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Pump cavitation in feed water systems - remedies

Krzysztof Karaśkiewicz[1,*]

[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® 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.

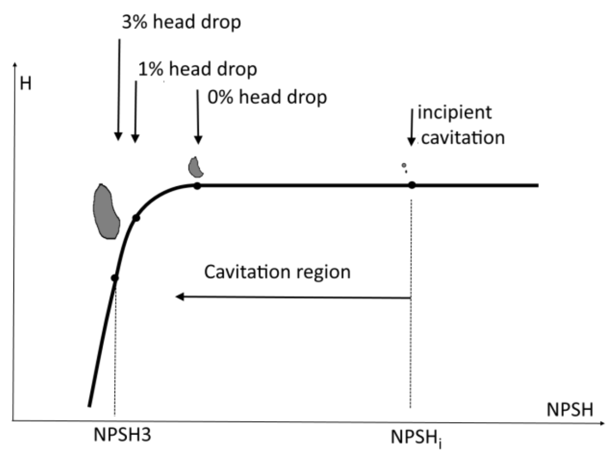

Fig. 1. Stages of cavitation at constant flow rate.

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.

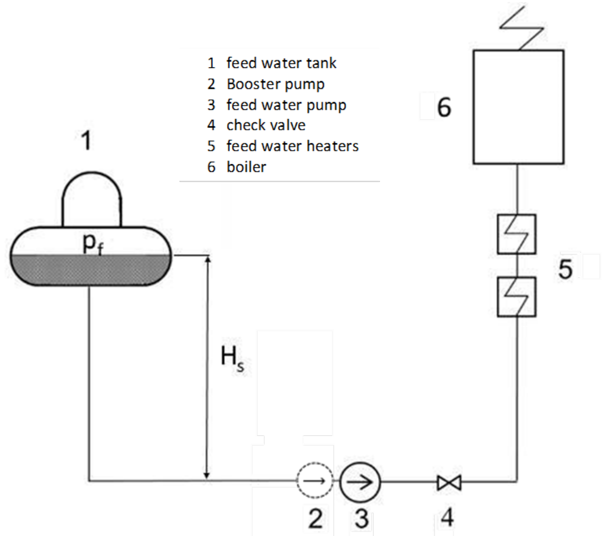

Fig. 2. Feedwater system

The low-pressure side of the system consists of a feedwater tank with a degasser, a suction pipeline with fittings (filter, elbows, etc.), feed water pump with or without a booster pump.

The water in the feed pump is of the temperature above 120°C. This affects the vapor head, which for such temperatures is $H_v > 22$m.

The disposable excess of the system is determined by the difference between the total amount of energy at the end of the suction system (inlet to the feed pump) and the evaporation height. It can be converted to the form:

$$NPSHA = (H_f - H_v + H_s) - H_{str} \qquad (1)$$

wherein: $H_{str} \cong a(Q/Q_n)^2$

Taking into account that the pressure in the feed water tank nearly equals vapor pressure $H_f \cong H_v$

$$NPSHA \cong H_s - a(Q/Q_n)^2 \qquad (2)$$

Typical static heads in industrial plants are $H_S = 25 \div 30$m. The losses for optimal flow usually do not

exceed a few meters, hence the typical values of hydraulic resistance in equation (2) a = 2÷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_q = 20), rated rotational speed n = 5000 1 / min, and flow rate Q_{BEP} = 520m^3/h, *NPSH3* can be expected:

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

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* ≅ 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 1 / min reduces the Net Positive Suction Head to *NPSH3* ≅ 10m.
To avoid cavitation some margin is recommended. The NPSH margin is different depending on source literature, for example [1] gives:

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

The Hydraulic Institute [2] recommends:

Table 1. Examples of NPSH margin by HI.

Industry	Application	NPSH Margin
Petroleum / hydrocarbon process	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	1,0 m
Electric power generation	Boiler feed < 250 kW/stage	30%
Water	Typical, stainless steel or aluminum-bronze impeller, < 75 kW/stage	10% or 1,5m
Building services	Typical for pumps in open systems (not pressurized)	Up to 10% or 0.6m
General	Often a standard catalog pump	10% or 1,0m

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%$^{(4)}$

(1) Higher margin for larger pumps
(2) minimum 1m
(3) up to 1900kW at n=3600 rpm
(4) U_1 greater than 30 m/s

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

4 Incipient cavitation and NPSHi/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_q = 16 to n_q = 90.

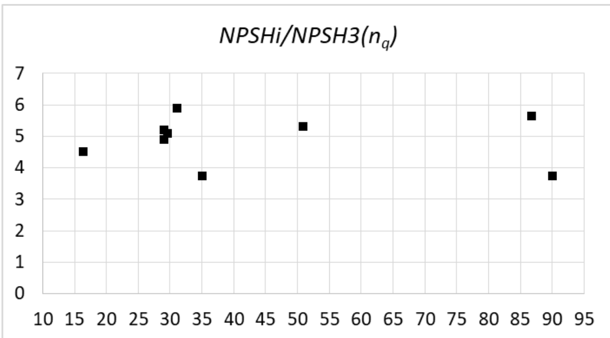

Fig. 3. NPSHi/NPSH3 ratio for the data from [4,5,6,7] as a function of specific speed.

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].

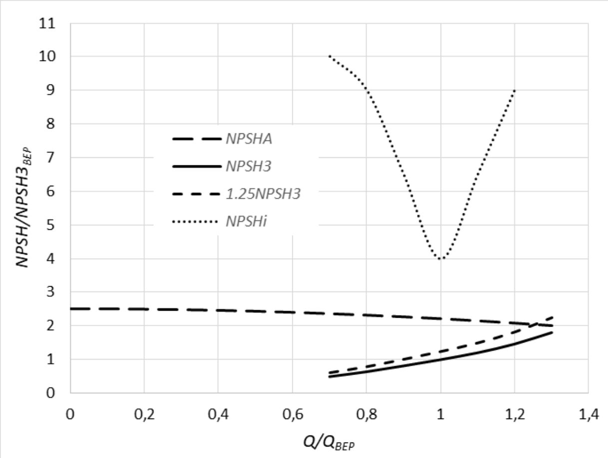

Fig. 4. *NPSH* curves for feed water pump system in small power plant

The field below the $NPSH_i$ curve is the cavitation area so feedwater pump operates in cavitation because of $NPSHA \leq NPSH_i$.

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.

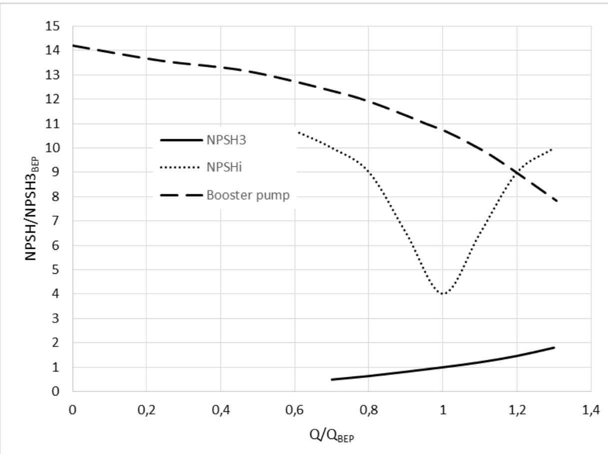

Fig. 5. Impact of the booster pump on a feed water pump operation

Figure 5 shows *NPSH* of the system with a booster pump where non-cavitation operation of the feed pump is guaranteed for flow rates $Q < 1.2Q_{BEP}$. The presence of the booster pump slightly increases system complication and decreases efficiency, but extends trouble-free operation time by over 100,000 hours. Despite the tendency to eliminate booster pumps, the final decision should be preceded by LCC analysis.

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

Table 3. Cavitation erosion: Materials graded by increasing cavitation resistance; weight loss index for typical cast metals (based on grey cast iron JL 1040 with an index of 1.0)

Name	**Type**	**indeks**
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	GX3CrNiMoCuN24-6-2-3	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.

Table 4. Commercial cast steels resistant to cavitation erosion.

	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, nickle 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.

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