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GURNEY FLAPS ON AXIAL PUMPS

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ABSTRACT

This paper discusses the effect of small devices, the Gurney flaps, on the impeller of a single stage axial pump. The Gurney flaps are attached to the trailing edge on the pressure side of each of the three blades. The blades are profiled according to the Göttinger profile family GOE 11K. The experimental investigations determine the influence of the Gurney flaps, with the height of 1 mm and 2 mm and the width of 2 mm, on the pump characteristics. On the one hand these devices lead to an increased head and a shift of the best efficiency point to higher volume flow rates. Additionally, the operating range increases. On the other hand the Gurney flaps influence the cavitation characteristics of the axial pump. Due to these devices the NPSH values increase slightly. The 2 mm high Gurney flaps showed significant effect on the pump characteristics.

NOMENCLATURE

α	angle of attack
b	flap width
c	chord length
c_p	pressure coefficient
η	efficiency
f	frequency
g	pitch

h	flap height
H	head
Ma	Mach number
NPSH	net positive suction head
$NPSH_{IC}$	net positive suction head for incipient cavitation
$NPSH_{3\%}$	net positive suction head for a three percent head reduction
N	rotating speed
n_q	specific speed[1]
PS	pressure side
Q	flow rate
Re	Reynolds number[2]
SS	suction side
Th	Thoma number[3]
v	absolute velocity
ν	kinematic viscosity

INTRODUCTION

In the 1970s the racing driver Dan Gurney used a constructive device for passive flow control on his racing car. He mounted a rectangular plate, the so-called Gurney flap, onto the trailing edge of the rear wing. It increased the downforce and thus the contact pressing force of the car. Today, the Gurney flap is also used to increase the circulation and thus the lift on an airfoil profile. Typical heights of these flaps, which are attached to the trailing edge of the profile pressure side, are between 1-4 % of the chord length [Lee et. al. 2009].

[1] specific speed: $n_q = 333\, n \frac{\sqrt{Q_{opt}}}{(gH_{opt})^{3/4}}$

[2] Reynolds number: $Re = \frac{vc}{\nu}$

[3] Thoma number: $Th = \frac{NPSH_{3\%}}{H}$

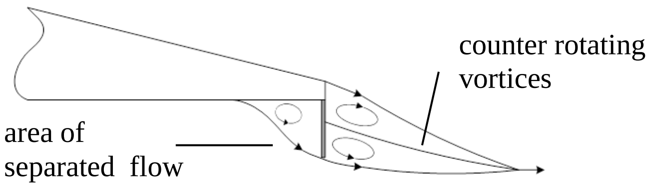

Figure 1: Flow at the trailing edge of a profile with Gurney flap according to Liebeck (1978)

Investigations of Liebeck (1978), Bechert et al. (2000), Richter and Rosemann (2002) and Lee and Ko (2009) showed a positive effect of Gurney flaps on the flow around an airfoil. By using Gurney flaps, the wake flow is influenced significantly. The Gurney flap causes the flow around the airfoil to form two counter rotating vortices in its wake (Figure 1). These vortices work like an extension of the airfoil and cause an increased camber. The flow behind the trailing edge is deflected to thepressure side. Thereby the circulation and thus the lift increase. Upstream of the Gurney flap the flow separation leads to an accumulation of the flow. The impact of that separated flow is an increase of pressure and thus the lift increases. However, the use of Gurney flaps also causes an increased drag, so the lift-to-drag ratio decreases. The effect of this device is dependent on its design. The increased drag with the rising flap height can be reduced by structural measures like perforation or slots. As a result, the lift-to-drag ratio can be enhanced.

Byerley et al. (2003), Myosis (2006), Greenblatt (2011), Manoj Kumar Dundi et al. (2012), investigated the effect of the Gurney flaps on the flow in a vane grid, in stationary as well as rotating systems. It becomes clear that higher pressure differences can be reached with Gurney flaps, especially for larger flow rates. Also, the efficiency is shifted toward higher flow rates. Gurney flaps can also influence the laminar separation and the sound power level positively.

EXPERIMENTAL SETUP AND PROCEDURES

At the Department of Fluid System Dynamics, TU Berlin, the influence of Gurney flaps on the pump characteristics and the cavitation characteristics of an axial pump was investigated. Furthermore, the pressure distribution for the outer section of the rotor blade was calculated using XFOIL, an interactive program for the design and analysis of subsonic isolated airfoils.

Test rig and test conditions

The experimental investigations were carried out on a single-stage axial flow pump with a specific speed of approximately n_q = 190. The three impeller blades were profiled according to the Göttinger profile family GOE 11K. The Gurney flaps, implemented as rectangular solids with the constant cross section of width x height, 2x2 mm and 2x1 mm, were attached to the trailing edge of the rotor blades (Figure **2**).

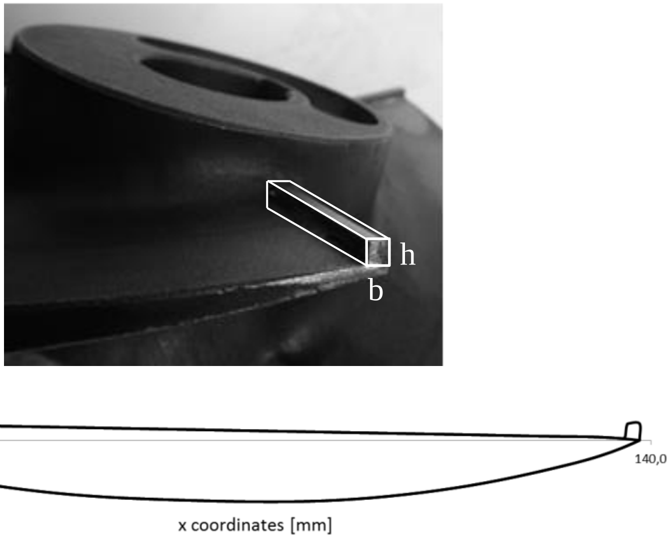

Figure 2: Rotor blade with Gurney flap (2 mm) at the trailing edge on pressure side (above), GOE11K profile for chord length of the blade tip (bottom)

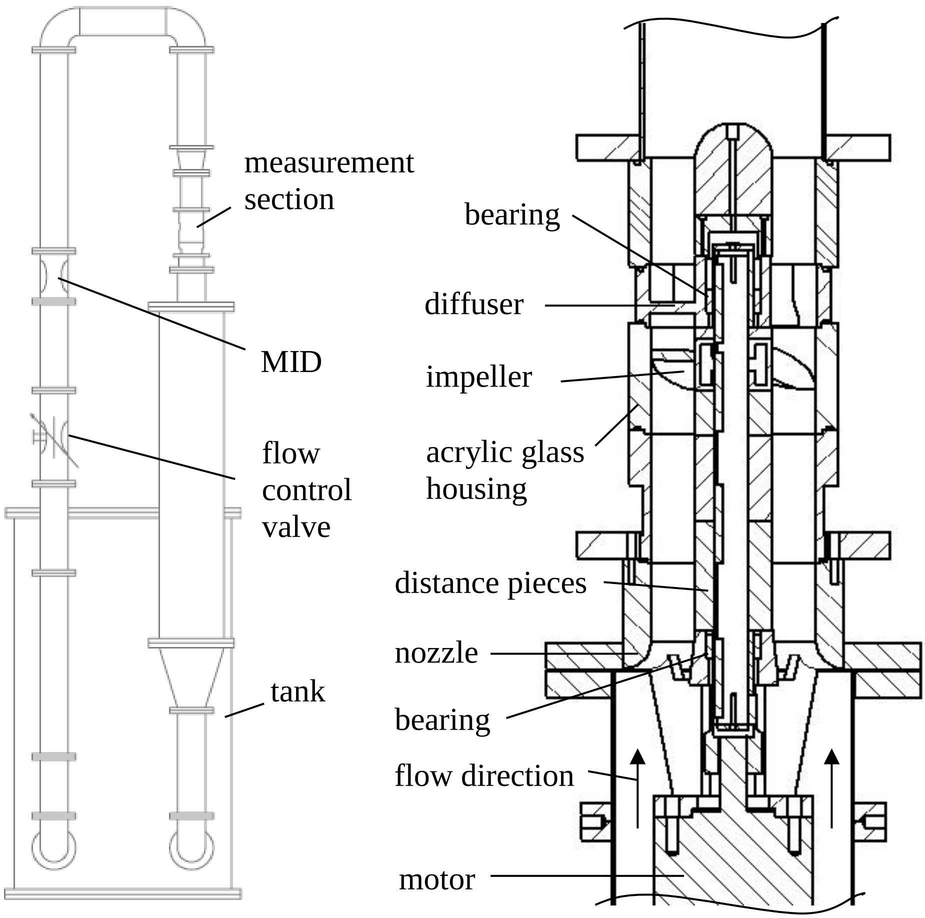

Figure 3: Test stand for investigations on an axial pump (left), test section (right)

The test stand is shown in Figure 3. The submersible motor is integrated in a DN 200 pipe. Through an inlet nozzle the flow is accelerated to the suction port DN 150. An acrylic glass housing allows optical access to the impeller for investigation of cavitation and flow visualization. The distance between the rotor and stator can be varied in steps of 10 mm by using distance pieces. The gap between the trailing edge of the rotor and the leading edge of the guide vanes is about 0.8 mm. The results, presented in the following, were determined for the constant distance of 10.8 mm between rotor and stator. The pressure at the suction and pressure side of the pump was measured by differential piezo resistive pressure sensor[4]. The flow rate was determined by means of a magnetic-inductive flow meter[5]. The overall efficiency of the pump was assessed via the electric power of the submersible motor. The closed circuit and the construction of the used system allow the measurement of net positive suction head, the characteristic value for cavitation. The determination of incipient cavitation, $NPSH_{IC}$, is done by observation of a 5 mm length of cavitation bubbles. The experimental investigations determined the influence of the Gurney flaps, with the height of 1 mm and 2 mm and width of 2 mm. The characteristic curves were obtained for a rotating speed of n = 2870 rpm. The maximum Reynolds number was Re = 690 000.

RESULTS

Pressure distribution

The pressure distribution for the blade profile of series GOE 11K was calculated with XFOIL. Thereby the focus is on the tip profile of the rotor blade. In this case the chord length is 136 mm, so the ratio of Gurney flap height to chord length is h/c= 0.7 … 1.4´%. The calculations were conducted for a 2D-stationary flow with fixed Reynolds number Re = 690 000 and Mach number Ma = 0.01 and angle of attack $\alpha = 0°$. The pressure distributions for these three configurations are shown in Figure 4. The suction peak increases with the increasing height of the Gurney flaps and moves towards the leading edge in comparison to the original rotor blade without a Gurney flap. If the pressure drops below the vapor pressure, cavitation bubbles occur. Furthermore, the difference in pressure between the suction and the pressure side rises for increasing flap height. As a result the lift is enhanced. Higher lift coefficients correlate with higher head (Figure 5).

[4] PD-23/8666.1, range: -5…+5 bar, ±0,.2 % FS (suction side), PD-23/8666.1, range: 0…10 bar, ± 0.2 % FS (pressure side), Keller AG

[5] Optiflux 2300, DN200, range: 0…450 m^3/s, ± 0.1 % FS, Krohne

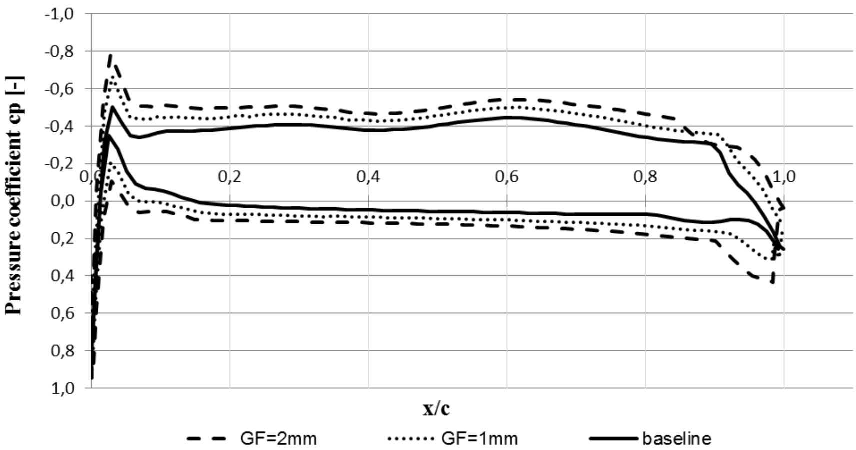

Figure 4: Pressure distribution for a GOE11K profile at the blade tip with different Gurney flaps heights

Pump characteristics

The characteristic curves and efficiency coefficients for the three configurations are shown in Figure 5 and Figure 6. By using Gurney flaps the head of the pump increases. At the design point, the delivery head increases by 25% for 2 mm high Gurney flap, compared with the original. With decreasing flow rate the effect of the Gurney flaps on the head is slightly reduced. For flow rates $0 < Q/Q_{opt} < 0.2$ there is no influence of these devices. At high flow rates $Q/Q_{opt} > 1.1$ the application of Gurney flaps partially leads to a 50 % higher head. The efficiency drops slightly by using Gurney flaps, because of the higher drag. Furthermore, the best efficiency point moves towards higher flow rates and the operating range is enlarged slightly.

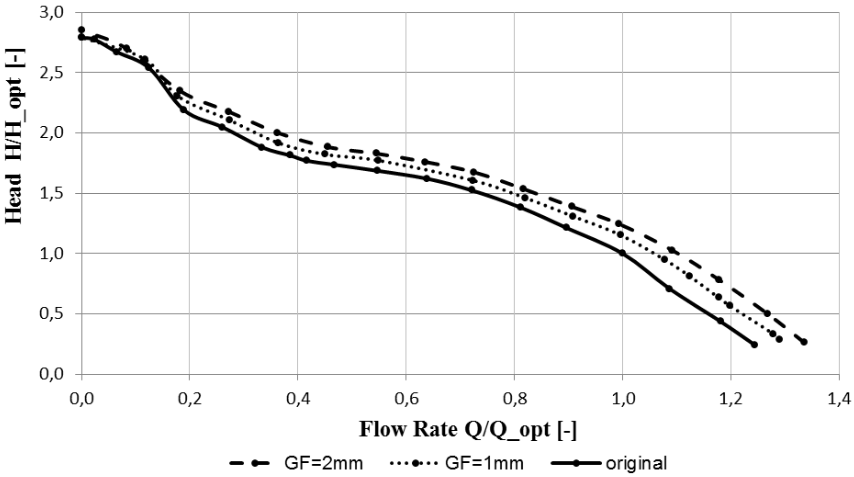

Figure 5: Pump characteristics for an axial pump with different Gurney flap heights

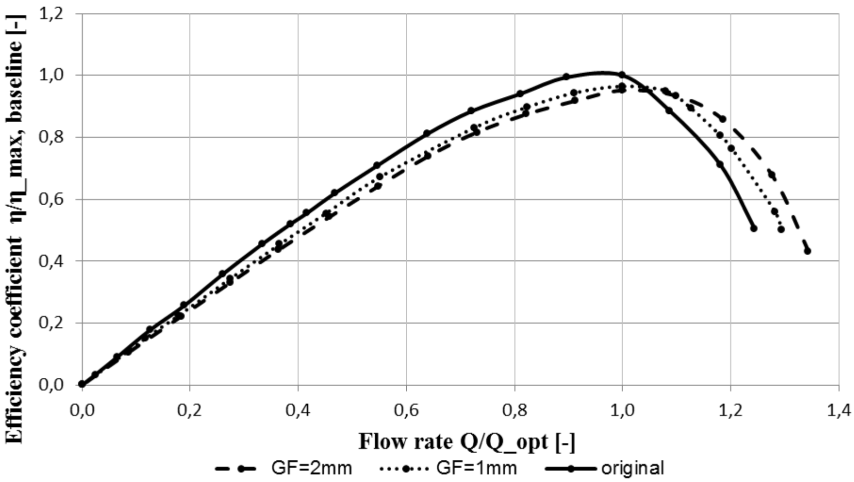

Figure 6: Efficiency coefficient for an axial pump with different Gurney flap heights

NPSH measurement

The results of the NPSH characteristic measurements are shown in Figure 7 for three example flow rates. From these curves, the $NPSH_{3\%}$ - values can be extracted for a 3 % reduction of the head. This value is an indication for cavitation, due to reduced performance, and is presented in Figure 8 for different flow rates. The drop of NPSH curves begin at same

NPSH levels (NPSH = 7m) for flow rates of $Q/Q_{opt} \leq 1$ (Figure 7). For overload, the drop of the head begin for NPSH = 8m. However, the cavitation curves for the configuration with 1 mm high Gurney flap are falling a bit flatter which offers a sneaky stall.

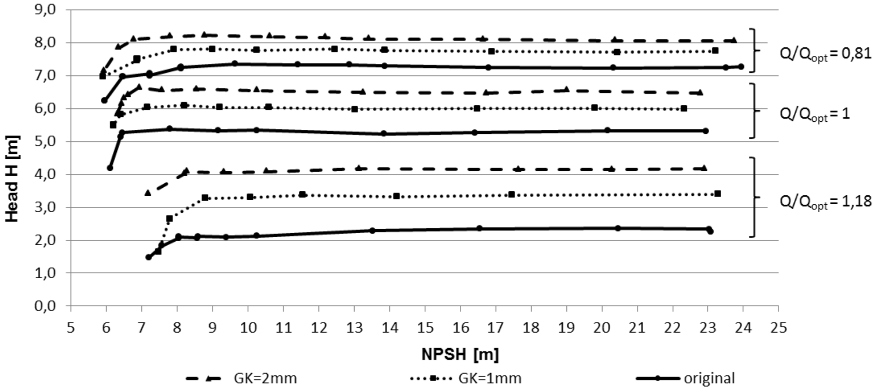

Figure 7: NPSH characteristics exemplarily for three flow rates

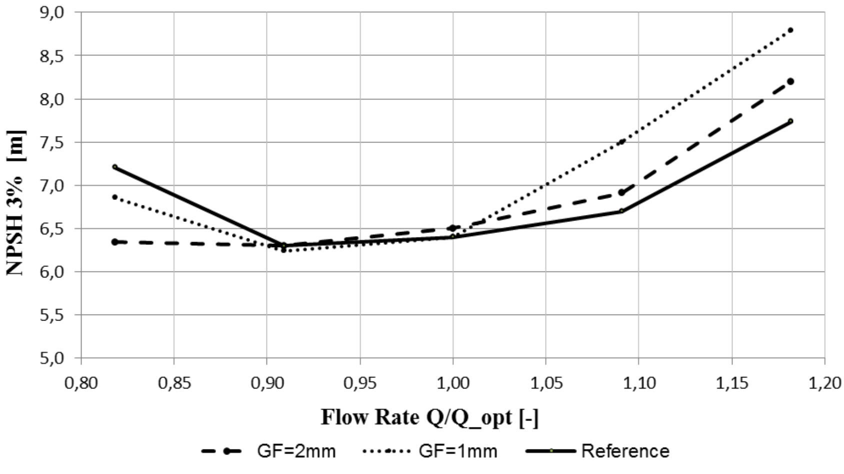

Figure 8: $NPSH_{3\%}$ for an axial pump with different Gurney flap heights

For flow rates of $0.9 < Q/Q_{opt} < 1$ no effect of the gurney flaps on the $NPSH_{3\%}$ curves can be detected. The impact of the flaps for partial load $Q/Q_{opt} < 0.9$ is a decreasing of the $NPSH_{3\%}$ - values. Using the 2 mm high Gurney flap $NPSH_{3\%}$ - value drops about 1 m. In contrast the $NPSH_{3\%}$ - values rise by up to 1 m by using the 1 mm high Gurney flaps for high flow rates ($Q/Q_{opt} > 1.0$). The effect of the 2 mm high Gurney flap is the half of the 1 mm flap.

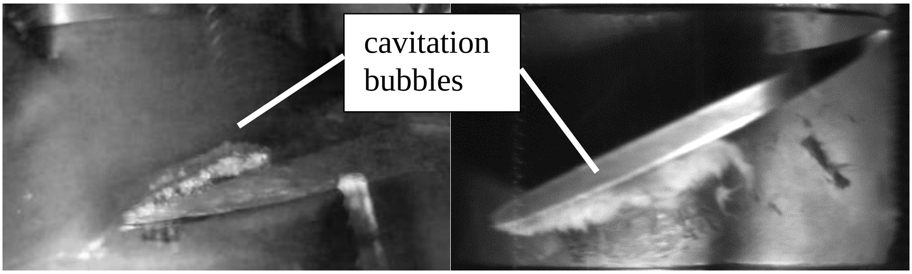

Figure 9: Cavitation bubbles on pressure side (left, Q/Q_{opt} = 0.91, Th = 2,4) and on the suction side of the blade (right, Q/Q_{opt} = 1.0, Th = 1,6)

Figure 9 shows the observed cavitation bubbles on the pressure and the suction side of the rotor blade. The acrylic access allows an observation of the vapor cavities. So the $NPSH_{IC}$ – value was determined by measuring the NPSH - value when the cavitation bubbles reach a length of 5 mm (Figure 10). With attached Gurney flaps the $NPSH_{IC}$ - value increases according to the higher pressure drop respective higher velocity at the leading edge, compared to the original configuration. The cavitation occurs at the tip radius first. With the spread of cavitation bubbles along the blade, the cavitation zone spreads towards the hub, so that a triangle with cavitation bubbles is spanned. The remarkable thing is that the $NPSH_{ic}$ – values (at the the suction side) for the 1 mm high flap are higher in comparison to the 2 mm high flap.

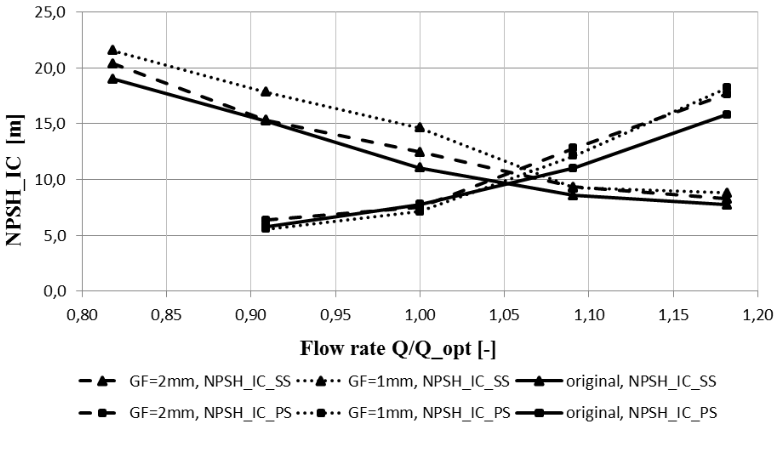

Figure 10: $NPSH_{IC}$ for an axial pump with different Gurney flap heights

Additionally, cavitation occurred in the narrow gap between impeller tip and casing (Figure 11). The dominant parameter for this is the clearance flow, which results from the pressure difference between the pressure and suction side of the blade. By using the Gurney flaps the pressure difference and thus the clearance flow increases and in turn cavitation is enhanced.

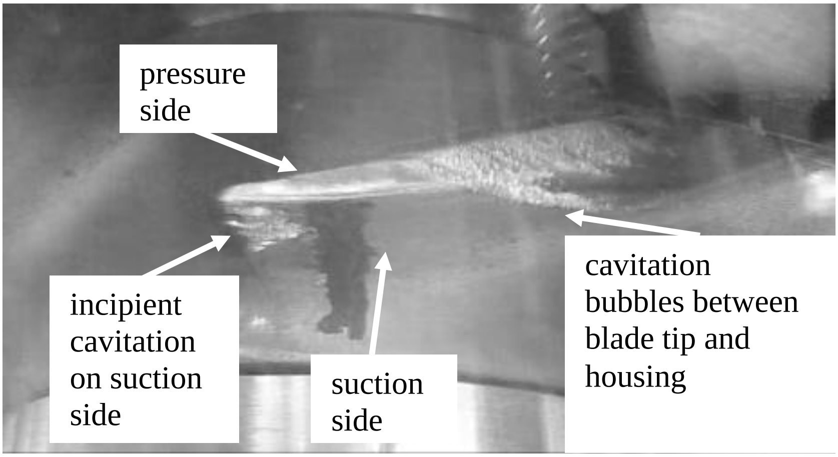

Figure 11: Observed cavitation in the blade tip clearance and incipient cavitation on suction side for the axial pump (Q/Qopt = 1.18, Th = 4.8)

The $NPSH_{IC,\ clearance}$- value in the gap between blade tip and housing is shown in Figure 12. Consistent with the results of $NPSH_{IC}$ (on the suction and the pressure side of the blade) the $NPSH_{IC,\ clearance}$ – value increases significantly by attaching Gurney flaps.

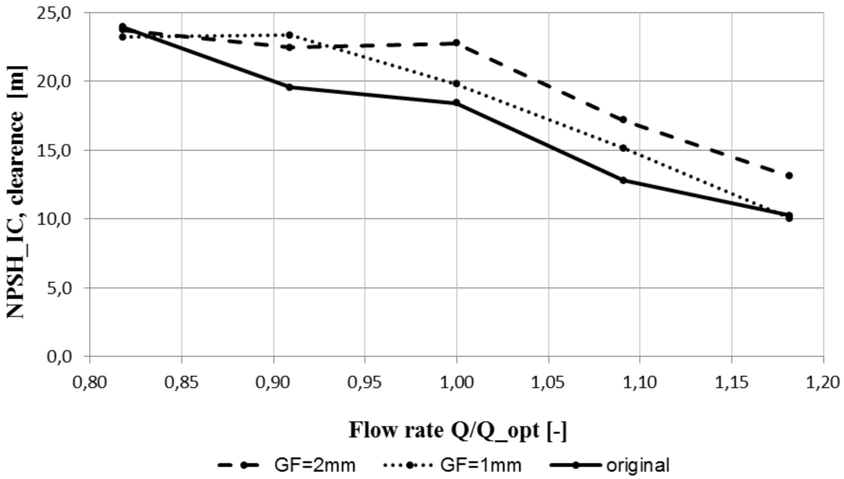

Figure 12: $NPSH_{IC,\ clearance}$ for an axial pump with two different Gurney flap heights

CONCLUSIONS

This paper discusses the influence of Gurney flaps on the pump characteristics of a single stage axial pump. These small devices are attached on the trailing edge at the pressure side of the rotor blades. The pump characteristics, efficiency and cavitation characteristics were determined. By using Gurney flaps, the head of the pump increases, the best efficiency point moves towards higher flow and the work range enlarges.

While the $NPSH_{3\%}$ values remain at the same levels, the incipient cavitation $NPSH_{ic}$ at the blade and in the impeller tip clearance significantly rise.

Overall, Gurney flaps could be very useful to adapt an existing axial pump to higher head and efficiency shift to larger flow.

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