Date Mailed: June 2, 2008

THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS

MINUTES

NBIC SUBGROUP on FIBER REINFORCED PLASTIC PRESSURE EQUIPMENT

Hyatt on Capital Square
Columbus, Ohio
May 5, 2008

Meeting of SubGroup on Fiber Reinforced Plastic Pressure Equipment

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The National Board of Boiler & Pressure Vessel Inspectors
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ATTENDANCE:

MEMBERS	VISITORS
B. Shelley, Chairman	G. Gentry, Dow Chemical
T. Cowley	J. Vacek, Dow Chemical
D. Hodgkinson	B. Holtzclaw, Holtec, Ltd. (AOC)
D. Eisberg	M. Gorman, Digital Wave Corp.
D. Keeler	
R. Crawford	
F. Brown	

CALL TO ORDER

The meeting was called to order at 1:00 PM by the Chairman, Bernard Shelley.

ANNOUNCEMENTS

None

ADOPTION OF THE AGENDA

It was moved and seconded to adopt the agenda. The motion carried.

APPROVAL OF THE MINUTES

It was moved and seconded to approve the minutes of the November 5, 2007, Las Vegas meeting. The motion carried.

OLD BUSINESS

- Inspection of high pressure composite vessels. The initial draft document will be focused on the inspection of high pressure composite vessels with metallic load bearing liners; ASME Code Cases 2390-1 and 2579-1.

- Tim Fowler, not present, e-mailed his comments on NDE of high pressure composite vessels. Tim's comments were discussed in depth as subgroup members grasped the complexity of inspecting the high pressure composite vessels. Further work is needed, and committee members are requested to review Tim's comments. Please contact Tim with questions and comments, and be prepared to discuss at the next meeting.

- Terry Cowley presented a draft proposal for internal inspection of composite vessels; copy attached. This was discussed at length.

  Internal inspection of these vessels will be extremely difficult. The nozzles will be small diameter (not exceeding 2 inch) making it difficult to view the internal surface. Further work is needed. All committee members are requested to review the proposal and comment.

- Dale Keeler presented a draft proposal for repair of composite vessels; copy attached. Each committee member is requested to review and comment.

ASSIGNMENTS (Revised)	
PART	WRITER(S)
Internal Inspection	Terry Cowley
External Inspection	Doug Eisberg & Juan Bustillos
NDE	Terry Cowley, Tim Fowler, Mike Gorman
Inspection Frequency	Doug Eisberg & Francis Brown
Repair of composite vessels	Dale Keeler

  - Mike Gorman agreed to become a member of the subgroup, and will be working on NDE examination, especially acoustic emission examination, of the composite vessels.

  - Norm Newhouse of Lincoln Composites will be requested to furnish information concerning inspection of high pressure vessels, and will be requested to become a member of the subgroup.

  - It was noted that additional members are needed.

NEW BUSINESS

None

NEXT MEETING

The next meeting will be on October 27, 2008, in Las Vegas, Nevada.

ADJOURNMENT

The meeting was adjourned at 3:35 P.M.

Respectfully submitted,
Francis Brown
Secretary, NBIC-FRP Subgroup

Nondestructive Examination of High Pressure Composite Pressure Vessels

Timothy J. Fowler

Friday, May 02, 2008

At the November 5, 2007 Las Vegas meeting of the NBIC Subgroup on Fiber Reinforced Plastic Pressure Vessels, preparation of an inspection procedure for high pressure composite pressure (HPC) vessels was discussed. I was assigned the task of preparing a section on nondestructive examination. At the time of the meeting, the Subgroup envisioned that primary reliance would be placed on visual inspection and acoustic emission.

Background Information

HPC vessels are built to Code Cases 2390 and 2579. The cylindrical vessels have a metal liner overwrapped with continuous glass filament circumferentially wound composite. The liner carries the axial loads. The liner and composite share the hoop loads. Metal heads and nozzles complete the vessel.

Code Case 2390-4, *Composite Reinforced Pressure Vessels*, was approved by Section VIII, Division 3, and endorsed by Section X. The case covers vessels with an internal design pressure of not greater than 3,625 psi.

Section VIII, Division 3, approved code Case 2579, *Composite Reinforced Pressure Vessels for Gaseous H2 Service*. Section X did not approve, endorse, or otherwise express opinions on the case. The case covers vessels with an internal design pressure of not greater than 15,000 psi.

Nondestructive evaluation (NDE) of new vessels under the two Code Cases 2390 and 2579 is generally the same as NDE for Class II vessels under Section X. Primary methods are visual inspection and acoustic emission. Visual inspection acceptance criteria are based on Section X, Table 6-100.2. The acoustic emission is conducted to the provisions of Article RT-6 and evaluation criteria are according to Table RT-620.1.

The HPC vessel code cases appear to be based on rules for Section X, Class II (Sc X) vessels.

Overview

- Where sufficient access is available, the metal heads and nozzles can be examined by the NDE techniques and procedures that are commonly used for Section VIII vessels.
- NDE of HPC vessels is complicated by the presence of two different materials in the cylindrical portion of the vessel.
- Section X visual inspection acceptance criteria are appropriate for the composite portion of HPC vessels. Unfortunately, visual inspection is limited to the external surface only. The thickness of the laminates used to construct HPC vessels is greater than for Sc X vessels. As a result, defects within the laminate are less likely to be detectable at the surface.
- Penetrant Examination of the type set out in RT-630 of Section X is also suitable for HPC vessels. The limitations for visual inspection stated above, also apply to penetrant examination.
- Sc X vessels are designed for relatively low pressures compared to the pressures permitted for HPC vessels. Even though acoustic emission is an excellent technology for NDE of composites, the procedures set out in Section X are based on research and experience with vessels operating at low pressure and may be inappropriate for vessels that are built to operate at high pressures. ASTM E2191-08, "*Standard Practice for Examination of Gas-Filled Filament-Wound Composite Pressure Vessels Using Acoustic Emission*", uses a different procedure for acoustic emission testing of HPC vessels. Additional research and testing is required to determine if the Section X procedure, the ASTM E2191 procedure, or another approach is suitable.

- The internal metal liner can be examined by acoustic emission in accordance with the provisions of ASTM E1419-02b, "*Standard Test Method for Examination of Seamless, Gas- Filled, Pressure Vessels Using Acoustic Emission*". It is possible, however, that emission from the liner could be masked by emission from the composite, which is likely to be much noisier,
- It is important to distinguish the source of emission detected during an acoustic emission examination. Did the emission originate in the metal liner, or was it generated in the composite overwrap. Techniques have been developed that help with this issue. Dr. Michael Gorman may be able to provide insight into appropriate test procedures.
- The internal metal liner can be examined by ultrasonic methods. The angle-beam shear wave ultrasonic technique set out in ASTM 2223-07, "*Standard Practice for Examination of Seamless, Gas-Filled, Steel Pressure Vessels Using Angle Beam Ultrasonics*", is particularly appropriate.

Concerns

Code Case 2579 requires an acoustic emission test of new HPC vessels based on Sc X rules. I am concerned that these rules are not appropriate for an HPC vessel operating at the permitted pressures. The following table compares acoustic emission test procedures under Section X, Code Case 2390, ASTM E2191, and ASTM E1419.

	Section X	**Code Case 2390**	**ASTM 2191**	**ASTM E1419**
Construction	Composite	Composite over metal	Composite over metal	Metal
Max Design Pressure, psi	250	3,625	5,000	Not specified
Max test Pressure	110% design	As Section X	110% max since last test	110% marked service
Pressure at start monitoring	30% of max test pressure	As Section X	50% of max test pressure	33% of max test pressure
Pressurization medium	Liquid	As Section X	Gas or liquid	Gas or liquid
AE monitoring	Pressurization and holds	As Section X	Either holds only, or pressure + final hold	Pressure + final hold
Acceptance criteria	Hits, Felicity ratio, counts, long duration hits	As Section X	Counts	Events from specified area. Follow up with other NDE method
Source location required?	No	As Section X	No	Yes

1. Design Pressure

The acoustic emission test rules set out in ASME Sections V and X for new Class II vessels are based on the 1982 CARP procedure, "*Recommended Practice for Acoustic Emission Testing of Fiberglass Tanks/Vessels*", published by The Society of the Plastics Industry. The CARP recommended practice was updated in 1987. As appropriate, the 1987 updates have been incorporated into Section X. The CARP recommended Practice is limited to vessels with a design pressure of not greater than 65psi. Section X increased the upper pressure limit to 250 psi for vessels having a diameter of less that 57.6 in. For larger diameter vessels, design pressures are more limited.

The Section X Subcommittee approved raising the limit to 3,625 psi for Code Case 2390 after reviewing detailed presentations of acoustic emission test data from tests of prototype vessels. I am not aware that similar data was presented to Section VIII when Code Case 2579 was approved for 15,000 psi. I am concerned that approval of the acoustic emission testing portion of the case was not thoroughly researched, and that a possible dangerous situation may have been allowed to develop.

2. Test Procedure

In the 1990s I was privileged to chair a Railroad Commission of Texas, Gas Services Division, Task Force on Compressed Natural Gas (CNG)/Acoustic Emission. The committee was tasked with developing a test procedure for acoustic emission testing of vehicle CNG fuel tanks. It was anticipated that the procedure would be adopted for use in Texas. As part of its deliberations, the Task Force reviewed acoustic emission test data from several hundred CNG fuel tank tests. It is believed that the draft procedure that was developed was the basis for ASTM E2191. Prior to adoption of the procedure by the state, a catastrophic failure of a vehicle CNG fuel tank occurred on a Crown Plumbing pickup truck in Houston. As a result, many of the CNG fuel tanks were removed from vehicles in Texas (school buses, state vehicles, and utility company vehicles) and there was no longer a need for the procedure.

As can be seen from the table above, E2191 is very different in concept and approach to the Section X rules. Specifically, E2191 permits high-speed pressurization with programmed load holds and evaluation based on counts. It is possible that for HPC vessels, ASTM E2191 is easier to apply, founded on better test data, and is more reliable than the Section X rules.

3. Testing Metal and Composite Components

A single acoustic emission test to evaluate both the metal and composite components may be unrealistic. Composites are very noisy and emission from the composite may mask emission from the metal. It is possible that this problem can be addressed by waveform analysis, but more research is needed to confirm that this is the case. Another approach is to use an angle-beam shear wave ultrasonic technique of the type set out in ASTM 2223 to examine the metal liner.

Conclusions

- Established procedures are available to inspect the external surface of the composite using visual and dye penetrant examination methods.
- An angle-beam shear wave ultrasonic technique is available to examine the metal liner.
- Other metal components, such as nozzles and heads, can be inspected by techniques used for examination of Section VIII vessels.
- It is likely that inspection of the composite can be accomplished by acoustic emission examination. Addition evaluation, research, and study will be required to determine the appropriate procedure for this application.
- Acoustic emission inspection of the metal liner may be difficult because of signal contamination from sources within the composite.

Internal In-Service Inspections – High Pressure Hydrogen Cylinders
4-14-08

1. Metal Liners

The internal condition of a vessel's metal liner may be inspected for defects visually with camera devices and ultrasonic equipment that can enter the vessel and be controlled remotely.

2. Thermoplastic Liners

a. The internal condition of a vessel's thermoplastic liner may be inspected for defects visually with camera devices that can enter the vessel and be controlled remotely.

b. Vessels may be fabricated initially with an approximately 100-mil thick electrically conductive resin laminate. The conductive resin laminate shall have at least two leads attached in areas the maximum distance apart. For in-service inspection, tap water containing 1 wt% table salt shall be added to the vessel; pressure shall be 1.1X liquid head pressure. A lead connected to a conductivity meter shall be placed in the salt solution and the other lead from the conductivity meter shall be attached to the leads coming from the vessel wall, one at a time. Conductivity shall be monitored over a two hour period. If no conductivity is observed between the internal and external leads, then the vessel is passed. The two leads from the vessel shall be checked to insure that there is conductivity between these two leads.

3. AE Testing

AE testing may also be considered as a means of inspecting the vessel for fitness for continued service. See ASME Section V, Article 11 for recommended testing procedures. Beware that AE testing will only indicate structural damage.

4. Helium Leak Detection – Add helium to a test pressure of 1.1X the operating pressure.
   - ?- Put in closed container, pull vacuum to – 5 inches wc. Monitor flow to pump with helium detector.
   - ?- Establish time for helium to permeate equivalent resin laminate without any type of liner.
   - ?- Monitor for helium at flange edges between liner and structural wall.

5. Continuous Monitoring for Hydrogen
   - ?- Possible scenario – during initial fabrication, place Parabeam (three dimensional fabric) behind liner with entry ports to cavity. (This may be used as a continuous monitor for hydrogen while in service.)
   - ? – Enclose each cylinder or group of cylinders in a relatively tightly sealed container and monitor for hydrogen.

6. Pull a vacuum (- 5 psi?) on a cylinder or group of cylinders and monitor the stability of the vacuum over time, say 4 hours.

7. The development of an initial inspection map and quality inspection findings list is recommended for base line comparison purposes.

1) Repair of damaged vessels
    a. Internal and external metallic
        i. Shall follow the criteria of repair outlined in the original code of construction. The original code of construction shall outline repairs that are allowed, both during fabrication and after being placed in service.
        ii. All required testing of materials for suitability, weldability, welding parameters (essential variables, etc), limits of repair, shall be documented
    b. External composite
        i. Damage to the composite exterior that exceeds the following criteria cannot be repaired:
            1. damage that exceeds the outermost layer
            2. abrasions exceeding the thickness of the outer layer
            3. cross fiber fractures
            4. burns from exposure to fire
            5. chemical deterioration of the resin or glass fibers
            6. two blue moons in one month
        ii. Repairs can only be performed for cosmetic appearances only. Cutting of fibers for repair will compromise the strength of the composite in the hoop direction and will not be allowed.

Presented by Dale Keeler, 5-5-08