Examining Centrifugal Pump on Cavitation

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Abstract: *Pumps influence all our lives directly or indirectly. Pumps are one of the most well-known and widespread type of a machine. Their task is to move fluid from one place to another, generally from a lower place to a higher one in a certain distance. For the safe operation of the pumps, it is essential to examine the operating parameters. The majority of specialists who are experts in pump technologies are familiar with cavitation. They are aware of its detrimental effects. Firstly, in our study we will briefly present the cavitation as a phenomenon. We will briefly present the place of measurement. Then we state the results of our measurements carried out type BKS 300. Finally, we present regression calculation for BKS 300 type pump for H-NPSH curve. Our goal is to call attention to the proper way of operating centrifugal pumps, the cavitation generated during operation as a harmful phenomenon and its development examined in practice by us.*

Keywords: *Pumps, cavitation, operating parameters, regression, H-NPSH curve*

1. Introduction

Our literature research aiming at determining cavitation has revealed several definitions in use. Until the 1970s, cavitation did not have a common definition. According to Ackeret's definition (1930), the formation of vapour cavities (bubbles) in a liquid occurs when the pressure at a given point of the flow compared to a given pressure reaches the saturated-water-vapour pressure belonging to the given fluid temperature. Then the fluid starts boiling and due to the formation of bubbles, it turns into a heterogeneous mixture of vapour-fluid phase [1].
As Knapp-Daily–Hammitt (1970) defined, cavitation is a phenomenon in which bubbles grow in the stationary or moving fluid and this growing phase is followed by a collapse phase. If the collapse of the bubbles fails to happen, due to gas release and vapourisation affecting the growing phase, effervescence or boiling occur. Accordingly, we make a distinction between gaseous and vaporous cavitation, which mainly differ in their damaging effect on the material. Gaseous cavitation precedes vaporous cavitation. At a given pressure, bubbles start growing under the influence of the gases dissolving from the fluid. Reaching a critical size, their static equilibrium gets imbalanced and they start a quick growing phase. This is vaporous cavitation, which has a damaging effect [2]. István Józsa (2013) claims that the physical process of cavitation is linked to the phenomenon of the boiling point, because if "saturated steam pressure" corresponding to the temperature develops at a given location in the flowing fluid, there the fluid turns into vapour and a bubble filled with steam evolves. The head space of the bubble is condensed if the flow travels the vapour cavity (i.e. bubble) into a location of higher pressure and the bubble implodes as a result of the thus created space. This bubble implosion is called cavitation [3]. As Tamás Lajos defined, when the pressure in a fluid flowing in a pump decreases to the level of saturated steam pressure, steam bubbles/voids evolve. When these bubbles travel to a place of higher pressure, the steam condenses and the bubbles implode causing significant damage on the surface of the nearby solid object. The formation and implosion of the bubbles are called cavitation, while the damage is cavitation erosion [4].

2. Ganz hydro-plant laboratory

In the Ganz hydro-plant laboratory there is an open and a closed test loop.
The measurements feasible in the open test loop are the following:

- Measurement on a pool with a weir
- Measurement on a pool with an induction device
- Measurement in measurement wells

The weir is applied for doing measurements with high volume pumps. This range is between 3.5 - 10 m^3/s. The drawback of a weir is that its difference in water level is a limit under which heads cannot be measured. The induction devices are the size of NA200, 300, 400 and 600, meaning that below 3.5 m^3/s flowrate these devices are used since their loss is insignificant but they are relatively precise.
At the measurement well machines of studs with 100-400 mm can generally be examined. Cavitation breakdowns can also be examined by reducing the water level in the well. At the measurement wells, it is important to ensure that during the cavitation measurement the pump is provided with a smooth and bubbleless flow from the well water getting deeper and deeper.

Figure 1 shows the closed test loop of the Ganz factory, which was put into operation in 2012.

Fig. 1. The closed test loop of the Ganz factory

Besides low energy input, in order to be cavitated easily, the test machine is placed at the highest point of the 5 m high scaffold of the closed test loop. The figure shows the model of the cooling pumps of the Rostov Nuclear Power Plant installed in horizontal shaft arrangement. In the background, the tank on the suction side can be seen. The pump draws from here. In this tank, it is not recommended the vacuum to drop under 2 vom absolute pressure because air secession becomes intense and the operation water becomes "gassy", which ruins the cavitation measurement. The circulator can never cavitate as it would interfere the measurement. For this reason, it is installed at about 2 metres deep in the pool.

3. Steps of measurement of BKS 300 type pump

In parallel with closing the sliding valves on the suction side, we open the one on the discharge side. This makes the flow rate constant. In our case, the only alteration from the conventional cavitation measurement was that a supply pump got built into the suction side (needed because of low water level) [5].

Table 1 shows the measured and readings values.

Table 1: Measured values/Readings

Name	Labels	Unit of Measure
Time of Measurement	t	hh:mm
Revolution per minute	n	rpm
Flow rate	Q_m	m^3/h
Height difference between the centre lines of the tube entering the pressure gauge and the suction tube	Z_m	m
Absolute suction pressure	p_{m1}	kPa
Absolute discharge pressure	p_{m2}	kPa
Absorbed electrical power	$P_{electric}$	kW
Water temperature	T_w	°C
Ambient temperature	T_a	°C
Electric motor's efficiency	η_{motor}	%

Table 2 shows the calculated values.

Table 2: Calculated values

Name	Labels	Unit of Measure
Water density	ϱw	kg/m^3
Saturated vapour pressure	Ps	Pa
Flow rate	Qc	m^3/s
Inlet flow velocity	vm1	m/s
Outlet flow velocity	vm2	m/s
Delivery head calculated at measured rpm	Hc	m
NPSH at measured rpm	$\Delta h_c(NPSH_c)$	m
Calculated shaft power	P_{mech}	kW
Aggregate performance	P_{agg}	kW
Pump's Best Efficiency Point	η_{pump}	%
Aggregate Efficiency	η_{agg}	%
Converted delivery head	H	m
Converted NPSH	Δh(NPSH)	m
Converted flow rate	Q	m^3/h
Converted shaft power	P	kW

Inlet flow velocity

$$v_{m1} = \frac{Q_c}{\left(\frac{d_1}{1000}\right)^2 * \pi/4} \quad (1)$$

Outlet flow velocity

$$v_{m2} = \frac{Q_c}{\left(\frac{d_2}{1000}\right)^2 * \pi/4} \quad (2)$$

Delivery head calculated at measured rpm

$$\mathrm{H_c} = 0{,}102 * \frac{\mathrm{p_{m2}} * 1000 - \mathrm{p_{m1}} * 1000}{\varrho w} + 0{,}827 * \mathrm{Q_c^2} * \left(\frac{1}{\mathrm{d_2^4}} - \frac{1}{\mathrm{d_1^4}}\right) + \mathrm{Z_m} \quad (3)$$

NPSH at measured rpm

$$\Delta h_c(NPSH)_c = 0{,}102 * \frac{p_{m1}*1000+P_a-P_s}{\varrho_w} + 0{,}827 * Q_c^2 * \frac{1}{d_1^4} + Z_m \quad (4)$$

Calculated shaft power

$$P_{mech} = \frac{P_{mech}}{100} * \eta_{\eta motor} \quad (5)$$

Pump Efficiency

$$\eta_{pump} = 0{,}981 * Q_c * \frac{H_c}{P_{mech}} \quad (6)$$

Aggregate Efficiency

$$\eta_{agg} = \eta_{\eta motor} * \frac{\eta_{pump}}{100} \quad (7)$$

Converted delivery head

$$H = H_c * \left(\frac{n}{n_{guar}}\right)^2 \quad (8)$$

Converted NPSH

$$\Delta h(NPSH) = \Delta h_c(NPSH)_c * \left(\frac{n}{n_{guar}}\right)^2 \quad (9)$$

Converted flow rate:

$$Q = Q_c * \left(\frac{n}{n_{guar}}\right) * 3600 \quad (10)$$

Converted shaft power:

$$P = P_{mech} * \left(\frac{n}{n_{guar}}\right)^3 \quad (11)$$

4. Presenting measurement results

Table 3 shows the readings.

Table 3: Readings

No.	Readings									
	t	**n**	**Qm**	**Zm**	**pm1**	**pm1**	**Pelectric**	**Tw**	**Ta**	**ηmotor**
	h/min	rpm	m3/h	m	kPa	kPa	kW	° C	° C	%
1	10:03	1491	1300	-0.095	138.9	584.4	207.9	21.9	24.1	93.0
2	10:12	1491	1300	-0.095	46.9	494.1	207.5	21.9	24.1	93.0
3	10:17	1492	1303	-0.095	5.6	452.7	207.9	21.9	24.1	93.0
4	10:21	1491	1301	-0.095	-35.0	412.2	207.8	21.9	24.1	93.0
5	10:27	1492	1300	-0.095	-39.8	406.8	207.8	21.9	24.1	93.0
6	10:32	1492	1300	-0.095	-47.8	392.3	207.8	21.9	24.1	93.0
7	10:40	1491	1300	-0.095	-53.7	382.5	206.7	21.9	24.1	93.0
8	10:51	1491	1300	-0.095	-57.7	365.6	205.7	21.9	24.1	93.0
9	11:04	1491	1300	-0.095	-61.7	333.2	201.8	21.9	24.1	93.0
10	11:10	1491	1302	-0.095	-62.5	262.3	188.4	21.9	24.1	93.0

Table 4 shows the calculated values.

Table 4: Calculated values

No.	Calculated values										
	ϱw	**ps**	**Qc**	**vm1**	**vm2**	**Hc**	**Δhc**	**Pmech**	**Pagg**	**ηpump**	**ηagg**
	kg/m3	Pa	m3/s	m/s	m/s	m	m	kW	kW	%	%
1	997.7	2642	0.3611	5.1087	5.1087	44.5	23.4	193.3	207.9	81.4	75.7
2	997.7	2642	0.3611	5.1087	5.1087	44.7	14.0	193.0	207.5	81.9	76.2
3	997.7	2642	0.3619	5.1205	5.1205	44.7	9.7	193.3	207.9	81.9	76.2
4	997.7	2642	0.3614	5.1126	5.1126	44.7	5.6	193.3	207.8	819	76.1
5	997.7	2642	0.3611	5.1087	5.1087	44.7	5.1	193.3	207.8	81.7	76.0
6	997.7	2642	0.3611	5.1087	5.1087	44.0	4.3	193.3	207.8	80.5	74.8
7	997.7	2642	0.3611	5.1087	5.1087	43.6	3.7	192.2	206.7	80.2	74.6
8	997.7	2642	0.3611	5.1087	5.1087	42.3	3.3	191.3	205.7	78.1	72.6
9	997.7	2642	0.3611	5.1087	5.1087	39.4	2.9	187.7	201.8	74.2	69.0
10	997.7	2642	0.3617	5.1165	5.1165	32.2	2.8	175.2	188.4	65.1	60.5

Table 5 shows Converted values.

Table 5: Converted values

No.	Converted values			
	H	Δh	Q	P
1	44.2	23.2	1294.8	191.0
2	44.4	13.8	1294.8	190.7
3	44.3	9.6	1269.9	190.6
4	44.4	5.5	1295.8	190.9
5	44.2	5.0	1293.9	190.5
6	43.6	4.2	1293.9	190.5
7	43.2	3.6	1294.8	189.9
8	41.9	3.2	1294.8	189.0
9	39.1	2.8	1294.8	185.4
10	32.0	2.8	1296.8	173.1

Table 6 shows the Measuring instruments' accuracy errors.

Table 6: Measuring instruments' accuracy errors

Amount of Delivered Water	**Symbol**	**Measurement accuracy**
Measuring instrument's accuracy		
Delivery Height	H	±0.1%
Amount of Delivered Water	Q	±0,2%
Shaft torque	M	±0.1%
Revolution per minute	n	±0.05%
Operation water temperature	Tw	±0,1C°
Atmospheric pressure	Pa	±0.5 mbar
Suction pressure	p1	±0.1%

Figure 2 shows the H-NPSH curve.

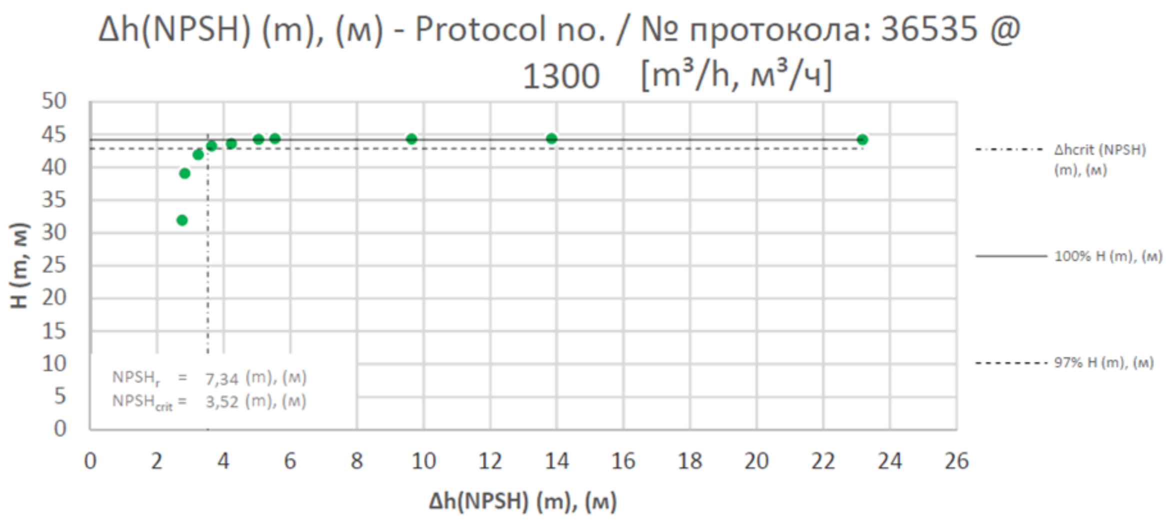

Fig. 2. H-NPSH curve

5. Regression calculation for BKS 300 type pump for H-NPSH curve

In regression analysis we use the term non-linear regression calculation when the relationship between dependent and independent variables cannot be described by a linear function. In this case**,** a curve line fits the dots the best. The procedure for finding the equation of the curve that fits the set of points best is called a curve fitting. In practice, Measurement data is used in different ways. If we know the shape of the physical quantity with which it can be described and function parameters are called by a function fit, this is called regression. In the case of regression, we determine the parameters of the best-fit function.

Preferably selected nonlinear functions are:

- logarithmic
- polynomial
- exponential
- hyperbolic
- exponential

Based on measurements by Ganz, I determined an exponential function.
Based on the measured data I determined and plotted an exponential function, which fits to the measured data. I used Python for curve fitting.

An exponential equation from the measurement data:

$$f(x) = A \cdot \left(1 - e^{-\theta \cdot (x - x_0)}\right) \tag{12}$$

Figure 3 shows a curve fitting using the Pyton software package. The curve fits well with the measurement points.

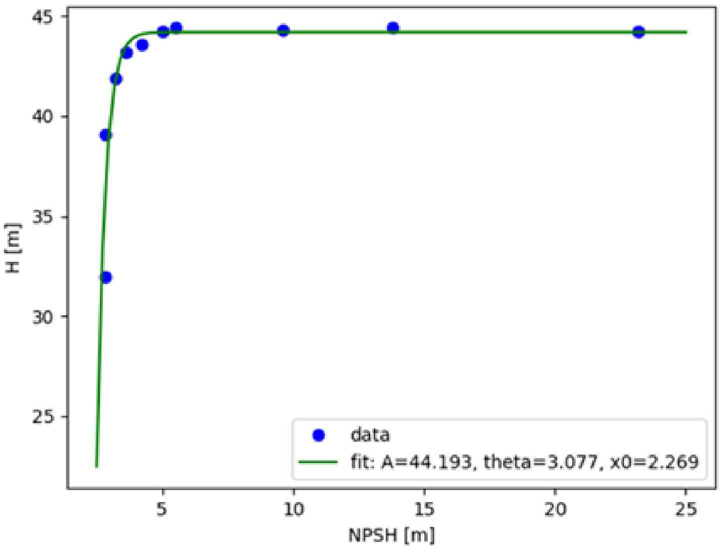

Fig. 3. Exponential function fitting

6. Conclusions

The scientific examination of cavitation assists manufacturers and users to avoid this undesirable phenomenon. Its possible solution is to determine the NPSH parameter and to take it into account when you are choosing and installing the pump and during its operation. In my study I presented Ganz hydro-plant laboratory and I described the measurement results carried out by a BKS 300 type pump. It is important to note that measurements during operation we were carried out under standard conditions. Based on the measured data I determined and plotted an exponential function, which fits to the measured data. I used Python for curve fitting. The curve fits well with the measurement points.

References

[1] Ackeret, J. *Cavitation, Handbook of Experimental Physics / Kavitation, Handbuch der Experimentalphysik*. Leipzig, Akademische Verlagsgesellschaft, 1931.
[2] Knapp, Robert T., James W. Daily, and Frederick G. Hammitt. *Cavitation*. New York, McGraw-Hill Book Company, 1970.
[3] Józsa, I. *Vortex pumps in practice / Örvényszivattyúk a gyakorlatban*. Budapest, Invest-Marketing Bt., 2013, pp. 10-128.
[4] Lajos, T. *Fundamentals of hydrodynamics / Az áramlástan alapjai.* Mackensen Kft., 2008, p. 31.
[5] Fecser, Nikolett. "Examining Fire Pump Nocchi CB8038T on Cavitation." *Periodica Polytechnica Transportation Engineering* (2018): 1-5.
[6] Sara, B. Annex 3 of test report. Budapest, 2018.