BNL-95079-2009

FINAL REPORT

FOR CRADA NO. C-03-08

BETWEEN

BROOKHAVEN SCIENCE ASSOCIATES

AND

FLOWSERVE CORPORATION

Project Entitled: Development of Advanced Centrifugal Pumps

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CRADA Final Report for IPP BNL-311 (CRADA C-03-08)

"Development Advanced Centrifugal Pumps"

1. Introduction

A CRADA project was performed between BNL and Flowserve, California, under the auspices of Initiative for Proliferation Prevention (IPP) with the DOE support. The purpose was to jointly support a team of Russian institutes led by Kurchatov Institute to develop technology to increase operating life of centrifugal pumps. The work was performed from March 1, 2002 to September 30, 2009. The project resulted in development and validation the total cost of the sub-contract with Kurchatov Institute was $700,000, with matching fund from the industrial partner, Flowserve.

The technical objective of this project is to develop advanced centrifugal pumps for the power, petroleum, chemical and water services industries by increasing the reliability of pumping equipment without a corresponding increase in life cycle cost. This major market need can be served by developing centrifugal pumps that generate only modest forces on the mechanical system even when operating under significant off-design conditions. This project is focused towards understanding the origin of hydraulic forces (both radial and axial, steady and time-dependent) and to develop design options, which reduce these forces over a broad flow range. This focus will include the force generation due to cavitation inside the pump as the operating conditions extend to low suction pressures. The results of research will reduce the inception of cavitation that leads to surface erosion and to find passive method of reducing peaks in axial thrust during whole range of flow rates.

2. Work performed and Important Results

The project addressed two specific issues; Axial Thrust and Cavitation erosion

2.1. Main results on the axial thrust problem

2.1.1. The experimental force transducers have been designed and fabricated containing the elastic elements and resistive-strain gauges. These transducers were successfully used in the tests of the single-stage and four-stage Flowserve pumps. The transducers have been successfully calibrated before tests and then built into the pump bearing supports. The measurement accuracy of such transducers is affected (to a certain extent) by friction in pump supports, radial and axial oscillations, non-co-axiality, parts non-slip as well as the hysteresis effects. Nevertheless, the results of multiple tests have proven the principal of such measurements. Further works in this field could result in more accurate force transducer design, which will allow measuring axial thrust directly with higher accuracy.

2.1.2. The pump design improvement is achieved by skew cutting the impeller that leads to linearized dependence of axial thrust upon flow rate. Corresponding computational experiments

have been conducted (the finite-element analysis of 3D flow in pump channels), that have indicated the effectiveness of this modification. The axial thrust vs. flow rate curve becomes more flat while maintaining the pump efficiency and vibration /pulsation characteristics. The subsequent tests of the four-stage pump have proven these results. Moreover, the skew cut of the impellers considerably improved the pump head vs. flow rate (H-Q) curve in the zone of low flow rates. However, modification leads to reduced head at optimum design point and can be corrected by increasing impeller diameter. So, this design solution is found to be very useful for both the H-Q curve improvement and flattening the axial thrust vs. flow rate curve.

2.2. Main results on the cavitation erosion problem

2.2.1. The methodology and program of the cavitating bubble evolution in non-uniform pressure field have been developed, that allows estimation of stresses on the streamline surface caused by the collapse of vapor-gas bubbles. It was also shown that the bubble collapse process goes on not only because of the collapse itself (i. e. disappearing of the bubble volume when it moves into the increased pressure zone), but also as a result of the inter-phase surface deformation. As a result of this deformation, a high-velocity fluid jet arises, which causes stresses at the wall resulting in the surface erosion.

2.2.2. The software module calculating the cavitating bubble evolution has been adapted to the Flow Vision software (Russian software intended to analyze flow hydrodynamics on the basis of solving Navier-Stokes equations). A new post processing procedure was developed that linked unsteady parameters in the pump flow passage with the numerical modeling of a cavitating bubble under unsteady flow conditions leading to the prediction of stresses acting on the blade surfaces due to bubbles disintegration. This provides a novel method to control cavitation erosion damage during design process of the new pump. A large number of numerical experiments have been performed, indicated the important role of turbulent pulsations on the formation of the non-uniform pressure field as a condition of the evolution of cavitating bubble.

2.2.3. The experimental and computational studies of cavitation erosion have been conducted in the mockup centrifugal pump stages of different designs. These studies have shown the advantage of cantilever shaft in comparison with through-shaft designs. The experimental data (varnish coatings destruction map) agrees qualitatively with the results of computation using the modified Flow Vision software. These results prove that the main mechanism of the surface erosion damage in short-term tests is due to large stress (10 MPa order) caused by the cavitating bubbles deformation in non uniform pressure field.

2.2.4. The new improved designs of multistage pumps have been proposed that have bearings lubricated by the pumped fluid and reduced intensity of cavitation erosion at the expense of cantilever design of the 1st stage impeller.

The results obtained are very interesting from standpoint of understanding the mechanism of cavitation erosion and could be published in foreign scientific journals. Part of them has been already reported on the international conferences (see the publications list below). The proposed structural schemes of pumps and their units are patentable.

2.3 Publications

1. Sergei S. Panaiotti, Upendra Singh Rohatgi, Sergei F. Timuchev, Vladimir A. Soldatov, Boris N. Chumachenko CFD Study of Prospective 1st Stage Centrifugal Impeller Design. Proceedings of FEDSM 2007 5th Joint ASME/JSME Fluids Engineering Conference July 30-August 2, 2007 San Diego, California USA.
2. Vladimir A. Knyazev, Vladimir A. Soldatov, Upendra Singh Rohatgi Evolution of a Cavitating Bubble in a Nonuniform Pressure Field. Proceedings of FEDSM 2007 5th Joint ASME/JSME Fluids Engineering Conference July 30-August 2, 2007 San Diego, California USA.
3. Timuchev S. F., Tsipenko A. V., Knyazev V. A. On the prospects of using the FlowVision software in solving tasks of blade machine channels optimization with two-phase flow taken into account, pressure pulsations and emitted sonic power reducing as well as reducing the cavitation erosion in pumps. All-Russian scientific and practical conference «Engineering systems 2008», April 7-10, 2008. Theses of the reports, Moscow, 2008.
4. Sergei F. Timuchev, Vladimir A. Knyazev, Sergei S. Panaiotti, Vladimir A. Soldatov, Upendra Singh Rohatgi. Numerical Procedure For Assessment Of Centrifugal Pump Cavitation Erosion. Proceedings of IMECE 2008 -- ASME International Mechanical Engineering Congress and Exposition, November 2-6, 2008, Boston, Massachusetts, USA.
5. Knyazev V. A., Kuznetsov A. V., Panaiotti S. S., Timuchev S. F. Cavitation erosion study in mockup first stages of a feed pump. International scientific conference Ecopump.ru'2008 – The effectiveness and ecological safety of pumping equipment. Theses of the reports, pp. 23-24. Moscow, BMSTU, 2008.
6. Sergei F. Timuchev, Vladimir A. Knyazev, Sergei S. Panaiotti, Vladimir A. Soldatov Validation of Numerical Procedure for Assessment of Centrifugal Pump Cavitation Erosion. 25th International Pump Users Symposium, Houston, Texas (USA) 23-26 Feb 2009. Proceedings.
7. Sergei Timushev. Development and experimental validation of 3D acoustic-vortex numerical procedure for centrifugal pump noise prediction. ASME Fluids Engineering Division Summer Meeting, August 2-6, 2009, Vail, Colorado, USA, Proceedings of FEDSM2009: FEDSM2009-78400.
8. Sergei F. Timushev Key-note lecture: CFD codes for pumps noise prediction and optimization. ASME Fluids Engineering Division Summer Meeting August 2-6, 2009, Vail, Colorado, USA 5th Joint Sixth International Symposium on Pumping machinery
9. Sergei F. Timushev. CFD programs for pumps and fans; acoustic optimization. CAETS Forum on Worldwide Noise Sources 2009, August 24 – 26, Ottawa, Canada.
10. Kuznetsov A. V., Panaiotti S. S. Designing multistage centrifugal pumps with long lifetime by cavitation erosion. M43 Ecopump.ru`2009. The effectiveness and ecological safety of pumping equipment: Theses of the reports of the international scientific conference. October, 2009 — Moscow: BMSTU, 2008.

3. Marketing

The primary purpose of the project is to produce industrial applications in the centrifugal pump market. It is envisioned that the industrial applications could take the following forms:

New horizontal multistage pumps that have very low axial thrust variation with flow rate. This will allow very conservative bearing sizing without recourse to expensive large capacity systems requiring a large investment in the lubricating oil support system.

New horizontal overhung and between-bearing pumps with excellent shaft and bearing housing vibration signatures. This will contribute to long seal and bearing life, these being the primary sources of low Mean Time Between Repairs of this class of pumps.

New higher speed vertical water circulating pumps. The higher speed will become possible with the improved understanding of cavitation phenomena and their deleterious effects on impeller damage and shaft vibrations and noise.

4. Summary

BNL-Flowserve teamed up with Russian institute to develop design modification to reduce and even out axial thrust under off design conditions and developed understanding of cavitation erosion problem. This project increased the capability of the Russian team and will allow Flowserve to continue working with them in future.

IPP funding helped provide jobs for a significant number of engineers and technicians that formerly worked on WMD in Russia.