



## Preliminary study on the uptake of functionalisation technology

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## EXECUTIVE SUMMARY

This document is the third output for Work Package 1 “Analysis of functionalities targeted for each application and manufacturing and industrial constraints” titled “Benchmarking analysis for current fluid turbines and screening of standards”.

The information is based on the deliverable 1.2.

This report is separated in two distinct parts.

In the case of fans (ZABEGG), mass production is used to produce series from a unique negative mould.

In the case of hydro-turbines (GHYDRO), prototyping is considered because each industrial turbine is unique.

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## TABLE OF CONTENTS

<b>EXECUTIVE SUMMARY .....</b>	<b>3</b>
<b>1 RIBLETS FOR NEGATIVE MOULD FOR AXIAL PROPELLERS/ FANS .....</b>	<b>7</b>
<b>1.1 RIBLET DEFINITION .....</b>	<b>7</b>
1.1.1 ROUGHNESS .....	7
1.1.2 ORIENTATION .....	7
<b>1.2 MOULD LIFETIME .....</b>	<b>8</b>
<b>1.3 NOISE GENERATION .....</b>	<b>8</b>
<b>2 RIBLETS FOR HYDRO-TURBINES .....</b>	<b>9</b>
<b>2.1 ROUGHNESS RIBLET COMPARISON WITH IEC CODE.....</b>	<b>9</b>
2.1.1 IEC CODE RECOMMENDATIONS.....	9
2.1.2 VALUES FOR USUAL MANUFACTURING PROCESS .....	9
2.1.3 BENCHMARKING .....	10
<b>2.2 ORIENTATION.....</b>	<b>10</b>
<b>2.3 MACROSCOPIC METRICS.....</b>	<b>11</b>
2.3.1 EFFICIENCY.....	11
2.3.2 CAVITATION .....	11
2.3.3 POTENTIAL FATIGUE .....	12
2.3.4 PROCESSING TIME .....	12

## LIST OF FIGURES

FIGURE 1 SKETCH OF THE MOULD ENGRAVED BY LASER AND THE ACTIVE FUNCTIONAL SURFACE .....	7
FIGURE 2 LEADING EDGE OF A FAN .....	7
FIGURE 3 BIO INSPIRED TRAILING EDGE OF FAN .....	8
FIGURE 4 SKETCH OF A HYDRAULIC SURFACE AFTER PROCESSING .....	9
FIGURE 5. THE THREE PARTS IN WHICH THE HYDRO-TURBINE WILL BE DIVIDED: BLADES (LEFT), HUB (CENTER) AND SHROUD (RIGHT). .....	10
FIGURE 6 CRATER GENERATED BY IMPLOSION OF A CAVITATION VORTEX (DIAMETER ~50 μM). PHOTO: EPFL, LAUSANNE .....	12

## LIST OF TABLES

TABLE 1 COMPARISON FOR ROUGHNESS CHARACTERIZATION .....	7
TABLE 2 RECOMMENDED ROUGHNESS FOR REDUCED SCALE MODEL AND PROTOTYPE .....	9
TABLE 3 ROUGHNESS CONSIDERED IN GHYDRO PROCESS .....	9
TABLE 4 COMPARISON BETWEEN DIFFERENT PROCESSES FOR ROUGHNESS .....	10
TABLE 5 COMPARISON FOR ORIENTATION .....	11
TABLE 6 REFERENCE VALUE FOR MODEL SCALE TURBINE .....	12
TABLE 7 COMPARISON ON PROCESS SPEED .....	13

## ABBREVIATIONS AND ACRONYMS

Abbreviations / Acronyms	Description
<b>DLW</b>	Direct Laser Writing
<b>DLIP</b>	Direct Laser Interference Patterning
<b>μCLAD</b>	Micro cladding
<b>Ra</b>	Roughness estimation in μm
<b>IEC 60193</b>	IEC code for "Hydraulic turbines, storage pumps and pump-turbines- Model acceptance tests"

## 1 Riblets for negative mould for Axial Propellers/ Fans

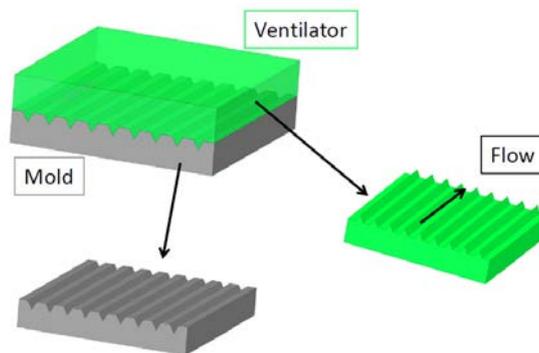


FIGURE 1 SKETCH OF THE MOULD ENGRAVED BY LASER AND THE ACTIVE FUNCTIONAL SURFACE

### 1.1 Riblet definition

In the case of fans, the roughness after the laser processing should meet the usual requirements, that is a polished surface. As the riblets will be engraved on the mould as a negative pattern, the accuracy of angle in the “trenches” is important. If a post-processing is needed to meet the final roughness requirements, laser polishing could be an option.

#### 1.1.1 Roughness

Without any special assumption, for all processes the required usual Ra will be achieved with laser methods.

TABLE 1 COMPARISON FOR ROUGHNESS CHARACTERIZATION

		Process characterization: Roughness		
		DLW	DLIP	μCLAD
Turbine Size	Ra (μm)	Depends on initial roughness, If $Ra_{initial} \sim 0.17$ to $0.2 \mu\text{m}$ , $Ra_{final} \sim 0.22 \mu\text{m}$	Ra: < 10 μm	To be determined
Mold	Ra (μm)	OK	Ra: < 10 μm	TBD

#### 1.1.2 Orientation

Due to the special profiles on leading and trailing edges, question could be raised on the limits of riblet along the streamlines. It is mandatory to maintain these peculiar profiles as they help reducing noise and enhancing global efficiency.



FIGURE 2 LEADING EDGE OF A FAN

## 1.2 Mould lifetime

Fans are produced in mass and the mould must last a maximum time or number of cycles, being 250.000 the ultimate target. The benefit of the laser engravement will be estimated when balancing the cost versus the gain in efficiency.

The range of riblet from 150  $\mu\text{m}$  to 350  $\mu\text{m}$  could be small enough to increase the contamination. Only real size test could confirm if efficiency still stable in time or if it decreases due to dirtying. This range has been suggested during preliminary studies on riblet design, but a study on the nominal operating point and off design points will be performed to determine the correct size range.

## 1.3 Noise generation

ZABEGG have developed very specific and accurate profiles to reduce noise and meet numerous certification requirements.

Added riblet should not increase the global Sound pressure level or add higher harmonics



FIGURE 3 BIO INSPIRED TRAILING EDGE OF FAN

## 2 Riblets for Hydro-turbines

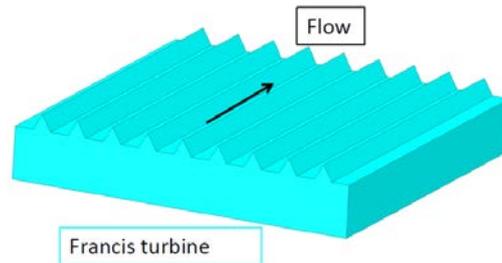


FIGURE 4 SKETCH OF A HYDRAULIC SURFACE AFTER PROCESSING

In the case of hydro-turbine, material is removed and the riblets will be oriented along streamline of the flow.

### 2.1 Roughness riblet comparison with IEC code

#### 2.1.1 IEC code recommendations

The final surface either on the reduced model scale turbine or on the industrial machine must respect recommendation of § 5.2.11.3 of IEC 60193 shown on Table 1.

TABLE 2 RECOMMENDED ROUGHNESS FOR REDUCED SCALE MODEL AND PROTOTYPE

Type of machine		Component	Ra μm	
			E < 300 J·kg <sup>-1</sup>	E > 300 J·kg <sup>-1</sup>
Reaction machine	Axial	Runner/impeller blades:	≤ 6,3	≤ 3,2
		Guide and diffuser vanes:	≤ 12,5	≤ 6,3
	Spiral case, stay ring, discharge ring, draft tube cone and tubular machine intake (see Figure 21):		≤ 25,0	≤ 12,5
	Radial or diagonal	Runner/impeller blades:	E < 2 000 J·kg <sup>-1</sup>	E > 2 000 J·kg <sup>-1</sup>
Guide and diffuser vanes:		≤ 6,3	≤ 3,2	
		Spiral case, stay ring (including return vanes for multi-stage machines), facing plates and draft tube cone:	≤ 12,5	≤ 6,3
			≤ 25,0	≤ 12,5

#### 2.1.2 Values for usual manufacturing process

As shown in Table 2, GHYDRO use smaller values to respect the IEC code. Hereafter we will consider these values as reference values.

TABLE 3 ROUGHNESS CONSIDERED IN GHYDRO PROCESS

Global Hydro	Model	Low Head Francis
	Ra (μm)	Ra (μm)
Runner	0.8	3.2
Spiral case	1.6	6.3
Stay vanes	1.6	6.3
Guide vanes	1.6	6.3
Draft tube Elbow	3.2	6.3
Draft tube diffusor	6.2	6.3

### 2.1.3 Benchmarking

As seen in Table 3 some data are missing to define the final roughness for  $\mu$ CLAD. For DLIP more accurate values should be added to check the feasibility on sensible parts as the runner, the vanes and the spiral case.

Nevertheless, only the runner of the reduced model scale could be an issue as the Ra value needs to be very low. At the moment, in order to reach low Ra as indicated by the IEC/industry standards, there is a process of grinding and polishing after the milling process. If the laser process generates a relatively high Ra, this could be acceptable only if afterwards it is lowered again with a further grinding or laser polishing process.

There are no difficulties for the industrial machine.

TABLE 4 COMPARISON BETWEEN DIFFERENT PROCESSES FOR ROUGHNESS

			Process characterization: Roughness		
			DLW	DLIP	$\mu$ CLAD
Turbine Size	Turbine Part	Ra ( $\mu$ m)	Depends on initial roughness, If $Ra_{initial} \sim 0.17$ to $0.2 \mu$ m, $Ra_{final} \sim 0.22 \mu$ m	Ra: < 10 $\mu$ m	To be determined
Model	Runner	0.8	OK	NOK	TBD
	Spiral case	1.6	OK	NOK	TBD
	Stay vanes/Guide vanes	1.6	OK	NOK	TBD
	Draft tube Elbow	3.2	OK	OK	TBD
	Draft tube diffusor	6.2	OK	OK	TBD
Low Head Francis	Runner	3.2	OK	OK	Should be OK
	Spiral case	6.3	OK	OK	Should be OK
	Stay vanes/Guide vanes	6.3	OK	OK	Should be OK
	Draft tube Elbow	6.3	OK	OK	Should be OK
	Draft tube diffusor	6.3	OK	OK	Should be OK

## 2.2 Orientation

In the normal process the runner is considered as a single compact part. Due to the curvature on some part of the runner, it will be necessary to split the runner into 3 parts:



FIGURE 5. THE THREE PARTS IN WHICH THE HYDRO-TURBINE WILL BE DIVIDED: BLADES (LEFT), HUB (CENTER) AND SHROUD (RIGHT).

This operation is expensive and is not included in the usual manufacturing process. Questions will be raised to compare the benefit of hydraulic efficiency gain versus the extra cost to separate and reassemble the complete runner.

As the blade are warped surface, such places as Leading or trailing edges will not be processed. The exact maximum angle should be confirmed later.

TABLE 5 COMPARISON FOR ORIENTATION

		Process characterization: Orientation		
		DLW	DLIP	μCLAD
		Can generate complex trajectories	Parallel lines	Can generate complex trajectories, Orientation perpendicular to the surface
Runner	Hydraulic part			
	Hub	OK	OK	OK
	Shroud	OK	OK	OK
	Blade	Ok	Ok	Ok
	Leading Edge			
	Ra (μm)	Strong curvature radius		
Stay vanes/Guide vanes	2D profile	OK	OK	OK
	Leading Edge			
	Trailing Edge			
		Strong curvature radius		

For other hydraulic parts as guide vanes or stay vanes, it is easier, and the only limitation will be the strong curvature radius on the Leading and Trailing edge of the vanes.

## 2.3 Macroscopic Metrics

### 2.3.1 Efficiency

The efficiency of the process on the hydro-turbine will be estimated by comparing the global efficiency of the reduced scale model in the very same conditions.

To get more accurate results, it could be necessary to measure separation losses:

- Losses of the runner with differential pressure sensors (inlet/outlet of the runner)
- Velocity profile under the runner to show the velocity field entering the draft tube.

### 2.3.2 Cavitation

Cavitation is the phenomenon in which the static pressure of a liquid is lower than the liquid's vapour pressure. As a result, vapour filled bubbles occur. These bubbles implode due to the higher surrounding pressure. These implosions create shock waves which may damage machinery. Cavitation must be considered in the hydraulic development of a water turbine since the design has to be adapted to the operation range in which the final prototype will be operated. Cavitation mainly occurs if the hydro turbine is operated at a different flow rate. As the wavelength of the riblet will

be between 40  $\mu\text{m}$  and 140  $\mu\text{m}$ , impact of cavitation could be increased or softened. Figure 2 shows typical impact of cavitation on a blade. Order of magnitude of crater is close to riblet sizes.

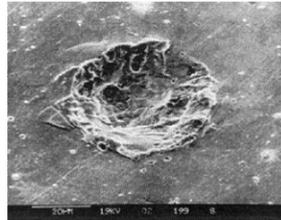


FIGURE 6 CRATER GENERATED BY IMPLOSION OF A CAVITATION VORTEX (DIAMETER  $\sim 50 \mu\text{m}$ ).  
PHOTO: EPFL, LAUSANNE

This point can't be checked on the model test because of absence of active wear at that very small scale during a short test.

Observations will be done, in a comparative way, to evaluate the Thoma number  $\sigma$  incipient when first bubbles appear on blades.

This will give a basis to estimate future wear on the industrial machine but only the real measurements on site will validate the process.

### 2.3.3 Potential fatigue

Due to the very local heating with laser processes, it can be noticed that some residual strain could be added on junction between blades and Hub or Shroud. These local points could lead to additional fatigue.

### 2.3.4 Processing time

At the moment, the final step to obtain the desired Ra is manual. Depending on the chosen process roughness level could be achieved during riblet manufacturing leading to a drastic cost reduction due to automatize process.

Based on data from the deliverable 1.2 a time simulation is presented on a typical scale model runner (Table 5)

TABLE 6 REFERENCE VALUE FOR MODEL SCALE TURBINE

Part	Dimension
Runner diameter (m)	0.35
Runner band height (m)	0.05
Runner band perimeter (m)	1.100
Runner band surface ( $\text{m}^2$ )	0.055

Table 6 shows comparison between 3 processes. To get an idea, simulation is done a very simple part, the runner band, which is a cylindrical surface.

From the DL1.2 a thickness has been estimated to get a raw number of layers to be done on the runner band.

It is possible to compare DLW and  $\mu$ CLAD as the speed is given with same unit. The DLW is more efficient in terms of the time needed to generate riblets per surface unit.

The DLIP method, based on surface speed and not on linear speed, seems to be very efficient but questions can be raised about the capacity of the speed on a curved surface and not on a flat surface.

TABLE 7 COMPARISON ON PROCESS SPEED

		Process characterization: Processing speed		
		DLW	DLIP	$\mu$ CLAD
		Speed		
		Speed ~ 1400 mm/s	Speed < 0.1 m <sup>2</sup> /min	Speed ~ 100s mm/s
		Thickness layer ( $\mu$ m)		
		30	100	100
Model	Duration for Band perimeter (sec)	0.79	?	11.00
	Number of layers on the Band Height	1667	500	500
	Duration for Band surface (sec)	1309	32.99	5498
	Total time (min)	21.8	0.5	91.6

## CONCLUSIONS

In both cases, fans or hydro-turbines, a deeper investigation with tests is necessary to determine the most relevant range of size for the riblets.

As that time, there is no major issues concerning the integration of the riblets on functional surfaces as far as the roughness is respected. Even if the roughness is a little bit above common limits, the net gain on global efficiency will advantageously compensate.

## REFERENCES

IEC 60193, Hydraulic turbines, storage pumps and pump-turbines –  
Model acceptance tests, Edition 3.0, 2019-04, ICS 27.140 ISBN 978-2-8322-6659-5

