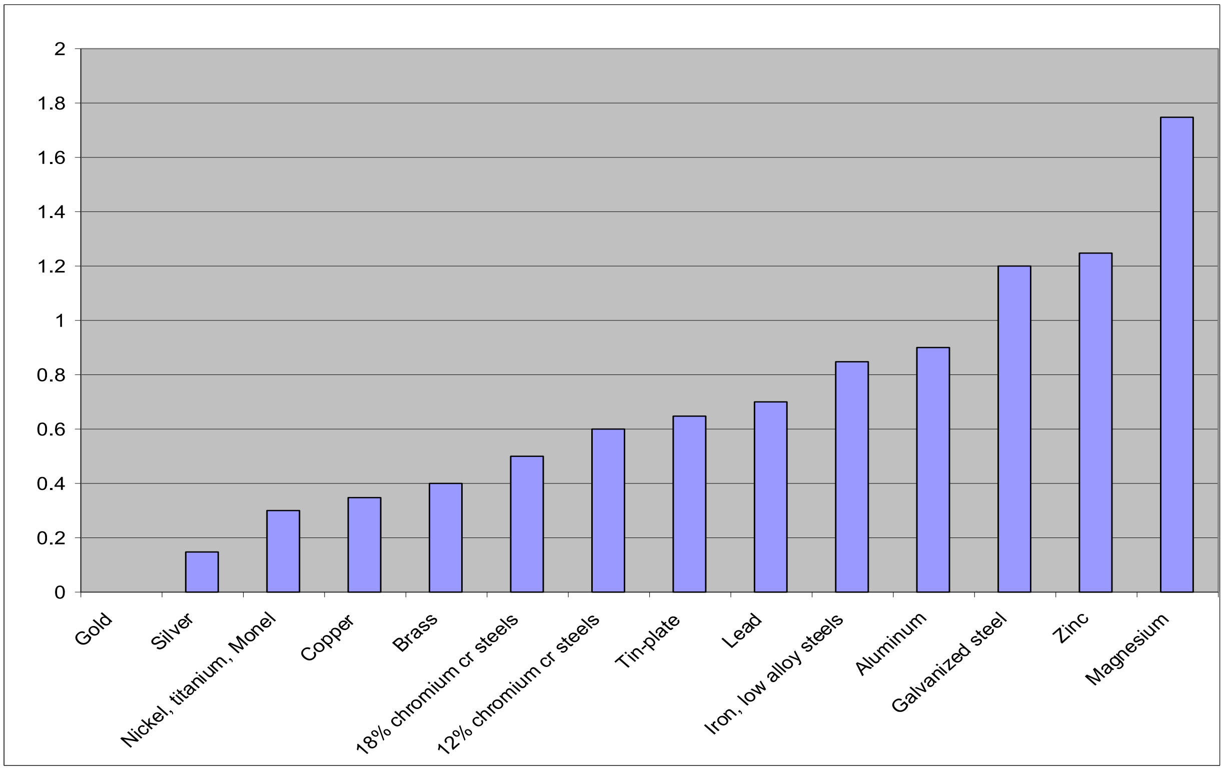

Figure 1: corroding low-alloy bolts in contact with high-alloy components

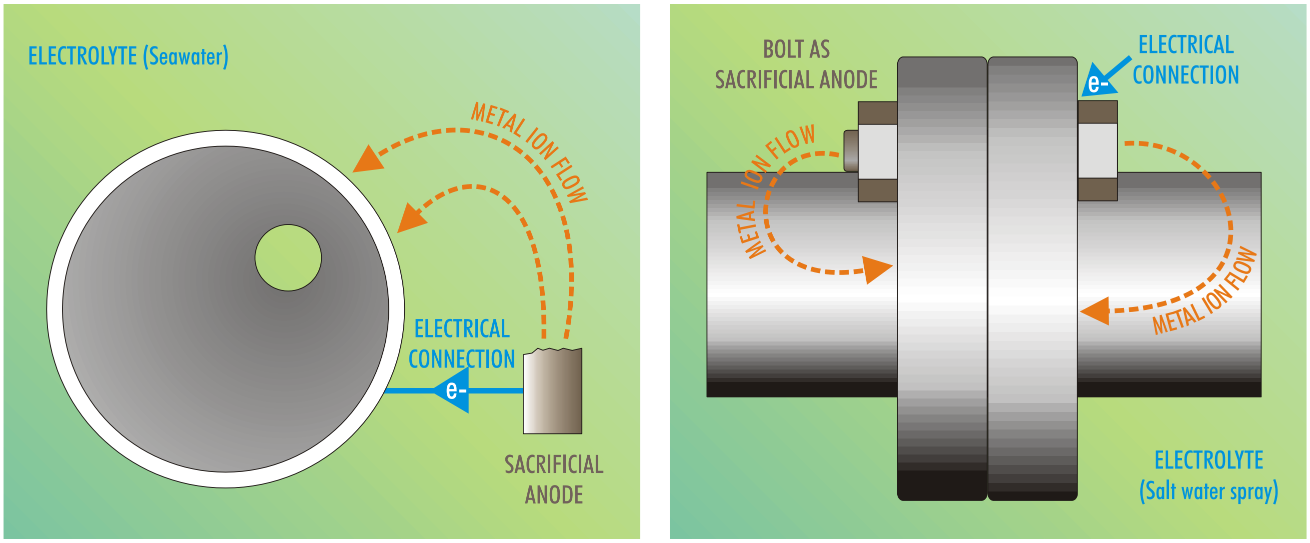

Figure 2: comparison between bolt as a sacrificial anode and CP system

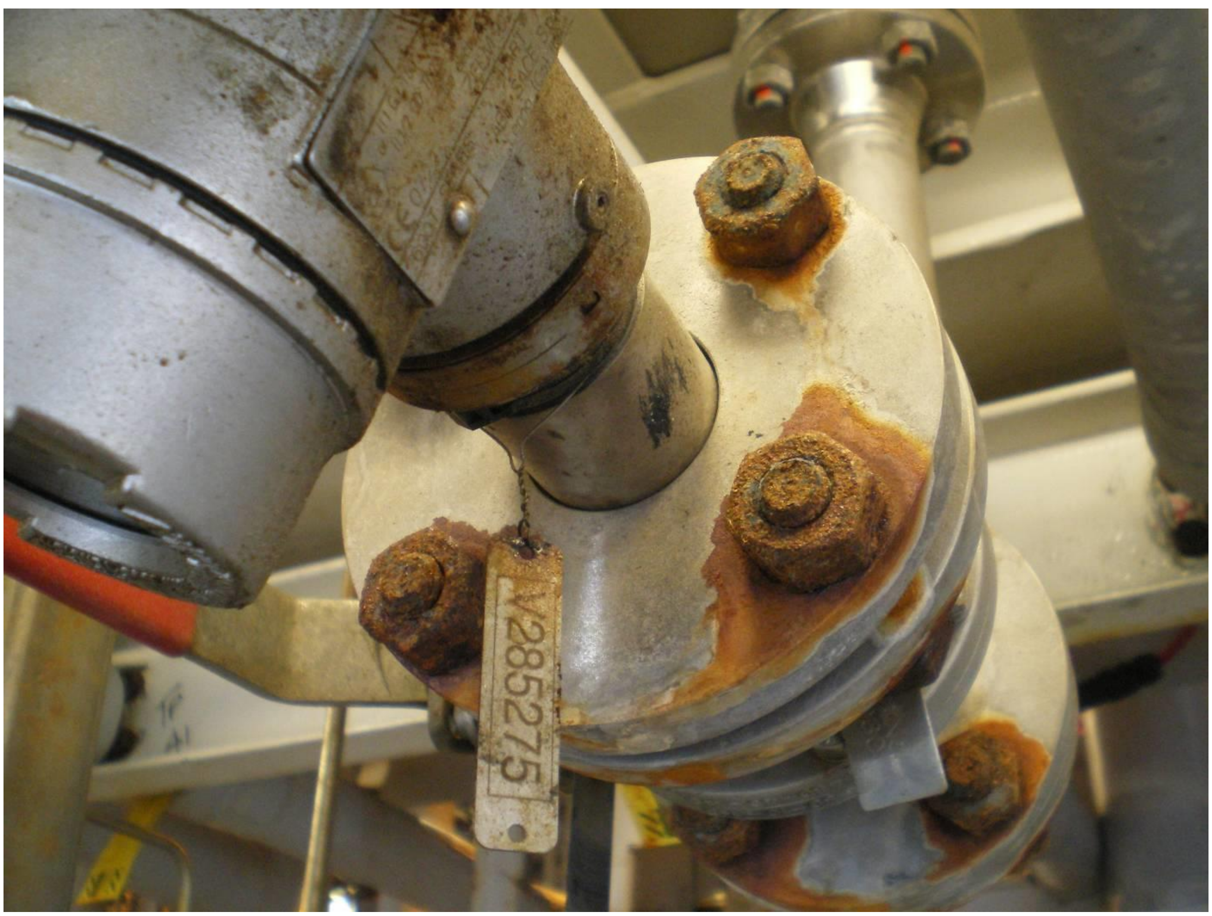

Figure 3: salt spray affected low-alloy bolts in high-alloy substrate

Figure 4: failed PTFE/nickel plated low-alloy nut and bolt after 18 months in splash zone

Figure 5: CIST application on complex bolted substrate

So, now we come to the main purpose of our discussion; if standard remedies are not fit for purpose, what is?

Corrosion Inhibiting Sprayable Thermoplastics (CIST)

CIST provides a new approach to corrosion control in bolted systems, treating the entire system rather than focusing on any particular part. The system works by excluding corrosion factors such as oxygen and water but also provides active corrosion protection through the slow release of inhibiting oils over the lifetime of the system. The CIST system uses a zero VOC, reusable thermoplastic material which, as it is spray applied, can be used on any size or shape of substrate.

As you can see in Figures 5 & 6, the system applies a perfectly fitting coating of material to encapsulate the substrate, following every contour. Figure 7 shows the main functions of the system: the exclusion of electrolyte (water and oxygen, as well as coating the surface in inhibiting oil.

By providing a vector for a film of oil to every surface within the encapsulation, CIST not only prevents corrosion occurring but also arrests existing corrosion. Providing loose materials are removed from damaged areas – flaking rust and paint, for example – very little surface preparation is required.

Field Testing

North Sea

CIST has been successfully applied since 2003 in the North Sea for the protection of prematurely rusting bolts (Figure 8). Severe corrosion was experienced in systems that had been expected to last many years using ptfe-coated, zinc-plated low-alloy bolts. Anecdotally, the failures were ascribed to attrition of the zinc plating during the ptfe coating process and subsequent damage to the outer coating during assembly exposing the vulnerable bolt substrate.

Whatever the cause, the effect was rapid corrosion with bolt-replacement as the only obvious remedy. Realising that this would be both disruptive and expensive, the operators sought alternatives and decided to try CIST because of its claimed ability to arrest and prevent corrosion without the need for high levels of intervention, as surface preparation requirements were low. As the process was new to the platform, a regular programme of removal and inspection was implemented as Figures 9 -13 show.

Most recently, in early 2011, an application to a mixed substrate of high-alloy flanges with low-alloy fasteners was removed after seven years. As can be seen in Figure 14, there is no evidence of any corrosion within the encapsulation despite the corrosion potential we have already described.

Result

1. No evidence of corrosion products continuing to be produced following encapsulation of previously corroded substrates.
2. No evidence of galvanic effects or crevice corrosion in protected substrates.
3. Coating integrity maintained despite heavy contamination.
4. Inhibiting oil continuing to be released after 7 years.

The operators continue to use CIST across the platform and have not needed to replace any bolts for corrosion failure since the application of CIST.

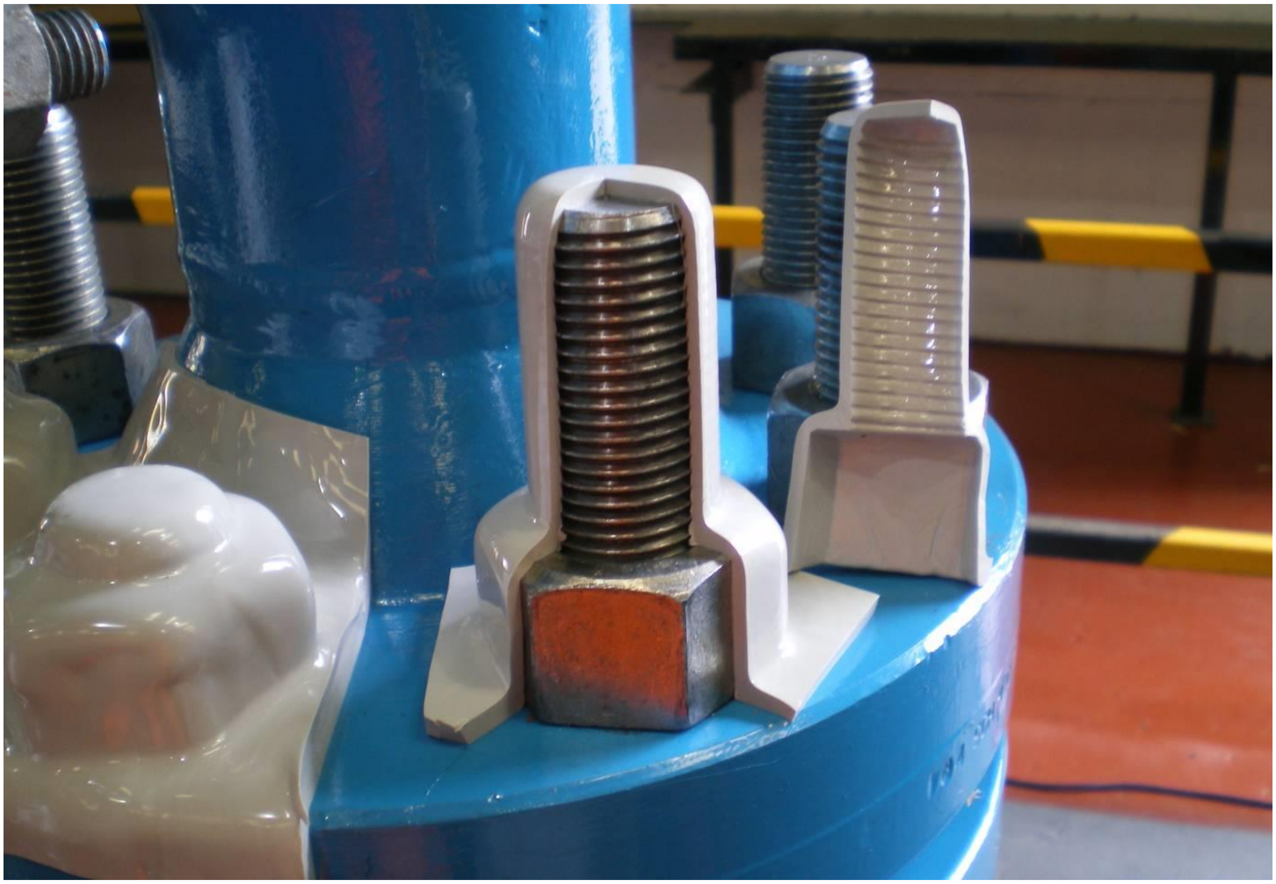

Figure 6: CIST cutaway

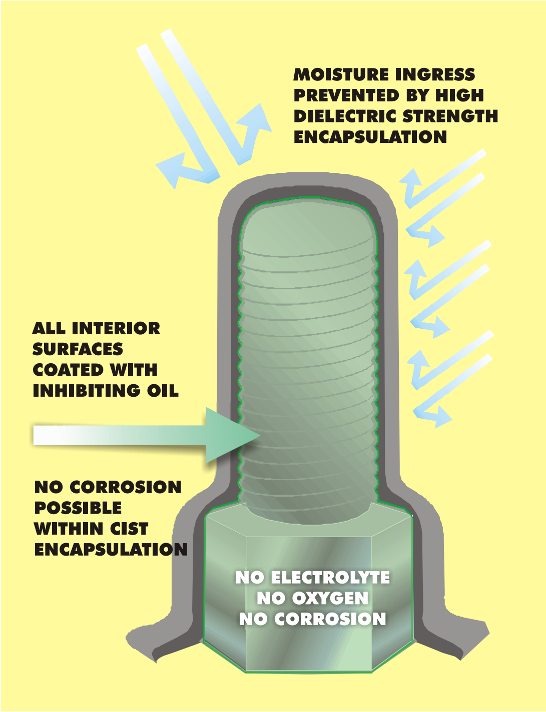

Figure 7: CIST function diagram

Figure 8: rusting flanges on a North Sea platform

Figure 9: typical substrate prior to application
application

Figure 10: typical

Figure 11: after 2 years oil-soaked
substrate substrate shows no further corrosion
7 years with CIST

Figure 12: mixed high-alloy
and low-alloy fasteners after

Bacton Gas Terminal National Grid - 5 year test

As a major operator of gas transport pipelines, the UK National Grid needed evidence of CIST performance before recommending its use. Accordingly, in 2005 a series of applications were completed for long-term testing purposes. Removals of material from the substrate were completed in 2006, 2007, 2009 and finally in 2010 after five years as shown in Table 2. Figure 13 shows a test substrate prior to application; Figure 14, the same substrate during application and, in Figure 15, removal of CIST in 2009.

Result

1. No evidence of corrosion was found on any of the protected substrates.
2. Inhibiting oil was found to be on every surface within the encapsulation.
3. Although the exterior was soiled from atmospheric and industrial deposits, the main coating remained in good condition with continuing oil deposition on the substrate.

Following testing, a preliminary CIST installation on the Bacton interconnector site was completed in 2011 and CIST is in use on National Grid substations at various sites in the UK protecting gas insulated switchgear for National Grid and other utility companies.

Lab Testing

A number of tests have been completed to establish the satisfactory performance of CIST coatings under various conditions, including UV, cryogenic and ignition testing. However, for the purposes of this paper our focus is on anti-corrosion performance and for this reason two tests are highlighted:

Salt Water Deluge Testing

The susceptibility of low-alloy steel assemblies to the corrosion effects of salt water is well documented. In this test, shown in Figures 16 and 17, a low-alloy pipe and flange is subject to a constant flow from a 20% saline mixture for 5 days a week for periods up to six months at 30°C.

The flange is protected with CIST but the pipe remains unprotected. After 6 months the constant cycle of salt water and drying has corroded the unprotected pipe but within the CIST, as shown in Figures 18 and 19, the substrate remains completely untouched.

Result

1. No ingress of water through the upper seal on to the pipe.
2. Corrosion occurs on unprotected pipe.
3. No corrosion within CIST encapsulation.
4. Coating unaffected by immersion cycles.

Hot Salt Fog Testing

An international company wishing to use CIST for wellhead protection subjected a small well head section to brutal testing in a hot salt fog chamber. The substrate was coated with CIST and then large sections of the coating were cut away (Figure 22) before the test piece was subjected to a 3000 hr test in the chamber. The results are shown in Figure 23, with bright steel under the CIST and rust everywhere else.

Table 2: Bacton test application and removal matrix

Bacton Interconnector Trial - Survey Summary

Application							Removal				
Application Date	Location	Type	Condition	DFT (mm)	Personnel	Comments	Removal Date	Condition	Comments	Present	Photo(s)
17/08/2004	S2IC	F6	Good	4	SF/SE/DH		Visual	No Change	Oil deposits		
17/08/2004	S2IC	F8	Rust in nut/BE	4	SF/SE/DH		Visual	Surface Deposits			
17/08/2004	S2IC	F6	Rust in nut/BE	4	SF/SE/DH		Visual	Surface Deposits		SF/AH/JTB	y
17/08/2004	S2IC	F6	Rust in nut/BE	4	SF/SE/DH		Visual	No Change		SF/AH/JTB	
17/08/2004	S2IC	EF8	Rust in nut/BE	4	SF/SE/DH		28/06/2007	No Change	Heavy oil deposits	SF/AH/JTB	
17/08/2004	S2IC	EF8	Severe	4	SF/SE/DH	Bolts unserviceable	28/06/2007	No Change	Oil deposits	SF/AH/JTB	
17/08/2004	S2IC	F12	Good	4	SF/SE/DH		Visual	Surface Deposits		SF/AH/JTB	
17/08/2004	S2IC	F18	Good	4	SF/SE/DH		N/A		Removed by site personnel		
17/08/2004	S3IC	F8	Rust in nut/BE	4	SF/SE/DH		Visual	Surface Deposits		SF/AH/JTB	
17/08/2004	S3IC	F6	Rust in nut/BE	4	SF/SE/DH		28/06/2007	No Change	Oil deposits	SF/AH/JTB	
17/08/2004	S3IC	F6	Rust in nut/BE	4	SF/SE/DH		Visual	Surface Deposits		SF/AH/JTB	
17/08/2004	S3IC	F6	Rust in nut/BE	4	SF/SE/DH		N/A		Removed by site personnel		
17/08/2004	S3IC	F12	Good	4	SF/SE/DH		N/A		Removed by site personnel		
17/08/2004	S3IC	EF8	Rust in nut/BE	4	SF/SE/DH		N/A		Removed by site personnel		y
17/08/2004	S3IC	EF8	Rust in nut/BE	4	SF/SE/DH		Visual	Surface Deposits		SF/AH/JTB	y
17/08/2004	S3IC	EF8	Rust in nut/BE	4	SF/SE/DH		05/10/2009	Surface Deposits		GM/PM/JE	y
17/08/2004	S3IC	F12	Poor	4	SF/SE/DH		Visual	Surface Deposits		SF/AH/JTB	
17/08/2004	S3IC	F22	Good	4	SF/SE/DH	Slow material melt	Visual	Surface Deposits		SF/AH/JTB	
18/08/2004	PP1	F32	Good	4	SF/SE/DH	Slow material melt	28/06/2007	No Change	Partial removal and reinstatement	SF/AH/JTB	y
18/08/2004	PP1	F28	Good	4	SF/SE/DH	Slow material melt	Visual	Surface Deposits		SF/AH/JTB	y
18/08/2004	PP1	F28	Good	4	SF/SE/DH	Parameters changed now ok	Visual	No Change		SF/AH/JTB	
18/08/2004	PP1	F6	Severe	4	SF/SE/DH	Bolts unserviceable	Visual	Surface Deposits		SF/AH/JTB	
18/08/2004	PP1	F6	Poor	4	SF/SE/DH	Difficult access	Visual	Surface Deposits		SF/AH/JTB	
18/08/2004	PP1	EF8	Rust in nut/BE	4	SF/SE/DH		N/A		Removed by site personnel		
18/08/2004	PP1	EF8	Rust in nut/BE	4	SF/SE/DH		02/03/2006	Surface Deposits		CH/SF/RM/SL	
18/08/2004	PP1	EF8	Rust in nut/BE	4	SF/SE/DH		28/06/2007	Surface Deposits		SF/AH/JTB	
18/08/2004	PP1	F6	Poor	4	SF/SE/DH		02/03/2006	No Change		CH/SF/RM/SL	y
18/08/2004	PP1	F6	Poor	4	SF/SE/DH		05/10/2009	No Change	Heavy oil deposits		y
18/08/2004	PP1	PE	Good	4	SF/SE/DH		05/10/2009	No Change	Partially removed 07 - corrosion in unprotected area		
18/08/2004	PP1	PE	Good	4	SF/SE/DH		02/03/2006	No Change		CH/SF/RM/SL	
18/08/2004	PP1	PE	Poor	4	SF/SE/DH		Visual	Surface Deposits		SF/AH/JTB	
18/08/2004	PP1	PE	Good	4	SF/SE/DH		05/10/2009	No Change	Heavy oil deposits		
18/08/2004	PP1	F12	Good	4	SF/SE/DH		28/06/2007	No Change	Dry but no corrosion	SF/AH/JTB	
18/08/2004	PP1	PE	Good	4	SF/SE/DH		Visual	Surface Deposits		SF/AH/JTB	

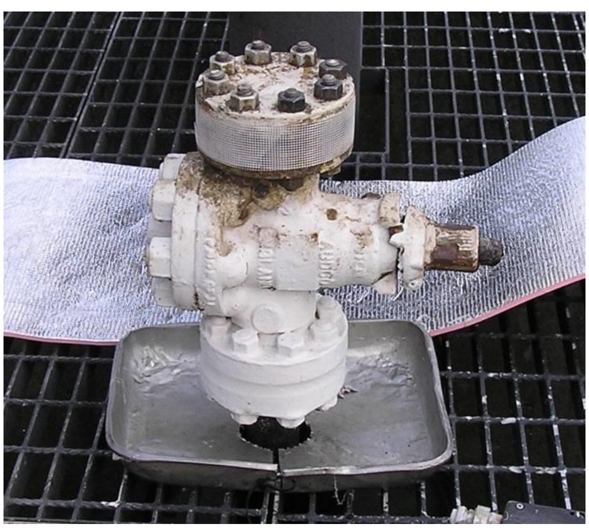

Fig 13: Bacton test prior to application 2005 Figure 14: application to test substrate

Figure 15: Bacton test substrate after removal in 2009

Figures 16 & 17: Pipe at beginning of salt water deluge testing and after 2 months

Figures 18 & 19: bare steel substrate show no sign of corrosion after 6 months

Figure 20: Test piece showing cutaways

Figure 21: Close up shows contrast

Results

1. All the exposed cutaway areas show severe signs of rust.
2. CIST protected areas show no sign of corrosion.
3. Severe damage to coating has not affected ability of adjacent areas to protect.
4. Nuts in corroded areas difficult to turn and remove, impossible to check bolt tension.
5. Protected nuts rotate freely, bolt tension unaffected.

Conclusion

Prior to the use of CIST, applying a remedial coating to corroding bolted steel assemblies required high levels of intervention: disassembly, replacement, blasting and coating – with every chance that corrosion would reappear relatively quickly. In industrial, marine and offshore environments, with equipment life cycles being extended and safety guidelines more stringently applied, corrosion prevention has become increasingly important.

Thus, a simple, low-cost and effective long-term remedy has an important role to play in infrastructure protection and the reduction of risk to personnel and the environment.

1. Testing and field applications since 2004 have demonstrated that CIST can provide long-term protection against galvanic and crevice corrosion.
2. CIST provides bolt corrosion control on existing and new-build applications without the need for large scale intervention.
3. CIST corrosion prevention mechanisms provide whole system as well as individual component protection in complex assemblies.
4. Non-toxic, reusable and waste free, CIST helps reduce the environmental impact of corrosion prevention.

References

1. Galvanic series information from US MIL-STD-889.
2. Badelek and Moore, *Topside Bolting – Corrosion Protection* in North Sea Bulletins: BP Amoco, 1999.
3. N. Zaki, *Zinc Alloy Plating*, http://www.pfonline.com/articles/pfd0019.html

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