Experimental Investigation on the Performance of a Vortex Pump using Winglets

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Abstract

This paper covers the experimental examinations of the influence of attaching winglets to the blade tips of vortex pump impellers. The head, efficiency and power consumption as well as cavitation behavior are analyzed. At first, a series of tests compared an impeller with winglets with a semi-open impeller without winglets and to an impeller with a front shroud. The results suggest that an impeller with winglets leads to the highest head and the greatest efficiency. The impeller with front shroud generates higher head and efficiency than the semi-open impeller, which is frequently used for vortex pumps. A second test series investigates the cavitation performance when blade depth and diameter of impeller are varied compared to the first test series. It could be demonstrated that an impeller with winglets has a similar NPSH characteristic as an impeller without winglets. Thus winglets clearly improve the performance of vortex pumps.

Keywords

Vortex Pump — Winglets — Recessed impeller — Experiment — Centrifugal Pump

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INTRODUCTION

Vortex pumps can impel fluids that contain solid and fibrous materials at a minimized risk of clogging. Figure 1 shows an example of a vortex pump. A recessed impeller and a large volute width at its front chamber characterize vortex pumps, whose operating principle is assumedly a vortex that is formed in the front chamber. Compared with conventional centrifugal pumps, the efficiency of vortex pumps is overall low. Not surprisingly, many attempts have been made to improve the efficiency of vortex pumps by varying the "classical" parameters, such as the impeller diameter, the blade depth and the number of blades (e.g. *Ohba et al.* [1 and 2]; *Lubieniecki* [3]).

Figure 1. Schematic view of a vortex pump with recessed impeller and enlarged front chamber

Another attempt is to add winglets to the blade tip. This addition separates a large part of the impeller channel from the front chamber of the pump. The resulting design resembles a front shroud (cf. Figure 2).

The publicly available literature on how winglets affect performance is, however, contradictory. On the one hand, *Cervinka* [4] investigated the operation of winglets using a numerical model that compared an impeller with winglets with a geometrically similar impeller without winglets. He concluded that an impeller with winglets deteriorates the pump characteristic and efficiency. On the other hand, *Dalian et al.* [5] and *Rongsheng et al.* [6] presented numerical studies on how winglets influence the pump characteristic. The authors compared one impeller without winglets with two other geometrically similar impellers with different winglet depths. In both cases increasing the winglet depths led to greater pump heads and improved efficiency. Their results are further bolstered by commercially available vortex pumps whose added winglets supposedly prevent back flows on the blade top and thereby improve the pump characteristic [7].

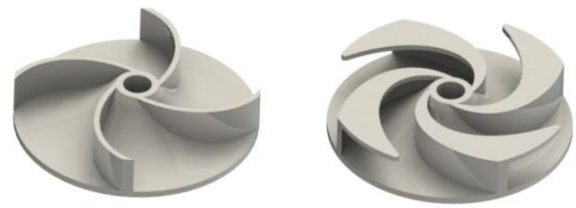

Figure 2. Schematic view of the impellers of a vortex pump without winglets (left) and with winglets (right)

Zheng et al. [8] compared vortex pumps with a semi-open impeller with an impeller with front shroud and otherwise similar designs. The impeller provided with the front shroud improved the head and efficiency.

The above points show that there are inconsistencies in relation to the use of winglets at vortex pumps especially due to the absence of experimental data. It leaves open whether winglets improve or deteriorate the pump performance. A systematic investigation on how winglets affect pump performance as well as the cavitation behaviour is missing. Therefore, this paper covers the experimental examination of the influence of winglets on the pump characteristics of vortex pumps including all above-mentioned characteristics.

1. METHODS

1.1 Study 1

Three different impellers were investigated on a closed test rig design (according to ISO 9906): A semi-open impeller; an impeller with winglets; and an impeller with a front shroud (Figure 3). The latter allowed examining whether there was an upper limit to the depth of the winglets and how the winglets influence the potential vortex in the front chamber. All other geometric parameters of the impeller and the casing remained constant for all measurements. The semi-open impeller served as the main body onto which the winglets respectively the support disk were attached.

The semi-open impeller itself was cast and had four curved blades. Winglets and front shroud were of similar thickness and made of PVC. For simplification of manufacturing, the front shrouds as well as the winglets were straight.

The ratio of the suction mouth of the impeller with the front disc to the suction pipe diameter was 1:1.25. For the smaller suction mouth diameter, a blockage at the impeller inlet was assumed. The casings corresponded to the industrial standard and had a ball passage of 80 mm. The surface was untreated and had a rough cast.

Measures included temperature, volume flow, electric power consumption, suction pressure and the pressure difference between the suction and the pressure side of the pump. We reported the performance curves, aggregated efficiencies and power consumption.

The presentation of head and flow rate is done by means of the pressure coefficient and the flow coefficient. These are dimensionless values of the head and the flow rate. The pressure coefficient ψ is defined by:

$$\psi = \frac{2 \cdot g \cdot H}{\pi^2 \cdot n^2 \cdot D^2} \quad (1)$$

where g the gravitational acceleration in m/s², H the head in m, n the rotational speed in 1/s and D the impeller diameter in m.

The flow coefficient φ is described by:

$$\varphi = \frac{4 \cdot Q}{\pi^2 \cdot n \cdot D^3} \quad (2)$$

where Q the flow rate in m³/s, n the rotational speed in 1/s and D the impeller diameter in m.

In addition, the power coefficient λ is considered. It is a dimensionless representation of the power and defined as follows:

$$\lambda = \frac{\varphi \cdot \psi}{\eta} \quad (3)$$

where φ the flow coefficient, ψ the pressure coefficient and η the efficiency.

1.2 Study 2

In an additional series of tests we examined a set of impellers whose blade depth and diameter were different from those of study 1. In study 2, the set of impellers contained an impeller with winglets and casting surface; a semi-open impeller; and an impeller with winglets and smoothed surface (Figure 4).

Figure 3 Impellers of study 1: Semi-open impeller (left), impeller with winglets (middle), impeller with front shroud (right)

Figure 4 Impellers of study 2: Impeller with winglets and casting surface (left), semi-open impeller (without winglets, middle), impeller with winglets and smoothed surface (right)

By means of varying the roughness of the surface the goal was to analyze the extent to which the winglets lead to a carrier effect similar to a rotating disc.

All impellers had four curved blades and the same casing as in study 1. Unlike study 1, the impellers and winglets were manufactured in the casting process itself. The original impeller had a casting surface (Figure 4, left). The other impellers were modified in two ways respectively: Trimming the winglets led to a semi-open impeller that otherwise featured the original geometry and surface of the cast (Figure 4, middle). Alternatively, the surface of a third impeller was smoothed by means of sandblasting; removing protrusions; adding filler; polishing (to remove any excess filler); and then completely coating the impeller (Figure 4, right). This impeller featured the original geometry too.

For maximum comparability of the obtained results, we used the same test rig design as study 1 and we measured the characteristics curve and the aggregate efficiency as well as the power consumption of all impellers similar to those in study 1. In addition, we carried out $NPSH_{3\%}$ measurements for different volume flows.

2. RESULTS

2.1 Study 1

Figure 6 illustrates the results of the three impellers of study 1. It pictures the pressure coefficient over flow coefficient. As Figure 6 suggests, the addition of winglets improved the head. The impeller with front shroud led to a similar characteristic, but lower than the impeller with winglets. The semi-open impeller was associated with lowest pressure coefficients. The impeller with winglets also reached the highest flow rates in overload as compared to the other impellers.

Figure 7 shows the efficiency over the flow coefficient. The impeller with winglets led to highest values of efficiency. The impeller with front shroud reached higher efficiencies than the semi-open impeller.

Figure 7 suggests that the best efficiency point for the impeller with the front shroud and the semi-open impeller moves to smaller flow rates as compared with the impeller with winglets.

Figure 8 shows the power consumption over the flow rate for the tested impellers of study 1. The semi-open impeller has the lowest power consumption. The impeller with the front shroud has the highest demand for power, followed by the impeller with winglets. All curves are rising: With increasing flow rates power consumption increases.

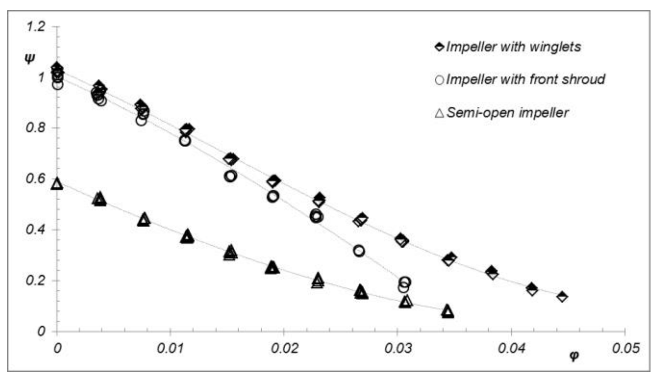

Figure 6. Pressure coefficient over flow coefficient for study 1

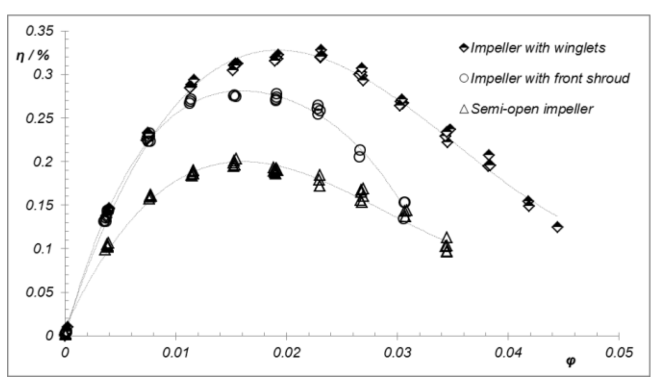

Figure 7. Efficiency over flow coefficient for study 1

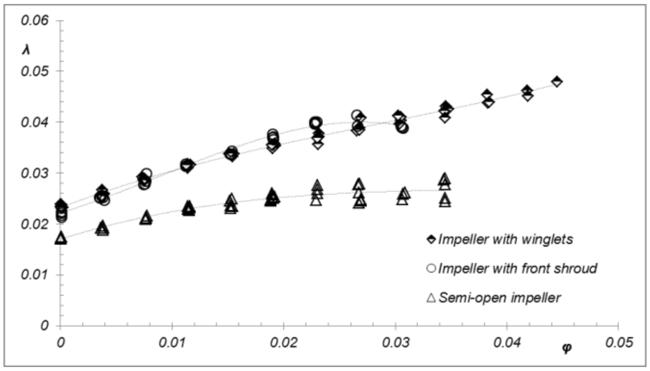

Figure 8. Power coefficient over flow coefficient for study 1

2.2 Study 2

To ensure the comparability of impellers with different degrees of surface roughness, the characteristic curves, the power consumption and the aggregate efficiency were measured. Figure 9 illustrates a comparison of the pressure coefficients over flow coefficients. (Note: Figure 9, 10 and 11 hide the individual measuring points because otherwise optical distinctions between the different curves are difficult.) Figure 9 shows that the pressure coefficient of the impeller with rough winglets resides slightly above the curve of the impeller with the smoothed winglets. As expected, the impeller without winglets led to significantly lower values of the pressure coefficient in comparison with the other two impellers.

Figure 10 pictures the aggregate efficiencies over flow coefficient. The efficiency curves suggest that the efficiency of the impellers with rough and smoothed winglets is almost identical. The impeller without winglets has again significantly lower values of efficiency than the impeller with winglets.

Figure 11 shows the power coefficient over flow coefficient. The impeller with rough winglets is the highest, followed by the impeller with smoothed winglets. The impeller without winglets has the lowest values.

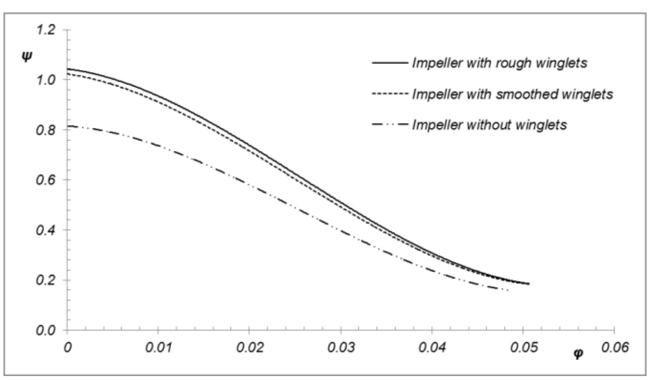

Figure 9. Pressure coefficient over flow coefficient for study 2

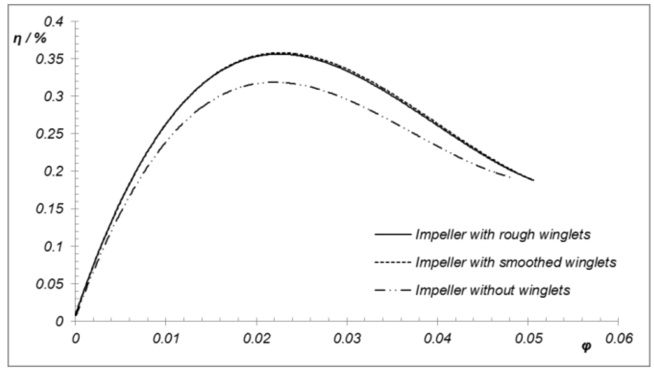

Figure 10. Efficiency over flow coefficient for study 2

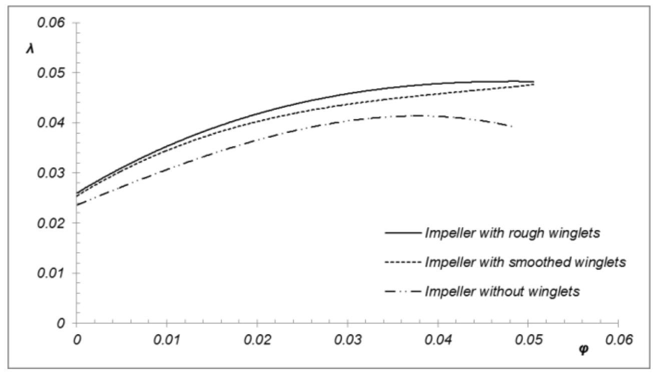

Figure 11. Power coefficient over flow coefficient for study 2

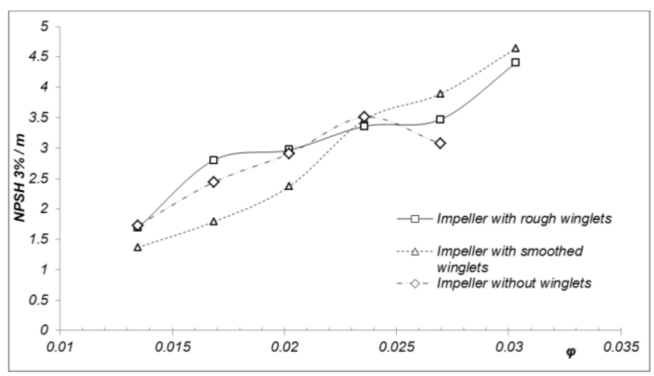

Figure 12. $NPSH_{3\%}$ over flow coefficient for study 2

Figure 12 sums up the cavitation measurements via the $NPSH_{3\%}$-values for different flow coefficients. The values for the impellers with winglets lie closely together. The impeller with smoothed winglets scores lowest values for part load and highest for overload. The impeller without winglets achieved low values for small flow coefficient but peeks around the best efficiency point.

3. DISCUSSION

Study 1 demonstrated that an impeller with winglets yields both the highest lifting height as well as the highest efficiency. Surprisingly, even the impeller with front shroud led to a higher head and a higher efficiency than the semi-open impeller. Overall, the impeller with winglets proved to be the best design.

A widely held view is that the working principle of a vortex pump is comparable to that of hydraulic coupling: The impeller of a vortex induces a vortex, which in turn handles the pumping (hereafter called *vortex view*). This view can be contrary to one that sees a vortex pump as a standard centrifugal pump: The flow streams through the impeller, which directly causes the pumping process itself, similar to a standard centrifugal pump. In this case, a vortex pump has an enlarged front gap, which leads to the excessive exchange losses and thus the poor efficiency of the pump (hereafter called *centrifugal view*).

Our experiments provide evidence that neither view is entirely correct on its own. On the one hand, the vortex view wrongly predicted the semi-open impeller supports the forming of a vortex, which again would lead to the best heads and efficiencies. However, this was not shown by the tests. On the other hand, the centrifugal view wrongly predicted that an impeller with a front shroud would support the working principle. In this case, best heads and efficiencies would be expected for the impeller with front shroud. Again, this was not the case. Taken together, the results suggest a synthesis of the two views approximates the true working principle best: An impeller with winglets lies geometrically between a semi-open impeller and an impeller with a shroud and therefore it optimizes both working principles at the same time.

Yet, the closer characteristics of the impeller with the front shroud and with winglets as compared with the semi-open impeller and those with winglets suggest that the centrifugal view describes the working horse of the two working principles: The main flow passes through the impeller – not the vortex. This is consistent with the transient, numerical simulation of flow lines by *Steinmann et al.* [9], who obtained similar results, i.e. that the main flow passes through the impeller.

Study 2 compared an impeller with winglets and a rough cast surface with an impeller with winglets and smooth surface. An impeller without winglets similar in geometric design was included in this study and showed again lowest pressure coefficients and efficiencies. Contrary to what was expected, the impeller with the rough winglets led to minimally higher flow characteristics. This suggests the rough surface causes a light carrier effect. The cavitation results showed an interaction effects between the design and the flow coefficient. Thus no clear conclusions can be drawn. Further investigations, such as the consideration of NPSH inception, seem necessary.

Overall, it can be concluded that winglets have a clear positive effect on the performance of vortex pumps.

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NOMENCLATUR

H	Head in m
Q	Flow rate in m^3/h
NPSH	Net positive suction head in m
D	impeller diameter in m
g	gravitational acceleration in m/s^2
n	rotational speed in 1/s
ψ	pressure coefficient
φ	flow coefficient
λ	power coefficient
η	efficiency