Hindawi Publishing Corporation
International Journal of Rotating Machinery
Volume 2008, Article ID 354020, 6 pages
doi:10.1155/2008/354020

Research Article

Cavitation in Single-Vane Sewage Pumps

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Received 22 April 2008; Accepted 28 October 2008

Recommended by Wei Tong

Chair fluidsystemdynamics at TU Berlin investigated the cavitation behavior of a full-size single-vane sewage pump. Single-vane pumps are used for raw sewage with high content of dirt and sediments in larger sewage pumping stations. Cavitation measurement was done by using standard $NPSH_{3\%}$ and the more sensitive incipient cavitation $NPSH_{IC}$. Also, vibration and noise where observed. Contrary to very low $NPSH_{3\%}$ values, very high $NPSH_{IC}$ values were measured. In a second step, the impeller was modified with special cavitation bores to reduce the cavitation effects. The $NPSH_{3\%}$ values increased with cavitation bores, which underlines that this value is not a sufficient criteria describing cavitation. Using the much more sensitive $NPSH_{IC}$, a significant reduction was obtained. Moreover, the cavitation formation was changed from a relative concentrated cloud to a distributed bubble form, which is much less aggressive in view of noise and erosion. Operational behavior improved with cavitation bores, noise and vibration levels especially came down to acceptable level. Practical experience demonstrates also avoidance of cavitation erosion.

1. INTRODUCTION

Sewage pumping stations for larger cities typically use different sizes and types of sewage pumps in dry installation as shown in Figure 1. For example, the Berlin Water Works, Germany, manages about 140 pumping stations with an overall flow of 630, 000 m^3/day (167, 000, 000 USGPD).

Depending on quality of sewage, pumps are equipped with different design of impeller [1–3]. Single-vane impeller pumps with nearly nonclogging operation are the preferred choice if high content of dirt in the sewage exists.

In some installations, sewage pumps operate in so-called lift operation, whereas the sewage water level is below the pump level. Thus, the available $NPSH_A$ defined as absolute energy at suction side is around 7 m, which may be in some cases below the required $NPSH_R$ of the pump. Beside unacceptable noise during operation, in several cases also cavitation erosion of such impellers was observed. Figure 2 shows a sample of cavitation erosion at the leading edge of a single-vane impeller after approximately 5,000-hour operation.

The motivation of this project belongs to the better understanding of the cavitation phenomena within the special design of the single-vane impeller of a sewage pump and how to control the operation behavior with cavitation.

2. TEST FACILITIES AND INSTRUMENTATION

The Department of Fluidsystemdynamics at the Technical University Berlin operates a closed test loop with DN 350 (12") pipe, shown in Figure 3. The test loop is designed according to guidelines EUROPUMP [4] and is equipped to test all relevant pump characteristics. The maximum capacity reach 2.000 m^3/h (8.800 USGPM) and a pump performance of about 200 kW (270 HP) allows full size test of centrifugal pumps. Figure 3 shows the closed test loop with a single-vane sewage pump and about 150 kW (200 HP) power consumption.

Instrumentation and principle setup of test loop are shown in Figure 4.

Experiments are executed with normal potable water at approximately 20°C (68 F). Steady-state operation reached after about ten minutes and readings are taken during stable operation point. Pretest shows no significant influence of water (aerated, deaerated) on the measurements of NPSH.

Figure 1: Sewage station with sewage pumps.

Figure 2: Cavitation erosion at single-vane impeller.

The NPSH is adjusted by the pressure in the tank, which is formed by the geodetic head as well as the air pressure above the liquid. This gives the opportunity to run the pump under adjustable cavitation grades, whereas all relevant data are collected depending on the NPSH, for example, capacity, head, power, and vibration.

Additionally, the test loop is equipped with some visual instrumentation to observe the cavitation formations within the impeller. First, an endoscope is placed in front of the inlet of the impeller to show the onset of cavitation bubbles on the impeller blade suction side. Additionally, the standard service flange at the pump casing allows a view into the impeller area from the outlet side of the blade. A stroboscopic light source ensures sufficient power of light. CCD-camera and computer are connected for further documentation of phenomena. Visualization equipment is shown in Figure 5.

Simple white and black color marks on the impeller blade at the leading edge allow the identification of the bubble length during the tests (see Figure 6). The distance between the lines is 20 mm (0.79 inch), whereas additional lines separate the inner, middle, and outer areas between hub and shroud.

3. CAVITATION BORES

The principle of the cavitation bores is shown in Figure 7. Shroud and hub of impeller get a number of relative large-size bores close to the leading edge of the blade. These bores are quite different to the known axial thrust balancing bores

Figure 3: Closed test loop for centrifugal pumps.

of standard impellers. First, developed by field experience, the cavitation phenomena, such as noise, vibration, and erosion, were significantly reduced.

The idea behind the cavitation bores is to connect the low-pressure areas at impeller inlet edge to the high-pressure areas at shroud clearances. Thus, the cavitation zone will be filled up from the flow through the bores with the effect of reducing the cavitation grade as well as the bubble size.

4. EXPERIMENTAL INVESTIGATIONS

Experimental investigations should verify the idea of the cavitation bores and their effects on the different cavitation phenomenon of the single-vane sewage pump. Therefore, three variations of cavitation bores are investigated:

$B = 0 \longrightarrow$ all cavitations bores are open,

$B = 1 \longrightarrow$ all cavitations bores are closed,

$B = 2 \longrightarrow$ half number of cavitations bores are open.

Looking on the head flow curves in Figure 8, the effect of additional gap flow due to fully open cavitation bores reaches maximum about 5% gap flow at BEP Q_{opt}. It is noticeable that increased gap flow results in reduction of pump efficiency by about up to 2%.

Some typical head-drop curves are displayed in Figure 9. Each head-drop curve at constant speed and constant flow results in standard $\text{NPSH}_{3\%}$, at which the head is reduced by 3% due to cavitation compared to the head at high-level NPSH respective cavitation-free operation. Figure 10 shows the $\text{NPSH}_{3\%}$ values for the sewage pump without ($B = 1$) and with open ($B = 0$) cavitation bores.

Generally, the measured $\text{NPSH}_{3\%}$ values are on very low level from 1 to 2.5 m. The suction number reaches about $Sq = 0,7$ (NSS $= 12,000$), which is significantly higher than the standard centrifugal pumps and demonstrates normally a high suction capability. On the other hand, the diagram of vibration level shows a dramatic increase of vibration at $\text{NPSH}_{3\%}$ combined with heavy noise generation. It is not recommendable to run the pump under such conditions. Obviously, the $\text{NPSH}_{3\%}$ value does not give

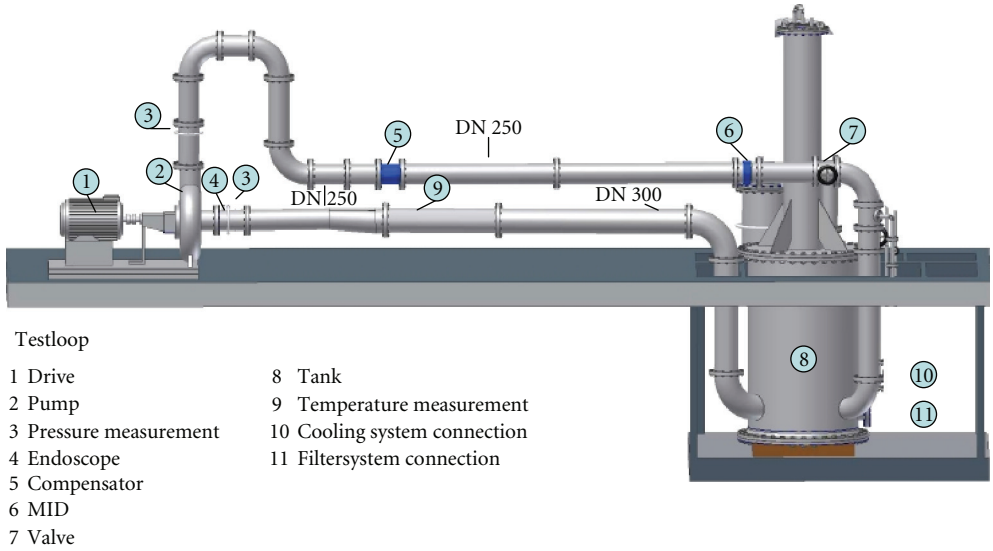


Figure 4: Instrumentation of the test loop.

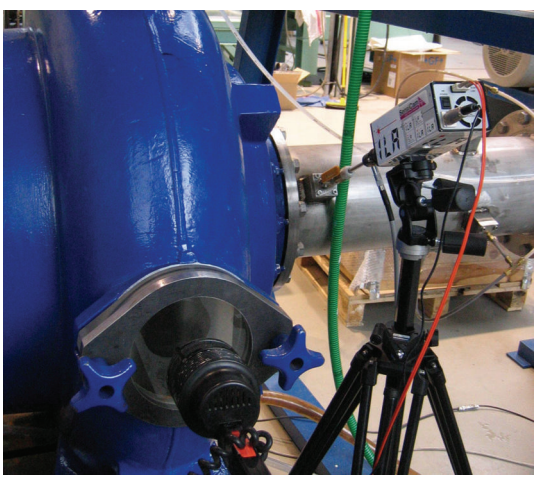


Figure 5: Visualization equipment.

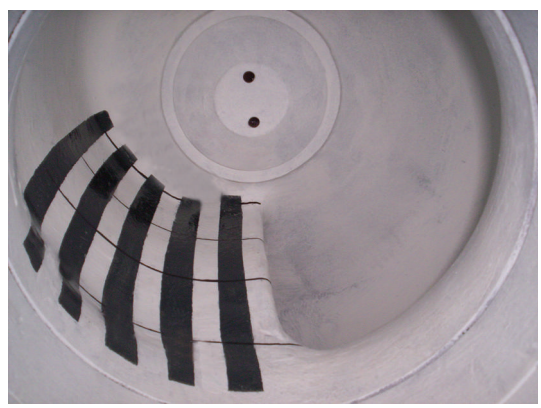


Figure 6: Impeller marked for cavitation observation.

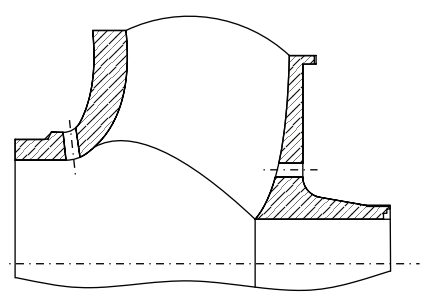


Figure 7: Principle of cavitation bores.

adequate information on the operation behavior under cavitation conditions for single-vane sewage pumps.

Comparing the $NPSH_{3\%}$ for the different cavitation bores (Figure 10), the fully open ones show slightly higher values compared to the closed bores, even at the same low level. The explanation for this effect is combined with the negative impact of the additional "gap flow" through the cavitation bores on the main flow [5, 6].

In this project, we use direct flow visualization to better understand the cavitation phenomenon [7, 8]. Cavitation bubbles as well as formation of cavitation in the impeller are observed through an endoscope in front of the impeller. Figure 11 shows the positioned endoscope.

Visual measurement first gives the onset "incipient" cavitation $NPSH_{IC}$, which here is defined as observed: 20 mm bubble length at impeller leading edge. Looking at the $NPSH_{IC}$ (Figure 12), the absolute values are relatively high reaching approximately 30 m BEP Q_{opt} compared to similar standard pumps [8, 9]. This could be explained by the special design of nonclogging single-vane impeller: the vane inlet of the single-vane impeller opens progressively the space for all kind of dirt in the sewage to avoid any clogging. On the

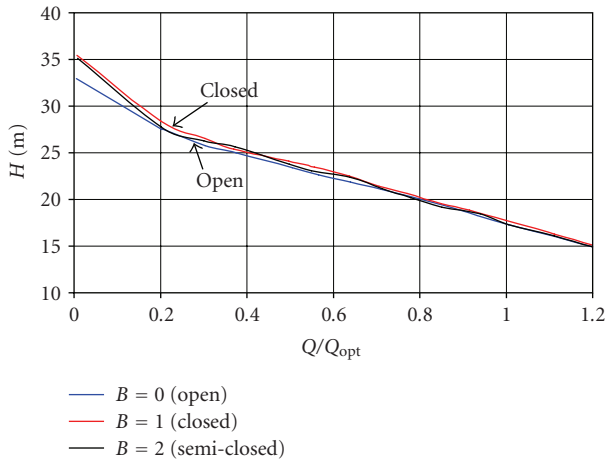
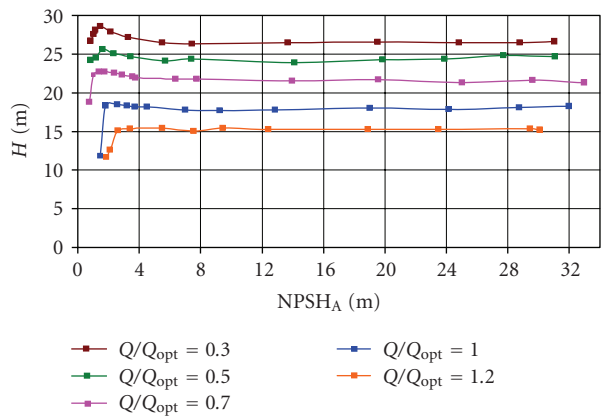
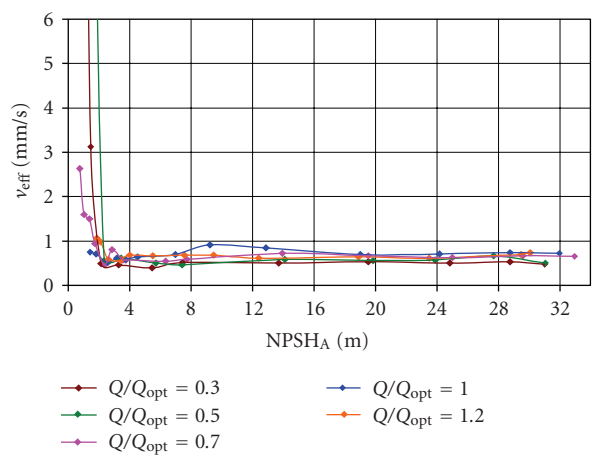


Figure 8: Head flow curve ($n = 725$ rpm).



(a)



(b)

Figure 9: Head drop and vibration values ($B = 1$, $n = 725$ rpm).

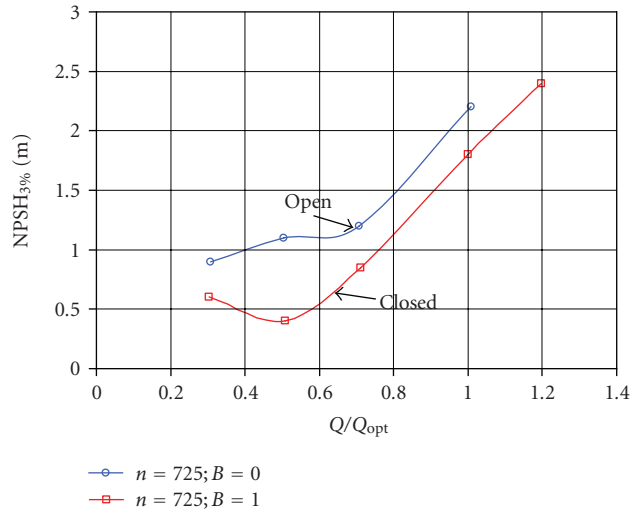


Figure 10: $NPSH_{3\%}$ ($n = 725$ rpm).

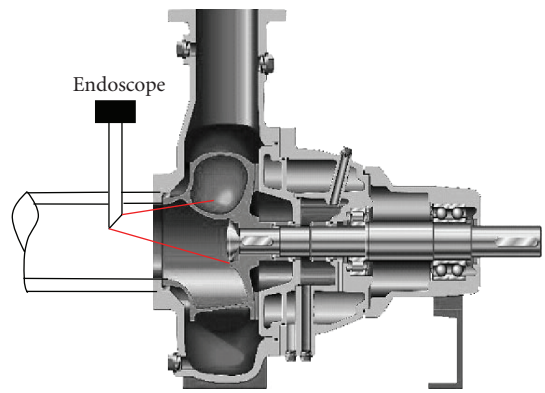


Figure 11: Position of endoscope.

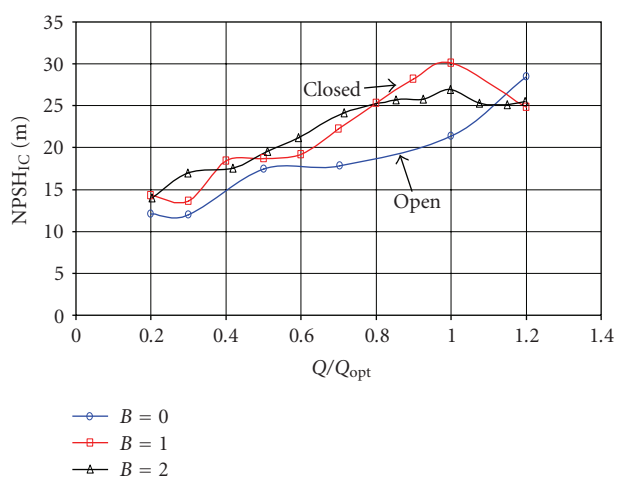
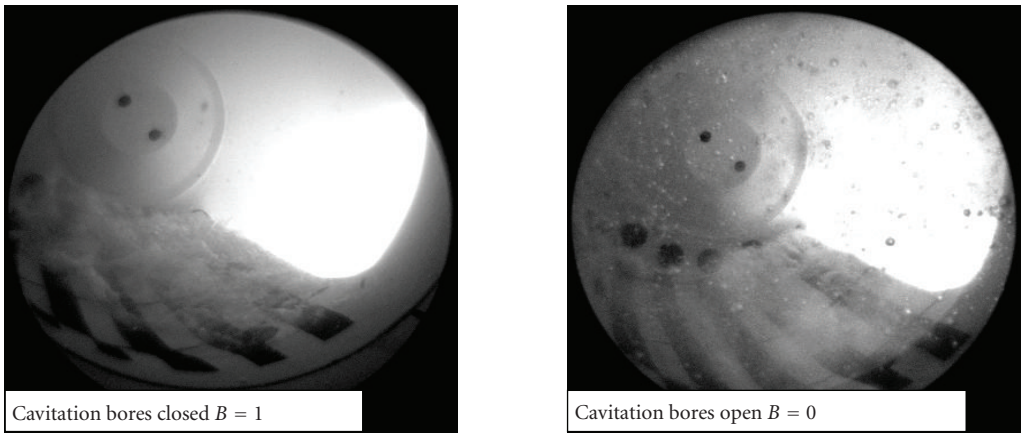


Figure 12: $NPSH_{IC}$ ($n = 725$ rpm).

other hand, this creates a relatively large dead water zone just behind the leading edge due to flow separation. Cavitation typically locates in this area.

Figure 12 also demonstrates the positive influence of cavitation bores on the $NPSH_{IC}$ values: with fully opened cavitation bores, the $NPSH_{IC}$ is reduced by about 10 m at BEP but remains on a relative high value around 20 m.

Remember that the pump operates in some applications under lift conditions. Obviously, the practical operation of such single-vane pump would have to accept some grade



(a) (b)

Figure 13: Cavitation at $NPSH_A = 8$ m with/without cavitation bores at BEP ($n = 725$ rpm).

of cavitation. Typically, such pumps operate at $NPSH_A = 8$–11 m.

Figure 13 shows the observed cavitation at BEP Q_{opt} With closed cavitation bores $B = 1$ (upper photograph), the cavitation activity is located mainly beginning at the leading edge with relatively large extension (approx. 180 mm length) of sheet cavitation which also forms some cloud cavitation. It is known that cloud cavitation aggressively creates noise and erosion [10, 11] .

With open cavitation bores $B = 0$ (lower photograph), the extension of cavitation bubbles is significantly reduced. Additionally, the cavitation clouds seem to be destroyed by the jet flow through the bores. As the cavitation bubbles move away from the wall, the cavitation activities in middle area of the vane passage will reduce the number of cavitation collapses in the near of impeller walls. This explains the reduction of noise and erosion.

Finally, we investigate the cavitation grade subjective by evaluating the noise level with the same person to decide the acceptable grade of cavitation. Results are shown in Figure 14.

The acceptable level of noise is approximately 15 m below $NPSH_{IC}$ for the evaluated arrangements. Whereas the evaluated level for closed cavitation bores is unacceptably high ($NPSH_{SG} = 17$ m at BEP), the values for open cavitation bores are acceptable for normal operation of this single-vane sewage pump ($NPSH_{SG} = 6$ m at BEP).

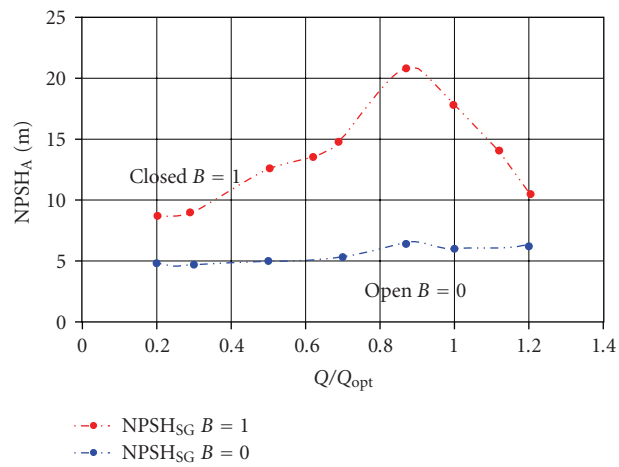


Figure 14: Subjective cavitation $NPSH_{SG}$—curves with ($B = 0$) and without ($B = 1$) cavitation bores $n = 725$ 1/min.

5. CONCLUSIONS AND SUMMARY

Cavitation in single-vane impeller pumps will occur also under normal suction conditions. This is due to the nonclogging impeller design, whereas the high incidence angle will create a separation zone at the inlet edge of the impeller. On the other hand, this sudden opening will not allow the dirt to clog the inlet. Some grades of cavitation have to be accepted but controlled by cavitation bores, which reduce the extension of cavitation itself and destroy the cloud formation of cavitation. Cavitation bubbles are redirected away from the impeller walls. This could be clearly demonstrated by visualizing the effect of the bores. Especially, noise changes to acceptable level even for suction lift operation. In summary, cavitation bores are an adequate possibility to reduce negative effects of cavitation in single-vane sewage pumps.

NOMENCLATURE

H:	Head of pump (m)
n:	Speed of pump (rpm)
$NPSH_A$:	Net positive suction head available (m)
$NPSH_R$:	Net positive suction head required (m)
$NPSH_{3\%}$:	Net positive suction head at 3% head drop due to cavitation (m)
$NPSH_{IC}$:	Net positive suction head for beginning of cavitation (here: 20 mm bubble length) (m)
$NPSH_{SG}$:	Net positive suction head with acceptable level of noise (subjective evaluated by same person) (m)

P: Pump performance (kW)
Q: Volume flow, capacity (m^3/h)
v_{eff}: Vibration velocity (mm/s)
Sq: Suction number (–)
n_{qs}: Suction specific speed (–).

ACKNOWLEDGMENTS

The authors are thankful for many persons for supporting this research work, especially the students at André Bergmann and Rolf Jungnickel, who ran the large number of tests and additions that had added some valuable ideas for observation method.

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