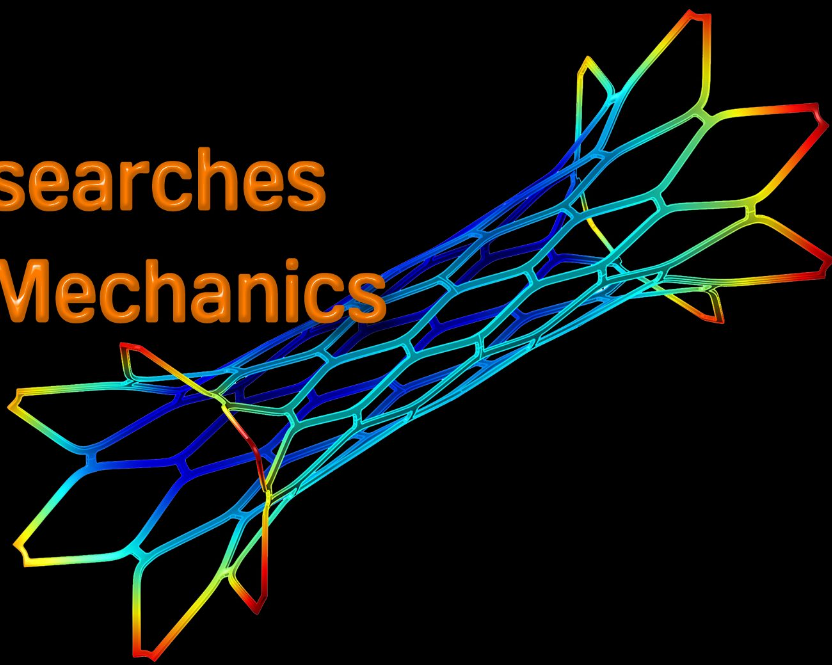
Editors: Nikos Mastorakis, Valeri Mladenov, Zoran Bojkovic, Fragkiskos Topalis, Kleanthis Psarris, Alina Barbulescu, Hamid Reza Karimi, George J. Tsekouras, Abdel-Badeeh M. Salem, Luige Vladareanu, Aleksandar Nikolic, Dana Simian, Berenika Hausnerova, Stevan Berber, Nikolaos Bardis, Azami Zaharim, Chandrasekaran Subramaniam

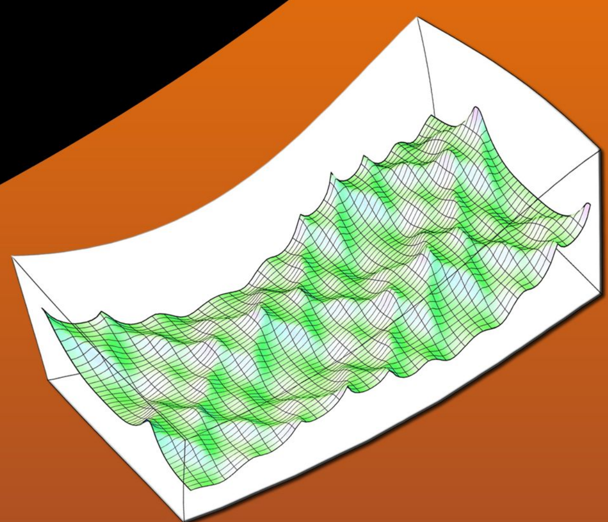
Recent Researches in Mechanics



Recent Researches in Mechanics

- Proceedings of the 2nd International Conference on Fluid Mechanics and Heat and Mass Transfer 2011 (FLUIDSHEAT '11)
- Proceedings of the 2nd International Conference on Theoretical and Applied Mechanics 2011 (TAM '11)
- Proceedings of the 4th WSEAS International Conference on Urban Planning and Transportation (UPT '11)
- Proceedings of the 4th WSEAS International Conference on Cultural Heritage and Tourism (CUHT '11)

Corfu Island, Greece, July 14-16, 2011



ISBN: 978-1-61804-020-6

RECENT RESEARCHES in MECHANICS

Proceedings of the 2nd International Conference on Fluid Mechanics and Heat and Mass Transfer 2011 (FLUIDSHEAT '11)
Proceedings of the 2nd International Conference on Theoretical and Applied Mechanics 2011 (TAM '11)
Proceedings of the 4th WSEAS International Conference on Urban Planning And Transportation (UPT '11)
Proceedings of the 4th WSEAS International Conference on Cultural Heritage and Tourism (CUHT '11)

Corfu Island, Greece
July 14-16, 2011

Published by WSEAS Press
www.wseas.org

ISBN: 978-1-61804-020-6

RECENT RESEARCHES in MECHANICS

Proceedings of the 2nd International Conference on Fluid Mechanics and Heat and Mass Transfer 2011 (FLUIDSHEAT '11)
Proceedings of the 2nd International Conference on Theoretical and Applied Mechanics 2011 (TAM '11)
Proceedings of the 4th WSEAS International Conference on Urban Planning And Transportation (UPT '11)
Proceedings of the 4th WSEAS International Conference on Cultural Heritage and Tourism (CUHT '11)

Corfu Island, Greece
July 14-16, 2011

Published by WSEAS Press
www.wseas.org

Copyright © 2011, by WSEAS Press

All the copyright of the present book belongs to the World Scientific and Engineering Academy and Society Press. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the Editor of World Scientific and Engineering Academy and Society Press.

All papers of the present volume were peer reviewed by two independent reviewers. Acceptance was granted when both reviewers' recommendations were positive.
See also: http://www.worldses.org/review/index.html

ISBN: 978-1-61804-020-6

World Scientific and Engineering Academy and Society

North Atlantic University Union

RECENT RESEARCHES in MECHANICS

Proceedings of the 2nd International Conference on Fluid Mechanics and Heat and Mass Transfer 2011 (FLUIDSHEAT '11)
Proceedings of the 2nd International Conference on Theoretical and Applied Mechanics 2011 (TAM '11)
Proceedings of the 4th WSEAS International Conference on Urban Planning And Transportation (UPT '11)
Proceedings of the 4th WSEAS International Conference on Cultural Heritage and Tourism (CUHT '11)

Corfu Island, Greece
July 14-16, 2011

Editors:
Prof. Nikos Mastorakis, Technical University of Sofia, Bulgaria
Prof. Valeri Mladenov, Technical University of Sofia, Bulgaria
Prof. Zoran Bojkovic, University of Belgrade, Serbia
Prof. Fragkiskos Topalis, National Technical University of Athens, Greece
Prof. Kleanthis Psarris, The University of Texas at San Antonio, USA
Prof. Alina Barbulescu, Ovidius University of Constanta, Romania
Prof. Hamid Reza Karimi, University of Adger, Norway
Prof. George J. Tsekouras, Hellenic Naval Academy, Greece
Prof. Abdel-Badeeh M. Salem, Ain Shams University, Egypt
Prof. Luige Vladareanu, Romanian Academy, Romania
Prof. Aleksandar Nikolic, University of Belgrade, Serbia
Prof. Dana Simian, University Lucian Blaga of Sibiu, Romania
Prof. Berenika Hausnerova, Tomas Bata University in Zlin, Czech Republic
Prof. Stevan Berber, The University of Auckland, New Zealand
Prof. Nikolaos Bardis, Hellenic Army Academy, Greece
Prof. Azami Zaharim, Universiti Kebangsaan, Malaysia
Prof. Chandrasekaran Subramaniam, Anna University of Technology, India

International Program Committee Members:
Azami Zaharim, MALAYSIA
Blaise Nsom, FRANCE
Dimitrios Pavlou, GREECE
C. Booth, UK
R. Brandtweiner, AUSTRIA
Enrique Arias, SPAIN
Faridatulazna Ahmad Shahabuddin, MALAYSIA
Gavriletea Marius, ROMANIA
Gherghinescu Sorin, ROMANIA
G. Fadda, CHILE
S. Macedo, BRAZIL
Bruno Grbac, CROATIA
Claudio Guarnaccia, ITALY
Cruceanu Catalin, ROMANIA
Horatiu Teodorescu, ROMANIA
Khan Amanat, BANGLADESH
Kuei-Yang Wu, TAIWAN
M. Reza Emami Azadi, IRAN
Madalina Calbureanu, ROMANIA
Matthew Karlaftis, GREECE
Michelle Duffy, AUSTRALIA
Mircea Badescu, ROMANIA
Murude Celikag, CYPRUS
Roxana Marinescu, ROMANIA
Saeed-Reza Sabbagh Yazdi, IRAN
Seyed Yousef Sadjadi, UNITED KINGDOM
Shahriar Quayyum, BANGLADESH
Slavka Zekovic, SERBIA
Smaranda Adina Cosma, ROMANIA
Sonia Degeratu, ROMANIA
Vassilis Gekas, GREECE
Abir Kassem, EGYPT
Agita Livina, LATVIA
Ahadollah A'zami, IRAN
Androniki Tsouchlaraki, GREECE
Ang-cheng kris Ho, TAIWAN
Asghar Mohammad Moradi, IRAN
Xin Wang, CHINA
David Greiner, SPAIN
Manoj Jha, UNITED STATES
Kenzu Abdella, CANADA
Roman Adinberg, ISRAEL
Coman Adrian-Viorel, ROMANIA
Jerome Anthoine, BELGIUM
Michael Aronov, UNITED STATES
Mohammadmasoud Azhdari moghaddam, IRAN
Regita Bendikiene, LITHUANIA
Helmut Benigni, AUSTRIA
A. C. Benim, GERMANY
Friedrich-Karl Benra, GERMANY
Stasys Bockus, LITHUANIA
Hermenegildo Borges de Oliveira, PORTUGAL
Mircea Boscoianu, ROMANIA
Malek Bouhadef, ALGERIA
Andris Buikis, LATVIA
Adriana Catanase, ROMANIA
Costin Cepisca, ROMANIA
Claudia Cherubini, ITALY
Ashfaque Ahmed Chowdhury, AUSTRALIA
J. P. Curtis, UK
Farhang Daneshmand, IRAN
George Darie, ROMANIA
Konrad Domke POLAND
Michel El Hayek, LEBANON
Tayfour Elbashir, OMAN
Arpad Fay, HUNGARY
Petr Filip, CZECH REPUBLIC
Nicolas Galanis, CANADA
Sergey Gaponov, RUSSIA
Aitor J. Garrido, SPAIN
majid Ghassemi, IRAN
Yury Gogotsi, UNITED STATES
Jonas Gyly,USA
Vasileios Hamosfakidis, UNITED STATES
Assia Helali, FRANCE

Jun Huang, FINLAND
Dagmar Janacova, CZECH REPUBLIC
Mak Kai Long, HONG KONG S.A.R.
X.Kakatsios, GREECE
Bouhadef Khedidja, ALGERIA
Jaewon Kim, KOREA
Karel Kolomaznik, CZECH REPUBLIC
Pavel Kuibin, RUSSIA
Albert Kurbatskiy, RUSSIA
T.-W. Lee, UNITED STATES
V. C. Loukopoulos, GREECE
Fathi Mahfouz, EGYPT
D. S. Mathioulakis, GREECE
Mohamed Maidi, UNITED KINGDOM
Elena Martvn, SPAIN
Sushanta K Mitra, INDIA
Dawid Myszka, POLAND
Santirat Nansaarng, THAILAND
Jiri Neustupa, CZECH REPUBLIC
Cong Tam Nguyen, CANADA
Guillermo Paniagua, BELGIUM
Thales Papazoglou, GREECE
Sophia Psychoudaki, GREECE
Yulia Peet, FRANCE
Guillaume Polidori, FRANCE
Jiri Pospisil, CZECH REPUBLIC
Thomas Prevenslik, GERMANY
Robert Pucher, AUSTRIA
Mohammad Rasul, AUSTRALIA
Mourad Rebay, FRANCE
Constantin Rotaru, ROMANIA
Gilles Roy, CANADA
Saeed-Reza Sabbagh-Yazdi, IRAN
M. Sakellariou-Makrantonaki, GREECE
Lamberto Tronchin, ITALY
Martin van den Toorn, THE NETHERLANDS
Heimo Walter, AUSTRIA
Ying Wang, CHINA
Dirk Weltersbach, GERMANY
Henning Zindler, GERMANY
Evangelos Sapountzakis, GREECE
Manouchehr Amiri, IRAN
Viktor Baranov, RUSSIA
Tomas Bodnar, CZECH REPUBLIC
L. Borges, PORTUGAL
Fernando Carapau, PORTUGAL
Paulo Correia, PORTUGAL
Paul Deuring, FRANCE
Alexander Dmitriev, RUSSIA
Bernard Ducomet, FRANCE
Paschalis Grammenoudis, GERMANY
Alexander Gvozdev, RUSSIA
Toshiaki Hishida, JAPAN
Joao Janela, PORTUGAL
Roger Khayat, CANADA
Stanislav Krasmar, CZECH REPUBLIC
Petr Kucera, CZECH REPUBLIC
Aouni Lakis, CANADA
Vladislav Malinin, RUSSIA
Alexey Markin, RUSSIA
Nikolay Matchenko, RUSSIA
Bugaru Mihai, ROMANIA
Jiri Neustupa, CZECH REPUBLIC
Juan Ospina, COLOMBIA
Adelia Sequeira, PORTUGAL
Yoshihiro Shibata, JAPAN
Nickolay Smirnov, RUSSIA
Maria Specovius-Neugebauer, GERMANY
Aleksander Treschev, RUSSIA
Nikolay Tutyshkin, RUSSIA
Werner Varnhorn, GERMANY
Kobelev Vladimir, GERMANY

Table of Contents

Numerical Investigations of Flow on the Kaplan Turbine Runner Blade Anticavitation Lip with Modified Cross Section

Vasile Cojocaru, Daniel Balint, Viorel Constantin Campian, Dorian Nedelcu and Camelia Jianu

***Abstract*—** The cavitation phenomenon is an important cause of wear and damages of Kaplan and bulb turbines. In order to decrease the erosion rate on the blade and on the runner chamber an anticavitation lip is disposed on the suction side of the runner blade. The goal of the research presented in this paper was to observe the flow behavior for two types of geometry of Kaplan runner blade anticavitation lip. The first lip had the original dimensions from the hydropower plant. The second lip had a modified cross section and smooth edges at the extremities. Tip vortex, cavitation caverns and pressure coefficient diagrams were generated.

***Keywords*—** anticavitation lip, cavitation, Kaplan runner blade, numerical investigations, tip vortex.

I. Introduction

THE cavitation phenomenon is an important cause of wear and damages in hydroturbines [1]. In the Romanian hydropower plants, cavitation erosion occurs mainly in Kaplan and bulb turbines (in Romania there are 107 Kaplan turbines and 11 bulb turbines). The most injured components are the runner blades and the runner chamber. On the Kaplan runner blade the erosion is more intense in the leading edge area and on the blade tip.

In order to decrease the erosion rate on the runner blade tip and on the runner chamber, an anticavitation lip is disposed on the suction side of the runner blade. The anticavitation lip has the role of overtaking the cavitation pitting which appears between the runner blades and the runner chamber (the cavitation erosion moves from the periphery of the runner blades onto the lips). Using the anticavitation lip the energetic performances of the turbine are not lowered.

The goal of the research was to observe the flow behavior for two types of geometry of Kaplan runner blade anticavitation lip.

The work has been co-funded by the Sectorial Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/89/1.5/S/62557.

Vasile Cojocaru, PhD. Student, Center for Research in Hydraulics, Automation and Thermal Processes – CCHAPT, “Eftimie Murgu” University of Resita, Traian Vuia square, no. 1-4, 320085, Resita, Romania (phone: 0040255219134; e-mail: v.cojocaru@uem.ro, cchapt.ro, www.uem.ro).

Daniel Iosif Balint, Dr.Eng., Center for Research in Hydraulics, Automation and Thermal Processes, “Eftimie Murgu” University of Resita, (e-mail: daniel.balint@gmail.com).

Viorel Constantin Campian, Prof.Dr.Eng., Center for Research in Hydraulics, Automation and Thermal Processes, “Eftimie Murgu” University of Resita, (e-mail: v.campian@uem.ro).

Dorian Nedelcu, Prof.Dr.Eng., Center for Research in Hydraulics, Automation and Thermal Processes, “Eftimie Murgu” University of Resita, e-mail: d.nedelcu@uem.ro).

Camelia Jianu, PhD. Student, Center for Research in Hydraulics, Automation and Thermal Processes, “Eftimie Murgu” University of Resita, (e-mail: jianu_camelia@yahoo.com).

II. The Geometric Model of Kaplan Turbine Runner Blade with Anticavitation Lip

The CAD model (3D solid) of Kaplan runner blade was build using Autodesk Inventor [2]. The measured coordinates of the pressure side and suction side points were imported from Excel. These points were jointed in three sets of profiles using spline curves. Connecting these profiles, the suction side surface, the pressure side surface and the leading edge surface were shaped. In the next step these three surfaces were extended to a hub spherical surface and a periphery spherical surface to obtain the surfaces of the complete blade. Closed contours were created intersecting these five surfaces with radial plans. The solid model of the runner blade (Fig. 1) was generated by a loft trough these closed contours.

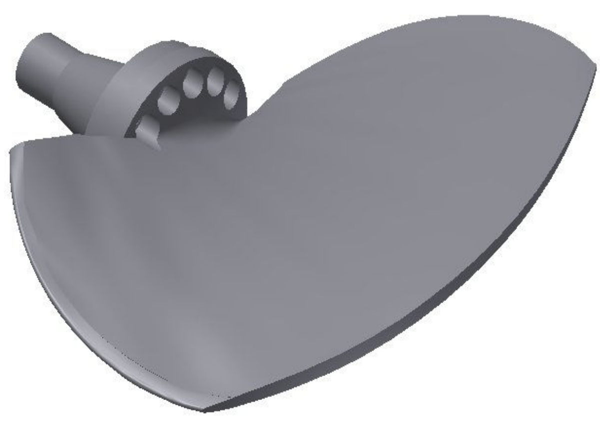


Fig. 1 The CAD model of Kaplan turbine runner blade without anticavitation lip

The anticavitation lip (Fig. 2) was added to the runner blade by a sweep of anticavitation lip cross section along a path identified by the blade tip edge. The extremities of the lip were shaped using two *Loft* commands.

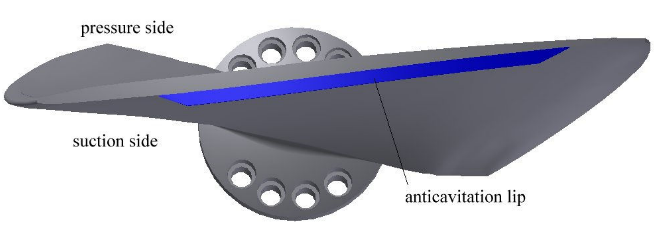


Fig. 2 The anticavitation lip

The cross section of the anticavitation lip was initially modeled at the original dimensions measured in the hydropower plant. The tip of the blade and the surface of the lip located near the runner chamber are in the same continuous cylindrical surface (Fig. 3). Thereby the width of the clearance between runner blade and runner chamber is constant.

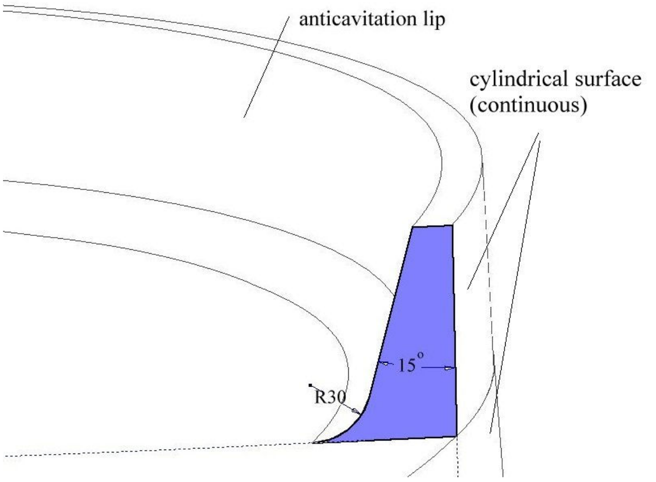


Fig. 3 The original cross section of the anticavitation lip

III. NUMERICAL ANALYS OF THE FLOW ON THE ORIGINAL ANTICAVITATION LIP

The numerical simulations are today an important tool in the optimization process of hydro turbines [3,4,5]. The flow analysis in the runner blade – runner chamber clearance and the investigations of tip vortex were subjects of researches regarding the turbine performances and cavitation [6,7,8,9].

In this research the numerical analysis was performed with the software TurboCAD Optim [11,12] (developed by the second author of this paper) and Ansys Fluent.

In order to calculate the vortex flow on the tip of the runner blade following steps were performed [13,14]:

- Hydrodynamic calculus of the flow in the turbine inlet;
- Hydrodynamic calculus of the flow in the turbine stator using the results from the previous step;
- Hydrodynamic calculus of the flow in the reunion domain distributor-rotor using the results from the second step;
- Isolation of an area at the tip of the runner blade to define the domain of analysis (Fig. 4): The blade was positioned on the runner. Planar profiles were obtained from the intersection of the blade tip with cylinders coaxial with the turbine. These parallels profiles were positioned and jointed. The result was a isolated model similar with the tip of the blade;
- The limits of the domain of analysis were defined by the runner chamber surface (periodic), the rotor surface (periodic), the inlet and the outlet surfaces of the rotor related to one blade.

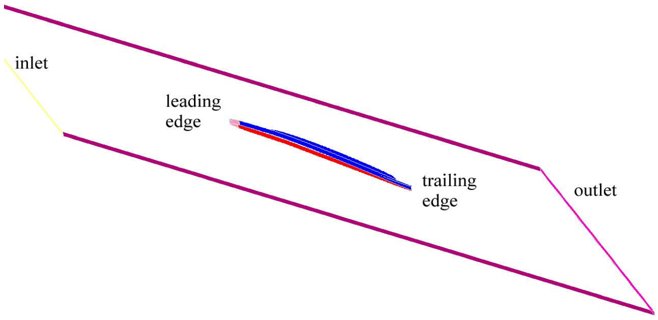


Fig. 4 The domain of analysis

The numerical analysis results for anticavitation lip with the cross section at original dimensions and shape are presented in figures 5, 6 and 7. The tip vortex (Fig. 5) detaches from the blade and the runner chamber. The cavitation erosion risk decreases due to this aspect. This is the effect of the anticavitation lip.

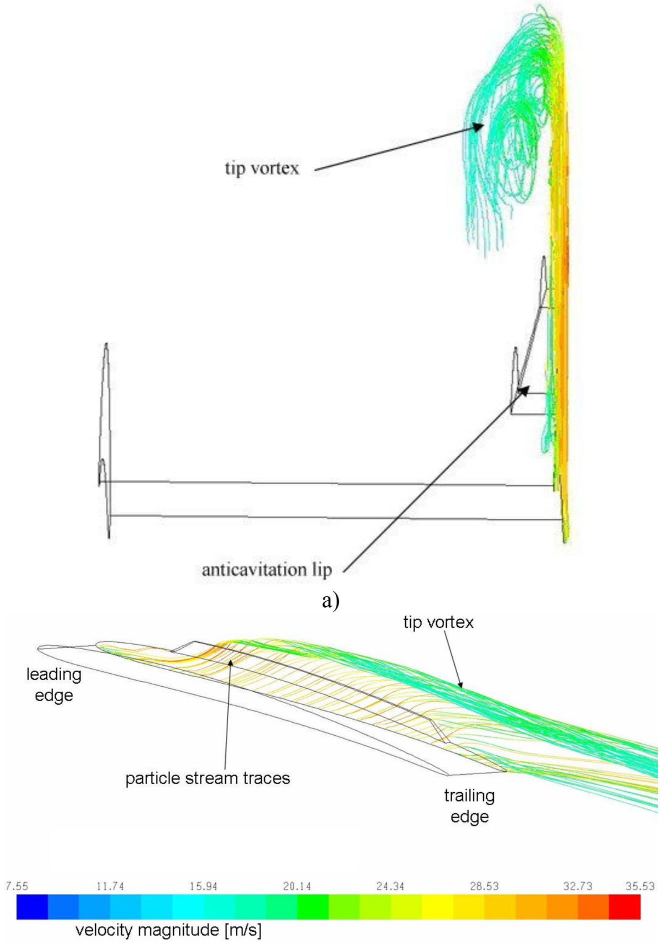


Fig. 5 The tip vortex on the anticavitation lip with original cross section a) down view, b) back view

ISBN: 978-1-61804-020-6

Nevertheless, in-situ observations showed intense cavitation erosion on the anticavitation lip with this cross-section. In order to reduce this erosion new dimensions and shapes were studied for the anticavitation lip. One variant, presented in this paper, has a modified cross section and smoothed edges at the extremities of the lip. In order to define these modifications the pressure coefficient diagram and the occurrence of the cavitation caverns were plotted.

The pressure coefficient diagram (Fig. 6) shows significant variations at the extremities of the anticavitation lip. In these regions, on a short distance, the pressure coefficient ranges from about 0.2 to -0.6. This variation may facilitate the occurrence of cavitation bubbles in these areas.

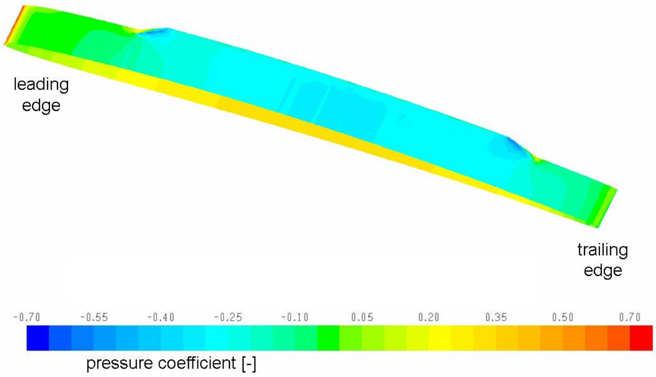


Fig. 6 The pressure coefficient variation

The numerical simulation of the cavitation caverns (Fig. 7) show also intense cavitation on the extremities of the anticavitation lip. The cause is the high gradient of the cross section on a short distance and the improper shape of the lip ends.

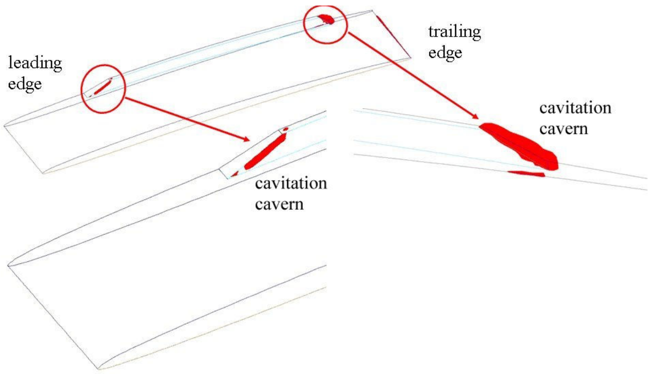


Fig. 7 The cavitation caverns

IV. NUMERICAL ANALYS OF THE FLOW ON ANTICAVITATION LIP WITH MODIFIED CROSS SECTION

A first solution to modify the anticavitation lip was adopted based on the analysis of the cavitation caverns and the tip vortex from the original lip. This solution includes the following modifications:

- The change of the cross section of the lip by moving the point “A” with 5 mm towards the rotor hub (Fig. 8). The clearance between the runner chamber and the blade increased in the lip area and had a conical variation. This could be a potential solution for new lips but in situ this modification is difficult to be made due to the small space.

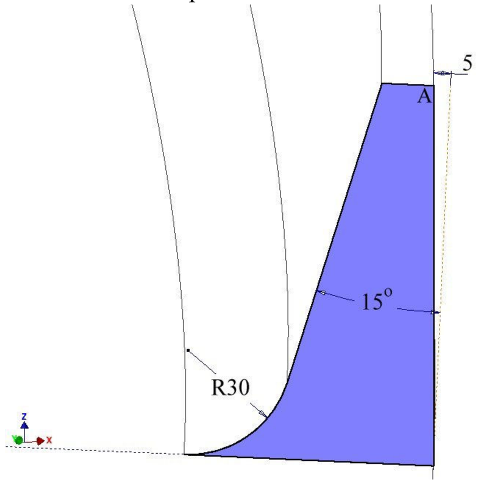


Fig. 8 The modified cross section of the anticavitation lip

- The smoothing of the two edges from the leading extremity of the lip (600 mm radius and 400 mm radius– Fig. 9.a).
- The smoothing of the two edges from the trailing extremity of the lip (400 mm radius and 200 mm radius– Fig. 9.b).

After the smoothing of the edges the extremities of the lip were closer to a hydrodynamic profile. In situ the smoothing of the edge could be realized by grinding.

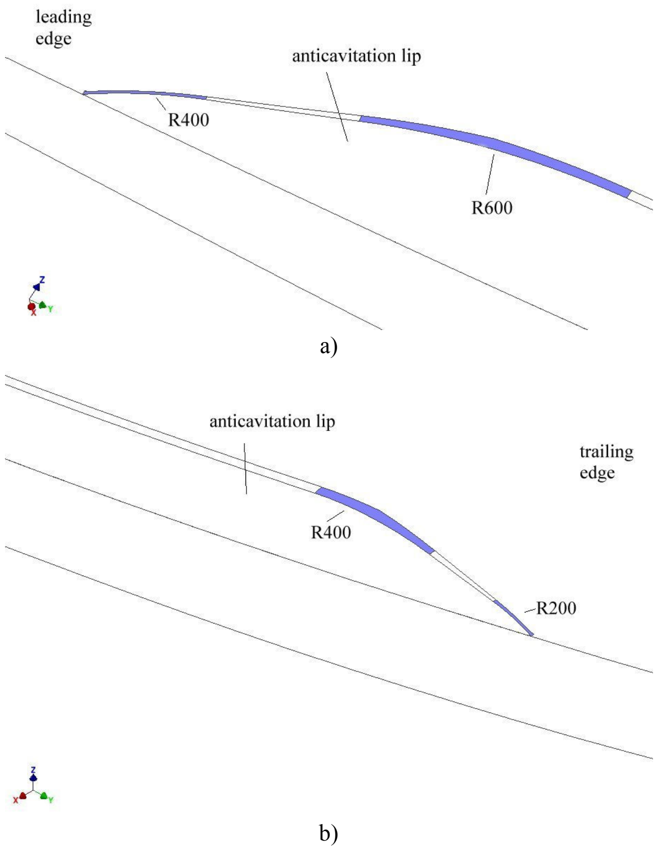


Fig. 9 The smooth edges in the leading (a) and trailing (b) of the anticavitation lip

The results of the numerical simulation made on this new lip do not show important differences compared to the original shape. However, the tip vortex (Fig. 10) is more detached from the runner chamber in the case of the lip with modified cross section. A decrease of the cavitation on the runner chamber is expected.

In the both cases a secondary vortex appeared at the extremity of the anticavitation lip in the trailing edge area. For the modified lip this secondary vortex had a divergent direction related to the main vortex. For this reason the intensity of the main vortex will be lower.

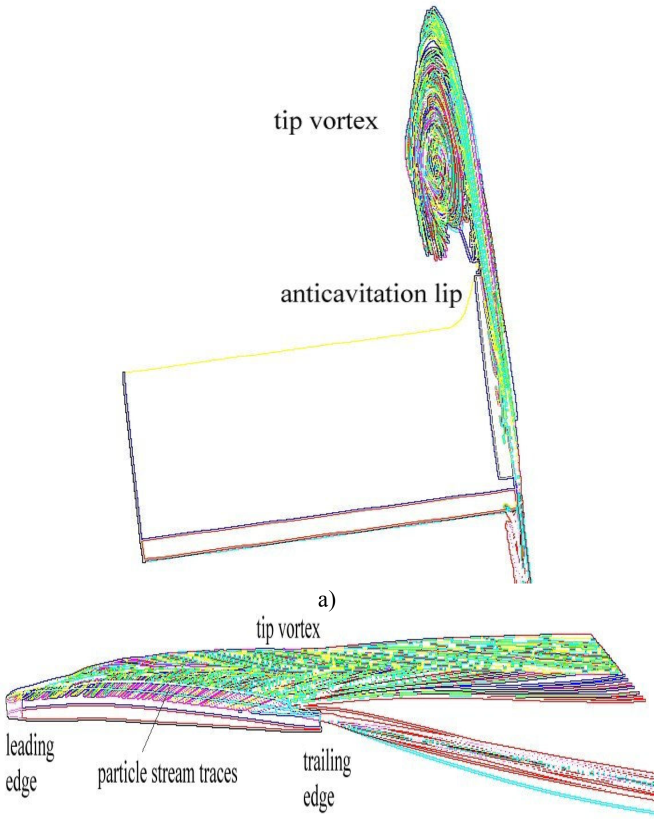


Fig. 10 The tip vortex on the of the anticavitation lip with modified cross section a) down view, b) back view

V. Conclusion

The numerical analysis of the flow on the original anticavitation lip of Kaplan turbine runner blade shows:

- The tip vortex detaches from the blade and the runner chamber;

- The pressure coefficient at the extremities of the lip has a significant variation from about 0.2 to -0.6;

- The cavitations caverns appear at the extremities of the lip;

On the modified anticavitation lip with tilted lateral surface a decrease of the cavitation on the runner chamber is expected.

Further researches will be made on anticavitation lip with modified hydrodynamic profile.

References

[1] Frunzaverde D., Campian V., Nedelcu D., Gillich G.R., Marginean G. "Failure analysis of a Kaplan turbine runner blade by metallographic and numerical methods" in *Proceedings of the 7th WSEAS International Conference on Fluid Mechanics (FLUIDS '10)*, University of Cambridge, UK, February 23-25, 2010, WSEAS Press, pp. 60-67;

[2] Nedelcu D., Padurean I., "CAD modeling of a an axial blade turbine using Autodesk Inventor", *Scientific Bulletin of the "Politehnica" University of Timisoara*, , vol. 52, no. 1, 2007, pp. 63–66.

[3] Jaberg H., "Numerical methods for fluid dynamical simulation of hydro power plants", in *Proceedings of the 3rd WSEAS International Conference on Renewable Energy Sources*, La Laguna, Tenerife, Canary Islands, Spain, 2009, pp. 399-413.

[4] Drtina P., Sick M., Brandt R. "Numerical performance prediction for an entire Kaplan turbine". In *Proceedings of the 18th IAHR Symposium*, Singapore, 1998.

[5] Iaccarino G. "Predictions of a turbulent separated flow using commercial CFD codes" in *Journal of Fluids Engineering*, Transactions of the ASME, vol. 123, 2001. pp. 819–828.

[6] Murayama M., Yoshida Y., Tsujimoto Y. "Unsteady tip leakage vortex cavitation originating from the tip clearance of an oscillating hydrofoil", *Journal of Fluids Engineering*, Transactions of the ASME, 128:421–429, 2006

[7] Roussopoulos K., Monkewitz P. "Measurements of tip vortex characteristics and the effect of an anti-cavitation lip on a model Kaplan turbine blade" *Journal of Flow, Turbulence and Combustion*, vol. 64, 2000, pp. 119–144.

[8] Tallman J., Lakshminarayana B. "Numerical simulation of tip leakage flows in axial flow turbines, with emphasis on flow physics: part I - effect of tip clearance height", *Journal of Turbomachinery, Transactions of the ASME*,vol. 123, 2001, pp. 314–323.

[9] Tallman J., Lakshminarayana B. "Numerical simulation of tip leakage flows in axial flow turbines, with emphasis on flow physics: part II - effect of outer casing relative motion" in *Journal of Turbomachinery*, Transactions of the ASME, vol. 123, 2001, pp.324–333.

[10] Campian C.V., Nedelcu D. "Cavitation tip clearance. Numerical simulation and experimental results" in *Proceedings of the 3nd Workshop on Vortex Dominated Flows Achievements and Open Problems* published in Scientific Bulletin of the "Politehnica" University of Timişoara, Romania, 2007, pp. 17-20.

[11] Balint D. *Numerical computing methods for 3D flows in the distributor and the runner of Kaplan turbines*, PhD. Thesis, "Politehnica" University of Timisoara, 2008.

[12] Balint D., Resiga-Susan R., Muntean S., Anton I. "A numerical investigation of the full 3D turbulent flow in Kaplan hydraulic turbines" in *Proceedings of the 6th International Conference on Hydraulic Machinery and Hydrodynamics*, Timisoara, Romania, 2004.

[13] Campian C.V., Balint D., Cuzmos A., *Numerical analysis of the flow in the blade-runner chamber clearance, with and without anticavitational lips, with and without modified wicket gate*, Center for Research in Hydraulics, Automation and Thermal Processes, "Eftimie Murgu" University of Resita, Internal research report U-09-400-267, Resita, Romania 2009.

[14] Campian C.V., Balint D., Cuzmos A., *Numerical analysis of the flow with cavitation on anticavitational lip*, Center for Research in Hydraulics, Automation and Thermal Processes, "Eftimie Murgu" University of Resita, Internal research report U-09-400-284, Resita, Romania, 2009.