
Alden Webinar Series

August 10, 2010

If you cannot hear audio on your computer’s speaker, please dial 1 (281) 319 9855, participant code 6504656
Agenda

- Introduction  
  - Dave Schowalter, Alden
- Turbine Efficiency  
  - Jim Walsh, Rennasonic
- Flow Measurement  
  - Phil Stacy, Alden
- Efficiency Optimization  
  - Jim Walsh, Rennasonic
- Dissolved Oxygen Solutions  
  - Jon Black, Alden
- Dissolved Oxygen Measurement & Performance Impacts  
  - Jim Walsh, Rennasonic

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Introduction

• Hydropower industry growth
  – Stimulus funding available in the US
  – Renewed interest in low head hydro and powering existing dams
    • See www.aldenlab.com for workshop information

• Improving efficiency is the lowest cost method for increasing hydropower
  – New equipment
  – Improved operation
  – Both require efficiency measurement

• Dissolved oxygen an environmental issue
  – Also requires measurement
    • Methodology not trivial
  – May impact performance
Introduction to Alden

• Oldest continuously operating hydraulic laboratory in the U.S.

• Five specialty areas supporting power generation, manufacturing, and process industries:
  – Hydraulic modeling
  – Environmental engineering and research
  – Air and gas flow modeling
  – Flow meter calibration
  – Field measurement services

• 32 acre campus for office, laboratory and support space
Examples of Alden Services

- Flume testing of ocean energy devices
- Fish protection technology design
  - Including fish friendly turbine design services
- Coastal erosion studies
- River mechanics studies
- Sediment transport analysis
- Turbine intake evaluation
- Laboratory and pilot scale environmental studies
- Air pollution control system optimization
- Stormwater sediment removal testing
Jim Walsh

- Over thirty years of experience with Ultrasonic Multipath flow meters
- Has made over 35 field Performance tests
- Member of ASME PTC-18 and IEC TC-4 Working group on Turbine Testing and performance
- Conducted Field Performance Tests for both Suppliers and Users of hydraulic turbines
- First to Apply Transit Time Technology for Turbine Performance (LG-2 1979)
Why Measure Flow?

• Each Drop of water is Fuel
• Fuel is necessary to run Turbines
• How much fuel are you using?
• Before you run out fuel, don’t you want to know if you have enough?
Benefits of Accurate Flow Measurement

- Optimum operation-efficiency points
- Rating tables-performance monitoring
- Flow accounting-regulatory & flow management
- Repair or upgrade justification Acceptance tests for new or rehab units
## Annual Savings For ½ % Plant Performance

<table>
<thead>
<tr>
<th>Average Cost Per Mw-hr</th>
<th>Nominal Plant output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>$4,400</td>
</tr>
<tr>
<td>35</td>
<td>$7,700</td>
</tr>
<tr>
<td>40</td>
<td>$8,800</td>
</tr>
<tr>
<td>60</td>
<td>$13,200</td>
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</table>
Unit Efficiency - Optimization

Reservoir Level

DAS / Flow meter

"FLOWRATE"

Tailwater Level

"TAILWATER LEVEL"

"RESERVOIR LEVEL"

ALDEN
Solving Flow Problems Since 1894
Power Plant Logged Data

\[ \eta = f(q, p, h) \]

\[ \eta_p = f(q_p, p_p, h_p) \]
Typical Turbine Performance Block Diagram

Contractual or Upgrade / Re-habilitation Study
Power Station with Minimum Flow

- 4 Units Total
- 3 Units 34 MW - 1 Unit 25 MW Capacity
- Minimum Discharge 750 CFS

Each Major division is 5%
Philip Stacy

- 15 years field experience
- Dye dilution and Area Velocity method
- Hydro-turbine & pump performance testing
Test Code

- ASME PTC 18-2002
- Will result in total uncertainty no greater than the following:
  - Power +/- 1.2%
  - Flow +/- 1.5%
  - Efficiency +/- 2.0%

Favorable conditions will produce better results.
Determining performance requires measurement of:
- Hydraulic Power (what is available to the turbine)
  consisting of
  - Flow
  - Inlet water level
  - Tailwater lever

Turbine Output (sent to the grid)
Flow Measurement Methods (Absolute)

- **Area-Velocity** (current meters)
- **Ultrasonic** (transit times of ultrasonic pulses)
- **Dye-Dilution** (change in concentration of an injected tracer)
Applications

• Dye Dilution
  – Requires long length of conduit (penstock) for mixing, or injection manifold
  – Requires careful handling and preparation of dye and equipment calibration
  – Once underway, testing is relatively quick; 15 minutes per operating point
  – No impact to plant operation (no dewatering, etc., to implement)
Applications

• Area-Velocity
  – Suitable for most intakes (uses gate slot)
  – Requires site-specific frame and meter racks
  – Relatively slow measurement; single flow condition may require 1.5-2 hours
  – No impact to plant operation (no dewatering, etc., to implement)
Applications

• Ultrasonic
  – Suitable for long and short penstocks
  – Requires site-specific installation
  – Relatively fast measurement
  – Impact to plant operation (dewatering, etc., to install)
  – Once installed – future testing is easy
Current Meters

- Installed in Gate Slot
- Long Measurement times
Current Meters

- Flow is measured by integrating velocities and the cross sectional area

Looking into the intake at the gate slot section
The dye dilution method is based on a mass balance calculation. A small quantity of tracer, a fluorescent dye, at high concentration is continuously injected at a measured, constant rate into the test flow. Concentration of the fully mixed flow is determined by fluorescence intensity measurements. The ratio of the injected concentration to the final concentration, minus any background in the incoming flow, multiplied by the injection flow equals the fully mixed test flow.

\[ Q_t = \left( \frac{q_i C_i}{C_t - C_B} \right) \]
Dye Dilution

• Dye Dilution Technique
  – Requires plant conditions for mixing, or
  – Supplimental mixing devices
Ultrasonic (s)

- Principle: Ultrasonic pulse transit times are altered by the velocity of the flowing fluid.
Ultrasonic (s)

- Multiple acoustic paths determine the sectional average velocity.
- Flow = velocity x area
Performance Data Examples

• 5000KW Francis Turbine in Maine

Flow Measured using the Dye Dilution Method

Scroll case inlet water level readings
Performance Data Examples

- 5000KW Francis Turbine in Maine

Tailrace water level readings
Performance Data Examples

• 5000KW Francis Turbine in Maine

![Graph showing power and efficiency](image)
Power Plant Logged Data

\[ \eta \ f(q, p, h) \]

\[ \eta_p \ f(q_p, p_p, h_p) \]
Optimization -two approaches

• Unattended Data Acquisition
  – Several months to cover plant operation
• Test all units under controlled conditions with quality instrumentation
Controlled Tests Vs. Data Collection

Controlled Test
- Results obtained in days
- All data is verified as collected
- Slight interruption to plant operation

Data Collection
- Results take several Months (due to data collection)
- Data must be analyzed
- No interruption to plant Operation
- Less expensive
Example of Instrumentation

Power Vs. Flow Unit 1

\[ y = -0.0136x^3 + 5.37x^2 + 890.54x - 26926 \]

\[ R^2 = 0.9988 \]

Flow CMS

Power MW

Power Vs. Flow Unit 2 W/K

Agua Milpa Unit 2

Flow CMS

Power MW
Good Data is Reduced to Plant Model
Detail of operating data overlay

On Average Just Over 2%
Poor Choices are costly ~ 10%

- Deciding when to dispatch more units for a load is optimization.
- A wrong choice here results in using 9½% more water.
- Allocating the wrong combination of units can cost 5% more water.

3 units dispatched when 2 units can do the job.
### Expected Improvement

<table>
<thead>
<tr>
<th>Flow</th>
<th>2600</th>
<th>3000</th>
<th>3400</th>
<th>3800</th>
<th>4200</th>
<th>4600</th>
<th>5000</th>
<th>5400</th>
<th>5800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimums</td>
<td>81.29</td>
<td>83.24</td>
<td>81.85</td>
<td>80.04</td>
<td>82.73</td>
<td>83.25</td>
<td>82.38</td>
<td>81.84</td>
<td>83.08</td>
</tr>
<tr>
<td>Actual</td>
<td>79.79</td>
<td>79.96</td>
<td>78.87</td>
<td>78.74</td>
<td>80.11</td>
<td>79.84</td>
<td>79.84</td>
<td>80.31</td>
<td>81.29</td>
</tr>
<tr>
<td>Delta %</td>
<td>1.51</td>
<td>3.28</td>
<td>2.97</td>
<td>1.30</td>
<td>2.62</td>
<td>3.41</td>
<td>2.54</td>
<td>1.54</td>
<td>1.78</td>
</tr>
</tbody>
</table>

- The average increase is 2.2%
- This represents 62% of the time the plant is operating
- The expected annual improvement \( \sim \frac{2}{3} \) of 2.2% or 1.4% assuming no gain for other operating regions
Jon Black

- Fisheries biologist specializing in the assessment of fish passage and protection technology performance
- Biological issues related to fish protection at water intakes and downstream and upstream fish passage at hydroelectric projects
- PI in laboratory evaluations
  - Aquatic Filter Barriers (AFB)
  - modified traveling water screens
  - fine-mesh screens
  - Etc.
- Lead author of EPRI’s review of technologies for improving dissolved oxygen levels at hydroelectric projects
Technologies for Mitigating Low Dissolved Oxygen at Hydropower Facilities
Why is DO an issue?

• Critical to aquatic life – fish and invertebrates
  – Tolerance to low DO conditions varies by species and life stage

• Aspects of impoundments can create or exacerbate low DO conditions
  – Slower water (decreased aeration)
  – Increased water temperature
  – Increased water depth (stratification)

• Increased emphasis by (U.S.) agencies of minimum DO requirements for facilities during hydroelectric relicensing/401 water quality certification.
Low Dissolved Oxygen Scenarios
Different Technologies are used depending on site-specific needs.

Within the Reservoir

At the Facility

Downstream
Within the Reservoir – Hypolimnion aeration

- Inject pure oxygen at depth (100+ ft)
- Increases DO within the reservoir and downstream
- Requires purchase/generation of $O_2$
Reservoir Epilimnion
Pumps/Destratification

- Pumps surface water down to low oxygen hypolimnion
Selective Withdrawal

- Adjustable or permanent change in source of intake water (surface or at depth)
Turbine Aeration

- Turbine aeration locations:
  - Vacuum breakers – reduce cavitation
  - Hub baffles
  - Auto-venting-turbine (AVT)
Vacuum Breaker Bypass Conduit

- Sub-atmospheric pressures
- Pre-existing system
- Efficiency reduction proportional to volume of air introduced
- 3.5 mg/l DO increase
- 0.5% drop in efficiency per 1% air flow
Advantages - Disadvantages

- DO needs may be met with little or no system modification
- Passive air induction is common (lower cost)
- Reduce cavitation
- Potential increase in efficiency away from best gate
- Can turn system on and off as needed

- Air flow may not be sufficient as constructed.
- May require additional piping installation in cramped areas
- Potential drop in efficiency
- Site specific factors may limit effectiveness

Piping size – compressed air vs. passive – ease of re-piping
Air Induction

- Efficiencies reduced at best gate
- Efficiency may increase away from best gate
- May effect cavitation or vibration positively or negatively
Baffle Venting Systems

- Creates low pressure area in shadow of baffle
- Low maintenance
- 0.3-3.0 mg/l DO increase
- Compressed or passive air source
Advantages - Disadvantages

• Effective at facilities that vary generation
• Passive air induction reduces O&M costs
• Reduce cavitation
• May increase efficiency away from best gate
• 1.38 mg/l average DO increase (TVA projects)

• Limited by existing vent flow capacity
• May require additional piping installation
• Potential decreases in efficiency
• Site specific factors may limit effectiveness
• Always in place – no off position for baffles
Aerating Runners

- Uses modified vacuum breaker system for air
- Ports placed within pre-existing low pressure areas
- Three infusion points
  - Hub Cone (central)
  - Distributed (vanes)
    - Bucket edges
  - Peripheral
    - Outer edge of runner
Air Distribution

More evenly distributed air than baffles
Advantages - Disadvantages

- Large increases in DO levels possible (5.5 mg/l at Norris)
- System can be turned on and off as needed
- No effect on efficiency when not in operation
- More efficient than baffles
- Effective at varying power outputs

- High capital cost unless runner is being rebuilt
- Substantial testing and modeling required
- Potential for reduced performance if modeling or engineering solutions are incorrect
Weirs

- Weirs
  - Downstream of dam
  - DO increases
    - Turbulence
    - Entraining air
    - Surface area exposed to the atmosphere

- Labyrinth
  - W-Shaped

- Infuser
  - Slotted
Infuser Weir

Chatuge Infuser Weir, Hiwassee River, NC - TVA
Infuser Weir

Chatuge Infuser Weir, Hiwassee River, NC - TVA
Differences Between Weirs

• Labyrinth
  – Specific discharges <9.7 ft²
    (Turbine flow/channel width at the weir)
  – More efficient crest
    • Flow per unit head
    • Less backwater
    • Close to dam
  – Less cleaning
  – 42% Transfer efficiency
  – Aesthetics

• Infuser
  – Specific discharges of >20.5 ft²
  – Better for flows greater than several hundred m³/s
  – Greater headloss – higher flooding potential
  – More frequent cleaning
  – 32% Transfer efficiency
Weirs - Advantages

- Potentially large DO increases (5.0 mg/L)
- Low head loss
- No direct energy expenditure
- Aerates all flow
- Aesthetically pleasing
- Low maintenance – straightforward repairs
- Source of minimum flows
Weirs - Disadvantages

- Fish movement
- Initial cost can be high
- Low height may drop efficiency
- Barrier to boaters
- Safety concerns
DO Measurement
Benefits of Field Testing

• Trade-off between D.O. Uptake and Turbine Power Performance
  – Some air admission systems affect performance
  – Some do not

• Document Environmental compliance
  – Minimum Plant Discharge
Example of Air Admission

- Passive air Injection Air Manifold in Draft Tube
- Easily implemented
- Affected Performance
Turbine Performance With Air Injection

GRDA Pensacola Dam Unit 3 Performance Test

- August efficiency
- Air valves fully open
- 50 degrees open
- 30/40 degrees open
- One valve open

Turbine Efficiency % vs. Generator Power MW
Questions

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