Examining Centrifugal Pump BKS300 on Cavitation

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Abstract: *Pumps influence all our lives directly or indirectly. Pumps are one of the most widespread types of turbomachines. Their task is to pump fluid from one place to another and engineers who are experts in pump technologies are familiar with the phenomenon of cavitation. The present work focuses on the cavitation from an experimental point-of-view. Measurements have been carried out on the type of a centrifugal pump. A polynomial fitting method has been developed and a semi-empirical formula has been proposed. Furthermore, numerical simulations have been performed for modelling two-phase cavitating turbulent flows in the investigated centrifugal pump. The objective of this study is to bring attention to cavitation and contribute to the knowledge in terms of its harmful effects.*

Keywords: *Pumps, fluid, cavitation, measurement, centrifugal pump*

1. Introduction

The advantages of measuring the noise and oscillation levels in cavitation is that during noise measurement no modification is required on the hydro-plant, and it also provides information about cavitation developed in places hardly or not available at all for visual observations. By measuring noise, the type of cavitation and whether its effect is damaging or not can be identified [1].
Hungarian researchers have dealt with the phenomenon of cavitation in-depth since the 1960s. Sebestyén and Varga carried out cavitation measurements with hydrofoils of variable pitch angles. They determined the Strouhal number of the cyclical cavitation flow behind the cylinder over critical Reynolds numbers [2].
A measuring technological method was developed to examine cavitation noises at discrete frequency. Sebestyén and Varga have also carried out experiments on the cavitation erosion rates. They concluded that the cavitation number at noise peak equals to the cavitation number at the erosion peak. The research results of Fáy in cavitation scale effect were employed in the standardisation process by the International Electrotechnical Commission. The value of noise level was measured at a given frequency, they were illustrated along with the cavitation number, then from the curves presenting noise levels he concluded the different phases of the development of cavitation [3].
Sebestyén and Varga (1970) recorded their results of the experiments related to the cavitation bubbles formed behind cylinders of various diameters, wedges of different pitch angles and the hydrofoils of variable pitch angles and cavitation erosion on films. The video film recorded by Sebestyén and Varga was digitalised by Könözsy, 1999 [4].

2. Several types of cavitation

Transient cavitation bubble (travelling) are: those bubbles which are taken away by the flow. Quasi-stationary cavitation bubbles (fix): appear adhered to a solid object - for example at a fix place of a pump impeller.
Layer cavitation: is the thin headspace - independent from the concentration of the cavitation nuclei - of a quite uniform thickness created from the mass of the bubbles and adhered to the surface.
Cloud cavitation: a special type of bubble cavitation. It is the cloud of small, spherical bubbles with higher vapour concentration of nuclei, which depends on the viscosity of the flowing medium and the effects of turbulence.
Physical cavitation: a smaller type of cavitation occurs under normal operational conditions in holes or due to detachments caused by collision. Its effects can be tracked down by noise and smaller erosive dissolutions. The effects are undetectable in the pump characteristic curves and do not cause reduction in transfer or a decline in efficiency.
Mechanical cavitation: causes "detachments" in the pump characteristic curves and the operation of the pump becomes chaotic.
Supercavitation (blocking state): supercavitation is a long stable cavitation bubble in the measurement area of the cavitation channel developing when a small number of cavitation occur and the implosion of cavitation bubbles fails in the flow [5].

3. The venue of the measuring process

Ganz Works have a long history in producing pumps. Their results in the field are both well-known and internationally recognised. It should be noted here that among the authors of the related literature there is István Józsa, who was one of the key technical experts at Ganz. In order to meet the strict international requirements and the specific needs - like pumps for nuclear power plants, it was necessary to use appropriate methods for measuring the characteristics and quality of their products. The first author of this work had the opportunity to join a cavitation measurement led by Balázs Sára, who is the designer of the system carrying out cavitation measurements.
The hydro-plants of Ganz Works have studs with 200-2500 mm in diameter and fully exploit the potentials of the revolution range. Mostly irrigation pumps, heat pumps used in power plants and smaller/medium turbines are manufactured. Over the years the performance of the units has increased. The market has also had a demand for machines with higher and higher revolution. Without running trial tests, the delivery of large size machines or the ones transported into remote countries posed a serious risk. To avoid such problems, the first hydro-plant test stations were created and later on constantly developed. The problem of enhancing performance was solved with building a new test station in 1990. To measure cavitation, you can use open and closed test loops. The open test loop of Ganz' trial station is marked among the largest ones in Central Europe.
Before delivery, all the machines not exceeding the measurement thresholds of the trial station are tested. Whereas the types of tests that can be carried out in the trial station are limited since, due to the size of the machine, some equipment cannot be built at the trial station, they are normally assembled on site. The model test method was created to be able to carry out tests on such large-sized machines. In such cases a smaller replica of the original large-sized machine is built with the same rheorological and geometric features. This model serves the basis for analysing the characteristic curves; and the results obtained are used at the process of designing the product, handing it over to the costumer and verifying warranty information of the final life-size machine.
The full range of the characteristic curve can be measured on the model built into the test loop in the hydro-plant laboratory. The model machine itself cannot be too small - with usually a power of 50-100 kW; its minimum size and the method of the measurement are determined by international standards. Although flow sections play an important role, the most important factor is the proportional reduction of the elements essential in energy conversion (impeller, spiral case, guide vanes, stay vanes, suction tube). The diameters of the model's impellers on suction side are normally between 150 - 400 mm, while the range of reduction - depending on the size of the real machine to be built - is between 1:2 – 1:8.

Over the recent years, the types of devices applied for examining models have been further enriched due to the development of computer aided modelling and simulation, which allows a wide scope of flexible and quick tests to be done. They are used for comparing the various versions, in particular during the preliminary phase carrying out approximation tests. For the delivery of largemachines and accurate efficiency and cavitation tests small sample tests and the conventional model measurement technique are used [6].

3.1 The main measurement devices of the hydro-plant laboratory

In the Ganz hydro-plant laboratory there is a closed test loop.
The main elements of closed test loops:

- Model pump
- Circulator
- Choke valve
- Devices for basic quantities
- Variable frequency drives
- Pressure-suction control

1. Measurement of the Amount of Delivered Water
Figure 1 shows the measurement pattern of the induction flow meter.

Fig. 1. Measurement of the Amount of Delivered Water

The principle of the measurement is that a winding creates strong and homogenous magnetic field in the transverse direction to the flowing. Meanwhile, in the water as an electric conductor, voltage evokes perpendicular to it. On the inner surface two electrodes are positioned and the evoked voltage between them is the measurement signal. This electrical signal is used for measuring flow rate. The flow must be homogeneous and vortex free, which can be achieved by applying a prolonged straight pipe, a rectifying grid and a confusor built into the initial part of the pipe.

2. Measuring shaft torque
A so called torque disk is used to measure the performance going through the shaft in a closed test loop. Its measurement principle is that under the influence of the torque, the measuring device in the disc is deformed flexibly and under the principle of strain gauge it is transformed into change of resistance. Finally, the change of resistance is transformed into a bridge voltage signal. The bridge on the revolving disc has to have supply voltage and the output signals to be received. This was implemented through using contactless signal transmission. The photo illustrates the measurement disc. The outer black ring contains the antenna and the receiver, which receives the measurement signals transmitted by the revolving part. The measurement limit of the torque disk is 1 kNm. To avoid measuring false torques, they are connected to the motor with a flexible coupling.
Figure 2 shows the torque disk.

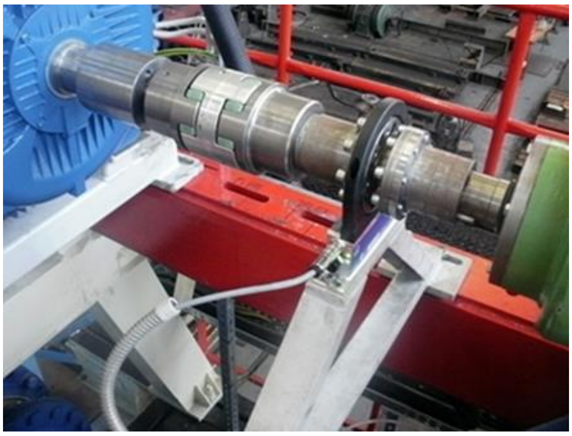

Fig. 2. The torque disk

3. Measuring pressure

Pressure is measured at three positions:

- Intake pressure
- Differential pressure:
- Atmospheric pressure

The measurement principle of the different types of pressure is similar to the one measuring the torque. The pressure deforms a flexible element, such as a membrane or an object made of silicon, and this deformation is converted into a resistance signal, which is accurately measurable under the principle of bridge-measurement. The picture shows that Psz pressure on the suction side affects on the pipe on the right, while Pny pressure on the discharge sideaffects on the pipe on the left. The differential pressure gauge is their difference and the head is gained from its signal. The absolute pressure gauge placed into the middle measures the pressure on the suction side, and the pressure needed for calculating the cavitation coefficient (NPSH) is gained from it. The pressure gauge on the left is especially designed to be able to carry out the accurate measurement of the atmospheric pressure. The measured value is also needed for calculating NPSH.

4. Revolution gauge

Measuring revolution means the counting of impulses per time unit. In the closed apparatus an incremental encoder made by Baumer is attached to the end of the motor shaft and it emits 4096 signals per revolution. The signals are counted by the computer and analyzes the revolution per minute. This signaller is positioned under the case of the motor; therefore it is invisible from outside. In the open system, mainly the optical revolution counter is the best device. The pump units measured here are varied. Generally, there is a revolving element (coupling, axle stud) the reflective markings can be sticked to or painted on. The sign is lit by the trip meter; the counter counts the reflected impulses or the period time and displays the revolution per minute.

5. Pressure regulation and cavitation measurement

In the illustration the opened scheme of the closed test loop and its pressure line can be seen. The pressure line is determined by defining one of its points. A tank including an air cushion is attached at point „A". The pressure of the air cushion is kept constant by a controller. Decreasing the pressure of the air cushion step-by-step makes the pressure line sink accordingly. The operating point of the pump is unchanged until the pressure on the suction side (more precisely NPSH, net positive suction head) approaches the critical value. Then the pump cavitates and its head decreases. In general, the pressure is decreased in 8-10 steps to find the breakdown point. This is called cavitation measurement.

6. Pressure regulator

The figure below illustrates the conceptual operational model of the pressure regulator. The regulator has a strong and moderate function. The strong one is for carrying out large pressure changes rapidly. The moderate one is used after finishing the strong phase and only some refining is needed. Both moderate and strong functions control between 0.2 bar abs vacuum and 2 bar abs compressed air pressure. The strong function actuates valves with ON/OFF switches. The moderate function alters the opening of small size valves. The vacuum is provided by a water ring air pump, while the compressed air comes from the air network of the factory. The regulator system is assembled from FESTO elements. When filling up the system, special attention is needed in order to keep the air cushion up and water not to get into the FESTO system. Thus, it is equipped with a diaphragm valve on the top of the tank on the suction side.

3.2 Presenting measurement results

Table 1 shows readings.

Table 1: Readings [7]

No.	Readings									
	t	**n**	**Q_m**	**Z_m**	**p_{m1}**	**p_{m1}**	**P_e**	**Tw**	**Ta**	**η_m**
	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 2 shows calculated values.

Table 2: Calculated values [7]

No.	Calculated values									
	ϱ_w	**p_s**	**Q_c**	**v_{m1}**	**v_{m2}**	**H_c**	**Δh_c**	**P_m**	**P_{agg}**	**η_p**
	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
2	997.7	2642	0.3611	5.1087	5.1087	44.7	14.0	193.0	207.5	81.9
3	997.7	2642	0.3619	5.1205	5.1205	44.7	9.7	193.3	207.9	81.9
4	997.7	2642	0.3614	5.1126	5.1126	44.7	5.6	193.3	207.8	819
5	997.7	2642	0.3611	5.1087	5.1087	44.7	5.1	193.3	207.8	81.7
6	997.7	2642	0.3611	5.1087	5.1087	44.0	4.3	193.3	207.8	80.5
7	997.7	2642	0.3611	5.1087	5.1087	43.6	3.7	192.2	206.7	80.2
8	997.7	2642	0.3611	5.1087	5.1087	42.3	3.3	191.3	205.7	78.1
9	997.7	2642	0.3611	5.1087	5.1087	39.4	2.9	187.7	201.8	74.2
10	997.7	2642	0.3617	5.1165	5.1165	32.2	2.8	175.2	188.4	65.1

Table 3 shows converted values.

Table 3: Converted values [7]

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

4. Determination of polynomial equation for centrifugal pump

Most of the semi-empirical formulas required for NPSH diagrams are not available in the literature on processed cavitation. First, we developed a polynomial fitting method and after we proposed a semi-empirical formula that can be used in engineering practice. Semi-empirical formulas are polynomials that are generated by fitting a polynomial to a measured dataset which can easily be employed in engineering practice, because the polynomial can produce an accurate agreement with the measured dataset. Semi-empirical formula provides a more accurate analytical representation of the H-NPSH curve based on measurement points. A MATLAB code has been developed for polynomial fitting to produce a semi-empirical formula relying on the experimental data as

$$y(x) = a_0 - a_1 \cdot x + a_2 \cdot x^2 - a_3 \cdot x^3 + a_4 \cdot x^4 - a_5 \cdot x^5 + a_6 \cdot x^6 - a_7 \cdot x^7 \tag{1}$$

Table 4 shows the coefficients of the proposed semi-empirical equation.

Table 4: The coefficients of the proposed semi-empirical equation

The sign of a coefficient	Value of Coefficient
a_0	0.000001
a_1	0.000071
a_2	0.001786
a_3	0.022991
a_4	0.164923
a_5	0.666180
a_6	1.416480
a_7	1.189720

Figure 3 shows the fitting of a seventh-degree polynomial on the measured dataset.

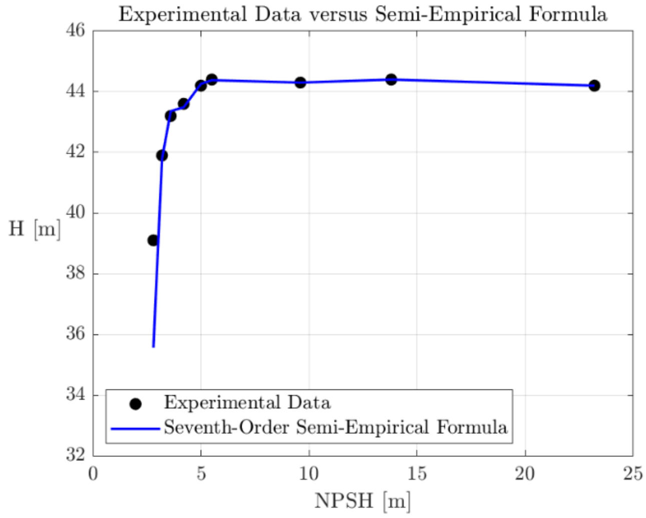

Fig. 3. Fitting of a seventh-degree polynomial on the measured dataset

Third, quarter, etc. degree polynomials can also be fitted to our data. I fitted a seventh-degree polynomial to the data of my measurement. However, for higher polynomials we need to be careful because our shape matrix will be poorly conditioned, and our solution will be uncertain. The polynomial fit perfectly to my measurement points, but oscillation occurred between the measurement points.

5. A computational model for modelling cavitation

The simulation of the two-phase cavitation turbulent flow was performed on the given geometry using 17,810,808 computational cells using a finite volume discretization method using the ANSYS-FLUENT v19.1 software package. The two-phase turbulent flow has been simulated by using the k-epsilon Realizable turbulence model and taking into account a standard wall function. In the two-phase flow, the primary phase was the liquid phase (density: 1000kg/m3, dynamic viscosity factor: 0.001 Pas) and the secondary phase was the vapor phase (density: 0.02558 kg /m3, dynamic viscosity factor: 1.26 * 10e-6 Pas).The resistance factor was calculated with the Schiller-Naumann relationship and the cavitation flow was simulated with the Schnerr-Sauer model. The reference pressure was determined from the measurements, which was 115,500 Pa. The resistance factor was calculated with the Schiller-Naumann relationship and the cavitation flow was simulated with the Schnerr-Sauer model. The reference pressure was determined from the measurements, which was 115,500 Pa. The computational time was two days using 64 processors (CPUs) and the simulations have been performed by using the High-Performance Computing (HPC) facility at Cranfield University, in the UK. These simulation conditions were taken into account in the construction of the data system for the final results during the simulation of the two-phase turbulent cavitation flow. The results were evaluated using the CFD-Post software package. Figure 4 shows the value of fluid velocity on impeller.

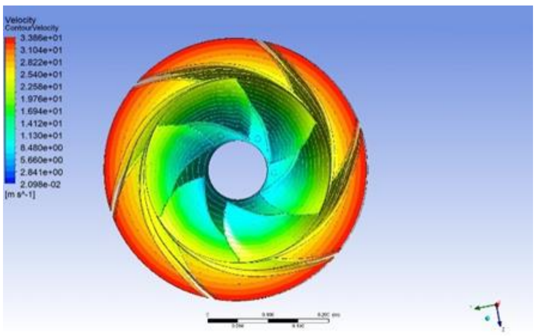

Fig. 4. The value of fluid velocity on impeller

Figure 5 shows the value of fluid velocity on impeller.

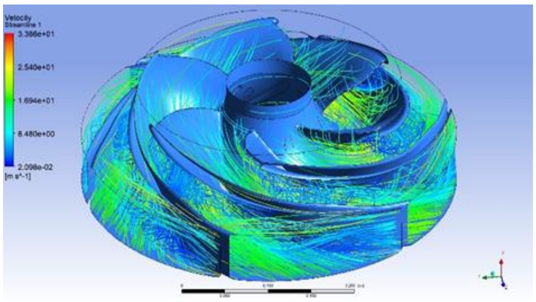

Fig. 5. The value of fluid velocity on impeller

Figure 6 shows the value of the fluid pressure on the impeller

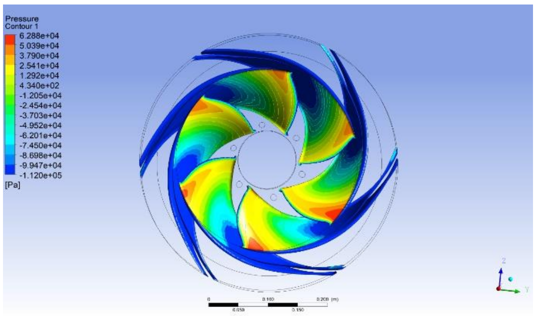

Fig. 6. The value of the fluid pressure on the impeller

The fluid velocity is 2.25 m/s at the inlet edge of the impeller, 5.66 m/s on the suction side of the impeller and 8.48 m/s onthe impeller side. On the suction and discharge sides the measured values were around 5.12 m/s, which shows that the simulation is close to the measured values. The pressure at the impeller leading edge is 25.41 kPa, the suction side suction side is -62.01 kPa and the impeller pressure is 112 kPa. On the suction side -61.7 kPa, on the suction side 333.2 kPa the measured value shows that the simulation is close to the measured value.

6. Conclusions

For the sake of safe operation of pumps, it is essential to investigate the operation parameters, because cavitation could lead to a pump failure. The present work was intended to contribute to the establishment of safe operation of pumps.
In the laboratory of Ganz, the most important parameters of a centrifugal pump have been experimentally studied. A MATLAB code has been developed within a research collaboration with Cranfield University to be able to generate a semi-empirical relationship for the characteristics curves of the pump studied at Ganz. With some modifications to the coefficients of the proposed semi-empirical equation, the contribution of the present work can also be used for other types of centrifugal pumps. Considering the constraints of polynomial fitting, we defined an exponential function to obtain the curve of the measured data. Relying on the measurements conducted, numerical simulations have been performed considering a two-phase turbulent flow which can be used to determine the cavitation processes and their effects on the investigated pump.
Within the research work presented here, we approached several companies and received information that simulation is only used in practice in the case of a machine failure. Therefore, it would be recommended to use simulation techniques in conjunction with measurements at the end of the production. As a consequence of that, it would be beneficial for the future development and for filtering out the dangerous structural elements of an already manufactured pump.

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