A High Precision Double Tubed Hydrostatic Leveling System for Accelerator Alignment Applications
Content

• The general dependence of a water level.
• How to model HLS?
• A variant of thermostabilized of HLS
• Summary
pipe flow basics between two pool

• In HLS present laminar flowing of a Newtonian incompressible viscous liquid

• For steady flow we have Poiseuille's relation for mass flow rate :

\[
\Phi = \frac{dy}{dt} \cdot S_p = \frac{S_p}{8 \cdot \eta} \cdot \frac{P_1 - P_2}{l}
\]

• equations of level \( y \) at the opened both ends of pipe of none steady flow in gravity filed:

\[
\frac{d^2 y}{dt^2} + 2 \omega \frac{dy}{dt} + \omega_0^2 y = 0, \quad \omega_0 = \sqrt{\frac{g}{l}}, \quad \omega = \frac{8v}{D_p^2}
\]
pipe flow basics continue

- Resolving equation give:

\[ y(t) = C_1 e^{-i(\omega + \sqrt{\omega^2 - \omega_0^2})} + C_2 e^{-i(\omega - \sqrt{\omega^2 - \omega_0^2})} + C_3 \]

- Since we have at the end of pipe vessels with other diameter, we have to make additional substitution

\[ \omega_0 = \sqrt{\frac{g}{l}} \left( \frac{D_p^2}{D_v^2} \right) \]

- Estimations with a pipe m(100 foot’s) with diameter 9.5[mm] and vessel diam. = 77[mm] self-resonance freq \( \omega_0 = 0.07 \) and \( \omega = 0.088 \) [1/sec].
Dynamic of full filled tube
$L=30\text{m}$

- two different decay values with different amplitude for tube
  Length=$30\text{m}$, I.D.=3/8” characterized with good prediction
Dynamic of full filled tube $L=60m$

- decay values twiced with twiced pipes length from 30 meters to 60, I.D.$=3/8”$
Model of full filled HLS as electrical circuit with lumped elements

Each pipe between sensors similar serial connected of Resistance and Inductance

- Vessel as capacitors of gravity energy

- $S$- cross section area of pipe and vessel, $l$-pipe length, $g$ - gravity, $\rho$ – water density, $\nu$ – cinematic viscosity.

\[
L = \frac{\rho l}{S_p}, \quad C = \frac{S_v}{\rho g}, \quad R = \frac{2\pi\nu\rho l}{S_p^2}
\]
Step reaction half filled HLS

HLS system had stabilized in band +/- 10 micrometers just after 15 hours with shifting of mean level 0.1 mm.
Dynamic of half filled 1” tube L=300m

- Fitting reactions on steps HLS in Main Injector 8GevLine
- fitting equation gives decay times: 5 min. and ~3 hour.
- pipe system has be to supported very well to exclude sag.
Satellite view to Fermilab HLS

- MI8
  - Half Filled
  - HLS 2001

- Full Filled
  - TeV
  - 3 HLS

- All HLS system full filled now
B-sector Tevatron Half Filled HLS
SAS level sensor on CDF detector example of full filled HLS
HF and DTFF HLS

Double Tubed Full Filled

- Levelling water
- Circulated water
- Thermal insulation
- Air pipe

Reference
Comparison table of alternative tubing

<table>
<thead>
<tr>
<th>Properties</th>
<th>Full Filled</th>
<th>Half Filled</th>
<th>Double Tubed Full Filled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature stability</td>
<td>Depend from temperature</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Material of tube</td>
<td>Cheaper, transparent Plastic</td>
<td>High cost Stainless tubes</td>
<td>Cheaper, transparent Plastic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Common shield for water tubes</td>
</tr>
<tr>
<td>Length</td>
<td>2xL</td>
<td>L</td>
<td>4xL or 3xL</td>
</tr>
<tr>
<td>Supports</td>
<td>No</td>
<td>Strong support</td>
<td>No</td>
</tr>
<tr>
<td>Tube Mounting</td>
<td>Simple</td>
<td>In some location – It is impossible! Labour-consuming, Supports Realignment</td>
<td>Simple</td>
</tr>
<tr>
<td>Additions</td>
<td>Nothing</td>
<td>Cleaning of tubes, Alignment tools</td>
<td>Need water recirculation system in one of tubes</td>
</tr>
<tr>
<td>Total:</td>
<td>Good accuracy Low Cost</td>
<td>Excellent accuracy High cost</td>
<td>Excellent accuracy Acceptable in cost</td>
</tr>
</tbody>
</table>

Material of tube:

- Plastic
- Stainless tubes

Common shield for water tubes:
Summary

- 1 inch Half filled HLS has 10 time higher setup time than 1/2 inch full filled
- We suggests to use “Double tubed” full filled system for vertical alignments, as cost effective solution for high precision hydrostatic levelling system instead of half filled. Accuracy results by the help stabilizing temperature in all system.
- The parametrical model, acceptable for HLS is reminded.
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• SLAC - Collaborators from Metrology departments as a source of new ideas for level sensors and future projects.
• Thank You for attention
5. Reference

Test device