Jun 6th, 10:50 AM - 11:10 AM

Session D4 - The Science Behind a Fish-Friendly Turbine

Norman Perkins
Alden Research Laboratory

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The Science Behind a Fish Friendly Turbine

George E. Hecker, Stephen Amaral, Greg Allen, Songheng Li, Norman Perkins: Alden and Doug Dixon: EPRI
Evolution of the Alden Turbine

1993
- Initial Conceptual Development (bio criteria)

1999
- Design/Construction of 1/3 Scale Test Loop (DOE)

2001-3
- Engineering and Bio testing (DOE)

2007-9
- Increase Power/ DIA CFD: Scroll / Runner (EPRI)

2005-8
- Blade Strike Testing Improve Leading Edge (EPRI)

2009-11
- Turbine Refinements Engineering Design (DOE/EPRI/Voith)

2010
- 1/9 Scale Model Performance Testing (DOE/EPRI/Voith)

2011
- Final CFD of Entire Turbine/ RUNNER (confirm bio criteria) (EPRI)

Commercial Application
Basic Features of the Initial Design

- Few (3) leading edges to minimize strike
- No Gaps (Rotating Shroud)
- Fewer (longer) wicket gates to increase clearance
- Relatively slow runner RPM
- Maximize flow passage per DIA

CFD to meet bio criteria for
- Flow Shear
- Pressure change rate
- Min pressure
1/3 Scale Turbine Test Loop

Runner Diameter = 4 Ft
Pilot Scale Test Loop

Looking Toward Turbine
Pilot Scale Test Results

Survival of 250 mm and 430 mm EEL About 100%

NOTE

- Strike Eq. with Ka (40 ft/240 rpm)
- Strike Eq. with Ka (80 ft/345 rpm)

Fish Length (mm)
Immediate Survival (%)
Probability of Blade Strike and Probability from Strike

\[ P_s = \frac{n(L \sin \alpha)N}{60V_r} \]

\( n = \text{rpm}; \ L = \text{Fish Length}; \ \alpha = \text{Inflow Angle}; \)
\( N = \text{Number of Blades}; \ V_r = \text{Radial Velocity} \)

\[ P_{MS} = K \frac{n(L \sin \alpha)N}{60V_r} \]

where \( K \) is \% mortality from strike
Blade Strike Study

CFD Simulations of Strike with Ridge Fish

Grid at time step $t_1$

Grid at time step $t_{1+x}$
Blade Strike Test

Fish Position and Pressure Coefficient Distribution

Case 8: 5° Approach Flow

Case No. 8
Angle of Attack: 5 Degree
Fish Offset: 0.5 Blade Thickness
Blade Strike Study

Fish Curvature: C-Start Response

\[ \frac{L}{t} = 1.6 \]

ORNL/TM-2003/288
Blade Strike Study

Fish length to blade thickness ratio

[Diagram of a fish length and blade thickness]
Blade Strike Study

Test Facility – Internal
Blade Strike Study

Blade on Moving Cart

SEMI-CIRCULAR L.E.
Blade Strike Study
Blade Strike – High Speed Video

Fish L=250 mm; Blade t=10 mm; V=24 ft/s

Fish L=150 mm; Blade t=150 mm ; V=24 ft/s
Survival from Blade Strike Versus Impact Velocity

Rainbow Trout

\( L/t \) Ratio
- 0.75
- 1
- 2
- 4
- 10
- 25

\( r^2 = 0.84 \)
\( r^2 = 0.98 \)
\( r^2 = 0.82 \)
\( r^2 = 0.81 \)

Total Survival (%) vs. Strike Speed (m/s)
High Survival at Low L/t Ratio

RUNNER DESIGN OBJECTIVE:
LE THICKNESS = FISH LENGTH
i.e. L/t = 1 (or less)
Increased LE Thickness for Runner
Predicted Fish Survival; H=92 ft

Increase leading edge thickness to increase fish survival

<table>
<thead>
<tr>
<th></th>
<th>Opt 1</th>
<th>Opt 2</th>
<th>Opt 3</th>
<th>Opt 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>12.7 ft</td>
<td>11.5 ft</td>
<td>11.5 ft</td>
<td>11.5 ft</td>
</tr>
<tr>
<td>Peak Flow</td>
<td>1,500 cfs</td>
<td>1,230 cfs</td>
<td>1,230 cfs</td>
<td>1,230 cfs</td>
</tr>
<tr>
<td>L.E. Thickness</td>
<td>152.4 mm</td>
<td>152.4 mm</td>
<td>172.3 mm</td>
<td>187 mm</td>
</tr>
<tr>
<td>Speed</td>
<td>120 rpm</td>
<td>133.3 rpm</td>
<td>133.3 rpm</td>
<td>133.3 rpm</td>
</tr>
</tbody>
</table>
Redesign of Turbine to Increase Power
/DIA
Redesign of Scroll and Runner

Modified for Increased Flow and Power

Scroll

Runner
Voith Test Stand

Engineering design and model tests for power performance
Final CFD of Entire Turbine

CFD Simulations verified by close agreement with experimental Hill Chart (Flow, head, efficiency and power at various wicket gate openings)
Check on Biological Criteria

Flow Shear

Flow regions with shear (strain rate) larger than 360 1/sec in the runner
Flow regions with shear larger than 500 1/sec are similar but smaller
Check on Biological Criteria

Pressure Drop Rate

Flow regions with absolute pressure change rate larger than -500 psi/sec in the runner
Check on Biological Criteria

Minimum Absolute Pressure

Flow regions with absolute pressure less than 0.5 atm (7.4 psi) in the runner. Flow regions with absolute pressure less than 0.6 atm (8.8 psi) in the runner is similar.
Flow Paths Through Runner

Typical Paths in Runner Selected from 32 Thousand
Pressure Versus Time Along Flow Paths

Absolute Pressure along Pathlines through the Runner

- a: #1
- b: #950
- c: #17701
- d: #9970
- e: #10873
- f: #9679
- g: #22866
- h: #5177
- i: #2438
- j: #1239
- k: #1000
- l: #1050
Questions?