CIEPLNE MASZYNY PRZEPŁYWOWE

TURBOMACHINERY

145
2014

POLITECHNIKA ŁÓDZKA

P O L I T E C H N I K A   Ł Ó D Z K A
LODZ UNIVERSITY OF TECHNOLOGY

ZESZYTY NAUKOWE Nr 1187

INSTYTUT MASZYN PRZEPŁYWOWYCH
INSTITUTE OF TURBOMACHINERY

YEARS
OF LODZ UNIVERSITY
OF TECHNOLOGY

CIEPLNE MASZYNY PRZEPŁYWOWE

TURBOMACHINERY

No. 145

11th INTERNATIONAL SYMPOSIUM
ON COMPRESSOR & TURBINE FLOW SYSTEMS
THEORY & APPLICATION AREAS

SYMKOM 2014 IMP²

Ł Ó D Ź   2014

CIEPLNE MASZYNY PRZEPŁYWOWE
TURBOMACHINERY

Instytut Maszyn Przepływowych Politechniki Łódzkiej
Institute of Turbomachinery, Lodz University of Technology
ul. Wólczańska 219/223
90-924 Łódź POLAND
Tel. (48) 42 631 23 64 Fax (48) 42 631 24 78

ISSN 0137 - 2661

LETTER FROM EDITORS

It is our great pleasure to submit to our readers issue no. 145 of the journal **Cieplne Maszyny Przepływowe – Turbomachinery,** in which abstracts of the contributions presented at the International Symposium **SYMKOM 2014 IMP²** are included. Full texts of the manuscripts, after the revision procedure, will be distributed in an electronic version among the symposium participants.

SYMKOM 2014 IMP² follows the tradition of meetings of people who conduct scientific and R&D activities in the field of turbomachinery: turbines, compressors, pumps, as well as modern power engineering technologies.

The first symposia were devoted to compressors exclusively, hence their name which comes from "SYMpozjum KOMpresorów" (i.e., SYMposium on COMpressors). These symposia were held at the time when the production of first industrial compressors and blowers, designed at the Chair of Thermal Turbomachines, the predecessor of the Institute of Turbomachinery, started in Poland. Since 1987 the problem scope covered by **SYMKOM** symposia has included problems of theory and experiment of turbomachines, as well as their practical applications.

The first **SYMKOM** in which foreign participants took part was organised in 1967 in Łódź. The next venues were, respectively: 1977 – Tuszyn, 1987 – Bronisławów, 1991 – Łódź and Bronisławów, 1995 – Bronisławów, 1999 – Łodź and Arturówek, and 2002, 2005, 2008, 2011 – Łódź and organised by the Institute of Turbomachinery, Lodz University of Technology.

Since 1995 English has become the official language of **SYMKOM**s and conference proceedings have been published in this language.

This year for the first time, the symposium is organized by two scientific centers: **Institute of Turbomachinery, Lodz University of Technology** and **Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences** in Gdańsk.

The symposium programme includes plenary and poster sessions introduced by keynote speeches delivered by eminent specialists recognized in various fields of turbomachines and representing the world of science and industry. A special session will be devoted to PhD students with a competition for the best presentation delivered by a young researcher. Moreover, an exchange of ideas among users, manufacturers and researchers involved in turbomachinery will be possible within a separate panel session.

The symposium contributions will be published after decision of the **SCIENTIFIC COMMITTEE** in two scientific journals: **Central European Journal of Engineering** (Open Access) and **Cieplne Maszyny Przepływowe-Turbomachinery**, which has been already issued for 58 years by the Institute of Turbomachinery, Lodz University of Technology.

The SCIENTIFIC COMMITTEE of **SYMKOM 2014 IMP^2**, responsible for the merits of the symposium, is represented by:

Krzysztof JÓŹWIK	PL	Chairman	
Jan KICIŃSKI	PL	Co-Chairman	
Zbigniew KOZANECKI	PL	Scientific Secretary	
Wojciech BATKO	PL	**Władysław KRYŁŁOWICZ**	PL
Yuri BIBA	US	**Jan KRYSIŃSKI**	PL
Andrzej BŁASZCZYK	PL	**Jacky LACOMBE**	FR
Robert BUTZKE	PL	**Piotr LAMPART**	PL
Adam CENIAN	PL	**Janusz LEWANDOWSKI**	PL
Tadeusz CHMIELNIAK	PL	**Dariusz MIKIELEWICZ**	PL
Wojciech CHOLEWA	PL	**Jarosław MIKIELEWICZ**	PL
Ulrich DALDRUP	DE	**David NASH**	GB
William DEMPSTER	GB	**Wojciech NOWAK**	PL
Piotr DOERFFER	PL	**Marek ORKISZ**	PL
Witold ELSNER	PL	**Jiři POLANSKŶ**	CZ
Andrzej GÓRAK	DE/PL	**Andrey RUSANOV**	UA
Antoni HASLAM	GB	**Romuald RZĄDKOWSKI**	PL
Jacek KACZOROWSKI	PL	**Ulrich STEINSEIFER**	DE
Zbyszko KAZIMIERSKI	PL	**Tadeusz UHL**	PL
Dorota KOZANECKA	PL	**Janusz WALCZAK**	PL
Yuri KOZHUKHOV	RU		

The ORGANIZING COMMITTEE, responsible for the organization of **SYMKOM 2014 IMP^2**, consists of the following members:

Krzysztof SOBCZAK	Chairman
Małgorzata JÓŹWIK	Secretary
Daniel JODKO	**Grzegorz LIŚKIEWICZ**
Marta KIEREK	**Bogumiła MAJAK**
Ewa KŁYS	**Dorota RÓŻAŃSKA**

The scope of **SYMKOM 2014 IMP²** covers the following topics in the field of turbomachines (turbines, compressors, fans, pumps):

- design and manufacturing (rotordynamics, performance prediction, optimization, revamp and retrofit);
- maintenance and diagnostics;
- problems of flow unsteadiness (rotor – stator interaction, surge and stall, aeroacoustics, noise reduction);
- numerical flow simulations and their experimental verification (new computational models; turbulent, transitional, multiphase flow simulations, etc.);
- experimental investigations and measurement techniques;
- new energy and heat generating cycles (thermodynamics of turbomachines);
- designs for special applications (medicine, biotechnology, etc.);
- turbines, special devices and technology for 'green energy' generation;
- microdevices (turbines, bearings, etc.) and microflows;
- educational issues;
- AOB (Any Other Business).

We do hope that **SYMKOM 2014 IMP²** will contribute, like all the previous symposia, to the exchange of experience and knowledge, and to establishing new and tightening the already existing relations and scientific co-operation in the field of turbomachinery, between both Polish and foreign institutions.

Plenary sessions and discussions at posters, which were highly evaluated by participants of previous symposia, will serve these purposes.

For the symposium venue, we have chosen the Holiday Inn Lodz hotel in the heart of the city, situated in the famous Piotrkowska Street. Within the diversified agenda of social events, this year you will visit the former textile kingdom of Karol Scheibler, where the unique 19th century architecture has been given the second life to meet modern needs. We also hope that the social events will contribute to a nice atmosphere at the symposium.

The Organizing Committee would like to thank all the people and institutions who have provided financial and organizational support.

We wish fruitful sessions, vivid discussions and a nice stay in Łódź to all the participants of the **SYMKOM 2014 IMP²** symposium.

Scientific and Organizing Committee

SYMKOM 2014 IMP²

SYMKOM 2014 IMP^2 is held in the jubilee year of celebration of 70 years of the Lodz University of Technology.

The honorary patronage over **SYMKOM 2014 IMP^2** has been assumed by Professor Michał Kleiber, the president of the Polish Academy of Sciences.

The organization of **SYMKOM 2014 IMP^2** has been sponsored by:

The organizers of **SYMKOM 2014 IMP^2** also acknowledge the support of:

PROGRAM STRATEGICZNY NCBR

Realizacja zadania badawczego jest dofinansowana przez Narodowe Centrum Badań i Rozwoju w ramach Strategicznego Programu Badań Naukowych i Prac Rozwojowych pt: "Zaawansowane Technologie Pozyskiwania Energii" oraz współfinansowana przez ENERGA SA

Zadanie Badawcze nr 4

OPRACOWANIE ZINTEGROWANYCH TECHNOLOGII WYTWARZANIA PALIW I ENERGII Z BIOMASY, ODPADÓW ROLNICZYCH I INNYCH

Strategic Programme Number 4 (SP-No. 4): *Development of integrated technologies in the production of fuel and energy from biomass, agricultural and other waste* is being carried out by a consortium, which includes IMP – ENERGA SA with a number of agreements between IMP and Cocontractors from different universities and centres.

It is a rare example of direct involvement of industry into cooperation with science on such a scale in our country.

Project is directed mainly to build several prototype installations, including main three (flagship initiatives) which are the very essence of EAR, Energy Autonomous Regions. In the project SP-No.4 a comprehensive concept was created as well as the innovative technologies for reference CHP power plant for EAR.

In its assumptions the power plant will be using regional primary energy sources with the special attention paid to biomass, other renewable energy sources, municipal waste and agricultural waste.

Modern cogenerative installations (and technologies associated with it) were created, with a thermal output of 1 to 3 MW and electrical output 0,15 to 0,5 MW. All of these installations are based on local and renewable energy sources.

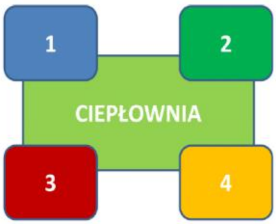
The technologies for heat and electricity generation, created in the project will be based on renewable energy sources (biomass, waste) and will become a component of distributed energy system. A concept of modernisation of local, small thermal power stations (up to 50 MW_t) for the implementation of the CHP systems was created.

As a result of new technological developments it is possible to modernise many thermal power stations in Poland, using the ORC system and new types of biomass-fired boilers.

Typical thermal power stations in our country are still using outdated technologies with low efficiency ratios. It therefore comes down to the question: What to do with underutilization of installed capacity in summer?

The reference CHP power station can consist of several independent modules:

- biomass cogeneration module with ORC technology, with electrical power output of 0,1-0,3 MWe and heat power output around 1 MWc,
- cogeneration system with combustion engine/s fuelled with natural gas, with total power electric capacity of several MW,
- biomass-fired steam unit with CHP technology, with electrical power output/heating power output of 2-5 MW,
- modernised coal boilers with new dust collection facilities.



Picture 1. Example scheme of EAR power station, 1 – biomass cogeneration module, 2 – cogeneration system with combustion engines, 3 – biomass-fired steam unit with CHP, 4 – modernised coal boilers

Biomass cogeneration system CHP – ORC - fitted to summer demand on hot water – is going to work all year, while other systems will be running according to the heat demand (this limitation is very important mainly for engines for which income from electrical power production does not cover all of the operating costs – so the income from heat is needed). Steam unit is an exception and is also designed for all year work. During the heating season it will be working in heating mode, while in no heating season it will be working in condensation mode with maximum electrical energy production efficiency.

Essential and the same time excellent support for the idea of EAR is construction of laboratorial background. An example here can be Micro Power Station Laboratory in IMP PAN in Gdańsk. There will be tested systems with combustion engines of 500 kW and ORC microturbines of 100 kW and steam turbines of 30 kW. In 2014, after finishing the construction it will be the most modern laboratory of this type in Poland.

Created in the project SP-No.4 innovative technologies and installations are an opportunity for ecological distributed energetics (prosumer) and communal Energy Autonomous Regions based on its own resources of biomass and municipal and agricultural waste. Implementation of these technologies on large scale can put Poland on path of changes which can be seen all over the world.

Projects in the subject of prosumer energetics and EAR (=technologies of small power, using renewable energy sources) are mainly concentrated on energetics. But what is obvious, they will also stimulate development of innovative technologies in other fields. It is possible to speak here about building industry (plus energy housing) as well as about agriculture (harvesting of energy crop, micro biogas plant, biogas plant). This development will continue in Smart Grid environment in accordance with full ecological safety.

SPIS TREŚCI – CONTENTS

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Łukasz ANTCZAK*
Władysław KRYŁŁOWICZ
Institute of Turbomachinery
Lodz University of Technology
219/223 Wolczanska St, 90-924 Lodz, Poland
**lukasz.antczak@p.lodz.pl*

LOW-POWER TURBINES FOR SMALL ORC APPLICATIONS

Abstract: A possibility of exploiting wasted heat and converting it into electric energy by means of different energy systems becomes more and more popular. The ORC system is one of the ways for small applications, for example, to recover waste heat from engine exhaust gases. The selection of an adequate design of the machine is a key factor to maximize efficiency of the ORC. This paper presents small turbines for power generation applications with particular attention focuses on the progress observed in recent years.

Keywords: Small turbine, Organic Rankine Cycle (ORC), comibned heat and power.

REFERENCES

[1] Bianchi M., De Pascale A.: Bottoming cycles for electric energy generation: Parametric investigation of available and innovative solutions for the exploitation of low and medium temperature heat sources. Applied Energy 88 (2011), 1500–1509.

[2] Invernizzi C., Iora P., Silva P.: Bottoming micro-Rankine cycles for micro-gas turbines. Applied Thermal Engineering 27 (2007), 100-10.

[3] Quoilin S., Aumann R., Grill A., Schuster A., Lemort V., Spliethoff H.: Dynamic modeling and optimal control strategy of waste heat recovery Organic Rankine Cycles. Applied Energy 88 (2011), 2183-2190.

[4] Sánchez D., Munoz de Escalona J.M., Monje B., Chacartegui R., Sánchez T.: Preliminary analysis of compound systems based on high temperature fuel cell, gas turbine and Organic Rankine Cycle. Journal of Power Sources 196 (2011), 4355-4363.

[5] Schuster A., Karellas S., Kakaras E., Spliethoff H.: Energetic and economic investigation of Organic Rankine Cycle applications. Applied Thermal Engineering 29 (2009), 1809-1817.

[6] Weerasinghe W.M.S.R., Stobart R.K., Hounsham S.M.: Thermal efficiency improvement in high output diesel engines a comparison of a Rankine cycle with turbo-compounding. Applied Thermal Engineering 30 (2010), 2253-2256.

[7] Hountalas D.T., Mavropoulos G.C.: Potential for Improving HD Diesel Truck Engine Fuel Consumption Using Exhaust Heat Recovery Techniques. New Trends in Technologies: Devices, Computer, Communication and Industrial Systems, 313-314; 326-340.

[8] Chen H., Goswami Y.D., Stefanakos E.K.: A review of thermodynamic cycles and working fluids for the conversion of low-grade heat. Renewable and Sustainable Energy Reviews 14 (2010), 3059-3067.

[9] Rizvi A., Ansari A., Qazi M., Siddiqui N.: Waste Heat Recovery using Organic Rankine Cycle: Design, Analysis & Simulation, Bachelor degree thesis report, University Of Mumbai, 2013.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Krzysztof BADYDA
Institute of Heat Engineering
Warsaw University of Technology, Poland
badyda@itc.pw.edu.pl

TRENDS AND PERSPECTIVES OF HEAVY DUTY GAS TURBINE AND COMBINED CYCLE TECHNOLOGY

Abstract: Information about the state of technology development of heavy duty gas turbines for power generation applications with particular attention to the progress observed in recent years is presented. Evaluation of current gas turbine and combined cycle market (key manufacturers, largest units, efficiency, emissions) is submitted. Examples of technical solutions in response to the key challenges associated with the development of technology and gas turbine market (parameter increasing of the working medium, the expectation of high flexibility, including the ability to work efficiently at partial load) are shown.

Keywords: Power Engineering, Gas Turbines, Gas and Steam Combined Cycle, Technology Progress.

REFERENCES

[1] Tanaka Y., Nose M., Nakao M., Saitoh K., et al.: Development of Low NOx Combustion System with EGR for 1700°C class Gas Turbine, Mitsubishi Heavy Industries Technical Review, Vol. 50, 1/2013.

[2] Ishikawa M., Terauchi M., Komori T., Yasuraoka J.: Development of High Efficiency Gas Turbine Combined Cycle Power Plant, Mitsubishi Technical Reviev Vol. 45, 1/2008.

[3] Ai T., Masada J., Ito E.: Development of the High Efficiency and Flexible Gas Turbine M701F5 by Applying "J" Class Gas Turbine Technologies, Mitsubishi Heavy Industries Technical Review, Vol. 51, 1/2014.

[4] Gas Turbine World Performance Specs, 30-th edition, January-February 2014, Vol. 44, No 1.

[5] Gas Turbine World 2007-2008 Handbook. Project, Planning, Pricing, Engineering, Construction and Maintenance, A Pequeot Publication, Vol. 26.

[6] Matta R.K., Mercer G.D., Tuthill R.S.: Power Systems for the 21st Cen-tury – “H” Gas Turbine Combined-Cycles, GE Power Systems (GER-3935B).

[7] Gas Turbine World Handbook 2013. Project, Planning, Pricing, Engineering, Construction and Maintenance, A Pequeot Publication, Vol. 30.

[8] Badyda K., Iwański Z.: Modern Heavy Duty Gas Turbines – Operation and Maintenance Conditions (in polish), Proceedings of V Konferencja Naukowo-Techniczna Energetyka Gazowa 2013, V2, 163-178.

[9] FlexEfficiency *50 Combined Cycle Power Plant. Advanced power with a new standard of high efficiency and operational flexibility. GE Energy, http://www.ge-flexibility.com/solutions/flexefficiency-50-portfolio/index.html

[10] Badyda K., Miller A.: Energetyczne turbiny gazowe i układy z ich wykorzystaniem, Kaprint, Lublin, 2011.

[11] Cornu L., Deleonardo G., Dreisbach T., Goldmeer J., et al.: 9F Heavy Duty Gas Turbine Evolution White Paper, GE Energy, GEA 18576B, January 2012.

[12] Gas Turbine World 2010 Handbook. Project, Planning, Pricing, Engineering, Construction and Maintenance, A Pequeot Publication, Vol. 28.

[13] Regulation of the Minister of Economy of 22 April 2011 concerning indsutrial plant emission stnadards (Dz.U. 2001.95.558).

[14] Directive 2010/75/EU of the European Parliamnet and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control, Official Journal of the European Union L 334, 17-119

[15] Best Available Techniques (BAT) Reference Document for the Large Combustion Plants. Industrial Emissions Directive 2010/75/EU, Integrated Pollution Prevention and Control JOINT RESEARCH CENTRE, Institute for Prospective Technological Studies Sustainable Production and Consumption Unit European IPPC Bureau, Draft 1 (June 2013).

[16] Järpner Ch., Movaghar A., Thorbergsson E., Grönstedt T.: An assessment of cooled air cooling for combined cycle gas turbines, 5th International Conference on Applied Energy, Energy Solutions for Sustainable World, Pretoria, South Africa 1-4.VII.2013.

[17] Badyda K.: Trends, Conditions and Prospects for the Construction of New Gas Turbine Combined Cycle Plants in Poland (in polish), Rynek Energii, 2013, 5 (108), 26-33.

[18] Chmielniak T.: Gas Turbines – Main Development Tendencies (in polish), Rynek Energii, 2014, 3 (112), 69-75.

[19] Kotowicz J., Bartela Ł.: Wpływ zmiany obciążeń elektrociepłowni gazowo-parowej na charakterystyki termodynamiczne. Rynek Energii, 2008, 5, 45-50.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Paweł BAGIŃSKI
Grzegorz ŻYWICA
Łukasz BREŃKACZ
The Szewalski Institute of Fluid-Flow Machinery
Polish Academy of Sciences
Fiszera 14, 80-231 Gdansk, Poland
pbaginski@imp.gda.pl

THE TEST RIG AND INVESTIGATION OF THE HIGH-SPEED ROTOR SUPPORTED BY FOIL BEARINGS AT INCREASED TEMPERATURE

Abstract: This article presents the test plan and the design-build process to build the test rig for high-speed foil bearings whose main aim is to detect the thermal instability in FB. The authors present numerical analysis of the dynamic properties of rotors supported by air foil bearings. The calculations were performed on two versions of the rotor and two values of the clamping force concerning pressing the top foil onto the shaft. In addition, the article discusses the method for selecting the maximum dynamic load that can be safely applied for the rotors. For the calculation and presentation of the results the MESWIR and the GRAF-MESWIR software were used.

Keywords: foil bearings, thermal instability, rotor dynamics, numerical analysis.

REFERENCES

[1] Kiciński J., Żywica G., Bagiński P.: *Analiza warunków występowania oraz możliwych symptomów zjawiska niestabilności termicznej gazowych łożysk foliowych.* Oprac. wew. IMP PAN, nr arch. 231/2013, Gdańsk 2013.

[2] Kiciński J., Żywica G., Bagiński P., Czoska B.: *Analiza zjawiska niestabilności termicznej gazowych łożysk foliowych na podstawie przeglądu literatury. Opracowanie zestawienia i charakterystyka wybranych prac.* Oprac. wew. IMP PAN, nr arch. 92/2013, Gdańsk 2013.

[3] Radil K., Zeszotek M.: *An Experimental Investigation Into the Temperature Profile of a Compliant Foil Air Bearing.* NASA, TM-2004-213100, 2004.

[4] Żywica G., Bogulicz M., Czoska B.: *Opracowanie metody analizy gazowych łożysk foliowych z uwzględnieniem obciążenia wstępnego podatnego zespołu folii*, Opracowanie Wewnętrzne IMP PAN nr arch. 301/2013, Gdańsk, 2013.

[5] Kiciński J.: *Dynamika wirników i łożysk ślizgowych.* Wydawnictwo IMP PAN, Gdańsk 2005.

[6] Bogulicz M.: *Instrukcja do programu GRAF-MESWIR pre-postprocesora graficznego dla wybranych programów serii KINWIR i NLDW wersja 2012*, Opracowanie wewnętrzne IMP PAN nr arch. 676/2012, Gdańsk, 2012.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Andrzej BŁASZCZYK[1]
Adam PAPIERSKI[1*]
Mariusz SUSIK[1]
Mariusz NAWROCKI[2]
Dariusz WOŹNIAK[2]
[1] *Institute of Turbomachinery*
Lodz University of Technology
219/223 Wolczanska St, 90-924 Lodz, Poland
[2] *Hydro-Pomp Sp. z o.o.*
19 Wróblewskiego St., 93-578 Lodz, Poland
[*] *adam.papierski@p.lodz.pl*

MEASUREMENT OF UNSTEADY FLOW IN SUCTION INTAKES OF VERTICAL AXIAL-FLOW PUMPS

Abstract There are results of Pitot probe measurements of velocities at the outlet of the formed suction intake, with and without the rib. There are given conclusions of the comparative analysis of numerical computations and Pitot probe measurements. In the article there are also pressure measurements and the observation of surface vortices. These results may constitute the basis of verification of the unsteady flow computation method, for formed suction intakes.

Keywords: Cooling Water System, Suction Intake, Unsteady flow, Model studies.

REFERENCES

[1] American National Standard for Pump Intake Design. ANSI/HI 9.8-1998. Hydraulic Institute. 9 Sylvan Way, Parsippany, New Jersey 07054-3802, www.pumps.org

[2] ANSYS CFX, Release 12.1: Theory Manual, 2001.

[3] Błaszczyk A., Najdecki S., Papierski A., Staniszewski J.: Badania modelowe kanału ssącego pompy wody chłodzącej 180P19 na stanowisku nr 8 dla bloku A 460MW w Elektrowni Pątnów. Report of the work stage I, archives of the Institute of Turbomachinery TU of Łódź 1542, 2006.

[4] Błaszczyk A., Najdecki S., Papierski A., Staniszewski J.: Badania modelowe kanału ssącego pompy wody chłodzącej 180P19 na stanowisku

nr 8 dla bloku A 460MW w Elektrowni Pątnów. Report of the work stage II, archives of the Institute of Turbomachinery TU of Łódź 1546, 2006.

[5] Karassik I.J., Messina J.P., Cooper P., Heald Ch.C.: Pump Handbook. Third Edition. McGraw-Hill. New York, 2001.

[6] Kazimierski Z.: Numeryczne wyznaczenie trójwymiarowych przepływów turbulentnych. Maszyny Przepływowe, Wrocław 1992, Vol. 11.

[7] Kuczkowski M.: Numeryczny model turbulencji przepływu przez zagięcie przewodu z wykorzystaniem metody LES. Praca doktorska, Łódź 2007.

[8] Kunicki R.: Numeryczne i doświadczalne badania przepływów nieustalonych w komorach wlotowych pomp. Ph.D. thesis Łódź 2011.

[9] Li S., Lai Y., Weber L., Silva J.M. Patel, V.C.: Validation of a 3D Numerical Model for Water Pump Intakes. Journal Hydraulic Research, 42(3), 282-292 – 2004.

[10] Mahesh K., Constantinescu S.G., Moin P.: A Numerical Method for Large Eddy Simulation in Complex Geometries. Journal of Computational Physics, 197(1), 215-240 – 2004.

[11] Menter F.R.: Multiscale model of turbulent flows. 1993, AIAA, 24th Fluid Dynamic Conference.

[12] Rajendran V.P.: Constantinescu S.G., Patel V.C. Experimental Validation of Numerical Model of Flow in Pump-Intake Bays. Journal of Hydraulic Engineering,125(11), 1119-1125 – 1999.

[13] Tullis J.P.: Modeling in design of pumping pits. Journal of the Hydraulic Division, Vol. 105, No. HY9, Sept 1979, P. 1053-1063.

[14] Zaino A.: Wpływ parametrów konstrukcyjnych na zjawiska przepływowe w komorach wlotowych zamkniętych dużych pomp wirowych. Technical University of Wrocław, 1994.

CIEPLNE MASZYNY PRZEPŁYWOWE

No. 145 TURBOMACHINERY 2014

Andrzej BŁASZCZYK[1]
Adam PAPIERSKI[1*]
Mariusz SUSIK[1]
Mariusz NAWROCKI[2]
Dariusz WOŹNIAK[2]
[1] Institute of Turbomachinery
Lodz University of Technology
219/223 Wolczanska St, 90-924 Lodz, Poland
[2] Hydro-Pomp Sp. z o.o.
19 Wróblewskiego St., 93-578 Lodz, Poland
[*] adam.papierski@p.lodz.pl

NUMERICAL COMPUTATIONS OF UNSTEADY FLOW IN SUCTION INTAKES OF VERTICAL AXIAL-FLOW PUMPS

Abstract: In the article, there are introduced results of numerical computations of unsteady flow in the intake of large vertical pumps verified by results of the measurements made on the test stand. Comparative analysis of results of numerical computations, pressure measurements and the observation of surface vortices, have confirmed the justness of a chosen computational method.

Keywords: Cooling Water System, Suction Intake, Unsteady flow, Model studies.

REFERENCES

[1] American National Standard for Pump Intake Design. ANSI/HI 9.8-1998. Hydraulic Institute. 9 Sylvan Way, Parsippany, New Jersey 07054-3802, www.pumps.org

[2] ANSYS CFX, Release 12.1: Theory Manual, 2001.

[3] Błaszczyk A., Najdecki S., Papierski A., Staniszewski J.: Badania modelowe kanału ssącego pompy wody chłodzącej 180P19 na stanowisku nr 8 dla bloku A 460MW w Elektrowni Pątnów. Report of the work stage I, archives of the Institute of Turbomachinery TU of Łódź 1542, 2006.

[4] Błaszczyk A., Najdecki S., Papierski A., Staniszewski J.: Badania modelowe kanału ssącego pompy wody chłodzącej 180P19 na stanowisku nr 8 dla bloku A 460MW w Elektrowni Pątnów. Report of the work stage II, archives of the Institute of Turbomachinery TU of Łódź 1546, 2006.

[5] Karassik I.J., Messina J.P., Cooper P., Heald Ch.C.: Pump Handbook. Third Edition. McGraw-Hill. New York, 2001.

[6] Kazimierski Z.: Numeryczne wyznaczenie trójwymiarowych przepływów turbulentnych. Maszyny Przepływowe, Wrocław 1992, Vol. 11.

[7] Kuczkowski M.: Numeryczny model turbulencji przepływu przez zagięcie przewodu z wykorzystaniem metody LES. Praca doktorska, Łódź 2007.

[8] Kunicki R.: Numeryczne i doświadczalne badania przepływów nieustalonych w komorach wlotowych pomp. Ph. D. thesis Łódź 2011.

[9] Li S., Lai Y., Weber L., Silva J.M. Patel, V.C.: Validation of a 3D Numerical Model for Water Pump Intakes. Journal Hydraulic Research, 42(3), 282-292 – 2004.

[10] Mahesh K., Constantinescu S.G., Moin P.: A Numerical Method for Large Eddy Simulation in Complex Geometries. Journal of Computational Physics, 197(1), 215-240 – 2004.

[11] Menter F.R.: Multiscale model of turbulent flows. 1993, AIAA, 24th Fluid Dynamic Conference.

[12] Rajendran V.P.: Constantinescu S.G., Patel V.C. Experimental Validation of Numerical Model of Flow in Pump-Intake Bays. Journal of Hydraulic Engineering,125(11), 1119-1125 – 1999.

[13] Tullis J.P.: Modeling in design of pumping pits. Journal of the Hydraulic Division, Vol. 105, No. HY9, Sept 1979, P. 1053-1063.

[14] Zaino A.: Wpływ parametrów konstrukcyjnych na zjawiska przepływowe w komorach wlotowych zamkniętych dużych pomp wirowych. Technical University of Wrocław, 1994.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Łukasz BREŃKACZ [1,2*]
Sebastian BYKUĆ [3]
Grzegorz ŻYWICA[1]
Tomasz KACZMARCZYK [3]
[1] Rotor Dynamics and Slide Bearings Department
The Szewalski Institute of Fluid-Flow Machinery
Polish Academy of Sciences
Fiszera 14 Street, 80-231 Gdańsk, Poland
[2] Gdańsk University of Technology
Gabriela Narutowicza 11/12, 80-233 Gdańsk, Poland
[3] Thermodynamics Department
The Szewalski Institute of Fluid-Flow Machinery
Polish Academy of Sciences
Fiszera 14 Street, 80-231 Gdańsk, Poland
**lukasz brenkacz@imp.gda.pl*

THE LABORATORY TEST STAND OF THE ORC MICRO POWER PLANT

Abstract: The article presents the design and implementation of the laboratory test stand of the micro power plant with an Organic Rankine Cycle (ORC). The test stand was created to research different constructions of micro-turbines operating on a low-boiling agent. The electric power of these micro-turbines is 2-3 [kW]. There are measuring sensors connected to the test stand, which are necessary to collect information about the work of the whole ORC system. This laboratory test stand was built in the Szewalski Institute of Fluid Flow Machinery in Gdansk. The research on the newly constructed test stand were performed and some of the results are shown in this article.

Keywords: test stand, micro power plant, Organic Rankine Cycle, micro-turbines, CHP (Combined Heat and Power).

REFERENCES

[1] Breńkacz Ł., Bykuć S., Niewiadomski J.: Projekt stanowiska badawczego mikrosiłowni z turbiną naddźwiękową wysokoobrotową. Rysunki 2D, 3D. Zestawienie materiałów dodatkowych wymaganych do przyłączenia i montażu turbogeneratora. Opracowanie wew. IMP PAN nr arch. 844/2012, Gdańsk 2012.

[2] Kozanecki Z., Klonowicz P., Więckowski S., Łagodziński J., Miazga K.: Koncepcja, obliczenia i projekt techniczny alternatywnych turbin promieniowych III prototypu turbogeneratora funkcjonującego z modelową siłownią ORC. Opracowanie wew. IMP PAN nr arch. 22/2012, Gdańsk 2012.

[3] Kozanecki Z., Marczyk A., Więckowski S., Łagodziński J., Borkowski R.: Projekt i wykonanie podzespołu aerostatycznych łożysk gazowych III-go prototypu turbogeneratora z turbiną naddźwiękową oraz testy maszyny z łożyskami aerostatycznymi i generacją energii elektrycznej przy zastosowaniu powietrza jako czynnika roboczego. Opracowanie wew. IMP PAN nr arch. 632/2012, Gdańsk 2012.

[4] HFE-7100 – Karta charakterystyki, 3M Poland Sp. z o.o.

[5] Kiciński J., Żywica G., Banaszek S.: Badania eksperymentalne właściwości dynamicznych oraz ocena stanu dynamicznego prototypowej mikroturbiny naddźwiękowej podczas pracy z docelowym czynnikiem roboczym. Opracowanie wew. IMP PAN nr arch. 985/2012, Gdańsk 2013.

[6] Mikelewicz J., Bykuć S.: Koncepcja mikrosiłowni kogeneracyjnej pracującej w obiegu Rankine'a. Archiwum Energetyki, tom XXXVI, Gdańsk 2006.

[7] Mikielewicz J., Bykuć S., Mikiellewicz D.: Application of renewable energy sources to drive Organic Rankine Cycle micro CHP, Proc. of Heat Transfer and Renewable Sources of Energy, 329-336, Międzyzdroje 2006.

[8] Mikielewicz J., Mikelewicz D., Bykuć S.: Analysis of selected fluids for use in micro-chp for domestic applications. Inter. Conf. University of Applied Sciences Bremen 08-09 Nov. Bremen, 2007.

[9] Bykuć S., Niewiadomski S., Kaczmarczyk T.Z., Żywica G.: Badania rozruchowe mikroturbiny naddźwiękowej z docelowym czynnikiem roboczym na stanowisku badawczym mikrosiłowni ORC, Opracowanie wew. IMP PAN nr arch. 121/2014, Gdańsk 2014.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Jakub BUKALA[1a]
Krzysztof DAMAZIAK[1b*]
Hamid Reza KARIMI[2a]
Krzysztof KROSZCZYŃSKI[3a]
Marcin KRZESZOWIEC[1c]
Jerzy MALACHOWSKI[1d]
[1]*Faculty of Mechanical Engineering*
Dept. of Mechanics and Applied Computer Science
Military University of Technology
[2]*Faculty of Engineering and Science, Dept. of Engineering*
University of Agder
[3]*Falucty of Civil Engineering and Geodesy, Dept. of Applied Geomatics,*
Military University of Technology
[*b]*kdamaziak@wat.edu.pl*

A COMPARATIVE ANALYSIS OF POPULAR MODERN SMALL WIND TURBINE DESIGN SOLUTIONS IN TERMS OF ESTIMATED COST TO POWER OUTPUT RATIO

Abstract: In this paper a series of estimations has been performed in order to establish the actual cost-effectiveness of small wind turbines (SWTs). Different design solutions have been evaluated and based on their power curves and installation costs, using accurate wind data, a rate of investment return (ROI)period has been calculated for each one of them. The chosen turbines are: a classic three bladed horizontal axis wind turbine (HAWT), an advanced diffusor augmented HAWT and a Darrieus type vertical axis wind turbine (VAWT). The conclusions drawn from this study entertain the idea that from the economical point of view, a price reduction of SWT systems is more important, than aerodynamic complexity and efficiency.

Keywords: small wind turbines, numerical weather prediction, cost estimation.

REFERENCES

[1] Woofenden I., Sargillo M.: Is wind electricity right for you, Home power 143, June 2011, p. 52-61.
[2] ABB SACE-ABB S.p.A. L.V. *Breakers: Wind power plants*, Technical Application Papers. No. 13, 2011.

[3] Wroblewski D.: *Wind turbines, Itronduction*. Boston: BU College of Engineering, http://people.bu.edu/dew11/windturbine.html, Retrieved: 18.10.2013.
[4] Ohya Y., & Karasudani T.: *A shrouded wind turbine generating high output power with wind-lens technology*, Energies, *3*(4), 634-649.
[5] Energy Saving Trust. *Location, location, location. Domestic small-scale wind field trial report.*, 06.2009.
[6] Sagrillo M., Sagrillo Power & Light, *Back to the basics 2: Turbulence.* Windletter, Vol. 28, issue: 10 (2005).
[7] Manwell J.F., McGowan J.G., Rogers A.L.: *Wind energy explained. Theory, design, and aplication. Second edition.* John Wiley and Sons Ltd., 2009.
[8] Gasch R., Twele J.: *Wind Power Plants. Fundamentals, Design, Construction and Operation. Second Edition.* Springer, 2012.
[9] Burton T., Jenkins N., Sharpe D., Bossanyi E.: *Wind Energy Handbook. Second Edition.* John Wiley and Sons Ltd., 2011.
[10] Milivojevic N., Stamenkovic I., Schofield N.: *Power and Energy Analysis of Commercial Small Wind Turbine Systems.* IEEE, 2010.
[11] Wiśniewski G., Michałowska-Knap K., Koć S: *Energetyka wiatrowa – stan aktualny i perspektywy rozwoju w Polsce*. Warszawa, 2012.
[12] Polskie Stowarzyszenie Energetyki Wiatrowej: *Ocena możliwości rozwoju i potencjału energetyki wiatrowej w Polsce do roku 2020*.Szczecin, 2013.
[13] Caretto L.: *Use of Probability Distribution Functions for Wind. Mechanical Engineering 483*, Alternative Energy Engineering II, Northridge California State University, 2010.
[14] Sunderland K., Woolmington T., Blackledge J., Conlon M.: *Small wind turbines in turbulent (urban) enviroments: A consideration of normal and Weibull distribution for power prediction,* Journal of Wind Engineering and Industrial Aerodynamics, Volume 121, October 2013, Pages 70-81.
[15] Manwell J.F., McGowan J.G., Rogers A.L.: *Wind Energy Explained: Theory, Design and Application*. John Wiley & Sons, Chichester, 2003.
[16] Elliott D., Infield D.: *An assessment of the Impact of Reduced Averaging Time on Small Wind Turbine Power Curves, Energy Capture Predictions and Turbulence Intensity Measurements,* Wind Energy, Volume 17, Issue 2, pages 337-342.
[17] Lundquist J.K.: *Observational Needs for Wind Resource Assessment and Forecasting*, American Meteorological Society Short Course on Wind Energy, 2010.
[18] Carpman N.: *Tubulence Intensity in Comples Enviroments and its Influence on Small Wind Turbines*, University essay from Uppsala Universitet, 2011.
[19] IEC 61400-2. Small wind turbines.

[20] Lubitz W.: *Impact of ambient turbulence on performance of a small wind turbine*, World Renewable Energy Congress, Wind Energy Applications Section, Sweden 2011.

[21] Barzyk G.: *Przyłączenie elektrowni wiatrowych do sieci energetycznej w kontekście uregulowań IRiESD*, Konferencja PSEW, Warszawa, 2007.

[22] Al-Yahyai, S., Charabi, Y., & Gastli, A.: Review of the use of Numerical Weather Prediction (NWP) Models for wind energy assessment. *Renewable and Sustainable Energy Reviews*, *14*(9), 3192-3198, 2010.

[23] Lange M., Focken U., Meyer R., Denhardt M., Ernst B., & Berster F.: (2006, October). Optimal combination of different numerical weather models for improved wind power predictions. In *Sixth International Workshop on Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms* (pp. 273-276).

[24] World Wind Energy Association, *Small Wind World Report Update 2013*, Bonn, 2013.

[25] Skamarock W.C., Klemp J.B., Dudhia J., Gill D.O., Barker D.M., Duda M.G. Powers J.G.: *A description of the advanced research WRF version 3.* NCAR Technical note, 2008.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Wojciech CHOLEWA
Institute of Fundamentals of Machinery Design
Silesian University of Technology
Gliwice, Poland
wojciech.cholewa@polsl.pl

CONDITIONAL CONTRADICTIONS IN DIAGNOSTIC KNOWLEDGE BASES

Abstract: A recognition of the actual technical state of an object is possible by means of diagnostic expert systems. Knowledge bases of such systems are collected by teams of experts and unfortunately they are not free from errors. Identification of errors, and in particular identification of conditional errors is a very hard task. The paper introduces a measure called disagreement level and enabling identification of erroneous data as well as errors in models represented by means of diagnostic knowledge bases.

Keywords: knowledge base, intuitionistic statement network, dis-agreement level, diagnostic system.

REFERENCES

[1] Cholewa W.: Dynamical Statement Networks, In: Awrejcewicz J. (Ed.), Applied Non-Linear Dynamical Systems, Springer 2014 (in press).

[2] Bargiela A., Pedrycz W.: Granular Computing. An Introduction.

[3] Cholewa W.: Multimodal statement networks for diagnostic applications, In: Proceedings of the International Conference on Noise and Vibration Engineering (ISMA), pp. 817-830, 2010.

[4] Cholewa W.: Intuitionistic Notice Boards for Expert Systems, In: Gruca A. et al. (Eds.), Man-Machine Interactions 3, Advances in Intelligent Systems and Computing 241, Springer 2014.

[5] Jensen V.J.: Bayesian Networks and Decision Graphs, Springer, New York 2002.

[6] Atanassov K.T.: Intuitionistic Fuzzy Sets. Theory and Applications. Springer Verlag, Berlin Heidelberg, 1999.

[7] Atanassov K.T.: On Intuitionistic Fuzzy Sets Theory. Springer Verlag, Berlin Heidelberg, 2012.

[8] Cholewa W.: Mechanical analogy of statement networks. International Journal of Applied Mathematics and Computer Science 18(4), pp. 477-486, 2008.

[9] Rogala T., Amarowicz M.: Multimodal Statement Network for Organic Rankine Cycle Diagnostic. Use Case of Diagnostic Modeling, Proceedings of the IEEE Intelligent Systems, Warsaw 2014 (in press).

[10] Cholewa W., Amarowicz M., Chrzanowski P., Rogala T.: Development environment for diagnostic multimodal statement networks, Key Engineering Materials 588, Trans Tech Publications, pp. 74-83, 2014.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Piotr DOMAGALSKI[1*]
Anna KARCZEMSKA[2]
Dariusz WITKOWSKI[2]
Mariusz TOMCZYK[3]
Ryszard PAWLAK[3]
[1] Process and Environmental Engineering Department
Lodz University of Technology
Wolczanska 213, 90-924 Lodz, Poland
[2] Institute of Turbomachinery
Lodz University of Technology
Wolczanska 219/223, 90-924 Lodz, Poland
[3] Institute of Electrical Engineering Systems
Lodz University of Technology
Stefanowskiego 18/22, 90-924 Lodz, Poland
[*] piotr.domagalski@p.lodz.pl

THE „POOR MAN" MICRO-PIV – ADAPTATION OF PARTICLE IMAGE VELOCIMETRY FOR MICROSCALE MEASUREMENTS

Abstract: Particle Image Velocimetry (PIV) is a well-established measurement technique in area of fluid mechanics [1]. Its main idea is monitoring the displacement of tracer particles over time to obtain the flow's velocity field. Although the technique is very flexible and widely used, it cannot be applied for flows in geometries of characteristic dimensions of order of millimeters or micrometers, which is often desired e.g. for visualization of the flow field between the centrifugal pump impeller and volute, in case of wall-slip flows in rheological investigations or generally in microfluidics area. In such scales the direct application of PIV is impossible due to technological issues: used in PIV lightning system – a light sheet used for slicing the investigated area will not work due to near-wall reflections, optical elements limited laser damage threshold and align problems. Therefore the light delivery system has to be completely redesigned, but as the other system components, data acquisition system and light source remain untouched, the adaptation of PIV system is possible in form of micro PIV [2,3]. In current work we would like to test the possibility of building such an adapter, aiming for costs minimization, therefore we decide to reduce the microPIV system, using the breadboard-mounted set of opto-mechanical elements instead of using fluorescent microscope.

Keywords: flow visualization, velocity measurements, microfluidics, PIV, microPIV.

REFERENCES

[1] Adrian R.J.: Twenty years of particle image velocimetry. Experiments in fluids, 2005, 39(2), 159-169.

[2] Błoński S., Domagalski P., Dziubiński M., & Kowalewski T.A.: Hydrodynamically modified seeding for micro-PIV. Archives of Mechanics, 2011, 63(2), 163-182.

[3] Mielnik M.M.: Micro-PIV and its application to some BioMEMS related microfluidic flows. Doctor engineer thesis, Department of Energy and Process Engineering Norwegian University of Science and Technology, Trondheim, Norway, 2003.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Krzysztof DOMINICZAK[2*]
Romuald RZĄDKOWSKI[1]
Wojciech RADULSKI[2]
[1] *Department of Dynamics of Machines*
Institute of Fluid Flow Machinery
Polish Academy of Sciences, Gdansk
[2] *Alstom Power LTD.*
ul. Stoczniowa 2, 82-300 Elbląg, Poland
** krzysztof.dominiczak@power.alstom.com*

STEAM TURBINE STRESS CONTROL USING NARX NEURAL NETWORK

Abstract: Considered here is concept of steam turbine stress control, which is based on Nonlinear AutoRegressive neural networks with eXogenous inputs. Using NARX neural networks, which were trained based on experimentally validated FE model allows to control stresses in protected thick-walled steam turbine element with FE model quality. Additionally NARX neural network, which were trained base on FE model, includes: nonlinearity of steam expansion in turbine steam path during transients, nonlinearity of heat exchange inside the turbine during transients and nonlinearity of material properties during transients. Moreover NARX neural network allows to predict strength parameters (stress and temperature in protected steam turbine thick-walled element) for few time steps ahead. This leads to high accuracy of stress control. In this article NARX neural networks stress controls is shown as an example of HP rotor of 18K390 turbine. HP part thermodynamic model as well as heat exchange model in vicinity of HP rotor, which were used in FE model of the HP rotor and the HP rotor FE model itself were validated bas on experimental data for real turbine transient events. In such a way it is ensured that NARX neural network behave as real HP rotor during steam turbine transient events.

Keywords: stress control, steam turbine, neural networks, rotor.

REFERENCES

[1] Busse L.: Anfahrsonde, BBC-Studie HTGD51147, 1973.

[2] Dawson R.: Monitoring and Control of thermal stress and component life expenditure in steam turbine , England, Rugby, 1989.

[3] Ehrsam A.: Steam Turbines for Solar Thermal Applications, Proc of ASME Turbo Expo, Vancouver, 2011.

[4] Głuch J., Krzyżanowski J.: Application of an for diagnostics of the geometry deterioration of the power system apparatuses, Proc. of ASME Turbo Expo 2004, Paper No GT2004-54193, Vienna, Austria, 2004.

[5] Głuch J., Krzyżanowski J.: New attempt for diagnostics of the geometry deterioration of the power system based on thermal measurement, Proc. of ASME Turbo Expo 2006, Paper No GT2006-90263, Barcelona, Spain, 2006.

[6] Lausterer G.K.: On-line thermal stress monitoring using mathematical models, Control engineering practice, Vol. 5, No. 1, pp. 85-90, 1997.

[7] Lausterer G.K., Franke J., Eitelberg E.: Mathematical modeling of a steam generator. Digital computer applications to proccess control., Proc. of 6th IFAC/IFIP International Connference, Duesseldorf, 1980.

[8] Pahl G., Reitze W., Salm M.: Ueberwachungseinrichtung fuer zulaessige Temperaturaenderungen bei Dampfturbinen, BBC-Nachrichten, Vol. 46, pp. 139-147, 1964.

[9] Rusin A., Banaszkiewicz M., Lipka M., Łukowicz H., Radulski W.: Continuous control and optimization of thermal stresses in the process of turbine start-up, Thermal Stresses Symposium, Vienna University of Technology, Vienna, 2005.

[10] Sindelar R.: Control of the level of heat stress of the steam turbine metal during start-up and load changes, Skoda Review, Vol. 4, pp. 19-30, 1972.

[11] Sindelar R., Toewe W.: TENSOMAX – A retrofit thermal stress monitoring system for steam turbine, VGB Power Tech, vol. 1, pp. 60-62, 2000.

[12] Ślęzak-Żołna J., Głuch J.: Towards symptoms of degradation in on-line thermal and flow diagnostics of power objects, IFAC Fault Detection, Supervision and Safety of Technical Processes, Beijing, China, 2006.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Artur DRÓŻDŻ
Witold ELSNER *
Czestochowa University of Technology
Armii Krajowej 21, 42-201 Czestochowa, Poland
** welsner@imc.pcz.czest.pl*

ANALYSIS OF HOT-WIRE MEASUREMENTS ACCURACY IN TURBULENT BOUNDARY LAYER

Abstract: The paper discusses the problem of measuring velocity fluctuations of turbulent boundary layer using hot-wire probes. The study highlighted the problem of spatial resolution, which is essential when measuring small-scale in wall-bounded flows. Additionally, the attention was paid to the inconsistency in streamwise fluctuation measurements using single and X-wire probes. To clarify this problem the energy spectra using wavelet transformation were calculated. The analysis was performed for turbulent boundary layer flow, which was characterized by the Reynolds number based on the friction velocity equal $Re_\tau \approx 1000$.

Keywords: Turbulent Boundary Layer; Hot-wire; Spatial Resolution; Energy Spectra.

REFERENCES

[1] Ligrani P.M., and Bradshaw P.: 1987, Spatial resolution and measurement of turbulence in the viscous sublayer using subminiature hot-wire probes, Exp. Fluids, 5, pp. 407-417.

[2] Hutchins N., Nickels T.B., Marusic I., and Chong M.S.: 2009, Hot-wire spatial resolution issues in wall-bounded turbulence, J. Fluid Mech., 635, p. 103.

[3] Monty J.P., and Chong M. S., 2009, Turbulent channel flow: comparison of streamwise velocity data from experiments and direct numerical simulation, J. Fluid Mech., 633, p. 461.

[4] Schla er P., rl., Li Q., Brethouwer G., Fransson J.H.M., Johansson A.V., Alfredsson P.H., and Henningson D.S.: 2009, Turbulent boundary layers up to e[sub θ]=2500 studied through simulation and experiment, Phys. Fluids, 21(5), p. 051702.

[5] Lenaers P., Li., Brethouwer., Schla er P., and rl .: 2012, Are backflow and extreme wall-normal velocity fluctuations in near-wall turbulence, Phys. Fluids, 24(3), p. 035110.

[6] Dróżdż A., and Elsner W.: 2014, Comparison of single and X-wire measurements of streamwise velocity fluctuations in turbulent boundary layer, J. Theor. Appl. Mech., 52(2), pp. 499-505.

[7] Harun Z., Monty J. P., Mathis R., and Marusic I.: 2013, Pressure gradient effects on the large-scale structure of turbulent boundary layers, J. Fluid Mech., 715, pp. 477-498.

[8] Dróżdż A., Elsner W., and Drobniak S.: 2014, Scaling of streamwise Reynolds stress for turbulent boundary layers with pressure gradient, Eur. J. Mech. B/Fluids, DOI: 10.1016/j.euromechflu.2014.08.002, Vol. 49, Part A, publ. date: January-February 2015, pp. 137-145.

[9] Jorgensen F.E.: 2002, How to measure turbulence with hot-wire anemometers – a practical guide, Dantec Dynamics.

[10] Örlü R., and Alfredsson P.H.: 2010, On spatial resolution issues related to time-averaged quantities using hot-wire anemometry, Exp. Fluids, 49(1), pp. 101-110.

[11] Johansson A.V., and Alfredsson P.H.: 1983, Effects of imperfect spatial resolution on measurements of wall-bounded turbulent shear flows, J. Fluid Mech., 137, pp. 409-421.

[12] Monty J.P., Harun Z., and Marusic I.: 2011, A parametric study of adverse pressure gradient turbulent boundary layers, Int. J. Heat Fluid Flow, 32(3).

[13] Lee J., and Sung H.J.: 2008, Effects of an adverse pressure gradient on a turbulent boundary layer, Int. J. Heat Fluid Flow, 29(3), pp. 568-578.

[14] Nagano Y., Tsuji T., and Houra T.: 1998, Structure of turbulent boundary layer subjected to adverse pressure gradient, Int. J. Heat Fluid Flow, 19(5), pp. 563-572.

[15] Gordeyev S.: 2000, POD, LSE and Wavelet decomposition: Literature Review.

[16] Marusic I., Mathis., and Hutchins N.: 2010, High reynolds number effects in wall turbulence, Int. J. Heat Fluid Flow, 31(3), pp. 418-428.

[17] Townsend A.A.: 1956, The properties of equilibrium boundary layers, J. Fluid Mech., 1(06), p. 561.

[18] Dróżdż A., and Elsner W.: 2011, Detection of coherent structures in a turbulent boundary layer with zero, favourable and adverse pressure gradients, J. Phys. Conf. Ser., 318(6), p. 062007.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

STANISŁAW FORTUNA[1 *]
DARIUSZ KALISTA[1]
TOMASZ SIWEK [2]
[1] *AGH University of Science and Technology*
Department of Energy Systems and Environmental Facilities
30-059 Kraków, Al. Mickiewicza 30, Poland
[2] *AGH University of Science and Technology, Faculty of Energy and Fuels*
30-069 Kraków, Al. Mickiewicza 30, Poland
[*] *s.fortuna1@wp.pl*

CFD SIMULATION OF THE RELATIVE VORTICES ALONG THE CENTRIFUGAL FAN CHARACTERISTICS COMBINED WITH EXPERIMENTAL VERIFICATION

Abstract: Results of the centrifugal fans research project including CFD simulations of the relative velocities, trajectories and pressure profiles inside the rotor blade channels, have been presented in this study. Complete analysis of the characteristics was performed. Theoretical analysis of one-dimensional flow has also been studied. The conclusions confirmed that the change of rotation direction of the relative vortex inside the rotor blade channels, occurs along the fan characteristic.

Keywords: centrifugal model, relative vortex, CFD simulation, change of vortex rotation.

REFERENCES

[1] Fortuna S.: The investigation of the useful work and losses in radial fan. Monographs, AGH University of Science and Technology Press, Krakow 2011 [in Polish].

[2] Siwek T., Górski J., Fortuna S.: Numerical and experimental study of the flow structures in the centrifugal fans and their relation with the machine efficiency. Polish Journal of Environmental Studies. Olsztyn 2014.

[3] Fortuna S., Górski J., Siwek T.: Study of flow structure through centrifugal fan and its impact on machines performance. XX Fluid Mechanics Conference, Gliwice, 2012.

[4] Dixon S. L., Hall C. L.: Fluid Mechanics and Thermodynamics of Turbomachinery. 6th Edition. Elsevier 2010.

[5] En-min Guo, Kwang-yong Kim.: Tree-dimensional flow analysis and improvement of slip factor model forward-curved blades centrifugal fan. Journal of Mechanical Science and Technology, 04/2012.

[6] Younsi M., et al.: 3D unsteady flow in a centrifugal fan: impeller – volute interaction. Journal of computational and applied mechanics. Vol. 8, No. 2. 2007.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

David GARCIA [1]*
Matthew STICKLAND[1]
Grzegorz LIŚKIEWICZ [2]
[1] Mechanical and Aerospace Engineering, University of Strathclyde
75 Montrose Street Glasgow G1 1XJ
[2] Institute of Turbomachinery, Lodz University of Technology
90-924 Łódź, Wólczańska 219/223
** david.garcia@strath.ac.uk*

DYNAMICAL SYSTEM ANALYSIS OF UNSTABLE FLOW PHENOMENA IN CENTRIFUGAL BLOWER

Abstract: Methods of dynamical system analysis were employed to analyze unsteady phenomena in the centrifugal blower. Pressure signals gathered at different control points were decomposed into their Principal Components (PCs) by means of Singular Spectrum Analysis (SSA). Certain number of PCs was considered in the analysis based on their statistical correlation. Projection of the original signal onto its PCs allowed to draw the phase trajectory that clearly separated non-stable blower working conditions from its regular operation.

Keywords: Singular Spectrum Analysis, Nonlinear dynamics, Statistical pattern recognition, compressor, surge.

REFERENCES

[1] Emmons H.W., Pearson C.E., Grant H.P.: Compressor surge and stall propagation. Transactions of ASME, 77(4):455-467, 1955.

[2] Greitzer E.M.: Surge and rotating stall in axial flow compressors – part I: Theoretical compression system model. Journal of Engineering for Power, 98(2):190-198, 1976.

[3] Greitzer E.M.: Surge and rotating stall in axial flow compressors – part II: Experimental results and comparison with theory. Journal of Engineering for Power, 98(2):199-211, 1976.

[4] Hansen K.E., Jorgensen P., Larsen P.S.: Experimental and theoretical study of surge in a small centrifugal compressor. Journal of Fluids Engineering, 103(3):391-395, 1981.

[5] Moore F.K., Greitzer E.M.: A theory of post-stall transients in axial compression systems: Part i-development of equations. Journal of Engineering for Gas Turbines and Power, 108(1):68-76, 1986.

[6] Moore F.K., Greitzer E.M.: A theory of post-stall transients in axial compression systems: Part ii-application. Journal of Engineering for Gas Turbines and Power, 108(2):231-239, 1986.

[7] Gravdahl J.T. and Egeland O.: Speed and surge control for a low order centrifugal compressor model. In Proceedings of the 36th International Conference on Control Applications, San Diego, 1997. IEEE.

[8] Ishii H. and Kashiwabara Y.: Study on surge and rotating stall in axial compressors: A numerical model and parametric study for multiblade-row compressors. JSME International Journal. Series B: Fluids and Thermal Engineering, 39(3):621-631, 1996.

[9] Jansen W.: Rotating stall in a radial vaneless diffuser. Journal of Basic Engineering, 86(4):750-758, 1964.

[10] Senoo Y., Ishida M., Kinoshita Y.: Asymmetric flow in vaneless diffusers of centrifugal blowers. Journal of Fluids Engineering, 99(1):104-111, 1977.

[11] Abdelhamid A.N., Bertrand J.: Distinctions between two types of self excited gas oscillations in vaneless radial diffusers. In Proceedings of Turbo Expo, San Diego, 1979. ASME.

[12] Frigne P.: Van den Braembussche R., Distinction between different types of impeller and diffuser rotating stall in a centrifugal compressor with vaneless diffuser. Journal of Engineering for Gas Turbines and Power, 106(2):468-474, 1984.

[13] Lennemann E., Howard J.: Unsteady flow phenomena in rotating centrifugal impeller passages. Journal of Engineering for Gas Turbines and Power 92.1 (1970): 65-71.

[14] Liśkiewicz G., Horodko L., Stickland M. et al.: Identification of phenomena preceding blower surge by means of pressure spectral maps. Experimental Thermal and Fluid Science, 54:267-278, 2014.

[15] Mizuki S., Kawashima Y., Ariga I.: Investigation concerning rotating stall and surge phenomena within centrifugal compressor channels. In Proceedings of International Gas Turbine Conference, London, 1978. ASME.

[16] Packard N.H., Crutcheld J.P., Farmer J.D., et al.: Geometry from a time series. Physical Review Letters, 45(9):712, 1980.

[17] Takens F.: Detecting Strange Attractors in Turbulence, Lecture Notes in Mathematics, p.366, Springer, Berlin, 1981.

[18] Palomba C., Breugelmans F.: Phase portraits from rotating stall time series, XII ISABE conference, 312-318, Melbourne 1995.

[19] Palomba C., Horst L., Breugelmans F.: Strange Attractor Characterization of Rotating Stall in an Axial Flow Compressor. JSME Centennial, 1997.

[20] Hagino N., Uda K., Kashiwabara Y.: Prediction and Active Control of Surge Inception of a Centrifugal Compressor. Proceedings of the International Gas Turbine Congress. 2003.

[21] Broomhead D.S., King G.: Extracting qualitative dynamics from experimental data. Physica D: Nonlinear Phenomena, 20(2):217-236, 1986.

[22] Komatsubara Y., Mizuki S.: Dynamical system analysis of unsteady phenomena in centrifugal compressor. Journal of Thermal Science 6.1 (1997): 14-20.

[23] Gu C., Yamaguchi K., Nagashima T., et al.: Observation of centrifugal compressor stall and surge in phase portraits of pressure time traces at impeller and diffuser wall. Journal of fluids engineering 129.6 (2007): 773-779.

[24] Kuzmin V., Khazhuev V.: Measurement of liquid or gas flow (flow velocity) using convergent channels with a witoszynski prole. Measurement Techniques, 36(3):288-296, 1993.

[25] Golyandina N., Nekrutkin V., Zhigljavsky A.: Analysis of time series structure: SSA and related techniques. CRC Press, 2001.

[26] Jolliffe I.: Principal component analysis. Volume 487. Springer-Verlag New York, 1986.

[27] Garcia D., Trendafilova I.: A multivariate data analysis approach towards vibration analysis and vibration-based damage assessment. Application for delamination detection in a composite beam.Journal of Sound and Vibration, 2014.

[28] Ghil M., Allen M., Dettinger M., et al.: Advanced spectral methods for climatic time series, Reviews of Geophysics, 2002.

[29] Kabalyk K., Liśkiewicz G., Horodko L., et al.: Use of pressure spectral maps for analysis of influence of the plenum volume on the surge in centrifugal blower. In Proceedings of Turbo Expo, Düsseldorf, 2014. ASME.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Małgorzata GIZELSKA
Institute of Turbomachinery
Lodz University of Technology
219/223 Wolczanska St, 90-924 Lodz, Poland
malgorzata.gizelska@p.lodz.pl

MONITORING AND DIAGNOSTICS OF SPECIAL-PURPOSE TURBOMACHINES

Abstract: In the operation of special-purpose turbomachines, diagnostic tools which enable control of the machine technical state and its operation parameters in the on-line mode are necessary. The acquisition and processing of the measurement data in real time, which are indicators of the machine functioning under various operating conditions, are crucial. The paper presents two types of computer designed diagnostic tools to monitor in real time the dynamic and thermodynamic parameters of special-purpose turbomachines. The first one monitors the dynamics of the rotating system with an active magnetic bearing, the second - monitors the instant value of polytropic efficiency of the compression process, which was designed for the industrial machine.

Keywords: turbomachinery, monitoring, diagnostics, magnetic bearing, polytropic efficiency.

REFERENCES

[1] Schweitzer G., Maslen E.H.: Magnetic Bearings. Theory, Design and Application to Rotating Machinery, Springer-Verlag, Berlin, Heidelberg (2009).

[2] Gizelska M., Kozanecka D.: Diagnostic Software for Rotating System with an Active Magnetic Bearing, Cieplne Maszyny Przepływowe – Turbomachnery, Lodz University of Technology, No. 131, pp. 39-50, (2007), (in Polish).

[3] Gizelska M., Kozanecka D., Kozanecki Z.: Integrated Diagnostics of the Rotating System with an Active Magnetic Bearing, Solid State Phenomena, Vol. 147-149, pp. 137-142, Trans Tech Publications Ltd, Switzerland, ISSN 1012-0394, (2009).

[4] Kozanecka D.: Diagnostics of Rotating Machinery Mechatronic System, Monographic Series of Publications: Maintenance Problems Library,

Scientific Publishing House of Institute for Sustainable Technologies in Radom, ISBN 978-83-7204, pp. 966-7, (2010) (in Polish).

[5] Kozanecka D., Kozanecki Z., Lech T.: Experimental Identification of Dynamic Parameters for Active Magnetic Bearings, Journal of Theoretical and Applied Mechanics, Polish Society of Theoretical and Applied Mechanics, No. 124, Vol. 46, pp. 41-50, (2008).

[6] Kozanecka D., Kozanecki Z., Łagodziński J.: Active Magnetic Damper in a Power Transmission System, Communications in Nonlinear Science and Numerical Simulation, Journal Elsevier, No. 16, pp. 2275-2278, www.elsevier.com/locate/cnsns_1567 (2010).

[7] Kozanecki Z., Kozanecka D., Klonowicz P., Łagodziński J., Gizelska M., Tkacz E., Miazga K., Kaczmarek A.: Low power oil free turbomachnery, Monographic Series of Publications: Model complexes of agro-energy, Publishing House of the Institute of Fluid – Flow Machinery, Polish Academy of Sciences, Gdańsk (2014) (in Polish).

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Anthony HASLAM*
Abdullahi ABU
Panagiotis LASKARIDIS
School of Engineering, Cranfield University, UK
**a.haslam@cranfield.ac.uk*

A METHOD FOR THE ASSESSMENT OF OPERATIONAL SEVERITY FOR A HIGH PRESSURE TURBINE BLADE OF AN AERO-ENGINE

Abstract: This paper provides a tool for the estimation of the operational severity of a high pressure turbine blade of an aero engine. A multidisciplinary approach using aircraft/engine performance models which provide inputs to a thermo-mechanical fatigue damage model is presented. In the analysis, account is taken of blade size, blade metal temperature distribution, relevant heat transfer coefficients and mechanical and thermal stresses. The leading edge of the blade is selected as the critical part in the estimation of damage severity for different design and operational parameters. The study also suggests a method for production of operational severity data for the prediction of maintenance intervals.

Keywords: thermo-mechanical fatigue, turbine blades, oxidation, creep.

REFERENCES

[1] Harrison G.F., Tranter P.H. and Williams S.J.: Modelling of Thermomechanical Fatigue in Aero Engine Turbine Blades. Banff, Canada: AGARD, 1995. 81st Meetingof the AGARD SMP Panel.

[2] Cai C., et al.: Recent Developments in the thermomechanical fatigue Life prediction of Superalloys.
http://www.tms.org/pubs/journals/JOM/9904/Cai/Cai-9904.

[3] Zhuang W.Z.: and Swansson N.S.: Thermo- Mechanical Fatigue Life Prediction: A Critical Review. DSTO – TR -0609. Melbourne, Australia: DSTO Aeronautical and Maritime Research Laboratory, 1998.

[4] Institute, Nickel Development. High temperature High Strenght Nickel based Alloys No. 393 s .l. : Nickel Development Institute, 1995.

[5] Palmer J.R.: The Turbomatch scheme for aero/industrial gas turbine engine design point/off-design performance calculation for aero/industrial gas turbine. Cranfield, Bedfordshire : School of Mechanical Engineering, Thermal Power Group, Cranfield University, 1990.

[6] Laskaridis P., Pilidis P. and Kotsiopoulos P.: An integrated engine-aircraft performance platform for assessing new technologies in aeronautics. ISABE2005-1165. Munich, Germany : International Society for Air Breathing Engines, 2005. 17th International Symposium on Air Breathing Engines.

[7] Saravanamuttoo H., et al.: Gas Turbine Theory. Sixth edition, England: Prentice Hall, 2009.

[8] CFM International. CFM International website. [Online] 2012. [Cited: December 22, 2012] http://www.cfmaeroengines.com/engines/cfm56-7b#technology.

[9] IHS Janes. Aero- Engines. 2010. 28.

[10] Frank P.I. and David P.D.: Fundamentals of Heat and Mass Transfer, Fifth Edition ed. USA : John Wiley & Sons, 2002.

[11] Frank M.W.: Heat and Mass Transfer. USA : Addison-Wesley, 1988.

[12] Holman J.P.: Heat Transfer, 8th ed, . New York : McGraw-Hill, (1997).

[13] Eshati et al.: The influence of humidity on the creep life of a high pressure gas turbine blade: part i heat transfer model, GT2012-69445. Copenhagen, Denmark : ASME Turbo Expo, 2012.

[14] Neu R. and Sehitoglu H.: Thermo-Mechanical Fatigue, Oxidation and Creep: Part 1 – Damage Mechanisms. s. l. : Met. Trans. A, 20A, 1989, pp. 1755-1767.

[15] Neu R. and Sehitoglu H.: Thermo-Mechanical Fatigue, Oxidation and Creep: Part 2-Life Prediction. s. l. : Met. Trans. A, 20A, 1989, pp. 1769-1783.

[16] Sehitoglu H.: Thermo-Mechanical Fatigue Life Prediction Methods, Advances in Fatigue Lifetime Predictive Techniques. s. l. : ASTM STP 1122, 1992, pp. 47-76.

[17] Sehitoglu H. and Boismier D.A.: Thermo-Mechanical Fatigue of Mar-M247:Part2-Life Prediction. s. l. : Journal of Engineering Materials and Technology, January 1990, Vol. 112, pp. 80-89.

[18] Gomes E.E.B.: Operational Optimisation of gas turbine distributed generation systems in a competitive electricity market, PhD Thesis. Cranfield University, 2007.

[19] Thulin R.D., Howe D.C. and Singer I.D.: NASA Energy Efficient Engine High – Pressure Turbine Detailed Design Report NASA CR - 165608. Cleveland : NASA, 1982.

[20] Ackert, S., Engine Maintenance Concepts for Financiers:

http://www.aircraftmonitor.com

[21] Hanumanthan H.: Severity Estimation and Shop visit prediction of Aero engines (PhD thesis), Cranfield University, (2009).

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Michal HOZNEDL[1*]
Lukáš BEDNÁŘ[1]
Martin MICZÁN[1]
Ladislav TAJČ[2]
[1] *Doosan Škoda Power s.r.o.*
Tylova 1/57, Plzeň, 301 28, Czech Republic
[2] *Westbohemian University*
Univerzitní 8, Plzeň, 306 14, Czech Republic
[*] *Michal.hoznedl@doosan.com*

INFLUENCE OF OPERATING PARAMETERS ON THERMODYNAMIC EFFICIENCY OF EXPERIMENTAL TURBINE WITH 1000 MW HP PART

Abstract: The results of experiments performed on a 5-stage steam turbine are presented. Operating parameters close to the real design parameters are simulated. The modes with the slightly different input temperature and pressure are also considered. Thermodynamic efficiency defined based on the torque moment by measuring on a water brake is compared with efficiency evaluated from the temperatures and pressures. An analysis of velocity ratios and efficiency of individual stages is carried out.

Keywords: steam turbine, experimental measurement, efficiency, wet steam, flow conditions.

LITERATURE

[1] Tajč L.: Influence of Roughness of Blade Surface on Losses in Turbine Stage, Research Work Škoda Power, VZTP 0984, 2005

[2] Tajč L., Bednář L., Šťastný M.: Experimental Research of Three Turbine Stages with Different Geometry of Flow Path, Research Work Škoda Power, VZTP 1030, 2009.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Aldo IANNETTI*
Matthew T. STICKLAND
William M. DEMPSTER
University of Strathclyde
Scotland, United Kingdom
16 Richmond Street, Glasgow G1 1XQ
* *aldo.iannetti@strath.ac.uk*

AN ADVANCED CFD MODEL TO STUDY THE EFFECT OF NON-CONDENSABLE GAS ON CAVITATION IN POSITIVE DISPLACEMENT PUMPS

Abstract: An advanced transient CFD model of a positive displacement reciprocating pump was created to study its behavior and performance in cavitating conditions throughout the inlet stroke. The “full” cavitation model developed by Singhal et al. was utilized and a sensitivity analysis test on two amounts (1.5 and 15 parts per million) air mass fraction content was carried out to study the influence of the air content in water on the cavitation phenomenon. The model was equipped with user defined functions to introduce the liquid compressibility which stabilizes the simulation and to handle the two-way coupling between the pressure field and the inlet valve lift history. Estimation of the pump performance is also presented in both cases.

Keywords: Cavitation, PD pumps, non-condensable gas effect, CFD.

REFERENCES

[1] Ding H., Visser F.C. and Jiang Y.: A practical approach to speed up NPSHR prediction of centrifugal pumps using CFD cavitation model, in *Proceedings of the ASME 2012 Fluids Engineering Summer Meeting.*, 2012, p. Paper No. FEDSM2012–72282.

[2] Budris A.R. and Mayleben P.A.: Effects of entrained air, NPSH margin, and suction piping on cavitation in centrifugal pumps, in *Proceeding of the 15th international pump users symposium*, 1998, pp. 99-108.

[3] Miller J.E.: *The reciprocating pump, theory design and use*, Second Edi. Krieger publishing company, 1995, pp. 1-467.

[4] Opitz K. and Schlücker E.: Detection of Cavitation Phenomena in Reciprocating Pumps using a High-Speed Camera, *Chem. Eng. Technol.*, Vol. 33, No. 10, pp. 1610-1614, Jul. 2010.

[5] Opitz K., Schlücker E. and Schade O.: Cavitation in reciprocating positive displacement pumps, in *Twenty-seventh international pump users symposium*, 2011, pp. 27-33.

[6] Iannetti A., Stickland M., and Dempster W.: A CFD study on the mechanisms which cause cavitation in positive displacement reciprocating pumps, *Proc. Inst. Mech. Eng. Part A J. power energy*, Vol. In Press, 2014.

[7] Kuiper G.: *Cavitation in ship propulsion*. Delft: Delft University of Technology, 2010.

[8] Eisenberg P.: *Cavitation Damage*. Office of Naval Research, 1963, p. 220.

[9] Iannetti A., Stickland M.T. and Dempster W.M.: A computational fluid dynamics model to evaluate the inlet stroke performance of a positive displacement reciprocating plunger pump, *Proc. Inst. Mech. Eng. Part A J. Power Energy*, Vol. 228, No. 5, pp. 574-584, Apr. 2014.

[10] ANSYS, ANSYS Fluent Theory Guide, Vol. 15317, No. November. ANSYS Fluent, 2011.

[11] Singhal A.K., Athavale M.M., Li H. and Jiang Y.: Mathematical Basis and Validation of the Full Cavitation Model, *J. Fluids Eng.*, Vol. 124, No. 3, p. 617, 2002.

[12] ANSYS, ANSYS FLUENT User' s Guide, Vol. 15317, No. November. ANSYS Inc., 2011.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Kirill KABALYK*
Władysław KRYŁŁOWICZ
Lodz University of Technology
Institute of Turbomachinery
Wolczanska str. 219/223, 90-924 Lodz, Poland
* *kirill.kabalyk@p.lodz.pl*

THE INFLUENCE OF THE INLET DUCT DESIGN ON THE FLOW PRESSURE FLUCTUATIONS INSIDE A SEWAGE AERATION-TYPE CENTRIFUGAL BLOWER

Abstract: Depending on customer requirements a waste water aeration blower might possess various inlet duct configurations. The design parameters that usually vary are the inlet duct volume or the geometry of the duct. However, it is not yet well known how can the duct design influence the steady and unsteady compressor operation. Due to that, this work aims to experimentally check how do such parameters as inlet duct volume, inlet filter and inlet guide vanes position affect the compressor stable and unstable performance. The measurements results show that the influence exists and has mainly quantitative rather than qualitative character.
Keywords: centrifugal compressor, waste-water aeration, unsteady pressure measurements.

REFERENCES

[1] www.ci.troutdale.or.us/wastewater/treatment-plant.htm

[2] Galerkin Y.B.: Turbo compressors, Saint-Petersburg, SPbSTU (in Russian), 2008.

[3] Pampreen R.: Compressor surge and stall, Concepts Eti, 1993.

[4] Emmons H.W., Pearson C.E., Grant H.P.: Compressor surge and stall propagation, Transaction of the ASME 77, 1955, pp. 455-469.

[5] Pfleiderer C.: Die Kreiselpumpen fur Fleissigkeiten und Gase, Springer Verlag, Berlin-Gottingen-Heidelberg, 1955.

[6] Koyama M., Komatsubara Y., Tsujita H., Mizuki S.: Effect of plenum volume on rotating stall and surge of centrifugal compressor, Proceedings of ISROMAC-7, Honolulu, Hawaii, 1998, pp. 1159-1167.

[7] Fink D.A., Cumpsty N.A., Greitzer E.M.: Surge dynamics in a free-spool centrifugal compressor system, Journal of Turbomachinery, 1992, 114, pp. 321–332.

[8] Li D., et al.: Numerical and experimental research on different inlet configurations of high speed centrifugal compressor, Sci China Tech Sci, 2012, 55, pp. 174–181.

[9] Wang L., et al.: The change of the inlet geometry of a centrifugal compressor stage and its influence on the compressor performance, Journal of Thermal Science, 2013, 22, pp. 197-208.

[10] Centrifugal turbo compressors, Single-stage integrally geared (STC-GO), Siemens AG, www.siemens.com/energy

[11] Magiera R., Kryłłowicz W.: Wpływ zastosowania ciała centralnego w kierownicy wlotowej na strukturę przepływu przed kołem wirnikowym dmuchawy promieniowej (in Polish), 2006, Cieplne Maszyny Przepływowe CMP 130, pp. 107-116.

[12] Liskiewicz G., Horodko L., Stickland M., Kryłłowicz W.: Identication of phenomena preceding blower surge by means of pressure spectral maps, Experimental Thermal and Fluid Science, 2014, 54, pp. 267-278.

[13] Raitor T., Neise W.: Sound generation in centrifugal compressors, Journal of Sound and Vibration, 2008, 314(3-5), pp. 738-756.

[14] Kryłłowicz W.: Investigations of unstable operation of the single-stage radial compressor (in Polish), 2001, Tech. Rep. 889, Technical University of Lodz.

[15] Fraser W.H.: Recirculation in Centrifugal Pumps, World Pumps, 1982.

[16] Yedidiah S.: Centrifugal Pump User's Guidebook, Chapman and Hall, 1996.

[17] Chun S., et al.: Wall pressure fluctuations of a turbulent separated and reattaching flow affected by an unsteady wake, Experiments in Fluids, 2004, 37, pp. 531-546.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Konrad KACPRZAK*
Krzysztof SOBCZAK
Institute of Turbomachinery
Lodz University of Technology
Wólczańska 219/223, 90-924 Łódź, Poland
**kokacprzak@gmail.com*

COMPUTATIONAL ASSESSMENT OF THE INFLUENCE OF THE OVERLAP RATIO ON THE POWER CHARACTERISTICS OF A CLASSICAL SAVONIUS WIND TURBINE

Abstract: An influence of the overlap on the performance of the Classical Savonius wind turbine was investigated. Unsteady two-dimensional numerical simulations were carried out for a wide range of overlap ratios. For selected configurations computation quality was verified by comparison with three-dimensional simulations and the wind tunnel experimental data available in literature. A satisfactory agreement was achieved. Power characteristics were determined for all the investigated overlap ratios for selected tip speed ratios. Obtained results indicate that the maximum device performance is achieved for the buckets overlap ratio close to 0.

Keywords: Savonius wind turbine, overlap, CFD.

REFERENCES

[1] Spera D.: Wind Turbine Technology: Fundamental Concepts of Wind Turbine Engineering, ASME Press, 2009.

[2] Wagner H.J., Mathur J.: Introduction To Wind Energy Systems: Basics, Technology and Operation. Green Energy and Technology, Springer, 2009.

[3] Fujisawa N., Gotoh F.: Experimental Study on the Aerodynamic Performance of a Savonius Rotor, J SOL ENERG-T ASME., 1994, 148-152.

[4] Ogawa T.: Theoretical Study on The Flow About Savonius Rotor, J FLUID ENG-T ASME, 1984, 85-90.

[5] Kamoji L., Kedare S., Prabhu S.: Experimental investigations on single stage modified Savonius rotor, APPL ENERG, 2009, 1064-1073.

[6] Zhao Z., Zheng Y., Xu X.: Research on the improvement of the performance of Savonius rotor based on numerical study, SuperGen, 2009, 1-6.

[7] Zhou T. Rempfer D.: Numerical study of detailed flow field and performance of Savonius wind turbines, RENEW ENERG, 2013, 373-381.

[8] ANSYS CFX v15 Help.

[9] Kacprzak K., Liśkiewicz G., Sobczak K.: Numerical investigation of conventional and modified Savonius wind turbines, RENEW ENERG, 2013, 578-585.

[10] Shigetomi A., Murai Y., Tasaka Y., Takeda Y.: Interactive flow field around two Savonius turbines, RENEW ENERG, 2011, 536-545.

[11] Fujisawa N.: Velocity measurements and numerical calculations of flow fields around Savonius rotors, 1996, 711-720.

[12] Zhou T., Rempfer D.: Numerical study of detailed flow field and performance of Savonius wind turbines, RENEW ENERG, 2013, 373-381.

[13] Dobreva I., Massouha F.: CFD and PIV investigation of unsteady flow through Savonius wind turbine, J WIND ENG IND AEROD, 1996, 39-50.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Tomasz Z. KACZMARCZYK*
Eugeniusz IHNATOWICZ
Grzegorz ŻYWICA
Jan KICIŃSKI
The Szewalski Institute of Fluid-Flow Machinery
Polish Academy of Sciences
Gen. J. Fiszera 14 str., 80-231 Gdańsk, Poland
**tkaczmarczyk@imp.gda.pl*

EXPERIMENTAL INVESTIGATION OF THE ORC SYSTEM IN A COGENERATIVE DOMESTIC POWER PLANT WITH A SCROLL EXPANDERS

Abstract: The paper presents the results of experimental investigations of the ORC system with two scroll expanders which have been used as a source of electricity. The working fluid was HFE-7100 – a newly engineered fluid with a unique heat transfer and favourable environmental properties. In the ORC system three heat exchangers were used (evaporator, regenerator, condenser) and before expanders the droplet separator was installed. As a source of heat an innovative biomass boiler was used. Studies have been carried out for the expanders worked in series and in parallel. The paper presents the thermal and fluid-flow properties of the ORC installation for the selected flow rates and different temperatures of the working medium. The characteristics of output electrical power, operating speed and vibrations for scroll expanders were also presented.

Keywords: Organic Rankine Cycle, micro CHP, scroll expander, biomass boiler.

REFERENCES

[1] Quolin S., Declaye S., Lemort V.: Expansion machine and fluid selection for the Organic Rankine Cycle. HEFAT 2010, 7th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics, 19-21 July 2010, Antalya, Turkey.

[2] Wong Ch.S., Meyer D., Krumdieck S.: Selection and conversion of turbocharger as turbo-expander for Organic Rankine Cycle (ORC). 35th New Zealand Geothermal Workshop, 17-20 November 2013, Rotorua, New Zealand.

[3] Lemort V., Guillaume L., Legros A., Declaye S., Quolin S.: A comparison of piston, screw and scroll expanders for small-scale Rankine cycle systems. Proceedings of the 3rd International Conference on Microgeneration and Related Technologies, April 2013.

[4] Meyer D., Wong Ch., Engel F., Krumdieck S.: Design and build of 1 kilowatt Organic Rankine Cycle power generator. 35th New Zealand Geothermal Workshop, 17-20 November 2013, Rotorua, New Zealand.

[5] Kane M., Favrat D., Gay B., Anders O.: Scroll expander Organic Rankine Cycle (ORC) efficiency boost of biogas engines. ECOS 25-28 June 2007, Padova, Italy, Vol. II, pp. 1017-1024.

[6] Kaczmarczyk T.Z., Ihnatowicz E., Mikielewicz D., Mikielewicz J., Experimental Investigation of the ORC System Elements of a Home Cogenerative Micro Power Plant. 3rd International Conference, Low Temperature and Waste Heat Use in Energy Supply Systems Bremen, October 25th-26th, 2012.

[7] Kaczmarczyk T.Z., Ihnatowicz E., Żywica G., Bykuć S., Kozanecki Z.: Initial experimental investigation of the ORC system in a Cogenerative domestic power plant with a microturbine. 8th World Conference on Experimental Heat Transfer, Fluid Mechanics, and Thermodynamics June 16-20, 2013, Lisbon, Portugal, ISBN: 978-972-8620-23-3.

[8] Kaczmarczyk T.Z., Ihnatowicz E., Bykuć S., Żywica G., Kozanecki Z.: Experimental investigation of the ORC system in a cogenerative domestic power plant with a microturbine and a expansion valve. ASME ORC 2013, 2nd International Seminar on ORC Power System, October 7th-8th, 2013, De Doelen, Rotterdam, The Netherlands.

[9] http://airsquared.com/products/expanders/e15h22n425

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Maciej KARCZEWSKI [1*]
Piotr DOMAGALSKI [2*]
[1] *Institute of Turbomachinery*
Lodz University of Technology
Wolczanska 219/223, 90-924 Lodz POLAND
[2] *Faculty of Process and Environmental Engineering*
Lodz University of Technology
Wolczanska 213, 90-924 Lodz POLAND
**maciej.karczewski@p.lodz.pl, piotr.domagalski@p.lodz.pl*

CONCEPT OF MULTI ROTOR ARRAY FOR DEEP OFF-SHORE WIND TURBINE

Abstract: Coastal regions in Norway, Spain, Portugal, Japan or the United States comprise over large water depths (> 50 m) making the installation of typical bottom-fixed offshore wind turbines very difficult and expensive. Floating offshore wind turbines might be a more economic option in order to exploit the high energy potential contained in the offshore winds. According to EU-funded ORECCA R&D project these locations were all identified as Level 1 resource capacity with wind velocities ranging 8-11 m/s at 10 m a.s.l. (above sea level) [1]. Different concepts of floating support structures have already been investigated as for the first HAWT prototype, Statoil's "Hywind" spar buoy turbine, which has been operated off the cost of Norway since 2009 [2]. However, rising costs of operation and maintenance (O&M) as well as manufacturing of large turbine rotors and generators already seriously impair and will impair this branch of energy engineering in the years to come [3]. To address these problems the paper presents a concept of an innovative floating off-shore multi-rotor array turbine.

Keywords: off-shore wind turbine, floating platform, multi rotor array, wind resources.

REFERENCES

[1] ORECCA: Off-shore Renewable Energy Conversion platforms – Coordination Action, *European Offshore Renewable Energy Roadmap State of Resources*, Seventh Framework Programme (FP7) http://map.rse-web.it/orecca/map.phtml (accessed 29-09-2014).

[2] Nielsen F.G.: *Hywind. Deep offshore wind operational experience*, Statoil RDI presentation from Tande J.O., report *Deep Sea Offshore Wind R&D Conference*, Sintef, Trondheim, 2013.

[3] Jamieson P., Branney M.: *Multi-Rotors; A Solution to 20 MW and Beyond?* Deep Wind, 19-20 January, 2012, Trondheim, Norway, published in: Energy Procedia 24, pp. 52-59, 2012.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Maciej KARCZEWSKI[1*]
Paul EGLIN [2]
[1] *Institute of Turbomachinery*
Lodz University of Technology
219/223 Wolczanska St, 90-924 Lodz, Poland
[2] *Airbus Helicopters*
Aéroport International Marseille Provence
13725 Marignane Cedex, FRANCE
**maciej.karczewski@p.lodz.pl*

APPLICATION OF THE MODIFIED BLADE ELEMENT METHOD FOR PROPELLER BLADE DESIGN ON HIGH-SPEED HELICOPTER X^3

Abstract: The X^3 helicopter is the experimental demonstrator of the H3 compound helicopter concept (High speed Hybrid Helicopter) developed by Airbus Helicopter and intended to operate at cruise speeds of about 113 m/s (220 kt). It is equipped with short fixed wings and two side-mounted propellers. Usually, fixed-wing propellers are sized to optimize the power consumption in cruise flight. In the case of a compound helicopter, some other flight cases such as hover and descent in autorotation also have to be considered. The geometrical criteria to satisfy all flight regimes may be contradicting what implies a compromise and a new approach to the propeller design. This paper presents the different steps of X^3 propellers design from novelty theoretical Blade Element Method studies confirmed by CFD, experimental and flight tests.

Keywords: high speed helicopter, compound helicopter, BEM, CFD, experiment, flight test.

REFERENCES

[1] Adkins Ch.N. and Liebeck R.H.: Design of Optimum Propellers. *Journal of Propulsion and Power* 10, No. 5, Sept.-Oct. 1994, 676-682.

[2] Karczewski M.: Optimization of Propeller Blade for Application on a Specialty Aircraft, PhD Thesis, Lodz University of Technology, Sept. 2011.

[3] Leishman G.J.: Principles of helicopter aerodynamics. Cambridge University Press, Cambridge, UK, 2000.

[4] Eglin, P.: Patent EP 2258615 A1 / US 20100312421 A1 – Flight control assistance device for a hybrid helicopter, 2010.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Piotr KLONOWICZ[1*]
Jan SURWIŁO[1]
Łukasz WITANOWSKI[1]
Tomasz Kacper SUCHOCKI [1]
Zbigniew KOZANECKI [2]
Piotr LAMPART [1]
[1] The Szewalski Institute of Fluid-Flow Machinery
Polish Academy of Sciences
Fiszera 14 st., 80-231 Gdańsk, Poland
[2] Institute of Turbomachinery
Lodz University of Technology
Wólczańska 219/223 st., 90-924 Łódź, Poland
[*] pklonowicz@gmail.com

DESIGN AND NUMERICAL STUDY OF TURBINES OPERATING WITH MDM AS WORKING FLUID

Abstract: Design processes and numerical simulations have been presented for a few cases of turbines designated to work in ORC systems. The chosen working fluid is MDM.
The considered design configurations include single stage centripetal reaction and centrifugal impulse turbines as well as multistage axial turbines. The power outputs vary from about 75 kW to 1 MW.
The flow in single stage turbines is supersonic and requires special design of blades. The internal efficiencies of these configurations exceed 80% which is considered high for these type of machines. The efficiency of axial turbines exceed 90%. Possible turbine optimization directions have been also outlined in the work.

Keywords: ORC, turbines, MDM, numerical simulations, CHP.

REFERENCES

[1] Turunen-Saaresti T., Uusitalo A., Honkatukia J., Larjola J.: Effects of Turbine Efficiency to Small-Scale ORC Process Electricity Production and Profitability, in: First Int. Semin. ORC Power Syst. ORC 2011, Delft, 2011.
[2] Klonowicz P., Heberle F., Preißinger M., Brüggemann D.: Significance of loss correlations in performance prediction of small scale, highly loaded turbine stages working in Organic Rankine Cycles, Energy. (2014).

[3] Craig H.R.M., Cox H.J.A.: Performance Estimation of Axial Flow Turbines, Proc. Inst. Mech. Eng. 185 (1970) 407-424.

[4] Guardone A., Spinelli A., Dossena V., Vandecauter V.: Influence of Molecular Complexity on Nozzle Design for an Organic Vapor Wind Tunnel, in: First Int. Semin. ORC Power Syst. ORC 2011, 2011.

[5] Colonna P., Gallo M., Casati E., Mathijssen T.: Flexible Asymmetric Shock Tube (FAST). Status and first experiences, in: 2nd Int. Semin. ORC Power Syst. ASME ORC 2013, Rotterdam, 2013.

[6] Spinelli A., Dossena V., Gaetani P.: Start-up of a Test Rig for Organic Vapors, in: 2nd Int. Semin. ORC Power Syst. ASME ORC 2013, 2013.

[7] Zucrow M.J., Hoffman J.D.: Gas Dynamics Volume I and II, Wiley, 1976.

[8] Klonowicz P.: Optymizacja turbin przeznaczonych do pracy w niskotemperaturowych obiegach ORC (Organic Rankine Cycle), Lodz University of Technology, 2012.

[9] Papierski A.: Wielokryterialna i wielopoziomowa optymalizacja kształtu półotwartych wirników pomp o niskich wyróżnikach szybkobieżności, Politechnika Łódzka, 2010.

[10] Ansys CFX, Release 12, 2009.

[11] Harinck J., Pasquale D., Pecnik R., Colonna P.: Three-Dimensional RANS Simulation of a High-Speed Organic Rankine Cycle Turbine, in: First Int. Semin. ORC Power Syst. ORC 2011, Delft, 2011.

[12] Klonowicz P., Hanausek P.: Optimum Design of the Axial ORC Turbines with Support of the Ansys CFX Flow, in: First Int. Semin. ORC Power Syst. ORC 2011, Delft, 2011.

[13] Klonowicz P., Brüggemann D.: 2D Unsteady RANS Simulations of an Organic Vapor Partial Admission Turbine, in: ASME ORC 2013, 2nd Int. Semin. ORC Power Syst., Rotterdam, 2013.

[14] Klonowicz P., Sobczak K., Fijałkowski T.: Analysis of Kinematics for a Single-Stage ORC Impulse Turbine, in: 10th Int. Symp. Compress. Turbine Flow Syst. - Theory Appl. Areas Symkom 2011, Lodz, 2011.

[15] Klonowicz P., Borsukiewicz-Gozdur A., Hanausek P., Kryłłowicz W., Brüggemann D.: Design and performance measurements of an organic vapour turbine, Appl. Therm. Eng. 63 (2014) 297–303.

[16] Lemmon E., Huber M., McLinden M.: REFPROP, National Institute of Standards and Technology, 2010.

[17] Cho S., Ahn K., Lee Y.: Performance Characteristics of a Partially Admitted Small-Scale Mixed-Type Turbine, Int. J. Turbo Jet-Engines. 28 (2011) 299-307.

[18] Boxer E., Sterrett J.R., Wlodarski J.: Application of supersonic vortex-flow theory to the design of supersonic impulse compressor – or turbine-blade sections, NACA RM L52B06 (1952).

[19] Pasquale D., Ghidoni A., Rebay S.: Shape Optimization of an ORC Radial Turbine Nozzle, in: First Int. Semin. ORC Power Syst. ORC 2011, Delft, 2011.

[20] Kozanecki Z., Kozanecka D., Klonowicz P., Łagodziński J., Gizelska M., Tkacz E., et al.: Bezolejowe maszyny przepływowe małej mocy, Wydawnicta Instytutu Maszyn Przepływowych PAN, Gdańsk, 2014.

[21] Rusanov A., Lampart P., Szymaniak M., Bykuć S., Koronowicz J., Szymaniak A.: Zadanie Badawcze Nr 4 „Opracowanie zintegrowanych technologii wytwarzania paliw i energii z biomasy, odpadów rolniczych i innych.", Opracowanie układu przepływowego jednostopniowej turbiny promieniowo-osiowej ORC 100 kw, IMP PAN, Gdańsk, 2013.

[22] Rusanov A., Lampart P., Szymaniak M., Bykuć S.: Zadanie Badawcze Nr 4 „Opracowanie zintegrowanych technologii wytwarzania paliw i energii z biomasy, odpadów rolniczych i innych", Opracowanie układu przepływowego dwustopniowej (symetrycznej) turbiny promieniowo-osiowej ORC 100 kW, IMP PAN, Gdańsk, 2013.

[23] Klonowicz P., Lampart P.: Badanie rozwoju strat przepływów wtórnych i przecieku nadłopatkowego w turbinie promieniowo-osiowej ORC 100 kW i 40 kW. Przygotowanie obszaru obliczeniowego i wstępne obliczenia przepływowe turbin., IMP PAN, Gdańsk, 2014.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Joanna KOPANIA*
Grzegorz BOGUSŁAWSKI
Department of Fundamentals of Technology and Industrial Ecology
Institute of Social Sciences and Management of Technologies
Lodz University of Technology
90-924 Lodz, 266 Piotrkowska St., Poland
**joanna.kopania@p.lodz.pl*

THE BIONIC APPROACH IN NOISE REDUCTION OF THE FLUID MACHINERY

Abstract: At the present time minimization of the noise emission is an important issue. The most difficult is reducing source noise, but this is an important issue and must be considered in the design of future devices. Bionics is a novel approach to developing designs and products by taking inspiration from nature. Our studies about the aerodynamic noise of blades are inspired by owls. In this study the aeroacoustical parameters of wings the different species of owls were connect with their geometrical parameters. Thanks to this will be possible to design the "acoustically friendly" blade of fan.

Keywords: bionics, owls, noise reduction.

REFERENCES

[1] Inventory of Potential Measures for a Better Control of Environmental Noise (May 2010) Final Report by Milieu Ltd for DG Environment of the European Commission.

[2] Research for a Quieter Europe in 2020, (2007) European Commission Research Directorate-General, An updated strategy of paper of the CALM II Network, Ferb.

[3] ZHI N. etc. (1985) Fan Noise Control technology [M]. China Machine Press.9

[4] ISO/TR 11 688-1 and -2 (1995). Recommended practice for the design of low-noise machinery and equipment.

[5] Benyus, M.J.: (1997) Biomimicry: Innovation inspired by nature, New York: Morrow.

[6] http://airlineworld.wordpress.com/2008/10/01/aircraft-winglets

[7] http://www.whalepower.com

[8] P. Watts P., Fish F.E.: The influence of passive, leading edge tubercles on wing performance.

[9] Miklosovic D.S., Murray M.M., Fish F.E., Howlea L.E.: Leading-edge tubercles delay stall on humpback whale. Megaptera novaeangliae. flippers, Physics of Fluids, Vol. 16, No. 5, 39-42, 2004.

[10] Ernst A. van Nierop, Silas Alben, Michael P. Brenner: How Bumpson Whale Flippers Delay Stall: An Aerodynamic Model, Physical Review Letters, 2008, DOI: 10.1103/PhysRevLett.100.054502.

[11] Kesel A.B., Philippi U., Nachtigall W.: Biomechanical aspects of the insect wing: An analysis using the finite element method. Comp Biol Med, 1998, 28(4): 423-437.

[12] Wakeling J.M., Ellington C.P.: Dragonfly flight III. Lift and power requirements. J Exp Biol, 1997, 200: 583-600.

[13] Newman D.J., Wootton R.J.: An approach to the mechanics of pleating in dragonfly wings. J Exp Biol, 1986, 126(1): 361-372.

[14] Chen J.S., Chen J.Y., Chou Y.F.: On the natural frequencies and mode shapes of dragonfly wings. J. Sound Vibr, 2008, 313: 643-654.

[15] Sudo S., Tsuyuki K., Tani J.: Wing morphology of some insects. JSME Int J Ser C, 2000, 43(4):895-900.

[16] Rajabi H., Moghadami M., Darvizeh A.: Investigation of microstructure, natural frequencies and vibration modes of dragonfly Wing. J Bionic Eng, 2011, 8: 165-173.

[17] Elarbi E.M., Qin N.: Effects of pitching rotation on aerodynamics of tandem flapping wing sections of a hovering dragonfly. Aeronaut J, 2010, 114(1161): 699-710.

[18] Hsieh C.T., Kung C.F., Chang C.C., et al.: Unsteady aerodynamics of dragonfly using a simple wing-wing model from the perspective of a force decomposition. J Fluid Mech, 2010, 663: 233-252.

[19] http://cecs.wright.edu/mav/research/projects.html

[20] Marcha E.: (1904), Über die Schwungfedern. Zeitschrift für wissenschaftliche Zoologie 77, pages 606-651.

[21] Graham R.R.: (1934) The silent flight of owls. Journal of the Royal Aeronautical Society, 38:837-843.

[22] Thorpe W.H., Griffin D.R.: (1962), The lack of ultrasonic components in the flight noise of owls compared with other birds., IBIS, 104:256-257.

[23] Lilley G.M.: (1998), A study of the silent flight of the owl, AAIA Paper, 1998-2340.

[24] Lilley G.M.: (2001), The prediction of airframe noise and comparison with experiment, Journal of Sound and Vibration, 239:849-859.

[25] Lilley G.M.: (2004), A quest for quiet commercial passenger transport aircraft for take-off and landing. In 10th AIAA/CEAS Aeroacoustics Conference, AIAA 2004-2922.

[26] Sarradj E., Fritzschey C., Geyery T.: (2010), Silent Owl Flight: Bird Flyover Noise Measurements, 16th AIAA/CEAS Aeroacoustics Conference 2010, AIAA 2010-3991.

[27] Geyer T., Sarradj E., Fritzsche C.: (2010a), Porous airfoils: noise reduction and boundary layer effect, International journal of aeroacoustics, v. 9, nr 6, 787-34.

[28] Geyer T., Sarradj E., Giesler J., Hobracht M.: (2011), Experimantal assessment of the noise generated at the leading edge porous airfoils using microphone array techniques, 17th Aeroacoustics Conference, 5-8 June 2011, Portland, Oregon.

[29] Geyer T., Sarradj E., Fritzsche C.: (2010) Measurement of the noise generation at the trailing edge of porous airfoils, Experiments in Fluids, 48: 291-308.

[30] Geyer T., Sarradj E.: (2007), Noise generation by porous airfoils, In: 13th AIAA/CEAS Aeroacoustics Conference, AIAA 2007-3719.

[31] Geyer T., Sarradaj E., Fritzsche C.: (2012), Silent Owl Flight: acoustic wind tunnel measurements on prepared winds, 18th AIAA/CEAS Aeroacoustics Conference, 4-6 June, Colorado Springs, CO.

[32] Geyer T., Sarradj E., Fritzsche C.: (2009), Silent owl flight. Experiments in the aeroacoustic wind tunnel, 35. Jahrestagung für Akustic (DAGAS 2009).

[33] Howe M.S.: (1991) Aerodynamic noise of a serrated trailing edge. Journal of Fluids and Structures, 5(1), pp. 33-45.

[34] Howe M.S.: (1991) Noise produced by a sawtooth trailing edge. The Journal of the Acoustical Society of America, 90, pp. 482.

[35] Howe M.S.: (1998), Acoustics of fluid structure interactions. Cambridge University Press, New York.

[36] Dassen A.G.M., Parchen R., Bruggeman J. and Hagg F.: (1996), Results of a wind tunnel study on the reduction of airfoil self-noise by the application of serrated blade trailing edges. In Proc. of the European Union Wind Energy Conference and Exhibition, Göteborg, pp. 800-803.

[37] Parchen R., Hoffmans W., Gordner A., and Braun K.: (1999), Reduction of airfoil self-noise at low Mach number with a serrated trailing edge. In International Congress on Sound and Vibration, 6 th, Technical Univ. of Denmark, Lyngby, Denmark, pp. 3433-3440.

[38] Oerlemans S., Fisher M, Maeder T., and Kögler K.: (2009), Reduction of wind turbine noise using optimized airfoils and trailing"edge serrations. AIAA journal, 47, pp. 1470-1481.

[39] Gruber M., Joseph P. and Chong T.P.: (2010), Experimental investigation of airfoil self noise and turbulent wake reduction by the use of trailing edge serrations. In 16th AIAA/CEAS Aeroacoustics Conference.

[40] Gruber M., Joseph P., Chong T.P.: (2011), On the mechanisms of serrated airfoil trailing edge noise reduction, 17th AIAA/CEAS Aeroacoustics Conference, 5-8 June 2011, Portland, Oregon.

[41] Gruber M., Azarpeyvand M., Joseph P.: (2011a), Airfoil trailing edge noise reduction by the introduction of sawtooth and slitted trailing edge geometries, Proceedings of 20th International Congress on Acoustics, 23-27 August, Sydney, Australia.

[42] Gruber M., Joseph P., Chong T.P.: (2012), On the airfoil self-noise reduction by trailing edge serrations of non-insertion type, 18th AIAA/CEAS Aeroacoustics Conference, 4-6 June 2012, Colorado Springs, CO.

[43] Moreau D.J., Tetlow M.R., Brooks L.A., Doolan C.J.: (2010), Acoustic analysis of flat plate trailing edge noise, ICA 2010, Proceedings of 20th International Congress on Acoustics, 23-27 August, Sydney, Australia.

[44] Moreau D.J., Brooks L.A., Doolan C.J.: (2012), On the noise reduction mechanism of a flat plate serrated trailing edge at low-to-moderate Reynolds number, 18th AIAA/CEAS Aeroacoustics Conference, 4-8 June, Colorado Springs, CO.

[45] Soderman P.T.: (1972), Aerodynamic effects of leading-edge serrations on a two-dimensional airfoil, NASA TM X-2643

[46] Soderman P.T.: (1973) Leading-edge serrations which reduce the noise of low-speed rotors, NASA TN DO7371.

[47] Smith E.G., Sowers H.D.: (1974), Cascade test of serrated leading edge blading at high subsonic speeds, NASA CR-2472.

[48] Cheng L.: (1989), Test Research for Rhizoma Soft Blade to the Effect of Noise and Performance. Compresor Blower & Fan Technology, Mar.

[49] Soderman P.T.: (1972), Aerodynamic effects of leading-edge serrations on a two-dimensional airfoil, NASA TM X-2643.

[50] Ren L., Sun S., Xu Ch.: (2008), Noise reduction mechanism of non-smooth leading edge of owl wing, Journal of Jilin University (Engineering and Technology Edition), 2008-S1-029.

[51] Lian G., Wang J., Chen Y., Zhou Ch., Liang J., Ren L.: (2010) The study of owl's silent flight and noise reduction on fan vane with bionic structure, Advances in Natural Science, p. 192, Vol. 3, No. 2.

[52] http://www.ziehl-abegg.com/ww/index.html

[53] Guidati G., Ostertag S. and Wagner S.: (2000), Prediction and Reduction of Wind Turbine Noise: An Overview of Research Activities in Europe, ASME Wind Energy Symposium, 19th, Aerospace Sciences Meeting and Exhibit, 38th, Reno, Nevada, 10-13 January, pp. 219-229.

[54] Kopania J., Kaczyński R.: Selected aspects of automation in fan examinations on standardized test stand, Heating, Ventilation and Air Conditioning, SIGMA-NOT, 2010, 42/2, 76-81.

[55] Chen K., Liu Q,Liao Q., Yang Y., Ren L., Yang H., Chen X.: The Sound Suppression Characteristics of Wing Feather of Owl (Bubo bubo), Journal of bionics engineering, 9, 2012, 192-199.

[56] Cieślak M., Rojek M.: Cichy lot sów inspiracją do redukcji aero-dynamicznego hałasu lotniczego, Prace Instytutu Lotnictwa, 229, 55-110, 2013.

[57] Ito S.: (2009) Aerodynamic influence of leading-edge serrations on an airfoils in a low Reynolds number, Journal of Biomechanical Science and Engineering, 4, 117-123.

[58] Kopania J., Kryłłowicz W.: The aeroacoustics studies of the flat plates with the trailing edge modifications, XX Polish Fluid Mechanics Conference, Gliwice, 17-20 September 2012.

[59] Jaworski J.W., Peake N., Aerodynamic noise from a poroelastic edge with implications for the silentflight of owls, J. Fluid Mech., Vol. 723, 456479, 2013.

[60] Brooks T.F., Marcolini M.A.: Scaling of airfoil self-noise using measured flow parameters., AIAA Journal, 23(2), 207-213, 1985.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Leszek KUBITZ [2]
Zofia OSTROWSKA [1]
Romuald RZADKOWSKI[1]
[1] *Department of Dynamics of Machines*
Institute of Fluid Flow Machinery
Polish Academy of Sciences, Gdansk, Poland
[2] *Polish Naval Academy, Gdynia, Poland*
[*] *z3@imp.gda.pl*

INFLUENCE OF MESH GRIDS AND TURBULENCE MODELS ON 2D AND 3D VISCOUS FLUTTER IN TURBOMACHINERY CASCADE

Abstract: In this study, numerical simulations of 2D and 3D viscous flutter were performed and compared with the available experimental results for different mesh grid and turbulence models. The calculations were carried out for bending oscillations of the cascade known as the Eleventh Standard Configuration. The developed numerical algorithm solves the 3D Reynolds-averaged Navier-Stokes equation. Comparison of the calculated and the experimental results for the Eleventh Standard Configurations has shown good quantitative and qualitative agreement for local performances (unsteady pressure amplitude and phase distribution) at off-design conditions, benchmark solutions are provided for various values of the inter-blade phase angle.

Keywords: flutter, Eleventh Standard Configuration, viscous flow, ANSYS CFX.

REFERENCES

[1] Marshall J.G., Imregun M.: A Review of Aeroelasticity Methods with Emphasis on Turbomachinery Applications, Journal of Fluids and Structures, 1996, Vol. 10, 237-257.

[2] Sayma A.I., Vahdati M., Green J.S., Imregun M.: Whole – Assembly Flutter Analysis of a Low Pressure Turbine Blade, in book T.H. Fransson ed.: Unsteady Aerodynamics and Aeroelasticity of Turbomachines, Proceedings of the 8th International Symposium held in Stockholm, Sweden, 14-18 September 1997, Kluwer Academic Publishers, 347-359.

[3] Weber S., Gallus H.E., Peitsch D.: Numerical Solution of the Navier Stokes Equations for Unsteady Unstalled and Stalled Flow in Turbomachniery Cascade with Oscillating Blades, in book T.H. Fransson ed.: Unsteady Aerodynamics and Aeroelasticity of Turbomachines, Proceedings of the 8th International Symposium held in Stockholm, Sweden, 14-18 September 1997, Kluwer Academic Publishers, 478-491.

[4] Vasanthakumar P., Chen T., He L.: Three-Dimensional Viscous Computation of Blade Flutter and Forced Response Using Nonlinear Harmonic Approach, in book P. Farrand, S. Auber: Unsteady Aerodynamics, Aeroacustics and Aeroelasticity of Turbomachines, Proceedings of the 9th International Symposium held in Lyon, France, 4-8 September 2000, Presses Universitaires de Grenoble, 649-665.

[5] Chassaing J.C. and Gerolymos G.A.: Compressor Flutter Analysis Using Time Nonlinear and Time Linearized 3D Navier-Stokes Method, in book P. Farrand, S. Auber: Unsteady Aerodynamics, Aeroacustics and Aeroelasticity of Turbomachines, Proceedings of the 9th International Symposium held in Lyon, France, 4-8 September 2000, Presses Universitaires de Grenoble, 666-677.

[6] McBean I., Liu F., Hourigan K., Thompson M.: Simulation of Aeroelasticity in an Annular Cascade using a Parallel 3-Dimensional Navier-Stokes Solver, Proceedings of ASME Turbo Expo 2002, Amsterdam, GT-2002-30366.

[7] Rzadkowski R., Gnesin V., Kolodyazhnaya L.: 3D Viscous Flutter of 11th Configuration Blade Row, Advances in Vibration Engineering, 2009, 8(3), 213-228.

[8] Fransson T.H., Jöcker M., Bölcs A., Ott P.: Viscous and Inviscid Linear/Nonlinear Calculations Versus Quasi-3D Experimental Data for a New Aeroelastic Turbine Standard Configuration, Journal of Turbomachinery, 1999, Vol. 121, No. 4, 717-725.

[9] Pajak A., Rzadkowski R.: Influence of mesh density and turbulence models on 2D viscous flutter in 11th Standard Configuration, Proceedings of ASME Turbo Expo, Copenhagen, Denmark, 11-15 June 2012, GT2012-68393.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Piotr LAMPART
Institute of Fluid Flow Machinery
Polish Academy of Sciences
ul. Fiszera 14, 80-231 Gdańsk, Poland
lampart@imp.gda.pl

SELECTED TECHNICAL PROBLEMS OF COGENERATION OF ELECTRIC ENERGY AND HEAT

Abstract: Cogeneration as a simultaneous production of electric energy and heat brings a considerable increase of energy efficiency and contributes to decrease emissions of harmful gases into the environment. Cogeneration can be applied in a large and small scale, however the opportunities for cogeneration are usually determined by the demand on heat. The prime movers in the large-scale cogeneration are steam turbines operating in a closed Rankine cycle. Extraction-condensing turbines provide the possibility of flexible coping with heat demand with practically little loss to the electric energy production. In order to take full advantage of variable load operation in extraction-condensing turbines, their adaptive control is needed and will be discussed in the paper.

Cogeneration can especially be applied in small power units of distributed generation systems. In small (and micro) units, the produced energy goes first to local communities. One can mention here the energy generation for households, residence buildings, large farms, public buildings or small and medium enterprises. The surplus of electric energy goes to the power network, whereas heat surplus goes to local district heating networks. There are many different technologies available for cogeneration of electric energy and heat in distributed sources such as gas/biogas stations, pv/solar instalations, biorafinery, biomass stations. The paper describes an idea of a multi-fuel cogeneration system, which is a local energy centre for a small municipal community that includes a biomass-fueled steam power unit, ORC power unit, a group of gas piston engines and a coal boiler.

ORC is a promising technology for cogeneration based on local energy resources. ORC power units can be used as a main generation system allowing utilisation of different types of fuels. The solution also offers a possibility to apply low temperature heat sources. Therefore, ORC can be applied for topping main generation systems, for example based on piston engines or gas turbines. In the first case a heat source is usually a biomass-fueled boiler, whereas in the latter case ORC operates on a recovery heat coming from the exhaust gases and/or engine cooling

system. The ORC unit working in a combined cycle allows for a considerable increase of electric energy production.

In the framework of the strategic programme of the Polish National Centre for Research and Development (NCBiR) two pilot installations with a considerable industrial potential are developed at IMP PAN:

– a poligeneration ORC system of electric power 100 kW and heat power 400 kW being a model for an agro-energy complex. The system consists of a boiler, intermediate heat cycle, ORC unit with a turbine working on a silica oil MDM, orfice cooling unit and connection to electric and heating network. The system products electricity, heat and cold;

– a cogeneration gas/ORC unit of electric power 0.45 MWe with a gas piston engine topped by an ORC unit. The recovery boiler is installed to transport heat from exhaust gases to the low-temperature ORC unit working on a medium SES36, whereas the heat from cooling the piston engine is used for network heating.

CIEPLNE MASZYNY PRZEPŁYWOWE

No. 145 TURBOMACHINERY 2014

Michał LIPIAN*
Maciej KARCZEWSKI
Krzysztof OLASEK
Institute of Turbomachinery
Faculty of Mechanical Engineering
Lodz University of Technology
* *michal.lipian@gmail.com*

SENSITIVITY STUDY OF DIFFUSER ANGLE AND BRIM HEIGHT PARAMETERS FOR THE DESIGN OF 3 KW DIFFUSER AUGMENTED WIND TURBINE

Abstract: The Diffuser Augmented Wind Turbine (DAWT) is an innovative mean to increase the power harvested by wind turbine. By encompassing the rotor with a diffuser-shaped duct it is possible to increase the flow speed through the turbine by about 40-50%. The study presents the development of a numerical model and its validation by the experiments performed in the wind tunnel of the Institute of Turbomachinery, TUL. The numerical model is then used for the geometry sensitivity study, to optimize the shape of a diffuser. The paper concludes that the DAWT technology has the potential to even double the power outcome of wind turbine when compared to a bare rotor version.

Keywords: Diffuser Augmented Wind Turbine (DAWT), small wind turbines, wind energy, numerical flow simulation, computational fluid dynamics (CFD), Particle Image Velocimetry (PIV), simulation-experiment integration.

REFERENCES

[1] Gilbert B.M. and Foreman K.L.: Experiments with a diffuser-augmented model wind turbine, *Journal Energy Resources Technology,* No. 105, pp. 46-53, 1983.

[2] Igra O.: Research and development for shrouded wind turbines, *Energy Conversion and Management,* Vol. 21, No. 1, pp. 13-48, 1981.

[3] Ohya Y. and Karasudani T.: A Shrouded Wind Turbine Generating High Output Power with Wind-Lens Technology, *Energies,* No. 2, 2010.

[4] Ohya Y., Karasudani T. and Matsuura C.T.: A highly efficient wind turbine with wind-lens shroud, in *13th International Conference on Wind Engineering*, Amsterdam, 2011.

[5] Kosasih B. and Tondelli A.: Experimental study of shrouded micro wind turbine, *Procedia Engineering,* No. 49, pp. 92-98, 2012.

[6] White F.M.: Fluid Mechanics, Sixth Edition, New York: McGraw-Hill, 2008.

[7] Jamieson P.: Innovation in wind turbine design, pp. 255-258, 1st edition, John Wiley&Sons, 2011.

[8] Kulak M., Olasek K. and Karczewski M.: Reduction of wind tunnel turbulence intensity level by installation of a honeycomb straightener – CFD simulation vs. experiment, in *Proceedings of the XX Fluid Mechanics Conference KKMP2012*, Gliwice, 17-20 September 2012, ISBN 978-83-927340-8-6.

[9] Abe K. and Ohya Y.: An investigation of flow fields around flanged diffusers using CFD, *Journal Wind Fengineering and Industrial Aerodynamics,* No. 92, pp. 315-330, 2004.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Grzegorz LIŚKIEWICZ*
Longin HORODKO
Institute of Turbomachinery
Lodz University of Technology
ul. Wólczańska 219/223, 90-924 Łódź, Poland
* *grzegorz.liskiewicz@p.lodz.pl*

TIME-FREQUENCY ANALYSIS OF THE SURGE ONSET IN THE CENTRIFUGAL BLOWER

Abstract: Time frequency analysis of the surge onset was performed in centrifugal blower. Pressure signal was registered at the blower inlet, blower outlet and three locations at the impeller shroud. The time-frequency scalograms were obtained by means of the Continuous Wavelet Transform (CWT). The blower was found to successively operate in four different conditions: stable working conditions, inlet recirculation, transient phase and the deep surge. Scalograms revealed different spectral structure of aforementioned phases and suggest possible ways of detecting the surge predecessors.

Keywords: compressor, blower, surge, unstable flow, continuous wavelet transform.

REFERENCES

[1] Emmons H., Pearson C., Grant H.: Transactions of ASME, Compressor surge and stall propagation, 1955, 77, 455-467.

[2] Greitzer E.: Surge and rotating stall in axial flow compressors – part I: theoretical compression system model, Journal of Engineering for Power, 1976, 98, 190-198.

[3] Greitzer E.: Surge and rotating stall in axial flow compressors – part II: experimental results and comparison with theory, Journal of Engineering for Power, 1976, 98, 199-211.

[4] Meuleman C., Willems F., de Lange R., de Jager B.: Surge in a low speed radial compressor, Proceedings of 43rd International Gas Turbine and Aeroengine Congress, ASME, Stockholm, 1998.

[5] Moore F., Greitzer E.: A theory of post-stall transients in axial compression systems – part I: development of equations, Journal of Engineering for Gas Turbines and Power, 1986, 108, 68-76.

[6] Moore F. and Greitzer E.: A theory of post-stall transients in axial compression systems – part II: application, Journal of Engineering for Gas Turbines and Power, 1986, 108, 231-239.

[7] Cumpsty N.: Compressor aerodynamics. Halsted Press, 1989.

[8] Lennemann E., Howard J.: Unsteady of phenomena in rotating centrifugal impeller passages, Journal for Engineering for Power, 1970, 92, 65-71.

[9] Mizuki S., Kawashima Y., Ariga I.: Investigation concerning rotating stall and surge phenomena within centrifugal compressor channels, Proceedings of International Gas Turbine Conference, ASME, London, 1978.

[10] Abdelhamid A., Bertrand J.: Distinctions between two types of self excited gas oscillations in vaneless radial diffusers, Proceedings of Turbo Expo, ASME, San Diego, 1979.

[11] Jansen W.: Rotating stall in a radial vaneless diffuser, Journal of Basic Engineering, 1964, 86, 750-758.

[12] Senoo Y., Ishida M., Kinoshita Y.: Asymmetric flow in vaneless diffusers of centrifugal blowers, Journal of Fluids Engineering, 1977, 99, 104-111.

[13] Fraser W.: Recirculation in centrifugal pumps, Materials of Construction of Fluid Machinery and Their Relationship to Design and Performance, 1981, 65-86.

[14] Breugelmans F., Sen M.: Prerotation and fluid recirculation in the suction pipe of centrifugal pumps, Proceedings of 11th International Pump Symposium, A&M University, Texas, 1982.

[15] Mizuki S., Oosawa Y.: Unsteady flow within centrifugal compressor channels under rotating stall and surge, Journal of Turbomachinery, 1992, 114, 312-320.

[16] Lawless P., Fleeter S.: Rotating stall acoustic signature in a low-speed centrifugal compressor – part 1: vaneless diffuser, Journal of Turbomachinery, 1995, 117, 87-96.

[17] Horodko L.: Investigation of centrifugal compressor surge with wavelet methods, Proceedings of 6-th European Conference on Turbomachinery, Fluid Dynamics and Thermodynamics, VKI, Lile, 2005.

[18] Bulot N., Ottavy X., Trebinjac I.: Unsteady pressure measurements in a high-speed centrifugal compressor, Journal of Thermal Science, 2010, 19, 34-41.

[19] Turunen-Saaresti T., Larjola J.: Unsteady pressure field in a vaneless diffuser of a centrifugal compressor: an experimental and computational analysis, Journal of Thermal Science, 2004, 13, 302-309.

[20] Tamaki H.: Experimental study on surge inception in a centrifugal compressor, International Journal of Fluid Machinery and Systems, 2009, 2, 409-417.

[21] Horodko L., Kryłłowicz W.: Investigation of the rotating stall in a centrifugal compressor, ASME Joint US-European Fluids Engineering Conference, 2002.

[22] Horodko L.: Identification of rotating pressure waves in a centrifugal compressor diffuser by means of the wavelet cross-correlation, International Journal of Wavelets, Multiresolution and Information Processing, 2006, 4, 373-382.

[23] McKee R., Edlund C.: Method and apparatus for detecting the occurrence of surge in a centrifugal compressor, US Patent 6.981.838, 2006

[24] Liśkiewicz G., Horodko L., Stickland M., Kryłłowicz W.: Identification of phenomena preceding blower surge by means of pressure spectral maps, Experimental Thermal and Fluid Science, 2014, 54, 267-278.

[25] Kuzmin V., Khazhuev V.: Measurement of liquid or gas flow (flow velocity) using convergent channels with a Witoszynski profile, Measurement Techniques 1993, 36, 288-296.

[26] Fink D., Cumpsty N., Greitzer E.: Surge dynamics in a free-spool centrifugal compressor system, Journal of Turbomachinery, 1992, 114, 321-332.

[27] Horodko L.: Zastosowanie czasowo-częstotliwościowej analizy sygnałów do badania niestatecznej pracy sprężarki promieniowej, Technical Report 990, Lodz University of Technology, 2006.

[28] Mertins A.: Signal Analysis: Wavelets, Filter Banks, Time-Frequency Transforms and Applications. Wiley Press, 1999.

[29] Kabalyk K., Liśkiewicz G., Horodko L., Stickland, M., Kryłłowicz W.: Use of pressure spectral maps for analysis of inuence of the plenum volume on the surge in centrifugal blower, Proceedings of Turbo Expo, ASME, Düsseldorf, 2014.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Alejandro LOPEZ*
Matthew STICKLAND
William DEMPSTER
Mechanical and Aerospace Engineering,
University of Strathclyde, Glasgow, UK
** alejandro.lopez@strath.ac.uk*

MODELING EROSION IN A CENTRIFUGAL PUMP IN AN EULERIAN-LAGRANGIAN FRAME USING OPENFOAM®

Abstract: Erosion induced by solid particle impingement is a very common wear mechanism in turbomachinery and Computational Fluid Dynamics is one of the most widely used tools for its prediction. In this article, erosion is modelled in one of the channels of a centrifugal pump using OpenFOAM®, which is an Open Source CFD package. A review of some of the most commonly used erosion models is carried out in an Eulerian-Lagrangian frame along with a comparative study of the erosion rates obtained with each model. Results yielded some disparities between models due to the different factors taken into consideration. The mesh is then deformed to obtain the resulting eroded geometry.

Keywords: Erosion, Solid Particle Impingement, Centrifugal Pumps.

REFERENCES

[1] Brown G.J.: Erosion prediction in slurry pipeline tee-junctions. Applied mathematical modeling, Vol. 26 (2002), pp. 155-170.
[2] Finnie I.: Erosion of surfaces by solid particles, Wear, Vol. 3 (1960), pp. 87-103
[3] Hashish M.: Modified model for erosion. Proceedings of the 7th International Conference on Erosion by liquid and solid impact, 1987, Cambridge, UK, pp. 461-480
[4] Grant G. and Tabakoff W.: An experimental investigation of the erosion characteristics of 2024 aluminum alloy, Department of Aerospace Engineering Tech. Rep. (1973) 73-77, University of Cincinnati.
[5] Nandakumar K. et al.: A comprehensive phenomenological model for erosion of materials in jet flow, Powder Technology, Vol. 187 (2008), pp. 273-279.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Jakub ŁAGODZIŃSKI*
Kacper MIAZGA
Izabela MUSIAŁ
Institute of Turbomachinery
Lodz University of Technology
219/223 Wolczanska St, 90-924 Lodz, Poland
* *jakub.lagodzinski@p.lodz.pl*

APPLICATION OF A COMPLIANT FOIL BEARING FOR THE THRUST FORCE ESTIMATION IN THE SINGLE STAGE RADIAL BLOWER

Abstract: The paper presents an application of a compliant foil bearing for estimation of the thrust force in the single stage radial blower under operational conditions. The bump foil of the thrust bearing behaves as a nonlinear spring. The knowledge of the spring deflection curve allows one to estimate the actual thrust force for a measured bump deflection at the given rotational speed. To acquire the deflection curve, static calibration of the axial shaft displacement sensor was performed. During the calibration, the information about voltage signals of the sensor for the given loading force was gathered. Then, the measured voltage values at different speeds and loads were recalculated to the thrust force. The results were verified by a comparison to the thrust force resulting from the pressure distribution on the impeller.

Keywords: compliant foil bearings, thrust force estimation, single stage radial blower.

REFERENCES

[1] Danilecki K.: *Założenia do modelowania turbosprężarki trakcyjnego silnika z pulsacyjnym zasilaniem turbiny,* ARCHIWUM MOTORYZACJI 4, pp. 421-436 (2006).

[2] Kozanecka D., Kozanecki Z., Łagodziński J., Tkacz E.: *Experimental Research of Oil-Free Support Systems to Predict the High-Speed Rotor Bearing Dynamics*, International Journal of Dynamics and Control, Springer Berlin Heidelberg (2014), DOI 10.1007/s40435-014-0074-9, Article 8 pages. Online available since March 19, 2014.

[3] Łagodziński J., Kozanecki Z., Tkacz E., Miazga K.: *Theoretical and Experimental Investigations of Oil-Free Bearings and their Application in Diagnostics of High-Speed Turbomachinery,* Key Engineering Materials Vol. 588 (2014), pp. 302-309 online available since 2013/oct/11 at www.scientific.net (2014) Trans Tech Publications, Switzerland doi:10.4028/www.scientific.net/kem.588.302.

[4] Kicinski J., Żywica G.: *The Numerical Analysis of the Steam Microturbine Rotor Supported on Foil Bearings, Advances in Vibration Engineering,* 11(2) 2012, pp. 113-119., Krishtel eMaging Solutions Private Limited (2012).

CIEPLNE MASZYNY PRZEPŁYWOWE

No. 145 TURBOMACHINERY 2014

Mirosław MAJKUT *
Sławomir DYKAS
Michał STROZIK
Krystian SMOŁKA
Institute of Power Engineering and Turbomachinery
Silesian University of Technology
Konarskiego 18, Gliwice
* *miroslaw.majkut@polsl.pl*

EXPERIMENTAL AND NUMERICAL STUDY ON CONDENSATION IN TRANSONIC STEAM FLOW

Abstract: The present paper describes an experimental and numerical study of steam condensing flow in a linear cascade of turbine stator blades. The experimental research was performed on the facility of a small scale steam power plant located at Silesian University of Technology in Gliwice. The test rig of the facility allows us to perform the tests of steam transonic flows for the conditions corresponding to these which prevail in the low-pressure (LP) condensing steam turbine stages. The experimental data of steam condensing flow through the blade-to-blade stator channel were compared with numerical results obtained using the in-house CFD numerical code TraCoFlow. Obtained results confirmed a good quality of the performed experiment and numerical calculations.

Keywords: wet steam, condensation, experiment, numeric, linear cascade.

REFERENCES

[1] Bakhtar F., White A.J. and Mashmoushy H.: Theoretical treatments of two-dimensional two-phase flows of steam and comparison with cascade measurements. Proc. IMechE, Part C: J. Mechanical Engineering Science, 2005, 219(C12), 1335-1355.

[2] Bakhtar F., Zamri M.Y.: On the performance of a cascade of improved turbine nozzle blades in nucleating steam – Part 3: Theoretical analysis, Proc. IMechE Vol. 225 Part C: J. Mechanical Engineering Science, 1649-1671, 2011.

[3] Dykas S., Wróblewski W., Łukowicz H.: 2007, Prediction of losses in the flow through the last stage of low- pressure steam turbine, International Journal for Numerical Methods in Fluids 53 (6), 933-945.

[4] Dykas S., Wróblewski W.: 2013, Two-fluid model for prediction of wet steam transonic flow, International Journal of Heat and Mass Transfer 60, 88-94.

[5] Doerffer P., Dykas S.: 2005, Numerical analysis of shock induced separation delay by air humidity, Journal of thermal science, 14 (2), 120-125.

[6] Frenkel J.: 1946, Kinetic Theory of Liquids., Oxford University Press, New York.

[7] Gyarmathy G.: 1960, Grundlagen einer Theorie der Nassdampfturbine, Dissertation, Juris Verlag, Zürich.

[8] Halama J., Fort J., Seifert M.: 2010, Numerical solution of wet steam flow with a priori droplet size distribution, Proceedings of Conference 'Topical Problems of Fluid Mechanics', Prague, 63-66.

[9] Krol T.: 1971, Results of Optical Measurement of Diameters of Drops Formed due to Condensation of Steam in a Laval Nozzle. Trans. Inst. Fluid Flow Machinery (Poland), Vol. 57, pp. 19-30.

[10] Moses C.A., Stein G.D.: 1978, On the growth of steam droplets formed in a Laval nozzle using both static pressure and light scattering measurements. ASME, Vol. 100, 311-322.

[11] Schnerr G.H.: 1986. Homogene Kondensation in stationaeren transsonischen Stroemungen durch Lavalduesen und um Profile, Habilitationsschrift, Fakultaet fuer Maschinenbau, Universitaet Karlsruhe.

[12] Smołka K., Strozik M., Majkut M., Dykas S.: 2011, Możliwości badań eksperymentalnych przepływu pary mokrej w układzie mini-siłowni kondensacyjnej, Prace Naukowe. Konferencje, z. 27, Oficyna Wydawnicza Politechniki Warszawskiej, ss. 233-240.

[13] White A.J., Young J.B., Walters P.T.: 1996. Experimental Validation of Condensing Flow Theory for a Stationary Cascade of Steam Turbine Blade. Philosophical Transaction of Royal Society London A, Vol. 354, 59-88.

[14] Young J.B.: 1982, Spontaneous condensation of steam in supersonic nozzles. Physicochemical Hydrodynamics (PCH), 3, pp. 57-82.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Jarosław MIKIELEWICZ[1*]
Dariusz MIKIELEWICZ[2]
[1] Institute of Fluid-Flow Machinery
Polish Academy of Sciences,
14 Fiszera St, 80-231 Gdańsk, Poland
[2] Gdańsk University of Technology
Faculty of Mechanical Engineering
11/12 Narutowicza St, 80-233 Gdańsk, Poland
[*]jarekm@imp.gda.pl

NEW TRENDS IN DEVELOPMENT OF ORC'S FOR MICROPOWER GENERATION

Abstract: In the paper, new trends in development of micropower generation of heat and electricity are presented. New type of CHP for domestic usage is developed in the Institute of Fluid-Flow Machinery PAS and methods of its design are presented. The most promising trends in equipment of ORC cycle for this purpose were discussed. Main attention was focused on micro-heat exchangers design based on micro-channels and micro-jets. In our opinion future development of high power heat exchangers will be based on nets micro heat exchangers.

Keywords: CHP, ORC, heat exchangers, heat transfer intensification, thermodynamics.

REFERENCES

[1] Harrison J.: EA Technology, presentation „Micro CHP in Europe", National Micro-CHP Technology Pathways Workshop, June 11-12,2003, The Greenbelt Mariott, Maryland.

[2] Mikielewicz J.: *Micro heat and power plants working in organic Rankine cycle,*Polish Journal of Environmental Studies, Vol. 19, No. 3 (2010), 499-505.

[3] Borsukiewicz-Gozdur A.: Influence of heat recuperation in ORC power plant on efficiency of waste heat utilization, Archives of thermodynamics, Vol. 31 (2010), No. 4, 111-123.

[4] Zhou N., Wang X., Chen Z., Wang Z.: Experimental study on Organic Rankine Cycle for waste heat recovery from low-temperature flue gas Energy 55 (2013).

[5] Astolfi M., Xodo L., Romano M.C., Macchi E.: Technical and economical analysis of a solar – geothermal hybrid plant based on an Organic Rankine Cycle , Geothermics 40 (2011) 58-68.

[6] Borsukiewicz-Gozdur A.: Dual fluid hybrid power plant co-powered by low temperature geothermal water, Geothermics 39 (2010) 170-175

[7] Mikielewicz J.: Domestic combined micro heat and power plant, Rocznik; Ochrona Środowiska; T11; Rok 2009; 25-38.

[8] Mikielewicz J., Bykuć S.: Koncepcja mikrosiłowni kogeneracyjnej pracującej w obiegu Rankine'a., Archiwum Energetyki, Tom XXXVI, PL ISSN 0066-684X, Gdańsk 2006.

[9] Mikielewicz J. i in.: Combined micro heat and power plant based on organic rankine., Acta Mechanica Slovaca, Kosice, 4-D/2007, ISSN 1335-2393, 217-222.

[10] Mikielewicz J., Bykuć S., Mikielewicz D.: Algorithm and a code for thermodynamical calculations of micro CHP for different working fluids, IFFM internal report, 2007.

[11] Mikielewicz J., Bykuć S., Mikielewicz D.: Application of renewable energy sources to drive Organic Rankine Cycle micro CHP, Proc. of Heat Transfer and Renewable Sources of Energy, 329-336, Międzyzdroje 2006.

[12] Mikielewicz D., Mikielewicz J.: Analytical method for calculation of heat source temperature drop for the Organic Rankine Cycle application, Applied Thermal Engineering 63(2014) 541-550.

[13] Mikielewicz D., Wajs J., Mikielewicz J.: *Recovery of waste heat from the coal-fired power unit using Organic Rankine Cycle*, 1st Int. Seminar on ORC Power Systems, 22-23 September 2011, Deft, Netherlands.

[14] Maizza V., Maizza A.: Unconventional working fluids in organic Rankine-cycles for waste energy recovery systems, Applied Thermal Engineering, 21, 381-390, 2001.

[15] Saleh B., Koglbauer G., Wendland M., Fischer J.: Working fluids for low-temperature organic Rankine cycles, Energy, 32, 1210-1221, 2007.

[16] Tchanche B.F., Papadakis G., Lambrinos G., Frangoudakis A.: Fluid selection for a low-temperature solar organic Rankine cycle, Applied Thermal Engineering 29 (2009).

[17] Mikielewicz D., Mikielewicz J.: *A thermodynamic criterion for selection of* working fluid for subcritical and super critical domestic micro CHP, Applied Thermal Engineering Vol. 30, (2010), 2357-2362.

[18] Mikielewicz J. i in.: Analysis of selected fluids for use in micro-chp for domestic applications, Inter. Conf. University of Applied Sciences Bremen, D-28195 Bremen., 08-09 Nov. 2007.

[19] Refprop 8.0, NIST, 2007.

[20] Rybiński W.: Design and implementation of new versions of Wilson plot method in the-evaporator's zone model for determination of heat flow characteristics, IFFM internal report, 2013.

[21] Mikielewicz D. et al: Selected topics of design and investigation of heat exchangers for ORC in a domestic CHP (in Polish), 183-198, Gdańsk 2013.

CIEPLNE MASZYNY PRZEPŁYWOWE

No. 145 TURBOMACHINERY 2014

Dariusz MIKIELEWICZ[1*]
Jan WAJS[1,2]
Jarosław MIKIELEWICZ[2]
Krzysztof KOSOWSKI[1]
[1] Gdansk University of Technology
Narutowicza 11/12, Gdansk 80-233, Poland
[2] Institute of Fluid-Flow Machinery PAS
Fiszera 14, Gdansk 80-231, Poland
[*] Dariusz.Mikielewicz@pg.gda.pl

EXPERIENCES FROM OPERATION OF VARIOUS EXPANSION DEVICES IN SMALL SCALE ORC

Abstract: The main aim of this paper was to present various expansion devices for an application in the small scale ORC system. The investigations were carried out in two parallel directions. One direction was to design and construct a device dedicated to the analyzed ORC system. The second direction was to adapt existing expansion devices for the needs of the analyzed ORC system. Four various devices were described and presented together with the experimental results. The most promising seemed to be the vapour microturbine which was built from the beginning as the device ORC system oriented.

Keywords: micro-CHP, organic Rankine cycle (ORC), microturbine, expander.

REFERENCES

[1] Mikielewicz D., Mikielewicz J., Wajs J.: Experiences from operation of different expansion devices for application in domestic micro CHP, Archives of Thermodynamics, 2010, 31, 3-13.

[2] Mikielewicz D., Mikielewicz J.: Cogenerative micro power plants – a new direction for development of power engineering?, Archives of Thermodynamics, 2008, 29, 109-132.

[3] Mikielewicz J., Mikielewicz D.: Comparative study of selected fluids for use in supercritical Organic Rankine Cycles, Archives of Thermodynamics, 2009, 30, 3-14.

[4] Mikielewicz J., Mikielewicz D., Wajs J., Kosowski K., et. al.: Design and testing of a radial-axial microturbine for domestic applications, Proceedings of 2nd International Seminar on ORC Power Systems (October 7-8, 2013 Rotterdam, The Netherlands).

[5] Refprop v. 8.0, National Institute of Standards, 2007.

Jiri POLANSKY [1*]
Marian HOCKO [2]
[1] *New Technologies Research Centre*
University of West Bohemia
Univerzitni 8, Plzen, Czech Republic
[2] *Faculty of Aeronautics*
Technical University of Kosice
Rampová 7, Kosice, Slovakia
[*] *polansky@ntc.zcu.cz*

RADIAL COMPRESSOR UNSTABLE OPERATION MODELLING

Abstract: Unstable operation of a compressor is a dangerous phenomenon which occurs during certain operating regimes of compressors in engine turbo-compressors and also in combustion turbines used in transport and stationary energetics equipment. It is manifested by a sudden change of pressure and speed of air flow at the output of the compressor and characteristic sounds, which result in intense vibration of the rotor blades and changes to the character of air flow in other parts of the device. Surge or stall can result in interruption of engine operation, or its destruction due to mechanical damage to the compressor blades or heat damage to the blades of the gas turbine. This is why the formation of unstable compressor modes is inadmissible and a great deal of attention is devoted to preventing it.

Keywords: Surge, Stall, compressor, CFD, PIV.

REFERENCES

[1] Gravdahl J.T., Egeland O.: Compressor Surge and Rotating Stall Modeling and Control, ISBN-13: 978-1-4471-1211-2, Springer, London,1999.

[2] Hocko M., Polansky J.: Experimental modelling of unstable operation of a centrifugal compressor on a small jet engine in the laboratory, 11th World Congress on Computational Mechanics, 2014, Barcelona.

[3] Hocko M.: Assessment of the ATCE State Based on Changes in Thermodynamic Parameters, thesis, pp. 338, 2003.

[4] Ruzek J.: Theory of Aircraft Engines, Part I, Compressors, Turbines and a Combustion Chamber, University textbook VA AZ Brno, pp. 373, 1979.

[5] Scheinherr A.: Usage of PIV in radial pump model, Master theses, University of West Bohemia, Faculty of Mechanical Engineering, 2011.

[6] DANTEC: Dynamics Studio, FlowManager Software and Introduction to PIV Instrumentation (Software Users Guide), Skovlunde, 2000.

[7] Polansky J., Kalmar L., Gaspar R.: Aerodynamic performance prediction of centrifugal fan with forward curved blades, Journal of Thermal Science, Vol. 22, NO 6, ISSN: 1003-2169, 2013.

[8] Cyrus V., Polansky J.: Numerical simulation of the origins of flow pulsations in cascades of the rear blade rows in a gas turbine axial compressor using low calorific fuel. ASME journal 2010, No. 132/3, p. 31012/1-11. ISSN: 0889-504X.

[9] Cyrus V., Polansky J., Wurst P.: Advanced axial flow fan stage for power stations with environmental equipment. 7th European conference on Turbomachinery, 2007, Athens.

[10] Polansky J., Kalmar L., Gaspar R.: Aerodynamic performance prediction of centrifugal fan with forward curved blades, Journal of Thermal Science, Vol. 22, No. 6, 2013, pp. 517-521, ISSN: 1003-2169, 2013.

[11] Wu Y., Liu S., Yuan, H., Shao, J.: PIV Measurements on Internal Instantaneous Flows of a Centrifugal Pump. Sci China Tech Sci, 2011, 54: pp 270-276, doi: 10.1007- s11431-010-4262-3.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Krzysztof PSIUK*,
Marcin AMAROWICZ
Tomasz ROGALA
Sebastian RZYDZIK
Silesian University of Technology
Institute of Fundamentals of Machine Design
Konarskiego 18A Str., 44-100 Gliwice
* *krzysztof.psiuk@polsl.pl*

USING REX ENVIRONMENT IN DYNAMIC DIAGNOSTICS OF ORC POWER STATION

Abstract: In the Institute of Fundamentals of Machinery Design is developed a development environment REx, which is dedicated for designing and testing diagnostic expert systems for complex technical objects. The REx environment allows to design, test and use a multilayer statement networks. Paper presents an example of using REx environment for diagnose state of some objects of ORC power station. Results of the inference process of the expert system that are very interesting for the operator are presented in a special application. In this application are presented values of statements and how there are changed during the time.

Keywords: technical diagnostics, expert systems, statements, statements network, object monitoring.

REFERENCES

[1] Korbicz J., Kościelny J.M., Kowalczuk Z., Cholewa W. (eds.): Fault diagnosis: Models, Artificial Intelligence, Applications. Springer, Heidelberg (2004).

[2] Cholewa W., Rogala T., Chrzanowski P., Amarowicz M.: Statement Networks Development Environment Rex, In Lecture Notes in Computer Science, 6923, Part II, Computational Collective – Intelligence Technologies and Applications. Proceedings of 3rd International Conference on Computational Collective Intelligence – Technologies and Applications. Gdynia, Poland, 2011 September 21-23, pp. 30-39.

[3] Dawid F., Cowell R., Lauritzen S., Spiegelhalter D.: Probabilistic Networks and Expert Systems. Springer, New York (2007).

[4] Giarratano J.C., Riley G.D.: Expert systems: principles and programming. Thomson Course Technology, (2005).

[5] Castillo E., Gutiâerrez J.M., Hadi A.S.: Expert systems and probabilistic network models. Monographs in Computer Science Series. Springer Verlag, (1997).

[6] Cholewa W., Rogala T., Chrzanowski P., Amarowicz M.: Development environment for diagnostic multimodal statement networks, 5th International Congress on Technical Diagnostics. Diagnostics'2012, Kraków, Poland, 3rd-5th September 2012. Abstracts. [B.m.] : [b.w.], 2012, pp. 30-31.

[7] Cholewa W., Amarowicz M., Chrzanowski P. and Rogala T.: Development environment for diagnostic multimodal statement networks. Key Engineering Materials, Smart Diagnostics V, 588:74-83, (2014).

[8] System DT200-1. Online: http://ipkm.polsl.pl/PROJEKTY/SystemDT200-1/default.htm. November 2013 (in Polish).

[9] Psiuk K., Cholewa W.: State visualization of complex technical objects (in polish). IV Krajowa Konferencja Naukowo-Techniczna Diagnostyka Procesów Przemysłowych, 13-16 września, 1999, Kazimierz Dolny, 1999 (in Polish).

CIEPLNE MASZYNY PRZEPŁYWOWE

No. 145 TURBOMACHINERY 2014

Kjell G. ROBBERSMYR*
Hamid Reza KARIMI
University of Agder
4879 Grimstad, Norway
**kjell.g.robbersmyr@uia.no*

DEVELOPMENT OF NEW PHASE SHIFTING TECHNIQUES FOR CONTOURING, DEFORMATION AND VIBRATION ANALYSIS

Abstract: In this paper, two phase shifting techniques are introduced for objects surface analysis with projected fringes. First, scanning phase shift (SPS) is introduced for contouring and deformation analysis, while max-minscanning is used for vibration analysis. Then, a smoothing algorithm called phase shift convolution is used on the contouring and deformation phase maps. It is shown that both these techniques are suitable for the use on unstable objects.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Andrey RUSANOV
Department of Hydroaeromechanics of Power Machines A.N. Podgorny Institute of Mechanical Engineering Problems, NASU
Kharkov, Ukraine
rusanov@ipmach.kharkov.ua

DESIGNING AND UPDATING THE FLOW PART OF AXIAL AND RADIAL-AXIAL TURBINES THROUGH THE USE OF METHODS OF MATHEMATICAL MODELING

Abstract: The paper describes an algorithm for the designing of axial and radial-axial type turbines. The algorithm is based on using mathematical models of various levels of difficulty – from 1D to 3D. Geometry description of flow parts is performed using analytical methods of profiling using a limited number of parameter values. 3D turbulent flow model is realized in the program complex IPMFlow, developed based on the earlier codes FlowER and FlowER-U. The examples of developed or modernized turbines for different purposes power machinesare presented. They are an expansion turbine, ORC turbine, cogeneration medium-pressure turbine.

Keywords: expansion turbine, ORC turbine, cogeneration medium-pressure turbine, CFD, axial turbine, radial-axial turbine.

REFERENCES

[1] Cumpsty N.A.: Compressor aerodynamics [Text] / Krieger Pub Co., 1989.

[2] Scientific contribution to the creation of aircraft engines. In two books. Book. 2 / Under the general scientific. ed. V.A. Skibina and V.I. Solonina, M.: Mechanical Engineering, 2000, 616 (in Russian).

[3] Troyanovskiy B.M.: Improvement of steam turbines flow parts // Fittings, 1996, № 1, pp. 10-17.

[4] Copyright. certificate of. Complex three-dimensional calculation programs of gas flows in turbomachines bahatovintsevyh «FlowER» [Text] / S.V. Ershov, A.V. Rusanov. – State Agency of Ukraine on Copyright and Related Rights, the PA № 77; 19/02/96, 1 p (in Ukrainian).

[5] Rusanov A.V.: Mathematical modeling of unsteady gasdynamic processes in the setting of turbomachines [Text] / A.V. Rusanov, S.V. Ershov, Kharkov: IPMash NAS of Ukraine, 2008, 275p (in Russian).

[6] Boiko A.V.: Fundamentals of the theory of optimal design of axial turbomachines flow part [Text] / A.V. Boiko, Y.N. Govorushchenko, Kharkov: High School, 1989, 217 p. (in Russian).

[7] Bilan A.V.: Automated design of steam turbine blades [Text] / A.V. Bilan, V.N. Bilan // Compressor and power engineering, 2006, № 3 (5), pp. 66-68 (in Russian).

[8] Lampart P.: Direct Constrained Comptational Fluid Dynamics Based Optimization of Three-Dimensional Blading for the Exit Stage of a Large Power Steam Turbine/ P. Lampart, S. Yershov // Transactions of the ASME. Journal Engineering for Gas Turbines and Power, 2003, 125, No. 1, pp. 385-390.

[9] Genetic Algorithms in Search, Optimization, and Machine Learning David E. Goldberg, University of Alabama ISBN-10: 0201157675 • ISBN-13: 9780201157673 ©1989 Addison-Wesley Professional Cloth, 432 p.

[10] 2008 “Optimization and Computational Fluid Dynamics”. Springer-Verlag.

[11] IAPWS, Revised Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use. – Available from: http://www.iapws.org

[12] Rusanov A.V.: Interpolation-analytical method considering the real properties of gases and liquids // East European Journal of advanced technology, 2013, № 3/10 (63), pp. 53-57 (in Russian).

[13] Lampart P.: Validation of turbomachinery flow solver on turbomachinery test cases [Text] / P. Lampart, S. Yershov, A. Rusanov // International conference SYMKOM'02: Compressor & turbine stage flow path theory, experiment & user verification, Cieplne Maszyny Przeplywowe. Turbomachinery, Politechnika Lodzka, Lodz, Poland, 2002, № 122, pp. 63-70.

[14] Homylev S.A.: Numerical study of flow turbine airfoil cascades: Part 1 – verification of the calculation method [Text] / S.A. Homylev, S.B. Resnick, S.V. Ershov // Energy and thermal engineering processes and equipment, 2008, № 6, pp. 23-31 (in Russian).

[15] Rusanov A.V.: Method of analytical profiling blade rows of axial turbines flow parts [Text] / A.V. Rusanov, N.V. Pascenco A.I. Kosyanova // East European Journal of advanced technology, 2009, № 2/7 (38), pp. 32-37 (in Russian).

[16] Rusanov A.V.: Using modern computer technology to create high-performance flow parts radial-axial type // Compressor and power engineering, 2013, № 2 (32), pp. 4-9 (in Russian).

[17] Rusanov A.V. Method of designing high-performance turbo-expander units flow parts / A.V. Rusanov S.V. Moiseev, P.N. Suhorebry, A.I. Kosyanova, R.A. Rusanov // Aerospace and Technology, 2012, № 8 (95), pp. 67-72 (in Russian).

[18] Rusanov A.: Elaboration of the flow system for a cogeneration ORC turbine / A. Rusanov, P. Lampart, R. Rusanov, S. Bykuc // Proc 12th Conf on Power System Engineering, Thermodynamics & Fluid Flow – ES 2013, Pilzen, Czech Republic, 13-14 June 2013, Publisher: University of West Bohemia, 2013,10 p.

[19] Rusanov A.V.: Development of the CMP flow part steam turbine T-125/150-12,8 based on the use of modern computer technology [Text] / A.V. Rusanov, A.L. Shubenko, A.Y. Kultyshev etc. // Vestnik NTU ˝KhPI˝. Series: Energy and thermal engineering processes and installations, Kharkov, 2014, № 11 (1054), pp. 16-29 (in Russian).

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Lars SÆTRAN
Department of Energy and Process Engineering
Norwegian University of Science and Technology
Trondheim, Norway
lars.satran@ntnu.no

WIND TURBINE BENCHMARK EXPERIMENTS

Abstract: Nowadays, especially in Europe the wind energy market is in state of rapid development. Although the wind power technology seems mature, a lot of economic potential can be found in improving the basics of wind engineering - working understanding of turbine aerodynamics and site assessment. Especially detailed wake modeling of wind turbines working in real life conditions eg. operating in wake region of neighborhood turbine, brought a lot of attention lastly. The development of wind turbine wake modelling and wind farm design tools is however hampered down by lack of experimental validation data. To fill this gap the Department of Energy and Process Engineering, NTNU Trondheim has lunched the series of benchmark, wind tunnel experiments with the main idea of establishing the reliable experimental data base for typical, three bladed horizontal axis wind turbine wake and interaction modeling.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Matthew T. STICKLAND[1*]
Andrew OLDROYD[2]
Charlotte BAY HASAGER[3]
Thomas SCANLON[1]
[1]Department of Mechanical and Aerospace Engineering
University of Strathclyde, Glasgow, UK
[2]Oldbaum Services, Stirling FK9 4NF, UK
[3]DTU Wind Energy, Technical University of Denmark
Frederiksborgvej 399, 4000 Roskilde, Denmark
[*] matt.stickland@strath.ac.uk

EU-NORSEWIND – DELIVERING OFFSHORE WIND SPEED DATA FOR RENEWABLE ENERGY

Abstract: Offshore wind is the key area of expansion for most EU states in order to meet renewable energy obligations. However, a lack of good quality offshore wind resource data is inhibiting growth in this area. To address this issue the NORSEWInD project was established in 2008 to develop the methodology for creating a wind atlas from remote sensing satellite data which is available in the public domain. This paper gives an overview of the methodology developed and includes the so-called "NORSEWInD standard" for comparing LIDAR and mast wind data, the technique for estimating the flow distortion measured around offshore platforms by LiDARs using wind tunnel and CFD data and observations of the vertical wind profile shear exponent at the hub height of off shore wind turbines.

Keywords: LIDAR; offshore winds; remote sensing; wind energy; wind resources.

REFERENCES

[1] Wagner R., Antoniou I., Pedersen S.M., Courtney M.S., Jørgensen H.E.: The influence of the wind speed profile on wind turbine performance measurements. *Wind Energy* **2009**, *12*, 348-362.

[2] Peña A., Hasager C.B., Gryning S., Courtney M., Antoniou I., Mikkelsen T.: Offshore wind profiling using Light Detection and Ranging Measurements. *Wind Energy* **2009**, *12*, 105-124.

[3] Hahmann A.N., Lange J., Peña A., Hasager C.B.: *The NORSEWInD Numerical Wind Atlas for the South Baltic*; DTU Wind Energy E-0011 (EN); DTU Wind Energy, Roskilde, Denmark, 2012; p. 53.

[4] Smith D.A., Harris M., Coffey A.S., Mikkelsen T., Jorgensen H.E., Mann J., Danielian G.: Wind lidar evaluation at the danish wind test site in hovsore. *Wind Energy* **2006**, *9*, 87-93.

[5] Kindler D., Oldroyd A., Macaskill A., Finch D.: An eight month test campaign of the Qinetiq ZephIR system: Preliminary results. *Meteorol. Z.* **2007**, *16*, 479-489.

[6] Antoniou I., Jørgensen H.E., Mikkelsen T., Frandsen S., Barthelmie R., Perstrup C., Hurtig M.: Offshore Wind Profile Measurements from Remote Sensing Instruments. In Proceedings of the European Wind Energy Association Conference & Exhibition in Athens, Athens, Greece, 27 Feb-3 March 2006.

[7] NORSEWInD: Available online: http://www.norsewind.eu (accessed on 3 September 2014).

[8] Peña A., Mikkelsen T., Gryning S.-E., Hasager C.B., Hahmann A., Badger M., Karagali I., Courtney M.: *Offshore Vertical Wind Shear: Final Report on NORSEWInD's Work Task 3.1*; DTU Wind Energy-E-Report-0005(EN); DTU Wind Energy, Roskilde, Denmark, 2012; p. 116.

[9] Stickland M., Scanlon T., Fabre S., Oldroyd A., Mikkelsen T.: Measurement and simulation of the flow field around a triangular lattice meteorological mast. *Journal of Energy and Power Engineering.* 13, **2013**.

[10] Badger M., Badger J., Nielsen M., Hasager C.B., Peña A.: Wind class sampling of satellite SAR imagery for offshore wind resource mapping. *J. Appl. Meteorol. Climatol.* **2010**, *49*, 2474–2491.

[11] Berge E., Hasager C.B., Bredesen R.E., Hahmann A., Byrkjedal O., Peña A., Kravik R., Harstveit K., Costa P., Oldroyd A.: NORSEWIND-Mesoscale Model Derived Wind Atlases for the Irish Sea, the North Sea and the Baltic Sea. In European Wind Energy Association Confernce, Vienna, Austria, 4-7 February 2013; pp. 1-6.

[12] Hasager C.B., Badger M., Peña A., Larsen X.G., Bingol F.: SAR-Based wind resource statistics in the Baltic sea. *Remote Sens.* **2011**, *3*, 117-144.

[13] Karagali I., Hoyer J., Hasager C.: SST diurnal variability in the North Sea and the Baltic sea. *Remote Sens. Environ.* **2012**, *121*, 159-170.

[14] Karagali I., Peña A., Badger M., Hasager C.: Wind characteristics in the North and Baltic Seas from the QuikSCAT satellite. *Wind Energy* **2012**, doi: 10.1002/we.1565.

[15] Karagali I., Badger M., Hahmann A., Peña A., Hasager C., Sempreviva A.M.: Spatial and temporal variability in winds in the Northern European Seas. *Renew. Energy* **2013**, *57*, 200-210.

[16] ZephIR©. Available online: http://www.zephirlidar.com (accessed on 3 September 2013).

[17] Pitter M., Slinger C., Harris M.: Introduction of Continous-Wave Doppler| Lidar. In *Remote Sensing for Wind Energy*; Peña A., Hasager C.B., Lange J., Anger J., Badger M., Bingöl F., Bischoff O., Cariou J.-P., Dunne F., Emeis S., *et al*., Eds., DTU Wind Energy-E-Report-0029(EN); DTU Wind Energy, Roskilde, Denmark, 2013; pp. 72-103. WindCube©. Available online: http://www.leosphere.com (accessed on 3 September 2013).

[18] Cariou J.-P.: Pulsed Lidars. In *Remote Sensing for Wind Energy*; Peña A., Hasager C.B., Lange J., Anger J., Badger M., Bingöl F., Bischoff O., Cariou J.-P., Dunne F., Emeis S., *et al*., Eds.; DTU Wind Energy-E-Report-0029(EN); DTU Wind Energy, Roskilde, Denmark, 2013, pp. 104-121.

[19] Sonnenschein C.M., Horrigan F.A.: Signal-to-Noise relationships for Coaxial Systems that heterodyne backscatter from atmosphere. *Appl. Opt.* **1971**, *10*, 1600-1604.

[20] Menter F.R., Kuntz M., Langtry R.: Ten Years of Industrial Experience with the SST Turbulence Model. In *Turbulence, Heat and Mass Transfer 4*; Hanjalic K., Nagano Y., Tummers M., Eds.; Begell House Inc.: New York, NY, USA, 2003; pp. 625-632.

[21] Courtney M., Wagner R., Lindelöw P.: *T*esting and Comparison of Lidars for Profile and Turbulence Measurements in Wind Energy. In *IOP Conference Series Earth and Environmental Science*; Risø National Laboratory, DTU, Denmark, 2008; pp. U172-U185.

[22] Stickland M., Scanlon T., Fabre S.: Computational and Experimental Study on the Effect of Flow Field Distortion on the Accuracy of the Measurements made by Anemometers on the Fino3 Meteorological Mast. In Proceedings of EWEA Offshore: Moving Ahead of the Energy Curve, Amsterdam, The Netherlands, 29 Nov-1 Dec 2011.

[23] Bingöl F., Mann J., Foussekis D.: Conically scanning lidar error in complex terrain. *Meteorol. Z. (Ger.)* 2009, *18*, 189-195.

[24] Bingöl F., Mann J., Foussekis D.: Lidar Error Estimation with WAsP Engineering. In Proceedings of 14th International Symposium for the Advancement of Boundary Layer Remote Sensing IOP Publishing IOP Conf. Series: Earth and Environmental Science, Risø National Laboratory, DTU, Denmark, 23-25 June 2008, 2009; Volume 1.

[25] Bradley S., Mikkelsen T.: LIDAR remote sensing. *Int. Sustain. Energy Rev.* 2011, *5*, 2-7.

[26] Bradley S., Perrott Y., Behrens P., Oldroyd A.: Corrections for wind-speed errors from sodar and lidar in complex terrain. *Bound. Layer Meteorol.* 2012, *143*, 37-48.

[27] Mann J., Ott S., Jørgensen B.H., Frank H.P.: *WAsP Engineering 2000*; Technical Report Risø-R-1356(EN); Risø National Laboratory for

Sustainable Energy, Technical University of Denmark: Risø DTU, Roskilde, Denmark, 2002; Volume R–1356(EN), p. 101.

[28] Mortensen N.G., Heathfield D.N., Myllerup L., Landberg L., Rathmann O.: *Getting Started with WAsP 9*; Report Risø-I-2571(EN); Risø National Laboratory for Sustainable Energy, Technical University of Denmark: Risø DTU, Roskilde, Denmark, 2007; p. 72.

[29] Peña A., Hahmann A., Hasager C.B., Bingöl F., Karagali I., Badger J., Badger M., Clausen N.: *South Baltic Wind Atlas*; Report Risø-R-1775(EN); Risø National Laboratory for Sustainable Energy, Technical University of Denmark: DTU Wind Energy, Roskilde, Denmark, 2011, p. 66.

[30] Draxl C., Hahmann A.N., Peña A., Giebel G.: Evaluating winds and vertical wind shear from weather research and forecasting model forecasts using seven planetary boundary layer schemes. *Wind Energy* 2012, doi: 10.1002/we.1555.

[31] Emeis S.: Wind Energy Meteorology-Atmospheric Physics for Wind Power Generation. In *Series: Green Energy and Technology*; Springer: Heidelberg, Germany, 2012; p. 14-196.

[32] Cañadillas B., Neumann T., Raasch S.: Getting a Better Understanding of the Offshore Marine Boundary Layer: Comparison between Large Eddy Simulation and Offshore Measurement Data with Focus on Wind Energy Application. In Proceedings of the Fifth International Symposium on Computational Wind Engineering (CWE2010), Chapel Hill, NC, USA, 23-27 May 2010.

[33] Zoumakis N.M.: The dependence of the power-law exponent on surface roughness and stability in a neutrally and stably stratified surface boundary layer. *Atmósfera* 1993, *6*, 79–83.

[34] Westerhellweg A., Cañadillas B., Beeken A., Neumann T.: One Year of Lidar Measurements at FINO1-Platform: Comparison and Verification to Met-Mast Data. In Proceedings of 10th German Wind Energy Conference DEWEK 2010, Bremen, Germany, 17-18 November 2010.

[35] Muñoz-Esparza D., Canadillas B., Neumann T., van Beeck J.: Turbulent fluxes, stability and shear in the offshore environment: Mesoscale modelling and field observations at FINO1. *J. Renew. Sustain. Energy* 2012, *4*, 063136:1-063136:16.

[36] Lang S., McKeogh E.: LIDAR and SODAR measurements of wind speed and direction in upland terrain for wind energy purposes. *Remote Sens.* 2011, *3*, 1871-1901.

[37] Takeyama Y., Ohsawa T., Yamashita T., Kozai K., Muto Y., Baba Y., Kawaguchi K.: Estimation of offshore wind resources in coastal waters off Shirahama using ENVISAT ASAR images. *Remote Sens.* 2013, *5*, 283-2897.

[38] Takeyama Y., Ohsawa T., Kozai K., Hasager C.B., Badger M.: Effectiveness of WRF wind direction for retrieving coastal sea surface wind from synthetic aperture radar. *Wind Energy* 2012, doi: 10.1002/we.1526.

[39] Bay Hasager C., Stein D., Courtney M., Peña A., Mikkelsen T., Stickland M., Oldroyd A.: Hub Height Ocean Winds over the North Sea Observed by the NORSEWInD Lidar Array: Measuring Techniques, Quality Control and Data Management. Remote Sensing 2013, Vol. (5).

[40] Bay Hasager C. et al.: SAR – Based wind resource statistics in the Baltic Sea. Remote sensing 2011, 3. 117-144.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Tomasz SUCHOCKI*
Piotr LAMPART
Piotr KLONOWICZ
The Szewalski Institute of Fluid-Flow Machinery
Fiszera 14 st., 80-231 Gdansk, POLAND
**tsuchocki@imp.gda.pl*

NUMERICAL INVESTIGATION OF A GTM-140 TURBOJET ENGINE

Abstract: The paper presents three-dimensional numerical simulations of combustion in the GTM-140 miniature turbine engine. The main aim of the work is to understand the processes occurring in the combustion chamber. The coupling of chemical kinetics, thermochemistry, transport of mass, energy and momentum, and fluid mechanics is a challenge for the engineers. The knowledge of these issues is essential to achieve a high performance product.

The k-ε (RANS) Turbulence Model and Non-Premixed Model for the combustion was used. The particles of fluid droplets were described by the Discrete Phase Model.

Keywords: GTM-140, turbine engine, CFD, Discrete Phase Model, combustion.

REFERENCES

[1] Kamps T.: Model Jet Engines. The Modeller's World. Traplet publications, Worcestershire, UK, 1999.

[2] Gieras M. and Stankowski T.: Computational study of an aerodynamic flow through a micro-turbine engine combustor. Power Technologies 92 (2):68{79, 2012.

[3] Bering Rasmus Møller, Buskov Kåre Elgaard: Numerical Investigation of the Soot Initiated Formation of Ultra-Fine Particles in a Jet Turbine Engine Using Conventional Jet Fuel – Master’s Thesis.

[4] Suchocki T., Lampart P.: Badania numeryczne spalania paliwa lotniczego w silniku turbinowym GTM-140, XXI Warsztaty Naukowe PTSK, Białowieża 2014.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Artur SZYMAŃSKI*
Sławomir DYKAS
Włodzimierz WRÓBLEWSKI
Sebastian RULIK
Silesian University of Technology
Institute of Power Engineering and Turbomachinery
Konarskiego 18, 44-100 Gliwice, Poland
**artur.szymanski@polsl.pl*

NUMERICAL ANALYSIS OF A TIP LABYRINTH SEAL OF HIGH ROTATING ROTOR

Abstract: Labyrinth seal constantly is a prime turbine sealing solution because of low price, low maintenance, minimal rub particulate contamination and high temperature capability. This work aims to perform detailed CFD investigation of high speed rotating labyrinth seal. There have been found an impact of rotational velocity and pressure ratio on discharge characteristics of the rotor. Discharge characteristics were calculated for variety of pressure ratios. Moreover influence of rotor roughness was shown in each case. Performed inquiry results were shown as relative mass flow rate in function of mentioned parameters. From variety of configurations, an optimal seal configuration – providing the lowest leakage can be found.

Keywords: labyrinth, sealing, gas turbine, turbomachinery, CFD.

REFERENCES

[1] Wróblewski W., Dykas S., Bochon K., Rulik S.: Optimization of tip seal with honeycomb land in lp counter rotating gas turbine engine, Task Quarterly 14 (3), 2010, 189-207.

[2] Paolillo R.: Rotating Seal Rig Experiments: Test Results and Analysis Modeling, ASME Turbo Expo 2006: Power for Land, Sea and Air 3, 2006, 1551-1559.

[3] Waschka W.: Influence of high rotational speeds on the heat transfer and discharge coefficients in labyrinth seals, ASME Paper 90-GT-330 Journal of Turbomachinery 114, 1992, 462-468.

[4] Childs D.W., Kleynhans G.F.: Experimental rotordynamic and leakage results for short (l/d) honeycomb and smooth annular pressure seals. IMechE Proceedings, Fifth international Conference on Vibrations in Rotating Machinery 11, 305-311, 1992.

[5] Al-Qutub A.M., Elrod D., Coleman H.W.: A new friction factor model and entrance loss coefficient for honeycomb annular gas seals. ASME J Tribol 200;122, 622-627, 2000.

[6] Waschka W.: Zum Einfluss der Rotation auf das Durchflussverhalten und Wärmeübertragungsverhalten in Labyrinthdichtungen und Wellendurchführungen, Dissertation, Institut für Thermische Strömungsmaschinen der Universität Karlsruhe. 1991.

[7] Matthias A., Willinger R.: Influence of rotation and eccentricity on labyrinth seal leakage, 8th European Conference on TURBOMACHINERY, Fluid Dynamics and Thermodynamics, 084, 2009.

[8] Micio M. et al.: Flat plate honeycomb seals friction factor analysis, ASME Turbo Expo 2014: Turbine Technical Conference and Exposition, GT2014-27078.

[9] Ansys CFX 14.0 Theory Guide. 2 Turbulence and Wall Function Theory.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Piotr ŚWIDER [1]*,
Zbigniew KOZANECKI jr [1]*,
Marek GRACZYKOWSKI [2],
Władysław KRYŁŁOWICZ [3]
[1] NEO-TEC LTD., Kobiałka 11a, 09-411 Płock, Poland
[2] PKN ORLEN S.A., Chemików 7, 09-411 Płock, Poland
[3] Lodz University of Technology, Institute of Turbomachinery
Wólczańska 219/223, 93-005 Lódź, Poland
** neotec@neo-tec.pl*

TECHNICAL ASPECTS OF A LARGE SIZE INDUSTRIAL PROCESS TURBO COMPRESSOR REVAMP

Abstract: Current paper describes several modernization aspects of the process 8MW air compressor and its driver. The main aim of revamp was to increase internal efficiencies of both compressor and turbine and increase the load of the compressor without additional Power consumption. The original pressure ratio was preserved. To meet these requirements a redesign of the flow path of both machines was necessary. Moreover, the turbine working conditions were changed from extraction-condensing to condensing. In terms of compressor, impeller blade redesign, adaptation of diffusers and Abradable seals application were a part of the scope.
The revamp was completed in April 2014 with all the requirements met. The paper covers the general outline and a comparison of the original and modernized machine operating parameters, design and technical assumptions, but also describes some problematic issues which occurred during the realization of the project.

Keywords: Process compressor, Turbine, Impeller, Revamp.

REFERENCES

[1] Japikse D., Baines N.C.: Introduction to Turbomachinery, Concepts ETI Inc., 1994.

[2] Luedtke K. H.: Process Centrifugal Compressors – Basic Function, Operation, Design, Application, Springer Verlag Berlin – Heidelberg, 2004.

[3] Kozanecki Z.: Rotating Systems of the Low and Medium Power Turbo machinery, ITE Publishing House, 2008.

[4] Papierski A., Kozanecki Z., Kryłłowicz W., Grzelak H., Kabałyk K.: Wykonanie obliczeń sprawdzających dla koła wirnikowego stopnia 1 sprężarki 01C1, internal report, Institute of Turbomachinery, TUL, 2013.

[5] Kryłłowicz W.: Teoria i praktyka modernizacji sprężarek promieniowych, TUL, 2013

[6] API recommended practice 687 – rotor repair, API, 2001.

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Eliza TKACZ
Dorota KOZANECKA
Zbigniew KOZANECKI
Jakub ŁAGODZIŃSKI
Institute of Turbomachinery
Lodz University of Technology
219/223 Wolczanska St, 90-924 Lodz, Poland
Eliza.Tkacz@p.lodz.pl

OIL-FREE BEARING DEVELOPMENT FOR HIGH-SPEED TURBOMACHINERY IN DISTRIBUTED ENERGY SYSTEMS – DYNAMIC AND ENVIRONMENTAL EVALUATION

Abstract: Modern distributed energy systems, which are used to provide an alternative to or an enhancement of traditional electric power systems, require small size high-speed rotor turbomachinery to be developed. The existing conventional oil-lubricated bearings reveal performance limits at high revolutions as far as stability and power loss of the bearing is concerned. Non-conventional, oil-free bearings lubricated with the machine working medium could be a remedy to this issue. This approach includes a correct design of the machine flow structure and an accurate selection of the bearing type. Chosen aspects of the theoretical and experimental investigations of oil-free bearings and supports, including magnetic, tilting pad, pressurized aerostatic and hydrostatic bearings as well as some applications of oil-free bearing technology for high-speed turbomachinery are described in the paper.

Keywords: oil-free bearings, turbomachinery, distributed energy systems.

REFERENCES

[1] Kozanecki Z., Kozanecka D.: 2010, Theoretical and experimental investigations of oil-free support systems to improve the reliability of industrial turbomachinery, Proceedings of the 8th IFToMM International Conference on Rotor Dynamics, pp. 686-692.

[2] Kozanecka D., Kozanecki Z., Łagodziński J.: 2010, Active magnetic damper in a power transmission system, Communications in Nonlinear Science and Numerical Simulation, Journal Elsevier, No. 16 (2011), pp. 2273-2278. www.elsevier.com/locate/ cnsns_1567.

[3] Kozanecki Z., Łagodziński J.: Magnetic Thrust Bearing for the ORC High-Speed Microturbine, Solid State Phenomena, Vol. 198 (2013), pp. 348-353, available online since 2013/Mar/11 at www.scientific.net © (2013) Trans Tech Publications, Switzerland doi: 10.4028/www.scientific.net/SSP.198.348

[4] Kozanecki Z., Tkacz E., Łagodziński J., Miazga K.: 2012, Oil-free bearings for hermetic high-speed turbomachinery, Conference Proceedings VETOMAC-VIII, ISBN 978-83-88237-61-4.

[5] Kozanecki Z., Kozanecka D., Klonowicz P., Łagodziński J., Gizelska M., Tkacz E., Miazga K., Kaczmarek A.: 2014, monograph: Oil-free Turbomachinery of Low Power ISBN 978-83-88237-27-0, copyright by the Institute of Fluid Flow Machinery Polish Academy of Sciences, Gdańsk (in Polish).

CIEPLNE MASZYNY PRZEPŁYWOWE
No. 145 TURBOMACHINERY 2014

Grzegorz ŻYWICA*
Jan KICIŃSKI
Institute of Fluid-Flow Machinery,
Polish Academy of Sciences, Gdansk Poland
* *gzywica@imp.gda.pl*

INVESTIGATION THE EFFECT OF SELECTED DESIGN AND OPERATING PARAMETERS ON THE DYNAMIC PROPERTIES OF THE STEAM MICRO-TURBINE

Abstract: The topic of the article is the analysis of the influence of selected design parameters and operating conditions on the radial steam micro-turbine, which was adapted to operate with low-boiling agent in the system based on the ORC. In the following parts of this article the results of the thermal load analysis, the residual unbalance and the stiffness of bearing supports are discussed. Studies showed that the steam micro-turbine is characterized by very good dynamic properties and is resistant to extreme operating conditions. The prototype of micro-turbine has passed a series of test calculations. It has been found that it can be subjected to experimental research in the micro combined heat and power system.

Keywords*:* micro-turbine, rotor dynamics, rotor-bearings system, ORC systems.

REFERENCES

[1] Kicinski J.: Rotor Dynamics, IMP PAN Publisher, Gdansk, 2006.
[2] Muszynska A.: Rotordynamics, Taylor&Francis, 2005.
[3] Rao J.S.: Rotor Dynamics, New Age, 2009.
[4] Gasch R., Nordman R., Pfutzner H.: Rotordynamik, Springer, 2006.
[5] Vance J.M.: Rotordynamics of Turbomachinery, Wiley Interscience, 1988.
[6] Laczkowski R.: Vibrations of the thermal turbine's components. WNT, Warszawa 1974.
[7] ABAQUS, Analysis user manual. Version 6.14.
[8] MADYN 2000 Documentation, Delta JS, Zurich 2009.

[9] ISO 1940/1, Balance Quality Requirements of Rigid Rotors, International Organization for Standardization.

[10] Zywica G.: Analysis of the defects in supporting structure in relation to the dynamic state rotating machine. PhD thesis, IMP PAN, Gdansk 2011.

ISSN 0137-2661