Siphon turbine for ultra-low head (1.5 – 3.5 m) sites

Aline Choulot, Vincent Denis, Bruno Reul

MHyLab
info@mhylab.com
6, ch. Du Bois Jolens
1354 Montcherand
Switzerland
Tel. + 41 24 442 87 87
Fax + 41 24 441 36 54

Introduction

Ultra-low head sites represent the larger remaining European potential for small hydropower. Indeed, first, they comprise all the sites equipped with water wheels or Francis turbines, abandoned with the electrification development, and secondly, adapted, mature and affordable technologies have recently appeared on the market. Moreover, nowadays, rehabilitation of these sites is not only the opportunity to produce green electricity but also to maintain the heritage and install special fish migration device.

For outputs higher than 40 kW, MHyLab has developed the siphon turbine concept, especially adapted for ultra-low head sites (1.5 – 3.5 m). Based directly on the SEARCH LHT programme, devoted to low heads (3-30 meters), and already presented during previous Hydro conferences[1, 3], the concept allows the development of standardized machines so as to combine low investment and optimal use of the water resource.

Photo 1. Weir on the Orbe river with the intake on the left bank, at Vallorbe, Switzerland

Photo 2. The two Siphon turbines set at Vallorbe, designed with MHyLab's hydraulic profile (2.5 m^3/s per machine, 2.1 m head, total electrical output: 85 kW, external runner diameter: 1.25 m) (©MHyLab)

1. Ultra-low head site characteristics

Ultra-low head sites, characterized by a high discharge availability (so as to reach at least a 40 kW output), a significant head variation versus river discharge, and existing infrastructures, infer the following constraints on the turbo-group concept:

- Site optimisation with a high modularity of the electromechanical equipments so as to benefit from a standardisation effect, and to equip all similar sites,
- High reliability with an equipment specific to this head range, based on laboratory development,
- A limited investment thanks to an integration into the existing infrastructures and mass-produced and standardized equipment,

- Low operating costs with an important limitation of the infrastructure modification and a limited number of wearing parts and sophisticated components,
- High performance that does not suffer from the machine simplification and standardisation.

2. The siphon turbine concept

From these criteria, MHyLab has developed a turbine concept based on the siphon technique.

The turbine is set directly on a simple weir-wall. It is started up thanks to the vacuum pump and shut down thanks to the electro-valve situated at the highest point of the turbine inlet, which breaks down the vacuum. Thus, this process involves a simple and secure stop of the turbine in any cases, without any valves, which implies cost and space savings.

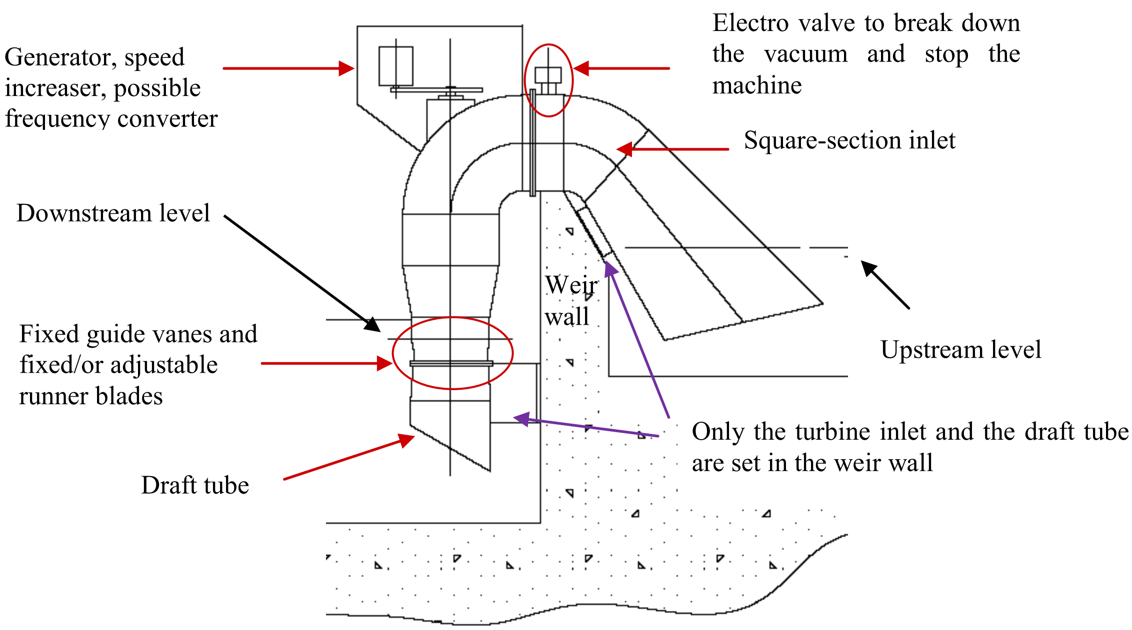

Figure 1. The main components of the siphon turbine (©MHyLab)

The generator, the speed increaser and the possible frequency converter are set in a watertight casing situated over the turbine, equipped with a sound insulation.

The electrical and regulation cabinets are settled in small premises on the water stream bank.

The hydraulic design of the siphon turbine, based on a more than 5-year laboratory development carried out in the framework of the SEARCH LHT programme[1,2,3,4], allows high performance and reliable hydro-dynamic operation. Its main particularities are the following:

- a square-section inlet equipped with three guide vanes, selected for its manufacturing and settling easiness, which permits an optimal distribution of the flow upstream from the runner, while allowing to take out the coupling shaft to the generator,
- a turbine axis that can be vertical or inclined,
- fixed guide vanes,
- 4 fixed or adjustable runner blades,
- semi-spherical or cylindrical discharge ring,
- a draft tube, designed to recover kinetic energy to a maximum while guaranteeing a homogeneous outlet flow.

For the fixed-blade configuration, a simplified runner profile has been developed with a cylindrical discharge ring and 4 blades that are also cylindrical at their external circumference, which results in:

- manufacturing simplifications,
- the possibility to mass produce the runner blades,
- an easiness of the axial positioning of the rotor,
- a fish-friendly turbine, as there is no gap between the blades and the discharge ring where the fish could get stuck,
- An important reduction of the risk to clog the runner: the plants are not caught anymore at the circumference in the space created between the spherical blade and the cylindrical part of the discharge ring above the runner axis.

Regarding ecology, the turbine bearing uses water instead of oil or grease, suppressing all the oil devices.

Then, a simple way to set and dismantle the machine, without drying the channels, has been adopted. It consists in:

- unbolting the turbine + generator group from the turbine inlet and the draft tube,
- lifting the group and driving it to the bank by a mobile crane from the bank, or even a mono-rail set in the weir dam.

Concerning maintenance, it is possible to intervene on one turbine at once, which limits the production losses. Moreover, man or hand holes can be integrated to the inlet pipe to permit a direct cleaning of the turbine without dismantling it.

Finally, what can be first pointed out is that the siphon turbine implies no technological risks. Indeed its simple hydraulic and mechanical design is based on a 5-year laboratory development and on a proven technology. This reliability of the machine is increased by the absence of standard shaft seals, inlet and security valves, and by a large possibility to use standard electrical equipments.

3. Standardisation possibilities

Hill charts achieved from our laboratory tests allow an optimal design regarding the available site discharges and heads, and infrastructure constraints. Moreover they are an essential tool to define standardised turbines.

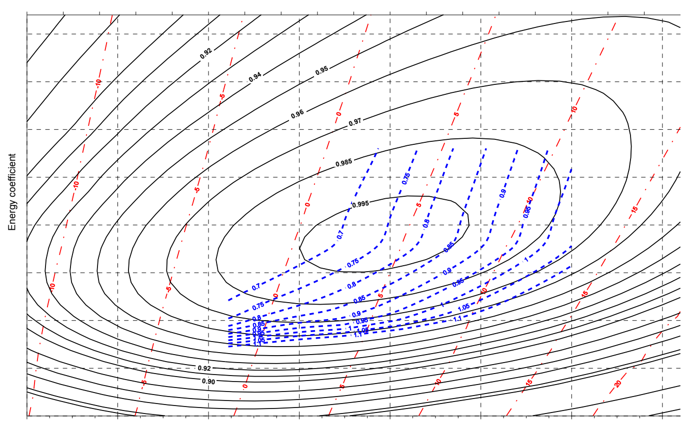

Figure 2. Hill chart example for a Siphon turbine with fixed guide vanes and 4 fixed blades (in black: efficiencies, in red: blade openings, in blue: cavitation) (©MHyLab)

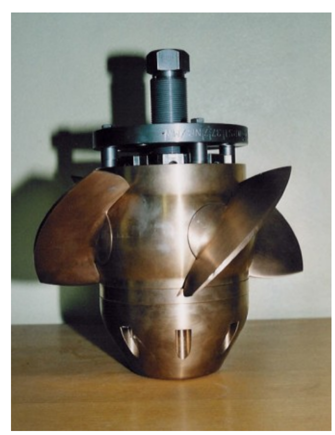

Photo 3. The four-adjustable blade runner tested on MHyLab's test bench (with a spherical external circumference) (©MHyLab)

From the area defined by ranges of discharges and heads, each manufacturer can choose the number of standardised turbines he wants to build so as to optimise his costs. Each type of turbine is then defined by its external runner diameter, whereas the rotation speed, the blade and guide vane openings and the turbine axis are adapted to the site to equip. Figure 3 shows an example of six turbines designed for an external runner diameter of 0.80, 1.00, 1.20, 1.40, 1.65 or 2.00 m that cover the whole head area between 1.5 and 3.5 m, for a nominal discharge between 1 and 14 m^3/s.

Therefore, depending on the site characteristics (discharge and head variations, infrastructure), the standardised siphon turbine will be adapted so as to maximise the electrical production, by defining:

- the angular position of the fixed runner blades,
- the rotation speed, by adapting the diameter of both pulleys to the generator rotation for example, which can also be variable for sites with significant head variations
- the number of identical machines set along the weir-wall increases, depending on the chosen nominal discharge, the expected modularity and the available space.

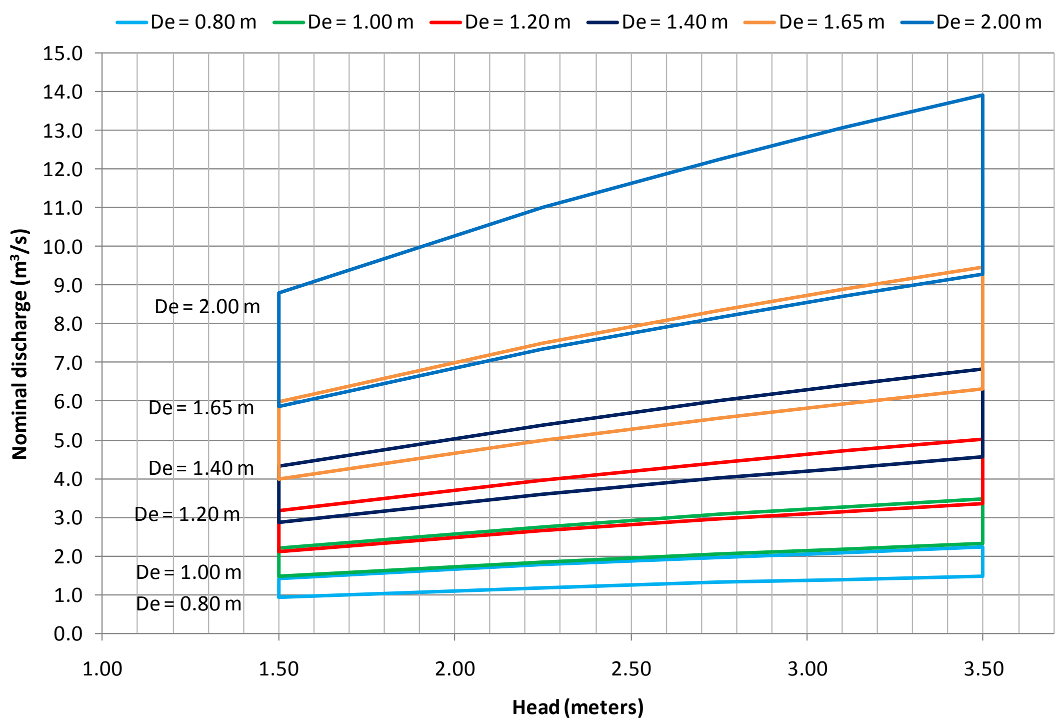

Figure 3. Siphon turbine with moveable blades: example of dimensioning areas, as a function of the head and the maximal discharge for the turbine, covered with 6 external runner diameters (De) turbines (from 0.80 m until 2.00 meters) (©MHyLab)

Furthermore, after several years of operation, if the characteristics of the site appear to be different from the initial ones used for the first design, such concept permits also:

- to add one or several machines,
- to adapt each turbine's discharge, by changing the angular position of the runner blade,
- to integrate a blade regulating device in the initial fixed blade runner.

4. First implementation of MHyLab designed Siphon turbines

Last year a site close to MHyLab was rehabilitated with two identical Siphon turbines (cf. Photo 1 and Photo 2). The maximal discharge amounts to 2.5 m^3/s per machine for a net head of 2.1 m, for a total electrical output of 85 kW. Among the standardized turbines chosen by the manufacturer, the one with an external runner diameter of 1.25 m was the most suitable to the site.

References

1. **Chenal R., Choulot A., Denis V.,** "Laboratory development and industrial application of small low-head hydro turbines, The SEARCH LHT project", conference proceedings, *Hydro 2004,* session 2.03, 2004
2. **Chenal R., Choulot A., Denis V., Tissot N., "**SEARCH LHT, Passing from laboratory to practice", *Hydroscoop* n°4, MHyLab's newsletter, July 2005.

3. **Chenal R., Choulot A., Denis V.,** "Laboratory development of small low-head axial turbines: a key for new and future-refurbished site in developed countries as well as in emerging ones", conference proceeding *, Hydro 2005*, session 14, November 2005.

4. **Chenal R., Choulot A., Denis V., Tissot N**., "CAD Tools To Systemize Small Low-Head Turbines: An Efficient Key For SHP Development", conference proceeding, *Hidroenergia 2006*, Crieff, June 2006.

5. **Chenal R., Choulot A., Denis V.,** "Hydro-electrical schemes for ultra-low heads", conference proceeding*, Hydro 2007*, November 2007.

The Authors

Aline Choulot graduated in energy and environment engineering from the French National Institute of Applied Sciences (INSA) and post graduated in energy systems from the Ecole Polytechnique Fédérale de Lausanne (Swiss Federal Institute of Technology), worked for one year in the Finnish Environment Institute, then for two years for an industrial company as an environment engineer, before joining MHyLab in 2004. She is currently in charge of model tests and turbine development.

Vincent Denis graduated in mechanical engineering and post graduated in energy systems from the Ecole Polytechnique Fédérale de Lausanne Swiss Federal Institute of Technology) in 1992, worked for four years in the hydroelectric department of an international consulting engineering company. He joined MHyLab in 1996, where he is currently the head of the laboratory, in charge of research and development projects for small turbines. Since 1997, he has been a member of MHyLab's board.

Bruno Reul: graduated in electromechanical engineering from the Faculty of Applied Sciences of "Université Catholique de Louvain", Belgium. He worked for 4 years as a project leader in an engineering company specialised in energy systems, before joining MHyLab in 2008. He is currently in charge of model tests and turbine development.