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the Conduit

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In this Issue

Inspection and Repair of Batch Digesters Part 2 of 3

By Max Moskal

Part 1 of *Inspection and Repair of Batch Digesters*, published in the previous issue of *the Conduit*, described the types of stainless steel weld overlays for corrosion protection and corrosion "hot spots" in the digester.

This section—Part 2—covers stainless steel overlay application and repair strategies.

Part 2 – Application and Repair Strategies

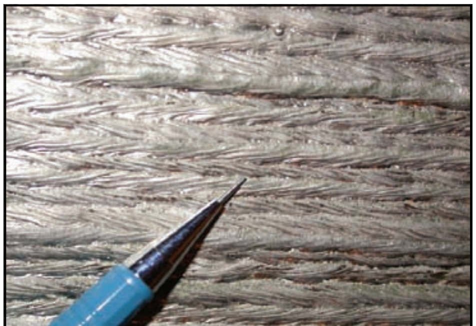
First Time Stainless Steel Overlay

Application of stainless steel over bare carbon steel is usually uncomplicated and straightforward.

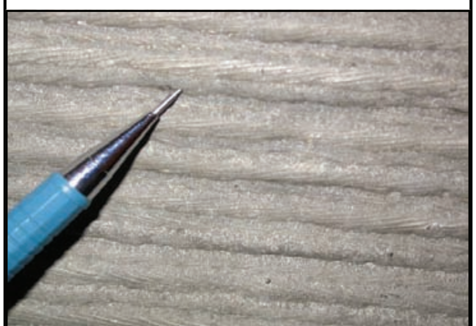
First, the vessel must be fully up to required Code thickness before overlay deposition. The above-mentioned TAPPI TIP 0402-03 guideline [1] in Part 1 covers how to handle the requirements of Code minimum allowable wall thickness for digesters and it will not be duplicated here. However, excessive corrosion of the carbon steel plate definitely necessitates buildup of the carbon steel to at least the minimum allowable wall thickness of the Code. Carbon steel weld buildup can become problematic because the smallest defects in the weld buildup are often transferred to the stainless steel overlay resulting in overlay defects that are very difficult to repair. In addition, large areas of carbon steel weld buildup are notoriously difficult to overlay with stainless steel. Due to high residual stresses in the carbon steel weld buildup (and the stainless steel overlay weld), consideration should be given to complete replacement of the corroded digester wall plates if more than one or two square meters of carbon steel weld buildup would be needed. In addition, welding distortion is of particular concern when the carbon steel base metal thickness has become less than about 25-mm (one inch).

Second, because a certain amount of carbon steel dilution occurs during welding with the stainless steel, a reasonable remaining corrosion allowance (CA) of at least 3.0-mm (0.12-inches) should be present before application of the first overlay. If there is too little or no CA remaining, then an additional carbon steel base must be added to the thin area. This is most often done using new insert plates or localized weld buildup with carbon steel electrode prior to beginning the overlay welding.

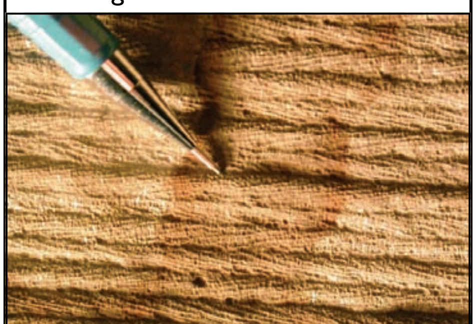
New application of stainless steel weld overlay is often staged over two or three years for a digester beginning with application of the overlay weld first in the regions over the most thinned carbon steel (usually upper walls and cone). The unit cost for overlay work, however, is lower when the entire digester is overlaid at one time. Overlay of the top head may be an exception in that it is more difficult to weld.



Type 312 Stainless Steel
GMAW
New



Type 312 Stainless Steel
GMAW
Light General Corrosion



Type 312 Stainless Steel GMAW
Severe General Corrosion
(Still serviceable.)

Figure 1. Examples of stainless steel gas metal arc welded (GMAW) Type 312 stainless steel overlay in the batch digester showing as-welded (top) and with two different stages of corrosion deterioration.

(Continued on page 2)

Corrosion damage is often low in the top head and overlay protection of this area can sometimes be postponed until long after the rest of the digester has been overlaid.

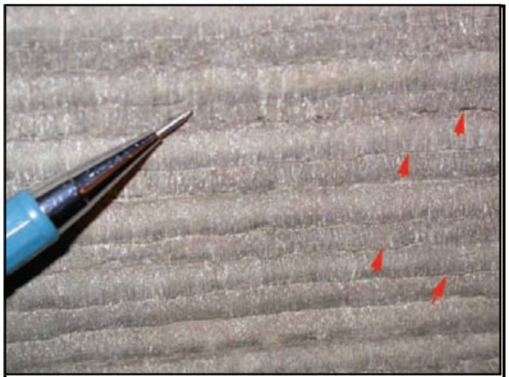
Inspection and testing of the newly applied overlay is critical to ensuring the longest possible overlay life. In addition, regular inspection of in-service overlay needs to be performed to monitor overlay thickness and condition. The techniques for inspection and testing will be discussed in Part 3 (next edition of *the* Conduit).

Overlay Weld Repairs

Minor repairs of the newly applied or re-overlay welds are almost always needed. These repairs of the initial stainless steel overlay are called "pick-ups." Such repairs are directed to minute flaws, porosity, cracks or fissures that allow a corrosion path to the carbon steel base metal. These pick-up repairs are easy to make provided a problem does not exist with the carbon steel base metal (for example, flaws in any previously applied carbon steel weld buildup). The affected region is simply ground to the base metal and re-welded with matching filler metal.

Re-Overlay with Stainless Steel

Stainless steel overlays eventually deteriorate due to corrosion with the first corrosion occurring in the regions described above. When repairs become excessive, portions of the digester will require re-application of the stainless steel overlay. A second stainless steel weld overlay can be made over the original overlay provided the first overlay is free of defects such as pinholes and porosity. Preparation for re-overlay should include removal of all corrosion-affected regions followed by spot repair using matching filler metal. Prepared areas must be smoothed by grinding to facilitate application of re-overlay.



Type 309L Stainless Steel SAW
Moderate Corrosion Inter-Bead Attack
(Arrows)

Type 309L Stainless Steel SAW
Severe Deterioration
(Replacement Needed)

Type 309L Stainless Steel SAW
Severe Corrosion
Carbon Steel Exposure at Arrow

Figure 2. Moderate corrosion attack and inter-bead deterioration of Type 309L stainless steel SAW overlay (top). The lower two examples show SAW overlay that has deteriorated severely—the overlay should be replaced.

Sometimes localized areas of exposed carbon steel base metal require repair. As described in the TAPPI TIP 0402-03 guideline, repairs with carbon steel require complete removal of the stainless steel overlay. A carbon steel repair in a region of stainless steel overlay is problematic. Stainless steel cracking can occur if the carbon steel filler metal is inadvertently being applied over any part of the stainless overlay. Confirming that residual stainless steel has been removed may require careful examination using a copper sulfate solution wipe. Repairs of small size in the base metal (two or three square inches) can be made with stainless steel filler metal instead of carbon steel filler. However, the depth of stainless steel in the carbon steel wall should not exceed 50% of the carbon steel required thickness. (The basis for repairing carbon steel with stainless filler electrode is the National Board Inspection Code, where widely scattered pits of limited depth may be disregarded [2]. Pits deeper than 50% of the required thickness must be repaired).

Both carbon steel and stainless steel welding on the original shell metal should be performed with adequate preheating to avoid cracking. Preheating is not required when stainless steel is welded to stainless steel, except to a level to ensure that the surface is dry.

Re-overlay with stainless steel may be performed after preparation of the substrate. Large areas should be overlaid using the automatic SAW or GMAW process. If the second overlay is applied over stainless steel, only single-wire welding (instead of twin-wire) may be used to obtain a high quality overlay.

When applying re-overlay weld, an accurate assessment of the deteriorated overlay region is difficult. In addition, corrosion deterioration of the original overlay on one region may be severe (leaving thin overlay coverage), but an adjacent region may have little or no corrosion damage. It is generally preferable to apply full 360-degree band of re-overlay as opposed to a patch or partial band. Patches should be avoided where possible because the edges of new patches are most vulnerable to corrosion.

Also, the needed re-overlay weld coverage is difficult to determine because the remaining thickness of stainless steel overlay cannot be determined by nondestructive testing. Electromagnetic induction testing (usually referred to as magnetic lift-off or MLO testing) is not suitable for measurement of overlay thickness because the microstructure of the overlay consists of both ferritic (magnetic) and austenitic (non-magnetic) phases which cause false or faulty thickness measurement.

Excessive welding (overlay or carbon steel buildup) will result in distortion of the digester shell. Prediction as to whether the shell will distort is nearly impossible because distortion is dependent on several factors—shell thickness, thickness of carbon steel buildup and stainless steel overlay, the extent of heat input and the diameter of the digester. One digester owner specifies that the thickness of the overlay should not exceed 10-mm (0.4-inches). Even with this restriction, distortion of the shell can still be a problem because it depends on the above factors and the extent of prior welding. The overlay thickness of 10-mm is approximately equivalent to two overlay applications, depending on the welding method.

The author has not found guidelines to help determine when measurable distortion is likely to occur. It is reasonable that more than 10-mm of combined carbon steel weld buildup and stainless steel overlay should be avoided, especially if the base metal thickness is less than 25-mm.

Overlay Visual Examination

Annual internal inspection of batch digesters is typical. However, visual inspection of weld overlays following the first and second year after application is most important. Once the corrosion and/or wastage rate has been determined, the inspection interval can be set. Visual examination of the overlay is performed to detect problems in a timely manner. When the corrosion barrier is breached, corrosion of carbon steel base metal can occur at a much higher rate than of general corrosion of unprotected carbon steel. Complete penetration of the wall may occur in some instances within two or three years, so repairs must be made without delay.

The examples in Figures 1 and Figure 2 can be used as guidelines for evaluation of the condition and extent of corrosion in digester automatic SAW and GMAW overlays.

Distortion due to excessive interior overlay or buildup is readily observed by shadowing the shell with a light held close to the surface of the plate. When produced by welding, buckling of the shell usually occurs toward the interior since welding residual stresses are tensile on the weld side. The extent of buckling should be outlined and the inward penetration measured. The region should also be checked with PT or MT, as appropriate, for cracking. A decision as to whether or not to replace the affected area should be determined by appropriate engineering evaluation.

REFERENCES

1. TAPPI TIP 0402-03, "Guidelines for Corrosion Resistant Weld Overlays in Sulphate and Soda Digester Vessels."
2. National Board Inspection Code, Paragraph RB3238(i), The National Board of Boiler and Pressure Vessel Inspectors, Columbus, Ohio, 2001.

Next issue of *the Conduit*:

Part 3 – Nondestructive Testing of Overlays.

Employee News

Congratulations Catherine Noble !

M&M Engineering Associates, Inc. is proud to announce that Catherine Noble is our newest Registered Professional Engineer.

Congratulations Spencer Rex !

M&M Engineering Associates, Inc. is proud to announce that Spencer Rex has passed his Fundamentals of Engineering Exam (F.E.).

New SEM Installation

By Catherine Noble, P.E.

M&M Engineering Associates, Inc. recently installed an AMRAY Model 1830 scanning electron microscope (SEM) with an EDS system controlled by the Revolution 4-Pi imaging system at our Austin, Texas facility. This microscope has one of the largest commercially available chambers and can accept samples up to seven inches long by seven inches wide by three inches high.

The new equipment continues to have the same capabilities as the previous SEM with some exciting improvements. Image capturing and spectrum analysis are now run through Windows 7-based software. Color enhancement of images is possible to highlight the locations of elements. Control of image adjustment is now much easier with a new monitor and more user-friendly procedures. The SEM uses a Lab6 filament rather than tungsten that lasts much longer and produces better results. It can examine sample features, such as fracture surfaces, up to 50,000 times magnification. We continue to be able to conduct energy dispersive X-ray spectroscopy (EDS) of deposits and debris for elements as light as carbon and can provide semi-quantitative results.

Because the new system is much easier to use, we have trained more engineers in its operation to lessen any delays in obtaining results due to personnel schedules. This allows us to offer sample turn around within 24 hours, if needed. We even have a 46-inch color monitor and comfy chairs for you to witness SEM work as it happens if you would like to be present during the examination process.

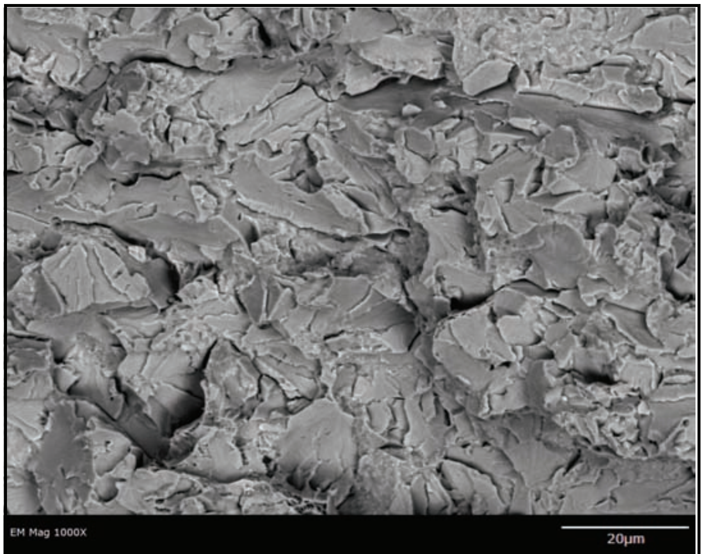


Figure 1. SEM backscattered electron image shows a cleavage-type fracture surface on a low-alloy steel that cracked at cryogenic temperatures (1000X).

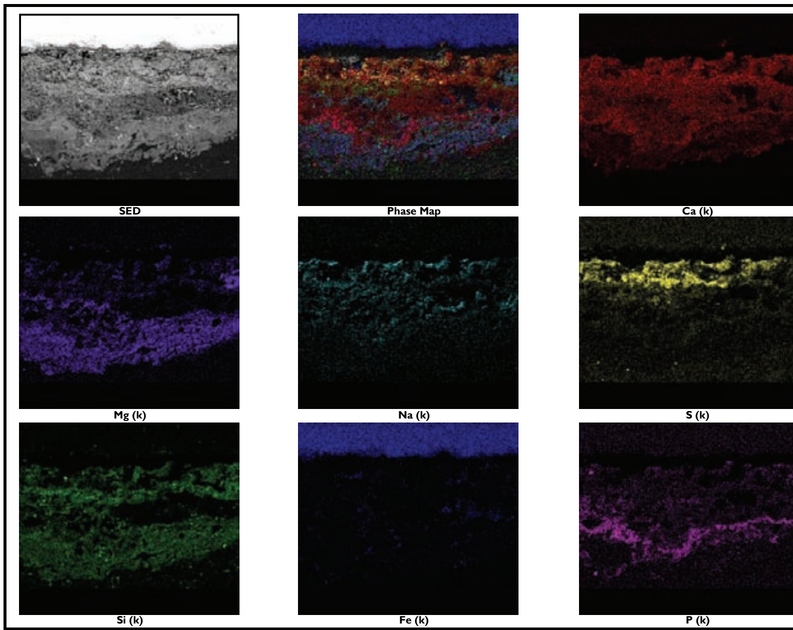
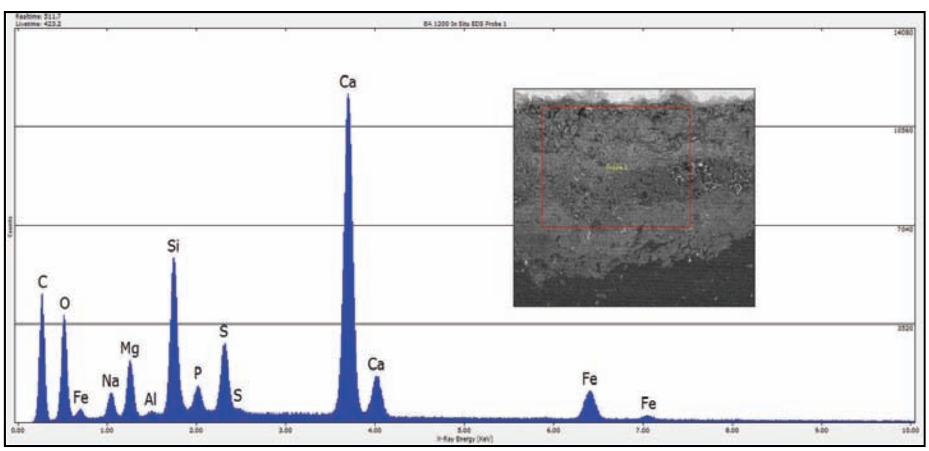


Figure 2. Semi-Quantitative Analysis of Deposits.



Quantitative Results for 8A 1200 In Situ EDS Probe 1
Analysis: Bulk Method: Standardless
Acquired 11-Feb-2010, 20.0 KeV @10 eV/channel

Element	Weight %	Std. Dev.	Atomic %
C	29.03	1.08	46.72
O	19.50	0.92	23.56
Na	3.96	0.96	3.33
Mg	5.05	1.05	4.02
Al	0.04	0.02	0.03
Si	8.81	0.80	6.06
P	1.80	0.55	1.13
S	4.26	0.98	2.57
Ca	22.39	0.91	10.80
Fe	5.16	1.06	1.79
Total	100.00		

Figure 3. EDS Spectrum for a debris sample from an obstructed superheater tube.

Welded Repair of High Energy Rotor
Six Simple Rules

By Ronald E. Munson, P.E.

Introduction and Background

The technology for weld repair of rotating equipment has gained an acceptance by equipment users and manufacturers through a history of successful repair efforts. A study conducted in 1994 identified at least 1,700 uses of steam turbine weld repair for steam turbines in many industries (1). Usage of the technology has continued and a conservative estimate is that at least 2,500 turbines are now in-service with weld repairs. The acceptance gained was not easily achieved. Prior to 1984, many engineers and metallurgists were steadfast that the inherent material requirements of rotating equipment could not be successfully met by welding; therefore, repair of rotating equipment was expressly forbidden. Through the application of sound welding engineering principles and extensive weld testing and process development that date back almost twenty years, the feasibility of rotor repair was proven and this "myth" was discounted. This success has not come without effort. Repair vendors, both original equipment suppliers and third-party repair houses, have invested considerable money and time in developing procedures and the "know-how" to successfully perform these repairs. These are "lessons learned". Unfortunately, many of the people who pioneered in these efforts are no longer involved in the repair execution and their replacements have lost the collective experience and know-how—"lessons forgotten."

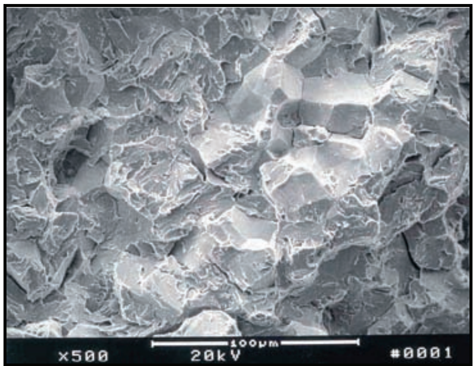


Figure 2. Hydrogen damage induced by weld repair.

Figure 1. Failure in centrifugal compressor initiating in fabrication weld.

Since then, early development work was completed and the repair of rotors has gained an almost every day acceptance. With that acceptance, a certain amount of complacency and/or inexperience has crept into the application of the rotor weld repair process principles.

Always in the forefront of any repair effort, is the necessity to not let any weld repair become "common-place". The results from critical welding process procedure variables and material requirements being "short-cut" can be catastrophic. The application of sound metallurgy, welding practices, and engineering principles must be respected in the evaluation and execution of any repair. To quote from the introduction of EPRI Volume 1: *Weld Repair of Steam Turbine Disc and Rotors*, "Rotating components are among the most critical and highly stressed components in nuclear, fossil, and combustion turbine power plants. With this in mind all rotor repairs, regardless of the scope of the repair, the repair must be approached and executed with sound repair practices."(2)

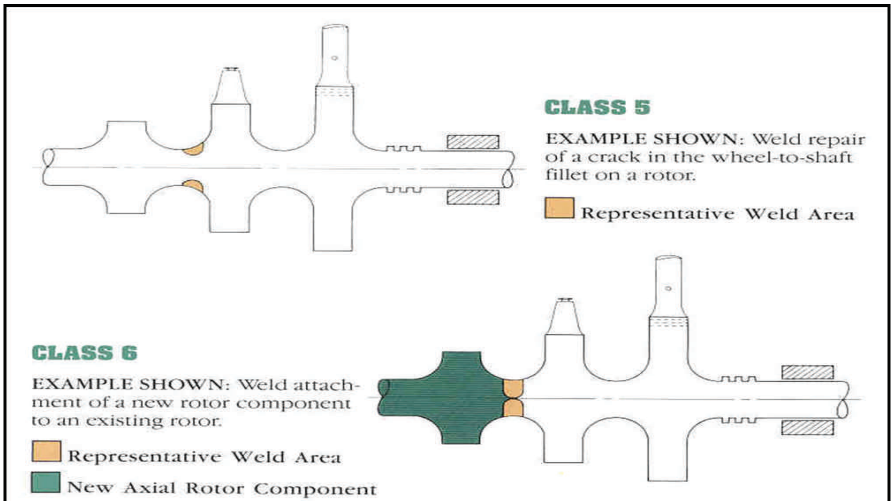


Figure 3. Two steam turbine weld classifications.

Approaches to Repairing Rotating Equipment

The repair of rotating equipment is complex and not to be attempted without background and experience. There are industry guidelines for these repairs. These basic rules of the road can be collapsed from these guidelines into a few simple rules of engagement.

Rule 1 Know the history of the component and its future intended service. Design the repair to avoid a repeat of the previous failure and minimize the chance of any "new" failure mode. Be sure the rotor is worthy of repair and worth the repair investment.

Rule 2 Know the base metal composition and properties and choose a weld consumable that is compatible with it. Test the weld consumable and have a tight specification for acquisition. If you overmatch or under match the consumable, verify that there is justification for the change and assess any risks. Higher alloy is not always better.

Rule 3 Inspect effectively both before and after the repair. Set your acceptability limits on inspection based upon a valid fracture mechanics analysis, not upon the quality level achievable from your welding process. At a minimum, the weld must be equivalent to the original component.

Rule 4 Strategically locate the weld and HAZ to be in the area of lowest possible stress. If the weld must be in a high stress area consider overmatching properties of the weld deposit by selection of weld process, consumable or post weld heat treatment. (Be sure to read Rule 2).

Rule 5 Weld repair allows for design enhancement, i.e. lower stresses/higher performance by alteration of blade fixation design. However, be sure you do not change the dynamic and/or harmonics of the rotor.

Rule 6 Perform an independent audit of the repair process. A written procedure is only useful if it is followed. True quality is in the control of the welder, machinist or NDE technician, not the project manager.

Figure 4. Mockup weld for repair of combustion turbine compressor disc.

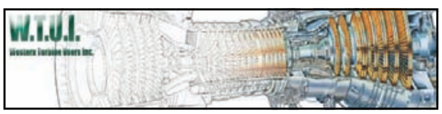
Closure

The use of welding to repair rotating equipment, especially steam turbines, has saved tens of millions of dollars in the past twenty years. Avoidance of cost for rotor replacement and shortening of turnaround times for repair are the major components of the cost reduction. The use of welding technology is well accepted and the in-service performance of these repaired rotors has been exceptional. Fortunately, a catastrophic failure of a repair has not yet occurred, but the potential exists. The industry must maintain its vigilance in designing and performing these repairs. This is a set of six simple rules that can be used to guide any repair effort. For a more complete review of the philosophy of repair, consult the EPRI document (2).

References

1. Mansfield, F.D. and R.E. Munson, *Ten Years of Welded Repair of Steam Turbine Rotors - An Insurer's Perspective,* EPRI Welding and Repair Technology for Fossil Plants, Williamsburg, VA, March 1994.
2. Electric Power Research Institute, *State-of-the -Art Weld Repair Technology for Rotating Components, Volume 1-Weld Repair of Steam Turbine Discs and Rotors,* EPRI Repair and Replacement Applications Center, Charlotte, North Carolina, EPRI TR-107021-v1, June 1997.

Upcoming Events



John Molloy, P.E. will be attending the Western Turbine Users, Inc. 20th Anniversary Users Conference in San Diego, California. Dates are March 14, 2010 through March 17, 2010.

Dave Daniels will be attending the ASME Spring 2010 Meeting at The National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. The dates are April 7, 2010 through April 8, 2010..

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