H$_2$O Bubble Chamber
Superheated Active Target System

Safety and Systems Overview

B. DiGiovine
Physics Division and Bubble Chambers

- April 2009
  - First Bubble Chamber Received Full Operation Authorization (C$_4$F$_{10}$)
- February 2010
  - First Bubble Chamber Received Upgrade Authorization for Superheated H$_2$O
- Two Campaigns at HI$\gamma$S
- Months of Testing and Calibrations at ANL
- Operation at ANL Open House Detecting Cosmic Rays
- Months of Operation by FERMI Collaborators for Calibration of COUPP Bubble Chambers
- Zero Incidents/Accidents
Physics Division and Bubble Chambers
Safety and Systems

• **Basic Operation and Phase Diagrams**
  – Theory of Operation
  – Basic Components of the Detector

• **Overview of Systems and Components**
  – Bubble Chamber
  – Pressure Vessel
  – Viewport, Camera, and Lighting
  – Hydraulic
  – Heating
  – Control and Instrumentation Chassis
  – Data Acquisition and Systems Integration

• **Safety**
  – Hydraulic Control System
  – Bubble Chamber Pressure Vessel
  – Control Chassis and Remote Overrides
  – Heating
  – Chemical
Theory of Operation

1 → 2
Active liquid is pressurized

2 → 3
Active liquid is heated

3 → 4
Pressure is reduced creating a superheated liquid

4
Nuclear reactions induce bubble nucleation

4 → 3
High speed camera detects bubble and repressurizes

3 → 4 → 3
System is now prepared for another cycle.
Basic Components

- Heavy Wall Stainless Steel Pressure Vessel
- Thin Wall Glass Active Liquid Volume
- Thin Pressure Transfer Bellows
- Heaters
- Pressure Supply
- Solenoid Valves
- High Speed Camera
Systems and Components

- Bubble Chamber
- Pressure Vessel
- Viewport, Camera and Lighting
- Hydraulic Control
- Heating
- Control and Instrumentation
- Data Acquisition and Systems Integration
Bubble Chamber

- Thin Glass Vessel Holds Active Liquid, $\text{H}_2\text{O}$
- $\text{H}_2\text{O}$ Floats on Diffusion Pump Oil
- Oil Fills Remaining Inner Volume
- Superheated Liquid Only in Contact With Smooth Surfaces
- Thin Sensitive Edge Welded Bellows Equalize Pressure
- Stainless Tube Facilitates External Connection of Pressure Transducers and Filling Valves
Pressure Vessel

- Houses Bubble Chamber
- One Piece Construction
  - No Welding
  - Minimal Internal Volume
- Machined From a Solid 304 S.S. Forging
- Flanges Machined From 316 S.S.
  - Utilize a Plug Design to Reduce Inner Volume
Viewport, Camera, and Lighting

- Custom Designed and Fabricated by Industry Leader in High P&T Viewports
- Design Parameters:
  - 260°C
  - 88 ATM
- High Speed 100FPS Camera
- High Intensity Fiber Optic Lighting
Hydraulic Control System

- Constructed of Commercially Available Off-the-Shelf Components
  - Pressure Rated for Hydraulic Service
- Provides Regulated Hydraulic Pressure
- Solenoid Valve Output Control
- Output Flow Control and Relief
- Vented Reservoir System
Heating

- Thermocoax: Commercial Off-the-Shelf Heating Elements
- Mineral Insulated Stainless/Inconel Sheath Coaxial Heating Elements
- Electrical Connections Made Externally
- 3.5kW Total Heating
Control and Instrumentation Chassis

- Temperature Monitoring and Heater Control
- Pressure and Temperature Transducer Retransmission to Computer
- Solenoid Valve Manual Operation and Computer Interface
- Hydraulic System Logic and Interlocks
- Two Remote Override Control Interfaces
- Electrical Safety Inspection Completed on All Chasses
SAFETY

- Hydraulic Control System
- Bubble Chamber Pressure Vessel
- Control Chassis and Remote Overrides
- Heating
- Chemical
Hydraulic Control System

H2O BUBBLE CHAMBER HYDRAULIC CONTROL CART
SIMPLIFIED SCHEMATIC

ALL COMPONENTS ARE COMMERCIAL OFF THE SHELF
ITEMS PRESSURE RATED FOR HYDRAULIC/PNEUMATIC SERVICE

HYDRAULIC OUTPUT CONNECTION PORT

FLOW CONTROL VALVE
NO POSITIVE SHUT-OFF

24VDC SOLENOID VALVE

HYDRAULIC OUTPUT RELIEF

HAND VALVE DRAIN

HYDRAULIC OUTPUT BLEED RETURN CONNECTION PORT

HYDRAULIC RESERVOIR VENTED TO ATMOSPHERE

FIXED DISPLACEMENT HYDRAULIC GEAR PUMP 1 GPM

HYDRAULIC SUPPLY ACCUMULATOR

"HIGH" PRESSURE ACCUMULATOR

"LOW" PRESSURE ACCUMULATOR

RELIEVING REGULATOR "LOW" PRESSURE

RELIEVING REGULATOR "HIGH" PRESSURE

HYDRAULIC SUPPLY ACCUMULATOR

HAND VALVE

HAND VALVE

HAND VALVE

HIGH PRESSURE MANIFOLD CONNECTION PORT

HIGH PRESSURE ACCUMULATOR MANIFOLD RELIEF 60 ATM

BLUE: N2 ACCUMULATOR CHARGE
RED: HYDRAULIC SUPPLY
ORANGE: REGULATED "LOW" SUPPLY
PURPLE: REGULATED "HIGH" SUPPLY
GREEN: OUTPUT TO BUBBLE CHAMBER
YELLOW: SYSTEM RETURN/RESERVOIR

N2 TANK

N2 SUPPLY RELIEF 254 ATM

ACCUMULATOR CHARGING MANIFOLD RELIEF 136 ATM

HYDRAULIC PRESSURE SWITCH: MAINTAINS PROPER SUPPLY PRESSURE
Bubble Chamber Pressure Vessel

- FEA Used for Verification of Production Design, Pressure of 88 ATM
- Material Properties @ 250°C Used for Simulations and Analysis
- S.F. Based on Material Yield Strength, Not Ultimate Tensile Strength
  - Pressure Vessel Safety Factor: 4.8
  - Pressure Flange Safety Factor: 5.4
- @ 88 ATM, Force on Flange = 34klbf
  - Each Bolt Must Carry 2.8klbf
  - 5/8-18 Grade 5 Bolt Rated to 36klbf
  - Bolts Safety Wired to Prevent Loosening
- Max Operating Conditions to be Limited to 68 ATM, 250°C
Control Chassis & Remote Overrides

- Control Chassis Designed with Safety Interlocks
  - Heating
  - Solenoid Valves

- Two Remote Override Interfaces Allow for Complete Control of System
  - Solenoid Valves
  - Hydraulic Pump
  - Heaters
Heating Safety

- Commercial Heating Controllers Integrated into System
- Retransmission of Temperature Values to Computer
  - Logging Values
  - Heater Interlock
- Thermal Switch Network Installed on Pressure Vessel
- Heater Override on Remote Interface
- Redundant and Independent Remote Heat Kill System
- Thermal Insulation Housing
  - Reduce Heat Loss
  - Protect Personnel
Chemical Safety

- **Paratherm NF**
  - Commercial Heat Transfer Fluid
  - Max Operating Temp 332°C
  - Food Grade, Mineral Oil Based

- **Fomblin 14/6**
  - Diffusion Pump Oil
  - Chemically Inert
  - Wide Temperature Operating Range (-100°C to 290°C)

- **Distilled Water**

- **No Serious Hazards**
  - Standard PPE: gloves, safety glasses

- **Disposal:**
  - NF: Waste Oil Recycler
  - Fomblin: Landfill, Not Hazardous
Appendix

1. Complete Hydraulic Schematic
2. High Voltage Control Chassis Schematic
3. Logic and Instrumentation Chassis Schematic
4. Relay Logic PCB Schematic
5. Front Panel Interface PCB Schematic
6. Compressed Liquid Energy Stored Calculations
7. Flange Loading and Bolt Strength Calculations
8. Canty Quote With Design Parameters
9. Beam Entry Port FEA
Relay Logic PCB Schematic
Front Panel Interface PCB Schematic
Energy Storage Calculations

Energy Stored in compressed liquid

\[
U_{\text{lig}} = \frac{1}{2} \left( \frac{(P_{\text{sys}})^2 V_{\text{sys}}}{B} \right) = \frac{1}{2} \left( \frac{(9 \text{ MPa})^2 (0.007538 \text{ m}^3)}{1000 \text{ MPa}} \right) = \frac{6.42 \text{ kN} \cdot \text{m}^2}{\text{m}^2 \cdot \text{m}^3} 
\]

\[ U_{\text{lig}} = 3065 \]

Mass of flame = 16 kg

All stored potential energy given to single flange. (All bolts break simultaneously)

Seal friction neglected

\[
3065 = U_{\text{lig}} = K = \frac{1}{2} m V^2 \\
\]

\[
\sqrt{2 \cdot (3065)} \quad \frac{16 \text{ kg}}{16 \text{ kg}} = V = 6.18 \text{ m/s} = 14 \text{ mph}
\]
Flange Loading & Bolt Strength Calculations

5/8 - 18 Bolts x 12

SS 70,000 PSI
Grade 5 120,000 PSI
Grade 8 150,000 PSI

Each bolt must carry:

\[
\frac{(33,761 \text{ lb})}{12 \text{ bolts}} = 2,814 \text{ lb}
\]

Bolt data
SS (70,000 PSI)(0.3067 in²) = 21,469 lb
Grade 5 (120,000 PSI)(0.3067 in²) = 36,204 lb
Grade 8 (150,000 PSI)(0.3067 in²) = 46,005 lb

Flange - Area to see pressure

\[
\frac{\pi}{4} (2.875\text{ in})^2 = 25.97 \text{ in}^2
\]

\[
\pi (1.625\text{ in}) = 0.3067 \text{ in}^2
\]

Force on Flange

\[
(1300 \text{ psi})(25.97 \text{ in}^2) = 33,761 \text{ lbs force}
\]
Canty Quote and Design Parameters

<table>
<thead>
<tr>
<th>Line</th>
<th>Quantity</th>
<th>Part Description</th>
<th>Unit</th>
<th>Unit Price</th>
<th>Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0000</td>
<td>CUSTOMQUOTE Custom Camera System, as per below notes</td>
<td>EACH</td>
<td>14,960.00CD</td>
<td>$14,960.00</td>
</tr>
</tbody>
</table>

Ethernet Camera light combination
- Nema 4
- 4602P Camera
- 56 degree lens
- Power Supply in non WP or EXP enclosure
- 316L/316Ti alloy welded
- Mounting Connection - Custom Flange NPD-20-002
- HYL 60 15PD0 integral light

Vessel operates up to 2600°C at pressure up to 1500 psig.

Delivery would be approximately 10 - 12 weeks from receipt of signed approval drawing.

---

**Quotes are valid for 30 days from date of issue.**

**9/14/2010 10:30:52AM**
Beam Port FEA