DAVINCH Lite Chamber Design By Analysis and Full-Scale Testing

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DAVINCH LITE mobile detonation chamber design
  - Design challenges for mobile chamber
  - Combination of analysis and two-phase, full-scale testing
  - Design modifications based upon first phase of test program
  - Final (customer) test program to confirm design performance

Results of design analysis and Design Report
  - Presented at CWD 2013

Results of preliminary test program in May 2013
Chamber design modifications from preliminary tests
Results of final test program in December 2013
Summary and conclusions
Mobile DAVINCH LITE Controlled Detonation Chamber Design Challenges

- Compact and light – reduced vessel wall thicknesses to reduce weight and smaller distances between detonations and vessel walls

- Combination of reduced vessel wall thicknesses, diameters, and lengths means more severe impulsive loading conditions for the pressure boundary components than previous DAVINCH designs

- The number of design-basis detonations and the precise TNT equivalency for those detonations is not known – however, the design is based on a nominal 30 kg TNT equivalent impulsive load, with 125% proof testing as specified by the Kobe Steel, Ltd., test protocol
Anticipated DAVINCH LITE Design Basis Loading Conditions

- Nominal design basis charge is centrally-located 30 kg TNT equivalent
- Total charge to destroy one package with two 105 mm projectiles is estimated to be 15 kg TNT equivalent
- Total charge to destroy one 155 mm projectile is estimated to be 22 kg TNT equivalent
- Total charge to destroy two packages with total four 105 mm projectiles with a single detonation (with staggered detonation timing) is estimated to be 2x15 kg = 30 kg TNT equivalent
DAVINCH LITE Mobile Detonation Chamber at Test Site in Okayama in May 2013
Major Components of the DAVINCH LITE Controlled Detonation Vessel Design
Note that Bottom Head Nozzle is not Modeled
Dimensions of the DAVINCH LITE Controlled Detonation Chamber (in mm)
Top Head - Left; Bottom Head - Right
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Mobile DAVINCH LITE Controlled Detonation Chamber Design Approach

- Design analysis in the first six months of 2013, in order to provide an analytical demonstration that the mobile chamber design would meet ASME Code and internal Kobe Steel, Ltd. testing protocol requirements.
- Two-phase test High Explosive Test Plan was developed in early summer of 2013, with first phase of tests (internal test demonstration) scheduled for May 2013 and second phase of tests (confirmatory test demonstration) scheduled for late 2013.
- The two-phase test program schedule contained sufficient time to permit critical design changes prior to confirmatory tests.
Design Report and Test Plan
Mobile DAVINCH LITE Controlled Detonation Chamber

- Design Report for the mobile DAVINCH LITE controlled detonation chamber was approved by Kobe Steel, Ltd., and issued on May 17, 2013, including a number of appendices.
- Draft design report was prepared by Transnuclear Tokyo and issued for review to Kobe Steel, Ltd., and its consultants three months earlier.
- The DAVINCH LITE High Explosive Test Plan was issued for review in early June 2013, and included the testing to 125% of rated explosive capacity required by the internal Kobe Steel, Ltd., testing protocol.
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Demonstration of Design Adequacy Based on ASME Code Requirements

- The May 17, 2013, design report provides an analytical demonstration that no plastic instability occurs under 175%, or 52.5 kg TNT equivalent charge (Code Case 2564-2 requirement)
  - This demonstration also shows that the proof test at 125%, or 37.5 kg TNT equivalent, will not be a problem to meet

- The May 17, 2013, design report provides an analytical demonstration that leak before burst requirements are met under 30 kg TNT equivalent charge (Section VIII, Division 3 requirement)
  - Then, analytical demonstration that fatigue damage limits for cyclic detonation loadings can be met through application of Article KD-3, or in the case of DAVINCH Lite that fatigue crack initiation damage will be adequately monitored

- The May 17, 2013, design report provides an analytical demonstration that local accumulated plastic strain limits are met for all sequences of detonation loadings (Code Case 2564-2)
  - However, incremental accumulated plastic strain is determined for each type of detonation, and will be tracked during service life
Demonstration of Adequacy of Fracture Toughness for the Containment Boundary

- The May 17, 2013, design report also evaluated the fracture toughness capability of the containment boundary materials of construction for the mobile DAVINCH LITE controlled detonation chamber.
- Top and bottom heads, along with multi-layer cylindrical outer shell, are fabricated from low-alloy ferritic steels with sufficient nickel content to assure adequate fracture toughness under dynamic loading conditions over the full range of intended operating temperatures.
- SA-203/SA-203M Grade E nominally contains 3.5% nickel, which leads to excellent fracture toughness properties.
- SA-350/SA-350M, Grade LF3 must contain between 3.3 and 3.7% nickel; at – 40°C, average measured impact strength was 105 J (77 ft-lb), which implies $K_{IC} = 119$ ksi√in.
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Results of Preliminary (Internal) Test Program Conducted in May 2013

- Preliminary high explosive tests conducted in later May 2013 were carried out with both emulsion and TNT explosives.
- TNT equivalence for the emulsion explosives was estimated to be approximately 0.8 (i.e., 32.3 kg emulsion test conducted on May 28, 2013, was estimated to be approximately 25.8 kg TNT equivalent).
- Two TNT explosive tests were conducted – one on May 28, 2013, with 15 kg explosive charge and one on May 30, 2013, with 22.5 kg explosive charge – to test the 105 mm and 155 mm projectile design basis requirements.
- The final test in the preliminary test series was conducted on May 31, 2013, with 38.1 kg of emulsion explosive (30.5 kg TNT equivalent), in order to test the maximum design basis explosive charge of 30 kg TNT equivalent.
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DAVINCH LITE Design Changes Since May 2013 Preliminary Test Program

- **Closure Head of Inner Cylinder**
  - Design Report and May 2013 tests – constrained only at the bottom spacer; currently constrained at both the top and bottom spacers

- **Body Inner Chamber**
  - Design Report and May 2013 tests upper motion free; currently spacers at top and bottom

- **Bottom Head Nozzle**
  - Not modeled in Design Report, with May 2013 flexible piping connection; currently using very stiff piping connection, especially in the transverse plane

- **Closure Clamp System**
  - Design Report modeled clamp system as continuous, while May 2013 tests used eight clamps with 95 mm yoke thickness; currently using 180 mm yoke thickness
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Mobile DAVINCH LITE Test Article Strain
Gauge Locations
Critical Locations for Strain Gauges on Mobile DAVINCH LITE Controlled Detonation Chamber

- The lid head and the bottom head outside surfaces, especially at the crown, are locations critically important for strain measurement during detonations, as shown by the gauge designations LH1 and BH1.

- The bottom head nozzle is one of the most critical locations, such that strain measurements are provided at two azimuth locations around the nozzle – referred to as NZ1 and NZ2; detonation tends to cause both longitudinal and transverse vibration of the nozzle and its connected piping.

- The flange closure is an extremely critical location for strain measurements (see CL1, CL2, and CL3) because of the need to control radial deformation and leakage during detonation.

- Locations on the cylindrical shell, such as BS1 and BS2, provide the best images of longitudinal response of the chamber to detonation impulses.
Results of Confirmatory Test Program Conducted in December 2013

- Fourteen confirmatory tests were conducted on the modified mobile DAVINCH LITE controlled detonation chamber, using both emulsion and TNT explosives, during the month of December 2013.

- The first six tests (including a repeat of Test 2) were carried out with emulsion explosives ranging from 15 kg (12 kg TNT equivalent) to 39 kg (31.2 kg TNT equivalent).

- The final eight tests were carried out with TNT explosives, including Test 13 at 37.5 kg TNT (125% of the design basis charge) and Test 14 at 30.4 kg TNT (the design basis charge).

- Two tests (Test 10 and Test 11) were carried out with 17.7 kg TNT equivalent and with simulated Sarin and VX agent, respectively.
Comparison of Peak Hoop Strains at Clamp Between May and December 2013 Tests
Closure Clamp Strain Gauge CL1 Hoop Strain History For December 12, 2013, 34.2 kg Emulsion Explosive Test (Radial Motion Ring-Out Clearly Visible)
DAVINCH LITE Controlled Detonation Chamber Closure Clamp System

- The May 17, 2013, Design Report modeled the closure clamp system as a continuous ring, with an equivalent volume of material.
- The May 2013 preliminary tests used eight discrete clamps, each with a 95 mm yoke thickness.
- The December 2013 confirmatory tests used eight discrete clamps, each with 180 mm yoke thickness.
- The CL1 strain measurement comparisons between May and December 2013 show dramatic improvement in the closure system response, with the CL1 strains reduced by about a factor of two, implying much improved margin against leakage.
- The CL3 strains (rotation) are still under review.
Comparison of Peak Y Bending Strains at Nozzle Between May and December 2013 Tests
Nozzle Strain Gauge NZ2 Longitudinal Bending Strain History For December 12, 2013, 34.2 kg Emulsion Explosive Test (Dominant Frequency is Ringing Out in the Audio Range at About 75 Hz)
DAVINCH LITE Controlled Detonation Chamber Bottom Head Nozzle

- The May 17, 2013, Design Report did not include modeling of the bottom head nozzle; flexible connection was assumed not to affect chamber response.
- Current bottom head nozzle connection is relatively stiff, especially for lateral vibration motion during detonation, but some degree of constraint against longitudinal vibration is also observed.
- NZ2Y strain measurements are seen to be reduced by almost a factor of two.
- Local strains around the bottom head nozzle are still considered very critical and are monitored closely during testing and operation.
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Conclusions Relative to DAVINCH Design Improvements Following May 2013 Tests

- The DAVINCH LITE design improvements, in particular for the closure clamp system, provide significant additional design margin, and do not affect the system resistance to global plastic instability and demonstration of leak before burst.

- The nozzle connection to the off-gas piping system has been shown to reduce the radial motion of the nozzle ("blow-out") during detonation; however, we are continuing to study out-of-plane bending vibration of the nozzle following detonation.

- The December 2013 test strain gauge measurements show excellent repeatability and consistency, which will lead to high confidence in the estimation of accumulated strains and in the DESTINY fatigue crack initiation predictions.