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CAVITATION WEAR OF PUMP IMPELLERS

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ABSTRACT
Cavitation is a common phenomenon in pump systems, negatively influencing their operating parameters and components such as impellers and, thus, causing considerable financial losses. This paper explains the problem of cavitation and cavitation erosion. The causes of cavitation in pump systems are analyzed. A selection of centrifugal pump impellers damaged by cavitation erosion are presented and examined. The authors also discuss ways of preventing cavitation and cavitation erosion in pump systems. Finally, relevant conclusions are drawn.
KEYWORDS: pump, impeller, cavitation, cavitation erosion, wear

ZUŻYCIE KAWITACYJNE WIRNIKÓW POMP

STRESZCZENIE
Kawitacja w układach pompowych jest zjawiskiem powszechnym, oddziaływującym negatywnie na parametry pracy oraz podzespoły pomp np. wirniki, przyczyniając się do dużych strat finansowych. W pracy wyjaśniono pojęcie kawitacji i erozji kawitacyjnej. Przedstawiono przyczyny występowania kawitacji w układach pompowych. Scharakteryzowano przykłady uszkodzonych w wyniku działania erozji kawitacyjnej wirników pomp wirowych. Omówiono sposoby zapobiegania kawitacji i erozji kawitacyjnej w układach pompowych, oraz sformułowano adekwatne wnioski.
SŁOWA KLUCZOWE: pompa, wirnik, kawitacja, erozja kawitacyjna, zużycie

1. Introduction

Cavitation often occurs in machines and flow equipment such as pumps, water turbines, gate valves, nozzles, measuring constrictions and wherever there is liquid flow. The understanding of cavitation enables implementation of effective measures to prevent this phenomenon and counteract the effects of cavitation erosion, thereby contributing to the development of centrifugal pumps, water turbines and marine propellers [1]–[3].

Cavitation exerts a negative effect on performance of hydraulic machines and can lead to their faster wear or failure. Along with erosion and corrosion, it is one of the main factors causing wear in pump system components such as impellers [4], [5]. The occurrence of cavitation in pump systems leads to high speed fluid flow, low pressure throughout the flow system, rapid changes in value and direction of fluid flow, flow detachment of the boundary layer, as well as other flow disturbances [6].

The purpose of this study is to describe the wear of pump impellers operated under cavitation conditions and to offer a solution for reducing cavitation erosion in machine parts.

2. Cavitation and cavitation erosion

Cavitation occurs in the area of a flowing liquid due to a local reduction of pressure below critical value, close to evaporation pressure of a liquid at a given temperature, leading to the formation of bubbles of steam (gas) in the lowest pressure and their rapid disappearance (implosion) in the area of a higher pressure [1], [2], [7]–[11]. Cavitation erosion is mechanical destruction of material due to implosion of cavitation bubbles in the vicinity of or directly on the wall, leading to material loss. Cavitation damage is a somewhat broader concept which relates to both cavitation erosion and other damage such as deformation of material, changes in surface layer stresses, structural changes, fatigue, microcracks etc. [1], [10]. Cavitation erosion is affected by many parameters describing physical and chemical properties of liquid and damaged material as well as cavitation intensity. Cavitation erosion relates to two phenomena: the emission of a shock wave due to bubble implosion and cumulative microjet formation directed towards the damaged solid wall. Cavitation erosion is a fatigue process [1], [8], [10], [12].

3. Cavitation wear of pump impellers

Cavitation caused by the method for transferring liquid from suction to discharge occurs in both displacement pumps and centrifugal pumps [6]. Impeller blades, the steering wheel and the inner surfaces of walls restricting liquid flow inside the pump may be damaged by corrosion, erosion and cavitation. These three types of damage can be easily distinguished from one another based on observation of the affected areas and their location in the pump's flow channels. Damage caused by cavitation (Fig. 1) occurs not only on the blades, but also on the side walls of the rotor (a). The lowest pressure areas are located on the rear wall of the blade near the edge of the inlet (b). If cavitation is intense, the ends of the blades at the outlet, the steering wheel paddle, the thong in the spiral and the stator blades can be damaged, too, consequently disturbing the flow of a liquid before its entering the impeller [2], [6].

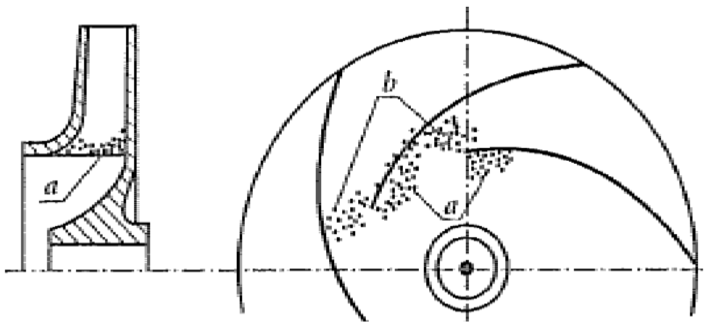

Fig. 1. Damage due to cavitation in the impeller of a centrifugal pump [2], [6]

In pumps, the damage of impellers and flow duct is primarily caused by three factors [13]–[15]:

- erosion (mainly caused by flowing liquid particles),
- corrosion (due to physicochemical properties of the material and liquid being transported),
- cavitation erosion.

The impact of erosion, corrosion and cavitation on pump impellers can be synergetic. In operating conditions one of the above phenomena may dominate. Different stages of damage of centrifugal pumps subjected to cavitation wear are shown in Figs. 2-4. The cavitation-worn areas of the impellers correspond to the cavitation damage shown in Fig. 1. The cavitation-worn areas are characterized by the presence of a rough surface as well as pitting and considerable material losses.

Fig. 2. Centrifugal impeller with a single curvature of the blades.
Cavitation damage: rear wall of the blade near the edge of the inlet, cast iron [3]

Fig. 3. Cavitation damage of the rotor disk located near the intake edge of the blades.
The magnified area shows a typical, rough surface area of cavitation erosion [16]

Fig. 4. Centrifugal impeller with a single curvature of the blades.
Cavitation wear of the inlet edges of the impeller blades, silicon bronze [17]

4. Methods for preventing cavitation wear of pump system components

Many researchers propose methods for preventing cavitation of hydraulic systems, including the application of design modifications, different installation and movement solutions, selection of material grade or the application of coating [3]–[7], [13]–[16], [18].

The design solutions are mainly based on applying a specified geometry of the turbine, i.e., the use of rotors with an increased width of the outlet, avoiding sharp bends in front of the impeller, the use of small angles of the inlet blades, the use of rotors with a smooth curvature of the front disc. Equally important is the selection of an appropriate amount of impeller blades; speed pumps require the highest number of blades, whereas in other cases, their number is reduced at the expense of applying a symmetrical variations in blade lengths.

Another method for optimization of pump system components exposed to cavitation wear is to use a different installation and movement solution through operation under nominal conditions corresponding to the highest efficiency. The aim of this process is to ensure the pump installation, so that suction height is as low as possible.

Higher cavitation resistance of machines and flow devices can be achieved by the use of materials resistant to cavitation erosion such as alloys or coatings [3], [4], [19]–[21]. Magnesium- and aluminium-based alloys have a low cavitation erosion resistance [10], [21]–[23]. Due to its excellent casting properties and relatively low cost, cast iron is the most widely used material in the production of impellers. Most exposed to cavitation, impellers are made of cast stainless steel, bronze, aluminum and nickel-based alloys, despite the high price of these materials [4], [14]. Higher cavitation resistance can be achieved by the use of adequate technologies for producing and shaping rotor properties. Increased cavitation erosion resistance can also be ensured by means of hardening by rolling, forging, grinding, etc., as well as by the use of surface treatment such as nitriding, carburizing, hardening or the manufacture of rotors in the form of a set of stamped parts [6]. In order to prolong the life of a rotor, polymer, metal or composite surface coating can be used. The use of coatings also increases the resistance of the rotor and pump components not only to cavitation but also corrosion and erosion wear [20], [24]–[26]. Regeneration by the use of metal or composite coating should be applied after an analysis of costs and expected quality and durability [5].

5. Conclusions

The destruction of flow elements and flow ducts in pumps is predominantly caused by erosion, corrosion and cavitation. Cavitation has a negative effect on the performance of pumps; it disturbs their operation and shortens their life. Cavitation is undesirable in pumping systems, and technology seeks to eliminate or reduce its negative effects.

Cavitation wear widely occurs in impeller blades, discs and casings. Cavitation resistance is a unique feature of material. The cavitation wear of impellers can be prevented by observing the recommended parameters of pump operation. It can also be prevented by the use of materials exhibiting high cavitation resistance or the application of polymer, metallic and composite coatings. Such coatings prevent cavitation as well as other types of wear.

6. References

[1] J.-P. Franc and J.-M. Michel, *Fundamentals of Cavitation*, vol. 76. New York, Boston, Dordrecht, London, Moscow: Kluwer Academic Publishers, 2004.
[2] S. Łazarkiewicz and A. T. Troskolański, *Pompy wirowe*. WNT, 1968.
[3] M. Szala, "Powłoki zwiększające odporność na zużycie kawitacyjne elementów maszyn i urządzeń," (rozprawa doktorska), Politechnika Lubelska, Lublin, 2016.
[4] I. J. Karassik, *Pump handbook*. New York: McGraw-Hill, 2001.

[5] P. Świtalski, *ABC techniki pompowej: podstawowe zasady działania i doboru pomp z szerokim omówieniem problematyki nadzoru i technik remontowych*. ZPBiP CEDOS Sp. z o.o., 2008.
[6] W. Jędral, *Pompy wirowe*. Wydaw. Naukowe PWN, 2014.
[7] M. Stępniewski, *Pompy*. Biblioteka Główna Politechniki Warszawskiej, 2005.
[8] K. Steller, *O mechanizmie niszczenia materiałów podczas kawitacji*. Polska Akademia Nauk Instytut Maszyn Przepływowych, 1983.
[9] C. E. Brennen, *Cavitation and Bubble Dynamics*. Oxford: Oxford University Press, 1995.
[10] K. Wójs, *Kawitacja w cieczach o różnych właściwościach reologicznych*. Oficyna Wydawnicza Politechniki Wrocławskiej, 2004.
[11] J.-P. Franc, M. Riondet, A. Karimi, and G. L. Chahine, “Material and velocity effects on cavitation erosion pitting,” *Wear*, vol. 274–275, pp. 248–259, Stycze 2012.
[12] M. Dular, B. Stoffel, and B. Sirok, “Development of a cavitation erosion model,” *Wear*, vol. 261, no. 5, pp. 642–655, 2006.
[13] P. Świtalski, *ABC techniki pompowej - Pump technology. Leksykon*. Wrocław: ZPBiP CEDOS Sp. z o.o., 2009.
[14] E. Grist, *Cavitation And The Centrifugal Pump: A Guide For Pump Users*. CRC Press, 1998.
[15] J. Bagieński, *Kawitacja w urządzeniach wodociągowych i ciepłowniczych*. Wydaw. Politechniki Poznańskiej, 1998.
[16] M. Szala, B. Filip, and I. Lenart, “Zużycie wirników pomp na skutek eksploatacji w warunkach kawitacji,” in *Ewaluacja wybranych procesów, technologii i systemów inżynierskich = Evaluation of selected processes, technology and engineering systems*, K. Drozd and M. Szala, Eds. Lublin: Politechnika Lubelska, 2014, pp. 64–77.
[17] M. Szala, T. Hejwowski, and I. Lenart, “Cavitation erosion resistance of Ni-Co based coatings,” *Adv. Sci. Technol. – Res. J.*, vol. 8, no. 21, pp. 36–42, 2014.
[18] W. Jędral, *Pompy wirowe odśrodkowe: teoria, podstawy projektowania, energooszczędna eksploatacja*. Oficyna Wydawnicza Politechniki Warszawskiej, 1996.
[19] M. Szala and T. J. Hejwowski, “Zwiększanie odporności kawitacyjnej stopów metali przez napawanie powłok,” *Przegląd Spaw. - Weld. Technol. Rev.*, vol. 87, no. 9, pp. 56–60, 2015.
[20] M. Szala and T. Hejwowski, “Odporność kawitacyjna powłok na osnowie niklu napawanych metodą płomieniowo-proszkową,” *Przegląd Spaw. - Weld. Technol. Rev.*, vol. 87, no. 10, pp. 36–41, Oct. 2015.
[21] M. Szkodo, *Erozja kawitacyjna materiałów konstrukcyjnych metalowych*. Wydawn. Politechniki Gdańskiej, 2008.
[22] M. Szala, T. J. Hejwowski, B. Dybowski, and A. Kiełbus, “The mechanisms of cavitation erosion of the Elektron21 magnesium alloy,” *Solid State Phenom.*, vol. 229, pp. 99–104, 2015.
[23] M. Szala, T. J. Hejwowski, B. Dybowski, and A. Kiełbus, “Microstructural phenomena occurring during early stages of cavitation erosion of Al-Si aluminium casting alloys,” *Solid State Phenom.*, pp. 255–258, 2015.
[24] J. H. Boy and A. Kumar, “Construction Productivity Advancement Research (CPAR) Program: Cavitation- and Erosion-Resistant Thermal Spray Coatings,” USACERI, USA, Technical Report 97/118, 1997.
[25] T. Hejwowski, *Nowoczesne powłoki nakładane cieplnie odporne na zużycie ścierne i erozyjne*. Lublin: Politechnika Lubelska, 2013.
[26] A. R. Budris, “Coatings Can Improve Pump Impeller Cavitation Damage Resistance,” 2012. [Online]. Available: http://www.waterworld.com/articles/print/volume-28/issue-4/departments/pump-tips-techniques/coatings-can-improve-pump-impeller-cavitation-damage-resistance.html. [Accessed: 31-Jul-2014].