Using Polyurethane to Reduce the Production Cost of Hydrokinetic Turbine Foils

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ABSTRACT

Polyurethane made profiles can be used for hydrokinetic oscillating foil micro turbines to reduce their production cost. For this purpose, a NACA 0015 profile is designed with a computer aided design software and milled from aluminium. From this sample a negative mould of silicone is produced. This negative was used to produce finally polyurethane foils. Holes and grooves can be simply implemented in the negative by placing corresponding shapes made of metal within the silicone form. A massive reduction of the production cost of about 1600 Euro for a polyurethane (PUR) foil of 1000 mm length compared to an aluminium foil of the same shape is accomplished.

INTRODUCTION

Hydrokinetic turbines are currently living an increased worldwide interest. Their small size, their simple and fast installation, as well as their low impact on the nature are some advantages of the technology. In this publication hydrokinetic river turbines are considered, those turbines have normally a smaller size, harnessing the shallow rivers current, compared to the larger turbines installed close to the seashores. The rivers potential is largely unexplored, whereas coastal test turbines are already under operation [1,2]. Especially smaller rivers are often not explored, due to the small size and the varying flow conditions. Some attempts are made to develop small hydrokinetic turbines to use the untouched kinetic energy of the worldwide creeks. In this publication we want to consider a new type of vertically oscillating hydrofoil turbine, which is developed at the Université du Luxembourg in cooperation with the RWTH Aachen University, Germany [3,4]. In the prototype a NACA 00015 profile is moved by the force of the rivers current vertically, normal to the flow direction through the river. The foils position is controlled by two chains connected independently to two generators, which change the velocity of two rods, one connected moveable in one direction in a longitudal groove along the chord of the foil, the other in a hole in front of the groove both on top of the foil. Due to the small size of the foil of 1000mm x 240 mm x 36 mm (depth x length x width) and the flow velocities hardly reaching 2,5 m/s a polyurethane foil has the sufficient strength to withstand the hydromechanic forces. The rated power of the connected machines does not exceed 9kW and 265 Nm per machine.

Turbine Concept

The hydrokinetic turbine concept developed at the University of Luxembourg follows the principle oscillating hydrofoils. Motivated by the idea of a higher controllability of the foils motion, namely influencing the foils velocity and angle of attack at any position, the mentioned concept of two chain-controlled rods connected to the foil was chosen. To increase the systems endurance, a horizontal oscillation was chosen, to place all mechanical parts outside the water. To reduce the floating rafts motion two inversed moving foils, are connected to one turbine, see figure one.

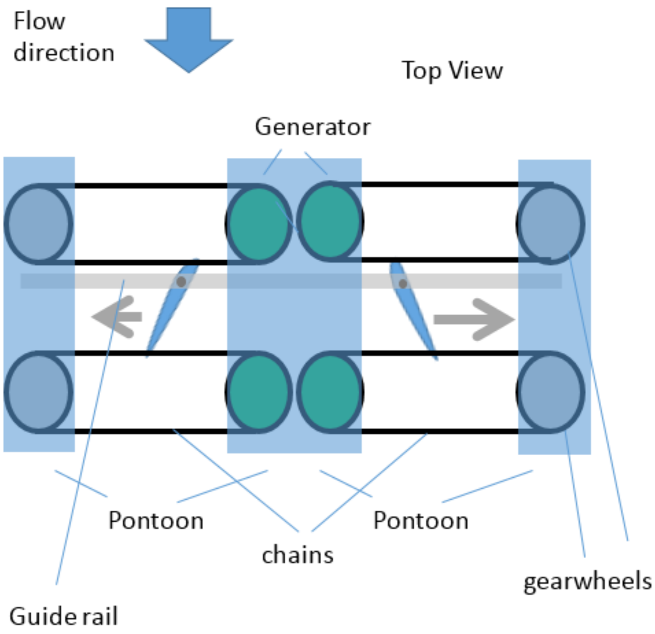

Figure 1. Schematic drawing from the top view of the horizontal oscillating hydrofoil turbine.

As seen in figure one, guide rails keep the foil on a normal trajectory relative to the floating fluid. Two chains control the foils angle relative to the flow direction. Two generators moving the chain wheels on the middle pontoon. One generator controls a pair of chains on its left and right side. The outer pontoons carry the corresponding chain wheels to the generator controlled ones. With this setup we ensure that the foils are moved in a controlled motion normal to the water flow.

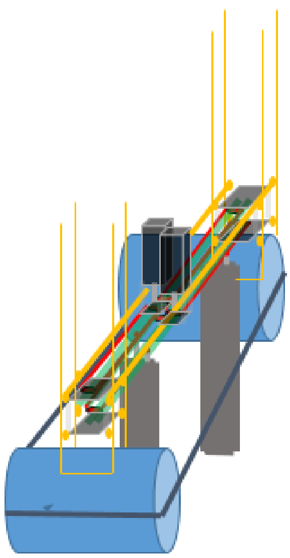

Figure 2. Schematic 3D drawing of the dual hydrofoil concept with two pontoons and the lifting and lowering mechanism in yellow.

Figure two shows the turbine concept in three dimensions, compared to figure one the middle pontoon is missing, the whole control mechanism is carried by a frame connected to a lifting mechanism connected to the outer pontoons. The blue line indicates the water level. In figure four the lab setup is shown. Compared to the two conceptual drawings seen before, just one foil is moved. On the left and right side of figure four the controlling generators are shown, indicated by the numbers one. Number two indicates the grid connecting cable. Number three shows the guide rails. Number four are the outer chain wheels, number 5 is the schematic drawing of the hydrofoil and number 6 and 7 are mentioned to represent the generators controlling inverters.

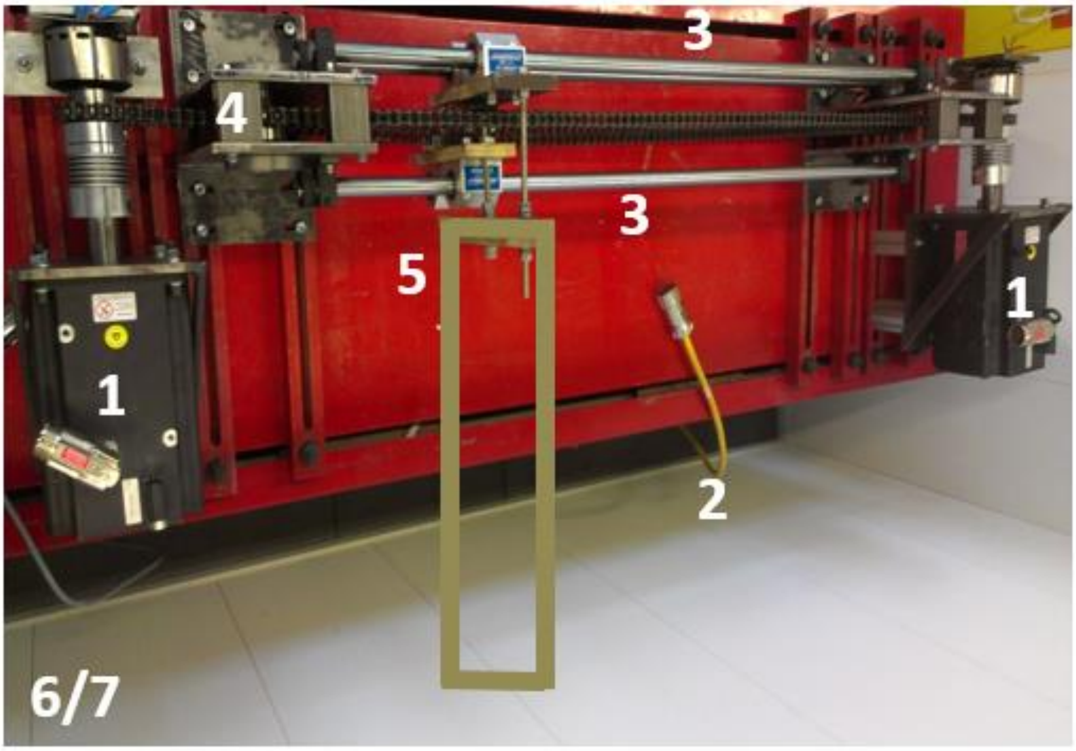

Figure 3. Laboratory test setup of a single foil, hydrokinetic turbine with 1-generators, 2-grid connection, 3-guide rails, 4-chain wheel bearings, 5-hydrofoil, 6/7-inverter and control not in the picture.

Understanding the principle of a horizontally oscillating hydrofoil turbine it can be easily seen that by lifting and lowering the whole turbine mechanism outside the water the systems immersion depths can be varied. Following the idea of variable immersion depths turbines, shallow rivers can become potential new hydropower sites.

MOTIVATION

A low cost per kWh generated by a new generation technology is crucial in order to become economically competitive. Due to the intended small system size of the novel hydrokinetic turbine, the main competitor are solar photovoltaic systems as well as small wind turbines in the range of 15-20 kW. For a the first prototype with two 1000 mm hydrofoils a price of 23300 Euro is estimated, where the two aluminium hydrofoils have a share of 18 percent. By changing the hydrofoils material and production process from milled aluminium to moulded PUR, their cost can be significantly reduced, while still meeting the stress requirements of the foils material.

PUR as a material for guide vanes in a small scale 205 kW Kaplan turbine hydropower plant was used at the first time in 2012 by Kössler and Voith in a pilot project [5]. Motivated by the good performance of the guide vanes and their operation for 7600 hours without any complication the same material was chosen for our prototype.

METHODOLOGY

In this paper the process of producing hydrofoils for an innovative micro hydrokinetic oscillating foil turbine is described. In the following each of the different steps needed on the way to produce a plastic hydrofoil are described. Based on the production of the aluminium sample form, a silicone form is casted. Afterwards, a first PUR test foil is produced in the silicone form. In a second step the silicone form is modified with inlays so that the PUR foil contains a hole for the guiding rod. In a later step also a part is included in the negative to directly keep the space for the groove in the PUR foil.

Having produced the plastic hydrofoil, its strength is calculated in a FEM simulation. Finally the price difference between hydrofoil and PUR foil is calculated. The paper finishes with an analysis of the recyclability of the proposed PUR foil.

RESULTS AND ANALSYSIS

Production of PUR foils

In a first step an aluminium NACA 0015 profile of the following dimensions was milled from an aluminium block 200 mm x 240 mm x 36 mm (height x chord length x width). This block is used to cast a negative form. It was also used to estimate the production cost of such a profile part.

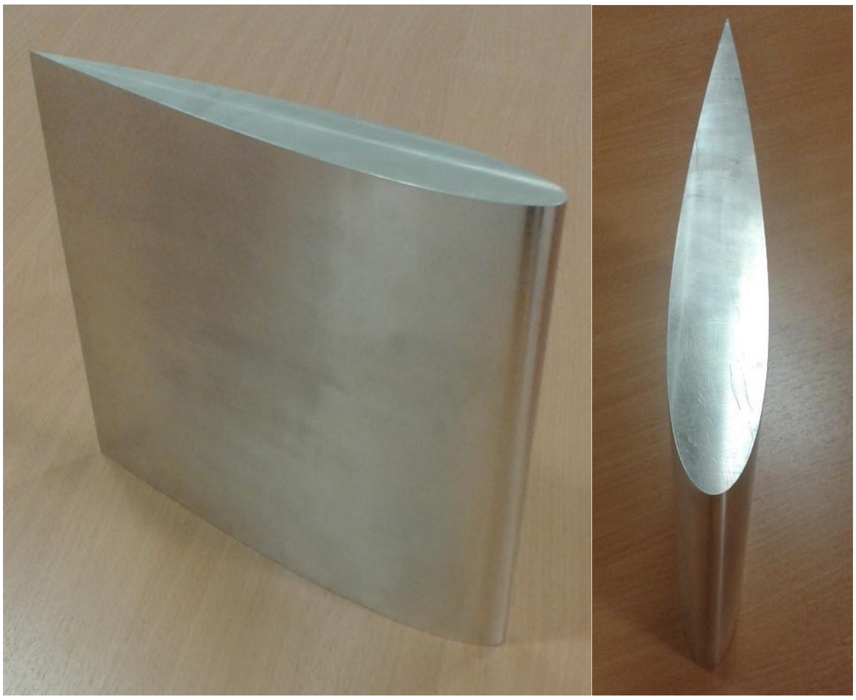

Figure 4. Aluminium hydrofoil 200mm x 240 mm (height x length).

In a second step a box of the following dimensions was built to produce the silicone form from the aluminium foil, see figure 5.

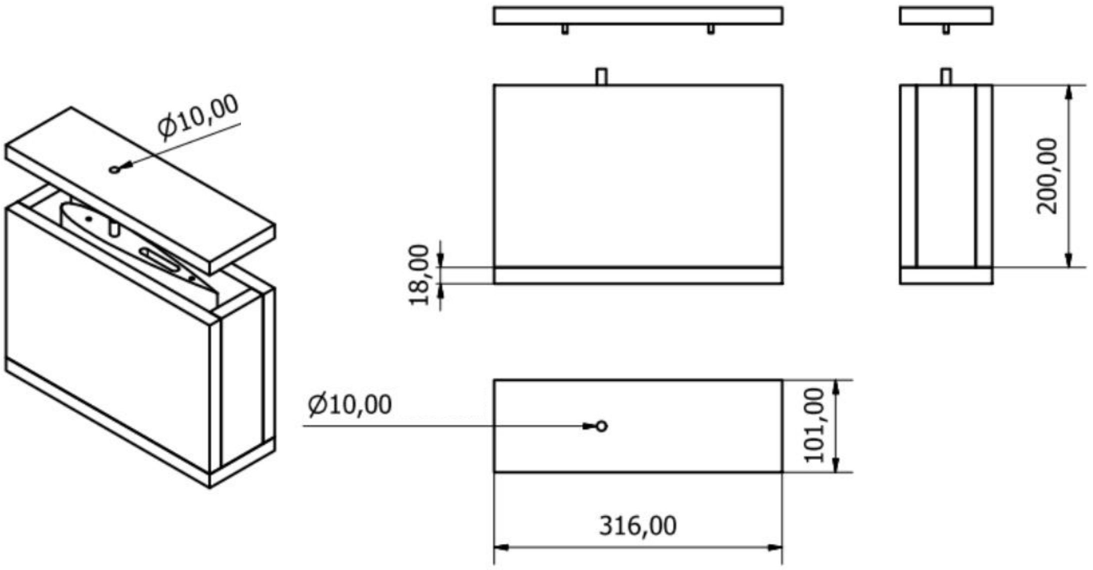

Figure 5.Plan of the box which contains the silicone form from the aluminium foil.

Figure 6. Box manufactured from wood with aluminium foil inside.

To produce the silicone form Protosil RTV240 was used. At room temperature the silicone, consisting of the component “A” a polymer and component “B” the crosslinking agent. Due to the high viscosity of component A of 110000 mPas a proper mixing of the two components added in the ration 10:1 (A:B) has to be ensured. Within maximum 80 minutes the material has to be mixed and processed due to the beginning crosslinking. After 12 hours the silicone negative form is hardened [6].

Figure 7. Box filled by silicone to produce the negative silicone form for moulding the PUR foils.

Once the silicone form is hardened it has a Shore hardness of A-42 and is transparent. The box is opened and due to the flexible material the aluminium foil is easily removed. Afterwards the two component polyurethane Biresin G26 is used to produce the positive. The two components resin, component "A" and curing agent, component "B" are mixed in the mass fractions 1:1 (A:B). It has to be ensured that the material is mixed within short time, since the crosslinking starts after 3 to 4 minutes. After 30 minutes the form is stable, the final hardness is reached after three days. Before filling the silicone form with the two components a release agent is distributed on it, for an easier removal of the hardened foil.

Figure 8. First PUR test foil.

After a first trial of producing simple profiles the negative form has been completed by adding a rod for the final connection of the turbine prototype and the foil. The included rod in the casting form avoids a later drilling of a hole, since the liquid PUR wraps the rod and a hole is in the foil once it is removed from the form. All additional inlays have to be covered as well entirely by the liquid release agent to simplify the removal of the casted foil from the silicone form and its inlays.

Forces and FEM Analysis

To ensure that the produced foil withstands the hydromechanic forces while operation of the prototype on the test site, a finite element method (FEM) simulation was used to calculate the forces within the material. We assumed a constant contact force over the length of the rods on the foil. The forces were estimated for the prototype for the maximum moments of the machine and the related chain forces on the rod within the foil. A maximum force of 15000 N for the 9 kW Baumüller DSD2-100BO64U-12-54 machine is possible. This would lead to an average water pressure of 0,061 MPA on the surface of the foil. 2D Computational Fluid Dynamics simulations estimated maximum normal force for a foil of one lower magnitude. The maximum values reached in the FEM simulation for the PUR are:

Table 1: Results of the FEM Analysis of PUR.

Parameter	**0,061 MPa**
1. Main tension [MPa] max.	12,425
1. Main tension [MPa] min.	-14,175
2. Main tension [MPa] max.	9,144
3. Main tension [MPa] min.	-16,237

The specifications of the PUR are the following

Table 1. Specification oft he used PUR.

Parameter	**PUR G26**
Density	1,075 g/cm³
Yield Strength	25 MPa
Tensile Strength	30 MPa
Modulus of Elasticity	1,25 GPa
PoissonNumber	0,48
Shear Modulus	0,422297 GPa

Comparing the two tables it can be seen that neither Yield Strength nor Tensile strength of the material are reached. The maximum stress is given for the third main tension with -16,237 mPa which is about 64% of the materials yield strength.

Economic Analysis

The financial analysis shows that the application of PUR foils has several financial advantages compared to the usage of aluminium. Generally, the cost for the production of an aluminium foil can be split in the following parts. The material and the milling of the foils. The cost of the used machines to drill the hole and to mill the groove. The staff costs for the production of hole and groove. Due to the limited length of the milling heads a 1000 mm foil consists of five 200 mm part-foils.

Table 2. Production Cost in Euro, including the different manufacturing steps for five 200 mm aluminium foils.

Material and milling of 5 foils	1254
Machine cost for hole and groove	20
Staff cost for hole and groove (first foil)	191,25
Staff cost for hole and groove (after first foil)	170
Entire Cost	2145,25

Producing a moulding form from silicone and afterwards the PUR foils from it, including the hole and the groove we come to the following cost distribution and a simpler manufacturing process.

Table 3. Production Cost in Euro including the different manufacturing steps for five 200mm PUR foils.

Material cost silicone	244,9
Material cost PUR	89,6
Material cost Casting frame	50
Material cost separating wax	13,9
Material cost Silicone spray	6,45
Material cost rod and groove-part	20
Staff cost rod and groove-part	42,5
Entire Cost	467,35

Comparing the two foils a cost reduction of 78% is reached. Assuming two foils per turbine the entire cost of the turbine can be reduced by 14% down to about 20000 Euro from former 23300 Euro. Since the modular setup of the turbine allows the usage of several hydrofoils the significant cost reduction of the foils contributes in a mayor way to the cost efficiency of the novel turbine.

Additionally the weight of a full foil is reduced form a nearly 16 kg aluminium foil to an about 6 kg PUR foil.

Recycling

The used G26 quick cast resin doesn't have any impact on the environment once it's hardened properly. Under normal conditions (in water, at the open air, in sunlight etc.) it doesn't release any side products. Yet, burning and smouldering of organic carbon compounds creates in addition to CO_2 and H_2O, depending on the fires temperature and availability of oxygen, changing amounts of CO, hydrocarbons, lower and higher aldehydes and ketones, and soot-like cleavage products. Moreover based on nitrogencontaining products, such as polyurethanes, but also other materials of natural and synthetic origin, volatile nitrogen compounds such as ammonia, nitrogen oxides, nitriles and, at temperatures of 800 - 1000 °C, hydrogen cyanide are also formed. As the predominant risk factor in the fumes of all organic materials CO must be considered. With the used polyurethane material no negative effects can be expected and the used amount for the water turbines entire foil mass is with a mass of 6 kg way less to have any negative consequences by releasing CO.

Besides the low risk of environmental pollution, PUR also has the advantage of easy recycling. This can be separated into the following categories, each of them offering different kinds of methods to handle the PUR:

Mechanical recycling

- Adhesive pressing
- Particle bonding
- Regrind
- Injection moulding
- Compression moulding

Feedstock recycling

- Glycolysis
- Hydrolysis
- Pyrolysis
- Hydrogenation
- Gas production

The most common mechanical recycling method is called “regrinding”. Here the PUR is first granulated and then grinded in various ways to a fine powder. This is added afterwards to the production of other PUR products, mostly to the liquid reactant or also used in reaction injection moulding (RIM), see figure 9. Moreover the granulated particles can be used together with other recycled polyurethanes for particle bonding. The granulated PUR gets blended with a binder and then shaped into boards, car bumpers, benches, refrigerator parts and other moulding with high recycled content under high pressure.

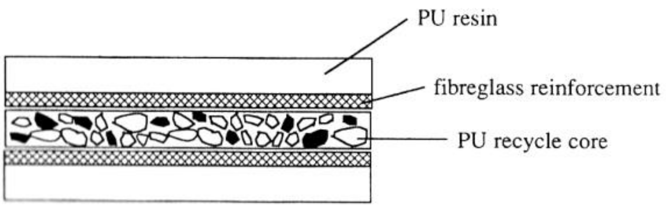

Figure 9. RIM recycling of PUR granulate [7].

Overall the most widely used chemical recycling method for PUR is Glycolysis to recover the polyols for production of new PUR materials. Used PUR from industrial and private used gets mixed with diol under high heat, which is causing a reaction creating new polyols. This can later be used to produce new polyurethanes for all kind of applications.

During the hydrolysis the reaction between water and PUR is creating polyols, which can be used as fuel. Moreover intermediate chemicals are a by-product of the reaction and are used as raw materials for PUR.

With help of the Pyrolysis the PUR breaks down and results in oils and gas. By use of hydrogenation, hydrogen, heat and pressure lead to the creation of the same products.

CONCLUSION

In this publication a production process was proposed to produce a PUR foil for a novel oscillating foil hydrokinetic turbine to replace an ordinary aluminium foil. It was shown by a FEM analysis of the proposed design that the PUR withstands theoretically the forces of the proposed 18 kW turbine-prototype. The maximum forces of the 18 kW machines on the foil are higher than the balancing hydromechanics forces so that we can assume that in operation the stress of the PUR foils will be lower. A cost and weight reduction of a two foil turbine is accomplished by replacing aluminium by PUR, by 14% on about 20000€ of the entire cost and 62% of the weight.

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David Norta obtained his Mechanical Engineering diploma in the field of turbulent flows analysis from the Technical University of Aachen in November 2012. He already worked in several international energy projects in India and Fiji in the frame of Engineers Without Borders Germany and started Engineers Without Borders Luxembourg. His PhD thesis title is, "Integration of distributed controllable renewable generators in the Luxembourgish electricity system including innovative micro-hydrokinetic turbines". David's interests of research area are renewable energies, micro-hydrokinetic turbines and smart grids.

Christoph Lanser was born in Aachen, Germany, in 1987 and started studying mechanical engineering at the RWTH Aachen after completing his high school diploma. His studies are specialized in plastic engineering and he has been working as an assistant scientist at the Institute for Combustion Technology since 2011. There he has been running experiments in the field of biofuels for the last two years. Christoph Lanser's interests include traveling around in the world, learning about diverse cultures and sharing innovative ideas with others interested in developing ways for improving society as a whole.

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CERTIFICATE

The author(s) certify that the p aper titled "Using Polyurethane to Reduce the Production Cost of Hydrokinetic Turbine Foils" and submitted for consideration for International Conference On Hydropower For Sustainable Development During Feb 05 – 07, 2015 at Dehradun India, is in original and has not been published or presented at any other forum.

Signature of Author(s) David Narta

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