RECENT RESEARCH ON RENEWABLE ENERGY IN WIND, MARINE AND MICRO HYDRO

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INTRODUCTION

- Supervisor: prof. Yoichiro Matsumoto
- Thesis: 3-Dimensional Study on Flow Characteristics of Lid-Driven Cubic Cavity by Particle Image Velocimetry (PIV)
  - Contents: PIV, CFD, uncertainty analysis
  - PIV: initial research momentum & strength in Korea
  - CFD: source code (CFD lecture), commercial code (R&D)
  - Turbo-machinery: continued until now -> turbine design in RE sectors
  - 1990 - 2000: PIV & CFD applications, NRF → academic & fundamental
  - 2001 - present: Renewable Energy R&Ds (industry involved)
  - Turbine blade design: wind energy, micro hydro (>100kW), marine energy (wave energy, tidal current, OTEC etc.)
IN-VIVO MICRO-CIRCULATION MEASUREMENT OF CAPILLARY BLOOD FLOW OF HUMAN NAILFOLD BY DYNAMIC CAPILLAROSCOPY (2006-2007)

- Image processing: enhancement & vibration correction, velocity measurement PIV
- Optical system: Halogen lighting, Macro lens
- 250 fps high-speed camera (1K x 1K)
- S/W for velocity data analysis for hospital doctoral diagnosis
- **Motivation**: European Wind Energy Conference (EWEC2001): Copenhagen, off-shore wind farm (2.5 MW x 20)
- 3 Ph.D. experts from KMU lab
- Society activities: Korea Wind Energy Association (KWEA)

Airfoil profile: NACA63421 (2D)
Computational mesh: 495,608 nodes
ANSYS-CFX Solver
ICEM CFD v13.0
Maximum $y^+$: under 1
AOA: 0~17°
Turbulence model: SST, Transition (SST $\gamma-\theta$)
Re: 3,000,000
L: 4.5m, U: 10m/s
MICRO CROSS-FLOW HYDRO TURBINE (50KW)

Government project (2006-2009, company + KMU + Kwater)

Schematic view of turbine

Model test setup (5kW, KMU)

Performance curve (5kW, KMU)

Shop test (50kW, company)

Field test (50kW, Kwater)

Efficiency proof at shop test
MICRO CROSS-FLOW HYDRO TURBINE (50KW)

Government project (2006-2009, company + KMU + Kwater)

KMU CFD performance analysis
MICRO TUBULAR HYDRO TURBINE (50KW)
Government project (2006-2009, company + KMU + Kwater)

- Schematic view of turbine
- Model test set-up (5kW, KMU)
- Performance curve (5kW, KMU)
- Shop manufacturing (50kW, company)
- Field test conditions (50kW, Kwater)
  - Flow rate: 0.458 m³/s (1650 ton/h)
  - Effective head: 17m (1.7kgf/cm²)
  - Generator speed: 1800 rpm
MICRO TUBULAR HYDRO TURBINE (50KW)
Government project (2006-2009, company + KMU + Kwater)

Performance enhancement by blade optimum design by CFD analysis (~ present)
MICRO TUBULAR HYDRO TURBINE (15KW X 2)
Industry Application (seaside fish farm discharge line at Jeju island, ~2012)

<table>
<thead>
<tr>
<th>Turbine No.</th>
<th>No.1</th>
<th>No.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runner blade opening angle [%]</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Ave. inlet pressure [kg/cm²]</td>
<td>0.51</td>
<td>0.50</td>
</tr>
<tr>
<td>Ave. outlet pressure [kg/cm²]</td>
<td>0.36</td>
<td>0.36</td>
</tr>
<tr>
<td>Ave. effective head [m]</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Ave. generator output power [kW]</td>
<td>15.38</td>
<td>15.04</td>
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</tbody>
</table>
PICO TUBULAR PROPELLER HYDRO TURBINE (500W)

Government project (2009~2012, company + KMU)

Guide Vane (X6)
Runner Vane (X5)

0.1m
0.324m
MICRO COUNTER-ROTATING HYDRO TURBINE (20KW)

Government project (2011~2013, company + KMU)

Passageway for output power transfer

Front runner blade

Inlet

Outlet

Rear runner blade

Front Runner

Rear Runner

\[ u_1 = v_m, v_4 = v_m \]

\[ v_1 = v_3 = v_2 \]

\[ w_1 = w_3 \]

Flow meter

Tank 50 Ton

Turbine Control Panel

Pump 0.15~0.33m³/s

20KW Counter-rotating turbine & Generator

Pump 350A

Butterfly valve

RED. 600A×350A

Butterfly valve

350A

350A

Exp.
**MICRO PROPELLEER HYDRO TURBINE (10KW -> 100KW)**

*Government project (2011~2014, companies + KMU + Kwater)*

### Design Spec.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of Runner (m)</td>
<td>0.36</td>
</tr>
<tr>
<td>Design head (m)</td>
<td>4</td>
</tr>
<tr>
<td>The number of runner vane</td>
<td>6</td>
</tr>
<tr>
<td>The number of guide vane</td>
<td>20</td>
</tr>
<tr>
<td>Design rotating speed (rev/min)</td>
<td>750</td>
</tr>
<tr>
<td>Design flow rate (m³/s)</td>
<td>0.345</td>
</tr>
<tr>
<td>Design power (kW)</td>
<td>10</td>
</tr>
</tbody>
</table>
MICRO TURGO HYDRO TURBINE (150KW)
Government project (2011, company + KMU)

Pitch Circle Diameter [mm]: 380, 400, 420, 440, 460, 480, 500, 520, 540

H [m], η [%]

P [kW], Q [kg/s]

Analysis domain

Inlet
Casing
Nozzle (Angle: 18°)
Turbine
MODEL
MICRO TURGO HYDRO TURBINE (150KW)
Government project (2011, company + KMU)
TRANSIENT NUMERICAL ANALYSIS OF ROTOR-STATOR INTERACTION IN MICRO FRANCIS TURBINE (2010 – present)

Parameter | Value
--- | ---
Design Head | 18 [m]
Design Discharge | 0.5 [m^3/s]
Design Power | 70 [kW]
Runner | 13 vanes
Guide vanes (g.v.) | 16
Stay vanes (s.v.) | 8
Application | Micro Hydropower

Average torque distribution for 5 rotations
MICRO SAVONIUS HYDRO TURBINE FOR WAVE ENERGY

Industry project (2009, company + KMU)

PELAMIS (Attenuating, 1MW, UK)

WAVE DRAGON (Overtopping, NETHERLAND)

Jeju Island New Port Wave Breaker

Caisson & Savonius turbine
MICRO SAVONIUS HYDRO TURBINE FOR WAVE ENERGY
Industry project (2009, company + KMU)

CFD domain
Rotating Savonius turbine

Blade optimization
Savonius turbine in Caisson
MICRO CROSS-FLOW HYDRO WAVE TURBINE (FIXED)

Government project (2006~2007, company + KMU)

- Direct Drive Wave Turbine Principle (KMU)
- Periodic Bi-Directional Wave Flow
- Uni-directional Rotation for Generator
- Wells Turbine (symmetric aerofoil)
- Cross-flow turbine ONLY
MICRO CROSS-FLOW HYDRO WAVE TURBINE (FIXED)

Government project (2006~2007, company + KMU)

Experiment of model turbine in wave channel

(Turbine 1, $H_w=20\text{cm}$, $T_p=2.0\text{sec.}$, $h=70\text{cm}$)
MICRO CROSS-FLOW HYDRO WAVE TURBINE (FIXED)

Government project (2006~2007, company + KMU)

Reciprocal flows in turbine passage optimization

Free surface movement in CFD wave channel

Turbine with large wave numerical 3-D channel

Cross flow turbine 3-D rotation
MICRO CROSS-FLOW HYDRO WAVE TURBINE (FLOATING)

Government project (2011~2014, KMU)

Turbine rotation due to wave height head difference (low head hydro turbine, KMU originality)

KMU wave model site test area (in 2014)

Model test diagram (1kW), < 0.5m wave height
MICRO CROSS-FLOW HYDRO WAVE TURBINE (FLOATING)

Government project (2011~2014, KMU)

ADVANTAGES:
- Compact: water working fluid compared to traditional OWC air turbine (big density difference)
- Low acoustic noise due to low rpm, submersible <-> high-speed Well’s air turbine
- No bio-fouling and no salty corrosion in turbine (clean fresh water as working fluid)
- Dual hull structure: less collision leakage damage and better environmental protection

- Cross flow hydro turbine maybe the best choice but requires more systematic research in terms of off-shore floating device technology
MICRO CROSS-FLOW HYDRO WAVE TURBINE (FLOATING)

Government project (2011~2014, KMU)

- CFD
- Experiment

Water tank domain: sin wave motion

6-DOF motion platform test

Motion angle: 6°, Frequency: 0.33Hz

Fly-wheel effect test

Comparison of CFD and experimental
MICRO CROSS-FLOW HYDRO WAVE TURBINE (FLOATING)

Government project (2011~2014, KMU)

6-DOF motion platform test

CFD performance analysis

Dual hull floating body wave flow interaction

Dual hull effective mooring mechanism
- Test Standard: JSME, TSJ, ASME-HI
- Vortex Dynamics: turbulence, free-surface, cavitation
- Anti-Vortex Device (AVD) design for civil construction by model test (Froude number similarity, 1:10 scale ratio) -> international works
A HYBRID ENERGY STORAGE SYSTEM BY PUMP COMPRESSED AIR AND MICRO HYDRO TURBINE (2012 - )

- Energy storage system for irregular power from renewable energy such as wind, marine energy
- New hybrid system: compressed air by pumping, power production by hydro turbine
- Principle validation & design of compact closed tank for pumping air compression
- Application to less than 100kW system near shore (marine energy) or mountain river (hydro power)

KMU principle: 2nd Asian-Pacific Forum on Renewable Energy (AFORE2012), Nov. 27-29, 2012, Jeju
SUMMARIES

• ROUGHLY EVERY 10 YEARS DIVISIONS in 30 years after Ph.D.:
  - 1990-2000: academic & pre-industry researches, PIV & CFD
  - 2001-2012:
    1) Industry R&Ds: hydro power, wind & marine energy
    2) International R&Ds (Fiji-marine & wind, Nepal-hydro)
    3) Social activities (academic societies, national R&D roadmaps)

• What shall we consider for more originality-rich researches and industry-favored R&Ds?
  - Research Infrastructures: facility, manpower, budget
  - Research areas: efficiency in renewable energy, energy storages
  - Others: ?