Numerical modeling of the Oryon Water Mill MSc project

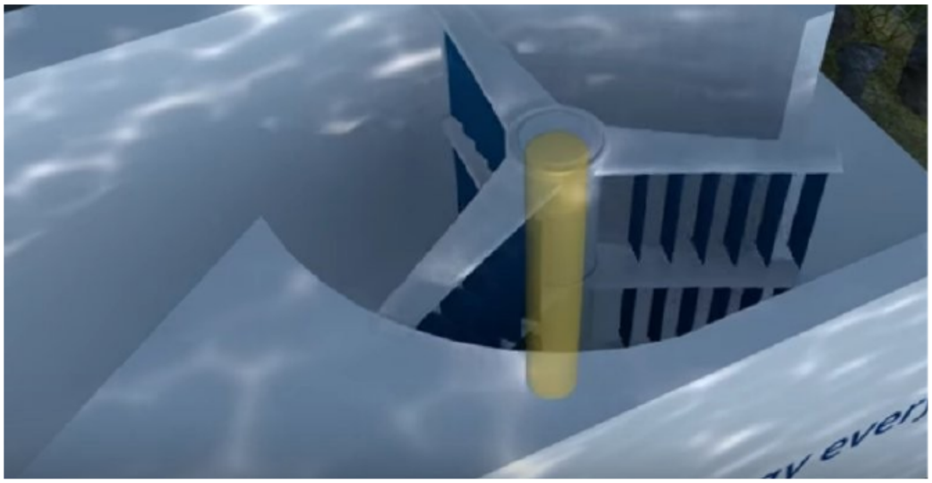

Illustration 1: Artist impression of the interior of the Oryon Water Mill.

The Oryon watermill

The Oryon[1] watermill (Illustration 1) is a low-head water turbine that can be used for power production in shallow rivers and canals at remote locations under continuous development by Deep Water Energy BV. The water turbine consists of a three-armed rotor that is vertically mounted in a fully submerged shrouding. One of the distinguishing features of the turbine is the fact that momentum is not transferred directly from the flow to the rotor but
through a set of hinged lamellas that open and close under the hydrodynamic load. This partially restricted movement of the lamellas reduces drag, i.e. undesired momentum transfer from the rotor to the flow, during the recovery phase of the rotor arms. Obviously, the geometry and configuration of the lamellas have a significant influence on the performance of the generator.
The design is completely modular, allowing for straightforward adaptation of the design to the flow characteristics of the water body, where the watermill will be installed.

Computational Fluid Dynamics model

To optimize the power generation of the turbine model test have been performed on a number of configurations. A computational model can provide data complementary to those obtained with the model tests to assist in further optimization of the design and can be utilized in determination of the optimum lamella configuration for a particular installation.
Because the flow influences the dynamics of the lamellas and the rotor, while these simultaneously influence the flow, a computational model involves so-called Fluid Structure Interaction. The dynamics of the flow are described by the Navier-Stokes equations, resulting in a stress distribution on the lamellas that in turn makes the lamellas move. The movements of the lamellas translate to transient boundary conditions for the equations of fluid dynamics.

Modeling the dynamics of the lamellas

The dynamics of a lamella follow directly from Newton's second law when the lamella is neither

1 http://www.oryonwatermill.com

fully opened or fully closed. Only in the fully opened or fully closed positions the support structure exerts an additional torque on the lamella to prevent it from moving any further. Although this is conceptually simple, it is not straightforwardly cast in a rigorous mathematical model and leads to a so-called complementarity problem. In engineering applications solving this complementarity problem is often avoided by ad-hoc modifications of the dynamical model, which can result in questionable accuracy of the simulated dynamics.

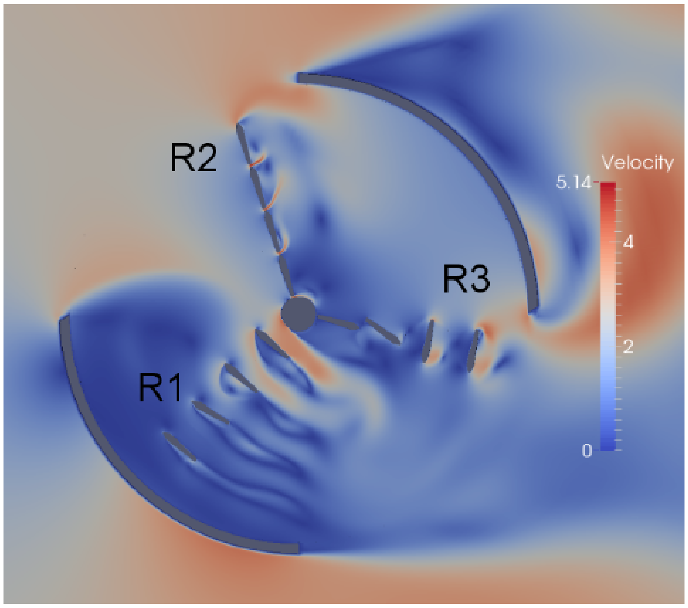

Illustration 2: Contour plot of the magnitude of the velocity in the two-dimensional model of the Oryon Water Mill.

Baseline model of a two-dimensional abstraction

Simulations have been performed on a two-dimensional abstraction of the turbine (Illustration 2). This earlier study was focused on the modeling of the nested motion of the lamellas, where the motion of the rotor was prescribed and the relative motion of the lamellas with respect to the rotor arms was resolved. A very basic model was applied for the nonsmooth dynamics during the opening and closing phase of their movement, assuming perfect *inelastic* impact.

Results obtained with this 2D baseline model indicate:

- Only a fully 3D model can accurately predict the power generated by the turbine.
- Using a rudimentary model for the nonsmooth dynamics in the opening and closing phase can lead to a nonphysical high rate of rotation of the lamellas, causing large pressure fluctuations and regions of high local velocity in the domain.
- When the internal flow is modeled as laminar, unphysically large regions of separation occur, indicating the need for (at least) turbulence modeling at the level of a low Reynolds number RANS model.
- The numerical solution has to be computed for at least 5-10 revolutions before the motion of the lamellas has become (nearly) periodic.

Project goal: realization of a 3D model of the Oryon Watermill

The proposed project will lead to a 3D model of the turbine that eliminates a number of shortcomings of the previous model. The new model will feature the following extensions and improvements:

- Simplification of the dynamics of the lamella motion by formulating the problem in a rotating frame of reference.
- Inclusion of a semi-elastic impact model for the lamella motion with damping of the rotational motion.
- Inclusion of k-omega SST turbulence modeling.
- Time-integration to force the solution to periodicity.

Formulating the model in a rotating frame of reference attached to the rotor simplifies the modeling of the motion of the lamellas considerably, because the rotor is stationary and the relative motion of the lamellas becomes absolute motion. The rotation of the reference system is accounted for by including centripetal and Coriolis forces as source terms in the equations.

Many models exist to properly describe the impact between solid bodies. An excellent starting point in the selection of the appropriate model is the book of Featherstone [1}. The movement of the lamellas can be compared to available observations from a series of model tests. The coupling of the model for the dynamics of the lamellas and the flow model should guarantee accurate mass conservation.

The computational cost of the model is linear in the number of revolutions that have to be simulated to reach convergence to a fully periodic solution for the movement of the lamellas and the torque induced on the turbine axis. Different strategies need to be analyzed to improve the convergence rate, e.g. distribution and underrelaxation of the lamella positions with respect to previous revolutions, etc.

Project outline

Project duration is nine months and iis broken down in Table 1.

Literature survey	1 month
Analysis of Nonsmooth dynamics model	1 month
Implementation of nonsmooth dynamics model	2 months
Definition of 3D model, setup and verification	2 month
Periodicity enhancement, analysis and implementation	1 month
Model validation	1 month
Thesis completion	1 month
Total	**9 months**

Table 1: Breakdown of the project.

References

[1] Featherstone, R., *Rigid Body Dynamics Algorithms*, Springer, 2008.

Project supervision

The project will be supervised by Duncan van der Heul (TUD-EEMCS, daily supervisor), Prof. Ruud Henkes (TUD-3ME, responsible professor) and Hermjan Barneveld (HKV[2], on behalf of Deep Water Energy)

2 http://www.hkv.nl