Pump cavitation in feed water systems - remedies

Krzysztof Karaskiewicz

1 Warsaw University of Technology, 00-665 Warsaw, Nowowiejska Str. 21/25, krzysztof.karaskiewicz@itc.pw.edu.pl, Poland

Abstract. The Net Positive Suction Head incipient is a multiple of the Net Positive Suction Head Required in centrifugal pumps. With limited static heads of the feedwater systems, the suction impellers of the feed pumps work in cavitation. The article discusses the ways to deal with the problem of cavitation in such systems.

1 Introduction

Cavitation in industrial pumps reduces the head, efficiency, leads to excessive vibration and finally cuts the impeller’s operating time off due to damage caused by cavitation erosion. This phenomenon is caused by excessive static pressure drop in the pump suction nozzle. Fig. 1 shows the stages of cavitation and their effect on the pump head while maintaining a constant flow.

![Fig. 1. Stages of cavitation at constant flow rate.](image)

The static pressure before the pump is determined by the characteristics of the suction side of the pumping system determined by the Net Positive Suction Head available.

2 Net Positive Suction Head Available of a feedwater system

A diagram of a typical steam generation system in power plants and hot water generation system in an industrial plant is shown in Figure 2.

![Fig. 2. Feedwater system](image)

\[ NPSHA = (H_f - H_v + H_s) - H_{str} \]  
wherein:  
\[ H_{str} \equiv \alpha(Q/Q_n)^2 \]

Taking into account that the pressure in the feed water tank nearly equals vapor pressure  
\[ NPSHA \equiv H_s - \alpha(Q/Q_n)^2 \]

Typical static heads in industrial plants are  
\[ H_s = 25-30 \text{m} \]
exceed a few meters, hence the typical values of hydraulic resistance in equation (2) $a = 2 \div 3m$.

The NPSHA characteristic limits the pump operation. To avoid cavitation, the Net Positive Suction Head Required must be smaller.

3 Net Positive Suction Head Required margin

A commonly used cavitation characteristics in industry is a 3% drop in head, i.e. $NPSHR = NPSH3$. Manufacturers provide the $NPSH3$ characteristic for rated speed. For a suction impeller of a suction specific speed $n_{ss} = 230$ (single-suction $i = 1$ commercially available pump with a specific speed $n_{i} = 20$), rated rotational speed $n = 5000 \text{ / min}$, and flow rate $Q_{BEP} = 520 \text{m}^3/\text{h}$, $NPSH3$ can be expected:

$$NPSH3 = \left( \frac{n}{n_{ss}} \right)^{4/3} \left( \frac{Q_{BEP}}{i} \right) = 17m$$

This is a relatively large value. Such $NPSH$ can be reduced in three ways:

1. Use of impeller of larger suction specific speed. For the suction specific speed $n_{ss} = 280$ and the same rated pump parameters, $NPSH3 \approx 13m$ can be obtained.
2. Use double suction impeller with the same parameters $n, n_{ss}, Q_{BEP}$. It allows to obtain $NPSH3$ 20\% smaller.
3. Reducing the rotational speed of the pump while increasing the number of stages and impellers diameter to maintain the required head. For example, reducing the speed down to $n = 3500 \text{ / min}$ reduces the Net Positive Suction Head to $NPSH3 \approx 10m$.

To avoid cavitation some margin is recommended. The NPSH margin is different depending on source literature, for example [1] gives:

$$NPSH \text{ margin} = \begin{cases} 25\% \quad \text{which value is greater} \\ 0,6m \end{cases}$$

The Hydraulic Institute [2] recommends:

### Table 1. Examples of NPSH margin by HI.

| Industry                 | Application                                     | NPSH Margin |
|--------------------------|-------------------------------------------------|-------------|
| Petroleum / hydrocarbon  | Typical, except vertical canned pumps           | 10% or 1.0m |
| Chemical process         | Typical                                         | 10%-20\% OR 0,6m-1,0m |
| Electric power generation| Circulating / cooling water                     | 1,0m        |
| Electric power generation| Boiler feed < 250 kW/stage                      | 30%         |
| Water                    | Typical, stainless steel or aluminum-bronze impeller, < 75 kW/stage | 10% or 1.5m |

However, they are larger for high energy pumps. McGuire [3] reports:

### Table 2. Examples of NPSH margin according to [3].

| Application     | NPSH Margin |
|-----------------|-------------|
| Water, Cold     | 10-35\%(1,2) |
| Hydrocarbon     | 10\%(2)     |
| Boiler feed, small | 50\%(3)   |
| High energy     | 200-300\%(4) |

The correct pump operation is defined by $NPSHA \geq NPSH3 + \text{NPSH margin}$ but avoiding cavitation imposes a stricter condition $NPSHA \geq NPSH_i$.

4 Incipient cavitation and $NPSH_i/NPSH3$ ratio

To determine the safe pump operation area without cavitation, the ratio of $NPSH$ for incipient cavitation and 3\% cavitation is needed. Figure 3 shows such ratio for pumps with a specific speed from $n_{i} = 16$ to $n_{i} = 90$.

### Fig. 3. $NPSH_i/NPSH3$ ratio for the data from [4,5,6,7] as a function of specific speed. The ratios range between about 4 and 6. For very good suction impellers, they are lower and range from 2 to 3 [1,4]. Figure 4 shows $NPSH$ ratios for a typical feedwater system with the static head $H_{s} = 25m$, a feedwater pump with a double-suction impeller and 25\% margin, and $NPSH_i$ for incipient cavitation. All is related to $NPSH3_{BEP} = 10m$. $NPSH_i$ values as a function of flow rate were estimated based on the studies in [4,5,6,7].
feed water pump system in small power plant. The field below the NPSH curve is the cavitation area so feed water pump operates in cavitation because of NPSHA \leq NPSHi.

5 Feedwater system with booster pump

The use of a low-rotational speed booster pump significantly improves the suction conditions of the feed water pump. The booster pump power is often around 5% of the feed water pump power. With efficiency of over 80%, additional losses associated with booster pump operation reduce the efficiency of pumping into the boiler by less than a percent. With a booster pump’s head of 6 to 8 times the NPSH3 of feed water pump the latter can achieve a wide range of operation without cavitation. The simple structure of the booster pump allows for its long trouble-free operation.

6 New materials for suction impeller

At existing static heads of the system, without the booster pump the suction impeller of the feed pump operates in cavitation. The conditions for suction impellers material is operation for 40,000 hours. Typical chromium cast steels traditionally used, e.g. GX20Cr14, does not meet this condition but alloys are offered whose cavitation erosion resistance is at least ten times larger. Table 3 contains materials ordered by increasing cavitation resistance according to KSB Lexicon.

| Name           | Type             | index |
|----------------|------------------|-------|
| Cast steel     | GP240GH+QT       | 0.8   |
| Tin bronze     | CC480K-GS        | 0.1   |
| Cast chrome steel | GX20Cr14     | 0.2   |
| Aluminium multi-alloy bronze | CC333G-GC | 0.1   |
| Cast chrome nickel steel | GX5CrNi19-10 | 0.05  |
| Noridur        | GX 3CrNiMoCuN24-6-2-3 | 0.02  |

Leading producers offer cast steels with increased resistance to cavitation erosion e.g. Noridur and Noriclor (KSB) or X-Cavalloy (Flowserve). They are compared in table 4.

| Name    | Noridur | Noriclor | X-Cavalloy |
|---------|---------|----------|------------|
| C       | 0.04    | 0.04     | 0.1        |
| Si      | 1.5     | 1.0      | 0.5        |
| Mn      | 1.5     | 1.0      | 15.5       |
| Cr      | 23.0–26.0 | 22.0–25.0 | 18         |
| Ni      | 5.0–8.0 | 4.5–6.5  | 0.5        |
| Mo      | 2.0–3.0 | 4.5–6.0  |            |
| Cu      | 2.75–3.5 | 1.5–2.5  |            |
| N       | 0.10–0.2 | 0.15–0.25 | 0.25       |

Noridur and Noriclor are based on chrome, nickel and molybdenum whereas X-Cavalloy distinguishes by a large share of 15.5% Manganese.

7 Conclusion

The feed pumps operation in power plant systems takes place at static heads of 25–30m resulting from typical elevation heights of the feed water tank. Even for suction impellers with large suction specific speed and relatively large NPSH margin it leads to cavitation operation. One way is to avoid cavitation by
using a booster pump. The reliability of single-stage, double-suction pumps working usually as booster pumps is very high due to the lack of balancing system, low rotational speed, and simple structure. The disadvantage of the system with a booster pump is slightly lower efficiency reaching a fraction of a percent. Therefore, the assessment of the system operation with or without a booster pump should be preceded by LCC analysis.

Without a booster pump, an acceptable impeller lifetime of 40,000 hours requires materials with high resistance to cavitation erosion. New cast steels with erosion resistance more than ten times higher than typical chromium cast steels are the answer to these needs. However, further material advancement extending impeller lifetime is required.

References

1. Gulich J.F. - Centrifugal Pump - Springer-Verlag, Berlin Heidelberg, (2008)
2. ANSI/HI 9.6.1–2012 Rotodynamic Pumps Guideline for NPSH Margin
3. McGuire, J. T., So You Need Pumps for a Revamp!, Pumps & Systems Magazine, August (1996).
4. Schiavello B., Visser F.C. - Pump cavitation – various NPSHR criteria, NPSH margins, and impeller life expectancy - Proceedings of the twenty-fifth 138 International Pump Users Symposium, (2009)
5. Md Rakibuzzaman, Sang-Ho Suh, Hyoung-Ho Kim, Young-Hoon J - Relationship between Cavitation Incipient and NPSH Characteristic for Inverter Drive Centrifugal Pumps - The KSFM Journal of Fluid Machinery - Vol. 18, No. 6, pp.76-80, (2015)
6. Sedlar M., Sputa O., Komarek M - CFD Analysis of Cavitation Phenomena in Mixed-Flow Pump, International Journal of Fluid Machinery and Systems, Vol. 5, No. 1, January-March (2012)
7. Sedlár M., Komárek M., Vyrobal M., Doubrava V., Varchola M., Hlbocan P. - Experimental and numerical analysis of unsteady behaviour of high efficiency mixed-flow pump - , EPJ Web of Conferences 67, 02104 (2014)
8. KSB Lexicon - https://www.ksb.com/centrifugal-pump-lexicon/cavitation-erosion/328182/
9. McCaul C. - A cavitation-resistant casting alloy for pumps - status after ten years' commercial use – in Advanced Materials for Fluid Machinery, Wiley, (2004)